The Life-Cycle Assessment of a Single-Storey Retail Building in Canada

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

In North America, the operation of buildings accounts for approximately one third of the total energy use and greenhouse gas emissions annually. Office buildings are responsible for roughly 35% of the total commercial/institutional secondary energy use in Canada, followed by retail buildings at 17% (NRCan, OEE, 2010).

In recent years, a number of researchers from around the world have conducted life-cycle assessment (LCA) studies to investigate the impacts of buildings on the environment. Most studies have focused on three types of buildings: office buildings, single residential dwellings, and multi-unit residential apartments. There have been almost no comprehensive LCA studies of retail buildings, specifically single-storey retail buildings. This is a problem, since compared to office buildings, single residential dwellings, and multi-unit residential apartments, retail buildings consume approximately 1.2, 2.0, and 2.3 times more energy per floor area respectively (NRCan, OEE, 2010). In addition, retail buildings usually undergo major resource intensive renovations far sooner than other building types. Therefore, the primary goal of this study was to conduct a comprehensive LCA for the components of a single-storey retail building located in Toronto, Canada, to determine which building components contribute the most towards the total life-cycle energy use and global warming potential (GWP) after 50 years.

Using the latest LCA techniques, the total life-cycle energy use and GWP was calculated for 220 different building components including: exterior infill walls, roofs, structural systems, floors, windows, doors, foundations, and interior partition walls. Also, a comprehensive LCA study was conducted for five single-storey retail buildings (including a pre-engineered steel building system which is lacking in the literature), in order to determine which components of a single-storey retail building are responsible for the most environmental damage.

For a typical single-storey retail building located in Toronto, Canada, the operating energy (and GWP) accounts for about 91% (88%) and the total embodied energy (and GWP) accounts for about 9% (12%) of the total energy (and GWP) after 50 years. The roof alone is responsible for nearly half of the total embodied energy and GWP of the entire building. The LCA study also found that after 50 years, the total energy (and GWP) of the five case study buildings only differed at most by 6% (7%), regardless of the choice of structural system, or whether the building was made predominately of steel or wood building components. This thesis concludes with a prioritized list of recommendations for reducing the total life-cycle energy use and GWP of a single-storey retail building in Canada.

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Glossary of Terms

ATHENA® Environmental Impact Estimator for Buildings	The only life-cycle assessment software in North America that is capable of evaluating whole buildings and individual building components based on internationally accepted LCA methodology. Refer to website: *(http://www.athenasmi.org/tools/impactEstimator/)*
Carbon Dioxide Equivalency (CO_2 eq.)	Carbon dioxide equivalency (CO_2 eq.) is a measure of the equivalent amount of CO_2 that would have the same global warming potential (GWP) as a mixture of CO_2 and other greenhouse gases in the Earth's atmosphere.
Embodied Energy	The total energy (usually primary energy) associated with the acquisition, processing, manufacturing, transportation, construction, repair, replacement, and end-of-life effects of whole buildings or building materials. The total embodied energy is the sum of the initial embodied energy and the recurring embodied energy and is usually measured in MJ (or GJ) of energy.
End-of-Life Energy	The energy (usually primary energy) associated with the demolition and recycling/disposal of whole buildings or building materials.
eQUEST	The 'Quick Energy Simulation Tool' (eQUEST) is an energy modelling software program for buildings that is available free of charge. eQUEST is based on the latest DOE-2 building simulation engine. Refer to website: (*http://www.doe2.com/equest/)*
Global Warming Potential (GWP)	A term that was developed to compare one greenhouse gas to another in terms of their ability to trap heat in the Earth's atmosphere. GWP is measured in mass of CO_2 equivalent. For buildings, the total GWP is the sum of the initial embodied GWP and the recurring embodied GWP and is typically expressed in either kg of CO_2 eq. or tonnes of CO_2 eq.
Greenhouse Gas (GHG)	Gases in the Earth's atmosphere that absorb and emit radiation and are the fundamental cause behind the greenhouse effect. Some common GHG's include carbon dioxide, methane, nitrous oxide, ozone, and water vapour.

Initial Embodied Energy (or GWP)	The energy (or GWP) used to acquire raw materials and manufacture, transport, and install building products in the initial construction of a building.
LEED	The 'Leadership in Energy and Environmental Design' green building rating system encourages global adoption of sustainable building practices through a performance based point system. LEED is operated by the U.S. Green Building Council (the Canadian Green Building Council in Canada). Refer to web site: (*http://www.cagbc.org/leed/what/index.php)*
Life-Cycle Assessment (LCA)	"A method used to quantify environmental burdens based on inventory of environmental factors for a product, process, or activity from the abstraction of raw materials to their final disposal" (Lee, O'Callaghan, & Allen, 1995).
Operating Energy	The use of either renewable or non-renewable energy in buildings to meet their demands for heating, cooling, lighting, ventilation, etc. during the occupancy phase of its life. Typically operating energy in buildings is measured in either kWh or GJ of energy.
Primary Energy	"Encompasses the total requirements for all uses of energy. This includes secondary energy use. Additionally, primary energy use refers to the energy required to transform one form of energy to another (e.g. coal to electricity). It also includes the energy used to bring energy supplies to the consumer (e.g. pipeline). Further, it entails the energy used to feed industrial production processes (e.g. the natural gas used by the chemical industries)" (NRCan, 2009).
Recurring Embodied Energy (or GWP)	The energy (or GWP) associated with maintaining, repairing, and replacing materials and components over the lifetime of the building.

Secondary Energy (or Site Energy)	"Energy used by the final consumer in various sectors of the economy. This includes, for example, the energy used by vehicles in the transportation sector. Secondary energy also encompasses energy required to heat and cool homes or businesses in the residential and commercial/institutional sectors. It also comprises energy required to run machinery in the industrial and agricultural sectors" (NRCan, 2009).
THERM	A two-dimensional (finite element based) heat flow analysis software program for building enclosures that is available free of charge. It was developed by the Lawrence Berkeley National Laboratory. Refer to web site: (*http://windows.lbl.gov/software/therm/therm.html)*
Total Life-Cycle Energy (or GWP)	The sum of the total embodied energy (or GWP) and the total operating energy (or GWP) of a building over a specified lifespan. The total life-cycle energy (or GWP) is usually expressed in MJ (or kg of CO_2 eq.).

Chapter 1
Introduction and Background

1.1 Introduction

The building industry in North America is changing. Over the past few decades, there has been an industry movement towards the design and construction of more energy efficient buildings. In North America, LEED® has become the foremost green building protocol and continues to encourage an aggressive reduction of energy use and greenhouse gas (GHG) emissions within the building industry. Over the past decade, the number of LEED® certified buildings in North America has increased at an exponential rate. There is a clear and growing market demand for energy efficient buildings. In the coming years, architects and engineers will need to adopt a more holistic design approach that fully considers the total life-cycle environmental impacts of the buildings that they design.

The building industry has an overwhelming impact on the environment. In the United States, buildings are responsible for around 39% of primary energy use, 38% of all carbon dioxide emissions, and nearly 40% of all raw material use annually (USGBC, 2010). The trends in Canada are much the same. In Canada, the building sector as a whole accounts for approximately 29% of the total secondary energy use (NRCan, OEE, 2010). This is effectively equal to the secondary energy consumption of the entire transportation sector in Canada. Of this, retail buildings are responsible for about 17% of the total commercial/institutional secondary energy use, second only to office buildings which consume roughly 35% (NRCan, OEE, 2010). However, compared to office buildings in Canada, retail buildings on average have a higher energy intensity, consuming approximately 23% more energy per square meter of floor space (NRCan, OEE, 2010). Despite the need for energy efficient retail buildings, issues of sustainability have rarely been addressed for retail buildings in Canada. Of the 137 total LEED® Canada certified commercial buildings (excluding single family homes less than three storeys), only 10 (7%) are retail buildings compared to 43 (31%) office buildings (CaGBC, 2009).

Operational energy use in buildings is only one part of the problem. Over the life of a building, the total energy use is a combination of both the operational energy use and the embodied energy of the building materials. In a typical building today, about 85% of the total life-cycle energy use after 50 years is a result of the building operations, while only about 15% is due to the energy that is embodied in the materials (Cole & Kernan, 1996). Given this, there is a misconception among some building professionals who place a disproportionally large emphasis on material selection as a means of achieving significant reductions in total life-cycle energy use. That being said, as the operating energy use of buildings continues to decrease through a combination of conservation and the use of renewable energy sources, an intelligent allocation of building materials will gain increasing importance.

1.2 Description of Problem

Over the past two decades, a number of researchers around the world have conducted life-cycle assessment (LCA) studies to investigate the impacts of buildings on the environment. However, the vast majority of these studies have focused on three types of buildings: office buildings, single residential dwellings, and multi-unit residential apartments. In Canada, these buildings account for 15%, 45%, and 10% of the secondary energy use in the building sector (NRCan, OEE, 2010). Despite retail buildings accounting for 7% of the secondary energy use in the building sector in Canada, they have not historically been the focus of many LCA studies (NRCan, OEE, 2010). The lack of focus on retail buildings is a problem, since compared to office buildings, single residential dwellings, and multi-unit residential apartments, retail buildings consume approximately 1.2, 2.0, and 2.3 times more energy per floor area respectively (NRCan, OEE, 2010). In addition, retail buildings usually undergo major renovations or demolition far sooner than office buildings or residential dwellings. Also, a large majority of retail buildings are single-storey buildings. There is currently a lack of understanding in the literature of the life-cycle environmental impacts of single-storey commercial buildings. Single-storey buildings have a very different roof-to-wall area ratio than multi-storey buildings. For this reason, among others, it is important to investigate single-storey retail buildings within the framework of a comprehensive LCA to identify ways of reducing their life-cycle energy consumption and global warming potential (GWP).

In addition to the fact that few LCA studies have been conducted for retail buildings, there is still as widespread lack of knowledge on the part of many building industry professionals when it comes to material/assembly selection in low-energy buildings. Specifically, some building professionals have an inherent bias against the use of certain materials or assemblies in low-energy buildings, based solely on the initial embodied energy of an individual material. However, buildings and their component parts are far from homogonous systems in terms of material use. Comparing the life-cycle environmental impacts of different building components (or entire buildings) based solely on a comparison of the initial embodied energy of an individual building material is a gross simplification that is flawed.

Historically, LCA studies for buildings have primarily focused on a comparison of either different wall assemblies or structural systems. In most cases, these studies focus on a comparison of wood, steel, and concrete alternatives. This approach inevitably distils to a comparison of the embodied energy of wood, steel, and concrete. However, this approach places a disproportionately large emphasis on one material as an effect gauge of determining the life-cycle environmental burdens of an overall building assembly (or an entire building).

Buildings are more than just a structural system or a wall assembly. They are complex systems with numerous components and sub-assemblies that act together as part of a greater system. Few studies have investigated a wider range of building components with the goal of determining the relative impacts of all of the components of a building, not just the wall assembly and the structural system. The few comprehensive studies that have been done all vary drastically in their approach, the building components that are studied, and their degree of complexity. There needs to be a sensitivity analysis of a large range of building components within one comprehensive study using the latest LCA techniques, to develop a more complete understanding of the relative environmental impacts of all the components of a building, specifically in a single-storey retail building.

1.3 Objectives of Research

The purpose of this study is to conduct a comprehensive LCA of the energy use and GWP of a single-storey retail building in Canada. A sensitivity analysis of numerous building components will be performed to determine which components of a single-storey retail building have the greatest impact on the environment. Using these findings, a range of different retail building types in Canada will be analyzed and compared based on their life-cycle environmental burdens. A key objective will be to rank the components of a single-storey retail building in order of the damage that they cause to the environment. The ultimate goal of this research is to develop a list of recommendations for reducing the life-cycle energy use and GWP of single-storey retail buildings in Canada.

The specific objectives of this research study are:

1. To review previous LCA studies of embodied energy, embodied GWP, operating energy, and operating GWP in commercial buildings.
2. To identify a comprehensive list of alternative design strategies for a single-storey retail building across the following seven areas:
    a. The exterior infill wall enclosures

   b. The roof enclosures
   c. The floor assemblies
   d. The windows and doors
   e. The structural systems (beams and columns)
   f. The foundations
   g. The interior partitions
3. To calculate the total life-cycle energy and total GWP of each alternative building component identified in objective 2, over a 50 year lifespan in Toronto, Canada.
4. Using the findings from Objective 3, perform a sensitivity analysis of the total life-cycle energy use and total GWP for a typical Canadian retail building, in order to determine which building components have the greatest negative impact on the environment after 50 years.
5. Using the results from Objective 3 and 4, conduct a LCA of energy use and GWP for a range of common Canadian retail building types, in order to identify if there is a significant difference in the total life-cycle energy use and total GWP of these buildings after 50 years.
6. To use the results of this study to develop a list of recommendations for reducing the total life-cycle energy use and GWP of single-storey retail buildings in Canada.

1.4 Organization of Thesis

The organization of this thesis closely parallels the list of objectives that were presented in the previous section.

Chapter 2 contains a literature review of previous LCA studies of buildings. As virtually no significant LCA studies have been published for retail buildings specifically, most of the literature review deals with commercial buildings in general. There is also a discussion of energy and GWP trends in the Canadian building sector, along with a presentation of some background terminology.

The method employed for calculating the total life-cycle energy use and total GWP of the extensive list of building components in this study is discussed in Chapter 3. A detailed description of the building components considered is also presented, along with the method that was followed for calculating both the embodied effects and the operating effects for each building component. The scope of the LCA is also discussed.

Chapter 4 presents a detailed description of the five single-storey retail buildings looked at in this study.

The results of the comprehensive LCA of energy use and GWP for the five case study retail buildings are presented in Chapter 5, along with a discussion of the results. In Chapter 6, the LCA results for the extensive list of buildings components are presented.

Chapter 7 contains a summary of the data presented in the previous two chapters and distils it into a list of key findings. A list of recommendations for reducing the total life-cycle energy use and total GWP of a retail building in Canada is also presented.

Provided in Chapter 8 are concluding remarks for this study, as well as a list of recommendations for future work.

There is also a detailed Appendix with supplementary information and results at the end of this thesis.

Chapter 2
Literature Review

2.1 Introduction

The life-cycle assessment of whole buildings and their components has been a growing area of research over the last 15 years. In the past, the focus of the vast majority of these studies has been on residential (single family dwellings and multi-unit apartments) and multi-storey office buildings. Significant strides have been made in the understanding of material effects and operating effects in these types of buildings. However, limited research has been conducted on the life-cycle environmental impact of single-storey retail buildings.

A large proportion of commercial buildings in North America are single-storey buildings. As well, retail buildings tend to be some of the least energy efficient buildings constructed today. Not only do they use more energy per square meter than office buildings, but they tend to undergo energy intensive renovations on a more frequent basis.

Unfortunately, the number of LCA studies dealing with retail buildings specifically are very scarce. Therefore, in this section a literature review of the important LCA studies of commercial buildings over the past 15 years will be conducted. The goal is to develop an understanding of the literature as it pertains to commercial buildings in general. Having an understanding of the relevant LCA studies of commercial buildings is an important first step towards a more complete understanding of the life-cycle environmental impacts of single-storey retail buildings. As well, some important terms and concepts relating to energy use in buildings will be discussed.

2.2 The 'Green' Building Movement

Since the 1800's, scientists have predicted that a rise in carbon dioxide (CO_2) concentrations in the atmosphere could result in unprecedented global climate change, due to an increase in global temperatures. As Dr. Gilbert Plass (a physicist at John Hopkins university and a pioneering researcher on the relationship between CO_2 and climate change) describes "humanity is conducting a large-scale experiment on the atmosphere, the results of which will not be available for several generations" (Fleming, 1998).

In terms of total GHG emissions, Canada emitted the seventh highest amount of GHG in 2005 of any country in the world and was second only to Australia in terms of GHG emissions per capita

(NRTEE, 2009). In 1997, the Kyoto Protocol agreement was signed under the United Nations Framework Convention on Climate Change (UNFCCC) by 37 industrialized nations including Canada (as well as a host of other nations) with the goal of reducing global climate change. The Protocol is aimed at tackling the problem of global climate change by providing member countries with binding targets for reducing their GHG emissions. Under the Kyoto Protocol, Canada has agreed to reduce its GHG emissions to 6% below what they were in 1990 by the year 2012. Figure 2-1 illustrates Canada's GHG emissions from 1990 to 2007. Given the most recent data (for 2007) Canada currently stands about 34% above its Kyoto target. Given that the Kyoto commitment period is from 2008 to 2012, it seems highly unlikely that Canada will be able to meet its Kyoto commitment.

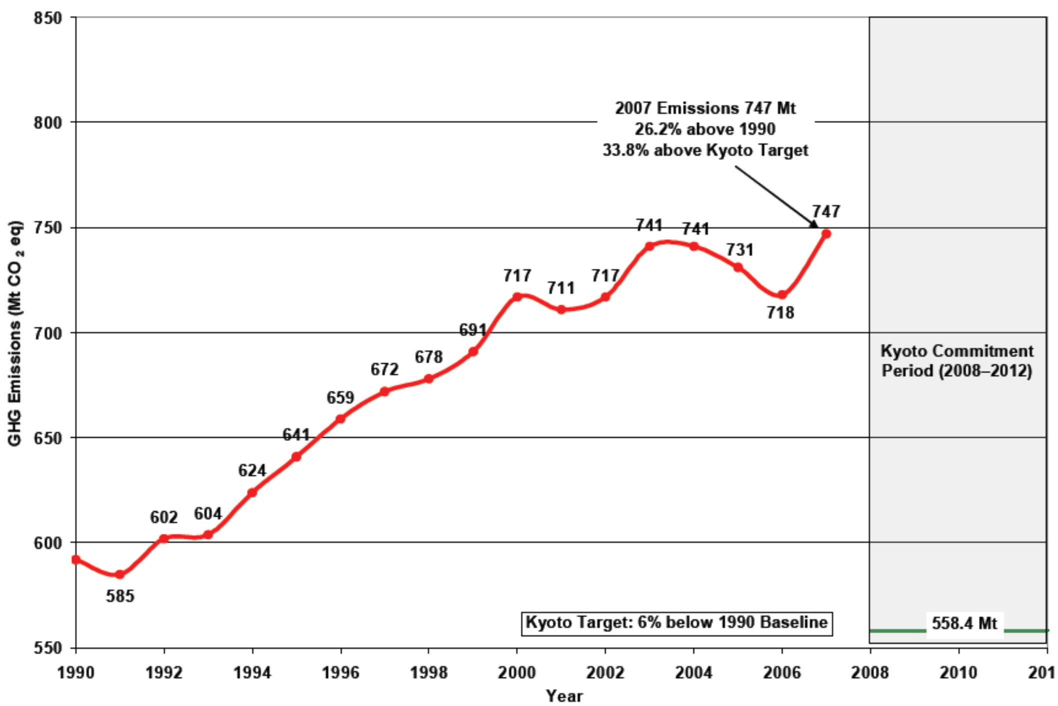


Figure 2-1: Canada's Greenhouse Gas Emissions from 1990-2007 (Environment Canada, 2009)

That being said, one of the single biggest contributors to CO_2 emissions worldwide is the building industry. In fact, the construction and operation of buildings accounts for over a third of the world's energy consumption and 40% of all the mined recourses (Straube J. F., 2006). In addition, the vast majority of buildings constructed in the developed world in the last 30-50 years have a shorter service life than older buildings (Straube J. F., 2006). This means that 'modern' building practices have resulted in inferior buildings from the standpoint of performance and durability. This often requires modern buildings to go through many resource intensive renovations over their lifespan.

The term 'sustainability' is used a lot in the building industry, often without a complete understating of what it means. The 'Brundtland Report' to the United Nations in 1987 defined the concept of sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (The World Commission on Environment and Development, 1987). "A subset of sustainable development, sustainable construction, addresses the role of the built environment in contributing to the overarching vision of sustainability" (Kibert, 2005). In terms of the building industry today, Straube (2006) provides a working definition of a 'green' building: "a building that uses energy and material more effectively both in production and operation while polluting and damaging natural systems as little as possible" (Straube J. F., 2006).

The push for more sustainable buildings in recent years has led to the development of numerous 'green' building protocols around the world. In North America, the most prominent 'green' building protocol is LEED. LEED stands for "Leadership in Energy and Environmental Design" and aims to encourage the adoption of sustainable building practices through the creation of performance criteria. LEED was first developed by the United States Green Building Council (USGBC) in 1998 and was later adopted by the Canadian Green Building Council (CaGBC). LEED operates on a points based system, whereby a score is awarded for performance in five key areas: sustainable site development, water efficiency, energy efficiency, materials selection, and indoor environmental quality (CaGBC, 2009). As of May 2010, 249 buildings in Canada (excluding residential projects less than 600 m^2) had achieved LEED certification and the number is increasingly rapidly (CaGBC, 2009). "Despite the success of LEED and the green building movement in general, challenges abound when implementing sustainability principles within the well-entrenched, traditional construction industry" (Kibert, 2005). At the end of the day, the reluctance of the building industry to change will likely present the biggest obstacle in the struggle to reach a new level of sustainability in the built environment.

2.3 Operating Energy of Buildings

Perhaps one of the biggest objectives of many of the green building protocols today is the pursuit of an aggressive reduction in the operating energy use of buildings. In general, there are two forms of energy available: non-renewable energy (e.g. coal, oil, natural gas, etc.) and renewable energy (e.g. solar, wind, water, etc.). Today, the vast majority of buildings depend on non-renewable energy to meet their demands for heating, cooling, lighting, ventilation, etc.

To begin a discussion of energy use in buildings, it is important to have an understanding of the relevant terms and definitions. In this section, some background terms relating to energy will be presented, along with a discussion of the energy use trends in the Canadian building sector.

2.3.1 Background on Operating Energy Statistics for Buildings

Energy use is typically expressed in terms of Joules (J). However, since the quantity of energy use in buildings is relatively large, it is often more convenient to express the energy use in terms of Megajoules (MJ), Gigajoules (GJ), or Petajoules (PJ). To help put these terms in context, one PJ is equivalent to "the energy required by almost 9,000 households (excluding transportation requirements) over one year" (NRCan, 2009).

According to Harvey (2006) there are three forms of energy: primary, secondary, and tertiary (or final end-use) energy. Primary energy is "energy as it occurs in nature" (Harvey, 2006). Examples of primary energy are oil, natural gas, coal, and uranium as they exist in the ground. Harvey (2006) explains that "to be useful to humans, these forms of energy need to be extracted and transformed into secondary energy" (Harvey, 2006). Examples of secondary energy are things like electricity and refined petroleum. Finally, tertiary energy (or end-use energy) are "things like warmth, motion, mechanical power, or light" (Harvey, 2006). Whenever energy is transformed, transported, or utilized there are losses. Harvey (2006) illustrates the relationships between primary, secondary, and tertiary energy in Figure 2-2.

Natural Resources Canada (NRCan) provides a similar distinction between primary and secondary energy:

> *"Secondary energy use is the energy used by the final consumer in various sectors of the economy. This includes, for example, the energy used by vehicles in the transportation sector. Secondary energy use also encompasses energy required to heat and cool homes*

or businesses in the residential and commercial/institutional sectors. In addition, it comprises energy required to run machinery in the industrial and agricultural sectors.

Primary energy use encompasses the total requirements for all uses of energy. This includes secondary energy use. Additionally, primary energy use refers to the energy required to transform one form of energy to another (e.g. coal to electricity). It also includes the energy used to bring energy supplies to the consumer (e.g. pipeline). Further, it entails the energy used to feed industrial production processes (e.g. the natural gas used by the chemical industries)" (NRCan, 2009).

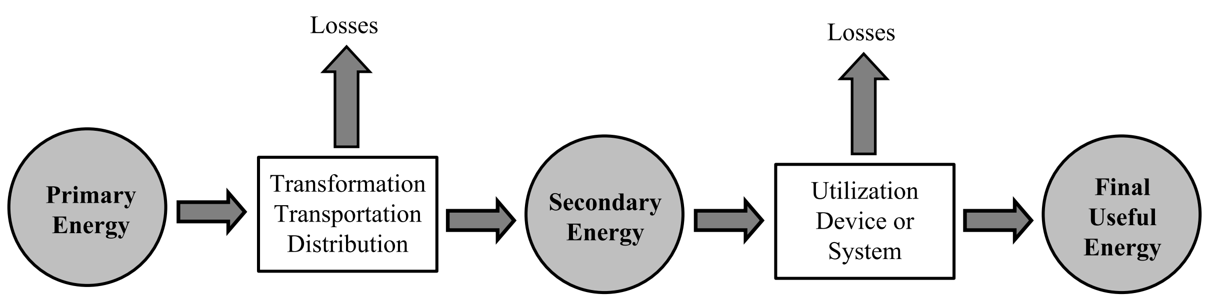


Figure 2-2: The Transformation from Primary to Secondary to Tertiary Energy (Harvey, 2006)

In the context of buildings, the operating energy can be defined as the amount of energy (renewable or non-renewable) that is required to maintain the functions of the building (e.g. heating, cooling, lighting, ventilation, equipment, etc.) and the activities of the occupants.

2.3.2 Operating Energy Statistics for Canadian Commercial Buildings

Each year the Office of Energy Efficiency (OEE) at National Resources Canada (NRCan) publishes the Energy Use Data Handbook (NRCan, OEE, 2010). The OEE completes an annual audit of the energy use by sector in Canada. The most recent data available is for 2007. According to the OEE, in 2007 the total primary energy consumed in Canada was about 12,786 PJ and the total secondary energy use was about 8,870.5 PJ (or about 69% of the total primary energy use) (NRCan, 2009). The OEE also provides a detailed breakdown of the energy consumption trends in each sector of the Canadian economy. Figure 2-3 illustrates the breakdown of the total secondary energy use by sector in Canada in 2007.

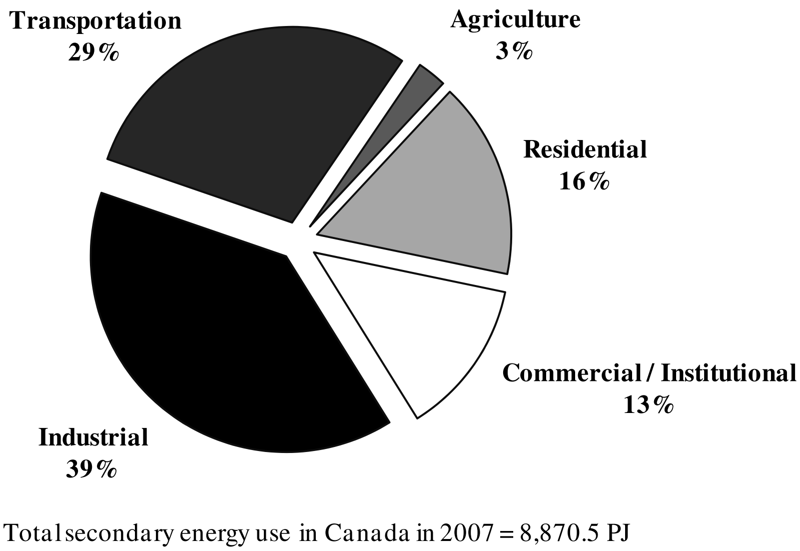
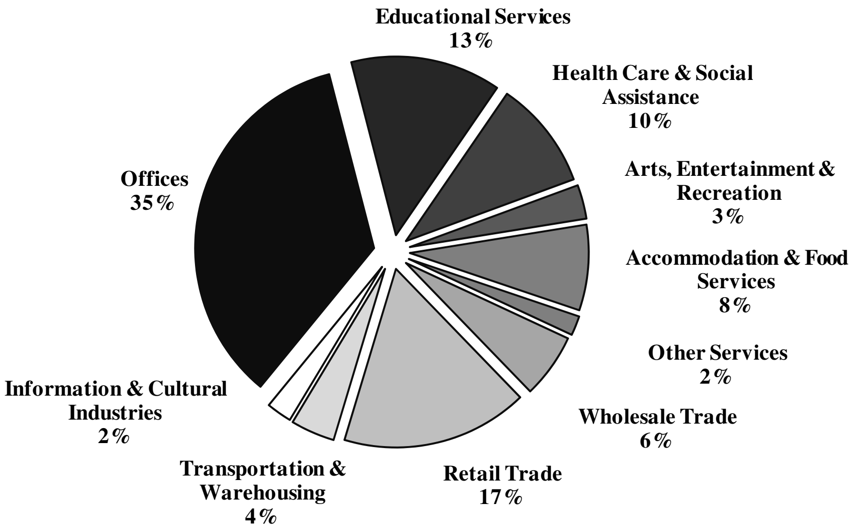


Figure 2-3: Breakdown of Total Secondary Energy Use by Sector in Canada in 2007 (NRCan, OEE, 2010)

By adding the residential secondary energy use (16%) with the commercial/institutional secondary energy use (13%), then the total secondary energy use of the building sector (not including material related effects or transportation) accounts for around 29% of the total secondary energy use in Canada. This is essentially equal to the secondary energy use of the entire transportation sector in Canada. However, the primary energy use changes the relative proportions and buildings are more significant.

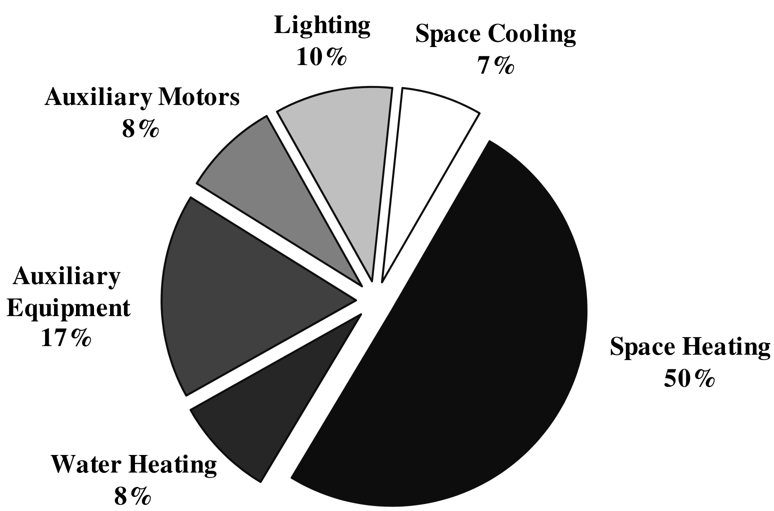
Figure 2-4 illustrates the breakdown of the total commercial/institutional secondary energy use by activity type in Canada in 2007. Office buildings are responsible for about 35% of the total secondary energy use in the commercial/institutional sector in Canada. This is interesting as office buildings have historically been the major focus of studies dealing with energy use in buildings. Interestingly enough, retail buildings are responsible for the next highest amount of secondary energy consumption at 17%. Despite the fact that retail buildings are responsible for the highest percentage of secondary energy use in Canada next only to office buildings, they have not historically been the focus of studies dealing with energy use in buildings.

Looking specifically at the case of retail buildings now, Figure 2-5 illustrates the breakdown of secondary energy use by end use in Canada in 2007 for retail buildings. Not surprisingly, space heating accounts for half of the energy use in retail buildings in Canada. Canada is a cold climate and buildings located here require a significant amount of energy for space heating.



Total commercial/institutional secondary energy use in Canada in 2007 = 1,141.6 PJ

Figure 2-4: Breakdown of Total Commercial/Institutional Secondary Energy Use by Activity Type in Canada in 2007 (NRCan, OEE, 2010)



Total retail secondary energy use in Canada in 2007 = 191.1 PJ

Figure 2-5: Breakdown of Retail Secondary Energy Use by End Use in Canada in 2007 (NRCan, OEE, 2010)

An interesting and useful way to compare the energy consumption of the various commercial/institutional type buildings in Canada is to consider their energy intensity. Energy intensity is essentially a measure of the amount of energy that is consumed per square meter of floor area. Figure 2-6 illustrates the average annual operating energy intensity by activity type for the commercial/institutional sector in Canada in 2007. Retail buildings actually consume about 1.2 times more operating energy per square meter than office buildings.

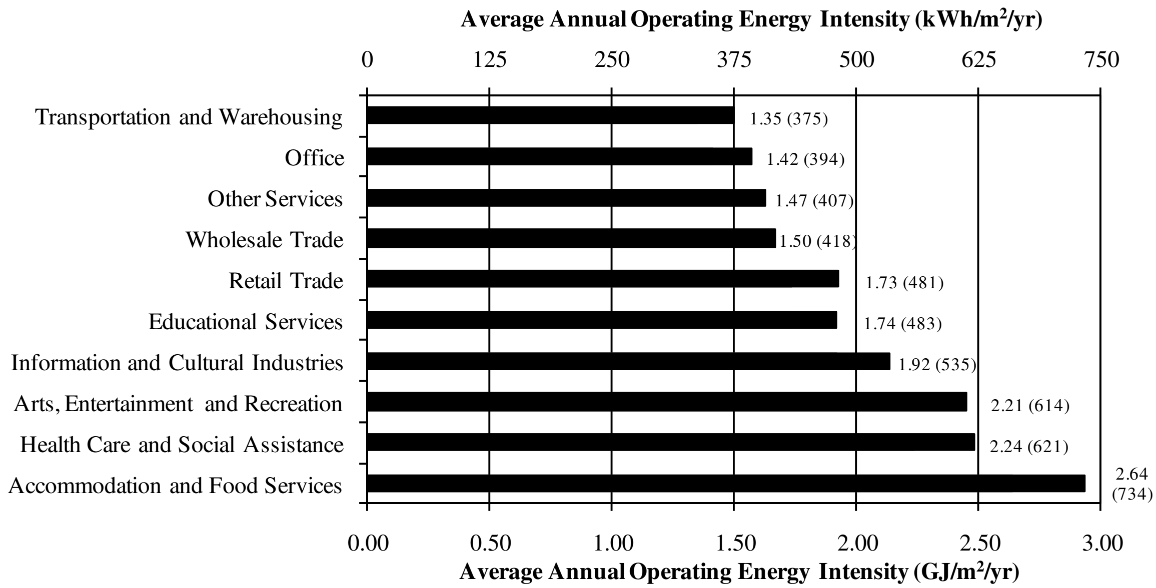


Figure 2-6: Commercial/Institutional Sector Average Annual Operating Energy Intensity by Activity in Canada for 2007 (NRCan, OEE, 2010)

2.4 Embodied Energy in Buildings

The operating energy consumption of buildings has been studied for years. Statistics are kept and reported by Natural Resources Canada each year for every sector of the Canadian economy. However, the energy associated with the acquisition, processing, manufacturing, transportation, construction, and repair/replacement of building materials is less familiar. The amount of energy that is associated with these activities is called embodied energy.

2.4.1 Background on Embodied Energy in Buildings

Embodied energy refers to "the total energy consumed in the acquisition and processing of raw materials, including manufacturing, transportation, and final installation" (Kibert, 2005). The embodied energy can be calculated for a building material, a component of a building, or even an entire building project. The embodied energy of a particular building material is usually reported in terms of MJ of primary energy per kg (or m^3) of material. There are two kinds of embodied energy: initial embodied energy and recurring embodied energy. The initial embodied energy of a building refers to "the energy used to acquire raw materials and manufacture, transport and install building products in the initial construction of a building" (Cole & Kernan, 1996). On the other hand, recurring embodied energy is "the energy associated with maintaining, repairing and replacing materials and components over the lifetime of the building" (Cole & Kernan, 1996). The total life-cycle embodied energy is simply the sum of the initial embodied energy plus the recurring embodied energy.

Embodied energy can be divided into direct embodied energy and indirect embodied energy. In terms of a building project, the direct embodied energy is the energy needed to transport building materials to the site and then construct the building. The indirect embodied energy is the energy required to extract and process the raw materials, the energy required to manufacture the building materials, and any related transportation energy. Determining the indirect embodied energy requires inputs from a large array of other industries. According to Harvey (2006), "there are a number of indirect energy inputs of first order, second order, third order, and so on. Fully accounting for the embodied energy in building materials requires accounting for a very large succession of linkages" (Harvey, 2006).

As mentioned, the total embodied energy (initial embodied energy plus recurring embodied energy) can be calculated for a building material, building component, or even an entire building. "Products with greater embodied energy usually have higher environmental impact due to the emissions and greenhouse gases associated with energy consumption" (Kibert, 2005). "The embodied energy depends on the energy intensity of the industries involved in producing building materials, while transportation energy depends on the energy intensity of transportation and the distances transported" (Harvey, 2006). "As the energy intensities (in the industrial and transportation sectors) improve, the embodied energy in new buildings will decrease" (Harvey, 2006).

In theory, calculating the embodied energy of a building is relatively straightforward if the embodied energies of the individual building materials are known. In reality, calculating the embodied energy of a building is anything but straightforward. The problem today is that the embodied energies of the various building materials are not well known. There is a lack of reliable information on the embodied energy of building materials. In fact, there is often a wide range of variability in these numbers from one source to the next. No industry standard for the embodied energy of building materials exits. Furthermore, since the embodied energy of a material depends on the local industries that manufacture them, the energy generation profile of the region where the materials are being produced, the availability of raw materials, etc., the embodied energy numbers vary from country to country and even from one region to the next. However, in theory calculating the embodied energy of a building "requires determining the embodied energy per unit mass or per unit volume of all the materials that go into a building, multiplying by the amounts of each material used, accounting for energy used during construction and adding all these terms" (Harvey, 2006).

2.4.2 Embodied Energy of Common Building Materials

To date, there are no industry standard embodied energy numbers for the various building materials. In fact, the embodied energy of a building material can vary (sometimes significantly) depending on the location that it is produced, the energy intensity of the manufacturing industries, the availability of raw materials, and numerous other factors. In addition, the embodied energies of the various building materials continually change as industries reduce their energy consumption and get more efficient at producing their products. That being said, it is still valuable to have an understanding of the range of values that are currently cited in the literature for the embodied energy of some common building materials. Table 2-1 lists a range of values for the embodied energy of some common building materials.

It can be seen that some materials like virgin aluminum have a relatively high embodied energy (201.0 to 217.0 MJ/kg). Insulation materials also tend to have a high embodied energy although little mass is used. For example, polystyrene insulation ranges from about 88.6 to 117.0 MJ/kg in Table 2-1. Depending on the recycled content, general virgin steel can vary from about 15.4 to 35.3 MJ/kg. Other naturally occurring materials such as stone have a relatively low embodied energy (0.8 to 6.8 MJ/kg). One important material to make mention of is concrete. In Table 2-1 the embodied energy of cement (4.6 to 15.0 MJ/kg) is listed as well as the embodied energy of concrete (1.1 to 4.5 MJ/kg). Concrete is actually about 75% aggregates, 10% water, and only 15% cement. Therefore, even though the embodied energy of cement can be relatively high, when combined with water and aggregates (which have very low embodied energy) the concrete mixture has a relatively low embodied energy. However, in building projects concrete is usually used in far greater mass than any other building material. Therefore, when the embodied energy of concrete is multiplied by the quantity of concrete, the total embodied energy of concrete used in a project can be significant. Once again, the embodied energy numbers presented here are by no means standard values for the industry. They have been collected from a sample of the literature and represent a range of values that one would find if they consulted the literature. It was difficult to find embodied energy numbers for building materials in Canada or the United States specifically, so most of the data in Table 2-1 was taken from comprehensive studies done in New Zealand and the United Kingdom.

Table 2-1: Initial Embodied Energy of Common Building Materials

Building Material	Initial Embodied Energy (MJ/kg) (Low / High)	Source (Low)	Source (High)
Aluminum (extruded, recycled)	17.3 / 34.1	(A)	(B)
Aluminum (extruded, virgin)	201.0 / 217.0	(A)	(B)
Bitumen	44.1 / 47.0	(A)	(B)
Building Paper	24.8 / 25.5	(B)	(A)
Carpet	72.4 / 74.4	(A)	(B)
Cement	4.6 / 15.0	(B)	(C)
Clay Brick	3.0	(B)	(B)
Concrete (30MPa)	1.1 / 4.5	(B)	(C)
Concrete Block	0.7 / 0.9	(B)	(A)
Float Glass	15.0 / 15.9	(B)	(A)
Gypsum Board	4.5 / 6.8	(A)	(B)
Insulation (cellulose)	0.9 / 3.3	(B)	(A)
Insulation (polystyrene)	88.6 / 117.0	(B)	(A)
Insulation (fiberglass)	28.0 / 30.3	(B)	(A)
Paint (solvent based)	68.0 / 98.1	(B)	(A)
Paint (water based)	68.0 / 88.5	(B)	(A)
Plywood	10.4 / 15.0	(A)	(B)
PVC Plastic	70.0 / 77.2	(A)	(B)
Steel (galvanized, virgin)	[1] 21.6 / 39.0	(D)	(B)
Steel (general, recycled)	9.5 / 10.1	(B)	(A)
Steel (general, virgin)	[2] 15.4 / 35.3	(D)	(B)
Steel (reinforcing)	8.9 / 13.3	(A)	(D)
Stone	0.8 / 6.8	(A)	(A)
Timber (glulam)	4.6 / 12.0	(A)	(B)
Timber (softwood, kiln dried)	1.6 / 7.4	(A)	(B)
Vinyl Flooring	65.6 / 79.1	(B)	(A)

Reference	*Country*	*Primary Energy (Y/N)*
(A) (Victoria University of Wellington, 2007)	*New Zealand*	*Unknown*
(B) (Hammond & Jones, 2008)	*United Kingdom*	*Y*
(C) (Treloar, Fay, Ilozor, & Love, 2001)	*Australia*	*Y*
(D) (International Iron and Steel Institute, 2005)	*Global Average*	*Y*

[1] *Includes global average initial recycled content*
[2] *Includes global average initial recycled content (value is for structural sections)*

2.4.3 Problems with Measures of Embodied Energy

It can not be stressed enough the variability of embodied energy numbers for building materials. The process of calculating the embodied energy of a building material depends on many factors. For example, to calculate the embodied energy of a material, one must rely on the manufacturers to accurately and comprehensively account for the energy use associated with every aspect of their manufacturing process. In reality, this is rarely the case. More often than not, a detailed accounting of the total energy associate with the raw material extraction, transportation, processing, and manufacturing of a building material is not done. Therefore, this makes it difficult to determine the true embodied energy of a building material with any certainty of accuracy.

Also, the various industries that produce building materials are continually updating their processes and becoming more efficient. Therefore, the true embodied energy of a building material is not static. It can vary from one year to the next and depends heavily on the specific location in which it is produce, as the energy generation, transportation, and manufacturing process in one location can vary drastically from the next.

When deciding on a material to use in a building project, it is a gross simplification to simply compare the embodied energy of two alternative materials and pass judgement on which is better for the environment. Recall that the embodied energy numbers are presented in terms of MJ of primary energy per kg (or m^3) of material. Therefore, one must also accurately determine the material quantities involved in order to determine the total embodied energy of a material that is used in a project. For example, even though the embodied energy per kg of concrete is relatively low, concrete tends to be one of the most significantly used materials in construction projects. As well, it weighs a great deal more than other building materials like insulation, which has a significantly higher embodied energy per kg, but weighs far less than concrete. Therefore, without a full accounting of materials in a project, it is difficult to make a comparison based solely on embodied energy.

2.5 Operating Global Warming Potential (GWP) of Buildings

In addition to understanding the consumption of energy in buildings, it is also useful to look at the related GHG emissions. In recent years, as the problem of global climate change has been thrust to the forefront of the public agenda, there has been an increasing effort to quantify and ultimately minimize the release of GHG emissions from buildings. Similar to the operating energy use, buildings also produce GHG emissions from their operation. In this section, some background terms relating to

GHG emissions will be presented, along with a discussion of the GHG emission trends in the Canadian building sector.

2.5.1 Background on Operating GWP Statistics for Buildings

The main reason why there has been an increase in the global temperature in recent decades is because of the presence of greenhouse gases in the atmosphere. Some of the more abundant greenhouse gases include: carbon dioxide, methane, nitrous oxide, ozone, and water vapour. These gases are unique in that they are 'spectrally selective' materials. Essentially, these gases in the Earth's atmosphere allow shortwave solar radiation to pass through them uninhibited, while at the same time not allowing longwave terrestrial radiation to pass back out. The net effect is a rise in global temperatures due to some of the terrestrial radiation being 'trapped' in the Earth's atmosphere by these spectrally selective gases.

As mentioned previously, greenhouse gases actually refer to more than just carbon dioxide. However, carbon dioxide is the most abundant GHG in the Earth's atmosphere. Therefore, scientists have developed the term call Global Warming Potential (GWP). The term, GWP was developed to compare one GHG to another in terms of their ability to trap heat in the Earth's atmosphere. GWP is measured in mass of CO_2 equivalent. Carbon dioxide equivalency (CO_2 eq.) is a measure of the equivalent amount of CO_2 that would have the same GWP as a mixture of CO_2 and other GHGs in the Earth's atmosphere. Often for the case of buildings the GWP is expressed in either kg of CO_2 eq. or tonnes of CO_2 eq.

2.5.2 Operating GWP Statistics for Canadian Commercial Buildings

Similar to operating energy, each year the OEE at NRCan publishes the GWP data for each sector of the Canadian economy. The data is published annually in the Energy Use Data Handbook (NRCan, OEE, 2010). The most recent data available is for 2007. According to the OEE, in 2007 the total GWP released in Canada was estimated to be about 746.7 Mt of CO_2 eq. and the total secondary GWP was about 501.6 Mt of CO_2 eq. (or about 67% of the total GWP). Figure 2-7 illustrates the breakdown of the total secondary GWP by sector in Canada in 2007.

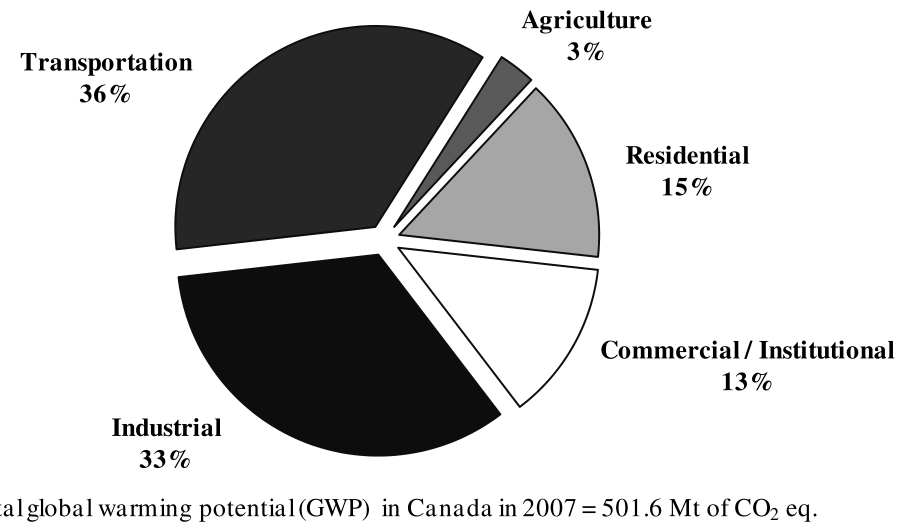


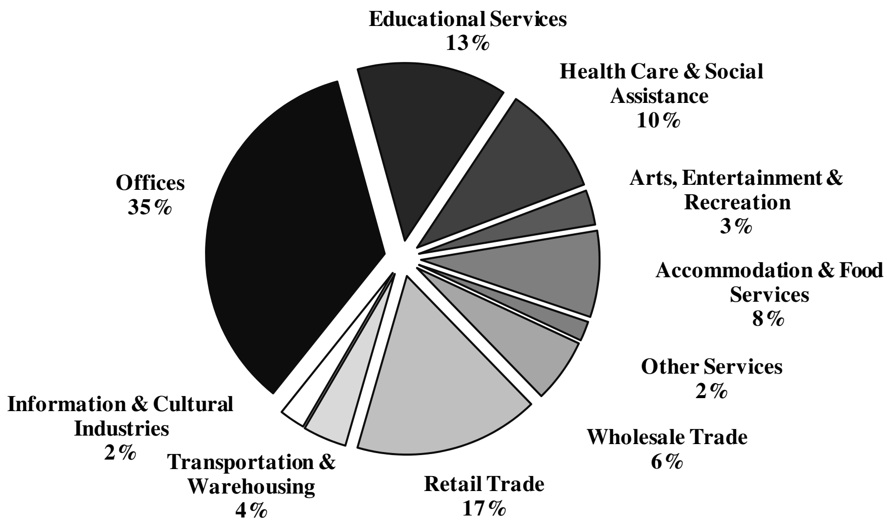
Figure 2-7: Breakdown of Total Secondary GWP by Sector in Canada in 2007 (NRCan, OEE, 2010)

By adding the residential and commercial/institutional sectors together, the building sector is responsible for about 28% of the total secondary GWP in Canada. This represents a significant percentage of the total GWP each year.

Next, Figure 2-8 illustrates the breakdown of commercial/institutional total secondary GWP by activity type in Canada in 2007. Office buildings account for about 35% of the total secondary GWP followed by retail buildings at 17%.

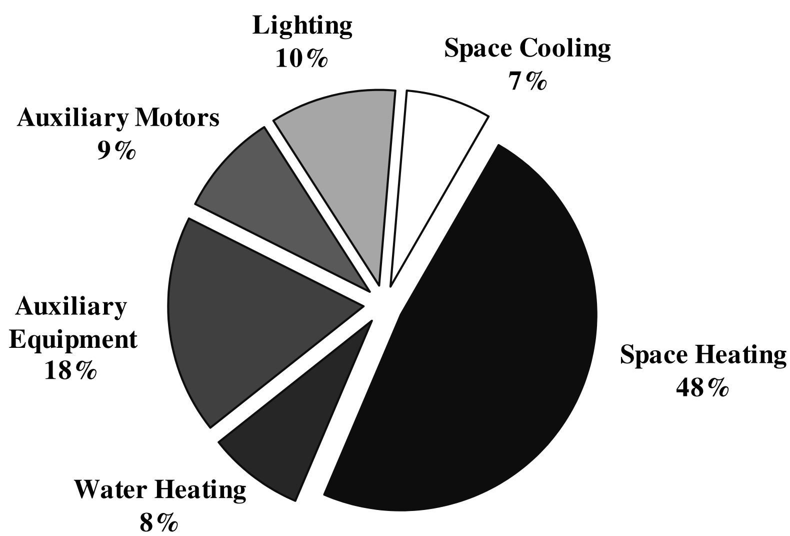
Focusing now on retail buildings specifically, Figure 2-9 illustrates the breakdown of the retail secondary GWP by end use in Canada in 2007. Not surprisingly space heating accounts for nearly half of the total secondary GWP of retail buildings. Notice how the trends in secondary GWP are very similar to the trends presented earlier for the secondary energy. There is a close relationship between energy use and GWP, as the release of greenhouse gases often accompanies the consumption of energy.

Next, Figure 2-10 illustrates the average annual GWP intensity by activity type for the commercial/institutional sector in Canada in 2007. Similarly to energy use, retail buildings produce about 1.2 times the GWP per square meter of floor area than office buildings.



Total commercial/institutional global warming potential (GWP) in Canada in 2007 = 64.5 Mt of CO_2 eq.

Figure 2-8: Breakdown of Commercial/Institutional Total Secondary GWP by Activity Type in Canada in 2007 (NRCan, OEE, 2010)



Total retail global warming potential (GWP) in Canada in 2007 = 10.7 Mt of CO_2 eq.

Figure 2-9: Breakdown of Retail Secondary GWP by End Use in Canada in 2007 (NRCan, OEE, 2010)

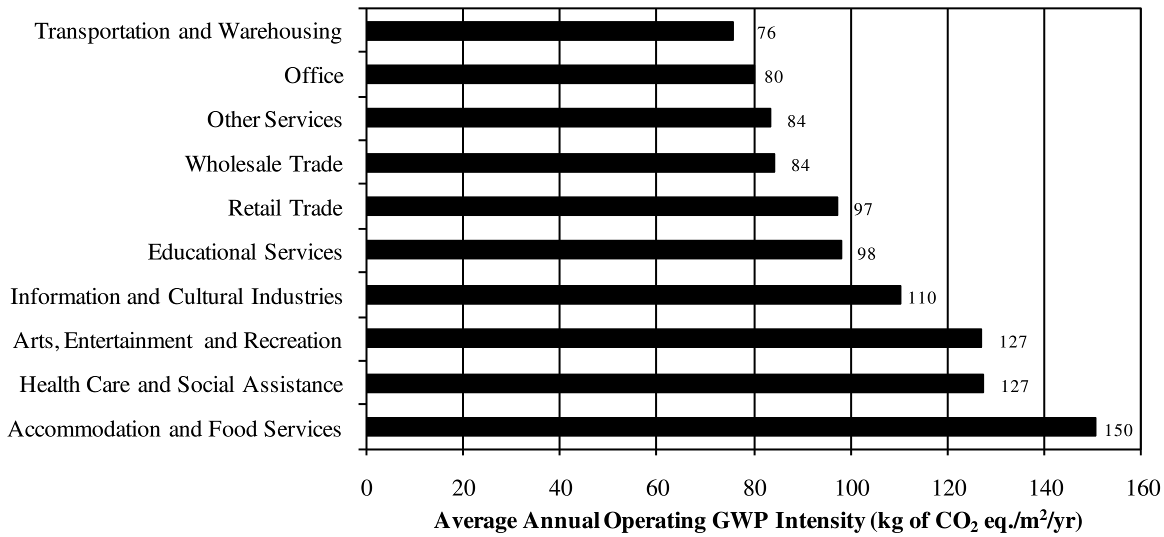


Figure 2-10: Commercial/Institutional Sector Average Annual Operating GWP Intensity by Activity in Canada for 2007 (NRCan, OEE, 2010)

2.6 Embodied Global Warming Potential (GWP) in Buildings

Recall that the energy use in buildings can be divided into operating energy and embodied energy. A similar division can be done for the GWP of buildings. Not only is there a release of GHG during the operating phase of a building, but there are also GHG emissions associated with the acquisition, processing, manufacturing, transportation, construction, and repair/replacement of building materials. The amount of GWP that is associated with these effects is called embodied GWP.

2.6.1 Background on Embodied GWP in Buildings

Embodied GWP refers to the total GWP produced in the acquisition and processing of raw materials, including manufacturing, transportation, and final installation. The embodied GWP can be calculated for a building material, a component of a building, or even an entire building project. The embodied GWP of a particular building material is usually reported in terms of kg of CO_2 eq. per kg (or m^3) of material. Similar to energy use, there are two kinds of embodied GWP: initial embodied GWP and recurring embodied GWP.

The embodied GWP of a building material depends on the GHG emissions of the industries that produce them. An accurate measure of embodied GWP is extremely difficult to determine for the various building materials. The same concerns and limitations that have already been discussed for the embodied energy numbers in previous sections, also apply to the case of embodied GWP numbers here. A repeat of that discussion will not be provided. However, it is important to note that the GWP numbers for building materials are even more difficult to find and exhibit a greater range of values than is the case for the embodied energy numbers. It is far easier to look at energy bills and determine how much energy was required to operate a manufacturing plant that produced a certain building material. However, since consumers do not pay for GHG emissions, there is no easy way of tracking the exact amount of GHG that is emitted during the production of a building material. These numbers can be estimated from the energy use, but such data is much harder to find and can vary significantly from one source to the next. Once again, there are no industry standard values for the embodied GWP of the various building materials. In the next section some common values for the embodied GWP of some common building materials will be presented.

2.6.2 Embodied GWP of Common Building Materials

To date, there are no industry standard embodied GWP numbers for the various building materials. Recall that the embodied GWP of a building material can vary (sometimes significantly) depending on the location that it is produced, the GWP intensity of the manufacturing industries, the availability of raw materials, and numerous other factors. In addition, the embodied GWP of the various building materials continually change as industries reduce their GWP emissions and get more efficient at producing their products. That being said, it is still valuable to have an understanding of the range of values that are currently cited in the literature for the embodied GWP of some common building materials. Table 2-2 lists a range of values for the embodied GWP of some common building materials.

Materials that have a high embodied energy also tend to have high embodied GWP. Those materials include things like virgin aluminum (8.4 to 11.2 kg of CO_2 eq./kg). General virgin steel has less embodied GWP (1.2 to 2.8 kg of CO_2 eq./kg) and can have less than this depending on the recycled content. Naturally occurring building materials like stone tend to have the least embodied GWP (0.1 kg of CO_2 eq./kg). Similar to embodied energy, embodied GWP values have been listed for both cement and concrete.

Once again, the embodied GWP numbers presented here are by no means standard values for the industry. They have been collected from a sample of the literature and represent a range of values that one would find if they consulted the literature. It was extremely difficult to find embodied GWP numbers for building materials in Canada or the United States specifically, so most of the data in Table 2-2 was taken from comprehensive studies done in New Zealand and the United Kingdom.

Table 2-2: Initial Embodied CO_2 of Common Building Materials

Building Material	Initial Embodied GWP (kg of CO_2/kg) (Low / High)	Source (Low)	Source (High)
Aluminum (extruded, recycled)	1.9 / 2.0	(A)	(B)
Aluminum (extruded, virgin)	8.4 / 11.2	(A)	(B)
Bitumen	0.2 / 0.5	(A)	(B)
Building Paper	1.3	(B)	(B)
Carpet	3.9	(B)	(B)
Cement	0.8 / 0.9	(B)	(A)
Clay Brick	0.2 / 0.7	(B)	(A)
Concrete (30MPa)	0.2 / 0.2	(A)	(B)
Concrete Block	0.1 / 0.1	(A)	(B)
Float Glass	0.9 / 1.7	(B)	(A)
Gypsum Board	0.4 / 0.4	(A)	(B)
Insulation (cellulose)	0.1	(A)	(A)
Insulation (polystyrene)	2.5 / 2.5	(A)	(B)
Insulation (fiberglass)	0.8 / 1.4	(A)	(B)
Paint (solvent based)	3.6	(B)	(B)
Paint (water based)	3.6	(B)	(B)
Plywood	0.8	(B)	(B)
PVC Plastic	2.4 / 4.3	(B)	(A)
Steel (galvanized, virgin)	2.8	(B)	(B)
Steel (general, recycled)	0.4	(B)	(B)
Steel (general, virgin)	1.2 / 2.8	(A)	(B)
Steel (reinforcing)	0.4	(A)	(A)
Stone	0.1	(B)	(B)
Timber (glulam)	0.7	(B)	(B)
Timber (softwood, kiln dried)	0.5	(B)	(B)
Vinyl Flooring	2.3	(B)	(B)

Reference	Country
(A) (Alcorn, 2003)	*New Zealand*
(B) (Hammond & Jones, 2008)	*United Kingdom*

** Initial embodied GWP are very difficult to find and can vary greatly from one source to the next*

2.6.3 Problems with Measures of Embodied GWP

The same problems and concerns that applied to embodied energy numbers also are applicable to embodied GWP numbers. These problems include: reliance on manufactures to accurately report embodied GWP numbers, continual improvements in the manufacturing process, and variation in numbers based on location for example.

Once again, it is important to accurately account for all the material quantities in a building project, in order to get an accurate measure of the total embodied GWP. Passing judgement on the GWP of different materials without considering the greater scope of a building project is a gross simplification that is flawed. In the next section, the proper way of accounting for the true life-cycle impact of both the operating effects and embodied effects in buildings will be presented.

2.7 Life-Cycle Assessment (LCA) of Buildings

In recent years, the process of tracking the environmental burdens of various products and processes from cradle-to-grave has been gaining in popularity. Across most industries today, there continues to be a push to reduce energy consumption and to decrease the environmental impacts associated with all aspects of production and operation. However, only recently has the initiative to reduce the cradle-to-grave environmental impacts in the building industry gained popularity.

Buildings are complex, multi-facet systems that have a direct and indirect impact on the environment. Their influence spans multiple industries and uncovering the relationships between the built and natural environment is not an easy task. Therefore, “given the complexities of interactions between the built and the natural environment, life-cycle assessment represents a comprehensive approach to examining the environmental impacts of an entire building” (Scheuer, Keoleian, & Reppe, 2003).

2.7.1 Background on LCA of Buildings

The European Committee for Standardization has defined LCA to be “a method used to quantify environmental burdens based on inventory of environmental factors for a product, process, or activity from the abstraction of raw materials to their final disposal” (Lee, O'Callaghan, & Allen, 1995). The International Organization for Standardization states that “LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product’s life-cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave) (ISO, 2006). Essentially, “LCA is a method for determining the environmental and resource impacts of a material, product, or even a whole building over its entire life" (Kibert, 2005). Typically, "the upstream (extraction, production, transportation, and construction), use, and downstream (deconstruction and disposal) flows of a product or service are inventoried. Next, the global and/or regional impacts are calculated based on energy consumption, GWP, and other measures" (Scheuer, Keoleian, & Reppe, 2003).

Although LCA techniques vary from once source to the next, ISO 14040 has emerged in recent years as the standard of choice. According to the International Organization for Standardization, ISO 14044 outlines the requirements of conducting a LCA and generally involves the following four phases:

1. Defining the goal and scope of the LCA
2. A life-cycle inventory (LCI) of the materials and their associated environmental impacts
3. A life-cycle impact assessment of the product or process using the LCI data
4. Interpretation of the results

The first stage of a LCA (goal and scope definition) defines the purpose, scope, and system boundaries of the LCA (ISO, 2006). In their LCA study of a new university building located on the University of Michigan campus, Scheuer, Keoleian, & Reppe, (2003) outlined the following system boundary for their LCA.

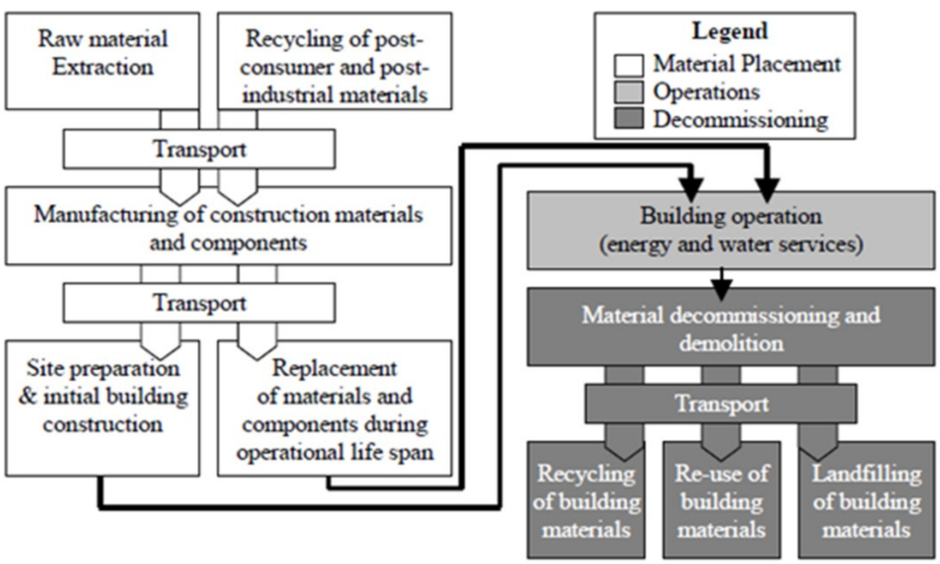


Figure 2-11: Life-Cycle Diagram for LCA of Buildings (Scheuer, Keoleian, & Reppe, 2003)

Stage two of a LCA (the LCI of materials) involves the collection of data to quantify the material and energy inputs and outputs of a system (ISO, 2006). Specifically, a LCI is "an objective data-based process of quantifying energy and raw material requirements, air emissions, water borne effluents, solid waste, and other environmental releases incurred throughout the life-cycle of a product, process, or activity" (Lee, O'Callaghan, & Allen, 1995).

In stage three of a LCA, a life-cycle impact assessment is conducted using the LCI data to calculate the significance of the potential environmental impacts of the product or process. Finally, the last stage of a LCA involves interpreting the results, which is important to do in order to provide a list of findings and recommendations.

For the case of a building specifically, a life-cycle assessment involves evaluating the environmental burdens of a building throughout its lifespan. This involves calculating the environmental burdens associated with all aspects of a building from manufacturing the building materials, to constructing the building, to operating the building, to renovating or disposing of it at the end of its life. Generally speaking, this most often involves calculating the embodied effects and the operating effects of a building (or components of a building) from cradle-to-grave.

Unfortunately there is no industry standard that is followed in the building industry when it comes to conducting a LCA. In fact, from country to country and within the literature, there is considerable variation in the scope of the LCA studies, their system boundaries, and in particular, the LCI data. Collecting a detailed database of material and energy inputs and outputs for all the various building materials, construction techniques, transportation methods, etc. is enormously complex. This data is regional specific, as the methods, techniques, and energy generation (or energy use profile) of one country (or region) to the next can differ dramatically. Therefore, the LCI data in one country (or region) can be entirely different, even for the same building material, in another country (or region).

2.7.2 Methods of Performing a LCA of Buildings

In recent years, numerous software programs have been developed (and continue to be developed) to simplify the LCA process. At the heart of these LCA programs is their LCI database of materials. Most developers of these programs have spent significant resources populating a LCI database for the various building materials. Trusty and Horst (2005) conducted a review of the most prominent LCA software tools in North America, as well as other international tools. Table 2-3 was taken from their study and summarizes the key LCA programs that are available today and what they do.

Table 2-3: A Summary of the Prominent LCA Tools and What They Do (Trusty & Horst, 2005)

LCA Tools and What They Do		
Level 1A Tools: Focus is on individual products or simple building assemblies (intended for use by LCA practitioners)		
SimaPro	Netherlands	While the countries of origin vary, these tools can be used in different regions by selecting or incorporating the appropriate data. But the task is best done by LCA practitioners for whom the tools are intended.
GaBi	Germany	
Umberto	Germany	
TEAM	France	
Level 1B Tools: Focus is on individual products or simple building assemblies (intended for those who want results, but detailed LCA work is done in the background)		
BEES	USA	Combines LCA and life cycle costing. Includes both brand-specific and generic data.
LCAiT	Sweden	Streamlined LCA tool for product designers and manufactures.
TAKE-LCA	Finland	LCA tool for comparison of HVAC products, including energy content of the product and energy consumption.
Level 2 Tools: Focus on whole building or complete building assemblies or elements (tend to apply from early conceptual through detailed design stages of project)		
ATHENA Environmental Impact Estimator (EIE)	Canada/USA	All of these tools use data and incorporate building systems that are specific to the country or regions for which they were designed.
BRI LCA (energy and CO_2)	Japan	
EcoQuantum	Netherlands	
Envest	United Kingdom	
Green Guide to Specifications	United Kingdom	
LISA	Australia	
LCADesign	Australia	
Level 3 Tools: Whole building assessment frameworks encompassing a broad range of environmental, economic, and social concerns relative to sustainability		
BREEAM	United Kingdom	Uses LCA results from the Level 2 Green Guide.
GBTool	International	Experimental platform that accepts LCA results or performs rudimentary LCA calculations using built-in calculators.
Green Globes	Canada/USA	Assigns a high percentage of resource use credits based on evidence that a design team has conducted LCA using recognized Level 1 or 2 tools.

Note: This table was taken from (Trusty & Horst, 2005)

A similar critical review of building environmental assessment tools was conducted by Haapio and Viitaniemi (2008). In their study, they found that "the comparison of the tools and their results is difficult, if not impossible. For example, the tools are designed for assessing different types of buildings, they emphasise different phases of the life cycle, and they rely on different databases, guidelines, and questionnaires" (Haapio & Viitaniemi, 2008). This highlights one of the major problems with conducting a LCA of a building: there is no clear industry standard to follow in terms of methodology or scope. The process remains extremely complicated and the results can vary, sometimes significantly, from one study to the next. As Trusty and Horst (2005) describe, "because LCA attempts to track a complex world, it remains a complex methodology" (Trusty & Horst, 2005).

2.7.3 Previous LCA Studies of Commercial Buildings

Over the past 15 years, there have been an increasing number of LCA studies of buildings. Historically, most of these studies have investigated the relationships between embodied energy and operating energy for the case of residential (single dwelling or multi-unit apartment) buildings and multi-storey office buildings. Extremely few LCA studies have looked at single-storey retail buildings, which is one of the reasons that this type of building was chosen for this study.

Most of the LCA studies tend to focus on calculating the relationships between embodied energy (initial and recurring) and operating energy of a building over a set lifespan. Figure 2-12 illustrates the typical life-cycle energy use of a building.

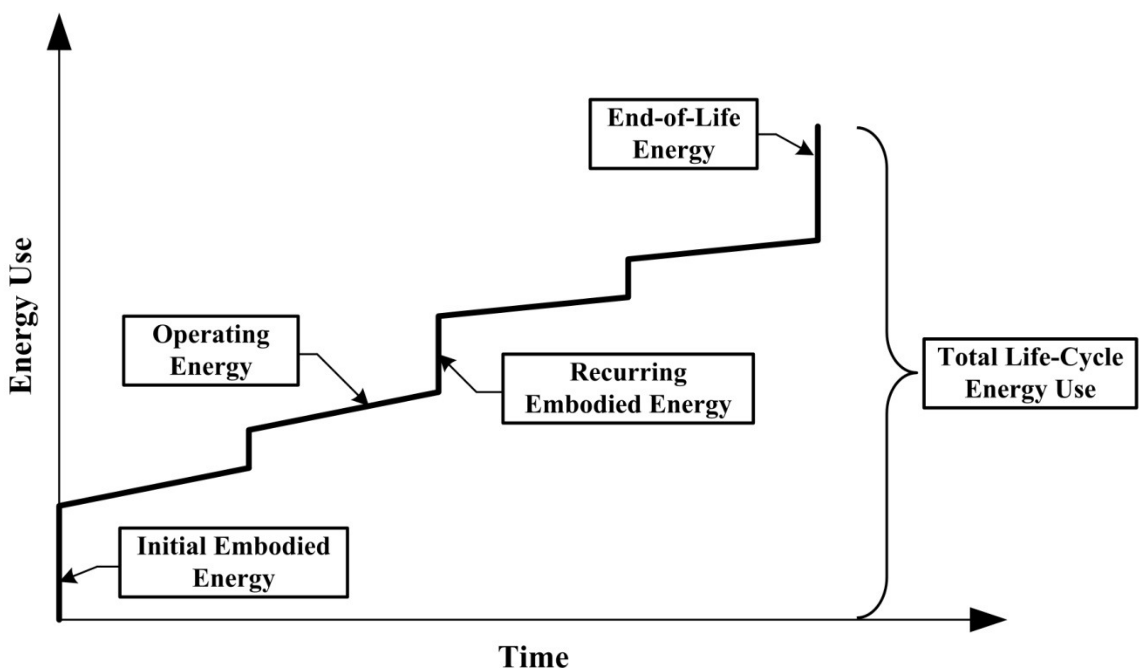


Figure 2-12: Typical Life-Cycle Energy Use of a Building (Itard & Klunder, 2007)

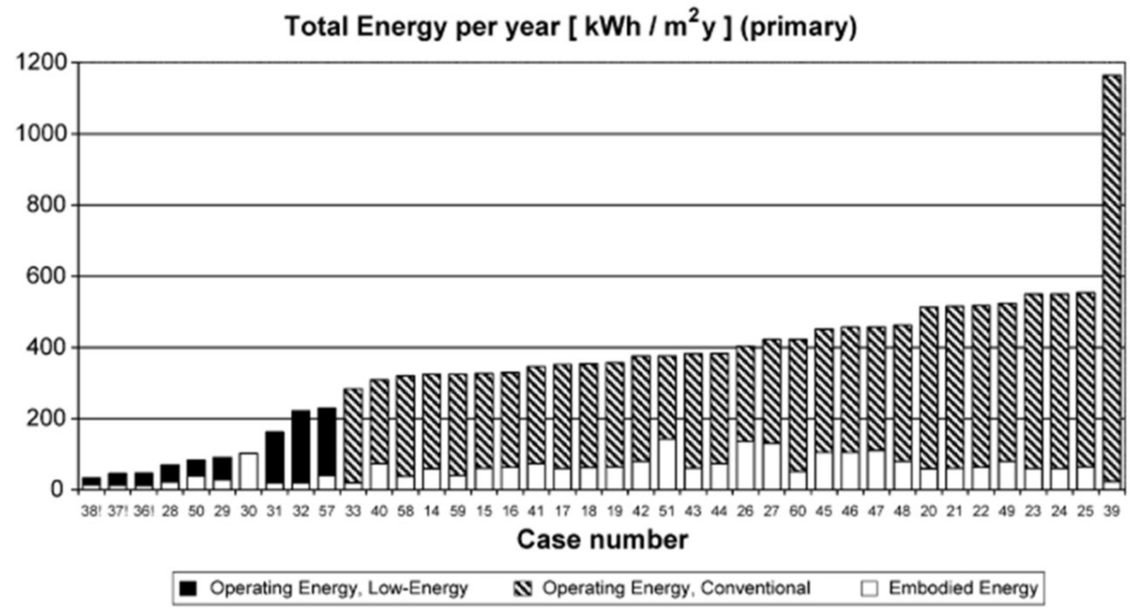
It can be seen how there is an initial amount of embodied energy that is incurred at time 0 due to the construction of the building. Then over time there is a linear increase in the total energy use due to the building operations. At certain intervals of the building's life, as materials and systems need repair and replacement, there are discrete intervals of recurring embodied energy (and possibly an end-of-life energy for decommissioning the building, depending on the scope of the LCA). At the end of the building's lifespan, the total energy use is simply the summation of the initial embodied energy, the recurring embodied energy (and the end-of-life energy if applicable), and the total life-cycle operating energy. The way in which each of these phases is calculated varies from one study to the next.

2.7.3.1 Sartori and Hestne's Study

In order to place the findings of this study into the appropriate context, it is important to have an understanding of the results from previous LCA studies of buildings. Sartori and Hestnes (2007) conducted a literature survey of the total life-cycle energy use of 60 different buildings (both residential and non-residential) from nine different countries. They focused on gathering information on the total embodied energy and operating energy of these buildings (no data was collected on GWP). The majority of buildings that were surveyed were either residential or office buildings. From their literature review, they concluded that despite climate and other differences between the case study buildings, a linear relationship between operating energy and total energy was found (Sartori & Hestnes, 2007). In other words, the operating energy of a building has the single greatest impact on the total life-cycle energy of a building.

Sartori and Hestnes (2007) also discussed one of the systemic problems with the literature dealing with the LCA of buildings. In their literature review, Sartori and Hestnes (2007) found that there was a wide variation in how the data was presented from one study to the next. For instance, the 60 case study buildings that they looked at, all varied in terms of their lifespan, whether energy data was presented in terms of secondary or primary energy, whether only the initial embodied energy or total embodied energy was calculated, and whether end-of-life effects (such as recycling) were considered. These variations in methodology from one study to the next highlight the major problem with the literature dealing with the LCA of buildings. There is no standard methodology that is followed from one LCA study to the next. This creates a huge problem when trying to compare the results from one LCA study to another. Regardless, a review of the literature is still important, as the general trends between embodied energy and operating energy remain consistent from study to study.

Figure 2-13 illustrates the range of total energy for the buildings examined by Sartori and Hestnes (2007) in their comprehensive literature review. It is important to note that only those studies that reported the energy in terms of primary energy (not secondary energy) were included in this graph. The total energy in each case has been divided into the total embodied energy and the total operating energy, annualized for one year. Their data gathering clearly shows the dominance of operating energy compared to embodied energy that is common throughout the literature. They demonstrated that a linear relationship between operating and total energy exists, despite climate and other contextual differences (Sartori & Hestnes, 2007). In their study, the also showed that in the design of low energy buildings (i.e. buildings with a lower operating energy than the typical case), that low energy buildings have a net decrease in total life-cycle energy, but generally also have an increase in total embodied energy (Sartori & Hestnes, 2007). This is because extra materials such as insulation (which is high in embodied energy) are used to help decrease the operating energy of the building.



<u>Note:</u> 1 kWh = 0.0036 GJ

Figure 2-13: Total Energy for a Range of Residential and Non-Residential Buildings from a Literature Review of LCA Studies (presented in terms of primary energy) (Sartori & Hestnes, 2007)

2.7.3.2 Cole and Kernan's Study

One of the most influential LCA studies of buildings was conducted by Cole and Kernan (1996). Their investigation of the life-cycle energy use in office buildings was one of the first studies to comprehensively investigate the relationships between embodied energy and operating energy (this study did not look at GWP). Since then, this paper has been referenced in almost every LCA study of buildings in the last 15 years.

In their investigation, Cole and Kernan looked at the relationships between initial embodied energy, recurring embodied energy, and operating energy for the case of a 4,620 m^2 (50,000 ft^2) three-storey generic office building, located in Toronto and Vancouver and constructed from alternative wood, steel, and concrete structural systems (with and without underground parking).

Figure 2-14 illustrates the breakdown of the initial embodied energy for the steel structure office building located in Toronto as determined by Cole and Kernan (1996). They found that the structure, envelope, and services accounted for 25%, 27%, and 23% of the initial embodied energy of the three-storey office building respectfully. The initial embodied energy was less impacted by the finishes (12%), construction (7%), and the site work (6%).

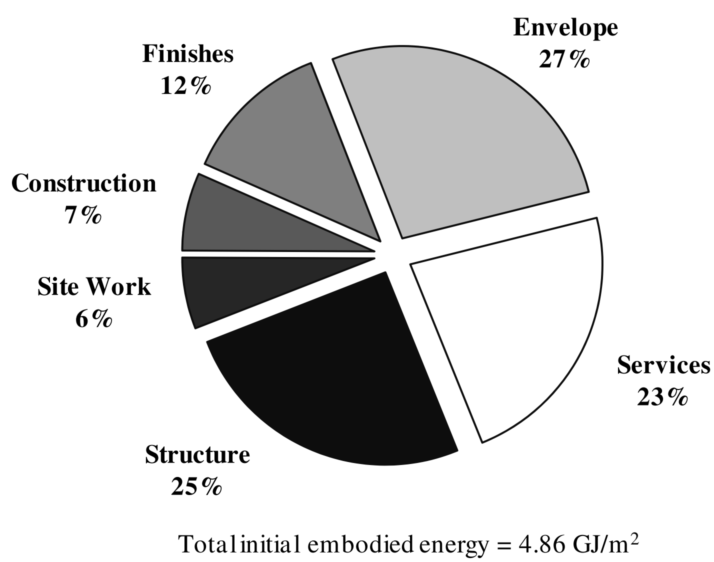
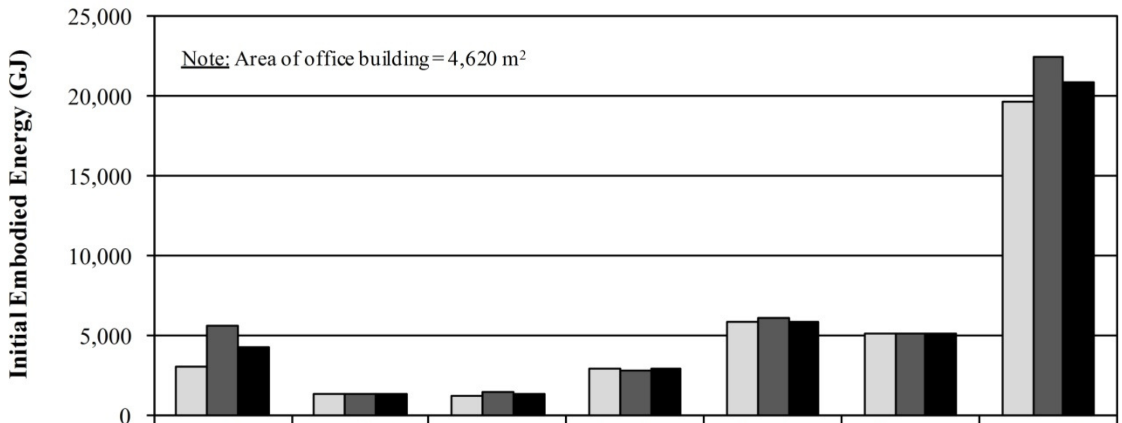


Figure 2-14: Breakdown of the Initial Embodied Energy for Steel Structural Office Building Located in Toronto (Cole & Kernan, 1996)

A similar breakdown of initial embodied energy was calculated for the wood and concrete structure office buildings as well. Figure 2-15 illustrates the initial embodied energy breakdown for the three office buildings (wood, steel, and concrete structure) as determined by Cole and Kernan (1996). It can be seen that there is a slight variation in the initial embodied energy of the structural systems, but that very little variation exists across the three different buildings for the site work, construction, finishes, envelope, and services (HVAC, conveyance, etc.). In essence, the components of the building that are common to all three buildings (i.e. other than the structure) tend to have a moderating effect on the total initial embodied energy of the buildings.



	Structure	Site Work	Construction	Finishes	Envelope	Services	Total
Wood	3,088	1,344	1,289	2,935	5,935	5,110	19,701
Steel	5,650	1,344	1,468	2,799	6,062	5,110	22,433
Concrete	4,303	1,344	1,365	2,920	5,822	5,110	20,864

Figure 2-15: Breakdown of Initial Embodied Energy for Wood, Steel, and Concrete Structure Office Buildings Located in Toronto (Cole & Kernan, 1996)

Looking specifically at the initial embodied energy of the structural systems for the three types of buildings, Figure 2-16 illustrates the initial embodied energy. Cole and Kernan (1996) found that the steel structure had about 1.83 and 1.31 times more initial embodied energy than the wood and concrete structural systems.

Cole and Kernan (1996) also looked at the relationships between the initial embodied energy and the recurring embodied energy for the three types of buildings. Figure 2-17 illustrates the relationships between the initial embodied energy and the recurring embodied energy for the case of the wood structure office building (the steel and concrete buildings are similar). One can see that somewhere between 25 years and 50 years, the recurring embodied energy becomes greater than the initial embodied energy. By the end of a 100 year lifespan, the recurring embodied energy is about 3.4 times greater than the initial embodied energy. Therefore, Cole and Kernan (1996) found that recurring embodied energy is a significant percentage of the total embodied energy of an office building after about 25 years.

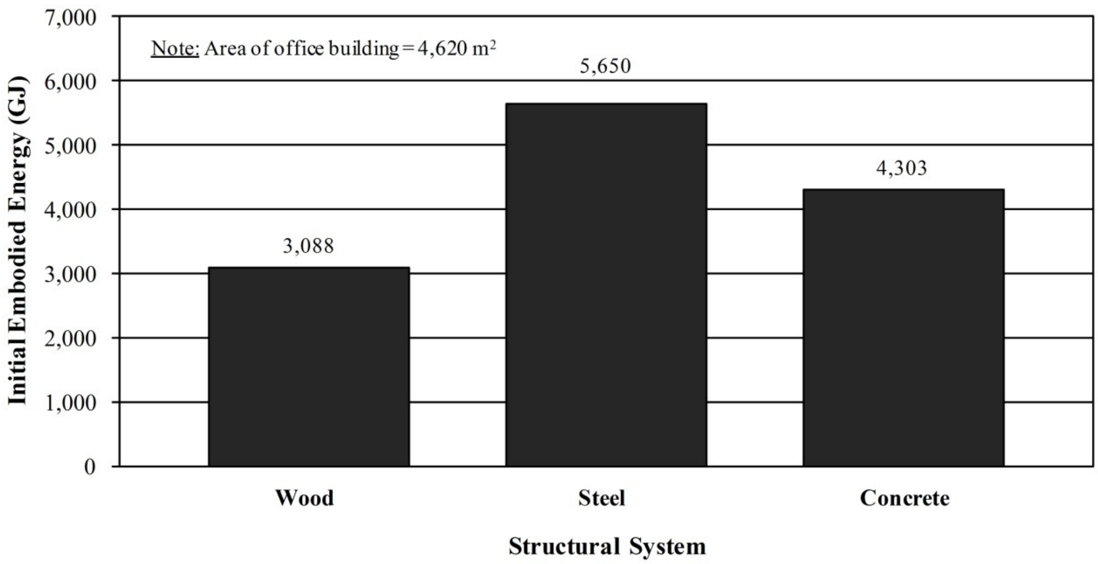


Figure 2-16: Initial Embodied Energy for Wood, Steel, and Concrete Structural Systems for Office Building Located in Toronto (Cole & Kernan, 1996)

The relationships between the initial embodied energy and the recurring embodied energy were also determined for the steel and concrete structure office buildings. Figure 2-18 illustrates the relationships between the initial and recurring embodied energy as determined by Cole and Kernan (1996). The most important point to note is that after about 50 years, the finishes, envelope, and services completely dominate the total embodied energy of the three buildings, since there is far more recurring embodied energy associated with these building components than there is with the structure, site work, or construction. One can imagine that the structure of the building is erect at time 0 and then little to no repair/maintenance is ever done. On the contrary, the finishes in the building are often repaired or replaced many times over the life of a building. Therefore, there is far more recurring embodied energy associated with the finishes over any significant length of time. These findings by Cole and Kernan (1996) show the insignificance of the embodied energy of the structure compared to the other components of the building like the finishes, envelope, and services.

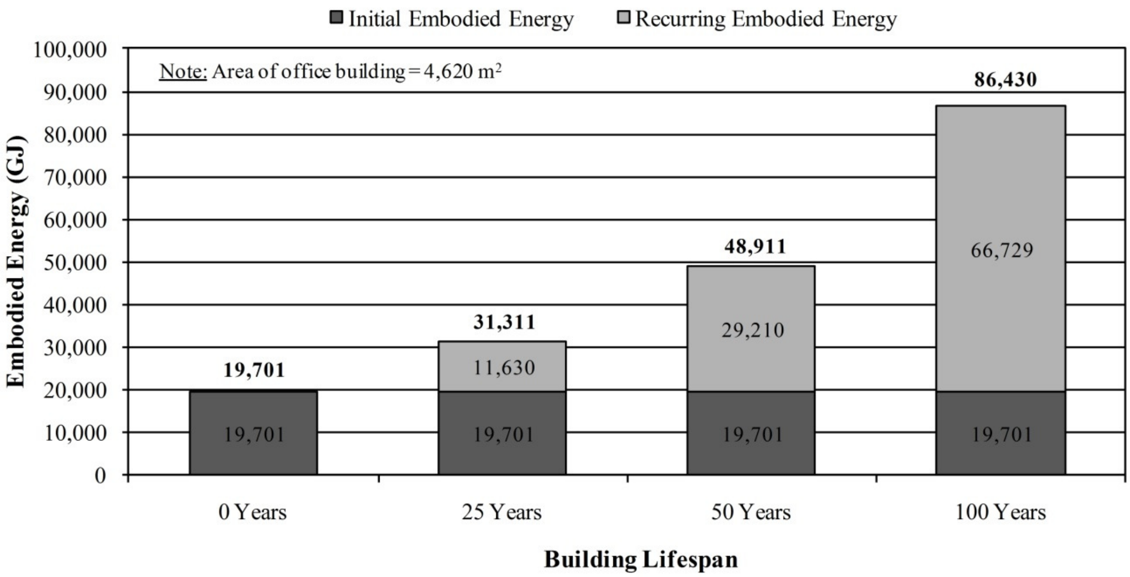
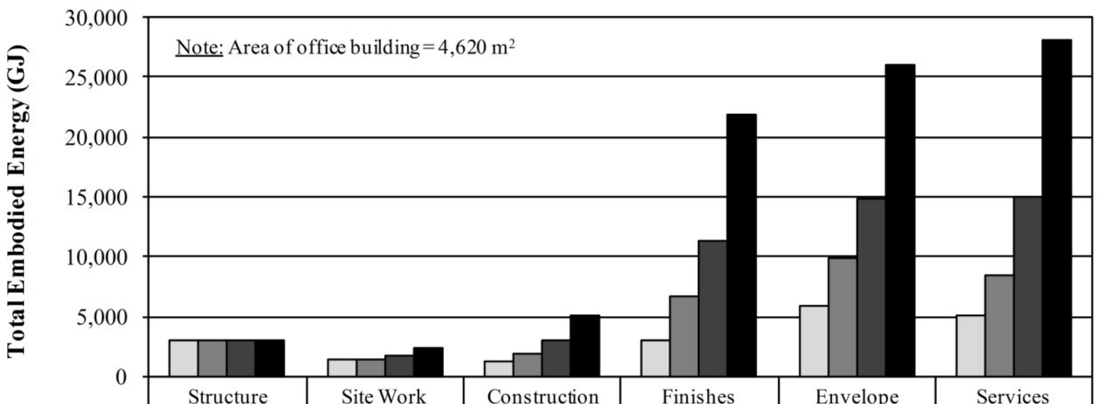


Figure 2-17: Breakdown of Initial Embodied Energy verses Recurring Embodied Energy for Wood Structure Office Building after 50 Year Lifespan in Toronto (Cole & Kernan, 1996)



	Structure	Site Work	Construction	Finishes	Envelope	Services
Initial (GJ)	3,088	1,344	1,289	2,935	5,935	5,110
25 Years (GJ)	3,088	1,409	1,947	6,631	9,808	8,448
50 Years (GJ)	3,088	1,702	2,942	11,332	14,878	14,969
100 Years (GJ)	3,088	2,345	5,066	21,871	25,995	28,065

Figure 2-18: Breakdown of Total Embodied Energy for Wood Structure Office Building after 50 Year Lifespan in Toronto (Cole & Kernan, 1996)

Cole and Kernan (1996) also calculated the operating energy of the three different office buildings. Figure 2-19 illustrates the relationships between the operating energy and the embodied energy for the three buildings. Cole and Kernan (1996) showed that after 50 years, the operating energy represents about 85% of the total energy, compared to only about 15% for the total embodied energy. They also determined that any differences in the embodied energy of the three different buildings are far outweighed by the similarities in the operating energy. In other words, the operating energy has a moderating effect, as it is very similar for the three buildings despite any differences in the material used for the structural system. In fact, the total energy of the steel building is only 1.01 times greater than either the wood or concrete structure office building. Therefore, Cole and Kernan (1996) showed that after 50 years of operation, the total energy is essentially identical for the three office buildings, despite the type of structural systems that is chosen.

Note: 1 kWh = 0.0036 GJ

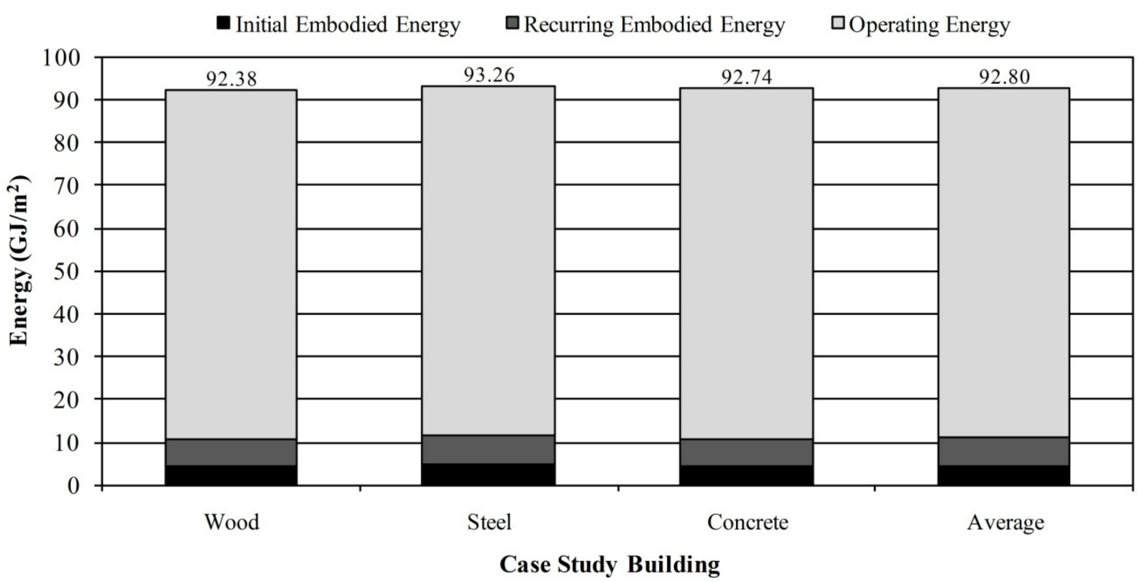


Figure 2-19: Life-Cycle Energy Use for Wood, Steel, and Concrete Structure Office Buildings after 50 Year Lifespan in Toronto (Cole & Kernan, 1996)

Finally, Figure 2-20 was created from the data that Cole and Kernan (1996) found for the three-storey generic office building located in Toronto. The values for the wood, steel, and concrete structure buildings were averaged and the results were plotted. In this case, a linear relationship between the recurring embodied energy and time was assumed for the purposes of this figure. This figure shows how after about 10 years, that operating energy of the building begins to complete dominate the total energy of the office building. After 50 years, the operating energy represents about 88% of the total energy, compared to only about 7% for the recurring embodied energy and 5% for the initial embodied energy.

Note: *1 kWh = 0.0036 GJ*

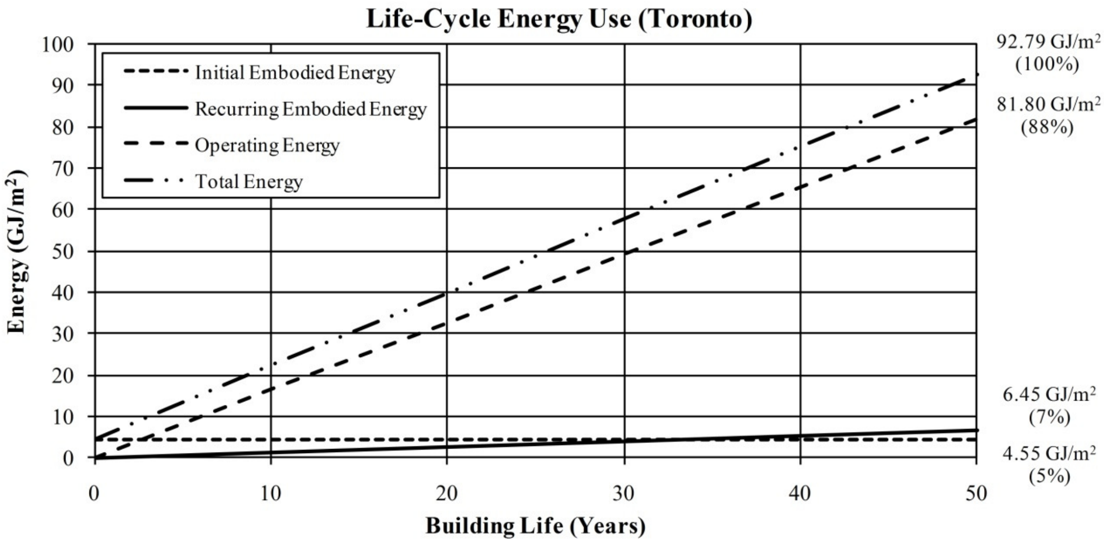


Figure 2-20: Life-Cycle Energy Use (Averaged for Wood, Steel, and Concrete Structure Office Buildings) over 50 Year Lifespan in Toronto (Cole & Kernan, 1996)

In summary, the main conclusions from this very important and influential LCA study of commercial office buildings by Cole and Kernan (1996) are:

1. After about 50 years, the total embodied energy associated with the finishes, envelope, and services far outweighs that of the structure, site work, and construction due to higher amounts of recurring embodied energy.

2. Structure can represent a significant proportion of the initial embodied energy of a commercial office building, but after 50 years the operating energy of the building represents about 85% of the total energy compared to only about 15% for the total embodied energy of the building.

3. Not until the operating energy is reduced by about 50% from typical values, does the embodied energy of the building become significant.

4. Strategies for reducing the life-cycle energy use of an office building should focus on those design considerations that significantly reduce the building's operating energy. Only when the operating energy has been significantly reduced should the emphasis be directed at reducing the building's embodied energy.

2.7.3.3 Ding's Study

An important LCA study that is relevant to this project was conducted by Ding (2007). In this study, Ding (2007) calculated the total energy consumption of 20 public secondary schools in New South Wales, Australia. These schools ranged in size from 1,300 m^2 to 16,000 m^2. In this study, Ding (2007) looked at the initial embodied energy, the recurring embodied energy, and the operating energy (not the end-of-life energy or GWP) of the schools.

In this project, the lifespan of the schools was assumed to be 60 years. The average initial embodied energy per square meter of gross floor area of the 20 schools was found to be about 7.83 GJ/m^2. The average recurring embodied energy was determined to be about 8.19 GJ/m^2 over the 60 year lifespan. In this study, the author also listed a range of values for the initial embodied energy and the recurring embodied energy from their literature review. For commercial buildings, the initial embodied energy per square meter of gross floor area was found to range from 3.4 GJ/m^2 to 19.0 GJ/m^2 (Ding, 2007). Ding (2007) also noted that the recurring embodied energy per square meter of gross floor area from the literature review ranged between 6.32 GJ/m^2 to 20.40 GJ/m^2 for commercial buildings. In this study, Ding (2007) found the average annual operating energy to be about 0.55 GJ/m^2 for the 20 schools in Australia. Recall that the average annual operating energy for an educational services building in Canada is about 1.73 GJ/m^2 (NRCan, OEE, 2010).

Ding (2007) found that the total embodied energy represented about 38% of the total energy after 60 years, compared to 62% for the operating energy. According to Ding (2007), the total embodied energy represents about 37 years of operating energy. Ding (2007) also noted that in the literature, the total embodied energy range from 15 to 37 years of operating energy. So, one can see that the significance of embodied energy relative to operating energy in this study is relatively high compared to the literature. This is likely due to the fact that little heating energy is required for these schools due to them being located in a warm climate in Australia. If these schools were located in a cold climate, like in Canada, then it would be reasonable to expect that the operating energy would be higher.

2.7.3.4 Junnila et al.'s Study

In this study, the authors conducted a LCA of a newly constructed office building in Finland and in the Midwest region of the United States. In both instances, the lifespan of the office building was taken to be 50 years. The office building in Finland was a four-storey, concrete frame building with a gross floor area of about 4,400 m^2. The office building in the United States was a five-storey, concrete frame building with a gross floor area of about 4,400m^2. In this study, the energy, CO_2 emissions, and other measures were reported.

After 50 years of operation, Junnila et al. (2006) calculated the breakdown of total energy use for the Finnish office building to be: materials (6.4%), construction (2.1%), use-phase (87.1%), maintenance (4.1%), end-of-life (0.3%). In terms of CO_2 emissions, this breakdown was: materials (9.8%), construction (1.5%), use-phase (83.0%), maintenance (5.3%), end-of-life (0.4%).

Similarly, after 50 years of operation, Junnila et al. (2006) calculated the breakdown of total energy use for the United States office building to be: materials (8.7 %), construction (1.5%), use-phase (82.9%), maintenance (6.0%), end-of-life (0.9%). In terms of CO_2 emissions, this breakdown was: materials (7.7%), construction (1.5%), use-phase (85.0%), maintenance (5.0%), end-of-life (0.8%).

After 50 years, the Finnish building consumed about 35% less total energy and emitted about 49% less total CO_2 than the office building in the United States (Junnila, Horvath, & Guggemos, 2006). In either case, despite the differences in climate and location, the two offices buildings had a similar breakdown of embodied energy (and CO_2 emissions) and operating energy (and CO_2 emissions).

2.7.3.5 Scheuer et al.'s Study

In this study, the authors conducted a comprehensive LCA of a 7,300 m^2, six-storey university building with a projected lifespan of 75 years. The building is located on the University of Michigan campus.

A complete inventory of all the materials was conducted covering the building structure, envelope, interior structure and finishes, as well as the utility and sanitary systems (Scheuer, Keoleian, & Reppe, 2003). As well, energy modelling was conducted to determine the primary energy use associated with the heating, cooling, ventilation, lighting, hot water, and sanitary water consumption. Demolition and end-of-life effects were also accounted for.

The total life-cycle primary energy intensity over the building's lifespan was calculated by the authors to be about 316 GJ/m^2. The production of the building materials, their transportation to site, and construction of the building was responsible for about 2.2% (7.0 GJ/m^2) of the total life-cycle primary energy of the building. HVAC, electricity, and water services (i.e. building operations) accounted for 97.7% (309 GJ/m^2) of the total life-cycle primary energy. Only about 0.2% (0.63 GJ/m^2) of the total life-cycle primary energy intensity was attributed to the building demolition. In this case, the operating phase primary energy demand exceeds the total embodied energy after only about 3.1 years.

In this particular study, the authors also calculated the GWP of the building. The total life-cycle GWP over the building's lifespan was calculated to be about 18.5 tonnes of CO_2 eq./m^2. They found that the operating phase alone accounted for about 96.5% (17.8 tonnes of CO_2 eq./m^2) of the total life-cycle GWP. The production of the building materials, their transportation to site, and construction of the building was responsible for about 3.2% (0.59 tonnes of CO_2 eq./m^2) of the total life-cycle GWP. Only about 0.2% (0.04 tonnes of CO_2 eq./m^2) of the total life-cycle GWP was attributed to the building demolition.

The findings in this study are much the same as other LCA studies of buildings. The operating phase was by far the greatest contributor to the total life-cycle energy and GWP. The authors noted that one of the greatest limitations on the applicability of LCA research is that it is difficult to do without the building having already been constructed. In fact, they state that "in order for life-cycle modeling to fulfill its potential in assisting design decisions, there is a need for detailed data on specific building systems and components" (Scheuer, Keoleian, & Reppe, 2003).

2.7.3.6 John et al.'s Study

This study is one of the most comprehensive LCA studies of multi-storey buildings that have been conducted to date. The study was completed for the Ministry of Agriculture and Forestry in New Zealand.

In this study, the authors modelled the life-cycle performance of four similar office buildings constructed from concrete, steel, timber, and timber-plus (similar to timber building but timber was also used for the exterior cladding, windows, and ceiling). All the buildings were based on an actual six-storey 4,200 m^2 office building located in Ne Zealand. Both the primary energy and the GWP were calculated over the life of the building for the various building components. The study assumed a 60 year lifespan for all the buildings.

The authors determined that in every case, the life-cycle operating energy and operating GWP of all four buildings contributed towards the total life-cycle energy and total GWP far more than the total life-cycle embodied energy and embodied GWP. In particular, the total life-cycle operating energy (and total life-cycle operating GWP) of the concrete, steel, timber, and timber-plus buildings were 89% (72%), 87% (73%), 91% (86%), and 94% (95%) of the total life-cycle energy (and total life-cycle GWP) (John, Nebel, Perez, & Buchanan, 2008). On the other hand, the total life-cycle embodied energy (and total life-cycle embodied GWP) of the concrete, steel, timber, and timber-plus buildings were 10% (25%), 12% (25%), 8% (18%), and 6% (13%) of the total life-cycle energy (and total life-cycle GWP) (John, Nebel, Perez, & Buchanan, 2008).

Once more, this study showed that for a typical multi-storey office building, the operating effects far outweigh the embodied effects after 60 years, even for buildings that use different materials.

2.7.3.7 A Summary of Previous LCA Studies of Buildings

So far, a brief summary of the LCA studies of buildings that are relevant to this project have been presented. However, it would also be useful to have a summary of a wider scope of LCA studies of commercial buildings, in order to understand the range of values for the total life-cycle energy and GWP of commercial buildings. In this section, the results from a number of LCA studies of buildings have been summarized in Table 2-4.

Only those LCA studies that focus on commercial type buildings have been included in Table 2-4. These include office buildings, schools, and mixed-use buildings (combination of office, retail, and other). A preference was taken towards those LCA studies that looked at buildings located in Canada. Both the operating effects and the embodied effects were recorded for each study. It was decided not to include residential buildings in this review, as residential buildings tend to have a different operating schedule than commercial buildings and are generally constructed using different systems. Therefore, a focus on commercial type buildings was taken.

From Table 2-4, it can be seen that the values for annual total life-cycle operating energy per gross floor area varied from 0.23 to 4.23 GJ/m^2/yr. Similarly, the operating GWP varied from 0.02 to 0.24 tonnes of CO_2 eq./m^2/yr. The total life-cycle embodied energy per gross floor area varied from 3.42 to 22.45 GJ/m^2. Likewise, the total embodied GWP varied from 0.20 to 0.89 tonnes of CO_2 eq/m^2.

Table 2-4: A Summary of Relevant LCA Studies of Commercial Buildings

Source	Location	Type of Building (# of Storeys)	Gross Floor Area (m^2)	Lifespan (years)	Annual Total Life-Cycle Operating Effects per Gross Floor Area		[2] Total Life-Cycle Embodied Effects per Gross Floor Area (after Lifespan)			
					[1] Operating Energy ($GJ/m^2/yr$)	Operating GWP (tonnes of CO_2 eq./m^2/yr)	Initial Embodied Energy (GJ/m^2)	Recurring Embodied Energy (GJ/m^2)	Total Embodied Energy (GJ/m^2)	Total Embodied GWP (tonnes of CO_2 eq./m^2)
(Cole & Kernan, 1996)	Toronto, Canada	[3] OFF, Timber Frame (3)	4,620	50	[4] 1.64 (U)	N/A	4.26	6.32	10.58	N/A
(Cole & Kernan, 1996)	Toronto, Canada	[3] OFF, Steel Frame (3)	4,620	50	[4] 1.64 (U)	N/A	4.86	6.60	11.46	N/A
(Cole & Kernan, 1996)	Toronto, Canada	[3] OFF, Concrete Frame (3)	4,620	50	[4] 1.64 (U)	N/A	4.52	6.42	10.94	N/A
[5] (Sartori & Hestnes, 2007)	Varies	Varies	Varies	Varies	0.23 to 4.23 (P)	N/A	N/A	N/A	0.04 $GJ/m^2/yr$ to 0.5 $GJ/m^2/yr$	N/A
(Junnila, Horvath, & Guggemos, 2006)	Finland	OFF, Concrete Frame (4)	4,400	50	0.93 (U)	[6] 0.05	4.50	2.16	[7] 6.84	[6] 0.51
(Junnila, Horvath, & Guggemos, 2006)	Midwest, U.S.A.	OFF, Concrete Frame (5)	4,400	50	1.35 (U)	[6] 0.10	8.32	4.91	[7] 13.98	[6] 0.89
(Morrison Hershfield Ltd., 2009)	Ottawa, Canada	MIX, Concrete Frame (2)	462	60	N/A	N/A	N/A	N/A	[7] 14.12	[7] 0.75
(Morrison Hershfield Ltd., 2009)	Winnipeg, Canada	OFF, Steel and Wood Frame (4)	3,030	60	N/A	N/A	N/A	N/A	[7] 18.69	[7] 0.80
(Morrison Hershfield Ltd., 2009)	Alberta, Canada	MIX, Concrete and Steel Frame (6)	8,882	60	N/A	N/A	N/A	N/A	[7] 11.21	[7] 0.81
(Morrison Hershfield Ltd., 2009)	Vancouver, Canada	MIX, Concrete and Steel Frame (4)	1,360	60	N/A	N/A	N/A	N/A	[7] 12.57	[7] 0.68
(Treloar, Fay, Ilozor, & Love, 2001)	Melbourne, Australia	OFF, Concrete Frame (3)	6,480	N/A	N/A	N/A	10.70	N/A	N/A	N/A
[8] (Ding, 2007)	New South Wales, Australia	SCH (varies)	Varies	60	0.29 to 1.61 (P)	N/A	2.95 to 12.96	5.87 to 9.49	8.83 to 22.45	N/A
(Scheuer, Keoleian, & Reppe, 2003)	Michigan, U.S.A.	SCH, Steel Frame (6)	7,300	75	4.12 (P)	0.24	N/A	N/A	7.63	0.63
(John, Nebel, Perez, & Buchanan, 2008)	New Zealand	OFF, Steel Frame (6)	4,200	60	0.55 (P)	0.02	0.52	0.52	[7] 5.09	0.45

Table 2-4 (Cont.): A Summary of Relevant LCA Studies of Commercial Buildings

Source	Location	Type of Building (# of Storeys)	Gross Floor Area (m^2)	Lifespan (years)	Annual Total Life-Cycle Operating Effects per Gross Floor Area		[2] Total Life-Cycle Embodied Effects per Gross Floor Area (after Lifespan)			
					[1] Operating Energy ($GJ/m^2/yr$)	Operating GWP (tonnes of CO_2 eq./m^2/yr)	Initial Embodied Energy (GJ/m^2)	Recurring Embodied Energy (GJ/m^2)	Total Embodied Energy (GJ/m^2)	Total Embodied GWP (tonnes of CO_2 eq./m^2)
(John, Nebel, Perez, & Buchanan, 2008)	New Zealand	OFF, Concrete Frame (6)	4,200	60	0.54 (P)	0.02	3.28	0.41	4.15	0.45
(John, Nebel, Perez, & Buchanan, 2008)	New Zealand	OFF, Timber Frame (6)	4,200	60	0.57 (P)	0.02	2.76	0.45	3.42	0.20
(Yohanis & Norton, 2002)	UK	OFF, Steel Frame (1)	584	N/A	N/A	N/A	9.5	N/A	N/A	N/A
Range					**0.23 to 4.23 (P)**	**0.02 to 0.24**	**0.52 to 12.96**	**0.45 to 9.49**	**3.42 to 22.45**	**0.20 to 0.89**

Note: 1 kWh = 0.0036 GJ

Note: OFF = Office, SCH = School, MIX = Mixed-Use (Office, Retail, Other)

[1] (P) = Primary Energy, (S) = Secondary Energy, (U) = Unknown

[2] Assumed that embodied energy was calculated in terms of primary energy (unclear in most studies)

[3] Office buildings with no underground parking

[4] Cole and Kernan (1996) also calculated operating energy for same building located in Vancouver, Canada to be 47.95 GJ/m^2 (0.96 $GJ/m^2/yr$)

[5] Sartori and Hestnes (2007) conducted a literature review of 60 buildings (both residential and non-residential) from nine different countries. The range of values in this table were estimated from their graphs

[6] GWP is presented in terms of CO_2 not CO_2 equivalent

[7] Also includes energy (and/or GWP) for end-of-life

[8] In this study, 20 public secondary schools were examined

2.7.4 Problems with LCA Studies of Buildings

As alluded to thus far, there are several problems with the way that LCA's of buildings have been conducted in the literature that make it difficult (if not impossible) to compare one LCA study to the next. Some of the more important limitations and discrepancies between the LCA studies from the literature are discussed in the paragraphs below.

Perhaps the most systemic problem with the LCA studies of buildings in the literature today is the lack of consistency when it comes to the life-cycle inventories (LCI) of building materials. Only in recent years has there been a concerted effort to quantify the embodied energy and GWP of the numerous building materials. However, to date there is still no industry standard LCI that is recognized. Without an industry standard LCI, it is virtually impossible to compare the results of one

LCA study to the next. Each study in the literature tends to use different embodied energy and GWP numbers for the various building materials (see Table 2-1and Table 2-2). Historically it has been left up to the LCA researchers to establish a range of possible values for the embodied energy and GWP of the various building materials and to estimate the expected lifespan of the materials. The significant variation in LCI data from one LCA study to the next makes it extremely difficult to compare results.

Another problem with the LCA studies of buildings in the literature is the confusion between primary energy and secondary energy. It is extremely important to distinguish between the two when talking about the embodied energy and the operating energy of a building. Secondary energy is the energy used by the final consumer. In terms of buildings, this is the heating, cooling, lighting, etc. energy use of a building. On the contrary, primary energy is a measure of the total energy including the energy used by the final consumer (i.e. the secondary energy) as well as the energy used in transforming one energy form to another (like coal to electricity), the energy used by providers in providing energy to the market, and more. In other words, the primary energy is a complete measure of the total energy, as it includes the energy requirements upstream of the final end use, such as the energy generation and transportation. In the literature, many of the studies neglect to mention if their results are in terms of primary or secondary energy. This is a problem, as the results cannot be compared with any degree of certainty from one LCA study to the next.

The absence of any data on the GWP of buildings in the literature is also a problem. It is difficult to find comprehensive LCA studies of energy use in buildings, but it is nearly impossible to find detailed LCA studies of the GWP of buildings. Those studies that do attempt to quantify the GWP of buildings either present the results in terms of CO_2 emissions or CO_2 equivalent emissions. Carbon dioxide equivalency (CO_2 eq.) is a measure of the equivalent amount of CO_2 that would have the same GWP as a mixture of CO_2 and other greenhouse gases in the Earth's atmosphere. Therefore, it includes a measure of other gases such as methane, nitrous oxide, ozone, even water vapour, which all have an ability to trap heat in the Earth's atmosphere and therefore contribute towards global warming. Those studies that only report CO_2 emissions fail to account for these other gases.

The level of complexity varies significantly between LCA studies in the literature. Some studies are very detailed and comprehensive, while others only attempt a simple approximation of the life-cycle environmental effects. For instance, some studies consider a wide range of building components such as the exterior walls, roofs, windows, doors, structure, interior finish, services, foundations, etc.

However, other studies only consider a few of these components in detail. The number of building materials that are considered in each case also differs. Some studies provide a detail material takeoff, while others only estimate the materials in the building on a gross scale. Not every LCA study considers the end-of-life effects, construction effects, transportation effects, or recurring effects. In other words, the scope of the various LCA studies can be drastically different, making a direct comparison between studies very challenging. On top of this, some LCA studies make use of advanced LCA software programs to conduct their analysis. Others tend to use simple material takeoffs and hand calculations to come up with an estimate of embodied effects and operating effects for a building.

A big problem that everyone who conducts a LCA of a building faces is a lack of information at the design phase of the project (which is when a detailed LCA would be most helpful). It is difficult to estimate the total life-cycle environmental effects of a building accurately when the building has yet to be designed or built. A detailed and accurate LCA of a building is possible only after it is designed or built. However, at this point one could argue that a LCA is not as useful, as the impact of the building on the environment has already been set. Scheuer, Keoleian, & Reppe (2003) state that one of the greatest limitations of LCA research for buildings is that it is difficult to do without the building having already been constructed. In fact, "in order for life-cycle modeling to fulfill its potential in assisting design decisions, there is a need for detailed data on specific building systems and components" (Scheuer, Keoleian, & Reppe, 2003). This is currently lacking in the literature.

Finally, a significant deficiency in the literature is the lack of information on the life-cycle environmental burdens of single-storey retail buildings. In fact, no relevant LCA studies dealing with single-storey retail buildings could be located in the literature. Most LCA studies for commercial buildings have been done for multi-storey buildings (usually office buildings or mixed-use buildings).

Chapter 3
Methodology: Life-Cycle Assessment of Building Components

3.1 Introduction

The LCA process in this study was carried out in accordance with the four phase approach suggested in ISO 14044 (ISO, 2006). According to ISO 14044, the first phase of any LCA study is to define a goal (ISO, 2006). The primary goal of this study was to conduct a comprehensive LCA for the components of a single-storey retail building located in Toronto, Canada, to determine which building components contribute the most towards the total life-cycle energy use and GWP after 50 years.

To date, the vast majority of LCA studies of buildings tend to focus on residential and multi-storey office buildings. Despite the fact that single-storey commercial buildings represent a large proportion of buildings in North America, there is little to no research on the LCA of these types of buildings. There is a need for a comprehensive LCA study of single-storey commercial buildings in Canada, specifically single-storey retail buildings. In particular, there is a need for a study that looks at a broad scope of building components for a single-storey retail building and that puts the life-cycle impacts of these various components into perspective. That is the goal of this study.

In order to evaluate the components of a single-storey retail building and to put the life-cycle impacts of the various components into perspective, the following two part methodology was followed:

1. First, a comprehensive LCA was conducted for the major components of a single-storey retail building in Canada. It is worth mentioning that many of the building components that were studied are also found in residential buildings. These building components can be divided into seven categories: exterior infill walls, roofs, floors, windows and doors, structural systems (beams and columns), foundations, and interior partitions. A description of these building components, along with an explanation of the method that was followed to calculate their total life-cycle energy use and GWP, is presented here in Chapter 3.

2. Next, the focus was expanded to include entire building systems rather than only individual building components. A detailed LCA was performed for five single-storey retail buildings located in Toronto. The energy use and GWP of the various components of a single-storey retail building (exterior infill walls, roofs, floors, windows and doors, structural systems, foundations, and interior partitions) were compared to the overall energy use and GWP of an entire building. The five case study retail buildings are described in Chapter 4.

3.2 Description of Baseline Retail Building

In order to conduct a comprehensive LCA of energy use and GWP for the components of a single-storey retail building, it was useful to establish a baseline building. The baseline building was created to represent the features of a typical single-storey retail building that would be constructed in Canada today. Using the baseline retail building as a datum, alternative design strategies were explored for the various building components (exterior infill walls, roofs, floors, windows and doors, structural systems, foundations, and interior partitions).

The baseline retail building was established based on a combination of ASHRAE Standard 90.1-2007 (ASHRAE, 2007) requirements for climate zone 6 (Toronto, Canada) and the RSMeans Assemblies Cost Data (RSMeans, 2003). A rendering of the baseline retail building can be seen in Figure 3-1.

Figure 3-1: Baseline Retail Building

A detailed description of the baseline retail building can be found in Appendix A. This includes architectural floor plans, sections, elevations, structural drawings, as well as a summary of the key building descriptors. However, a brief summary of some important features of the baseline retail building are presented next.

- Located in Toronto, Ontario, Canada
- 50 year lifespan
- Stand alone retail building

- Single-storey with a small mezzanine for offices
- Gross floor area (not including mezzanine) of 6,300 ft^2 (586 m^2)
- Building orientation: rectangular shape (long dimension aligned along E-W axis)
- Approximately 17% window-to-wall ratio
- Hours of operation: Monday to Saturday, 8am-9pm and Sunday, 9am-6pm
- Cooling equipment: direct expansion (DX) coils (electric)
- Heating equipment: combustion furnace (natural gas)
- System type: packaged single zone DX with furnace (central packaged single zone air conditioner with combustion furnace)
- Thermostat set-points:
    - Occupied spaces: cool to 76.0°F (24.4°C) and heat to 70.0°F (21.1°C)
    - Unoccupied spaces: cool to 82.0°F (27.8°C) and heat to 64.0°F (17.8°C)
- Zoning: 100% perimeter zone
- Designed for NBCC 2005 structural loads

A summary of the building components that make up the baseline retail building including: the exterior infill wall, roof, structure, mezzanine floor, windows, doors, interior partitions, and foundations can be found in Table 3-1. As mentioned earlier, these building components were chosen to represent typical assemblies that would be specified for a single-storey retail building in Canada. Although the building components for the baseline retail building were chosen as representative of common practice in Canada, there are countless alternative strategies that could have been chosen. The goal of this study is to investigate the components of a single-storey retail building within a comprehensive LCA, in order to determine which components have the greatest impact on the environment. Therefore, in the next section a range of alternative design strategies for the components of a typical single-storey retail building in Canada are presented.

Table 3-1: Description of Baseline Retail Building Components

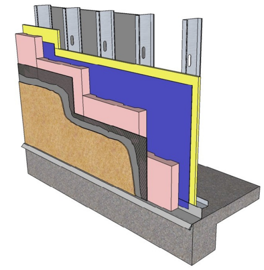
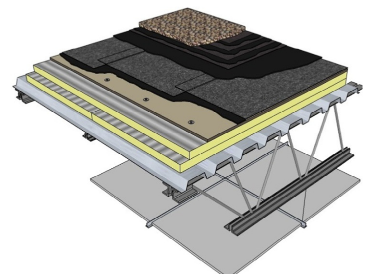
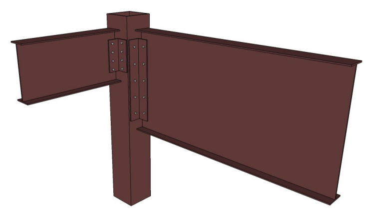
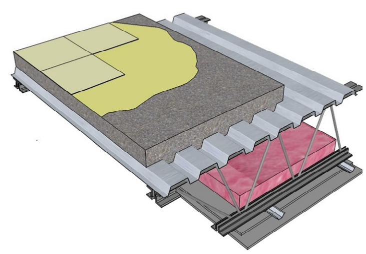
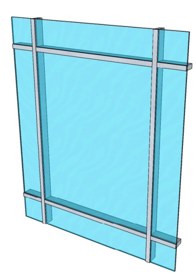
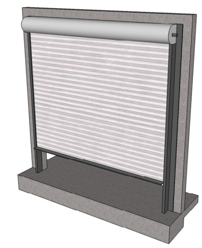
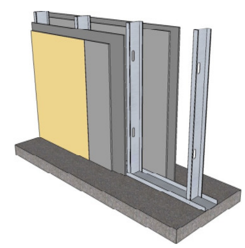
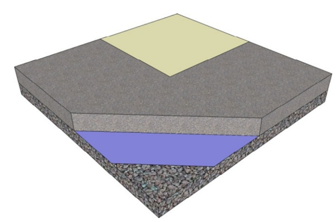
Exterior Infill Wall		
ID:	SS-W6 *(see Appendix B for details)*	
Description:	39 mm x 152 mm x 1.21 mm cold-formed steel studs (400 mm o/c) with 50 mm extruded polystyrene rigid insulation and exterior insulation and finish system (EIFS) coating over metal mesh	
Roof		
ID:	OWSJ-R2 *(see Appendix B for details)*	
Description:	OWSJ (1,200 mm o/c) and metal deck with continuous 75 mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	
Structure (Beams and Columns)		
ID:	S-1 *(see Appendix B for details)*	
Description:	Conventional braced steel frame (H.S.S. columns and W-section beams). Lateral bracing provide by steel rod X-bracing.	
Mezzanine Floor		
ID:	FL-3 *(see Appendix B for details)*	
Description:	OWSJ (1,200 mm o/c) and metal deck with 89 mm concrete topping, vinyl floor tile finish, and drywall ceiling	
Windows (i.e. Curtainwall)		
ID:	W-9 *(see Appendix B for details)*	
Description:	Self-supported aluminum curtainwall system with thermal break (two 6 mm sealed viewable glazing panes with 12.7 mm airspace, no low-E coating, and no argon between panes)	

Table 3-1 (Cont.): Description of Baseline Retail Building Components

Doors		
ID:	D-2, D-3, D-4 *(see Appendix B for details)*	 *(See Appendix B for D-2 and D-3)*
Description:	D-2: Insulated steel exterior door with no glazing D-3: Uninsulated aluminum exterior door with 80% glazing D-4: Insulated overhead steel door with no glazing	
Interior Partitions		
ID:	CMU-P1, SS-P2 *(see Appendix B for details)*	 *(See Appendix B for CMU-P1)*
Description:	CMU-P1: 200 mm concrete masonry unit partition SS-P2: 39 mm x 152 mm x 0.91 mm cold-formed steel studs (600 mm o/c) with two layers of drywall	
Foundations		
ID:	SOG-5, IF-5, PF-7 *(see Appendix B for details)*	 *(See Appendix B for IF-5 and PF-7)*
Description:	SOG-5: 200 mm thick concrete slab-on-grade (30 MPa concrete, average flyash content, and 10 mil poly) IF-1: Isolated concrete footing with concrete pier (20 MPa concrete and average flyash content) PF-5: Perimeter concrete strip footing with uninsulated concrete foundation wall (20 MPa concrete strength and average flyash content)	

3.3 Identifying Building Components for the LCA

As stated in the introduction of this chapter, the primary goal of this LCA study is to understand the breakdown of energy use and GWP as it pertains to the components of a single-storey retail building in Canada. In order to do this, 220 different building components were analyzed within the framework of a comprehensive LCA. The LCA of these building components was performed over a 50 year lifespan for a commercial building located in Toronto, Canada. These building components represent the spectrum of common assemblies that are used in commercial buildings in Canada, but many of the components are also used in residential buildings. A detailed description of each of the 220 different building components that were studied can be found in Appendix B.

The building components chosen for this study were selected based on two criteria: discussions with building industry professionals and from the RSMeans Assemblies Cost Data (RSMeans, 2003) manual. The RSMeans manual lists a range of typical assemblies for commercial buildings in Canada. The remainder of this section will introduce the range of buildings components that were examined in this study.

3.3.1 Description of Exterior Infill Wall Enclosures

A total of 109 commercial exterior infill wall enclosures were examined in this study. The wall assemblies represent a broad sample of exterior infill walls that are typically used in commercial buildings in Canada. Aside from resisting lateral loads, these walls were not designed for load bearing applications. A complete description of the wall enclosures (including all of the assembly layers and a list of the building material quantities) that were chosen for this study can be found in Appendix B-1.

The various wall assemblies have been classified based on their structural framing material and have been placed into the following eight categories:

- Concrete masonry unit walls (CMU-W)
- Concrete tilt-up walls (CTU-W)
- Wood structural insulated panel walls (WSIP-W)
- Metal structural insulated panel walls (MSIP-W)
- Cold-formed steel stud walls (SS-W)
- Wood stud walls (WS-W)
- Pre-engineered steel building walls (PENG-W)
- Aluminum curtainwalls (CWALL-W)

Displayed in Figure 3-2 are the typical assembly layers that were modelled for each of the exterior infill wall enclosures. In general, each wall consisted of: an exterior cladding material, an air space, exterior installed rigid insulation (if applicable), a water barrier membrane, the structural framing (with cavity insulation if applicable), and an interior finish. The air barriers (AB), vapour barriers/retarders (VB/VR), and water barriers (WB) were selected and located within the wall assemblies based on building science principles for a cold-climate in Canada.

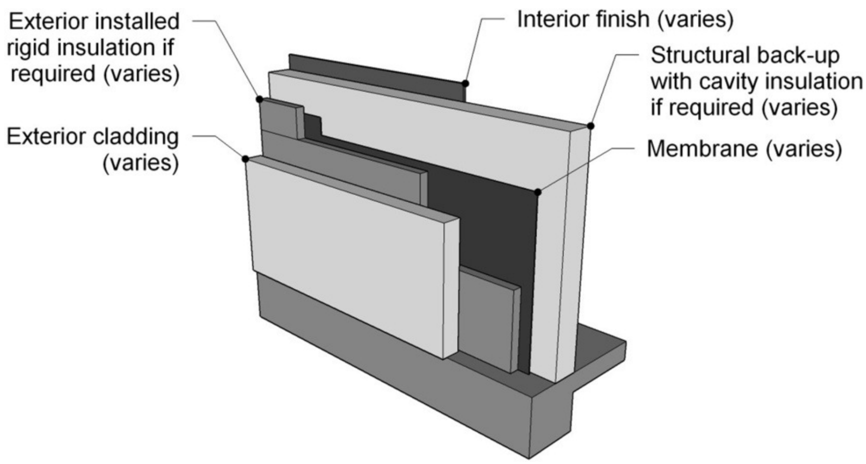


Figure 3-2: Typical Assembly Layers for Exterior Infill Wall Enclosures

The wall types examined in this study are listed in Table 3-2, along with a breakdown of the different options that were explored. It is important to note that most wall assemblies are a collection of multiple sub-assemblies, layers, and materials that all act together as part of a greater system. A change to one of these layers can have a significant impact on the performance of the entire enclosure (both in terms of thermal resistance and total energy use or GWP). One of the goals of this study is to compare the LCA results for various different types of walls. Therefore, it is not enough to simple look at one or two different steel stud walls for example. The interdependency of the layers within a wall assembly means that a change to one layer or material can have an impact on the remaining layers. It was important to look at a broad range of different wall enclosures, including several variations of the same wall. It was important to consider an array of strategies for each wall type that included different cladding materials, insulation strategies, structural materials, and finishes.

Table 3-2: Range of Exterior Infill Wall Design Strategies

Wall Type	Variables	Options
CMU-W	Cladding	– Standard (Ontario) clay brick cladding – Split-faced concrete brick cladding – 125 mm concrete pre-cast cladding – Pine wood bevel siding – 26 ga. (0.46 mm) galvanized corrugated cold-formed steel (CFS) cladding – EIFS coating over metal mesh
	Insulation	– 50 mm exterior installed extruded polystyrene rigid insulation – 100 mm exterior installed extruded polystyrene rigid insulation – 140 mm fibreglass batt insulation installed between CFS studs
	Structure	– 200 mm standard weight concrete block with grouted 15M rebars @ 400 mm o/c

Table 3-2 (Cont.): Range of Exterior Infill Wall Design Strategies

Wall Type	Variables	Options
CTU-W	Cladding	– None – 50 mm concrete front wythe – Standard (Ontario) clay brick cladding – Split-faced concrete brick cladding
	Insulation	– None – Same options as CMU
	Interior Finish	– Latex/alkyd based paint – Regular gypsum board – 26 ga. (0.46 mm) galvanized corrugated CFS cladding
	Structure	– 150 mm concrete tilt-up wall (30 MPa, 9% flyash) with reinforcement and miscellaneous steel angles
WSIP-W	Cladding	– Same options as CMU
	Insulation	– 50 mm exterior installed extruded polystyrene rigid insulation – 100 mm extruded polystyrene rigid insulation between two layers of OSB – 150 mm extruded polystyrene rigid insulation between two layers of OSB
	Structure	– Wood structural insulated panel comprised of 12 mm OSB, extruded polystyrene insulation (thickness varies), and 12 mm OSB with 200 mm, 14 ga. (1.90 mm) galvanized CFS Z-girts @ 1,200 mm o/c
MSIP-W	Insulation	– 150 mm polyurethane foam insulation installed between two corrugated CFS sheets – 100 mm polyurethane foam insulation installed between two corrugated CFS sheets – 75 mm polyurethane foam insulation installed between two corrugated CFS sheets
	Structure	– Metal structural insulated panel comprised of 26 ga. (0.46 mm) galvanized corrugated CFS cladding, polyurethane foam insulation (thickness varies), and 26 ga. (0.46 mm) galvanized corrugated CFS cladding with 200 mm, 14 ga. (1.90 mm) galvanized CFS Z-girts @ 1,200 mm o/c
SS-W	Cladding	– Same options as CMU
	Insulation	– Same options as CMU
	Structure	– 39 mm x 152 mm 18 ga. (1.21 mm) CFS studs @ 400 mm – 39 mm x 152 mm 16 ga. (1.52 mm) CFS studs @ 600 mm
WS-W	Cladding	– Same options as CMU
	Insulation	– Same options as CMU (except wood studs not CFS studs)
	Structure	– 38 mm x 140 mm wood studs @ 400 mm o/c – 38 mm x 140 mm wood studs @ 600 mm o/c
PENG-W	Insulation	– None – 140 mm fibreglass batt insulation (compressed at girt locations) – 150 mm extruded polystyrene rigid insulation between two corrugated CFS sheets – 250 mm extruded polystyrene rigid insulation between two corrugated CFS sheets
	Structure	– 26 ga. (0.46 mm) galvanized corrugated CFS cladding with 200 mm, 14 ga. (1.90 mm) galvanized CFS Z-girts @ 1,200 mm o/c
CWALL-W	Cladding	– Painted metal spandrel panel – Opaque glazing spandrel panel
	Insulation	– None – 90 mm high density fiberglass insulation with metal backpan
	Structure	– Self-supporting aluminum curtainwall system with thermal break (100 mm deep mullions spaced 2,000 mm o/c vertically and 1,500 mm o/c horizontally

3.3.2 Description of Roof Enclosures

A total of 58 different commercial roof enclosures were examined in this study. In the literature, very little research has been carried out on the LCA of roof enclosures, especially for single-storey commercial buildings. The roof enclosures that were included in this study represent a broad sample of typical roof enclosures for a commercial building in Canada. A complete description of the roofs (including all of the assembly layers and the material quantities) can be found in Appendix B-2.

The various roof assemblies have been classified based on their structural framing material and have been placed into the following seven categories:

- Concrete hollow core roof (CHC-R)
- Open web steel joist roofs (OWSJ-R)
- Cold-formed steel roofs (CFS-R)
- Glulam roofs (GLU-R)
- Wood structural insulated panel roofs (WSIP-R)
- Metal structural insulated panel roofs (MSIP-R)
- Pre-engineered steel building roofs (PENG-R)

Displayed in Figure 3-3 is the typical assembly layers that were identified for each of the roofs. In general, each roof enclosure consisted of: a roof covering, a roof coverboard (if required), insulation, a water barrier membrane, the roof deck, the roof structure, and a suspended acoustic tile ceiling.

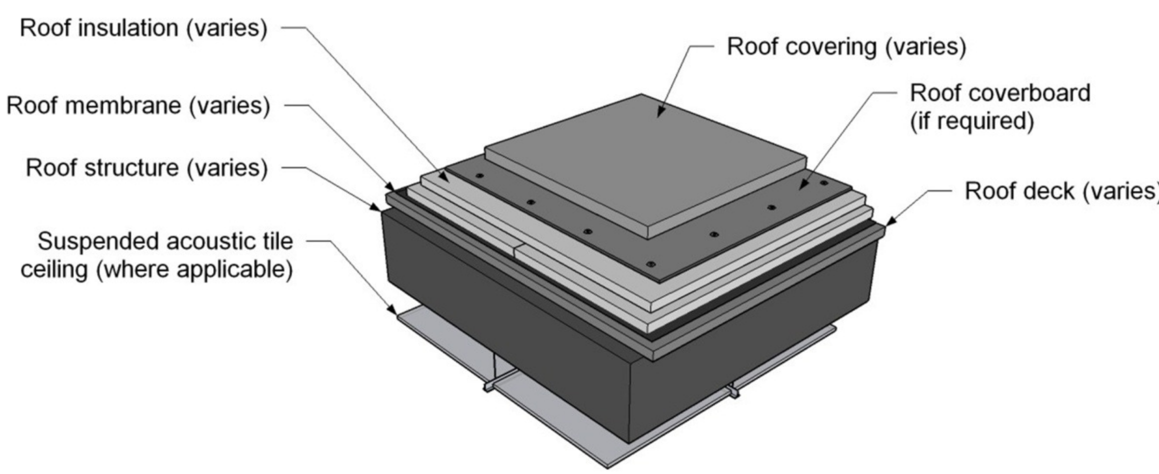


Figure 3-3: Typical Assembly Layers for Roof Enclosures

The roof types examined in this study are listed in Table 3-3, along with a breakdown of the different options that were explored. Similar to the exterior infill walls, a wide range of different roofs were identified, including many variations of the same roof type. It was acknowledged that even within the same type of roof, there could be significant variation in terms of the thermal resistance, the total energy use, and GWP. It was important to consider an array of strategies for each roof type that included different roof coverings, insulation strategies, and structural materials.

Table 3-3: Range of Roof Design Strategies

Roof Type	Variables	Options
CHC-R	Roof Covering	– SBS modified bitumen membrane roof assembly – 4-ply built-up asphalt roof assembly with gravel ballast – EPDM roof assembly with gravel ballast – PVC membrane roof assembly with gravel ballast – Commercial 26 ga. (0.46 mm) galvanized standing seam steel roof – Green roof assembly
	Insulation	– 75 mm polyisocyanurate insulation – 100 mm extruded polystyrene rigid insulation (green roof assembly only) – 150 mm polyisocyanurate insulation – 200 mm extruded polystyrene rigid insulation (green roof assembly only)
	Structure	– 200 mm concrete hollow core roof slab (45+ MPa, 9% flyash, typical reinforcement)
OWSJ-R	Roof Covering	– Same options as CHC
	Insulation	– Same options as CHC
	Structure	– 550 mm open web steel joists @ 1,200 mm o/c with 39 mm x 22 ga. (0.76 mm) galvanized corrugated CFS deck
CFS-R	Roof Covering	– Same options as CHC
	Insulation	– Same options as CHC
	Structure	– (1) – 39 mm x 245 mm, 16 ga. (1.52 mm) galvanized CFS C-joist @ 600 mm o/c with 19 mm plywood deck – (2) – 39 mm x 245 mm, 16 ga. (1.52 mm) galvanized CFS C-joists back-to-back @ 600 mm o/c with 19 mm plywood deck – 600 mm deep CFS trusses spaced @ 600 mm with 19 mm plywood deck – 762 mm deep CFS trusses spaced @ 1,200 mm with 39 mm x 22 ga. (0.76 mm) galvanized corrugated CFS deck
GLU-R	Roof Covering	– Same options as CHC
	Insulation	– Same options as CHC
	Structure	– 80 mm x 494 mm 24f-E D-Fir-L glulam joists @ 1,800 mm o/c with 38 mm tongue and groove solid wood plank decking

Table 3-3 (Cont.): Range of Roof Design Strategies

Roof Type	Variables	Options
WSIP-R	Roof Covering	– Same options as CHC
	Structure	– Wood structural insulated panel comprised of 12 mm OSB, extruded polystyrene insulation (thickness varies), and 12 mm OSB with 229 mm, 14 ga. (1.90 mm) galvanized CFS Z-shape purlins @ 1,200 mm o/c
MSIP-R	Roof Covering	– None – Green roof assembly
	Insulation	– 150 mm polyurethane foam insulation installed between two corrugated CFS sheets – 100 mm polyurethane foam insulation installed between two corrugated CFS sheets – 75 mm polyurethane foam insulation installed between two corrugated CFS sheets
	Structure	– Metal structural insulated panel comprised of 26 ga. (0.46 mm) galvanized corrugated CFS cladding, polyurethane foam insulation (thickness varies), and 26 ga. (0.46 mm) galvanized corrugated CFS cladding with 229 mm, 14 ga. (1.90 mm) galvanized CFS Z-shape purlins @ 1,200 mm o/c
PENG-R	Insulation	– None – 150 mm fibreglass batt insulation – 150 mm extruded polystyrene rigid insulation between two corrugated CFS sheets – 250 mm extruded polystyrene rigid insulation between two corrugated CFS sheets
	Structure	– 26 ga. (0.46 mm) galvanized corrugated CFS cladding with 200 mm, 16 ga. (1.52 mm) galvanized CFS Z-shape purlins @ 1,200 mm o/c

It is important to note that not all roof joists can span the same distance. Some reach their optimum design state when spanning longer distances and some at shorter spans. To account for this variability, each roof joist was designed for a typical span that it would likely be used for, rather than for one standard span for all. This ensured that unfair advantage/disadvantage was not placed on one system over another, by designing it for a span for which it was not intended. Each roof was designed for loads according to Part 4 of the NBCC 2005 (Canadian Commission on Building and Fire Codes, 2006) using the typical design span.

3.3.3 Description of Structural Systems

Three different structural systems were examined in this study. The structural systems that were looked at are described in more detail in Appendix B-3.

For the purposes of this study, the structural system is defined as the primary structural components of a building including the beams and columns. In this study, the wall framing and roof purlins are included in the exterior infill wall and roof assemblies respectfully. As this study is specifically dealing with a single-storey retail building, it was important to identify the most common types of structural systems that are used in these types of buildings today. Those structural systems include: conventional hot-rolled steel systems, heavy timber systems, and pre-engineered steel building systems. Previous LCA studies have examined many of the conventional types of structural systems including: hot-rolled steel, timber, and concrete structures. However, there is almost no research on the environmental impact of pre-engineered steel building systems, in comparison to other conventional structural systems. Pre-engineered building systems are highly optimized structural systems from a materials and cost perspective. It is thought that this high level of material optimization will translate into a structural system that is very competitive in terms of total life-cycle energy use and GWP. Therefore, one of the major contributions of this study will be the detailed LCA of a pre-engineered steel building system, which is currently lacking in the literature.

It should be noted that structural systems are very unique to the characteristics of an individual project. Therefore, rather than trying to evaluate the total life-cycle energy use and GWP for countless different arrangements of beams and columns here, the results in Appendix B-3 were calculated per m^2 of floor area for each type of structural system. A full LCA of the three different structural systems as applied to a typical single-storey retail building in Canada will be discussed in more detail in Chapter 4.

3.3.4 Description of Floor Assemblies

A total of five different commercial floors were examined in this study. A complete description of the floor assemblies (including all of the assembly layers and the material quantities) that were examined can be found in Appendix B-4.

In this study, only single-storey retail buildings were examined. Therefore, only the most common floor assemblies were examined. The floor assemblies in this study were restricted to typical floor systems that would be used for a mezzanine level where offices are located. Each floor was designed for structural loads according to Part 4 of the NBCC 2005 (Canadian Commission on Building and Fire Codes, 2006) using a typical design span (similar to the method described for the roof enclosures).

Figure 3-4 illustrates the typical assembly layers that were modelled for each of the floor systems. In general, each floor system consisted of: vinyl floor tile secured with adhesive, a floor deck, a floor structure (with fiberglass batt insulation if required), and two layers of regular gypsum board with steel resilient channels (if required).

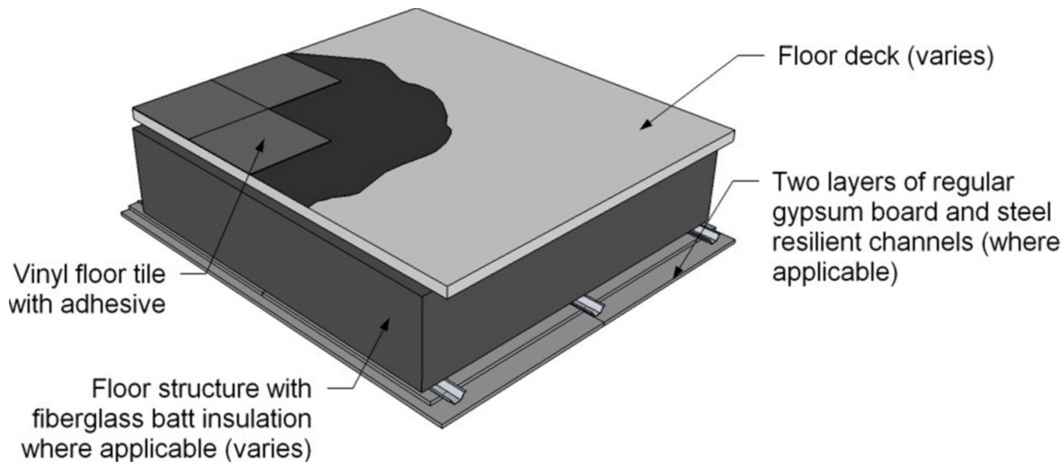


Figure 3-4: Typical Assembly Layers for Floor Systems

3.3.5 Description of Windows and Doors

A total of nine different windows and six different doors were examined in this study. The windows and doors were chosen to represent both what is typically used in commercial buildings in Canada today, as well as some more progressive alternatives. A complete description of the windows and doors that were chosen for this study can be found in Appendix B-5. Figure 3-5 displays the typical components that were modelled for the windows and doors in this study.

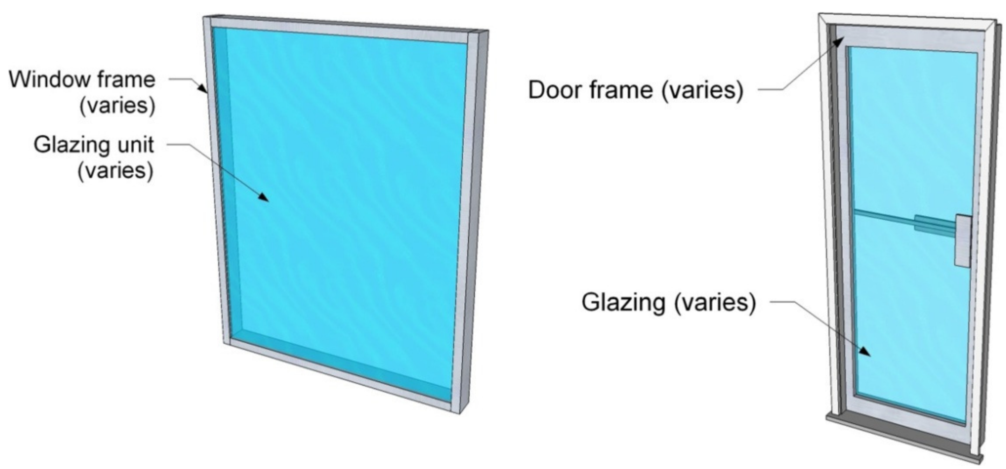


Figure 3-5: Typical Components of Windows and Doors

In general, each window consisted of a window frame and a glazing unit. No operable windows were considered. Each door consisted of a door frame and glazing (if applicable). The list of doors examined in this study included: exterior doors, interior doors, and an overhead sectional door. In each case, the frame material and the characteristics of the glazing were varied when populating the list of windows and doors to examine in this study.

The windows and doors examined in this study are listed in Table 3-4, along with a breakdown of the different options that were explored. In general, the frame material was varied in each case as well as the glazing (from typical glazing to a more progressive alternative).

Table 3-4: Range of Window and Door Design Strategies

Type	Variables	Options
WINDOWS (W)	Frame material	– Aluminum with thermal break – PVC clad wood with thermal break – PVC with thermal break – Wood with thermal break – Self-supporting aluminum curtainwall grid system with thermal break
	Glazing	– Typical sealed double pane glazing unit with 12.7 mm airspace (no argon between panes) and no low-E coating – Sealed double pane glazing unit with 12.7 mm argon space (argon gas between panes) and tin based low-E coating (e = 0.05) – Two 6 mm sealed viewable glazing panes with 12.7 mm airspace (no argon between panes and no low-E coating) (aluminum curtainwall only)
DOORS (D)	Type	– Solid wood, no glazing – Insulated steel, no glazing – Uninsulated aluminum, 80% glazing

3.3.6 Description of Foundations

Seven different isolated concrete footing and pier combinations, eight different concrete strip footing and foundation wall combinations, and six different concrete slab-on-grades were examined in this study. All of the foundation options considered in this study can be found in Appendix B-6.

Displayed in Figure 3-6 to Figure 3-8 are the typical components that were identified for each of the foundation systems. Figure 3-6 illustrates a typical isolated concrete footing and pier that was identified for this study. Figure 3-7 shows the typical parameters that were identified for the concrete strip footings and foundation walls. Likewise, Figure 3-8 illustrates the typical parameters for a slab-on-grade. The goal was to populate a list of common foundation systems that are used in commercial buildings in Canada. Typical sizes were selected based on design experience.

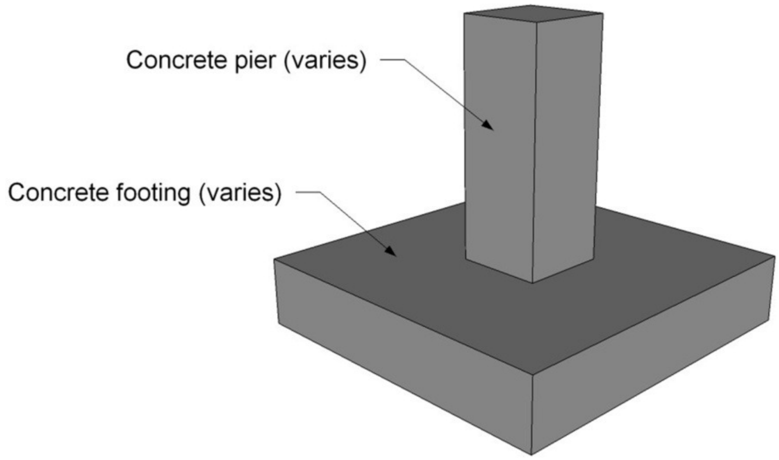


Figure 3-6: Typical Components of Isolated Footings with Piers

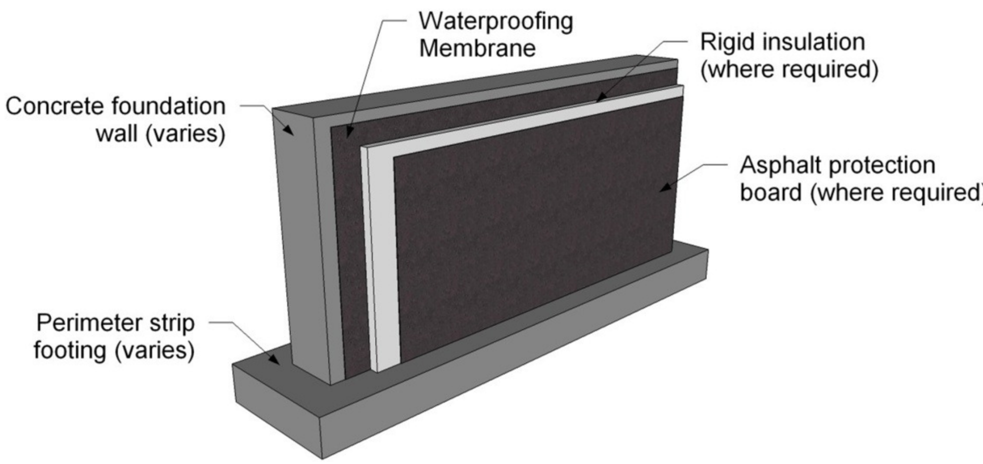


Figure 3-7: Typical Components of Perimeter Footings and Foundation Walls

The foundation components examined in this study are listed in Table 3-5, along with a breakdown of the different options that were explored. In each case, a number of different options were identified. Variables such as concrete strength, flyash content, insulation, and size were among the options that were explored. Obviously footing size and concrete strength vary depending on the structural loads that must be resisted and the nature of the soil conditions. However, it is still useful to identify a range of typical options for a single-storey retail building.

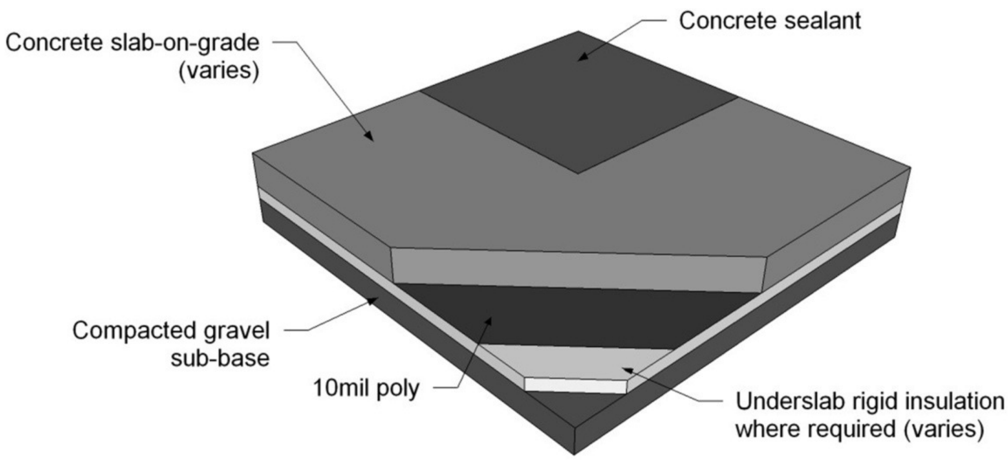


Figure 3-8: Typical Components of Slab-On-Grade

Table 3-5: Range of Foundation Design Strategies

Foundation Type	Variables	Options
IF-FDN	Strength	– 20 MPa – 30 MPa
	Flyash Content	– Average flyash content (9%) – High flyash content (35%)
	Footing Size	– 1,200 mm x1,200 mm x 350 mm – 1,500 mm x 1,500 mm x 350 mm – 1,800 mm x 1,800 mm x 350 mm – 2,400 mm x 2,400 mm x 400 mm
PF-FDN	Strength	– 20 MPa – 30 MPa
	Flyash Content	– Average flyash content (9%) – High flyash content (35%)
	Exterior Insulation	– None – 50 mm extruded polystyrene rigid insulation
SOG-FDN	Slab Thickness	– 100 mm – 200 mm
	Flyash Content	– Average flyash content (9%) – High flyash content (35%)
	Under Slab Insulation	– None – 50 mm extruded polystyrene rigid insulation

3.3.7 Description of Interior Partitions

Nine different interior partition walls were examined in this study. A detailed description of each interior partition wall (including all of the assembly layers and the material quantities) can be found in Appendix B-7.

The various interior partition walls have been classified based on their structural framing material and have been placed into the following three categories:

- Concrete masonry unit partition walls (CMU-P)
- Cold-formed steel stud partition walls (SS-P)
- Wood stud partition walls (WS-P)

Figure 3-9 displays the typical assembly layers that were identified for each of the interior partition walls. In general, each interior partition wall consisted of an interior finish on either side of the wall and the structural framing (with cavity installed fiberglass batt insulation if required). The interior partition walls were not designed for load bearing applications.

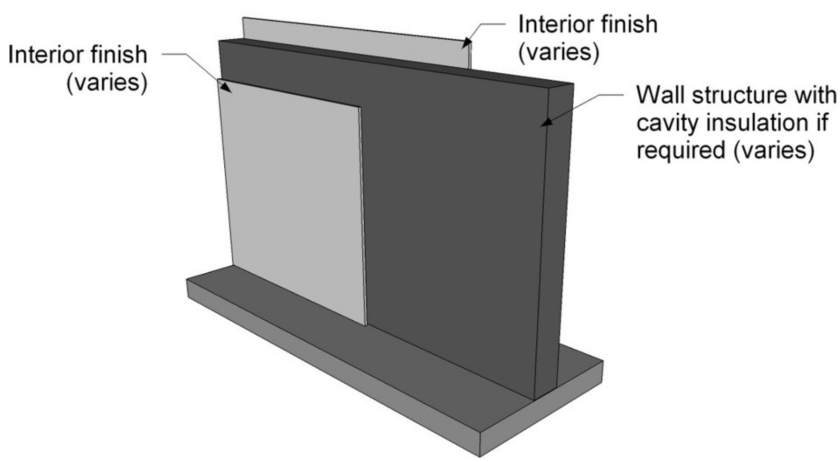


Figure 3-9: Typical Assembly Layers for Interior Partition Walls

The interior partition walls examined in this study are listed in Table 3-6, along with a breakdown of the different options that were explored. The primary variables considered were the framing material, the stud spacing, and the presence of insulation for fire-rating and sound dampening.

Table 3-6: Range of Interior Partition Wall Design Strategies

Type	Variables	Options
CMU-P	None	– Only one concrete masonry unit interior partition wall was examined. It consisted of 200 mm standard weight concrete block with grouted 15M rebars @ 400 mm o/c
SS-P	Structure	– 39 mm x 152 mm 20 ga. (0.91 mm) CFS studs @ 400 mm – 39 mm x 152 mm 20 ga. (0.91 mm) CFS studs @ 600 mm
	Insulation	– None – 140 mm fibreglass batt insulation installed between CFS studs
WS-P	Structure	– 38 mm x 140 mm wood studs @ 400 mm – 38 mm x 140 mm wood studs @ 600 mm
	Insulation	– Same as SS

Up to this point, the baseline retail building has been discussed along with the range of alternative building components to be considered in the comprehensive LCA. The remainder of this chapter will concentrate on outlining the method that was followed in carrying out the LCA study. In particular, the scope of the LCA will be identified, as well as the methods that were followed for calculating the life-cycle embodied energy, embodied GWP, operating energy, and operating GWP of a typical single-storey retail building in Canada.

3.4 Scope of LCA

According to ISO 14044, the first step in performing any LCA study is defining the goal and scope (ISO, 2006). The goal of this LCA study has already been discussed: to conduct a comprehensive LCA for the components of a single-storey retail building located in Toronto, Canada, to determine which building components contribute the most towards the total life-cycle energy use and GWP after 50 years. In this section, the scope of the LCA study will be presented.

From one LCA study to the next, there can be substantial variation in the scope of the analysis. Some LCA studies only consider the immediate effects, such as the on-site construction and operating energy of a building (and its components). Other studies get into more detail and look back up the supply chain to account for the environmental effects that are associated with mining the natural resources, manufacturing the building materials, transporting them to the construction site, and so on. Therefore, it is very important to specify the system boundaries as well as the outputs of the LCA analysis. Figure 3-10 illustrates the system boundaries and outputs for the LCA in this study.

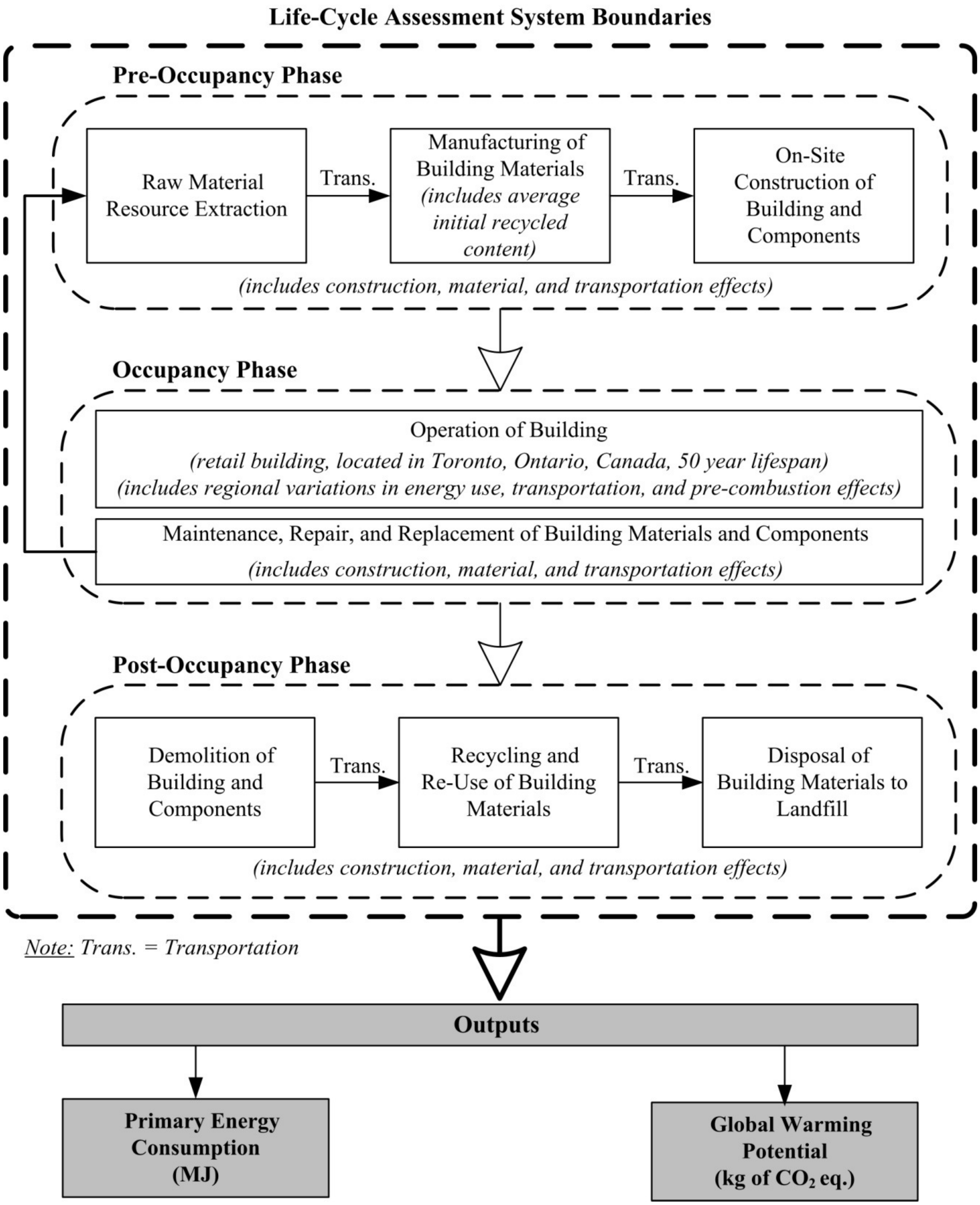


Figure 3-10: Life-Cycle Assessment System Boundaries and Outputs

In the LCA of the components of a single-storey retail building in this study, the system boundaries can essentially be divided into three categories: the pre-occupancy phase, the occupancy phase, and the post-occupancy phase. The outputs of this LCA study include the total primary energy consumption and the total GWP for all three phases.

The pre-occupancy phase includes the effects of mining the raw materials, manufacturing the building materials, and constructing the building (and its components) on-site. The occupancy phase is concerned with the operation of the building over its lifespan (i.e. the non-renewable resources used for heating, cooling, ventilating, lighting, etc.) as well as the effects of maintenance, repair, and replacement of the various building components over their lifespan. The post-occupancy phase deals with the demolition of the building, the recycling and re-use of the building materials, and the disposal of the remaining waste materials. At each stage, the total transportation effects are included, along with the construction and material effects. It is also important to note that the primary energy consumption and the GWP associated with each of the three phases were calculated based on region specific data. In this case, Toronto was used as the location for the LCA study. Therefore, the energy generation profile (i.e. percentage of energy from hydroelectric, nuclear, coal, oil, natural gas, etc.) of Toronto was used, as well as the transportation and repair/maintenance profiles of a building located in Toronto. In other words, the outputs were generated from location specific data.

The outputs of this LCA study were generated for a building with a 50 year lifespan. A 50 year lifespan is commonly used in LCA studies of buildings and allows for a reasonable cycle of maintenance, repair, and replacement of building components.

As mentioned, the two main outputs from this LCA study are primary energy consumption and GWP. Recall that primary energy includes "the effects of energy used by the final consumer (secondary energy use), non-energy uses, intermediate uses of energy, energy in transforming one energy form to another (e.g. coal to electricity), and energy used by suppliers in providing energy to the market (e.g. pipeline fuel)" (Natural Resources Canada, 2008). Some LCA studies only consider the secondary energy in their outputs. However, by using primary energy as one of the outputs of this study, the result is a more complete analysis of the actual energy use across all three phases.

3.5 Evaluating Embodied Energy and Embodied GWP

Now that the goal and scope of the LCA have been identified, a discussion of the methods for conducting the LCA can proceed. From the literature review it is known that energy use and GWP for a building can be divided into embodied effects and operating effects. The method for evaluating the embodied effects in this study will be presented first, followed by a discussion of how the operating effects were accounted for in the next section.

Accurately accounting for the environmental damage caused by a building over its lifespan is a very complex task. Buildings and their components are far from homogonous assemblies and often are comprised of an extensive array of materials that are intertwined within numerous sub-assemblies. Accurately identifying, quantifying, and optimizing all of the materials used over the lifespan of a building from an environmental perspective is extremely complex. A major source of difficult arises from the fact that buildings and their component parts are comprised of numerous different materials and their effects are linked to multiple different industries. Accounting for the energy use and GWP at each stage of the raw material acquisition, processing, manufacturing of building materials, transportation, construction, repair, replacement, and end-of-life effects of whole buildings (and their components) is computationally intense. Fortunately, there is a growing list of computer programs available to calculate the cradle-to-grave environmental impacts of both building materials and whole building projects.

In North America, the ATHENA® Environmental Impact Estimator (ATHENA® EIE) for Buildings is the only software tool available that is specific to the North American industry, can evaluate both whole buildings and individual assemblies, and is based on internationally recognized LCA methods. The ATHENA® EIE for Buildings is quickly becoming the standard for LCA calculations in the North American building industry. The ATHENA® EIE for Buildings v4.0.64 (The Athena Institute, 2010) was used in this study to calculate the embodied energy and embodied GWP for each alternative building component of a single-storey retail building over a 50 year lifespan in Toronto, Canada.

The ATHENA® Institute is a non-profit organization that has been around for over a decade. The Institute is dedicated to improving the sustainability of the built environment by providing a tool that can be used at the conceptual design phase of a building to evaluate and compare alternative design options within a comprehensive LCA methodology.

Recall that according to ISO 14044, the second stage of any LCA study is the definition of a life-cycle inventory LCI) of the materials and their associated environmental impacts (ISO, 2006). As one might imagine, calculating the environmental impacts of all the materials in a building project would be incredibly complex and time consuming. In fact, without access to the energy use and GWP data from the manufactures of the building materials, this would be impossible. Fortunately, the ATHENA® Institute has spent a great deal of money, time, and resources compiling a comprehensive LCI database for the various building materials and continues to update the database as new information becomes available. A major strength of the LCI database is the fact that it is regionally specific to North America and considers variations in manufacturing technology, energy generation, recycled content, and transportation depending on the location of the building project. The ATHENA® LCI database is widely considered to be the most comprehensive and relevant LCI database for the North American building industry and is the main engine used in the ATHENA® EIE for Buildings.

Using its comprehensive LCI database, the ATHENA® EIE for Buildings v4.0.64 considers the full life-cycle impacts of (The Athena Institute, 2009):

- Building type and lifespan
- Material manufacturing, including resource extraction and initial recycled content
- Related transportation effects
- On-site construction effects
- Regional variation in energy use, energy generation, transportation, and other factors
- Maintenance, repair, and replacement effects over the building's lifespan
- Demolition, disposal, and recycling effects at the end of the building's lifespan
- Operating energy emissions and pre-combustion effects over the building's lifespan

The ATHENA® EIE is able to summarize the complex LCA calculations into a series of useful measures. For the purposes of this study, the primary energy consumption and the GWP were the two important outputs that were calculated.

Each building component identified in this study was individually modeled as accurately as possible using the standard inputs in the ATHENA® EIE for Buildings v4.0.64. A bill of materials was then generated in the ATHENA® EIE for each case. This bill of materials was compared to expected results and any discrepancies were overcome by adjusting the material quantities for the building component via. the user specified additional materials input feature of the software. It should be mentioned that the ATHENA® EIE is currently unable of calculating the embodied effects associated with the mechanical, electrical, and plumping services in a building directly. Therefore, the embodied effects associated with these services have not been accounted for in this study.

Ultimately, calculating the life-cycle primary energy consumption and GWP of a building and its component parts is not an exact science. Some degree of uncertainty is inevitable given the complexity of the calculations and the inherent degree of uncertainty in the LCI data. However, the ATHENA® EIE for Buildings v4.0.64 provides the best method for estimating these effects for the North America building industry today. According to the ATHENA® Institute, the ATHENA® EIE for Buildings is able to "model well over 1000 structural and envelope assembly combinations and is generally applicable to more than 90% of the typical North American building stock" (The Athena Institute, 2008). However, there is one significant limitation of this software. The ATHENA® EIE for Buildings is unable of calculating the operating energy consumption and operating GWP of a building directly. In fact, the total energy use and total GWP of a building is a combination of the embodied energy, embodied GWP, operating energy, and operating GWP. Therefore, since the ATHENA® EIE is only capable of calculating the embodied effects, additional means had to be employed to calculate the operating effects. The method for calculating the operating effects for the components of a building will be discussed next.

3.6 Evaluating Operating Energy and Operating GWP

Recall that the total energy use of a building is a combination of the total embodied energy and the total operating energy. The ATHENA® EIE for Buildings is able to calculate the embodied energy of the building materials, but is unable to calculate the operating energy consumption of a building directly. It does have a calculator that converts operating energy (i.e. secondary energy) into primary energy and GWP over a building's lifespan. However, additional software programs are required to determine the appropriate fuel consumption due to building operations to input into the ATHENA® EIE converter. There are a number of different computer programs that are available to do this and they all vary in terms of their difficulty to use and their comprehensiveness. The 'Quick Energy Simulation Tool' (eQUEST) computer software provides an excellent combination of both a user friendly interface and detailed building energy simulation capability.

eQUEST is based on the latest DOE-2 building simulation engine. DOE-2 is the most widely respected building energy simulation program available today. It has been around since the 1970's and has been funded in large part by ASHRAE, NASA, and the United States Department of Energy.

eQUEST allows a user to perform sophisticated hourly energy simulations of a building to predict its operating energy use. Among other inputs, eQUEST allows for a detailed description of a building's geometry, layout, envelope, operating schedule, space conditioning systems (such as HVAC and lighting), climatic data, and much more. The result is a comprehensive and detailed output of monthly and annual energy use for the building. Recall from the literature review that two kinds of energy were identified: secondary energy (i.e. operating energy) and primary energy. Embodied energy is expressed in terms of primary energy. However, eQUEST (and other building energy modelling programs) calculate secondary energy. Therefore, once the annual energy use of a building has been determined from eQUEST, it can be entered into the ATHENA® EIE converter to calculate the resulting total primary energy consumption and total GWP. By converting the operating energy (i.e. secondary energy) into primary energy, the results can be compared directly with the embodied energy results from the ATHENA® EIE for Buildings.

Calculating the embodied energy for each of the 220 different building components in this study is relatively straightforward using the ATHENA® EIE for Buildings. However, estimating the impact on the operating energy of a building for each of the 220 different building components is less straightforward. In order to get an estimate of the operating energy for each of the 220 different building components in this study, an energy model was created for the baseline retail building using QUEST v3.63 (Hirsch, 2009). Using this model, the 50 year operating energy use was estimated for the baseline retail building. Once the breakdown of natural gas and electricity use was determined from eQUEST, the numbers were input in the ATHENA® EIE converter and the total operating primary energy use and GWP was determined for the baseline retail building. These values became the datum for all subsequent energy models in this study.

Next, using the eQUEST model of the baseline retail building as the datum, a new eQUEST model was created for each of the 220 different building components. In each model, all of the other building variables were held constant, except that one of the 220 different building components was substituted for the corresponding component in the baseline retail building model. In each case, the 50 year operating energy use of the modified baseline retail building was simulated in eQUEST. By doing this for each of the 220 different building components, the 50 year operating energy of the modified baseline retail building could be compared to the 50 year operating energy of the baseline retail building. The difference (either an increase in energy or a decrease in energy) from the baseline could be found and the difference attributed to the corresponding substitution of a particular building component. Therefore, one-by-one the impact on the 50 year operating energy of the baseline retail building due to the systematic substitution of the 220 different building components could be determined. In each case, the annual electricity and natural gas use of the modified baseline retail building from eQUEST was input into the ATHENA® EIE converter and the primary operating energy and GWP for each of the 220 building components was determined. In this way, the impact that each of the 220 different building components in this study had on the operating energy use of a single-storey retail building after 50 years could be estimated.

3.7 Calculating the Thermal Resistance of Building Enclosures

In the previous section, a method was presented for calculating the impact on the operating energy of a typical single-storey retail building for each of the 220 different building components. In each case, an eQUEST model was created and the 50 year operating energy of the modified baseline retail building was determined. However, in order to create the eQUEST models, the thermal resistance of the different building components had to be determined. In particular, it was important to get an accurate measure of the thermal resistance for each exterior infill wall, roof, window, door, and slab-on-grade in order to determine the corresponding operating energy and GWP related to each case.

This section begins with a brief overview of some basic principles of heat transfer through buildings and some of the underlying assumptions that were made for this study. This is followed by a comparison of the primary methods that were used in this study to calculate the thermal resistance of the different building components.

3.7.1 Background on Heat Transfer in Buildings

Accurately accounting for heat transfer through the building enclosure is critical to calculating the total life-cycle energy and GWP of a building. In addition, "understanding heat transfer and the temperature distribution through building materials and assemblies is important for assessing energy use, thermal movements, durability, and the potential for moisture problems" (Straube & Burnett, 2005).

A number of LCA studies have estimated that the operating energy of a typical building (either residential or commercial) is upwards of 85% or more of the total life-cycle energy after 50 years. With operating energy contributing so heavily towards the overall environmental burdens of a building, it is critical to accurately calculate the resistance to heat flow through each alternative building enclosure, in order to determine which systems use less energy over time.

Thermal resistance is a measure of the ability of a building material (or assembly) to resist heat flow though it. In the imperial system, thermal resistance is expressed in terms of R-value and has units of (hr·ft^{2}·^{0}F)/Btu. In the SI system, thermal resistance is expressed in terms of R_{SI}-value and has units of (m^{2}·K)/W.

Alternatively, the heat flow through an enclosure assembly is sometimes expressed in terms of the overall heat transfer coefficient (U-value or U_{SI}-value). The overall heat transfer coefficient is "a system measure of the amount of heat flow that will occur across a unit area of an enclosure system or other assembly for a unit temperature difference" (Burnett & Straube, 2005). The overall heat transfer coefficient is simply the inverse of the thermal resistance and is often referred to in these types of calculations.

Heat flow through the building enclosure can occur in one, two, or three dimensions. It can also be steady state or transient, where temperature and/or heat flow vary with time. The appropriate method for calculating the thermal resistance of a building enclosure depends on the type of problem at hand. That being said, there are several ways of calculating the thermal resistance of the building enclosure. The three most common methods are discussed next, as well as the method that was chosen for this study.

3.7.2 Calculating One-Dimensional Heat Flow Using the Tabular Method

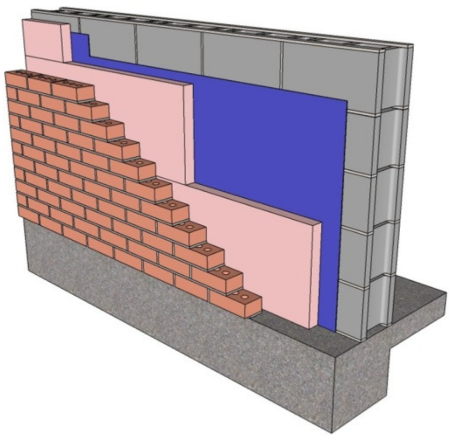
The tabular (or series) method is the simplest of the three methods and as such, has a limited range of usefulness. It is appropriate to use when the enclosure assembly can be considered to be a one-dimensional, steady-state heat flow system, where no significant thermal bridges (a short circuit for heat flow) exist such as wood, steel, or concrete penetrations through the enclosure.

According to Burnett and Straube, to calculate the R-value (or R_{SI}-value) of an enclosure assembly using the tabular method, the following steps should be taken (Burnett & Straube, 2005):

1. List each material in the enclosure assembly, its conductivity (k), and its thickness (l)
2. Calculate the conductance (C) of each layer using $C = k / l$
3. Calculate the thermal resistance of each layer ($R_{SI\ Layer}$) using $R_{SI\ Layer} = 1 / C$
4. Sum the individual thermal resistances of each layer ($R_{SI\ Layer}$) to get the overall thermal resistance ($R_{SI\ Overall}$) of the entire assembly: $R_{SI\ Overall} = \sum R_{SI\ Layer}$

5. Take the inverse of the overall thermal resistance to get the overall heat transfer coefficient ($U_{SI\ Overall}$): $U_{SI\ Overall} = 1 / R_{SI\ Overall}$

Figure 3-11 shows an example of a wall assembly in this study, where the thermal resistance can be reasonably approximated using the tabular method. There are no significant thermal bridges through this assembly, so a one-dimensional analysis can be applied with reasonable accuracy. Table 3-7 illustrates how an application of the tabular method can result in an approximation of the overall resistance to heat flow through the wall system.



Assembly Layers

Outside

Ontario (standard clay brick cladding)

25mm air gap

50mm extruded polystyrene rigid insulation

Self-adhesive membrane with primer (AB, VB, WB)

200mm standard weight concrete block

(includes #15M bars @ 400mm o/c with grout)

Latex paint

Inside

Figure 3-11: Assembly Layers for Concrete Masonry Unit Wall #1 (CMU-W1)

As mentioned earlier, this method has its limitations. It can only be used to calculate the thermal resistance of very simple building enclosures. In this study, it was not appropriate to assume steady state, one-dimensional heat flow for all of the building enclosures. Many of the building enclosures in this study had thermal bridging, which requires at least a two-dimensional analysis to accurately calculate the overall thermal resistance. In this study, the tabular method was used to verify the results of other methods and not as the primary method for calculating the thermal resistance of the enclosures. The two primary methods that were used to calculate the two-dimensional heat flow through the building enclosures in this study are discussed next.

Table 3-7: Calculating Thermal Resistance of CMU-W1 Using the Tabular Method

Layer Material	Conductivity (k) W / (m · K)	Thickness (l) m	Conductance (C) W / (m^2 · K)	Resistance ($R_{SI\ Layer}$) (m^2 · K) / W
Exterior air film (moving air, winter conditions, ε = 0.90)	-	-	33.40	0.03
Ontario (standard) clay brick cladding	1.30	0.09	14.44	0.07
25mm air gap	-	-	5.19	0.19
50mm extruded polystyrene rigid insulation	0.03	0.05	0.58	1.72
Self-adhesive membrane with primer	N/A	N/A	N/A	N/A
200mm standard weight concrete block with solid grouted cores @ 400mm o/c	-	-	5.10	0.20
Latex paint	N/A	N/A	N/A	N/A
Interior air film (still air, ε = 0.90)	-	-	8.35	0.12

$R_{SI\ Overall}$ = 2.33 (m^2 · K) / W

Overall Heat Transfer Coefficient ($U_{SI\ Overall}$) = 0.43 W / (m^2 · K)

Note: *To convert R_{SI}-value to R-value, multiple R_{SI}-value by 5.678*

3.7.3 Calculating Two-Dimensional Heat Flow Using THERM

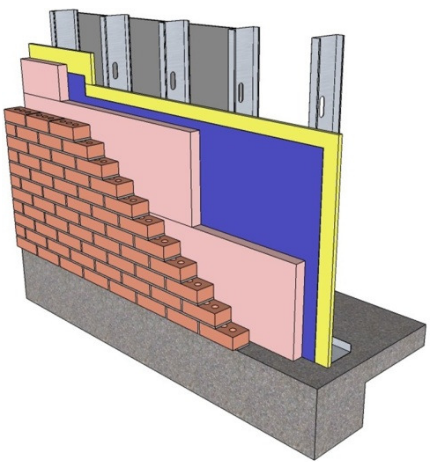
One-dimensional, steady-state heat flow calculations using the tabular method no longer accurately predict the heat flow through an enclosure, when one of the following conditions exist (Burnett & Straube, 2005):

1. Thermal bridging - a short circuit for heat flow through the building enclosure when a structural member such as wood, steel, or concrete penetrates through the enclosure.
2. Thermal mass – storage of heat in thermally massive materials (such as concrete and stone) which is stored and released throughout the day. This process is not steady-state.
3. Air leakage – a loss of air through the building enclosure which results in excess heat loss that would not be accounted for by a one-dimensional analysis.

Given any of these conditions, a two or three-dimensional heat flow analysis is required. In this study, two-dimensional heat flow analysis was required due to all three of the above conditions being true.

There are many readily available computer programs that can perform a two-dimensional heat flow analysis of building enclosures. These programs rely on a finite element analysis to predict the heat flow in two dimensions. In this study, THERM v5.2.14 (LBNL, 2009) was used. THERM was developed by the Lawrence Berkeley Laboratory in California and is well respected within the building science industry. In this study, each alternative building enclosure was modelled in THERM to get an estimate of the overall heat transfer coefficient ($U_{SI\ Overall}$).

Figure 3-12 shows an example of a typical wall assembly from this study that was modelled in THERM, to determine the overall heat transfer coefficient ($U_{SI\ Overall}$). Figure 3-13 shows both the THERM model that was created for this wall assembly, as well as a plot of the resulting temperature distribution (heat flow) through the enclosure.



Assembly Layers

Outside

Ontario (standard clay brick cladding)

25mm air gap

50mm extruded polystyrene rigid insulation

Self-adhesive membrane with primer (AB, VB, WB)

16mm non paper-faced gypsum sheathing

39mm x 152mm 18ga. (1.21mm) steel studs @ 400mm o/c

Regular 16mm gypsum board

Latex paint

Inside

Figure 3-12: Assembly Layers for Cold-Formed Steel Stud Wall #1 (SS-W1)

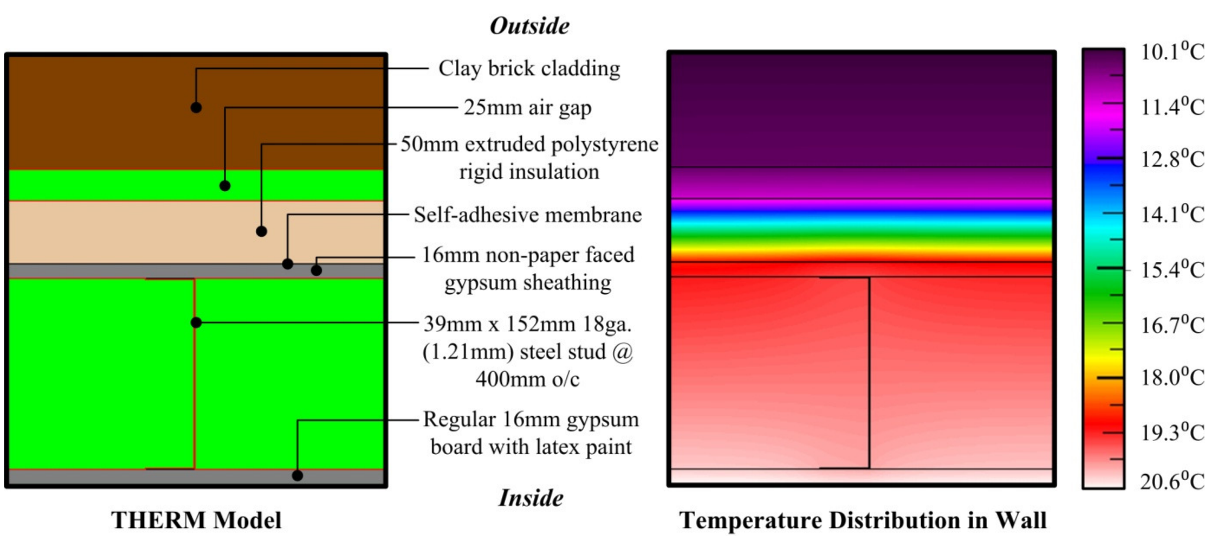


Figure 3-13: Example of Two-Dimensional Heat Flow through SS-W1 Using THERM

A similar model was constructed for each building enclosure component in this study, for which an approximation of the thermal resistance was required. The thermal resistance of each building component can be found in Appendix B.

For each THERM model in this study, both the geometric properties of the building enclosure, as well as the conductivity (k) of each different building material were specified. For each different building material there is a range of possible values for the conductivity based on numerous parameters (such as the moisture content of a material, the specific chemical or physical composition of the material, etc.). In this study, the conductivity of the individual building materials were primarily taken from the THERM database, ASHRAE Standard 90.1-2007 (ASHRAE, 2007), and "Building Science for Building Enclosures" (Straube & Burnett, 2005). In each THERM model, appropriate interior and exterior air films were included on the exterior cladding surface and the interior finish surface of the assemblies. In each case, an adiabatic boundary condition was also specified at either end of the enclosure, as only a portion of the entire building enclosure was modelled in THERM.

Although a two-dimensional heat flow analysis is reasonably accurate for the types of building enclosures that were modelled in this study, there are some sources of error. For example, the heat loss through the sill plate and top plate of the wood stud and steel stud walls was not accounted for. Neither was the heat loss due to additional framing around window and door openings. The THERM model only considered a typical section cut through the building enclosure, not all of the unique framing effects. Also, thermal bridging at the corners of buildings (where two walls intersect) was a source of heat loss that was not accounted for in this study. To accurately account for the heat loss through these irregularities (such as sill plates, top plates, framing effects around openings and at corners of walls), a three-dimensional, or even four-dimensional (which includes thermal mass effects) heat flow analysis would be required. This level of accuracy is beyond the scope of this project.

3.7.4 Calculating Two-Dimensional Heat Flow Using ASHRAE Standard 90.1-2007

In addition to calculating the thermal resistance of each building enclosure in this study using THERM, ASHRAE Standard 90.1-2007 was also used for comparison/verification of the results.

The original American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard was first published in 1975. The purpose of the Standard is "to provide minimum requirements for the energy-efficient design of buildings, except low-rise residential buildings"

(ASHRAE, 2007). The ASHRAE Standard 90.1-2007 is the most recent publication and it outlines the minimum energy-efficient requirements for the design and construction of new buildings (and their systems) and new portions of buildings (and their systems). This includes provisions for the envelope of buildings and the systems and equipment of buildings. Compliance with the ASHRAE Standard is completely voluntary and it is not enforceable under any building codes in Canada at this time. However, the ASHRAE 90.1 Standard is widely adopted within the building industry, so it was important to evaluate the thermal resistance of the building enclosures in this study using this method as well. Section 5 of ASHRAE Standard 90.1-2007 deals with the building envelope. Generally speaking, this section provides guidelines for estimating the thermal resistance of walls, roofs, fenestrations (windows), doors, and foundations (slab-on-grades).

For the purposes of this study, ASHRAE climate zone 6 (Toronto, Canada) was assumed. Generally speaking, for each building enclosure type (exterior infill walls, roofs, fenestrations, doors, and foundations), a base assembly is specified in the ASHRAE Standard. This base assembly is usually representative of a typical assembly that would be specified in a commercial type building. To determine the thermal resistance of a specific building enclosure using the ASHRAE Standard, the general procedure involves:

1. Identifying the ASHRAE base assembly that most closely approximates the building enclosure in question.
2. Following the various guidelines and tables in the ASHRAE Standard to modify the ASHRAE base assembly until it accurately represents the building enclosure in question.
3. Calculating the thermal resistance of the building enclosure in question.

As mentioned earlier, both THERM and ASHRAE Standard 90.1-2007 were used to determine the thermal resistance of the building enclosures identified in this study. However, there were some exceptions to this, when only one of the two methods was used. The following list identifies which method was used to calculate the thermal resistance of the building enclosures in this study:

- Exterior infill walls: THERM and ASHRAE Standard 90.1-2007
- Roofs: THERM and ASHRAE Standard 90.1-2007
- Fenestration (windows) and doors: ASHRAE Standard 90.1-2007 only
- Foundations (slab-on-grades): THERM only

When calculating the thermal resistance of the exterior infill walls and roofs, both the THERM and ASHRAE Standard 90.1-2007 values were calculated. Both values have been listed for each applicable building component in Appendix B.

In practice, there are a huge number of different windows and doors that could be specified. These types of enclosures can vary in a number of ways including: frame material, number of glazing layers, argon-filled verses air-filled, low-E coatings, and fixed verses operable. The ASHRAE Standard lists the overall U-value (including the frame effects and glazing effects) for a large variety of fenestration types. Rather than trying to model a large number of these very unique and complex types of enclosures using THERM, typical U-values were simply selected from the supplementary information on fenestrations found in the ASHRAE Standard (ASHRAE Fundamentals SI, 2009). Therefore, when it came to calculating the thermal resistance of the windows and doors in this study, only the ASHRAE Standard 90.1-2007 values were used.

When if came to calculating the thermal resistance of the foundations (slab-on-grades) in this study, only the THERM results were used and not the ASHRAE Standard values. The ASHRAE Standard uses what they call an 'F-factor' (rather than an R-value) for specifying the thermal resistance of slab-on-grades. The F-factor is a measure of the perimeter heat loss around the slab-on-grade. In this study, THERM was the sole means of calculating the thermal resistance of the slab-on-grades, not the F-factor method as specified in the ASHRAE Standard.

In cases where the thermal resistance was calculated using both the THERM and the ASHRAE Standard, some slight differences were noticed. The next section will discuss some of the reasons that the results from these two methods are slightly different.

3.7.5 Explanation of Differences in Thermal Resistance between THERM and ASHRAE Standard 90.1-2007

As mentioned in the previous section, when it came to calculating the thermal resistance of the exterior infill wall and roof enclosures in this study, two methods were used: THERM and ASHRAE Standard 90.1-2007. The thermal resistance of each exterior infill wall and roof in this study can be found in Appendix B. Both the results from THERM as well as the results that were calculated using the ASHRAE Standard 90.1-2007 have been included for comparison purposes. An explanation of the differences between the two methods will be presented next. As well, an explanation of the method that was ultimately chosen for this study will also be discussed.

In many cases, the ASHRAE Standard values were found to be somewhat generic and simplified values, due to the fact that they must be applicable to a wide range of alternative enclosures. In many cases, so long as the major components of a wall or roof assembly are indentified in ASHRAE (i.e. the structure and the insulation), then the thermal resistance of that assembly can be calculated with reasonable accuracy. However, the generic approached to calculating the thermal resistance of building enclosures using the ASHRAE method often neglects the unique differences between assemblies. This can have a tendency to underestimate the true thermal resistance of an enclosure.

Exterior Infill Wall Enclosures

In almost every case, the thermal resistances of the walls calculated using THERM were found to be slightly higher than the values calculated using the ASHRAE Standard. Typically, the thermal resistance that was calculated using THERM was between 1% and 15% higher than the thermal resistance that was calculated for the same wall enclosure using the ASHRAE Standard 90.1-2007. The maximum difference between the two methods in any case was found to be about 23%. The reason that the THERM values are higher than the ASHRAE values is because the ASHRAE method does not consider the thermal resistance of the cladding material or any air spaces within the enclosure. On the contrary, the THERM values include the thermal resistance contributions from every single layer of the enclosure assembly, including the different cladding materials and the air spaces. Therefore, the THERM method is slightly more comprehensive than the ASHRAE method, in that every single layer of the assembly was included in the calculation of thermal resistance. Thus, in this study the THERM R_{SI}-values were used instead of the ASHRAE values, as it was felt that the THERM values were even more accurate that the ASHRAE values. The ASHRAE values were included in Appendix B along with the THERM values for comparison.

Roof Enclosures

Similar to the wall enclosures, the thermal resistances of the roofs that were calculated using THERM were found to be slightly higher in most cases than the values calculated using the ASHRAE Standard. Typically, the thermal resistance that was calculated using THERM was between 1% and 10% higher than the thermal resistance calculated for the same roof enclosure using the ASHRAE Standard 90.1-2007. The maximum difference between the two methods in any case was found to be about 12%. The reason that the THERM values are slightly higher than the ASHRAE values is because the ASHRAE method does not consider the thermal resistance of the roof covering or the roof deck (other than for the case of a metal deck). On the contrary, the THERM values include the thermal resistance contributions from every single layer of the roof assembly, including the different roof coverings and roof deck materials. Thus, in this study the THERM R_{SI}-values were used instead of the ASHRAE values, as it was felt that the THERM values were more accurate. The ASHRAE values were again included in Appendix B along with the THERM values for comparison.

Therefore, in many instances, the thermal resistance values that were calculated using the ASHRAE Standard were found to be slightly conservative, in that they underestimated the true thermal resistance of the enclosures. The ASHRAE Standard is somewhat generic and simplified, due to the fact that it must be applicable to a wide range of similar enclosures that only differ in some small way. Although the omissions by the ASHRAE Standard are small in terms of the overall thermal resistance of the building enclosures (usually less than 10%), this study is concerned with evaluating the life-cycle environmental burdens of many similar enclosures and requires a higher degree of accuracy. This higher degree of accuracy was provided by the THERM method. Every single assembly layer (including the cladding materials, air spaces, roof coverings, and roof decking) were input and modelled in THERM. Thus, in this study the THERM R_{SI}-values were used instead of the ASHRAE values, as it was felt that the THERM values were more accurate that the ASHRAE values. However, the ASHRAE values were still calculated and included in the results for comparison purposes.

3.8 Evaluating Total Energy and Total GWP

Thus far the discussion has focused on methods of calculating embodied energy, embodied GWP, operating energy, and operating GWP for buildings and their components. In this section, the two results are combined as a method for calculating the total life-cycle energy and total GWP of a building and its components is discussed.

The total energy or total GWP is a combination of the total embodied energy, total embodied GWP, total operating energy, and total operating GWP. This can be explained using the example of a wall enclosure. Suppose there is a choice of using two different wall enclosures on a building project. These two walls will be made up of different materials. Therefore, there will be a difference in the embodied energy or embodied GWP between the two walls. However, depending on the assembly layers (such as the cladding material, insulation, structural framing, etc.) these two walls will also have a different thermal resistance (R_{SI}-value). Therefore, over the lifespan of a building, both of these walls will have a different influence on the operating energy of the building. It is important to note that just because a building assembly has a higher embodied energy or embodied GWP this does not necessarily mean that it will have a higher operating energy or operating GWP. For example, adding insulation to a wall assembly will increase the embodied energy of the wall, but will result in a lower operating energy. This is also true of other building components such as the roof, windows, and foundations for example. The total energy and total GWP accounts for both the materials effects and the operating effects of a building assembly.

The total embodied energy (and total embodied GWP) and the 50 year operating energy (and operating GWP) for the baseline retail building can be calculated. Then, by systematically substituting the 220 different building components in this study for the corresponding building component in the baseline retail building, the difference in the total energy or total GWP from the baseline building can be determined in each case. Therefore, the difference in the total energy from the baseline retail building for each of the 220 different building components in this study was calculated according to Eq. 1 for a 50 year lifespan.

$$\Delta T.E. = \Delta T.E.E. + \Delta T.O.E. \qquad (1)$$

Where ΔT.E = difference in the total energy from the baseline retail building after 50 years due to changing baseline building component to an alternative building component, ΔT.E.E. = difference in the total embodied energy from the baseline retail building (from ATHENA® EIE for Buildings) after 50 years, and ΔT.O.E. = difference in total operating energy from baseline building (from eQUEST) after 50 years.

Likewise, the difference in the total GWP from the baseline retail building for each of the 220 different building components in this study was calculated according to Eq. 2 for a 50 year lifespan.

$$\Delta T.GWP = \Delta T.E.GWP + \Delta T.O.GWP \qquad (2)$$

Where ΔT.GWP = difference in the total GWP from the baseline retail building after 50 years due to changing baseline retail building component to an alternative building component, ΔT.E.GWP = difference in the total embodied GWP from the baseline retail building (from ATHENA® EIE for Buildings) after 50 years, and ΔT.O.GWP = difference in total operating GWP from baseline building (from eQUEST) after 50 years.

Chapter 4
Methodology: Life-Cycle Assessment of Whole Buildings

4.1 Introduction

In Chapter 3, a method was outlined for calculating the total life-cycle energy use and GWP of 220 individual building components that are typically used in single-storey retail buildings. A baseline retail building was established and the process of systematically replacing the baseline retail building components with the 220 different building components in this study was discussed. However, so far the discussion has only focused on individual building components. It would be useful to have an understanding of the relationships between the individual building components as they pertain to an entire building project. In this section, a method is presented for calculating the total life-cycle energy use and GWP of five different single-storey retail buildings, located in Toronto, with a 50 year lifespan. The goal is to determine whether there is a significant difference in the life-cycle energy use and GWP of different types of single-storey retail buildings. Also, a list of recommendations for reducing the environmental burdens of a single-storey retail building will be developed, once a detailed breakdown of energy use and GWP in an entire building project is determined.

4.2 LCA of Case Study Retail Buildings

In Chapter 3, a method was discussed for calculating the life-cycle energy use and GWP of 220 individual building components. In this section, the scope of the LCA study is broadened to included entire building systems. In this section, the five case study single-storey retail buildings that were investigated within the framework of a comprehensive LCA are introduced. These five case study buildings have been designed specifically for this study. They are the result of collaboration between the author of this study and a colleague from the School of Architecture at the University of Waterloo.

As mentioned in the introduction, five different single-storey retail buildings were developed for this study. When selecting the case study buildings, the goal was to identify the most common types of single-storey retail buildings that are constructed in Canada today. The five case study buildings presented next are identical to the baseline retail building in every respect (see description of baseline retail building in Chapter 3 and Appendix A), except as outlined here. The five retail buildings include:

1. A typical hot-rolled steel structure, single-storey retail building
2. A typical heavy timber structure, single-storey retail building
3. A typical pre-engineered steel, single-storey retail building
4. A predominately steel, single-storey retail building
5. A predominately timber, single-storey retail building

The first three case study buildings represent common types of single-storey retail buildings in Canada today. The predominately steel and predominately timber case study buildings were developed to investigate the influence of material selection on the life-cycle energy use and GWP of a single-storey retail building. As mentioned, all of these buildings are identical to the baseline retail building in this study, except for the differences that will be outlined in the next sections.

4.2.1 Description of Typical Hot-Rolled Steel Structure Retail Building (Case Study #1)

A large proportion of single-storey retail buildings in Canada are built with a conventional hot-rolled steel structure. For this reason, it was important to select this type of building to examine within a comprehensive LCA.

Recall the baseline retail building that was introduced in Chapter 3. The baseline retail building in this study was chosen to be one of the five case study buildings. Specifically, Case Study #1: Typical Hot-Rolled Steel Structure Retail Building is exactly the same as the baseline retail building in every respect.

This building is comprised of 350W hollow structural steel columns and W-section beams. The structure is a series of braced frames, which rely on cross bracing and a concrete masonry stair tower for lateral stability. For the foundations, isolated concrete footings with piers were designed at every column location. As well, strip footings and concrete foundation wall were specified where required. A 200 mm (8 in.) thick slab-on-grade with 10mil poly was also used in this case. The exterior infill walls are comprised of cold-formed steel studs with exterior installed rigid insulation and an exterior insulation and finish system (EIFS). This assembly is very common in single-storey retail buildings, which is why it was chosen here. An open web steel joist roof with metal deck was designed in this case. A 4-ply built-up asphalt roof assembly was specified, along with 75 mm (3 in.) of insulation. The mezzanine floor is made up of open web steel joists with a metal deck and a concrete topping. A common floor finish in retail applications is vinyl tile, which was used in this building. The interior partitions are cold-formed steel studs with two layers of drywall finish. The windows are a self-supported aluminum curtainwall system with thermal break (two 6 mm sealed viewable glazing panes with 12.7 mm airspace, no low-E coating, and no argon between panes). The doors are a combination of opaque steel doors, aluminum doors with glazing, and an insulated overhead steel door in the shipping and receiving area. As Case Study #1 is exactly the same as the baseline retail building in this study, a detailed description of this building can be found in Appendix A. An illustration of Case Study #1 (i.e. the baseline retail building) can bee seen in Figure 4-1.

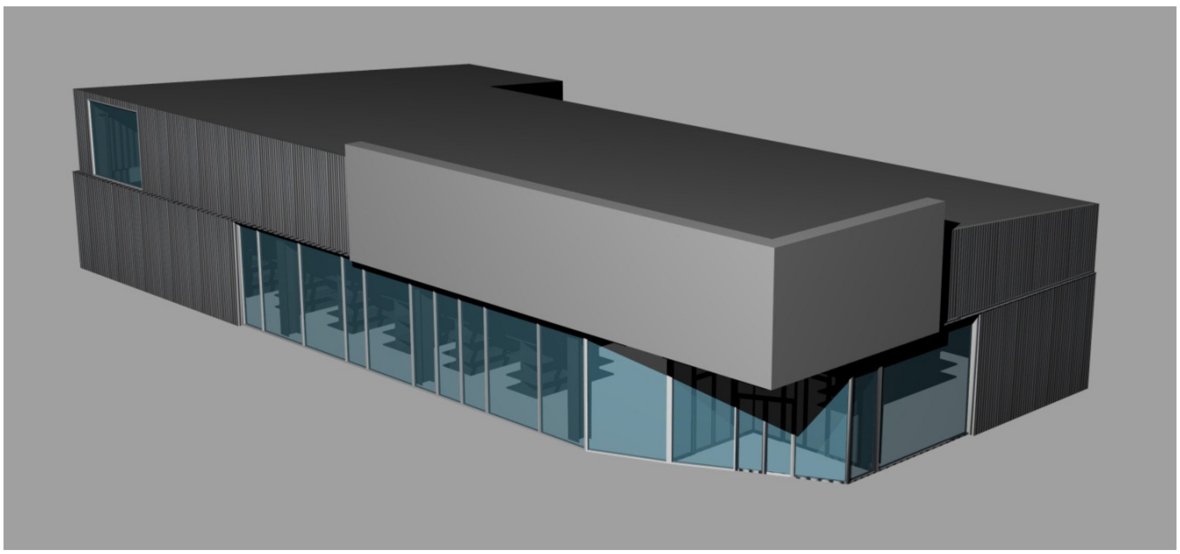


Figure 4-1: Case Study #1 – Typical Hot-Rolled Steel Structure Single-Storey Retail Building

Table 4-1 contains a breakdown of the various building components that were specified for Case Study #1, as well as the estimated quantity of each component. The building components have been listed by their ID, so Appendix B can be referenced for a further description of these components.

Table 4-1: Building Component Quantities for Case Study #1

Building Component	Building Component Quantities		
	ID	Estimated Quantity	Unit
Exterior Infill Wall Enclosure	BASE-W	581.0	sq.m
Roof Enclosure (Includes Roof Joists, JOIST-1)	BASE-R	586.0	sq.m
Structural System - 350W Hot-Rolled Steel	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-1	11.8	tonnes
Columns (Includes COL-A)	S-1	3.3	tonnes
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes
Fasteners	N/A	0.2	tonnes
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m
Windows	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m
Windows	W-1	20.3	sq.m
Doors	-	-	-
Overhead Doors	D-4	1.0	doors
Exterior Doors - Opaque	D-2	1.0	doors
Exterior Doors - Glazing	D-3	6.0	doors
Interior Doors	D-6	9.0	doors
Interior Partitions	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m
6mm Tempered Glass	N/A	5.7	sq.m
Foundations	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m

* *See Appendix B for a detailed description of the building components corresponding to the building component ID*

4.2.2 Description of Typical Heavy Timber Structure Retail Building (Case Study #2)

The second type of single-storey retail building considered in this study is a heavy timber structure building. This is the same building as Case Study #1, except that a heavy timber structure is used instead of a hot-rolled steel structure.

In this study, Case Study #2: Typical Heavy Timber Structure Retail Building is exactly the same as Case Study #1, with the exception of the structural system. The heavy timber structure is comprised of Douglas-Fir-Larch (D-Fir-L) glulam columns and beams. The structure is a series of braced frames, which rely on cross bracing and a concrete masonry stair tower for lateral stability. In every other respect (the foundations, walls, roofs, floor, interior partitions, windows, and doors), Case Study #2 is exactly the same as Case Study #1. The difference between Case Study #1 and #2 comes down to the structural system only. An illustration of Case Study #2 can bee seen in Figure 4-2. Table 4-2 contains a breakdown of the various building components that were specified for Case Study #2.

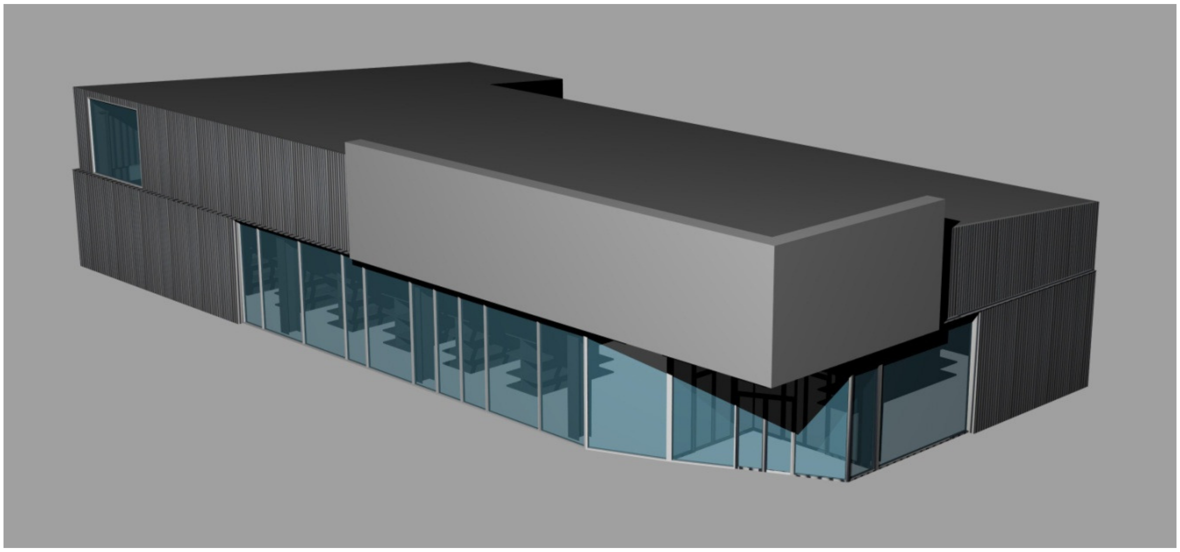


Figure 4-2: Case Study #2 – Typical Heavy Timber Structure Single-Storey Retail Building

Table 4-2: Building Component Quantities for Case Study #2

Building Component	Building Component Quantities		
	ID	Estimated Quantity	Unit
Exterior Infill Wall Enclosure	BASE-W	581.0	sq.m
Roof Enclosure (Includes Roof Joists, JOIST-1)	BASE-R	586.0	sq.m
Structural System - 24f-E Glulam Timber	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-2	25.4	cu.m
Columns (Includes COL-A)	S-2	8.0	cu.m
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes
Fasteners	N/A	0.2	tonnes
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m
Windows	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m
Windows	W-1	20.3	sq.m
Doors	-	-	-
Overhead Doors	D-4	1.0	doors
Exterior Doors - Opaque	D-2	1.0	doors
Exterior Doors - Glazing	D-3	6.0	doors
Interior Doors	D-6	9.0	doors
Interior Partitions	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m
6mm Tempered Glass	N/A	5.7	sq.m
Foundations	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m

* *See Appendix B for a detailed description of the building components corresponding to the building component ID*

4.2.3 Description of Typical Pre-Engineered Steel Retail Building (Case Study #3)

The third common type of single-storey retail building in Canada is the pre-engineered steel retail building. The components of these buildings are designed and built off-site, then transported to the building location and erected. Typically, these buildings are comprised of a series of rigid steel frames, with corrugate cold-formed steel wall cladding and a standing seam steel roof. Fiberglass batt insulation is usually installed between the wall girts and roof purlins. The main advantages of pre-engineered buildings are: they are highly optimized structures in terms of cost and material use, they are less expensive than other systems, and they have a shorter construction time. For these reasons they have become popular in the single-storey retail building market. However, almost no research has been conducted at this point on the LCA of pre-engineered steel building systems. It is unknown how these types of buildings compare to conventional systems like the previous two buildings.

In this case, a company that specializes in the design of pre-engineered steel buildings was asked to design a building for the purposes of this study. The company provided a design, including a series of construction drawings and material quantities that met the specifications of this project. Case Study #3: Typical Pre-Engineered Steel Retail Building was designed to have exactly the same characteristics as the previous two buildings, except for the differences that will be discussed next.

The structure of Case Study #3 is made up of a series of 350W hot-rolled steel rigid frames. Cross bracing is provided for lateral stability between the frames. Isolated concrete footings with piers were designed at every column location. As well, strip footings and concrete foundation wall were specified where required. A 200 mm (8 in.) thick slab-on-grade with 10mil poly was also specified in this case. The exterior infill wall consists of cold-formed steel girts with galvanized cold-formed steel cladding. Fiberglass batt insulation is installed within the wall cavity and is compressed at the girt locations. The roof consists of cold-formed steel purlins and a galvanized standing seam steel roof with fiberglass batt insulation compressed at the purlin locations. The mezzanine floor is comprised of cold-formed steel joists with a metal deck, concrete topping, and vinyl floor tile. The interior partitions are cold-formed steel studs with two layers of drywall finish. The windows are a self-supported aluminum curtainwall system with thermal break (two 6 mm sealed viewable glazing panes with 12.7 mm airspace, no low-E coating, and no argon between panes). The doors are a combination of opaque steel doors, aluminum doors with glazing, and an insulated overhead steel door in the shipping/receiving area. An illustration of Case Study #3 can bee seen in Figure 4-3. Table 4-3 contains a breakdown of the various building components that were specified for Case Study #3.

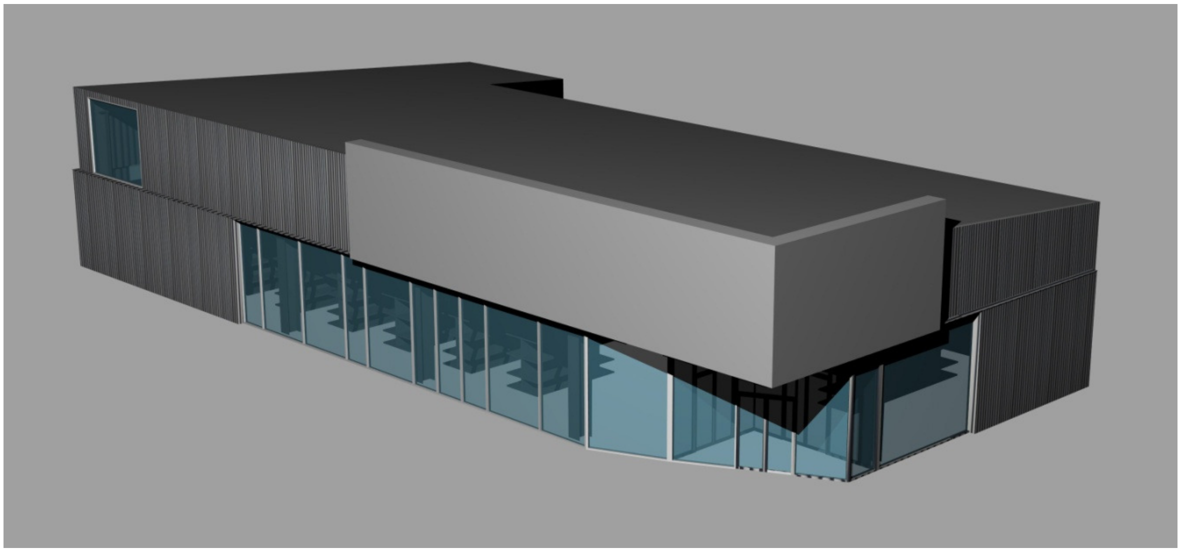


Figure 4-3: Case Study #3 – Typical Pre-Engineered Steel Single-Storey Retail Building

Table 4-3: Building Component Quantities for Case Study #3

Building Component	Building Component Quantities		
	ID	Estimated Quantity	Unit
Exterior Infill Wall Enclosure (Includes Girts)	PENG-W2	581.0	sq.m
Roof Enclosure (Includes Roof Joists)	PENG-R2	586.0	sq.m
Structural System - Pre-Engineered Steel	-	-	-
Beams and Columns (Hot-Rolled Steel)	N/A	13.1	tonnes
Fasteners	N/A	0.2	tonnes
Additional Hot-Rolled Steel	N/A	1.3	tonnes
(Including Hot-Rolled Steel Connection Plates)	N/A	1.2	tonnes
Additional Cold-Formed Steel	N/A	1.8	tonnes
Mezzanine Floor (Includes Floor Joists)	N/A	48.0	sq.m
Windows	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m
Windows	W-1	20.3	sq.m
Doors	-	-	-
Overhead Doors	D-4	1.0	doors
Exterior Doors - Opaque	D-2	1.0	doors
Exterior Doors - Glazing	D-3	6.0	doors
Interior Doors	D-6	9.0	doors
Interior Partitions	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m
6mm Tempered Glass	N/A	5.7	sq.m
Foundations	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m

* *See Appendix B for a detailed description of the building components corresponding to the building component ID*

4.2.4 Description of Predominately Steel Retail Building (Case Study #4)

The fourth single-storey retail building looked at in this study was a predominately steel retail building. The goal was to create a building that used steel building components wherever it was possible to do so. The objective was to investigate the influence of material selection on the life-cycle energy use and GWP of a single-storey retail building constructed primarily of steel, compared to other buildings where a broad mix of materials were used.

For Case Study #4: Predominately Steel Retail Building, the structural system, foundations, mezzanine floor, interior partitions, windows, and doors are exactly the same as Case Study #1. However, in Case Study #4 the exterior infill walls are comprised of cold-formed steel studs with exterior installed rigid insulation and a galvanized cold-formed steel cladding. An open web steel joist roof with metal deck was designed in this case, along with a galvanized standing seam steel roof with 75 mm (3 in.) of insulation. Otherwise, Case Study #4 is exactly the same as Case Study #1. An illustration of Case Study #4 can bee seen in Figure 4-4.

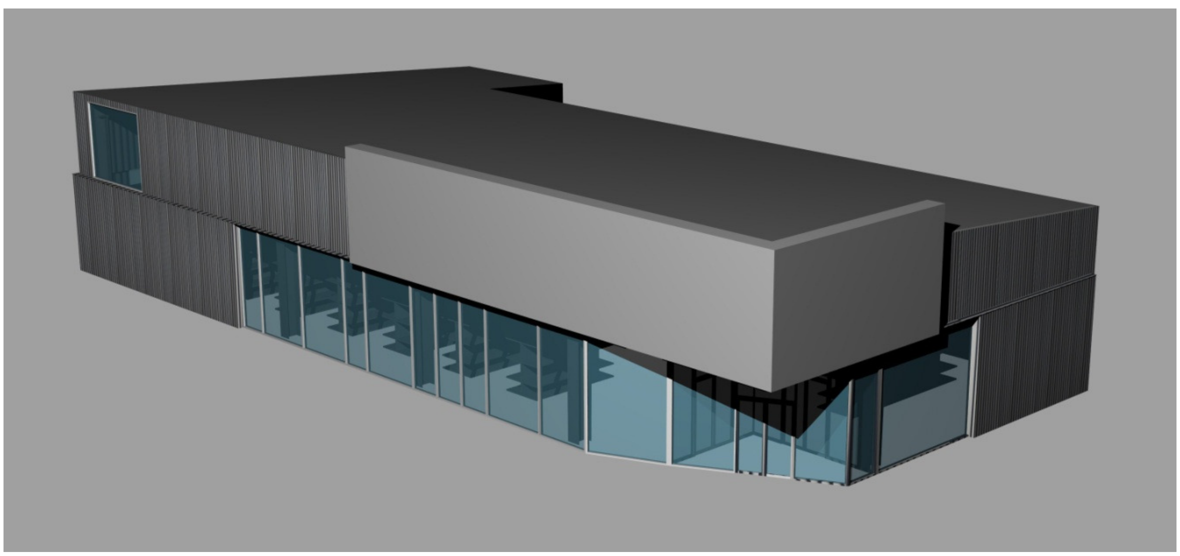


Figure 4-4: Case Study #4 – Predominately Steel Single-Storey Retail Building

Table 4-4 contains a breakdown of the various building components that were specified for Case Study #4. The building components have been listed by their ID, so Appendix B can be consulted for a detailed description of each building component.

Table 4-4: Building Component Quantities for Case Study #4

Building Component	Building Component Quantities		
	ID	Estimated Quantity	Unit
Exterior Infill Wall Enclosure	SS-W17	581.0	sq.m
Roof Enclosure (Includes Roof Joists, JOIST-1)	OWSJ-R5	586.0	sq.m
Structural System - 350W Hot-Rolled Steel	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-1	11.8	tonnes
Columns (Includes COL-A)	S-1	3.3	tonnes
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes
Fasteners	N/A	0.2	tonnes
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m
Windows	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m
Windows	W-1	20.3	sq.m
Doors	-	-	-
Overhead Doors	D-4	1.0	doors
Exterior Doors - Opaque	D-2	1.0	doors
Exterior Doors - Glazing	D-3	6.0	doors
Interior Doors	D-6	9.0	doors
Interior Partitions	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m
6mm Tempered Glass	N/A	5.7	sq.m
Foundations	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m

[*] See Appendix B for a detailed description of the building components corresponding to the building component ID

4.2.5 Description of Predominately Timber Retail Building (Case Study #5)

The fifth single-storey retail building considered was a predominately timber retail building. The goal was to create a building using timber building components wherever timber was the best choice. Once again, the objective was to investigate the influence of material selection on the life-cycle energy use and GWP of a single-storey retail building constructed primarily of timber, compared to other buildings where a broad mix of materials were used.

For Case Study #5: Predominately Timber Retail Building, the structural system and foundations are exactly the same as Case Study #2. However, in Case Study #5 the exterior infill walls are comprised of wood studs with exterior installed rigid insulation and wood siding. The roof structure consists of glulam joists with tongue and groove solid wood plank decking. Since no timber roof coverings are commonly used in commercial buildings, a 4-ply built-up asphalt roof assembly was specified along with 75 mm (3 in.) of insulation. This is a very common roof assembly for single-storey retail buildings and was also used for Case Study #1 and #2. The mezzanine floor is made up of glulam joists with tongue and groove solid wood plank decking and a vinyl tile floor finish. The interior partitions are wood studs with two layers of drywall finish. The windows are timber frame with a thermal break (two sealed viewable glazing panes with 12.7 mm airspace, no low-E coating, and no argon between panes). The doors are a combination of opaque wood doors, wood doors with glazing, and an insulated overhead steel door in the shipping and receiving area. An illustration of Case Study #5 can bee seen in Figure 4-5.

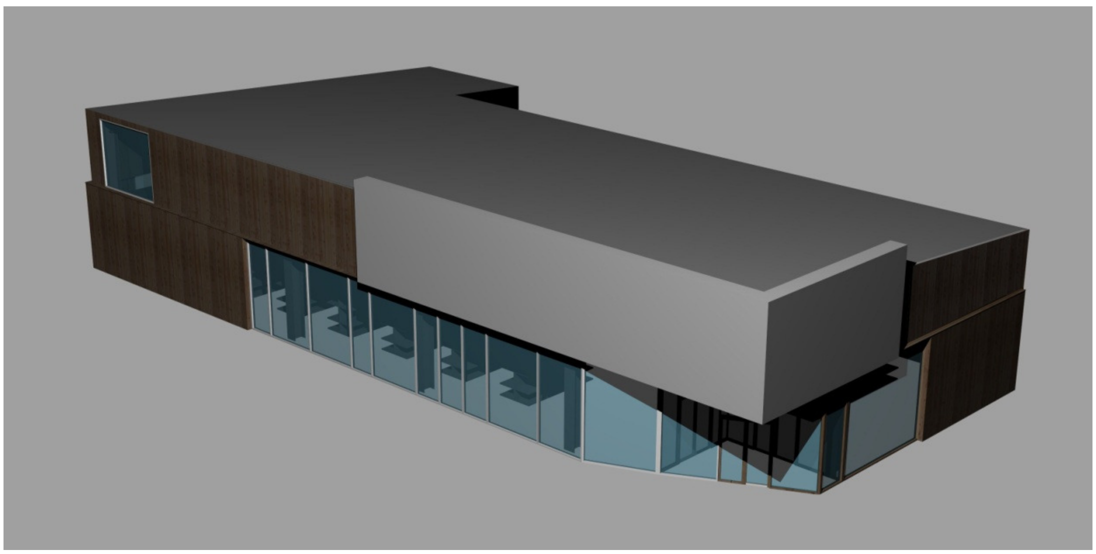


Figure 4-5: Case Study #5 – Predominately Timber Single-Storey Retail Building

Table 4-5 contains a breakdown of the various building components that were specified for Case Study #5. The building components have been listed by their ID, so Appendix B can be consulted for a detailed description of each building component.

In this chapter, five single-storey retail buildings were presented. These five buildings were examined within the framework of a comprehensive LCA, in order to determine the relative significance of the various building components in relation to the overall environmental burdens of an entire building. In Chapter 3 a method for calculating the life-cycle energy use and GWP of entire buildings and individual building components was discussed. In addition, 220 different building components that are commonly used in single-storey retail buildings in Canada were identified. The remainder of this study will focus on the results of the life-cycle assessment of the 220 different building components and the five case study buildings, as well as an interpretation of the results.

Table 4-5: Building Component Quantities for Case Study #5

Building Component	Building Component Quantities		
	ID	Estimated Quantity	Unit
Exterior Infill Wall Enclosure	WS-W4	581.0	sq.m
Roof Enclosure (Includes Roof Joists, JOIST-1)	GLU-R2	586.0	sq.m
Structural System - 24f-E Glulam Timber	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-2	25.4	cu.m
Columns (Includes COL-A)	S-2	8.0	cu.m
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes
Fasteners	N/A	0.2	tonnes
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-2	48.0	sq.m
Windows	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m
Windows	W-4	20.3	sq.m
Doors	-	-	-
Overhead Doors	D-4	1.0	doors
Exterior Doors - Opaque	D-1	1.0	doors
Exterior Doors - Glazing	D-3	6.0	doors
Interior Doors	D-5	9.0	doors
Interior Partitions	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m
Insulated Interior Stud Wall Partition	WS-P3	75.0	sq.m
Uninsulated Interior Stud Wall Partition	WS-P1	52.0	sq.m
6mm Tempered Glass	N/A	5.7	sq.m
Foundations	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m

* *See Appendix B for a detailed description of the building components corresponding to the building component ID*

Chapter 5
Results: Life-Cycle Assessment of Whole Buildings

5.1 Introduction

Over the life of a building, the total energy use and total GWP is a combination of the embodied energy and embodied GWP of the building materials and the operating energy and operating GWP of the building. In a typical multi-storey office building, about 85% of the total life-cycle energy use after 50 years is a result of the building operations, while only about 15% is due to the energy that is embodied in the materials (Cole & Kernan, 1996).

A similar relationship between embodied effects and operating effects is thought to exist for the case of a single-storey retail building, but the data to support this is difficult to find. Therefore, this study examined the breakdown of embodied energy, embodied GWP, operating energy, and operating GWP for five different single-storey retail buildings, located in Toronto, Canada, with a 50 year lifespan. The five retail buildings included: a typical hot-rolled steel structure retail building, a typical heavy timber structure retail buildings, a typical pre-engineered steel retail building, a predominately steel retail building, and a predominately timber retail building.

Similar to the studies of multi-storey office buildings (Cole & Kernan, 1996), the operating effects of the five single-storey retail buildings in this study were found to dominate over the lifespan of the buildings. However, some interesting relationships in terms of the embodied energy and embodied GWP for the components of the retail buildings were found. The aim of this chapter is to present a summary of the LCA results for the five case study retail buildings. It is important to develop an understanding of the energy use and GWP for whole buildings first, before moving onto a detailed analysis of the individual building components. Having an understanding of the energy use and GWP of an entire building will allow the detailed analysis of the 220 different building components in this study to be placed in context. Therefore, the results for the LCA study of the five case study buildings will be presented first, followed by a discussion of the life-cycle energy use and GWP of the 220 alternative building components in Chapter 6.

5.2 LCA Results for the Baseline Retail Building (Case Study #1)

A LCA was performed for the baseline retail building (Case Study #1) described in Chapter 3 and Appendix A, in order to establish a datum of total embodied energy, embodied GWP, operating energy, and operating GWP for a single-storey retail building. Recall that the baseline retail building is a typical hot-rolled steel structure building. This building represents a typical single-storey retail building that would be constructed in Canada today. The remainder of this section will present the results of the comprehensive LCA study for the baseline retail building. A summary of the LCA results can be found in Appendix C.

5.2.1 Operating Energy and GWP of the Baseline Retail Building (Case Study #1)

Based on Cole & Kernan (1996), the operating energy of a typical Canadian office building represents upwards of 85% of the total life-cycle energy after 50 years. An analysis of operating energy and operating GWP was conducted for the baseline retail building in this study using eQUEST and the ATHENA® EIE converter. A rendering of the baseline retail building, along with the corresponding eQUEST model are illustrated in Figure 5-1.

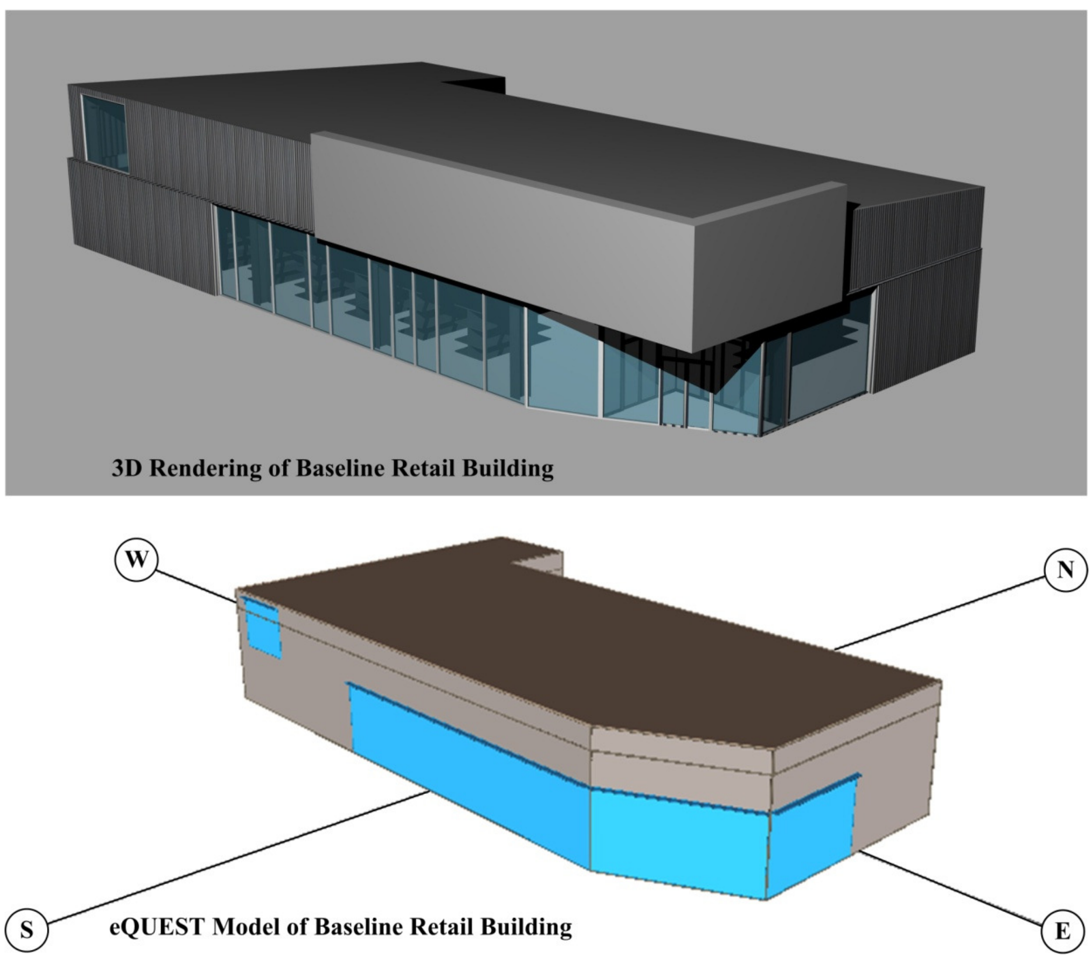


Figure 5-1: Rendering and eQUEST Model of Baseline Retail Building (Case Study #1)

The electricity and natural gas use for the baseline retail building were determined from eQUEST. A breakdown of the annual energy consumption for the baseline retail building is presented in Figure 5-2.

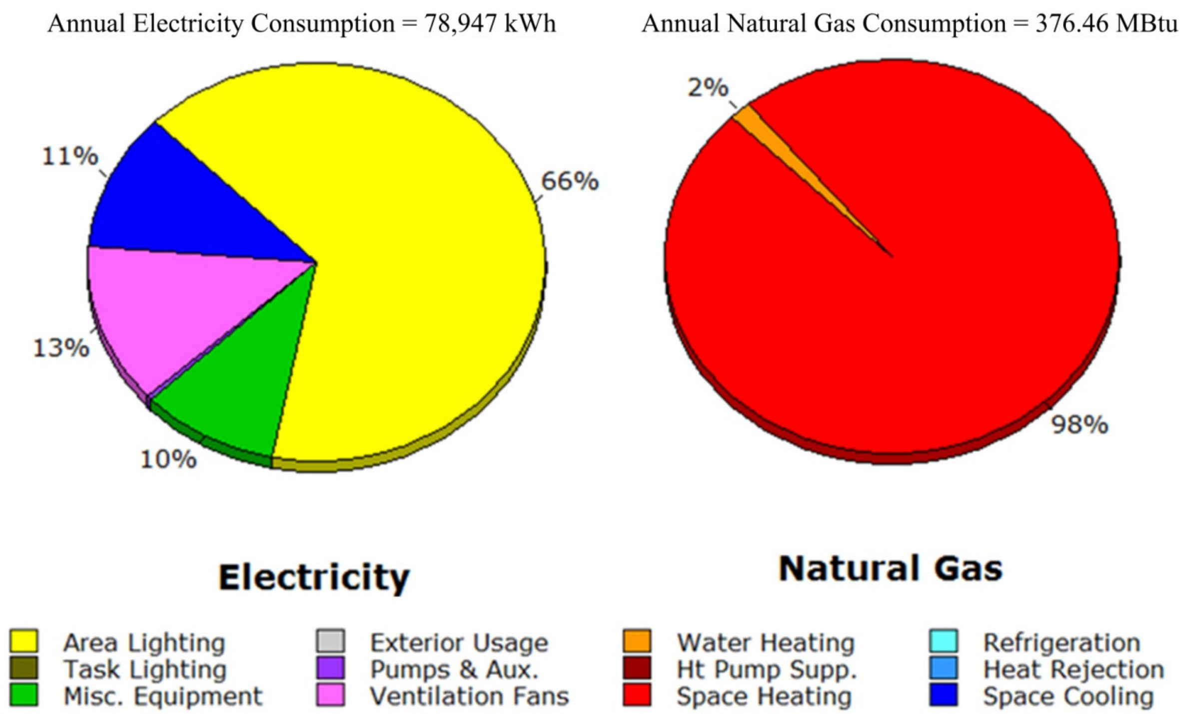


Figure 5-2: Breakdown of Annual Energy Consumption for the Baseline Retail Building (Case Study #1) from eQUEST

The eQUEST simulations found the annual electricity consumption of the baseline retail building to be about 79,000 kWh/year. Clearly, Figure 5-2 indicates that area lighting is responsible for the largest proportion of electricity use on an annual basis. In fact, area lighting is responsible for approximately 66% of the annual electricity use for the entire baseline retail building. This result is expected for a retail building. Electricity use in a retail type building is primarily due to lighting, given that a prominent display of retail merchandise is often a primary concern. The eQUEST results for the baseline retail building also indicate that ventilation fans (13%), space cooling (11%), and miscellaneous equipment such as office equipment (10%) are also significant consumers of electricity on an annual basis. Recall that the cooling equipment for the baseline retail building in this study was taken to be direct expansion (DX) coils, which operate on electricity. Therefore, space cooling load appears in the form of electricity use in the eQUEST results.

Focusing now on the annual natural gas consumption in Figure 5-2, the eQUEST simulations found the annual natural gas consumption of the baseline retail building to be about 376 MBtu/year. About 98% of this was due to space heating. This is expected as the heating equipment for the baseline retail building was specified as a natural gas combustion furnace, as the building is located in Toronto, Canada (which is a cold climate). Therefore, it is naturally expected to see a significant amount of energy for space heating as demonstrated herein.

Using the ATHENA® EIE converter, the annual electricity use and natural gas use were converted into a total of about 1,014 GJ/year of annual primary energy use. Over a 50 year lifespan, the baseline retail building therefore consumes about 50,700 GJ of primary energy. Similarly, using the ATHENA® EIE converter, this translates into about 46 tonnes of CO_2 eq./year (or 2,310 tonnes of CO_2 eq. over a 50 year lifespan). The total electricity use and the total natural gas use represent about 56.9% (47.3%) and 43.1% (52.7%) of the annual operating energy use (and operating GWP) respectfully. A breakdown of the annual operating energy use (and operating GWP) for the baseline retail building can be further divided into: space heating (assuming a natural gas furnace) = 42.4% (51.8%), area lighting = 37.3% (31.0%), ventilation fans = 7.4% (6.2%), space cooling (assuming DX electric coils) = 6.4% (5.4%), miscellaneous equipment = 5.6% (4.6%), water heating = 0.7% (0.9%), and pumps and auxiliary = 0.2% (0.1%).

The annual energy use for the baseline retail building from eQUEST can also be displayed in terms of the monthly energy consumption in Figure 5-3. The electricity consumption from area lighting is relatively constant each month, as is the ventilation fans and the miscellaneous equipment. However, the electricity consumption due to space cooling goes up in the summer months. This is expected, as space cooling is only required during the summer in a single-storey, 100% perimeter zone building such as this.

Figure 5-3 also shows the monthly distribution of natural gas use for the baseline retail building. Notice that in the summer months when the space cooling electricity use is the highest, this corresponds to when the natural gas use for space heating is the least. This makes sense, as there is no need to operate the furnace for space heating during the warm summer months. As expected, the natural gas use due to space heating is highest during the winter months. Recall that operating energy and operating GWP are only one part of the equation. The results for the total embodied energy and embodied GWP of the baseline retail building will be presented in the next section.

Annual Electricity Consumption = 78,947 kWh   Annual Natural Gas Consumption = 376.46 MBtu

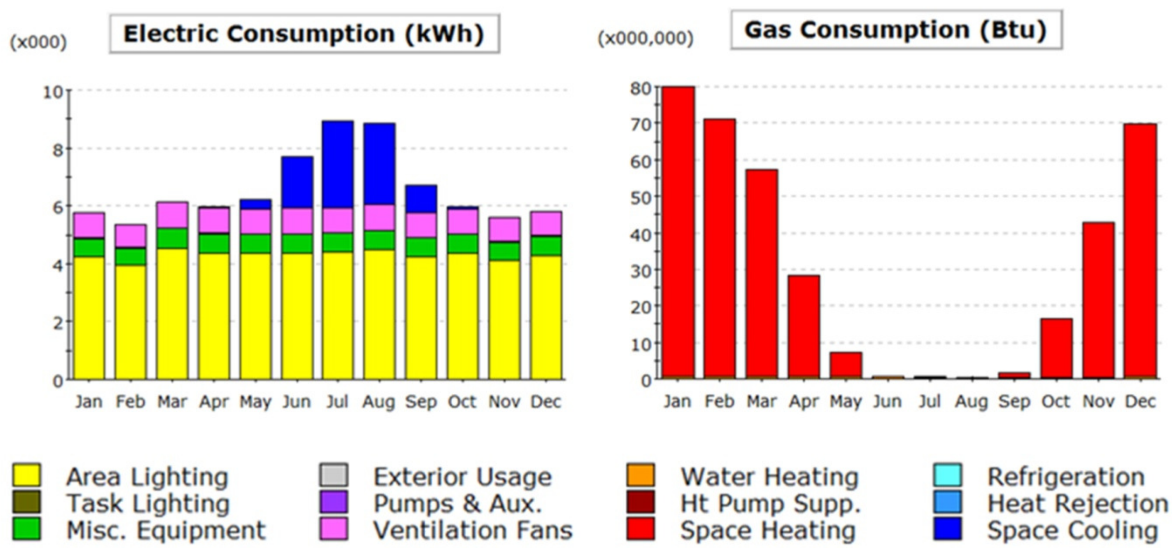


Figure 5-3: Monthly Energy Consumption for the Baseline Retail Building from eQUEST

5.2.2 Embodied Energy and GWP of the Baseline Retail Building (Case Study #1)

Using the ATHENA® EIE for Buildings v4.0.64, the total life-cycle embodied energy (initial embodied energy + recurring embodied energy) of the baseline retail building was calculated for a 50 year lifespan in Toronto. The results for the various components of the building are presented in Figure 5-4 in terms of the total primary energy.

The total embodied energy of the baseline retail building was calculated to be about 5,247 GJ. This includes both the initial embodied energy as well as the recurring embodied energy. The key observation to note is the relatively large total embodied energy of the roof compared to the other components of the baseline retail building. In fact, the roof alone represents about 52% of the total embodied energy of the entire building. This is primarily due to two factors: the roof-to-wall area ratio in a single-storey building and the relatively high total embodied energy of the roof structure compared to the other components of the building.

In a single-storey building like in this study, the roof-to-wall area ratio is typically much larger than in a multi-storey building. This ratio is dependent on the geometric proportions of the building. In a single-storey building, the roof is a larger proportion of the total enclosure area than in a multi-storey building. The roof-to-wall area ratio for the baseline retail building in this study is about 1.0

(including the window area in the calculation would result in a roof-to-vertical enclosure area ratio of about 0.80). In multi-storey buildings, these ratios are typically much less than 1.0. Therefore, in a single-storey retail building like in this study, the roof is a larger proportion of the total enclosure area and therefore plays a significant role in terms of the total embodied energy.

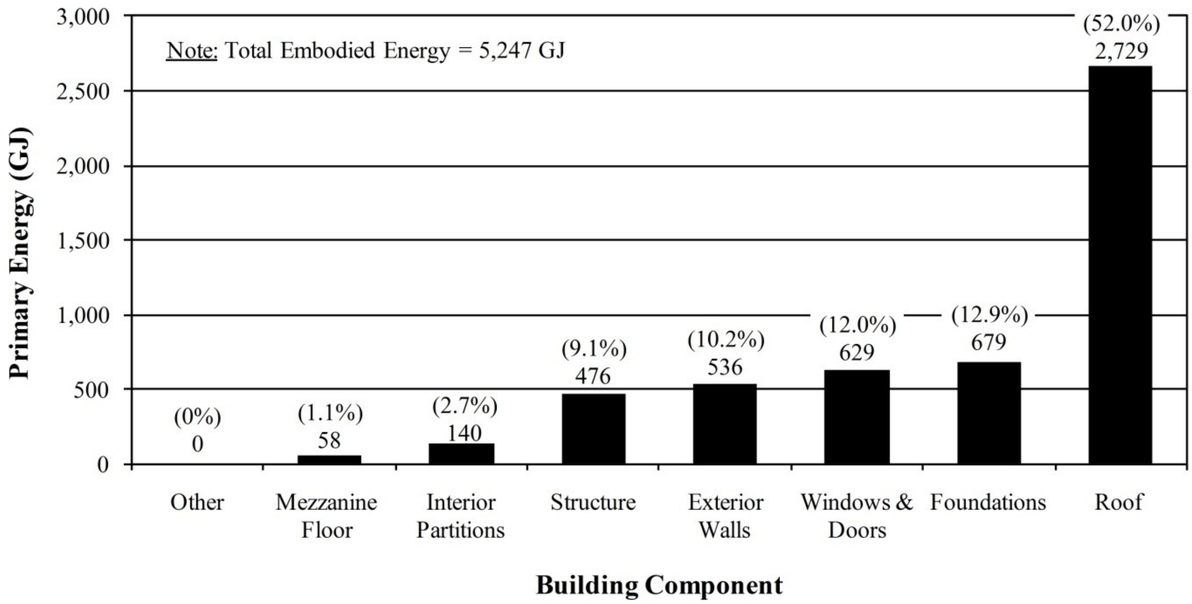


Figure 5-4: Total Life-Cycle Embodied Energy of the Baseline Retail Building (Case Study #1) after 50 Year Lifespan in Toronto

In addition to the roof being a large proportion of the total enclosure area, the embodied energy per m^2 of roof is relatively high compared to the embodied energy per m^2 of wall. For the exterior infill wall enclosures identified in Appendix B, the total embodied energy m^2 of wall ranged from 0.49 GJ/m^2 to 3.17 GJ/m^2. The average embodied energy per m^2 of exterior infill wall for the walls identified in Appendix B was about 1.42 GJ/m^2. On the contrary, the total embodied energy per m^2 of roof ranged from 0.74 GJ/m^2 to 5.18 GJ/m^2 for the roof enclosures identified in Appendix B. The average embodied energy per m^2 of roof for the roofs in Appendix B was about 2.67 GJ/m^2. Therefore, on average the total embodied energy per m^2 of enclosure for the roofs could be up to about two times greater than that of the exterior infill walls. This is because many of the roof coverings have to be replaced or repaired many times over a 50 year lifespan with the exception of the commercial standing seam steel roof. Also, many roof enclosures tend to use asphalt-based materials which are both high in embodied energy and need to be replaced/repaired often. On the contrary, the exterior infill walls tend to have less recurring embodied energy associated with them, as the cladding materials for example are not replaced/repaired as often as the roof covering. Therefore, the roof enclosures tend to have significantly higher recurring embodied energy than the walls, which results on average in a higher total embodied energy per m^2 of enclosure.

On its own, the total embodied energy of the roof is responsible for over half of the total embodied energy of the entire single-storey retail building. If the total embodied energy of the roofs, exterior infill walls, and windows/doors are grouped together (referred to as the building enclosure), then the total embodied energy of the enclosure would be responsible for about 74% of the total embodied energy of the building. Compared to the structural system, which is responsible for only about 9% of the total embodied energy of the building, the enclosure has a far greater impact on the environment than the structural system. The foundations actually represent about 13% of the total embodied energy of the building, which is more than that of the entire structural system.

In this study, the floor area refers to the mezzanine floor, not the slab-on-grade. The impacts from the slab-on-grade are included in the foundation results. In this building, the floor was only responsible for about 1% of the total embodied energy after 50 years. However, this is because the floor area in this building was relatively small (only a 50 m^2 mezzanine). The total embodied energy of the floors in Appendix B ranged from 0.56 GJ/m^2 to 1.21 GJ/m^2 of floor area. Therefore, in buildings with a larger proportion of floor area, the total embodied energy of the floor could potentially represent a much higher percentage of the total embodied energy of the building.

Next, a comparison of the total embodied GWP of the building components is made for the baseline retail building. The LCA results for the embodied GWP are displayed in Figure 5-5.

It can be seen that the relationships between the various building components for the baseline retail building in terms of embodied GWP are much the same as the relationships for embodied energy. Again, the roof enclosure represents the most significant contribution towards the total embodied GWP of the building. The building enclosure (roof, exterior infill walls, windows, and doors) is responsible for about 63% of the total embodied GWP of the building. The total embodied GWP of the building is slightly less influenced by the enclosure than was the case with the total embodied energy. This is mainly due to the fact that the embodied GWP of the foundations accounts for about 25% of the total embodied GWP of the building (compared to only 13% of the total embodied energy of the building). This is primarily because the foundations are comprised almost entirely of concrete and steel, which tend to have higher embodied GWP than many other building materials when used in large quantities.

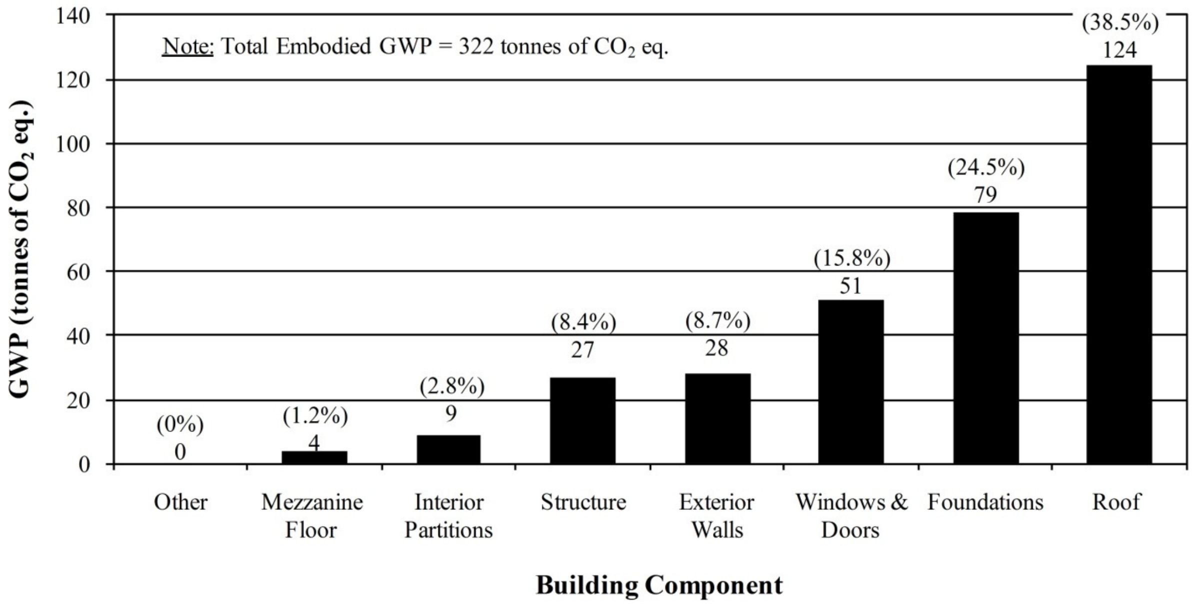


Figure 5-5: Total Life-Cycle Embodied GWP of the Baseline Retail Building (Case Study #1) after 50 Year Lifespan in Toronto

Therefore, total life-cycle embodied energy and embodied GWP of the baseline retail building was calculated for a 50 year lifespan. Next, the total embodied energy and embodied GWP are compared to the total operating energy and operating GWP for the baseline retail building, in order to determine the relative importance of each to the total energy and total GWP of the building.

5.2.3 Total Energy and GWP of the Baseline Retail Building (Case Study #1)

The operating energy, operating GWP, embodied energy, and embodied GWP of the baseline retail building have already been discussed. In this section, the results will be compared in order to determine the relative proportion of the total life-cycle energy use and total GWP that is attributed to the operations of the building verses the embodied effects.

Figure 5-6 illustrates the breakdown of the total life-cycle energy use for the baseline retail building. Over a 50 year lifespan, the operating energy is equal to about 50,700 GJ of primary energy use and the total embodied primary energy is about 5,247 GJ. This results in a total life-cycle primary energy use of about 55,947 GJ after 50 years for the baseline retail building.

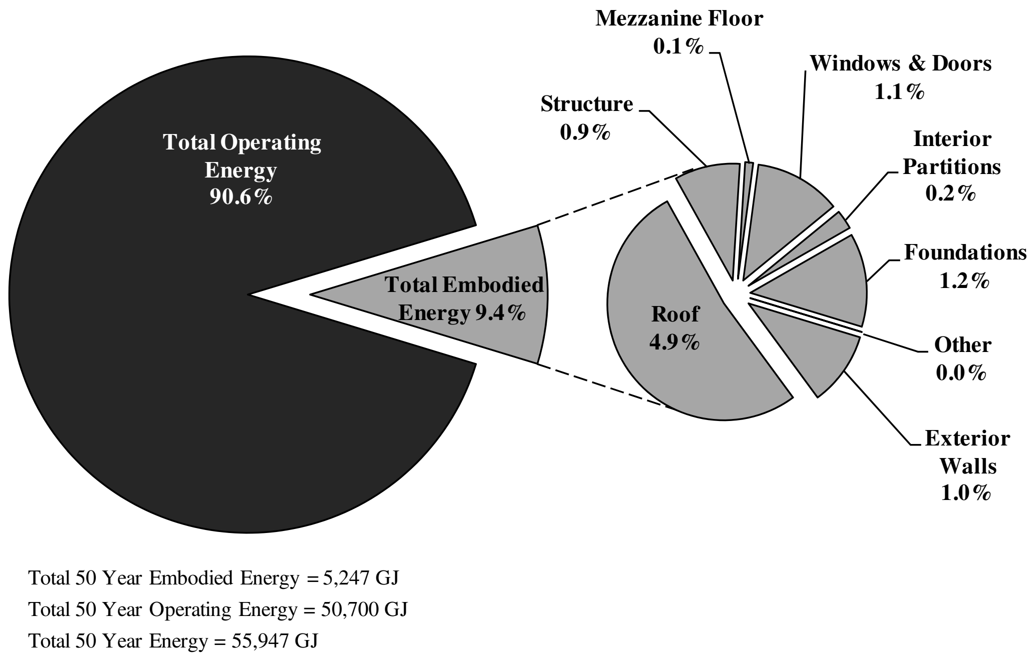


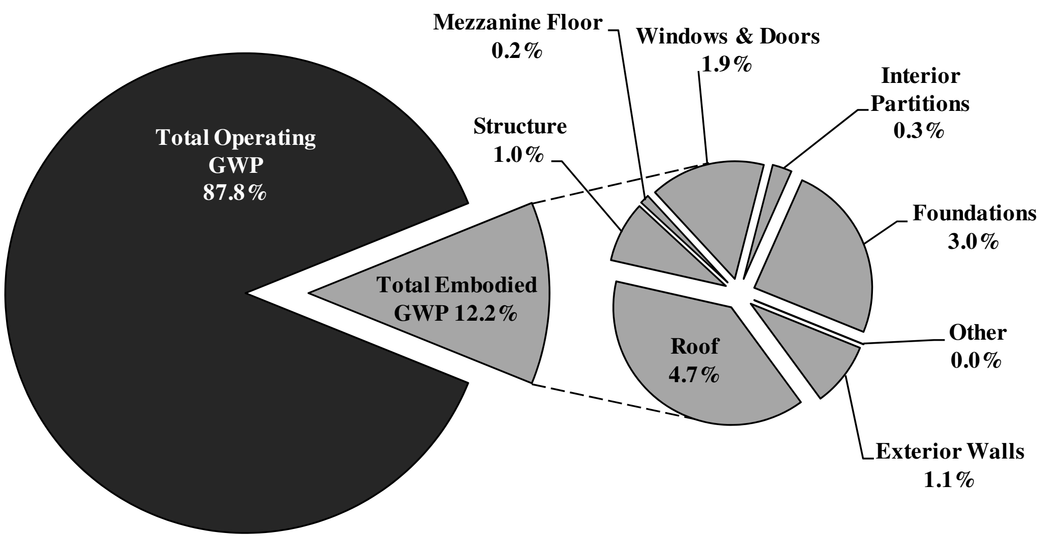
Figure 5-6: Total Life-Cycle Energy Breakdown of the Baseline Retail Building (Case Study #1) after 50 Year Lifespan in Toronto

Also indicated in Figure 5-6 is the distribution of embodied energy to operating energy for the baseline retail building. Some very interesting results can be derived from the Figure. First, after a 50 year lifespan the operating energy accounts for nearly 91% of the total life-cycle energy use. The total embodied energy is only about 9%. Recall that Cole and Kernan (1996) found the operating energy to be 85% and the total embodied energy to be 15% for a typical multi-storey office building in Toronto, with a 50 year lifespan. Therefore, after 50 years for the case of a single-storey, 100% perimeter zone retail building, located in Toronto, the embodied effects account for less than 10% of the total life-cycle energy use.

In the past, many people have argued that the choice of a structural system has a significant role to play in designing a low-energy building, simply due to the fact that a particular structural system has less embodied energy than another. This argument is most often made as the basis for selecting a wood-based system over a steel or concrete-based system. However, the results in Figure 5-6 clearly show that as less than 1% of the total life-cycle energy use after 50 years is due to the embodied energy of the structural system, the structural material is essentially negligible. In other words, the maximum savings in terms of life-cycle energy use after 50 years is limited to about 1% of the total energy for a typical retail building in Canada. In fact, reducing the annual operating energy use of the building by only 5% would save around five times as much energy over 50 years as is currently embodied in the entire structural system. Looking at the big picture, the embodied energy of the structural system is simply not a factor when the operating energy of the building is so much more significant. Only when the operating energy of the building is decreased drastically, would the embodied energy of the structural system gain greater importance.

Looking at the other components of the retail building in Figure 5-6, it can be seen that the total embodied energy of the roof accounts for about 5% of the total energy use of the baseline retail building after 50 years. Grouping the roof, exterior infill walls, windows, and doors together, the embodied energy of the exterior enclosure is responsible for about 7% of the total energy.

Next, looking at the breakdown of total GWP for the baseline retail building after 50 years, similar trends can be observed in terms of operating effects verses embodied effects as illustrated in Figure 5-7.



Total 50 Year Embodied GWP = 322 tonnes of CO_2 eq.
Total 50 Year Operating GWP = 2,310 tonnes of CO_2 eq.
Total 50 Year GWP = 2,632 tonnes of CO_2 eq.

Figure 5-7: Total Life-Cycle GWP Breakdown of the Baseline Retail Building (Case Study #1) after 50 Year Lifespan in Toronto

The total operating GWP represents about 88% of the total life-cycle GWP after 50 years, compared to only about 12% for the embodied GWP. The relative significance of embodied effects verses operating effects has gone up slightly for GWP compared to primary energy, due to the fact that the GWP of the foundations is relatively higher. The foundations are responsible for about 3% of the total GWP of the retail building after 50 years. The exterior enclosure is responsible for about 8% of the total GWP of the building, while the structural system accounts for a negligible 1%.

Therefore, for a typical single-storey retail building in Canada, the operating energy and operating GWP are by far the most significant contributors towards the total life-cycle energy use and total GWP after a 50 year lifespan. Not until the operating energy and operating GWP of the building are reduced by around 50% from typical values today, would the embodied energy and embodied GWP of the building components even begin to become a concern.

The relationship between operating effects and embodied effects for the baseline retail building are very significant. Understanding that the embodied effects play a minor role in terms of the total life-cycle effects in a typical retail building today, can go along way to designing better performing retail buildings from an energy and GWP standpoint. These relationships are not exclusive to retail type buildings. In fact, the conclusions that have been drawn for the baseline retail building thus far could conceivably be applied to any single-storey commercial building in Canada with a 50 year lifespan.

The LCA results of operating effects verses embodied effects for a typical single-storey retail building in Canada can be displayed in another way. Figure 5-8 displays the relative proportions of the embodied effects verses the operating effects for the components of the baseline retail building. Essentially, the percentage of the total life-cycle energy use and total GWP for the components of the baseline retail building have been represented as a scaled proportion of the total area of the building (or emission cloud for the case of GWP) in Figure 5-8. Again, one can see that when plotted to scale, the embodied effects are small compared to the operating effects. This figure simply serves to display these relationships in a different way.

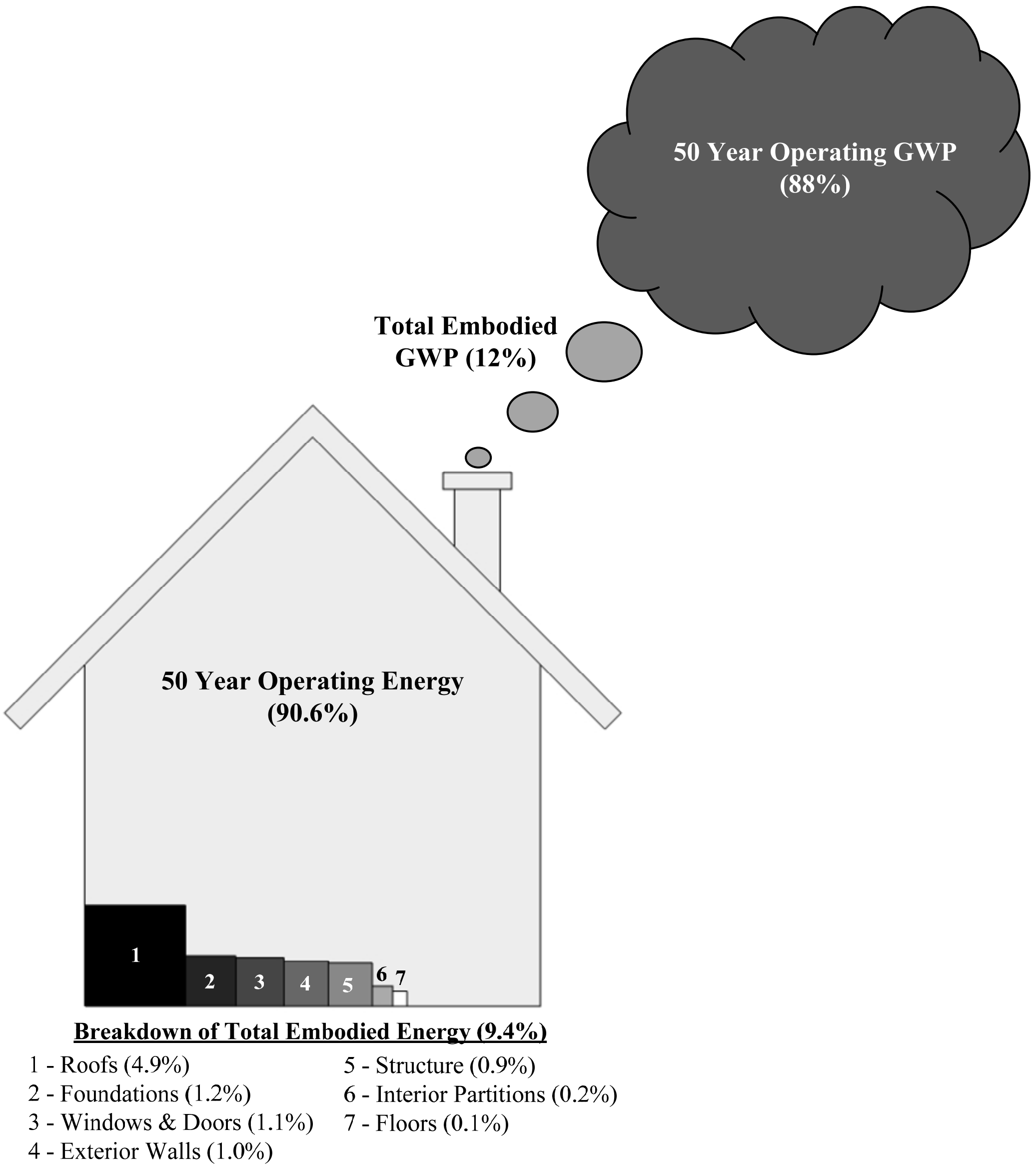


Figure 5-8: A Scaled Diagram of Total Life-Cycle Energy Use and GWP for a Typical Retail Building after a 50 Year Lifespan in Toronto

5.2.4 Comparison of the Baseline Retail Building (Case Study #1) to Average Canadian Retail Building

It is important to compare the LCA results for the baseline retail building to the average retail building in Canada, in order to determine how accurately this baseline retail building represents the typical retail building in Canada.

Recall that after a 50 year lifespan in Toronto, the total operating energy of the baseline retail building was found to be about 50,700 GJ of primary energy use. Given a total floor area of about 581 m^2, this translates into about 1,745 $MJ/m^2/yr$ of primary energy use. The total operating GWP of the baseline retail building was found to be about 2,310 tonnes of CO_2 eq. after 50 years (80 kg of CO_2 eq./m^2/yr).

The average retail building in Canada uses about 1,740 $MJ/m^2/yr$ of energy and emits about 97 kg of CO_2 eq./m^2/yr (NRCan, OEE, 2010). The baseline building in this study consumes about the same energy per year and emits approximately 18% less CO_2 eq. per year than the average retail building in Canada. Therefore, the baseline retail building in this study was deemed to adequately represent the life-cycle operating energy and operating GWP of a typical retail building in Canada.

Unfortunately, there is no data available when it comes to the embodied energy and embodied GWP of single-storey retail buildings. Therefore, it is difficult (if not impossible) to provide a comparison of the embodied energy or embodied GWP of the baseline retail building in this study to the average retail building in Canada.

So far the LCA results for the baseline retail building (Case Study #1) have been presented. In the next section, a comparison of the LCA results for the remaining four retail buildings will be discussed.

5.3 LCA Results for Case Study Retail Buildings

Thus far, the LCA results have been discussed for the baseline retail building (Case Study #1). In this section, the LCA results will be presented for the remaining four case study retail buildings.

The objective here is to investigate what affect changing the structural system from a typical hot-rolled steel structure (Case Study #1), to a typical heavy timber structure (Case Study #2), to a typical pre-engineered steel structure (Case Study #3) has on the total life-cycle energy use and GWP of a retail building. Also, the impact on the total life-cycle energy use and GWP will be determined for the case when a predominately steel building (Case Study #4) and a predominately timber building (Case Study #5) are designed.

All of the case study buildings are identical to the baseline retail building (Case Study #1), except for the specific variables that have been changed such as the structural system. Otherwise, all of the buildings have the same dimensions, layout, mechanical systems, operating hours, etc. A detail description of all the case study buildings, along with the LCA results, can be found in Appendix C.

Based on the results from the previous section for the baseline retail building, it is expected that the operating effects will dominate over the lifespan of the other four case study buildings. The remainder of this section will present the relationships between embodied effects and operating effects for all of the case study buildings.

5.3.1 Operating Energy and GWP of Case Study Retail Buildings

In the same way as the baseline retail building, the annual operating energy of each case study building was calculated using eQUEST. Using the ATHENA® EIE converter, the annual electricity use and natural gas use was then converted into an equivalent amount of annual primary energy and GWP. The annual operating energy and GWP results for all five case study buildings are listed in Table 5-1.

The trends in electricity use and natural gas use were found to be the same for all five case study buildings. Area lighting dominated the annual electricity use and space heating was responsible for almost all of the annual natural gas use.

Case Study # 4 (the predominately steel retail building) was found to have the highest annual operating energy use (and operating GWP) at about 1,040 GJ/yr (48 tonnes of CO_2 eq./yr). Case Study #3 (the typical pre-engineered steel structure retail building) actually had the least annual operating energy use (and operating GWP) at approximately 1,009 GJ/yr (46 tonnes of CO_2 eq./yr). These results are essentially identical. It is important to note that the operating effects are highly dependent on the degree of thermal resistance (i.e. R-value or RSI-value) provided by the exterior infill walls and roof. Therefore, the R-values (and RSI-values) are also listed in Table 5-1 alongside the operating energy and GWP results for each case study building. For each case study building, the exterior walls and roofs were designed based on typical practice. Wherever possible, the thermal resistances were taken to be as close as possible to Case Study #1, in order to ensure an equal comparison. However, in some instances the thermal resistances deviated slightly from Case Study #1 (either higher or lower). However, for the purposes of this study, these slight deviations were deemed to be acceptable.

In any case, the annual operating energy and operating GWP of all five case study buildings only differed at most by 3% and 4% respectfully. Therefore, given the level of accuracy required in this study, it can be said that all of these buildings had almost identical annual operating energy and operating GWP. Therefore, assuming that the thermal resistance of the exterior walls and roof are similar, the impact of changing the structural system from a timber system to a steel system has a negligible impact on the annual operating effects. The same is true of the predominately steel and predominately timber retail buildings. So long as the thermal resistance of the exterior walls and roof are similar, the differences in annual operating effects are minimal.

Table 5-1: Annual Operating Energy and GWP Results for Case Study Buildings

Case Study #	Building Description	* R-Value (RSI-Value)		Data from eQUEST		Data from ATHENA® EIE Converter	
		Exterior Walls	Roof	Annual Electricity Use (kWh/yr)	Annual Natural Gas Use (MBtu/yr)	Annual Primary Energy Use (GJ/yr)	Annual GWP (tonnes of CO_2 eq./yr)
1 (Baseline Retail Building)	Typical Hot-Rolled Steel Structure Retail Building	15.6 (2.7)	20.8 (3.7)	78,947	376.46	1,014	46
2	Typical Heavy Timber Structure Retail Building	15.6 (2.7)	20.8 (3.7)	78,947	376.46	1,014	46
3	Typical Pre-Engineered Steel Structure Retail Building	17.9 (3.2)	17.8 (3.1)	79,341	370.65	1,009	46
4	Predominately Steel Retail Building	13.0 (2.3)	17.8 (3.1)	79,839	393.53	1,040	48
5	Predominately Timber Retail Building	14.9 (2.6)	23.1 (4.1)	79,420	376.21	1,016	46

** Note: The exterior walls and roofs were designed based on typical practice for each type of building. Wherever possible, the R-values were taken to be as close as possible to the R-values of Case Study #1. However, in some circumstances the R-values deviate slightly from Case Study #1. The differences in R-values do affect the annual operating energy and GWP of the buildings, but this was assumed to be acceptable for the purposes of this study.*

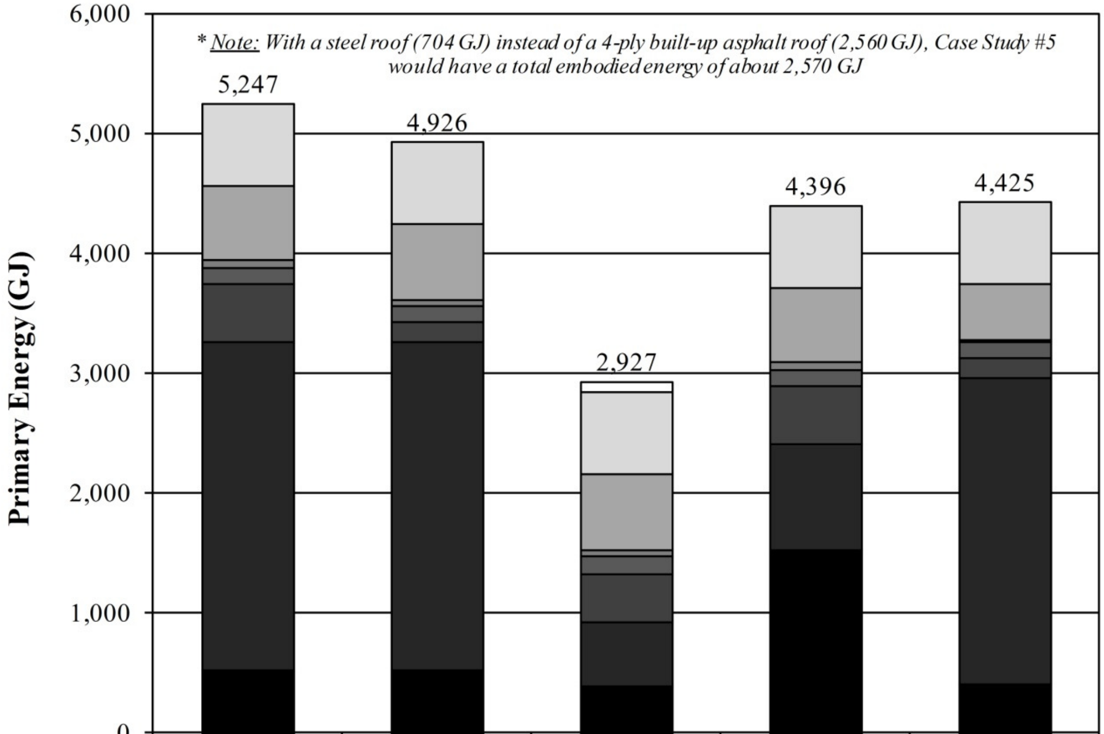
5.3.2 Embodied Energy and GWP of Case Study Retail Buildings

In this section, the results are presented for the total embodied energy and total embodied GWP of the five case study buildings. Figure 5-9 displays the total life-cycle embodied energy of each of the five case study buildings after a 50 year lifespan in Toronto using the ATHENA® EIE for Buildings.

The total embodied energy of each case study building has been divided into the relevant building components: exterior walls, roof, structure, interior partitions, floor, windows, doors, foundations, and other. Case Study #3 (the typical pre-engineered steel retail building) was found to have the least total embodied energy of all the buildings (2,927 GJ). This result is logical as pre-engineered steel buildings are highly engineered and optimized structures from a material standpoint. This is primarily achieved to save material and construction costs. However, this high degree of material optimization has the added benefit of creating a building that uses less material and therefore, has less embodied energy than other types of buildings. Although pre-engineered steel buildings are comprised mostly of steel (a material with a relatively high embodied energy), little recurring embodied energy is associated with this system as most of the building components can last 50 years with minimal repair/replacement. From an embodied energy standpoint, pre-engineered buildings show excellent potential as building systems for low-energy building applications.

Case Study #1 (the typical hot-rolled steel structure retail building) was found to have the highest total embodied energy of all five buildings (5,247 GJ). One might understandably expect Case Study #4 (the predominately steel retail building) to have a higher total embodied energy, but this is not the case. The reason for this is that the predominately steel retail building had a standing seam steel roof which had significantly less embodied energy than the 4-ply built-up asphalt roof that was specified for the typical hot-rolled steel structure retail building. This observation leads to a very important conclusion for single-storey commercial buildings.

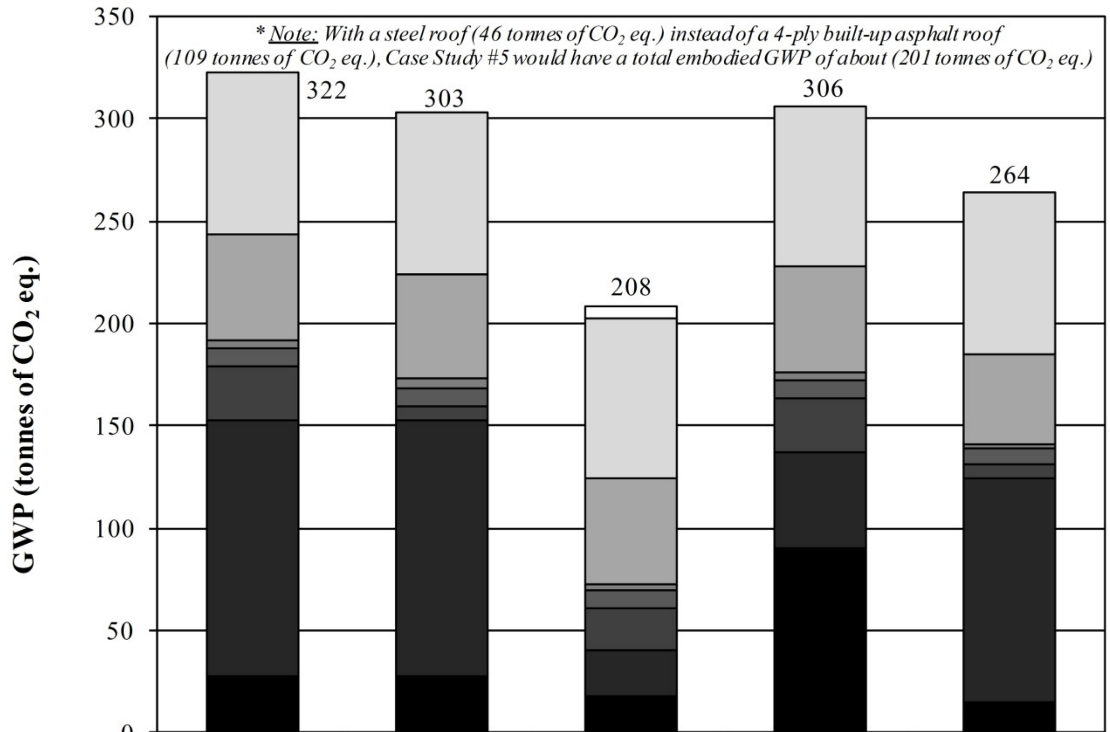
Of all the building components, the roof has by far the largest total embodied energy. Roof coverings are often made of asphalt-based materials which are very high in embodied energy and must be replaced often. Case Studies #1, #2, and #5 all have a 4-ply built-up asphalt roof system. On the contrary, Case Studies #3 and #4 have a commercial standing seam steel roof. The steel roof requires less maintenance, repair, and replacement than the asphalt-based roof. Therefore, the recurring embodied energy of the steel roof system is much smaller after 50 years. Although steel as a material has a relatively high embodied energy, steel roofs perform much better than asphalt-based roof systems due to less recurring embodied energy. It should be noted that if Case Study #5 (the predominately timber retail building) were to have a commercial standing seam steel roof instead of a 4-ply built-up asphalt roof, it would actually have the least total embodied energy of all five buildings. This just serves to reinforce the importance of the roof in the calculations of total embodied energy for a single-storey building. Generally speaking, if the concern is to reduce the total embodied energy of a single-storey building, then the attention should focus on reducing the total embodied energy of the roof.



	Case Study #1: Typical Hot-Rolled Steel Structure Retail Building	Case Study #2: Typical Heavy Timber Structure Retail Building	Case Study #3: Typical Pre-Engineered Steel Retail Building	Case Study #4: Predominately Steel Retail Building	* Case Study #5: Predominately Timber Retail Building
Other	0	0	82	0	0
Foundations	679	679	679	679	679
Windows and Doors	629	629	629	629	461
Floor	58	58	62	58	32
Interior Partitions	140	140	140	140	128
Structure	476	156	395	476	156
Roof	2,729	2,729	545	889	2,560
Exterior Walls	536	536	395	1,525	410

Figure 5-9: Total Life-Cycle Embodied Energy of the Case Study Buildings after 50 Year Lifespan in Toronto

With the discussion of the total embodied energy for the five case study buildings completed, the focus can now be shifted to a comparison of the total embodied GWP. As before, the embodied GWP was calculated using the ATHENA® EIE for buildings and the results for the five case study buildings are displayed in Figure 5-10.



	Case Study #1: Typical Hot-Rolled Steel Structure Retail Building	Case Study #2: Typical Heavy Timber Structure Retail Building	Case Study #3: Typical Pre-Engineered Steel Retail Building	Case Study #4: Predominately Steel Retail Building	* Case Study #5: Predominately Timber Retail Building
Other	0	0	5	0	0
Foundations	79	79	79	79	79
Windows and Doors	51	51	51	51	44
Floor	4	4	3	4	2
Interior Partitions	9	9	9	9	7
Structure	27	8	21	27	8
Roof	124	124	22	46	109
Exterior Walls	28	28	18	91	15

Figure 5-10: Total Life-Cycle Embodied GWP of the Case Study Buildings after 50 Year Lifespan in Toronto

Similar to the total embodied energy, Case Study #3 (the typical pre-engineered steel retail building) was found to have the least total GWP after 50 years (208 tonnes of CO_2 eq.). Again, this can be attributed to the high degree of material optimization that is inherent to these types of buildings. On the contrary, Case Study #1 (the typical hot-rolled steel structure retail building) was found to have the highest total embodied GWP (322 tonnes of CO_2 eq.). Again, the roof plays a significant role in this. The standing seam steel roof had much less embodied GWP compared to the 4-ply built-up asphalt roof systems, due to less recurring GWP. It should be pointed out that if Case Study #5 (the predominately timber retail building) were to switch from a 4-ply built-up asphalt roof to a steel roof, it would actually have the least total embodied GWP of any building after 50 years. Figure 5-10 also indicates that in most cases, the embodied GWP of the foundations was the highest single contributor towards the total embodied GWP next to the roof. This suggests that a concerted effort to optimize the foundation systems for low-energy buildings should be undertaken, if reducing the embodied GWP is a concern.

Now that the total life-cycle operating energy, operating GWP, embodied energy, and embodied GWP for the five case study buildings has been discussed, the results will be combined to determine which case study building has the least total energy and total GWP after 50 years.

5.3.3 Total Energy and GWP of Case Study Retail Buildings

So far it can be seen that the annual operating energy and operating GWP do not significantly differ among the five case study buildings. It was also observed that the embodied energy (and embodied GWP) does differ between the five buildings, sometimes by as much as 44% (35%). In this section, the total operating energy, operating GWP, embodied energy, and embodied GWP are combined to determine the total life-cycle energy and total GWP of the five case study buildings.

Displayed in Figure 5-11 are the total life-cycle energy and GWP for the five case study buildings after a 50 year lifespan in Toronto. After a 50 year lifespan, the total energy and GWP of the five case study buildings differs at most by only 6% and 7% respectfully. This is a very important result as it indicates that regardless of the choice of structural system, or whether the building is primarily made of steel or timber building components, the differences in total energy and GWP after 50 years are minimal. The operating energy and operating GWP completely dominate the total energy and total GWP of the buildings after 50 years.

It was found that Case Study #3 (the typical pre-engineered steel retail building) had the least total energy and total GWP of any building. However, the energy and GWP savings for Case Study #3 were minimal compared to the other buildings. Regardless, a pre-engineered steel retail building performs at least as well as other types of buildings (and in this case slightly better). It is difficult to say that in every case a pre-engineered steel building would perform better than other types of buildings in terms of life-cycle energy use and GWP. This is highly dependent on the thermal resistance of the enclosure among other variables. Historically, pre-engineered steel buildings have been plagued by massive thermal bridging problems at the location of wall girts and roof purlins. Therefore, a concerted effort has to be taken to limit the thermal bridging problems in pre-engineered steel buildings, in order for them to be competitive with other conventional building types.

It is important to note that since the differences in the total energy and GWP among the five case study buildings are so small, it is totally plausible that under slightly different circumstances (for example a slight change to the thermal resistance of the enclosure) that the rankings in Figure 5-11 could differ. However, this study proved that the type of building does not significantly impact the total life-cycle energy use and GWP. Only once the operating effects of a typical retail building are reduced significantly (by at least 50 %), would a comparison of the total embodied effects of different building types become important.

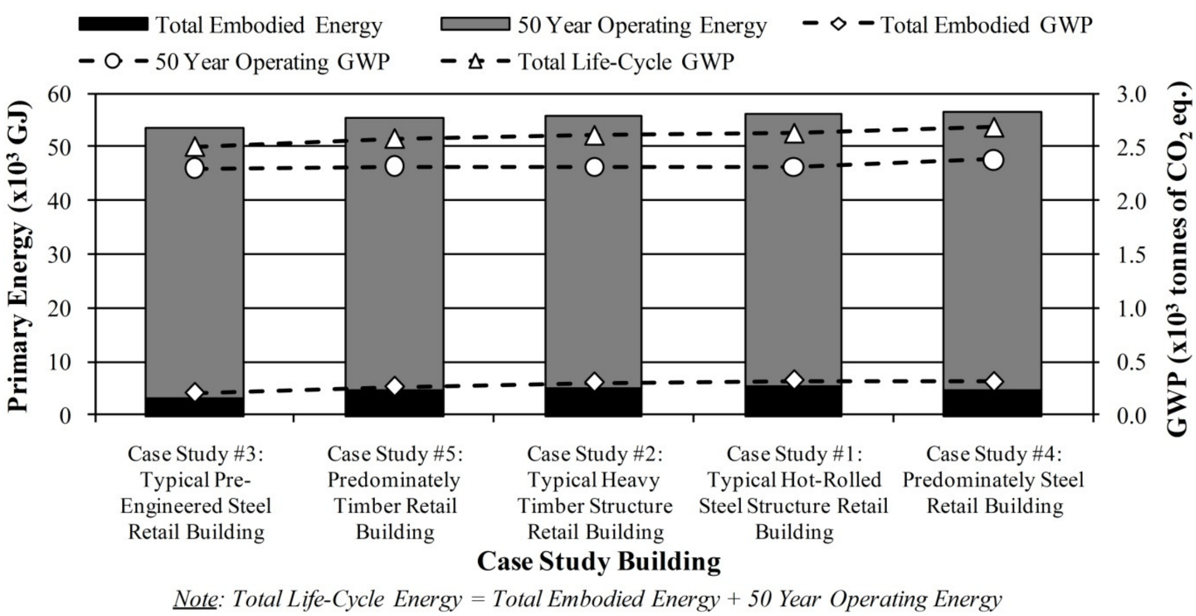


Figure 5-11: Total Life-Cycle Energy Consumption and GWP of the Case Study Buildings after 50 Year Lifespan in Toronto

To reinforce the importance of operating effects for the different building types, a breakdown of operating energy and embodied energy has been plotted for Case Study #2 and #3 in Figure 5-12 and

5-13 respectfully (recall that a similar breakdown for Case Study #1 has already been plotted previously).

Figure 5-12 illustrates the breakdown of total life-cycle operating energy and embodied energy for Case Study # 2 (the typical heavy timber structure retail building). The total operating energy in this case represents about 91% of the total life-cycle energy, while the total embodied energy is only responsible for about 9%.

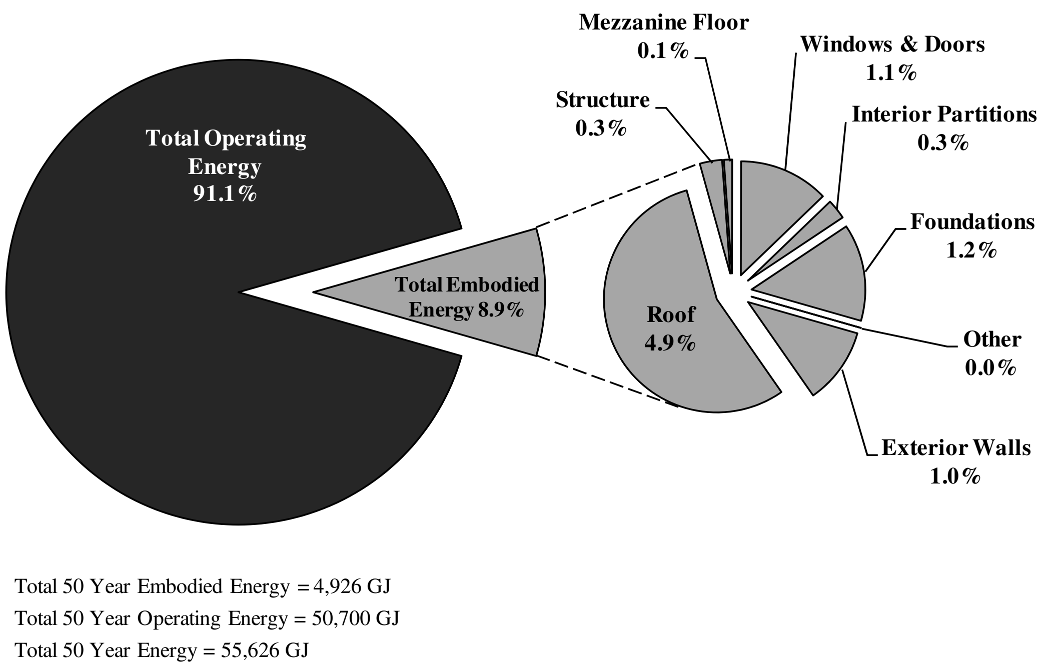
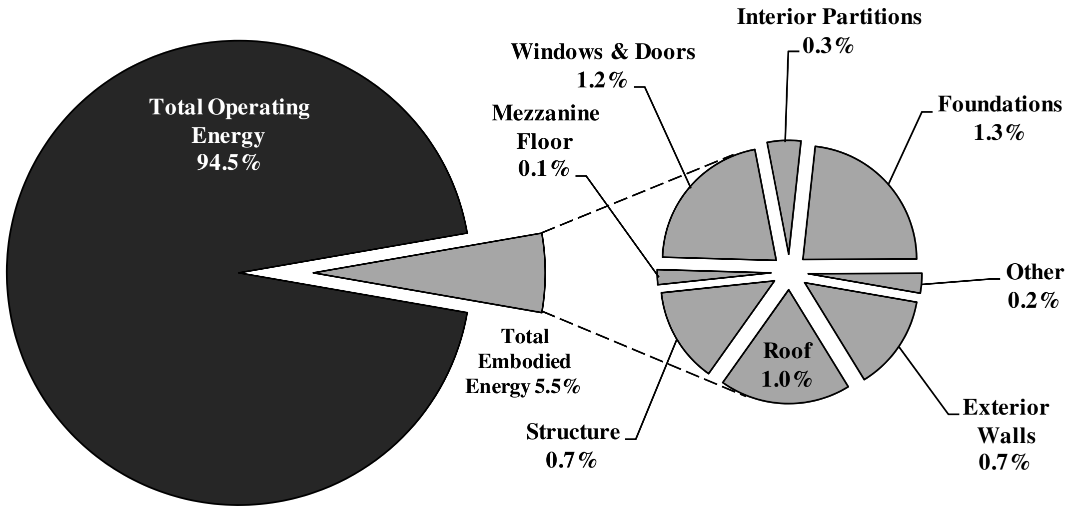


Figure 5-12: Total Life-Cycle Energy Breakdown of the Typical Heavy Timber Structure Retail Building (Case Study #2) after 50 Year Lifespan in Toronto

Similarly, Figure 5-13 illustrates the breakdown of total life-cycle operating energy and embodied energy for Case Study # 3 (the typical pre-engineered steel retail building). The total operating energy in this case represents about 94% of the total life-cycle energy, while the total embodied energy is only responsible for about 6%.

A similar breakdown of the total life-cycle operating GWP and embodied GWP can be done. Figure 5-14 and Figure 5-15 illustrate the results for Case Study #2 and #3 respectfully. Again, the dominance of the operating GWP compared to the embodied GWP is clear.

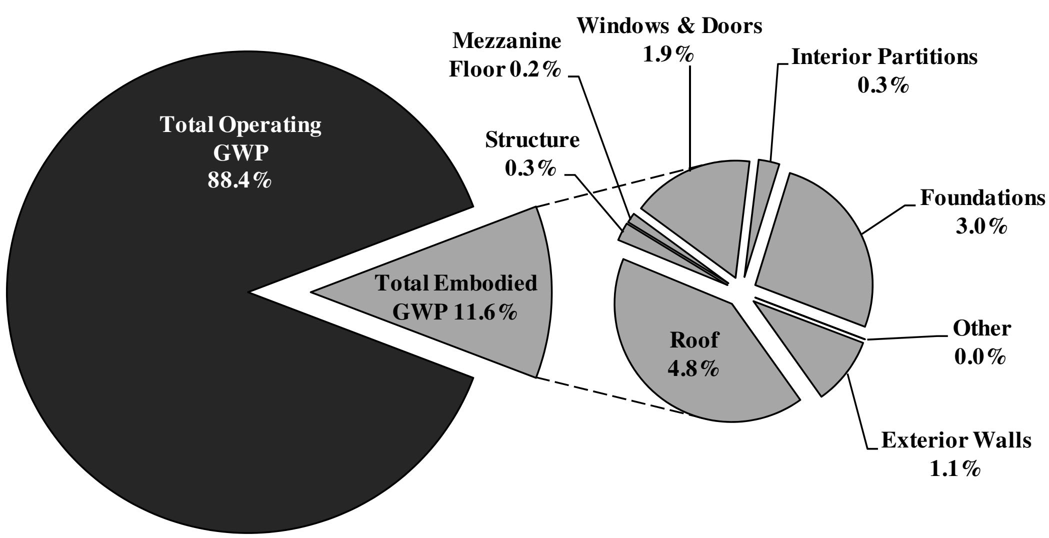


Total 50 Year Embodied Energy = 2,927 GJ

Total 50 Year Operating Energy = 50,470 GJ

Total 50 Year Energy = 53,396 GJ

Figure 5-13: Total Life-Cycle Energy Breakdown of the Typical Pre-Engineered Steel Retail Building (Case Study #3) after 50 Year Lifespan in Toronto



Total 50 Year Embodied GWP = 303 tonnes of CO_2 eq.

Total 50 Year Operating GWP = 2,310 tonnes of CO_2 eq.

Total 50 Year GWP = 2,613 tonnes of CO_2 eq.

Figure 5-14: Total Life-Cycle GWP Breakdown of the Typical Heavy Timber Structure Retail Building (Case Study #2) after 50 Year Lifespan in Toronto

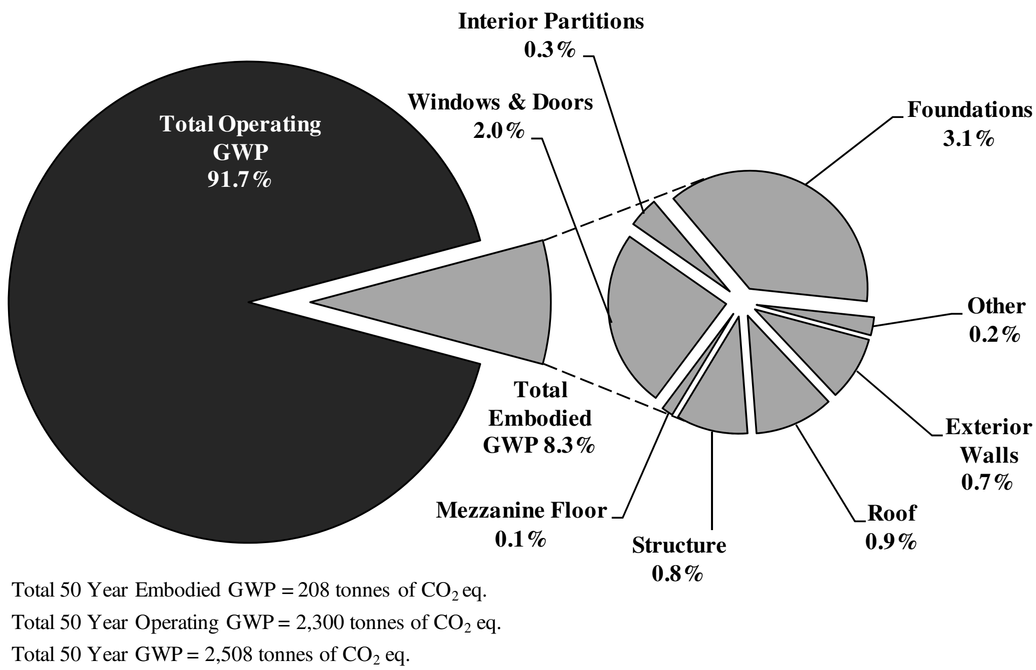


Figure 5-15: Total Life-Cycle GWP Breakdown of the Typical Pre-Engineered Steel Retail Building (Case Study #3) after 50 Year Lifespan in Toronto

These LCA results for the five case study retail buildings in Canada are very informative. The importance of operating effects verses embodied effects is obvious. Practically speaking, any building designer who is concerned with reducing the life-cycle energy and GWP of a single-storey retail building should focus primarily on reducing the operating energy and operating GWP of the building. Only once the operating effects can be reduced by at least 50% from typical values today, does a comparison of embodied effects become relevant.

That being said, as aggressive reductions in operating effects are achieved through such means as the LEED® certification process, it will be important to know which building components (exterior walls, roofs, floors, structural systems, foundations, windows, doors, and interior partitions) consume the most amount of energy and have the most GWP. The remainder of this study will examine in greater detail some of the differences between these various building components in terms of operating and embodied effects. However, one should not forget that in a typical retail building today, operating effects account for upwards of 90% of the total effects, while embodied effects only represent about 10%.

5.4 Data Quality and Assessment

Before moving onto a detailed discussion of the LCA results for the 220 different building components in this study, it would be prudent to briefly compare the LCA results for the five single-storey retail buildings in this study to the literature.

Recall from Table 2-4 in Chapter 2 that the annual total life-cycle operating energy per gross floor area for the LCA studies of commercial buildings in the literature ranged from about 0.23 to 4.23 GJ/m^2/yr. The annual total life-cycle operating energy per gross floor area for the five single-storey retail buildings in this study ranged from about 1.74 to 1.75 GJ/m^2/yr, which is within the range from the literature. Likewise, the annual total life-cycle operating GWP per gross floor area for the LCA studies of commercial buildings in the literature ranged from about 0.02 to 0.24 tonnes of CO_2 eq./m^2/yr. The annual total life-cycle operating GWP per gross floor area for the five single-storey retail buildings in this study was about 0.08 tonnes of CO_2 eq./m^2/yr, which is also within the range from the literature. Also, in the literature the total life-cycle embodied energy per gross floor area at the end of the building's lifespan ranged from about 3.42 to 22.45 GJ/m^2 for a commercial building. In this study, the equivalent values for the five single-storey retail buildings ranged from about 5.04 to 9.03 GJ/m^2, which is within the range from the literature. Likewise, the total life-cycle embodied GWP per gross floor area at the end of the building's lifespan from the commercial buildings in the literature ranged from about 0.20 to 0.89 tonnes of CO_2 eq./m^2/yr, compared to a range of about 0.36 to 0.55 tonnes of CO_2 eq./m^2/yr for the five single-storey retail buildings in this study. Therefore, the LCA results in this study fall within the range of LCA results for commercial buildings from the literature.

Chapter 6
Results: Life-Cycle Assessment of Building Components

6.1 Introduction

To this point, the LCA results have been presented for five different single-storey retail buildings with a 50 year lifespan in Toronto. The dominance of operating energy and operating GWP on the total life-cycle energy and total GWP has been established. Specifically, about 90% of the total life-cycle energy use and total GWP of a single-storey retail building after 50 years is a result of building operations, while only 10% or less is attributed to the embodied effects. However, as the building industry continues to strive for reductions in the annual operating energy and operating GWP of buildings, it will become increasingly important to consider the embodied energy and embodied GWP of the building components.

In this chapter, a brief overview of the total energy and total GWP for the 220 different building components that were examined in this study will be conducted. Recall that these building components are grouped into the following categories: exterior infill walls, roofs, structural systems, floors, windows, doors, interior partitions, and foundations. The LCA calculations are performed over a 50 year lifespan for the case of a building located in Toronto, Canada.

The ultimate objective of this chapter is to examine a wide array of strategies within each of the building component categories, in order to rank the alternative strategies in order of increasing total energy use and total GWP. By completing a detailed LCA of a wide array of strategies, this will serve as a reference to building professionals who are interested in a relative comparison of the total life-cycle energy use and total GWP of different walls, roofs, structural systems, floors, windows, doors, interior partitions, and foundations. The intent of this chapter is not to deal specifically with a direct comparison of one building component to another, but rather to present the range of values that are possible for the various categories of building components. Thus, the results in this chapter are a summary of the detailed LCA results that can be found in Appendix B.

6.2 Interpreting the LCA Graphs of Building Components

Interpreting the graphs of the total life-cycle energy and GWP presented in this chapter is relatively straightforward. The baseline retail building (Case Study #1) was used as the datum. Each building component of the baseline building was then systematically replaced with a new building component (for example the baseline exterior infill wall was replaced with a new exterior infill wall). The difference in the total embodied energy (Δ embodied energy) and the difference in the total operating energy (Δ operating energy) from the baseline case after 50 years was plotted. Similarly, the difference in the total embodied GWP (Δ embodied GWP) and the difference in the total operating GWP (Δ operating GWP) from the baseline case was also plotted.

The key point to note when interpreting these graphs is that the values (both embodied energy and operating energy) have been plotted relative to a baseline component. In each case, the baseline component is also plotted on the graphs and is highlighted in grey. The range of building components were potted in order of increasing total energy (embodied energy + operating energy). Therefore, those building components that are plotted to the left of the baseline component (highlighted in grey) consume less total energy after 50 years than the baseline component. Conversely, those building components that are plotted to the right of the baseline building component, consume more total energy after 50 years than the baseline component. In this way, one can quickly tell from these graphs how the various building components compare to one another, based on their relative comparison to a baseline building component.

6.3 LCA Results for Exterior Infill Wall Enclosures

In this section, the LCA results for the collection of exterior infill walls in Appendix B will be presented. The Δ total energy and Δ total GWP of the different types of exterior infill walls examined in this study relative to the baseline wall (BASE-W) can be seen in Figure 6-1 to Figure 6-6. Recall that a detailed description of these walls can be found in Appendix B.

From outside to inside, BASE-W is comprised of: an exterior insulation and finish system (EIFS), 64 mm of extruded polystyrene rigid insulation, a self-adhesive membrane with primer, 16 mm non paper-faced gypsum sheathing, 39 mm x 152 mm cold-formed steel studs spaced at 600 mm on center, regular 16 mm gypsum board, and a latex paint finish. After 50 years, the total embodied energy of BASE-W is about 0.927 GJ/m^2 of primary energy and the total embodied GWP is about 49 kg of CO_2 eq./m^2 (results are per m^2 of exterior wall).

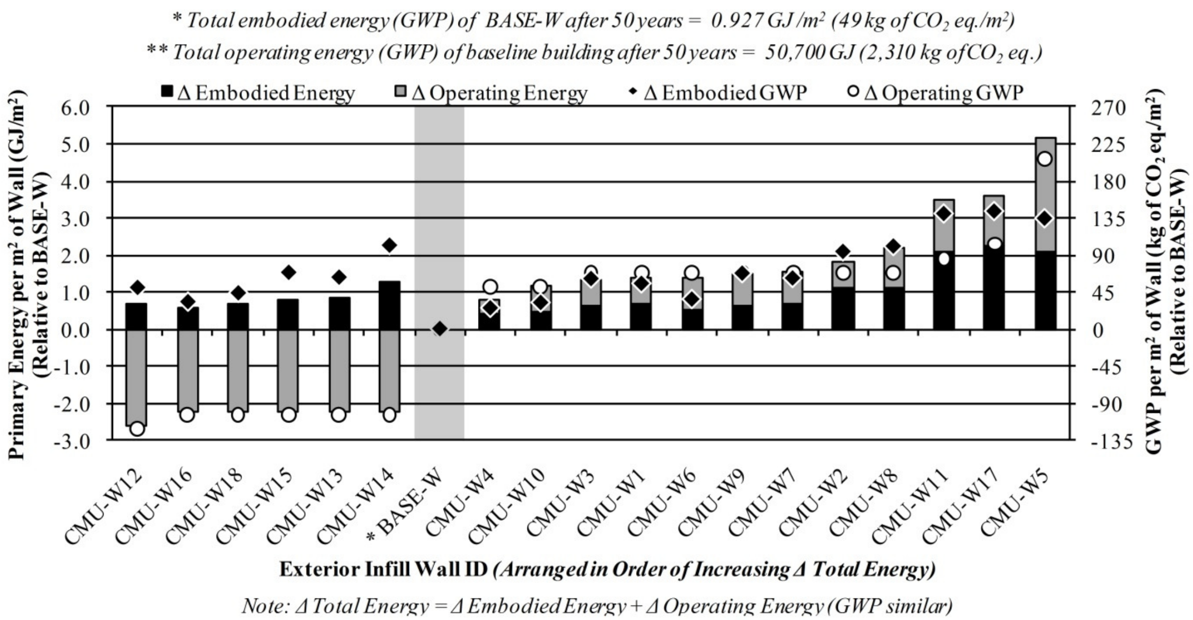


Figure 6-1: Total Life-Cycle Energy and GWP of Concrete Masonry Unit Exterior Infill Walls (CMU-W) after 50 Year Lifespan in Toronto

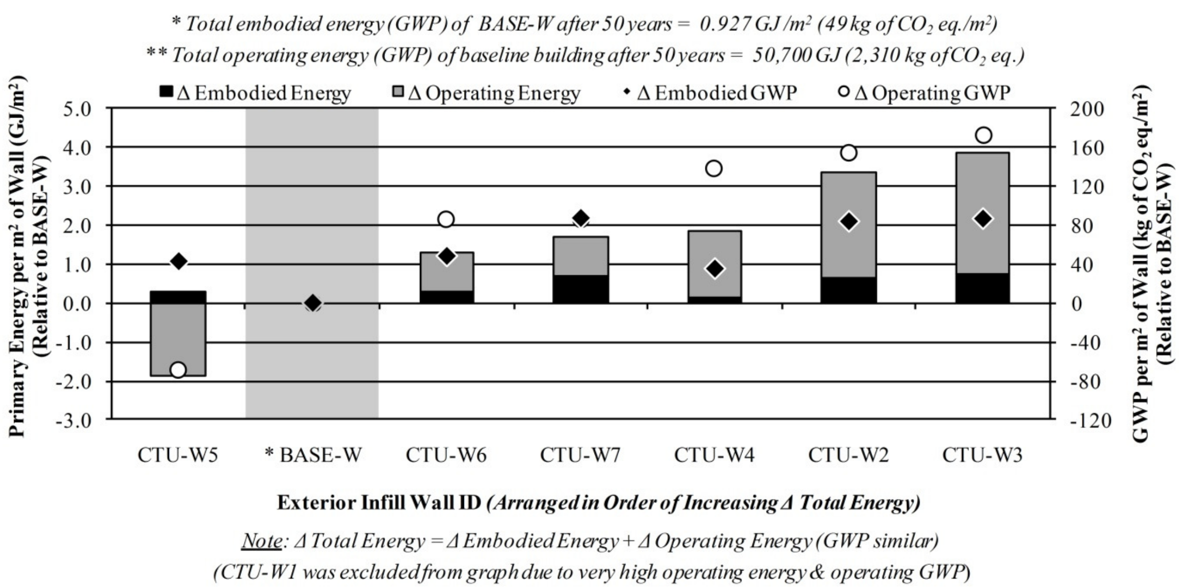


Figure 6-2: Total Life-Cycle Energy and GWP of Concrete Tilt-Up Exterior Infill Walls (CTU-W) after 50 Year Lifespan in Toronto

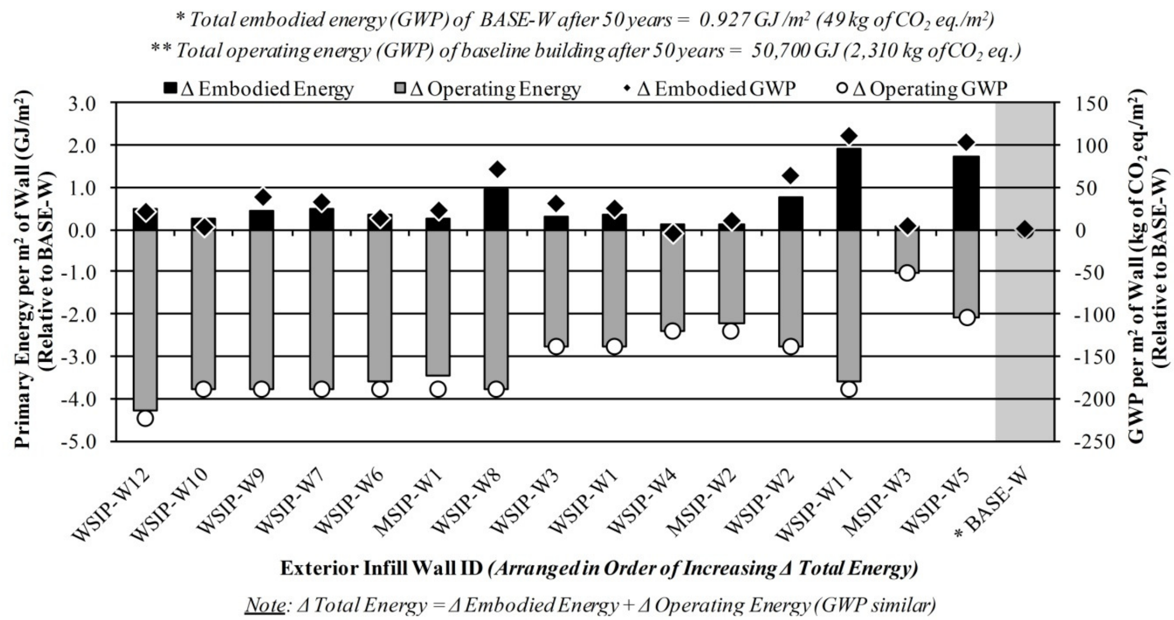


Figure 6-3: Total Life-Cycle Energy and GWP of Structural Insulated Panel Exterior Infill Walls (WSIP-W & MSIP-W) after 50 Year Lifespan in Toronto

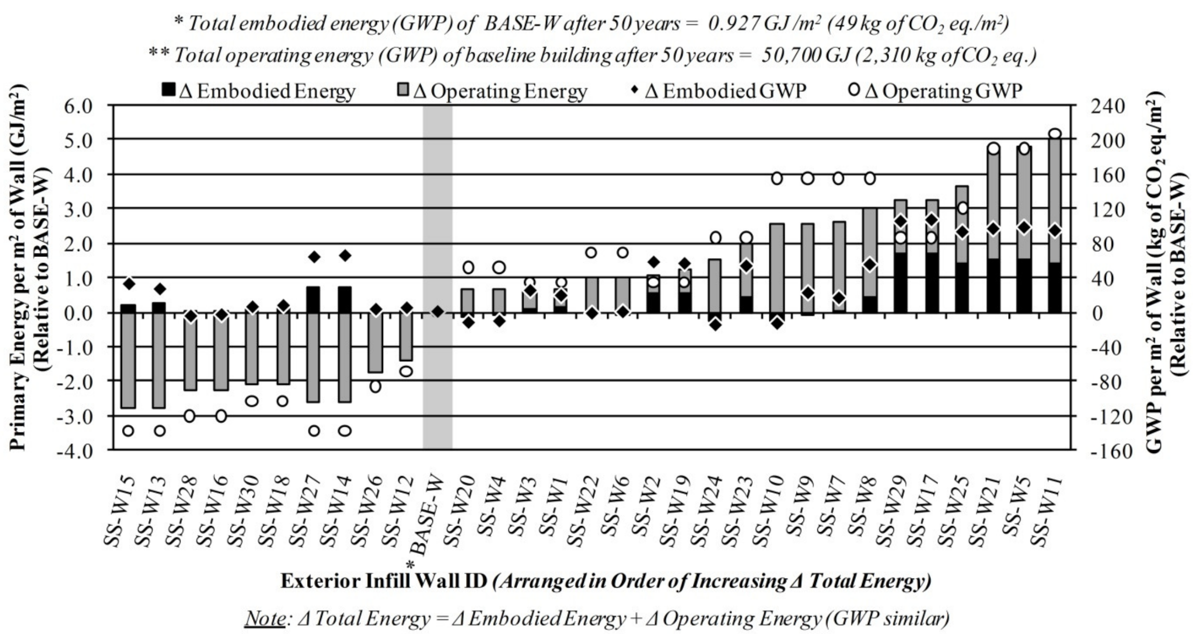


Figure 6-4: Total Life-Cycle Energy and GWP of Cold-Formed Steel Stud Exterior Infill Walls (SS-W) after 50 Year Lifespan in Toronto

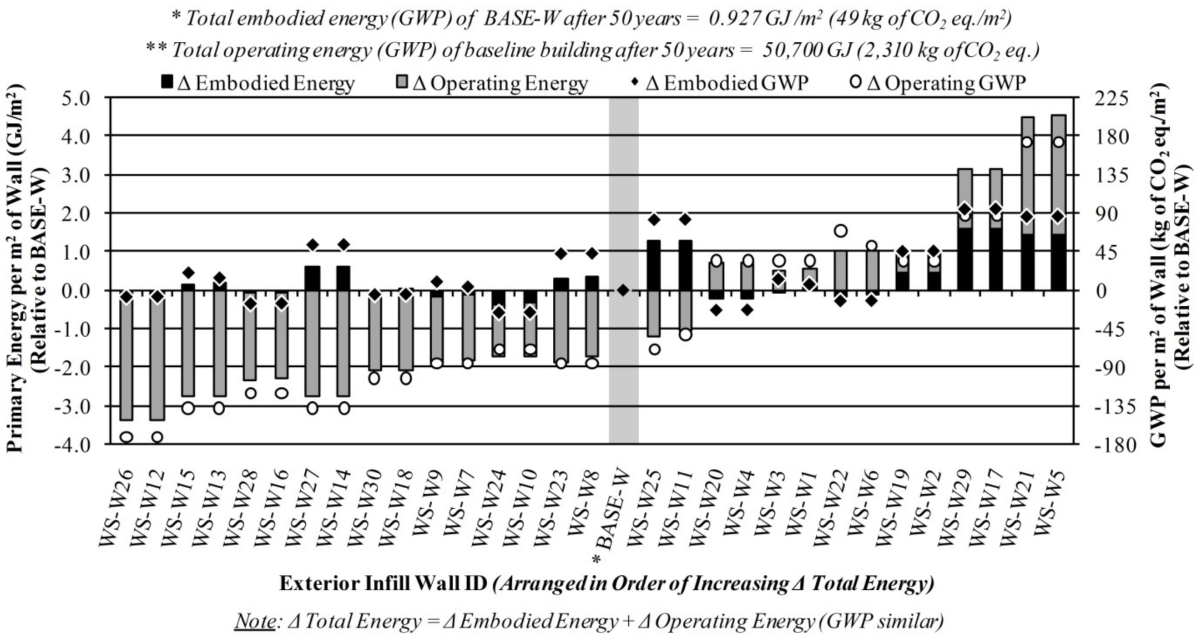


Figure 6-5: Total Life-Cycle Energy and GWP of Wood Stud Exterior Infill Walls (WS-W) after 50 Year Lifespan in Toronto

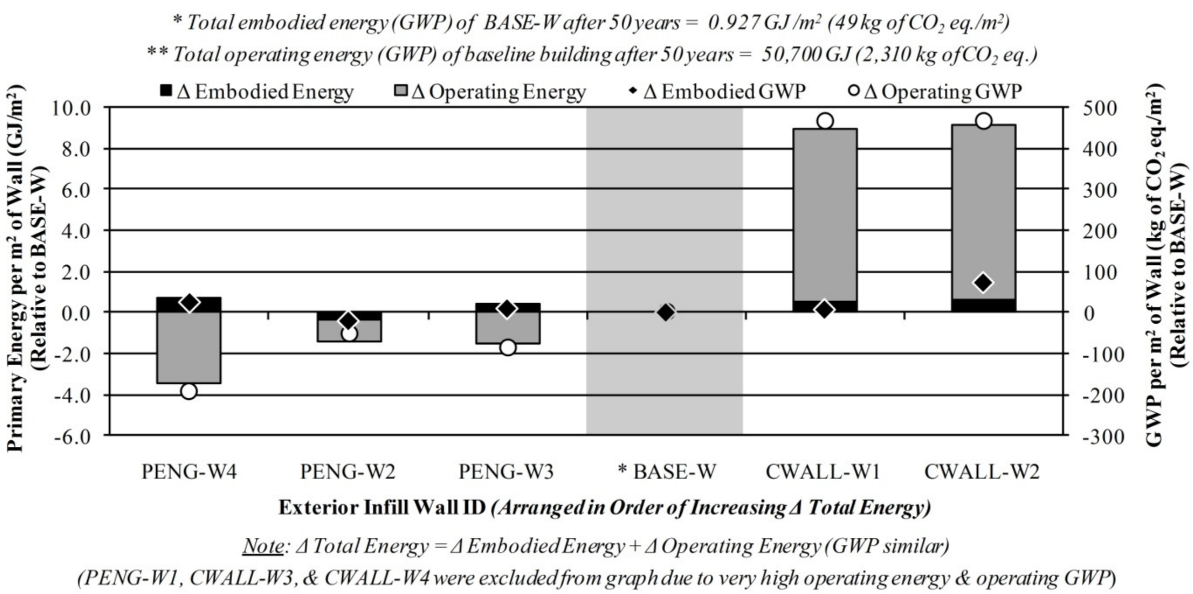


Figure 6-6: Total Life-Cycle Energy and GWP of Pre-Engineered Steel Building (PENG-W) and Opaque Spandrel Panel Exterior Infill Walls (CWALL-W) after 50 Year Lifespan in Toronto

Table 6-1 summarizes the data presented in the preceding figures, along with a summary of the data for the additional building components that will be presented in subsequent sections. The average, minimum, and maximum values for the Δ total energy and Δ total GWP from the baseline datum have been calculated for the 220 different building components in this study. Table 6-1 allows for a quick comparison of the range of values that are possible for the different types of exterior infill walls and other building components in this study, with respect to the Δ total energy and Δ total GWP. Negative values indicate a savings in energy and GWP and positive values indicate an increase.

Table 6-1: A Summary of the Δ Total Energy and Δ Total GWP from the Baseline Case for the Alternative Building Components in this Study after 50 Years

Building Component	Δ Total Primary Energy (GJ/m^2)			Δ Total GWP (kg of CO_2 eq./m^2)		
	Average	Min	Max	Average	Min	Max
Exterior Infill Walls						
Concrete Masonry Unit Walls (CMU-W)	0.911	-1.879 (CMU-W12)	5.180 (CMU-W5)	92	-70 (CMU-W12)	342 (CMU-W5)
[1] Concrete Tilt-Up Walls (CTU-W)	1.751	-1.597 (CTU-W5)	3.848 (CTU-W3)	159	-26 (CTU-W5)	259 (CTU-W3)
Wood Structural Insulated Panel Walls (WSIP-W)	-2.606	-3.810 (WSIP-W12)	-0.322 (WSIP-W5)	-125	-203 (WSIP-W12)	0 (WSIP-W5)
Metal Structural Insulated Panel Walls (MSIP-W)	-2.085	-3.189 (MSIP-W1)	-0.961 (MSIP-W3)	-109	-168 (MSIP-W1)	-48 (MSIP-W3)
Cold-Formed Steel Stud Walls (SS-W)	0.837	-2.521 (SS-W15)	5.022 (SS-W11)	65	-126 (SS-W28)	301 (SS-W11)
Wood Stud Walls (WS-W)	-0.465	-3.393 (WS-W26)	4.520 (WS-W5)	-13	-180 (WS-W26)	259 (WS-W5)
[2] Pre-Engineered Steel Building Walls (PENG-W)	-1.768	-2.759 (PENG-W4)	-1.165 (PENG-W3)	-105	-165 (PENG-W4)	-77 (PENG-W3)
[3] Opaque Curtainwalls (CWALL-W)	9.008	8.920 (CWALL-W1)	9.096 (CWALL-W2)	504	472 (CWALL-W1)	537 (CWALL-W2)
Roofs						
Concrete Hollow Core Roofs (CHC-R)	-2.675	-4.850 (CHC-R10)	-0.194 (CHC-R2)	-102	-210 (CHC-R10)	14 (CHC-R2)
Open Web Steel Joist Roofs (OWSJ-R)	-2.537	-4.602 (OWSJ-R10)	-0.171 (OWSJ-R2)	-112	-223 (OWSJ-R10)	0 (OWSJ-R2)
Cold-Formed Steel Joist Roofs (CFS-R)	-2.341	-4.925 (CFS-R10)	-0.240 (CFS-R13)	-102	-243 (CFS-R10)	-1 (CFS-R13)
Glulam Joist Roofs (GLU-R)	-3.123	-5.161 (GLU-R10)	-0.827 (GLU-R2)	-150	-255 (GLU-R10)	-44 (GLU-R2)
Wood Structural Insulated Panel Roofs (WSIP-R)	-3.186	-4.627 (WSIP-R5)	-1.314 (WSIP-R2)	-168	-218 (WSIP-R6)	-83 (WSIP-R2)
Metal Structural Insulated Panel Roofs (MSIP-R)	-4.313	-5.180 (MSIP-R1)	-3.313 (MSIP-R3)	-182	-225 (MSIP-R1)	-124 (MSIP-R3)
[4] Pre-Engineered Steel Building Roofs (PENG-R)	-3.754	-4.580 (PENG-R4)	-3.339 (PENG-R2)	-173	-222 (PENG-R4)	-144 (PENG-R2)

Table 6-1 (Cont.): A Summary of the Δ Total Energy and Δ Total GWP from the Baseline Case for the Alternative Building Components in this Study after 50 Years

Building Component	Δ Total Primary Energy (GJ/m^2)			Δ Total GWP (kg of CO_2 eq./m^2)		
	Average	Min	Max	Average	Min	Max
Structural Systems (S)	-0.343	-0.547 (S-2)	-0.139 (S-3)	-22	-33 (S-2)	-11 (S-3)
Floors (FL)	-0.527	-0.646 (FL-5)	-0.448 (FL-4)	-37	-55 (FL-5)	-6 (FL-1)
Windows (W)	-10.399	-18.082 (W-8)	-2.621 (W-3)	-476	-935 (W-8)	37 (W-3)
[5] **Doors (D)**	-17.404	-107.796 (D-1)	33.342 (D-4)	122	-273 (D-1)	1,158 (D-4)
Interior Partitions (WS-P, SS-P, & CMU-P)	-0.056	-0.196 (WS-P2)	0.394 (CMU-P1)	-5	-16 (WS-P2)	29 (CMU-P1)
Foundations						
[6] Isolated Footing and Concrete Pier (IF-FDN)	0.882	-0.091 (IF-FDN2)	3.224 (IF-FDN7)	110	-22 (IF-FDN2)	393 (IF-FDN7)
[7] Strip Footing and Concrete Wall (SF-FDN)	0.273	-0.044 (SF-FDN6)	0.550 (SF-FDN3)	16	-10 (SF-FDN6)	44 (SF-FDN3)
Slab-On-Grades (SOG-FDN)	-1.184	-2.976 (SOG-FDN3)	-0.056 (SOG-FDN5)	-77	-194 (SOG-FDN3)	-12 (SOG-FDN5)

[*] *<u>Note:</u> Baseline building components are not included in the average, min, and max calculations*

[1] *Results for CTU-W1 were not considered in table due to very high operating energy and operating GWP*

[2] *Results for PENG-W1 were not considered in table due to very high operating energy and operating GWP*

[3] *Results for CWALL-W3 & CWALL-W4 were not considered in table due to very high operating energy and operating GWP*

[4] *Results for PENG-R1 were not considered in table due to very high operating energy and operating GWP*

[5] *Numbers are expressed for one individual door not per m^2*

[6] *Numbers are expressed for one isolated footing and pier combination not per m^2*

[7] *Numbers are expressed per m of strip footing and wall not per m^2*

If the average values in Table 6-1 are used as an indicator of overall performance, then the different types of exterior infill walls in this study can be ranked in order of increasing total energy relative to the baseline case. Arranged in order of the highest savings in total energy to the highest increase in total energy after 50 years, the exterior infill walls in Table 6-1 would be ranked: WSIP-W, MSIP-W, PENG-W, WS-W, SS-W, CMU-W, CTU-W, and CWALL-W. In essence, the results indicate that on average the WSIP-W walls were the best performing exterior infill wall enclosure after 50 years and that the CWALL-W walls were the worst performing in terms of energy use. However, it may be misleading to draw any general conclusions about the competitiveness of a given wall type relative to other wall types based entirely on the average values in Table 6-1. The results in Table 6-1 also indicate that for each different type of exterior infill wall, a range of values were possible for the Δ total energy and Δ total GWP in each case, depending on the exact composition of the wall (i.e. the type of cladding material used, cavity insulation verses exterior installed rigid insulation, etc.). Therefore, the minimum and maximum values for the Δ total energy and Δ total GWP in each case are more representative of the competitiveness of a given wall type. Thus, the minimum and maximum values in Table 6-1 indicate the range of possible values for a given wall type and should be referenced when drawing any general conclusions about the relative competitiveness of a given wall type to another.

That being said, some important observations can be made for the exterior infill walls examined in this study based on the results in Table 6-1 and Figure 6-1 to Figure 6-6. In general, there was found to be a strong correlation between the thermal resistance of the exterior infill walls in this study and the Δ total energy and Δ total GWP. It was found that an increase in total energy and total GWP corresponded in general to a decrease in the thermal resistance of the exterior infill walls. Therefore, thermal resistance (i.e. R-value or RSI-value) played a more significant role in terms of energy use and GWP over the life of the building than any differences in embodied effects between the building materials in the walls. In other words, in almost every case there were far more significant energy and GWP savings to be had because of savings in operating effects than from savings in embodied effects for the various exterior infill walls examined in this study. In general, the best performing walls after 50 years were the ones that were able to reduce the total operating energy and total operating GWP due to an increased thermal resistance compared to the BASE-W. A similar comparison can also be done for the roof enclosures in this study.

6.4 LCA Results for Roof Enclosures

Presented in this section are the LCA results for the various roof enclosures from Appendix B. Figure 6-7 to Figure 6-12 illustrate the Δ total energy and Δ total GWP of the different types of roof enclosures examined in this study relative to the baseline roof (BASE-R).

From outside to inside, BASE-R is comprised of: gravel ballast, a 4-ply built-up asphalt roof, 12 mm roof coverboard, 75 mm of continuous polyisocyanurate insulation, 39 mm galvanized corrugated steel deck, open web steel joists spaced at 1,200 mm on center, and a suspended acoustic ceiling. After 50 years, the total embodied energy of BASE-R is about 4.684 GJ/m^2 of primary energy and the total embodied GWP is about 213 kg of CO_2 eq./m^2 (results are per m^2 of roof).

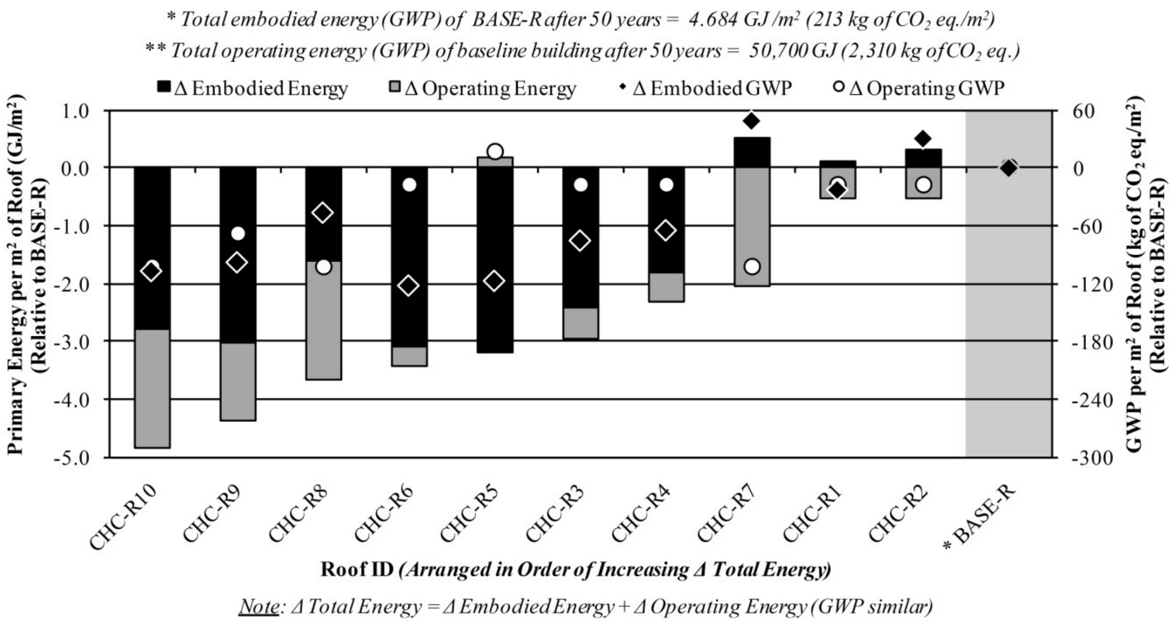


Figure 6-7: Total Life-Cycle Energy and GWP of Concrete Hollow Core Roofs (CHC-R) after 50 Year Lifespan in Toronto

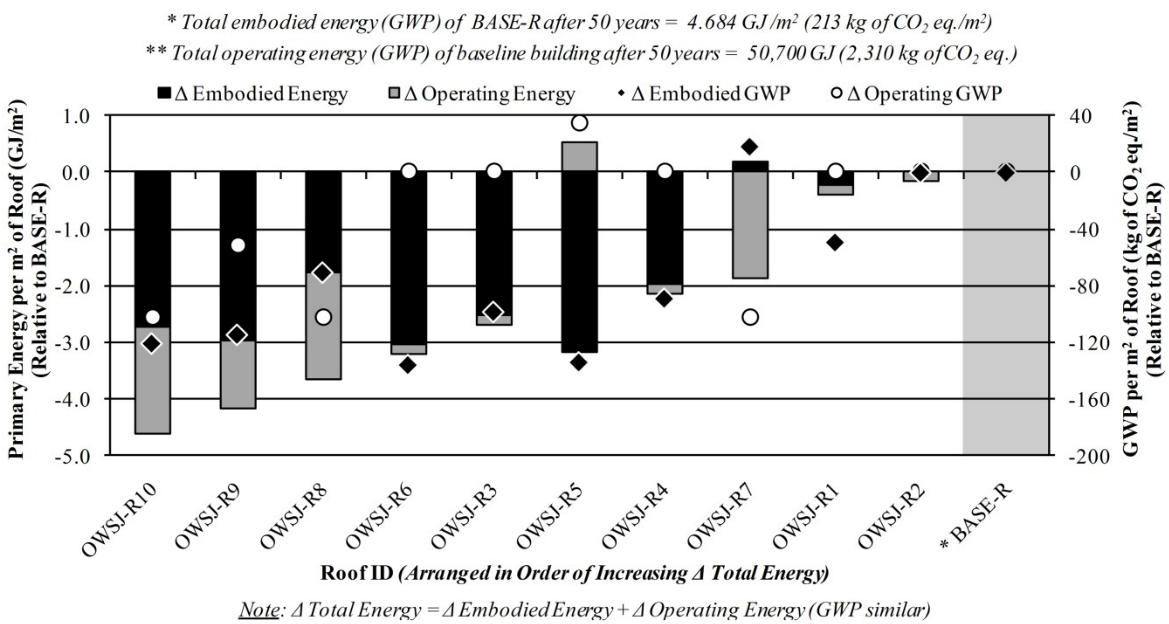


Figure 6-8: Total Life-Cycle Energy and GWP of Open Web Steel Joist Roofs (OWSJ-R) after 50 Year Lifespan in Toronto

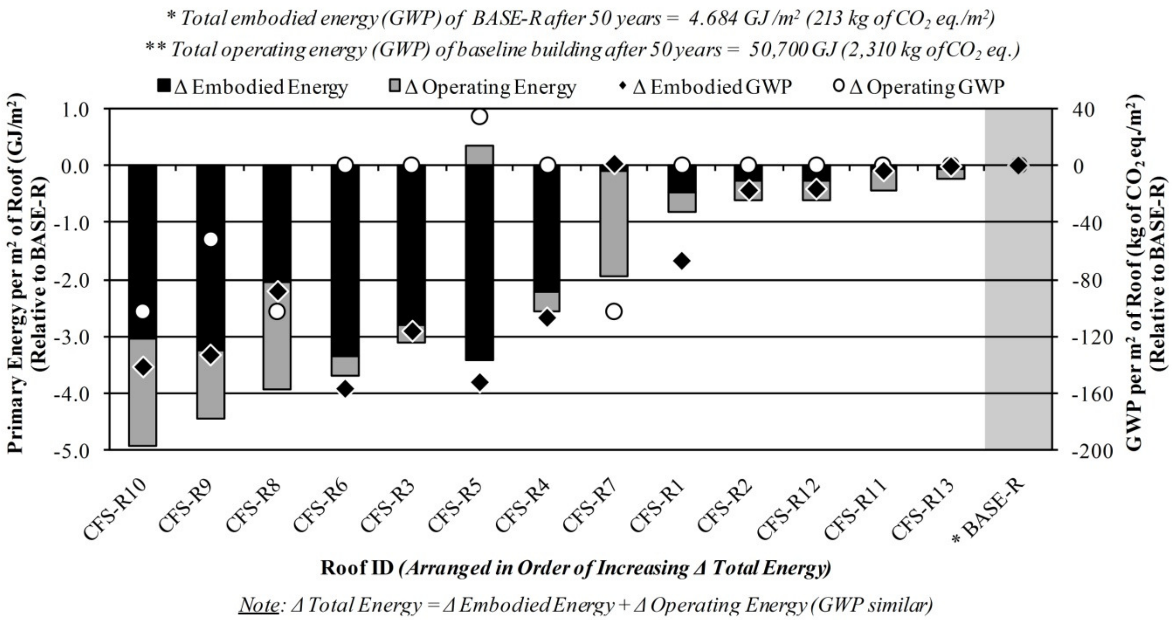


Figure 6-9: Total Life-Cycle Energy and GWP of Cold-Formed Steel Roofs (CFS-R) after 50 Year Lifespan in Toronto

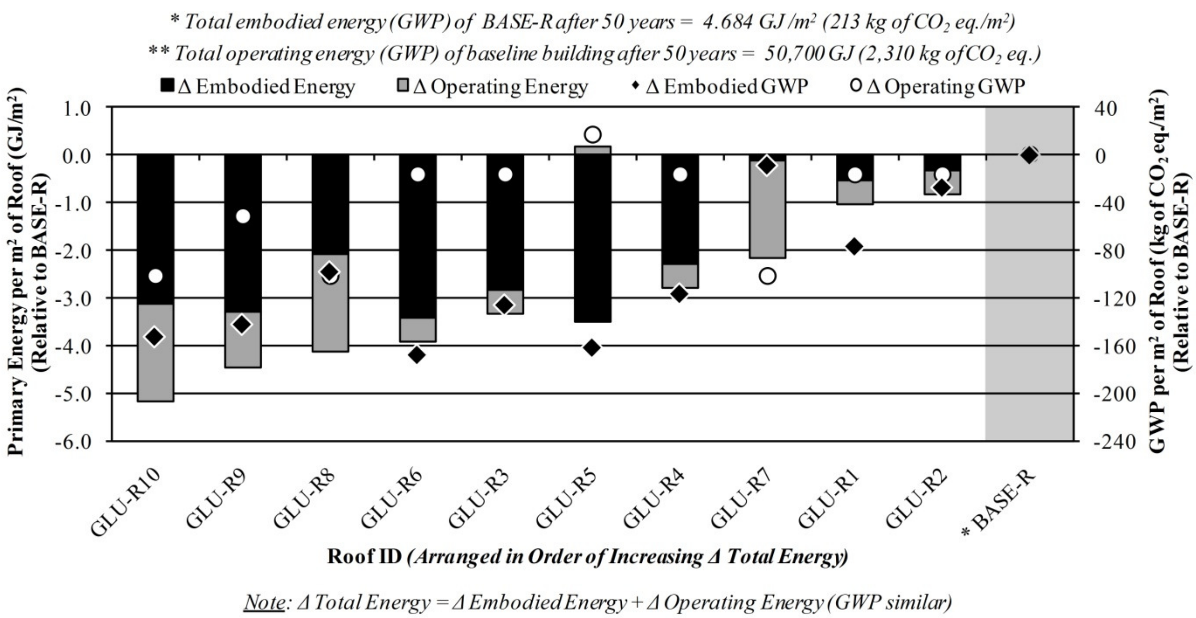


Figure 6-10: Total Life-Cycle Energy and GWP of Glulam Joist Roofs (GLU-R) after 50 Year Lifespan in Toronto

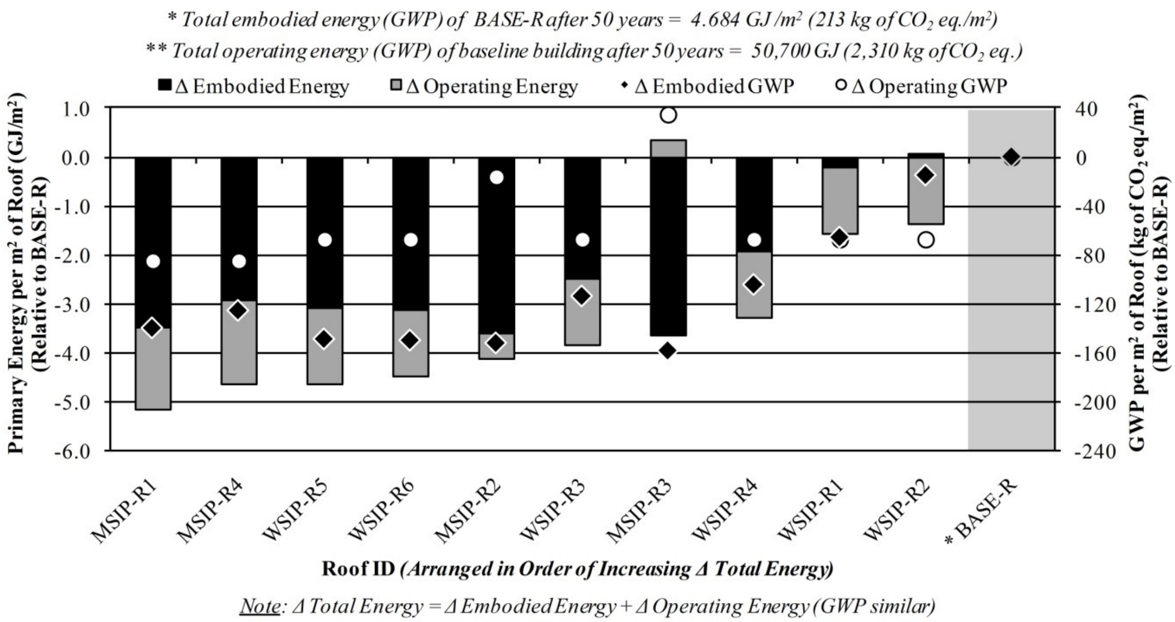


Figure 6-11: Total Life-Cycle Energy and GWP of Structural Insulated Panel Roofs (WSIP-R & MSIP-R) after 50 Year Lifespan in Toronto

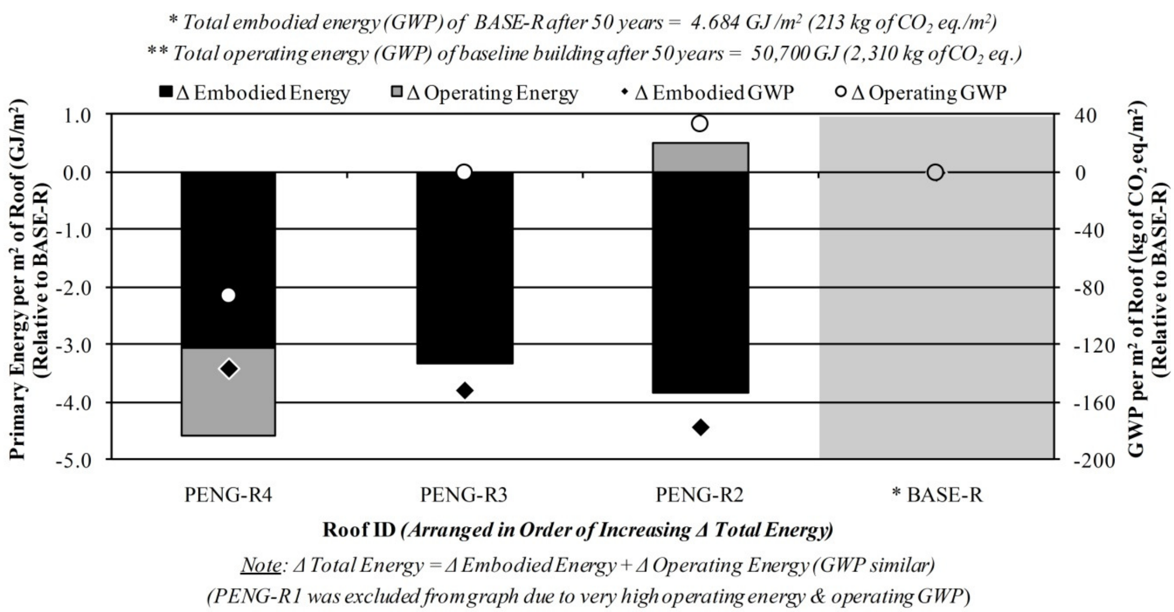


Figure 6-12: Total Life-Cycle Energy and GWP of Pre-Engineered Steel Building Roofs (PENG-R) after 50 Year Lifespan in Toronto

Table 6-1 also illustrates the range of possible values for the Δ total energy and Δ total GWP of the different types of roof enclosures in this study. Similar to the case of the exterior infill walls, the minimum and maximum values for the Δ total energy and Δ total GWP of each roof have been included for comparison.

Based on the results of this study, some general conclusions can be made about the various types of roof enclosures that were examined. First, there is a stronger correlation between the embodied energy and embodied GWP of the various roofs and the Δ total energy and Δ total GWP than was the case for the exterior infill walls. In fact, in many instances the embodied effects of the various roof enclosures outweighed the operating effects. This result suggests that for the roof enclosures, the building materials have a more significant affect on the Δ total energy and Δ total GWP than was observed for the exterior infill walls. That is not to say that the operating energy and operating GWP of the roof enclosures did not have an impact on the Δ total energy and Δ total GWP. In fact, an increase in the total energy and total GWP of the roofs corresponded in general to a decrease in the thermal resistance of the roof enclosures. However, this relationship was less marked than for the case of the exterior infill walls.

Another very important observation to note has to do with the roof covering. The results of this study suggest that significant savings can be achieved in terms of the total energy and total GWP if a green roof or a steel roof covering is used as opposed to an asphalt-based roof covering. This presumably has to do with the fact that green roofs have significantly less embodied effects compared to asphalt-based roof coverings and that steel roof systems tend to be very durable systems that need to be repaired or replaced less often.

Two of the most promising roof types that were looked at in this study were the WSIP-R and MSIP-R roofs. Structural insulated panel roofs tend to have a higher thermal resistance than other conventional types of roofs and they also tend to have similar or less embodied effects. Therefore, the WSIP-R and MSIP-R roofs performed very well in terms of total energy and total GWP after a 50 year lifespan in this study.

It should be noted that PENG-R roofs also show significant promise as relatively good systems in terms of energy use and GWP. These roofs tend to be significantly lower in embodied effects compared to other conventional roof types. However, one of the biggest drawbacks to conventional pre-engineered steel roofs is their poor thermal resistance due to massive thermal bridging problems. Therefore, if the thermal resistance of these types of enclosures can be improved, then these types of roof systems look promising in terms of life-cycle energy use and GWP compared to conventional roof enclosures.

6.5 LCA Results for Structural Systems

A comparison of the Δ total energy and Δ total GWP for the different structural systems from Appendix B is presented next. Figure 6-13 illustrates the Δ total energy and Δ total GWP of the three different structural systems examined in this study.

In this case, the Δ total energy and Δ total GWP of the different structural systems were compared relative to S-1 (typical hot-rolled steel structural system). This was the structural system that was used in the baseline retail building. After 50 years, the total embodied energy of S1 was found to be about 0.813 GJ/m^2 and the total embodied GWP was about 46 kg of CO_2 eq./m^2 (results are per m^2 of structural system).

It is important to note that the three structural systems only differed in terms of the total embodied energy and total embodied GWP. Changing the structural system did not impact the operating energy and operating GWP of the baseline building at all. Therefore, although S-2 and S-3 have less total energy and total GWP than S-1 after 50 years, in the overall scheme of things these differences are minimal. Recall that negative values in Figure 6-13 denote that those structural systems have less total energy and total GWP than the baseline structural system after 50 years. Therefore, it can be seen in Figure 6-13 that both the typical heavy timber structural system (S-2) and the pre-engineered steel building structural system (S-3) had less total energy and total GWP than the baseline case.

Table 6-1 also indicates the range of values that were calculated for the Δ total energy and Δ total GWP of the different structural systems examined in this study. Average, minimum, and maximum values have been calculated for the range of different structural systems.

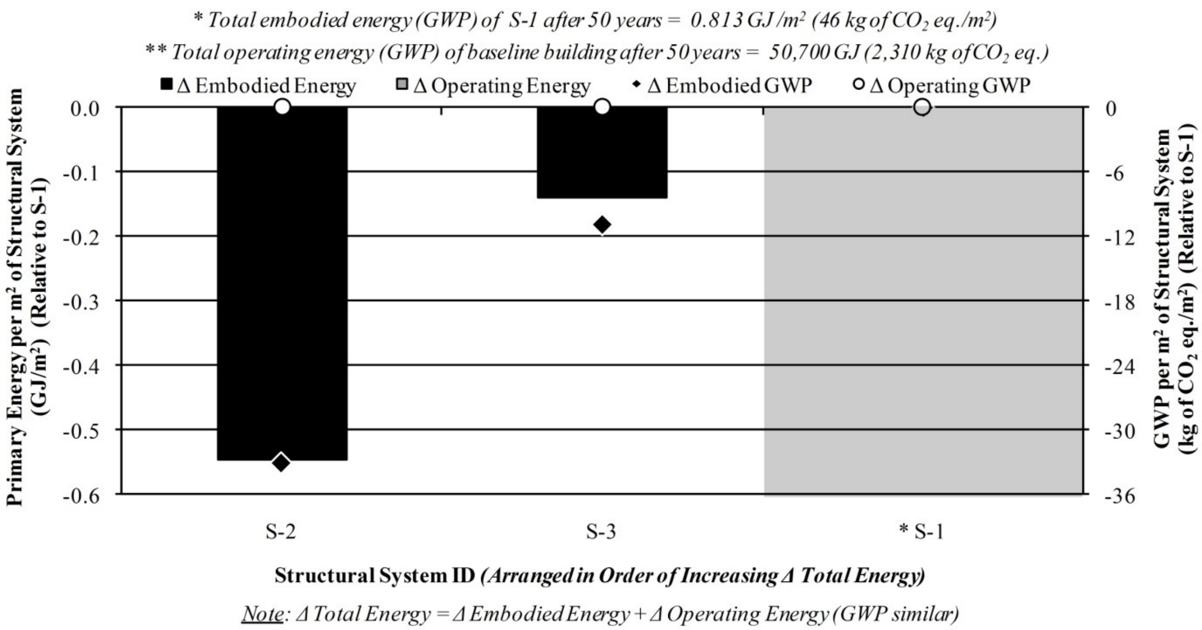


Figure 6-13: Total Life-Cycle Energy and GWP of Structural Systems after 50 Year Lifespan in Toronto

6.6 LCA Results for Floors

In this section, the LCA results are compared for the different floor assemblies from Appendix B. Figure 6-14 illustrates the Δ total energy and Δ total GWP of the different floor assemblies examined in this study. Table 6-1 also contains the range of values that were calculated for the Δ total energy and Δ total GWP of the different floor assemblies.

In this case, the Δ total energy and Δ total GWP of the different floor assemblies were compared relative to FL-3. This was the floor assembly that was used in the baseline retail building. FL-3 consists of: vinyl floor tile, 89 mm reinforced concrete topping, 39 mm galvanized corrugated steel deck, open web steel joists spaced at 1,200 mm on center, 90 mm fiberglass batt insulation, galvanized steel resilient channels, two layers of 12 mm gypsum board, and finished with latex paint. After 50 years, the total embodied energy of FL-3 was found to be about 1.205 GJ/m^2 and the total embodied GWP was about 86 kg of CO_2 eq./m^2 (results are per m^2 of floor).

All of the floor assemblies had less total energy and total GWP than FL-3. It is important to note that the floor assemblies only differed in terms of their total embodied energy and total embodied GWP. Changing the floor assembly did not significantly impact the operating energy or operating GWP of the baseline building in this case. It is interesting to note that the baseline floor assembly (FL-3) performed the worst of all the floor assemblies that were examined in this study. This is an interesting observation because this floor type is one of the most common types of floor systems used in commercial buildings today.

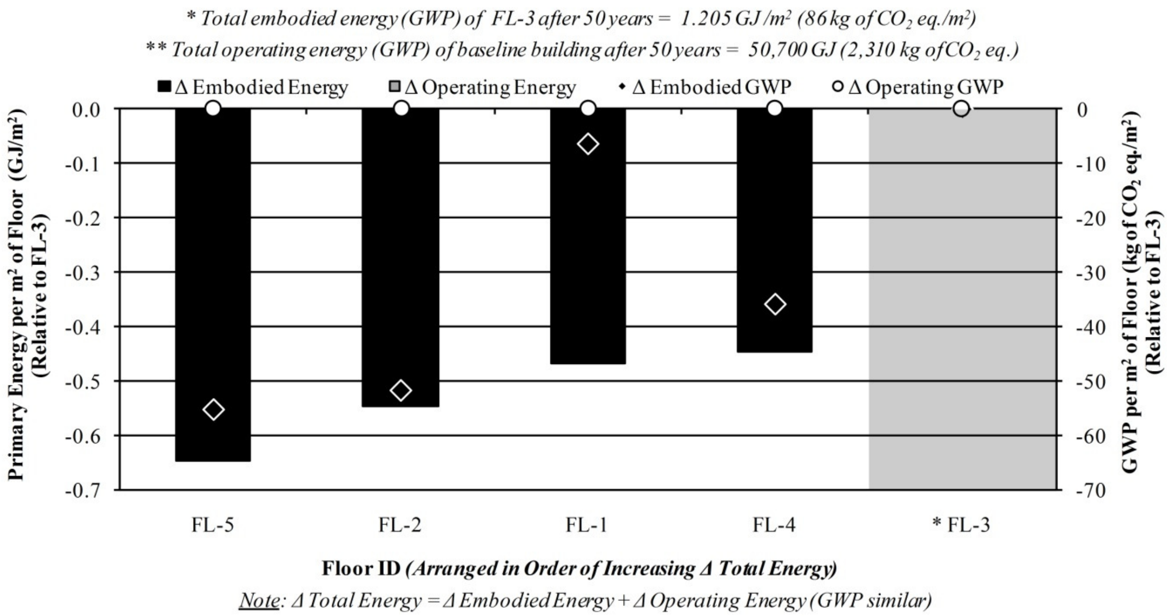


Figure 6-14: Total Life-Cycle Energy and GWP of Floors (FL) after 50 Year Lifespan in Toronto

6.7 LCA Results for Windows and Doors

A detailed LCA was conduced for the different windows and doors in Appendix B. The results of this LCA are displayed in Figure 6-15 and Figure 6-16. As well, Table 6-1 contains the range of values that were calculated for the Δ total energy and Δ total GWP of the different windows and doors.

In this case, the Δ total energy and Δ total GWP of the different windows were compared relative to W-1. W-1 consists of a thermally broken aluminum window frame, with a sealed double pane glazing unit filled with air (no low-E coating and no argon gas). After 50 years, the total embodied energy of W-1 was found to be about 8.657 GJ/m^2 and the total embodied GWP was about 537 kg of CO_2 eq./m^2 (results are per m^2 of window).

Figure 6-15 illustrates that the windows with high performance glazing (argon filled, low-E coating) outperformed the corresponding windows with typical glazing (air filled, no low-E coating). This is because the high performance glazing resulted in windows with a higher thermal resistance. The results found a strong correlation between the thermal resistance of the windows and the Δ total energy and Δ total GWP. In fact, it was found that an increase in total energy and total GWP corresponded to a decrease in the thermal resistance of the windows.

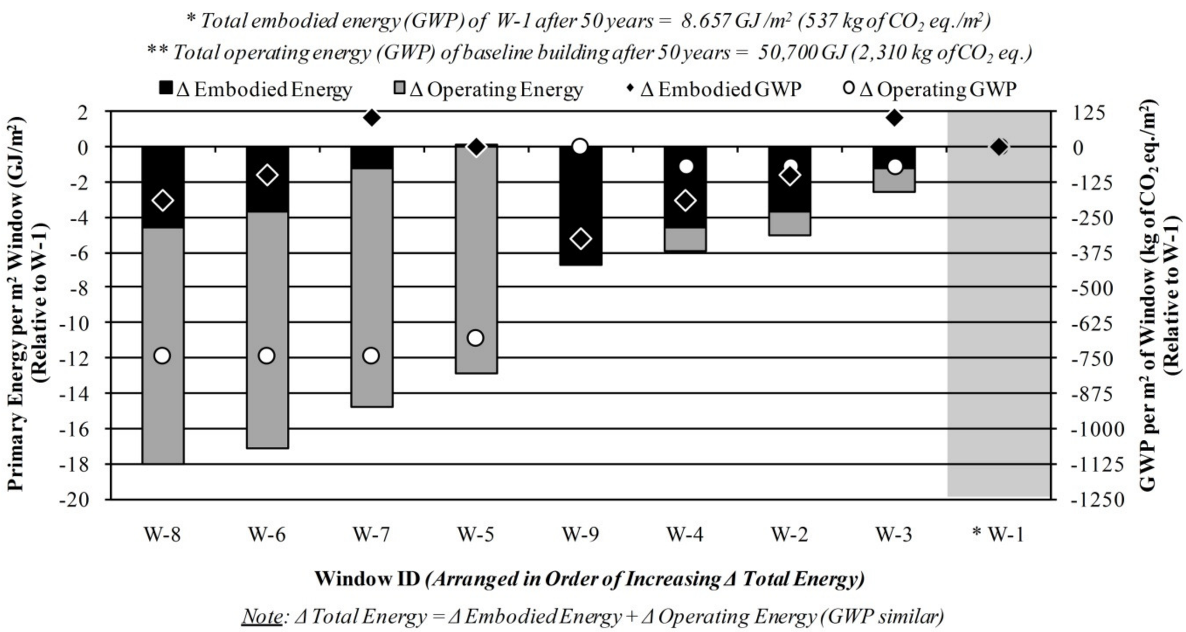


Figure 6-15: Total Life-Cycle Energy and GWP of Windows (W) after 50 Year Lifespan in Toronto

These results show that per m^2 of enclosure, windows actually have a relatively large total energy and total GWP compared to the exterior infill walls and roofs. In fact, both the embodied effects and the operating effects of the windows are relatively high. This suggests that when designing a building, the area of windows should be optimized from both a daylighting perspective, but also from an embodied energy and embodied GWP perspective. Having a very large window-to-wall ratio (say > 50%) could not only increase the operating requirements of the building, but also increase the embodied energy and embodied GWP of the building significantly. It is interesting to note that many of the retail buildings and office buildings in North America are made almost entirely of glass/aluminum curtainwall. The results from this study suggest that significant energy and GWP savings could result from a better balance of glass curtainwall with opaque enclosures in commercial buildings.

Figure 6-16 illustrates the Δ total energy and Δ total GWP for the doors in Appendix B. In this case, the values were plotted relative to D-2, which is an 813 x 2,134 mm insulated steel exterior door. After 50 years, the total embodied energy of D-2 was found to be about 8.335 GJ/door and the total embodied GWP was about 290 kg of CO_2 eq./door.

D-5 and D-6 are interior doors and were found to have no significant impact on the operating energy or operating GWP of the building. D-4 is an insulated sectional steel overhead door and has a significantly higher embodied energy and embodied GWP than the other doors. It can be seen from Figure 6-16 that D-1 (solid wood exterior door with no glazing) had a significant savings in terms of operating energy and operating GWP. After 50 years, D-1 resulted in a Δ total energy of about -108 GJ/door and a Δ total GWP of about -273 kg of CO_2 eq./door. The significance of the energy and GWP savings for D-1 was surprising. To date, very little research can be found in the literature on the primary energy and GWP of different types of doors. The results from this study suggest that further research should be conducted in this respect. Only three exterior doors were considered in this study (D-1, D-2, and D-3) and a larger sample of doors should be considered.

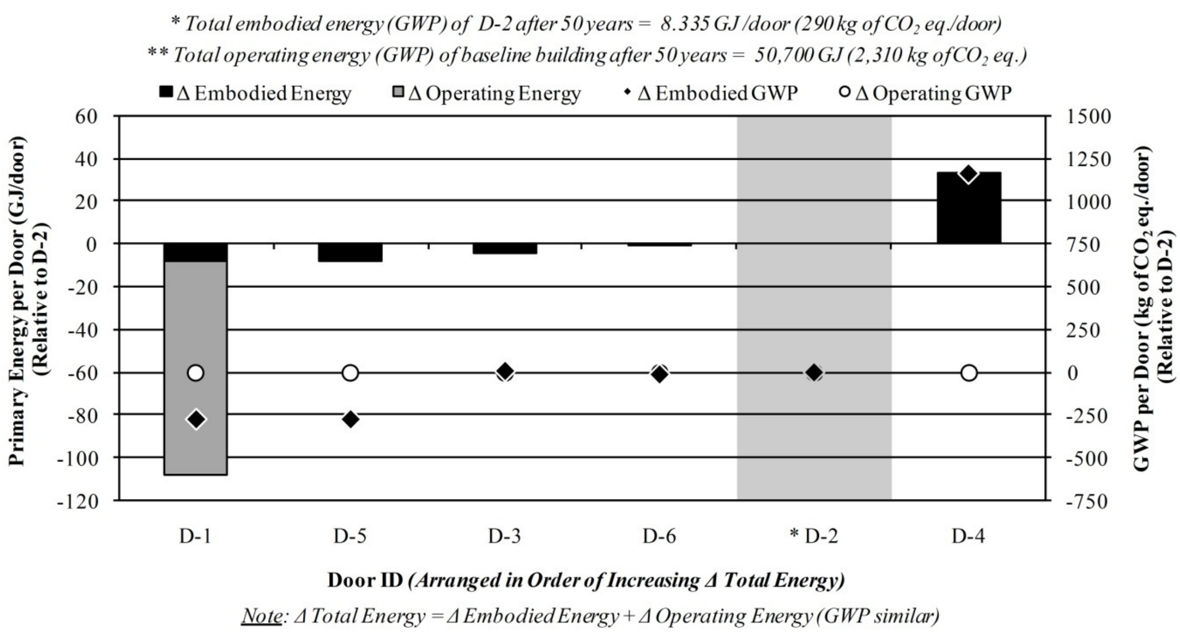


Figure 6-16: Total Life-Cycle Energy and GWP of Doors (D) after 50 Year Lifespan in Toronto

6.8 LCA Results for Interior Partitions

The range of interior partition walls examined in this study is outlined in Appendix B. Table 6-1 displays the range of values that were calculated for the Δ total energy and Δ total GWP and Figure 6-17 illustrates the results for the different interior partitions.

The Δ total energy and Δ total GWP of the different interior partitions were compared relative to SS-P3. From one side to the next, SS-P3 consists of: latex paint, two layers of regular 12 mm gypsum board, 39 x 152 mm cold-formed steel studs spaced at 400 mm on center, 140 mm fiberglass batt insulation, two layers of regular 12 mm gypsum board, and latex paint. After 50 years, the total embodied energy of SS-P3 was found to be about 0.523 GJ/m^2 and the total embodied GWP was about 30 kg of CO_2 eq./m^2 (results are per m^2 of wall).

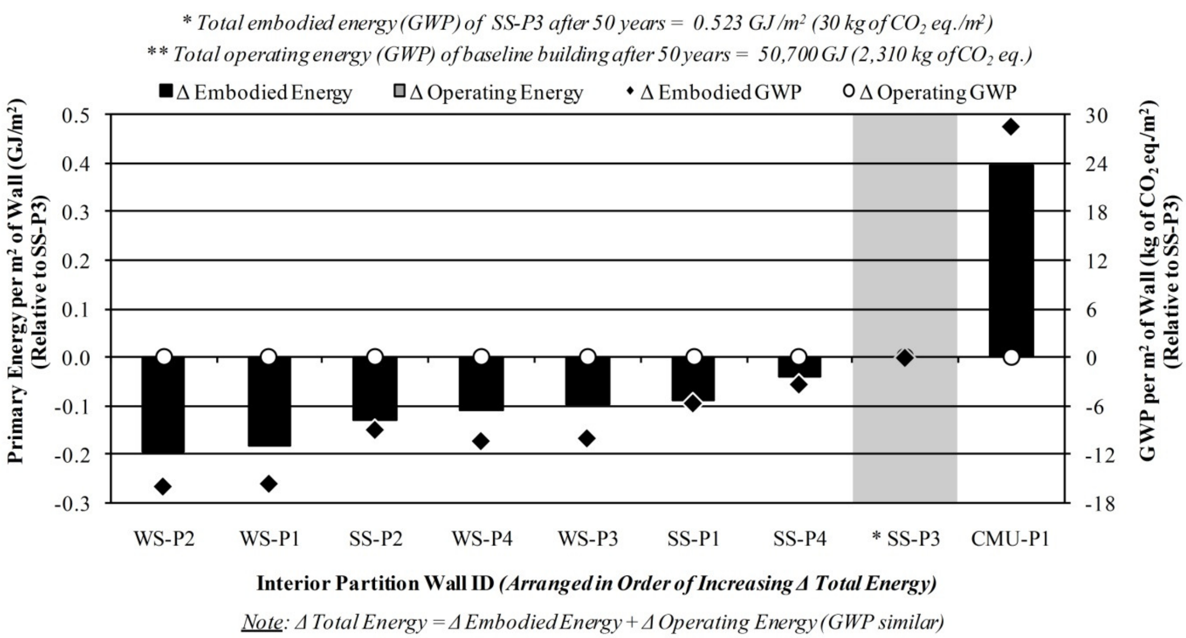


Figure 6-17: Total Life-Cycle Energy and GWP of Interior Partition Walls (WS-P, SS-P, & CMU-P) after 50 Year Lifespan in Toronto

In every case, the interior partitions did not have an affect on the operating energy or operating GWP of the building. Therefore, the differences between the various partition walls are solely a result of the differences in embodied effects. Generally speaking, the wood stud partition walls performed slightly better than the cold-formed steel stud equivalent. However, the concrete masonry unit partition wall had a significantly higher total energy and total GWP than either the wood stud or cold-formed steel stud partition walls.

6.9 LCA Results for Foundations

Lastly, in this section the LCA results are compared for the different foundations from Appendix B. Figure 6-18 illustrates the Δ total energy and Δ total GWP of the different isolated footings and concrete pier foundations (IF-FDN) examined in this study. Table 6-1 displays the range of values that were calculated for the Δ total energy and Δ total GWP for the different foundation components.

In this instance, the Δ total energy and Δ total GWP of the different IF-FDN's were compared relative to IF-FDN1. IF-FDN1 is a 1,200 x 1,200 x 350 mm isolated concrete footing with a 450 x 450 x 1,200 mm concrete pier (concrete is 20 MPa with 9% flyash content). After 50 years, the total embodied energy of IF-FDN1 was found to be about 1.609 GJ/unit and the total embodied GWP was about 175 kg of CO_2 eq./unit (results are per footing and pier combination).

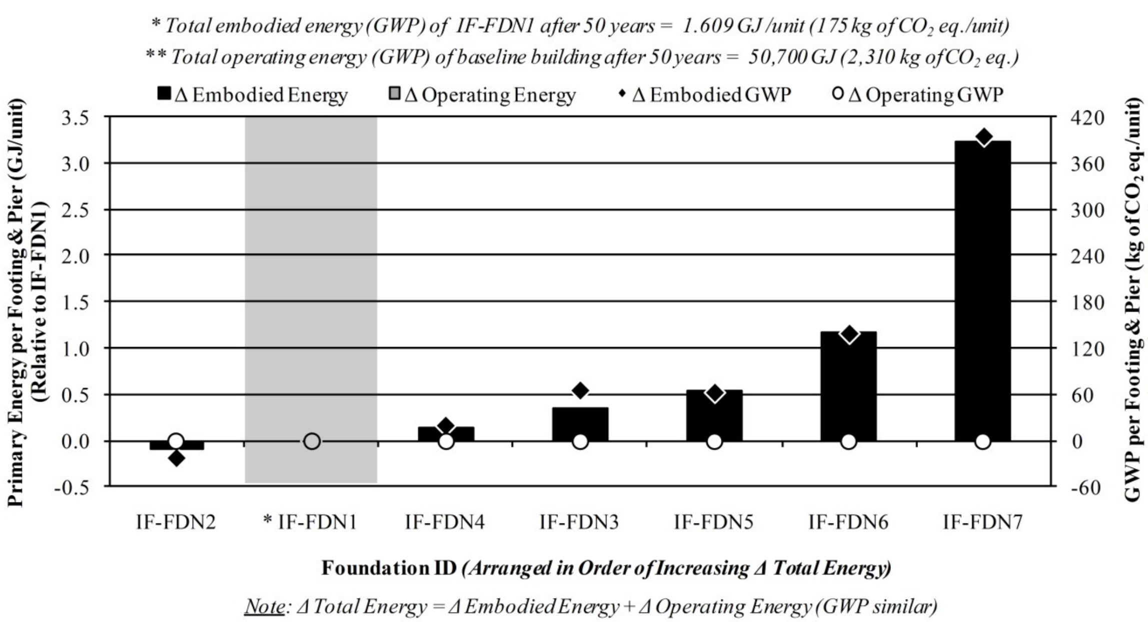


Figure 6-18: Total Life-Cycle Energy and GWP of Isolated Footing and Concrete Pier Foundations (IF-FDN) after 50 Year Lifespan in Toronto

Since the different IF-FDN's did not have any affect on the operating energy or operating GWP of the building, the differences in Figure 6-18 are a result of embodied effects alone. The variable that had the most significant affect on the Δ total energy and Δ total GWP of the IF-FDN's in this study was the size of the footing and pier. The larger footings and piers required more concrete and reinforcement, which resulted in a higher total energy and total GWP. Generally speaking, the use of higher percentages of flyash resulted in a lower total energy and total GWP.

Figure 6-19 illustrates the Δ total energy and Δ total GWP of the different strip footings and concrete foundations walls (SF-FDN) examined in this study. The values in this case are plotted relative to SF-FDN5, which consists of a 600 x 200 mm concrete strip footing with a 1,200 x 200 mm concrete foundation wall with waterproofing (concrete is 20 MPa with 9% flyash content). After 50 years, the total embodied energy of SF-FDN5 was found to be about 1.097 GJ/m and the total embodied GWP was about 94 kg of CO_2 eq./m (results are per linear m of footing and wall).

Once again, the different SF-FDN's did not have any affect on the operating energy or operating GWP of the building. Therefore, the differences observed in Figure 6-19 are solely based on differences in the embodied effects. The larger foundation components tended to result in a higher total energy and total GWP due to more concrete and reinforcement being required. The use of higher percentages of flyash was once again found to slightly decrease the total energy and total GWP.

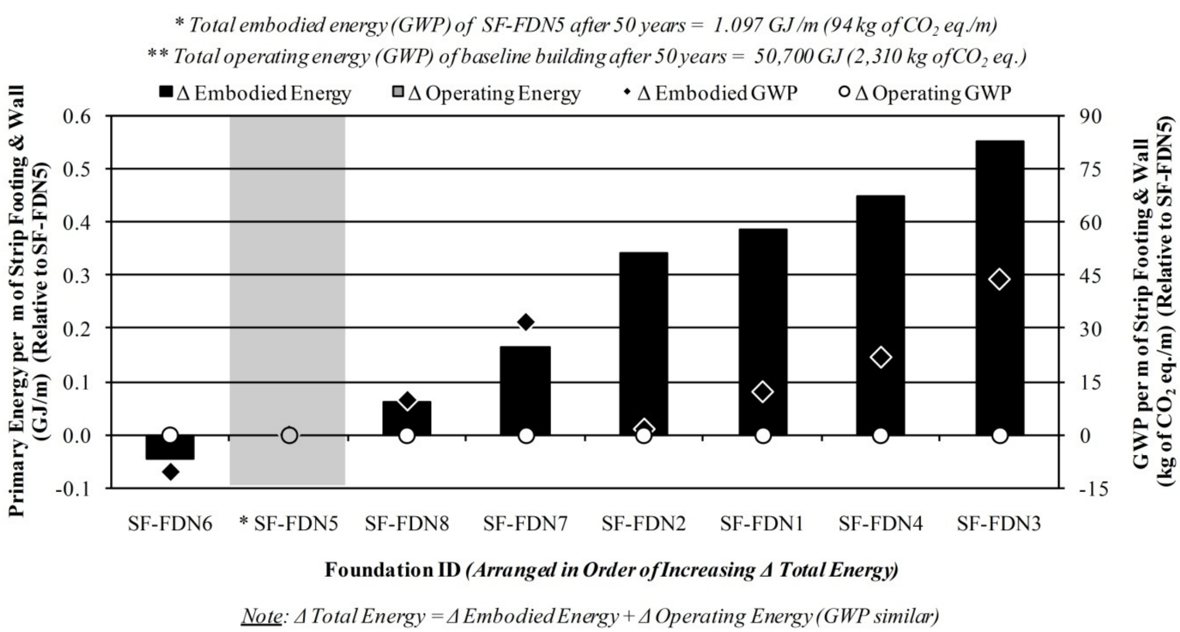


Figure 6-19: Total Life-Cycle Energy and GWP of Strip Footing and Concrete Wall Foundations (SF-FDN) after 50 Year Lifespan in Toronto

Lastly, Figure 6-20 illustrates the Δ total energy and Δ total GWP of the different concrete slab-on-grades (SOG-FDN) examined in this study. The values in this case are plotted relative to SOG-FDN4. SOG-FDN4 is a 200 mm thick, reinforced concrete slab, on a poly vapour barrier, and with a concrete sealant finish (concrete is 30 MPa with 9% flyash content). After 50 years, the total embodied energy of SOG-FDN4 was found to be about 0.515 GJ/m^2 and the total embodied GWP was about 65 kg of CO_2 eq./m^2 (results are per m^2 of slab-on-grade).

The best performing slab-on-grades were found to be the ones where under slab insulation was specified. This was because significant savings in operating effects were achieved. Also, in cases where a thinner slab-on-grade was specified, there was a slight savings in embodied effects.

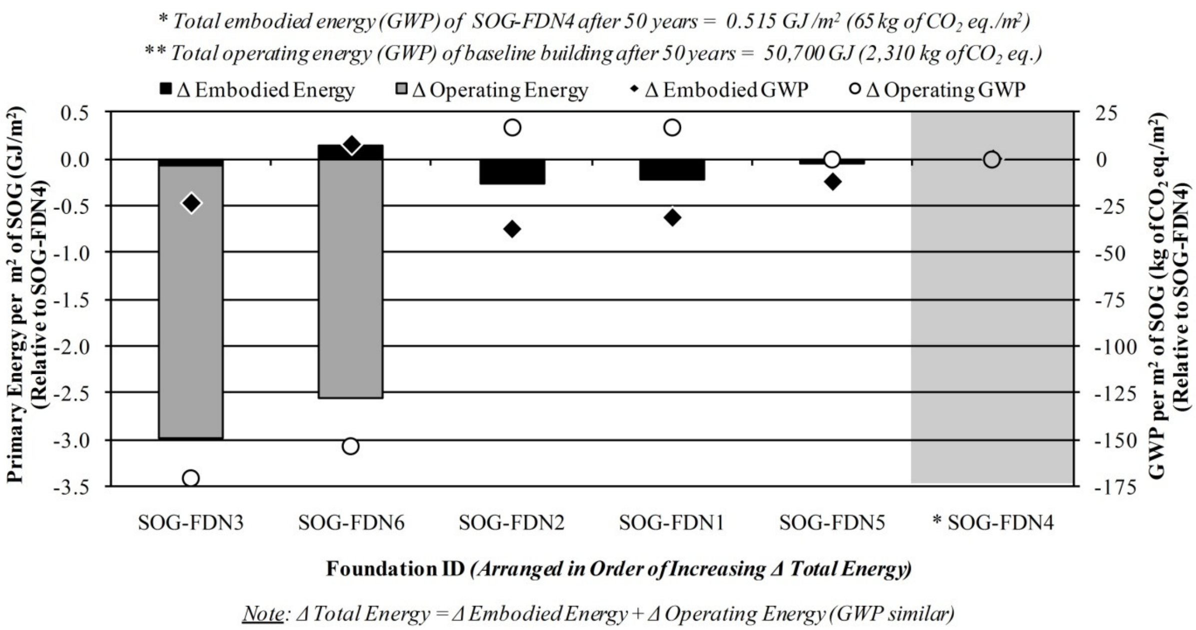


Figure 6-20: Total Life-Cycle Energy and GWP of Concrete Slab-On-Grades (SOG-FDN) after 50 Year Lifespan in Toronto

The goal of this chapter was to present the simplified LCA results for the range of different building components that were examined in this study. These buildings components have been ranked in order of increasing total energy, so that a building professional can quickly compare one system to the next from a life-cycle energy and GWP perspective. By summarizing the comprehensive LCA results in this way, a building professional is able to quickly make LCA decisions that otherwise would be extremely exhaustive both in time and effort.

6.10 Data Quality and Assessment

Now that the LCA results have been presented for the 220 different building components in this study, it is useful to compare the data to the values for similar components in the literature. Unfortunately, this task is extremely difficult. There are an endless number of unique building components that can be generated and so, the LCA data tends to differ from one study to the next. Therefore, it is difficult to directly compare the LCA results for the 220 building components in this study to the literature. However, the ATHENA® Institute has published a free program on their website called the ATHENA® EcoCalculator for Assemblies (The ATHENA Institute, 2010). It lists the embodied energy and embodied GWP for 400 common building components. The results do not include operating effects and were generated for a low-rise office building with a 60 year lifespan, but will be used for comparison in this study. Table 6-2 indicates that the embodied LCA data in this study is relatively close to the range of values listed in the ATHENA® EcoCalcualtor for Assemblies.

Table 6-2: Comparison of Embodied LCA Data in this Study to ATHENA® EcoCalculator

Building Component	ATHENA® EcoCalculator		This Study	
	Primary Energy (MJ/m^2)	GWP (kg of CO_2 eq./m^2)	Primary Energy (MJ/m^2)	GWP (kg of CO_2 eq./m^2)
Exterior Infill Walls	599 – 2,659	20 - 212	491 – 3,172	23 - 193
Concrete Masonry Unit Walls	1,228 – 2,659	72 – 212	1,365 – 3,172	75 - 193
Concrete Tilt-Up Walls	983 – 2,414	68 – 208	542 – 1,677	52 - 137
Wood Structural Insulated Panel Walls	1,224 – 2,401	34 - 169	1,037 – 2,820	44 - 160
Metal Structural Insulated Panel Walls	N/A	N/A	999 – 1,180	53 - 71
Cold-Formed Steel Stud Walls	599 – 1,945	28 - 172	680 – 2,631	33 - 156
Wood Stud Walls	602 – 1,851	20 – 156	570 – 2,513	23 - 145
Pre-Engineered Steel Building Walls	N/A	N/A	491 – 1,610	23 – 74
Opaque Curtainwalls	1,156 – 1,876	46 - 133	1,300 – 1,590	49 – 122
Roofs	1,399 – 9,050	50 - 306	738 – 5,184	29 - 263
Concrete Hollow Core Roofs	N/A	N/A	1,477 – 5,184	90 - 263
Open Web Steel Joist Roofs	1,449 – 9,050	53 – 306	1,516 – 4,866	77 - 232
Cold-Formed Steel Joist Roofs	N/A	N/A	1,252 – 4,615	57 - 214
Glulam Joist Roofs	1,399 – 8,850	50 - 287	1,201 – 4,551	46 – 205
Wood Structural Insulated Panel Roofs	N/A	N/A	1,564 – 4,735	63 - 198
Metal Structural Insulated Panel Roofs	N/A	N/A	1,029 – 1,736	55 - 88
Pre-Engineered Steel Building Roofs	N/A	N/A	738 – 1,639	29 - 76
Structural Systems	114 – 1,260	4 - 68	266 - 813	13 - 46
Floors	370 – 1,390	10 - 106	559 – 1,205	30 - 86
Windows	2,764 – 6,521	213 - 356	1,895 – 8,661	209 - 642
Interior Partitions	314 – 1,078	10 - 60	327 - 917	14 - 59

* *Note: Doors and foundations have been omitted from table due to lack of comparison data*

Chapter 7
Summary of Results

7.1 Introduction

In Chapter 5, the LCA results were presented for five single-storey retail buildings with a 50 year lifespan in Toronto. It was shown that after 50 years, operating energy and operating GWP accounts for about 90% of the total energy and total GWP, while embodied energy and embodied GWP is only responsible for about 10%. It was also determined that among the five buildings, there was very little difference in the total life-cycle energy use and total GWP after 50 years.

Next, focus was shifted from an analysis of whole buildings to a comparison of individual building components. In Chapter 6, 220 different building components including: exterior infill walls, roofs, structural systems, floors, windows and doors, interior partitions, and foundations were analyzed within the framework of a comprehensive LCA of energy use and GWP. Within each building component category, numerous alternative strategies were analyzed. The goal was to determine the range of possible values for the life-cycle energy and GWP of the different building components.

In this chapter, the data from Chapters 5 and 6 will be summarized into a series of useful measures to help reinforce the key findings. In essence, the data summary in this chapter will serve as an overview of the more detailed analysis that has been conducted in previous chapters. The goal here is to enable the reader to quickly grasp the most important concepts of this study through the use of a few key figures and tables. The ultimate objective is to provide a clear and simple summary of an otherwise incredibly complex and time consuming LCA study. In doing so, the final step of the LCA process according to ISO 14044 will be completed: an interpretation of the LCA results (ISO, 2006).

7.2 Sensitivity Analysis of Total Embodied Effects verses Operating Effects

In Chapter 6, the results from a detailed LCA of 220 different building components were presented. These results are very useful if one has several specific building components in mind that one wishes to compare. However, to get a better understanding of the greater picture, it is useful to plot the results for all of the 220 different building components on one graph.

Figure 7-1 illustrates the results of a sensitivity analysis of the total embodied energy for the components of the baseline retail building after 50 years. In this figure, the various building components of the baseline retail building were systematically replaced with each alternative building component in this study, such that a new estimate of the total embodied energy of the building could be determined. In this way, an approximation of the total embodied energy for each of the 220 different building components was calculated, appropriately scaled for the baseline retail building as a whole. In other words, the total embodied energy of each alternative building component has been multiplied (i.e. weighted) by the appropriate material quantities in order to take into consideration scale effects for the entire building. In doing so, some interesting observations can be made about the range of possible values for the weighted embodied energy of the building components.

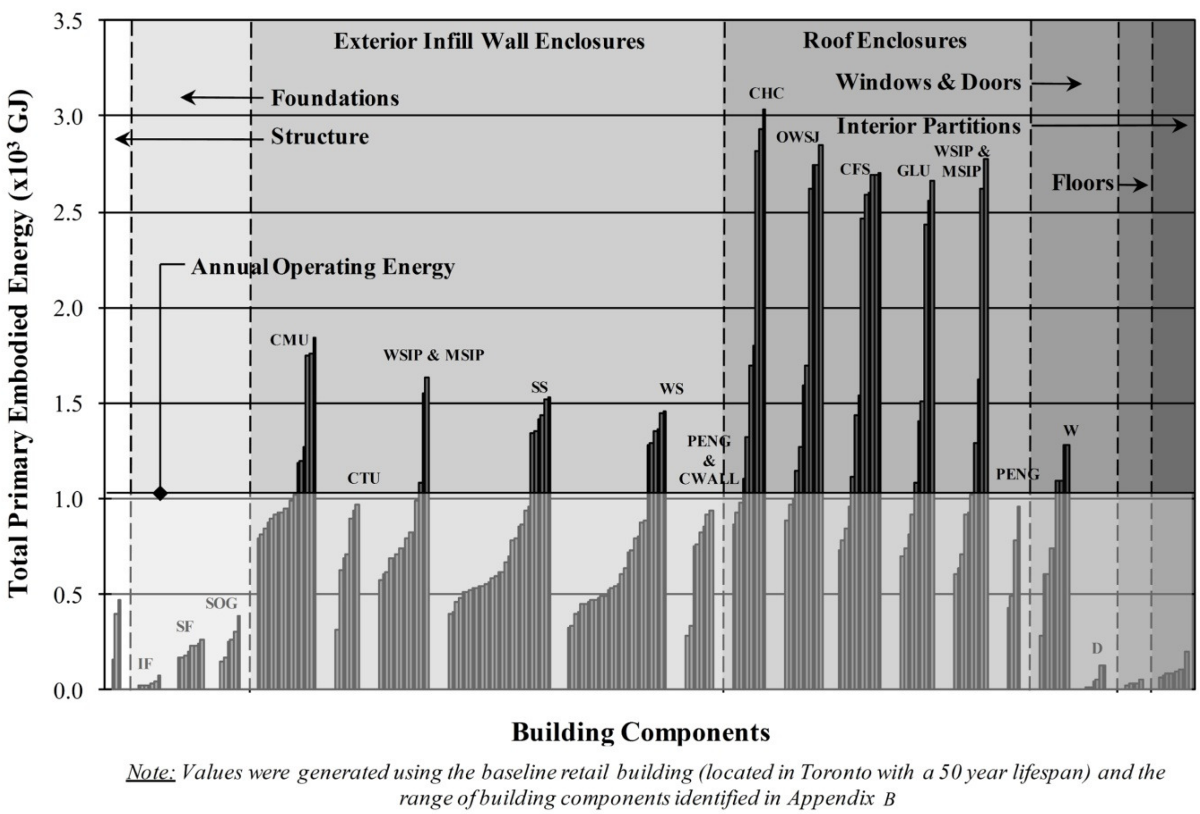


Figure 7-1: A Sensitivity Analysis of the Total Embodied Energy Use for the Components of a Typical Retail Building after a 50 Year Lifespan in Toronto

From Figure 7-1, it can be seen that within each building component category (structure, foundations, exterior walls, roofs, windows and doors, floors, and interior partitions) the various different alternatives from Appendix B have been grouped together. For example, for the exterior walls the different alternatives are grouped into CMU, CTU, WSIP & MSIP, SS, WS, PENG, and CWALL type walls. Also, the annual operating energy of the baseline retail building has been plotted for comparison. This allows one to quickly approximate the number of equivalent years of operating energy that is associated with the total embodied energy of the different building components.

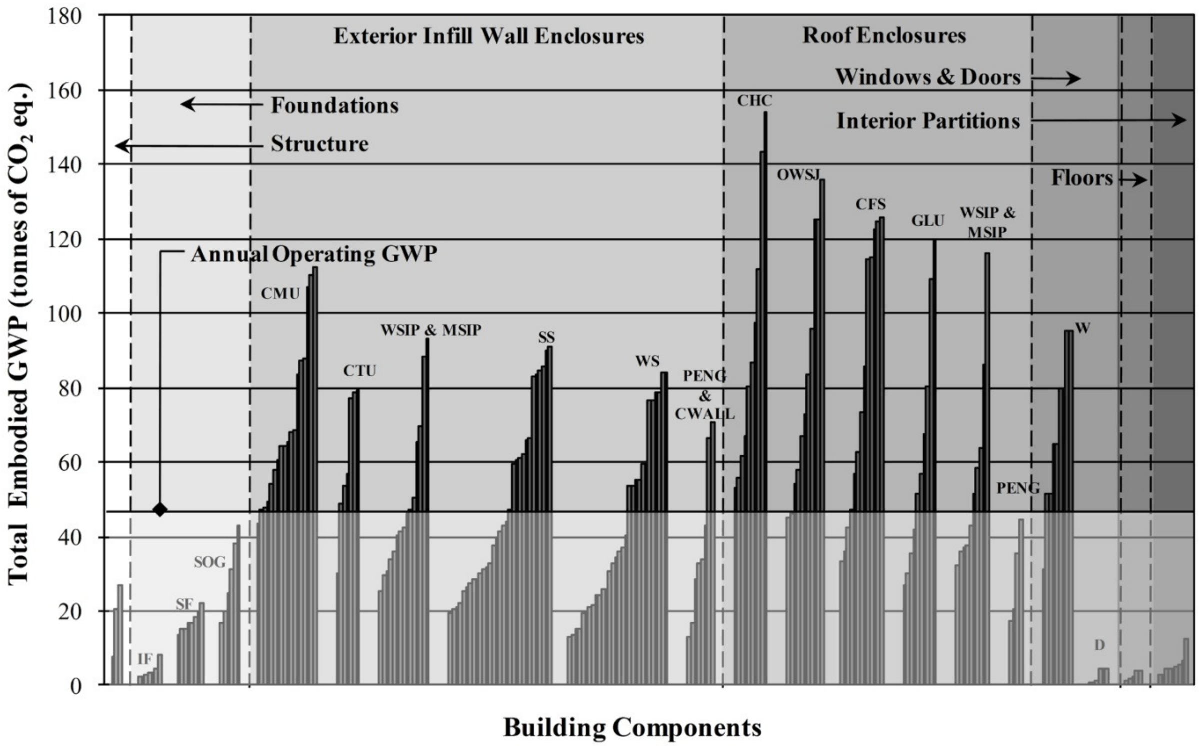
Quickly one can begin to see how little the total embodied energy of the structural system, foundations, doors, interior partitions, and floors matters compared to the total embodied energy of the exterior walls, roofs, and windows. It also becomes clear how much variation is possible in the total embodied energy of different alternatives within the same category of building component. For example, depending on which OWSJ one chooses, the total embodied energy can vary from as little as 0.9 years of equivalent operating energy to 2.9 years.

The multitude of conclusions and comparisons that could be drawn from this figure are too numerous to explain in detail here. The real usefulness of this figure is its ability to show the relative importance of the different building components and the range of possible values for the total embodied energy within each category.

In a similar way, Figure 7-2 illustrates the results from a sensitivity analysis of the total embodied GWP for the components of the baseline retail building after 50 years. Again, an approximation of the total embodied GWP for each of the 220 different building components was calculated for the case of the baseline retail building, in the same way that the total embodied energy was calculated (i.e. multiplied by the appropriate material quantities in order to take into consideration scale effects for the entire building). Once more, the annual operating GWP was also plotted for comparison.

Similar to the case of total embodied energy, there is a range of possible values for the total embodied GWP within each building component category. It is apparent in this case as well, that the total embodied GWP of the structural system, foundations, doors, interior partitions, and floors is insignificant compared to the total embodied GWP of the exterior walls, roofs, and windows. This figure is able to show the relative importance of the different building components and the range of possible values for the total embodied GWP within each category.

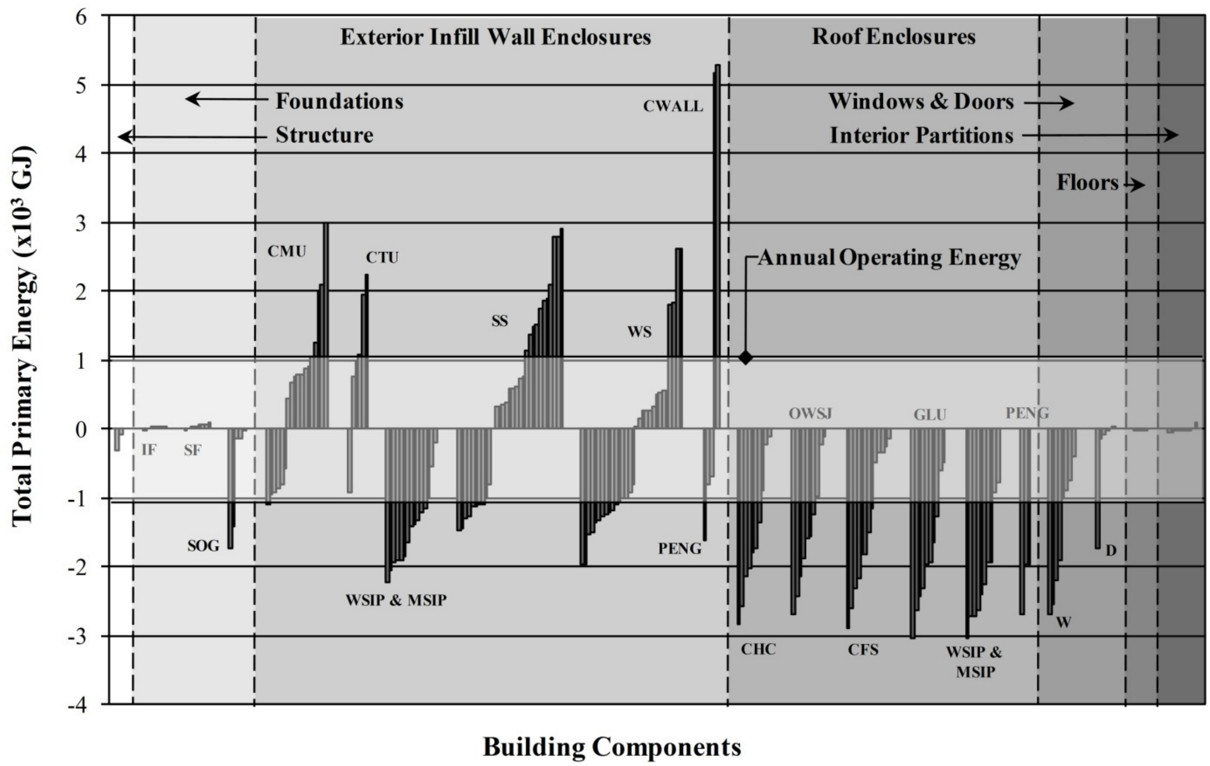
Now, it has been shown throughout this study that operating energy and operating GWP are a much greater concern than embodied energy and embodied GWP in a typical retail building today. Although a comparison of the total embodied energy and total embodied GWP are useful, it does not tell the whole story. For example, it has been shown that some building components come with an increase in total embodied energy and total embodied GWP, but result in an even greater decrease in operating energy and operating GWP after 50 years. To account for this, the Δ total life-cycle energy for each of the 220 different building components was plotted in Figure 7-3. In this case, the baseline retail building was used as the datum. Each of the building components of the baseline retail building was systematically replaced with the building components in Appendix B and the difference in embodied energy (Δ embodied energy) and operating energy (Δ operating energy) was calculated. Recall that Δ total energy is equal to Δ embodied energy plus Δ operating energy.



Note: Values were generated using the baseline retail building (located in Toronto with a 50 year lifespan) and the range of building components identified in Appendix B

Figure 7-2: A Sensitivity Analysis of the Total Embodied GWP for the Components of a Typical Retail Building after a 50 Year Lifespan in Toronto

Figure 7-3 is divided into the various different building component categories in much the same way as the previous two figures. Also, the annual operating energy for the baseline retail building has also been plotted. One will notice that the vertical axis of the graph has both positive and negative values. In some cases, certain substitutions of building components resulted in an increase in the total energy from the baseline case. In these cases, the values are plotted above the horizontal axis. The horizontal axis represents the baseline retail building (since the Δ total energy compared to the baseline retail building is 0). In other circumstances, certain substitutions of building components resulted in a decrease in the total energy from the baseline case and are plotted below the horizontal axis. Similar to before, the Δ total energy values have been scaled accordingly for the baseline retail building and represent total values for the building (i.e. they account for the appropriate quantities and numbers of the various building components in the baseline retail building).



Note: Values were generated using the baseline retail building (located in Toronto with a 50 year lifespan) and the range of building components identified in Appendix B

Interpreting the Figure

- Values plotted above the x-axis, represent those building components that resulted in an increase in the total energy use (Δ embodied energy + Δ operating energy) of the baseline building after 50 years
- Values plotted below the x-axis, represent those building components that resulted in a decrease in the total energy use (Δ embodied energy + Δ operating energy) of the baseline building after 50 years

Figure 7-3: A Sensitivity Analysis of the Δ Total Life-Cycle Energy Use for the Components of a Typical Retail Building after a 50 Year Lifespan in Toronto

From Figure 7-3, one can understand the possible range of Δ total energy associated with the baseline retail building, depending on the specific choice of building components. It is evident that building components that have no impact on the operating energy of a building (like the structural system), tend to pale in comparison to those building components that do have a direct influence on the operating energy of a building (like the exterior walls and roof). It can be seen that the exterior walls, roofs, and windows have the greatest variation in Δ total energy from the baseline. Depending on the specific exterior wall, roof, or window, it can be observed in Figure 7-3 that this could be equivalent to +/- about three years of operating energy. It is interesting to note that the curtainwalls (CWALL) result in the greatest potential increase in total energy compared to the baseline. In fact, using certain curtainwall enclosures can result in an increase of as much as five years of operating energy compared to the baseline.

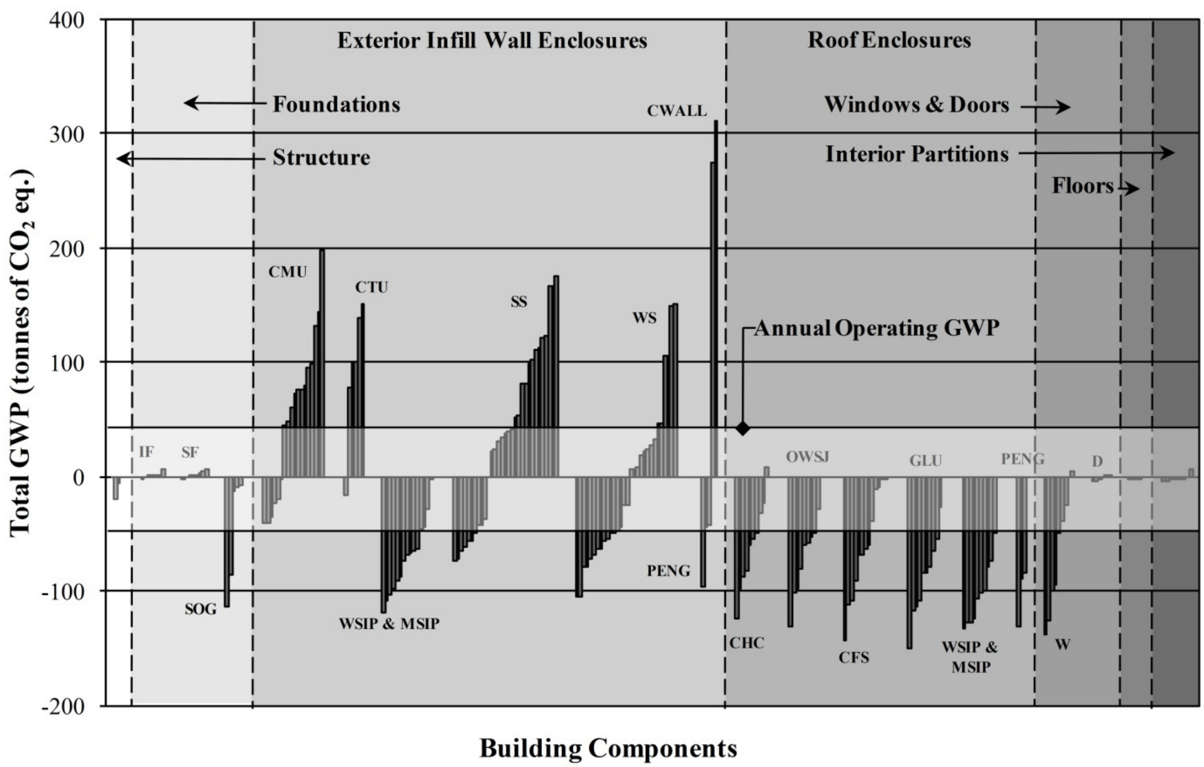
A similar figure was created for the Δ total GWP. Figure 7-4 illustrates the Δ total life-cycle GWP for each of the 220 different building components from Appendix B. Again, similar to before these values represent either an increase in total GWP (plotted above the horizontal axis) or a decrease in total GWP (plotted below the horizontal axis) compared to the baseline retail building components. The horizontal axis represents the baseline retail building components. The annual operating GWP has also been plotted.

Once again it is evident that those building components that tend to have an influence on the operating GWP of a building (like the exterior walls, roofs, and windows), have the greatest range in Δ total GWP. Those building components that tend not to affect the operating energy of a building show less range in Δ total GWP.

It can be seen in Figure 7-4 that there is the potential for a substantial amount of variation within each building component category. Depending on the building component, there could be a relatively insignificant deviation in the total GWP from the baseline, or an increase/decrease of up to four years of operating GWP (an increase of six years of operating GWP for the case of the curtainwall enclosures).

Once again, the purpose of these figures is to summarize what otherwise is a very complex and time consuming task of evaluating the LCA of the various components of a retail building over 50 years. These figures are a useful reference at the beginning stages of a building design process, as the priorities for reducing the total energy use and total GWP of a building can quickly be set. For example, these results would suggest that the efforts of the design team be spent on reducing the total energy and total GWP of the exterior infill walls, roofs, and windows of a building rather than worrying about the structural system, foundations, or interior partitions. Also, using these figures these decisions can quickly be placed in terms of the number of equivalent years of operating energy.

Therefore, given the expected lifespan of a building in question, one could reference these figures and quickly determine how many years of operating energy could be saved by specifying one building component strategy over the next. One could also quickly see how little a particular decision has on the total life-cycle energy use and GWP compared to one year of operating energy.



Note: Values were generated using the baseline retail building (located in Toronto with a 50 year lifespan) and the range of building components identified in Appendix B

Interpreting the Figure

- Values plotted above the x-axis, represent those building components that resulted in an increase in the total GWP (Δ embodied GWP + Δ operating GWP) of the baseline building after 50 years
- Values plotted below the x-axis, represent those building components that resulted in a decrease in the total GWP (Δ embodied GWP + Δ operating GWP) of the baseline building after 50 years

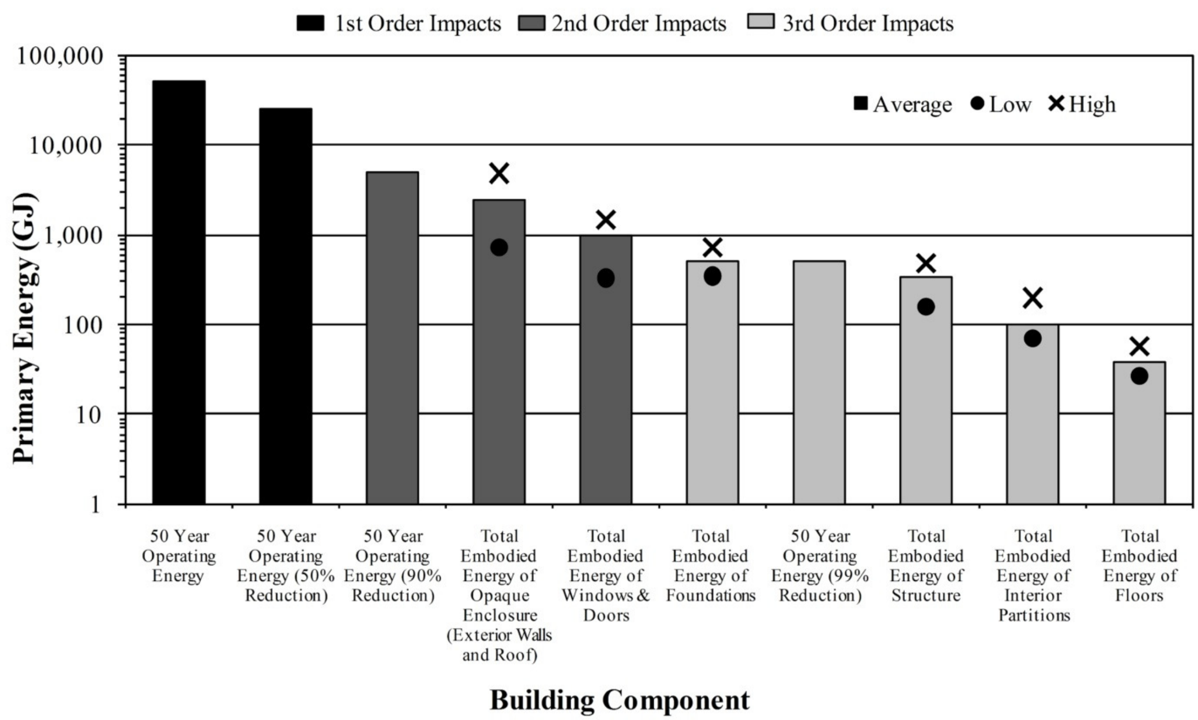
Figure 7-4: A Sensitivity Analysis of the Δ Total Life-Cycle GWP for the Components of a Typical Retail Building after a 50 Year Lifespan in Toronto

7.3 Magnitudes of Order in the LCA of Buildings

Throughout this study, the relationships between embodied energy, embodied GWP, operating energy, and operating GWP have been discussed. It has been shown that after 50 years, operating energy and operating GWP are a much greater concern than embodied energy and embodied GWP.

However, as the operating energy and operating GWP of buildings continues to decrease in the coming years, the embodied energy and embodied GWP will become an increasing concern. In this section, the embodied energy and embodied GWP of the components of a building are compared to various reductions in the operating energy and operating GWP of a typical retail building.

Compared to the 50 year operating energy of a typical retail building, the embodied energy of the various building components is relatively insignificant (less than 10%). However, suppose one was able to reduce the 50 year operating energy of a building by 50% or more. At what level of operating energy reduction would the effects be on par with the embodied energy of the building components? Figure 7-5 displays the relationships between the embodied energy of the building components and various levels of operating energy for the case of the baseline retail building.



Note: Values were generated using the baseline retail building (located in Toronto with a 50 year lifespan) and the range of building components identified in Appendix B

Figure 7-5: Orders of Magnitude for Energy Consumption of a Typical Retail Building after 50 Year Lifespan in Toronto

The results in Figure 7-5 were generated using the baseline retail building with a 50 year lifespan, as well as the range of building components identified in previous chapters. The results in Figure 7-5 have been plotted on a log-scale. This means that for every increment on the vertical axis, this corresponds to an increase by a factor of ten in primary energy. The building components have been classified based on the quantity of primary energy that is associated with them. In particular, the 1^{st} order impacts have ≥ 10,000 GJ, the 2^{nd} order impacts have < 10,000 GJ and ≥ 1,000 GJ, and the 3^{rd} order impacts have < 1,000 GJ of primary energy after 50 years. It can be seen that a low, average, and high value has been plotted for each building component category. These values were generated from the data in the previous section for the weighted embodied energy of the 220 different building components examined in this study. They represent the range of possible values for each building component.

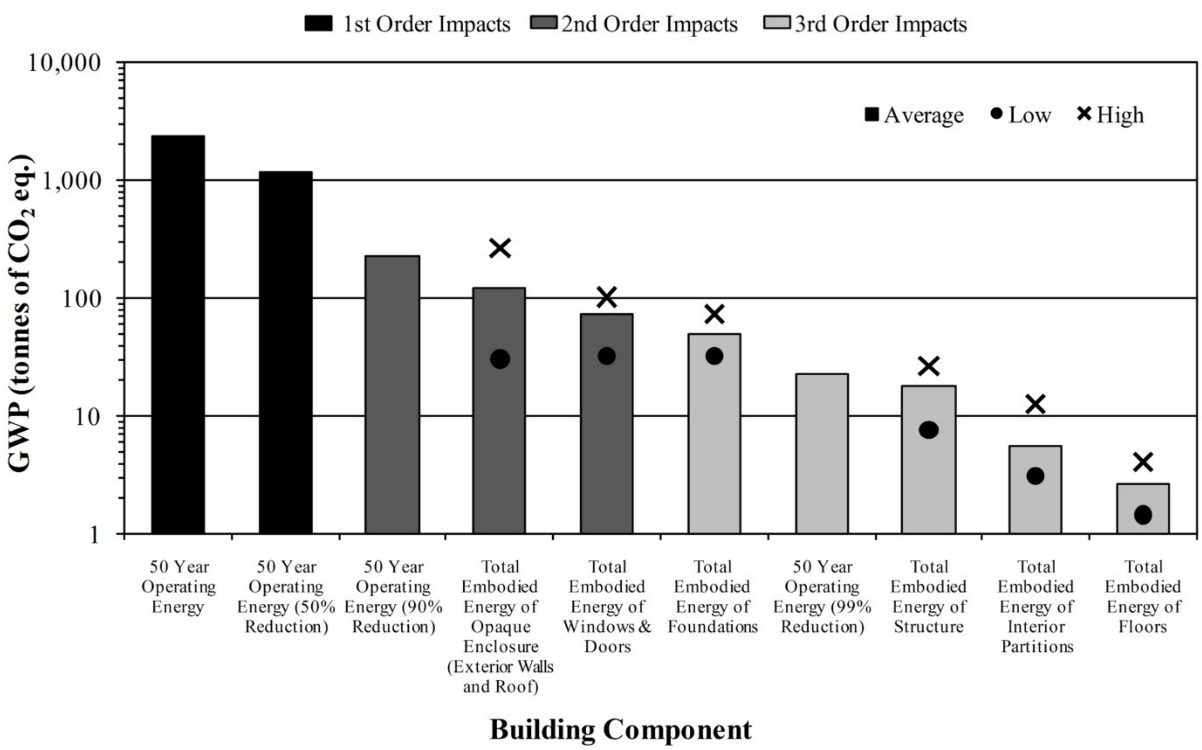
Using Figure 7-5 some important observations can be made about the level of operating energy reduction that would be required to be on par with the embodied energy of the building components. First, notice how the 50 year operating energy of the baseline retail building is a 1^{st} order impact. Essentially, this means that there is around 100 times more energy associated with the 50 year operating energy of the baseline retail building, than for a 3^{rd} order impact such as the total embodied energy of the foundations, structure, interior partitions, and floors. Compared to the 2^{nd} order impacts, the 50 year operating energy is responsible for around 10 times more energy after 50 years than the total embodied energy of opaque enclosure (exterior walls and roof) or the windows and doors.

Suppose that the 50 year operating energy of the baseline retail building was reduced by 50% through a combination of conservation, better design, and improved construction practices. Notice in Figure 7-5 that the 50 year operating energy reduced by 50% has been plotted. Interestingly, the 50% reduction in operating energy is still a 1^{st} order impact. Even if the typical 50 year operating energy was reduced by half, the amount of energy associated with building operations would still be about 50 to 100 times more than a 3^{rd} order impact and about 10 times more than a 2^{nd} order impact.

Now suppose that the 50 year operating energy of the baseline retail building was reduced by an aggressive 90% (extremely unlikely today). The 50 year operating energy reduced by 90% has been plotted. Only once the 50 year operating energy of the baseline retail building has been reduced by 90% does it become on par with a 2^{nd} order impact like the opaque enclosure or the windows and doors. Even at a 90% reduction in the 50 year operating energy, the operating effects still consume about 10 times more energy than a 3^{rd} order impact.

It is not until the 50 year operating energy of the baseline retail building has been reduced by 99% (almost impossible to do today), that the operating effects are on par with a 3^{rd} order impact. Clearly, a significant reduction in the operating energy is the most effective way to reduce the life-cycle energy consumption of a building. Not until the operating energy has been reduced by around 90% does the embodied energy of the building components begin to become a real concern.

A similar discussion can be done for the case of the life-cycle operating GWP verses embodied GWP for the baseline retail building. Figure 7-6 displays the relationships between the embodied GWP of the building components and various levels of operating GWP for the baseline retail building.



Note: Values were generated using the baseline retail building (located in Toronto with a 50 year lifespan) and the range of building components identified in Appendix B

Figure 7-6: Orders of Magnitude for Global Warming Potential of a Typical Retail Building after 50 Year Lifespan in Toronto

Again, the GWP has been plotted on a log-scale. The building components have been classified based on the quantity of GWP that is associated with them. In particular, the 1st order impacts have ≥ 1,000 tonnes of CO_2 eq., the 2nd order impacts have < 1,000 tonnes of CO_2 eq. and ≥ 100 tonnes of CO_2 eq., and the 3rd order impacts have < 100 tonnes of CO_2 eq. after 50 years. Similar to before, a low, average, and high value has been plotted for each building component, based on the sensitivity analysis of the weighted embodied GWP of the 220 building components in this study.

Similar to the primary energy, the same relationships between the various reductions in operating effects and the embodied effects for the GWP are observed. Not until the typical 50 year operating GWP is reduced by around 90% does it become on par with a 2nd order impact. Likewise, the typical 50 year operating GWP has to be reduced by around 99% before it is on par with a 3rd order impact. Once again, the importance of reducing the operating GWP relative to the embodied GWP is apparent.

7.4 A Summary of Design Strategies to Reduce the Total Life-Cycle Energy Use and GWP of Retail Buildings

Given the relationships between the operating energy, operating GWP, embodied energy, and embodied GWP for a typical single-storey retail building in Toronto with a 50 year lifespan, some design strategies for reducing the life-cycle effects can be explored.

Table 7-1 lists a number of alternative design strategies to reduce the total life-cycle energy use of the baseline retail building after a 50 year lifespan. Notice how the design strategies are divided based on the building component, as well as into low-impact, mid-impact, and high-impact design strategies. The low-impact design strategies are those changes to the baseline retail building that would result in ≤ 5% savings in the total life-cycle energy use of the building. Likewise, the mid-impact design strategies correspond to a savings in total life-cycle energy between 5% and 25%. High-impact design strategies are those that result in > 25% savings in total energy.

The first key observation to note is that none of the design strategies, other than reducing the annual operating energy by > 28%, can achieve the highest-level of energy savings. In other words, the only individual design strategy to decrease the total energy of the baseline retail building by more than 25% would be to reduce the operating energy. Not even a combination of all the best design strategies for the other building components would be able to achieve a 25% reduction in the total life-cycle energy use of the baseline building.

Looking now at the mid-impact design strategies, it can be seen that switching from the baseline roof enclosure (BASE-R) to the roof enclosure with the lowest total life-cycle energy (MSIP-R1), would result in a savings of just over 3,000 GJ of primary energy after 50 years. No other substitution of a single building component is able to achieve a mid-impact energy savings for the baseline building (other than a reduction in operating energy).

Table 7-1: Alternative Design Strategies to Reduce the Total Life-Cycle Energy Use of the Baseline Retail Building after a 50 Year Lifespan in Toronto

Design strategies are divided into low, mid, and high-impact strategies that correspond to a different percentage reduction in the total life-cycle energy use of the baseline retail building			
Building Component	**Low-Impact Design Strategies** ≤ 5% (≤ 2,800 GJ)	**Mid-Impact Design Strategies** > 5% and ≤ 25% (> 2,800 GJ and ≤ 14,000 GJ)	**High-Impact Design Strategies** > 25% (> 14,000 GJ)
Operations	Reduce annual operating energy by ≤ 5.5% *[Energy Savings ≤ -2,789 GJ]*	Reduce annual operating energy by > 5.5% and ≤ 27.6% *[Energy Savings* between *-2,789 GJ & -13,993 GJ]*	Reduce annual operating energy by > 27.6% *[Energy Savings > -13,993 GJ]*
Exterior Infill Wall Enclosures	Switch from baseline wall enclosure (BASE-W) to the wall enclosure with the lowest total life-cycle energy (WSIP-W12) *[Energy Savings = -2,214 GJ]*	Unable to achieve this level of energy reduction using only the exterior infill wall design strategies in Appendix B	Unable to achieve this level of energy reduction using only the exterior infill wall design strategies in Appendix B
Roof Enclosures	Switch from baseline roof enclosure (BASE-R) which has a 4-ply built-up asphalt roof covering to (OWSJ-R5) which has a galvanized standing seam steel roof *[Energy Savings = -1,556 GJ]*	Switch from baseline roof enclosure (BASE-R) to the roof enclosure with the lowest total life-cycle energy (MSIP-R1) *[Energy Savings = -3,035 GJ]*	Unable to achieve this level of energy reduction using only the roof design strategies in Appendix B
Structure	Switch from conviential hot-rolled steel structural system (S-1) to heavy timber glulam structural system (S-2) *[Energy Savings = -320 GJ]*	Unable to achieve this level of energy reduction using only the structural system design strategies in Appendix B	Unable to achieve this level of energy reduction using only the structural system design strategies in Appendix B
Mezannine Floor	Switch from baseline mezzanine floor (FL-3) to the mezzanine floor with the lowest total life-cycle energy (FL-5) *[Energy Savings = -31 GJ]*	Unable to achieve this level of energy reduction using only the mezzanine floor design strategies in Appendix B	Unable to achieve this level of energy reduction using only the mezzanine floor design strategies in Appendix B
Windows & Doors	Switch from aluminum curtainwall with no low-E coating and no argon (W-9) to (W-8) which has a wood frame, low-E coating, and argon gas *[Energy Savings = -1,679 GJ]*	Unable to achieve this level of energy reduction using only the window/door design strategies in Appendix B	Unable to achieve this level of energy reduction using only the window/door design strategies in Appendix B
Interior Partitions	Switch all interior partitions in the baseline retail building (incuding stair tower) to WS-P2 which uses the least amount of life-cycle energy *[Energy Savings = -42 GJ]*	Unable to achieve this level of energy reduction using only the interior partition design strategies in Appendix B	Unable to achieve this level of energy reduction using only the interior partition design strategies in Appendix B
Foundations	Switch from 200mm thick concrete SOG with no under slab insulation (SOG-FDN4) to 100mm thick concrete SOG with 50mm insulation (SOG-FDN3) *[Energy Savings = -1,744 GJ]*	Unable to achieve this level of energy reduction using only the foundation design strategies in Appendix B	Unable to achieve this level of energy reduction using only the foundation design strategies in Appendix B

Total life-cycle energy of baseline retail building = 55,947 GJ (100%)
Total life-cycle operating energy of baseline retail building = 50,700 GJ (90.6%)
Total life-cycle embodied energy of baseline retail building = 5,247 GJ (9.4%)

There are a number of different low-impact design strategies that could be implemented in order to save ≤ 5% of the total energy for the baseline retail building. For example, switching from a 200 mm thick concrete slab-on-grade with no under slab insulation (SOG-FDN4) to a 100 mm thick concrete slab-on-grade with 50 mm of under slab insulation (SOG-FDN3) would result in a savings of over 1,700 GJ of primary energy after 50 years. Similarly, switching from the baseline wall enclosure (BASE-W) to the wall enclosure with the lowest total life-cycle energy (WSIP-W12) would save over 2,200 GJ of primary energy.

Clearly, the best strategy to reduce the total life-cycle energy use of the baseline retail building would be to implement as many of the energy saving design strategies in Table 7-1 as possible. Only focusing on one or two design strategies probably won't save a great deal of energy in the end. The most effective way to reduce the total life-cycle energy of the baseline retail building is to find ways of reducing the annual operating energy (such as shortening the hours of operation, providing a better balance between daylighting and space heating, increasing the efficiency of the mechanical systems, implementing passive heating, cool, and ventilation strategies, etc.).

A similar list of design strategies for reducing the total GWP of the baseline retail building can also be developed. Table 7-2 lists the alternative design strategies for reducing the total life-cycle GWP of the baseline retail building after a 50 year lifespan.

Essentially the same trends apply for the case of total GWP as were just discussed for total energy. The only single strategy for reaching a high-impact of GWP savings is to reduce the annual operating GWP by more than about 29%. Switching from the baseline roof (BASE-R) to the roof enclosure with the lowest total life-cycle GWP, would save about 150 tonnes of CO_2 eq. after 50 years. A number of low-impact GWP saving design strategies are possible. For example, switching from aluminum curtainwall with no low-E coating and no argon gas (W-9) to a wood frame window with a low-E coating and filled with argon gas (W-8) would save about 90 tonnes of CO_2 eq. after 50 years. Only if all of the low-impact design strategies (excluding the operating GWP) were implemented, would one be able to achieve a mid-impact GWP savings. Similar to the case of primary energy, the best approach to saving the most about of total GWP would be a combination of as many design strategies as possible, with a focus on reducing the annual operating GWP.

Table 7-2: Alternative Design Strategies to Reduce the Total Life-Cycle GWP of the Baseline Retail Building after a 50 Year Lifespan in Toronto

Design strategies are divided into low, mid, and high-impact strategies that correspond to a different percentage reduction in the total life-cycle GWP of the baseline retail building)			
Building Component	**Low-Impact Design Strategies** ≤ 5% (≤ 130 tonnes of CO_2 eq.)	**Mid-Impact Design Strategies** > 5% and ≤ 25% (> 130 and ≤ 660 tonnes of CO_2 eq.)	**High-Impact Design Strategies** > 25% (> 660 tonnes of CO_2 eq.)
Operations	Reduce annual operating GWP by ≤ 5.6% *[GWP Savings ≤ -130 tonnes of CO_2 eq.]*	Reduce annual operating GWP by > 5.6% and ≤ 28.5% *[GWP Savings between 130 & 658 tonnes of CO_2 eq.]*	Reduce annual operating GWP by ≥ 28.5% *[GWP Savings > -658 tonnes of CO_2 eq.]*
Exterior Infill Wall Enclosures	Switch from baseline wall enclosure (BASE-W) to the wall enclosure with the lowest total life-cycle GWP (WSIP-W12) *[GWP Savings = -118 tonnes of CO_2 eq.]*	Unable to achieve this level of GWP reduction using only the exterior infill wall design strategies in Appendix B	Unable to achieve this level of GWP reduction using only the exterior infill wall design strategies in Appendix B
Roof Enclosures	Switch from baseline roof enclosure (BASE-R) which has a 4-ply built-up asphalt roof covering to (OWSJ-R5) which has a galvanized standing seam steel roof *[GWP Savings = -59 tonnes of CO_2 eq.]*	Switch from baseline roof enclosure (BASE-R) to the roof enclosure with the lowest total life-cycle GWP (GLU-R10) *[GWP Savings = -149 tonnes of CO_2 eq.]*	Unable to achieve this level of GWP reduction using only the roof design strategies in Appendix B
Structure	Switch from conviential hot-rolled steel structural system (S-1) to heavy timber glulam structural system (S-2) *[GWP Savings = -19 tonnes of CO_2 eq.]*	Unable to achieve this level of GWP reduction using only the structural system design strategies in Appendix B	Unable to achieve this level of GWP reduction using only the structural system design strategies in Appendix B
Mezannine Floor	Switch from baseline mezzanine floor (FL-3) to the mezzanine floor with the lowest total life-cycle energy (FL-5) *[GWP Savings = -3 tonnes of CO_2 eq.]*	Unable to achieve this level of GWP reduction using only the mezzanine floor design strategies in Appendix B	Unable to achieve this level of GWP reduction using only the mezzanine floor design strategies in Appendix B
Windows & Doors	Switch from aluminum curtainwall with no low-E coating and no argon (W-9) to (W-8) which has a wood frame, low-E coating, and argon gas *[GWP Savings = -90 tonnes of CO_2 eq.]*	Unable to achieve this level of GWP reduction using only the window/door design strategies in Appendix B	Unable to achieve this level of GWP reduction using only the window/door design strategies in Appendix B
Interior Partitions	Switch all interior partitions in the baseline retail building (including stair tower) to WS-P2 which uses the least amount of life-cycle GWP *[GWP Savings = -3 tonnes of CO_2 eq.]*	Unable to achieve this level of GWP reduction using only the interior partition design strategies in Appendix B	Unable to achieve this level of GWP reduction using only the interior partition design strategies in Appendix B
Foundations	Switch from 200mm thick concrete SOG with no under slab insulation (SOG-FDN4) to 100mm thick concrete SOG with 50mm insulation (SOG-FDN3) *[GWP Savings = -114 tonnes of CO_2 eq.]*	Unable to achieve this level of GWP reduction using only the foundation design strategies in Appendix B	Unable to achieve this level of GWP reduction using only the foundation design strategies in Appendix B

Total life-cycle GWP of baseline retail building = 2,632 tonnes of CO_2 eq. (100%)
Total life-cycle operating GWP of baseline retail building = 2,310 tonnes of CO_2 eq. (87.8%)
Total life-cycle embodied GWP of baseline retail building = 322 tonnes of CO_2 eq. (12.2%)

Chapter 8
Conclusions and Recommendations

8.1 Conclusions

A detailed review of the literature determined that there is a need for a comprehensive life-cycle assessment (LCA) study of single-storey commercial buildings in Canada, specifically single-storey retail buildings. Multi-storey office buildings and residential buildings have been the focus of the vast majority of LCA studies in the past, despite the fact that retail buildings consume more energy per floor area than both these types of buildings. As well, second only to office buildings, retail buildings in Canada are responsible for the largest percentage of energy use in the commercial/institutional building sector. This thesis addresses the need for a study that looks at a broad scope of building components for a single-storey retail building and that puts the life-cycle impacts of the various components into perspective.

That being said, the primary goal of this study was to conduct a comprehensive LCA study for the components of a single-storey retail building located in Toronto, Canada, to determine which building components contribute the most towards the total life-cycle energy use and global warming potential (GWP) after 50 years. In order to accomplish this goal, a two part methodology was followed.

First, the total life-cycle energy use and GWP was calculated for 220 different building components grouped into the following categories: exterior infill walls, roofs, structural systems, floors, windows, doors, foundations, and interior partition walls. Next, the scope of the study was broadened to include the LCA of five different single-storey retail buildings including: a typical hot-rolled steel structure retail building (i.e. the baseline retail building), a typical heavy timber structure retail building, a pre-engineered steel retail building, a predominately steel retail building, and a predominately timber retail building. For both the analysis of the individual building components and the entire buildings, the LCA calculations included the embodied and operating effects related to a pre-occupancy, occupancy, and post-occupancy phase.

Although a detailed analysis of 220 different individual building components was conducted in this study, the major thrust of this research work was focused on establishing the overall relationships between energy use and GWP for single-storey retail buildings as a whole. A detailed comparison of the LCA results for the individual building components was left to future work.

LCA Results for a Typical Single-Storey Retail Building (i.e. Baseline Retail Building)

A detailed LCA was conducted for a typical single-storey retail building, with a 50 year lifespan, located in Toronto, Canada. The relationships between operating energy, operating GWP, embodied energy, and embodied GWP were determined. Like previous studies of commercial type buildings (Cole & Kernan, 1996), operating effects accounted for the vast majority of the total effects as compared to embodied effects.

Total Energy and Total GWP

After a 50 year lifespan in Toronto, Canada, the typical single-storey retail building in this study was found to have a total life-cycle primary energy use of about 55,947 GJ and a total life-cycle GWP of around 2,632 tonnes of CO_2 eq.

As a percentage of the total life-cycle energy use (and total life-cycle GWP) the operating energy (and operating GWP) accounted for about 91% (88%) and the embodied energy (and embodied GWP) accounted for about 9% (12%) after 50 years. Therefore, it was determined that the best strategy for reducing the total life-cycle energy use and GWP of a typical single-storey retail building in Canada, is to decrease the energy use and GWP associated with the operating phase of the building. Any strategies that either directly or indirectly reduce the operating effects of the building should be a priority, if reducing the total life-cycle environmental impacts is a concern. In fact, the operating effects of a typical single-storey retail building in Canada would have to be reduced by about 90% from typical values today before a concerted effort to reduce embodied effects would be justified. That being said, as a percentage of the total energy (and total GWP) of the entire building, the following breakdown of the total embodied energy (and total embodied GWP) for the components of a single-storey retail building in Canada was found: roof = 4.9% (4.7%), foundations = 1.2% (3.0%), windows and doors = 1.1% (1.9%), exterior infill walls = 1.0% (1.1%), structure = 0.9% (1.0%), interior partitions = 0.2% (0.3%), and mezzanine floor = 0.1% (0.2%).

Total Operating Energy and Total Operating GWP

In a typical single-storey retail building in Canada, the operating effects were found to account for around 90% of the total effects after 50 years. In this study, the total electricity use and the total natural gas use represented about 56.9% (47.3%) and 43.1% (52.7%) of the annual total operating energy (and total operating GWP) respectfully. A breakdown of the annual total operating energy use (and total operating GWP) for the typical single-storey retail building in this study can be further divided into: space heating (assuming a natural gas furnace) = 42.4% (51.8%), area lighting = 37.3% (31.0%), ventilation fans = 7.4% (6.2%), space cooling (assuming DX electric coils) = 6.4% (5.4%), miscellaneous equipment = 5.6% (4.6%), water heating = 0.7% (0.9%), and pumps and auxiliary = 0.2% (0.1%).

Total Embodied Energy and Total Embodied GWP

In a typical single-storey retail building in Canada, the embodied effects were found to account for around 10% of the total effects after 50 years. The results of this study found that the roof accounted for nearly half of the total embodied energy of the entire building and about 40% of the total embodied GWP after 50 years. This is an important finding as the embodied effects of the roof were found to account for a significantly greater percentage of the total embodied effects compared to any other individual building component and were found to account for a significantly greater percentage of the total embodied effects compared to multi-storey buildings. The following breakdown of total embodied energy (and total embodied GWP) for a typical single-storey retail building was found in this study: roof = 52.0% (38.5%), foundations = 12.9% (24.5%), windows and doors = 12.0% (15.8%), exterior infill walls = 10.2% (8.7%), structure = 9.1% (8.4%), interior partitions = 2.7% (2.8%), and mezzanine floor = 1.1% (1.2%).

The Impact of Material Selection on the LCA of a Typical Single-Storey Retail Building

A detailed LCA of five single-storey retail buildings with a 50 year lifespan, located in Toronto, Canada was conducted. These five retail buildings included: a typical hot-rolled steel structure retail building (Case Study #1), a typical heavy-timber structure retail building (Case Study #2), a typical pre-engineered steel retail building (Case Study #3), a predominately steel retail building (Case Study #4), and a predominately timber retail building (Case Study #5). In each case, the operating effects were found to far outweigh the embodied effects after a 50 year lifespan.

Total Energy and Total GWP

A comprehensive LCA study was conduced for each of the five single-storey retail buildings in this study. After a 50 year lifespan, the total energy (and total GWP) of the five case study buildings was found to only differ at most by 6% (7%). Regardless of the material chosen for the structural system, or whether the building was primarily made of steel or timber building components, the range in the total energy and total GWP of the five case study buildings after 50 years was minimal. In each case, the operating effects far outweighed the embodied effects after 50 years. Therefore, as the annual operating energy (and operating GWP) of the five buildings only differed by about 3% (4%), the similarity in operating effects moderated any differences in embodied effects between the buildings due to using different building materials.

That being said, the typical pre-engineered steel building (Case Study #3) was found to have the least total energy and total GWP of any building after 50 years. However, the energy and GWP savings were minimal compared to the other buildings and was highly dependent on the thermal resistance of the enclosure. Therefore, it is possible that under slightly different conditions that another building would have less total energy and total GWP after 50 years. However, the typical pre-engineered steel retail building was found to have the least total energy and total GWP of any building in this study.

Total Operating Energy and Total Operating GWP

The annual operating energy (and operating GWP) of the five single-storey retail buildings in this study only differed at most by 3% (4%). Therefore, using steel or timber building components did not significantly affect the operating energy or operating GWP of a typical single-storey retail building, so long as the thermal resistance of the enclosure could be kept relatively consistent.

Total Embodied Energy and Total Embodied GWP

After a 50 year lifespan, the total embodied energy (and total embodied GWP) of the five single-storey retail buildings in this study differ by as much as 44% (35%). The typical pre-engineered steel retail building (Case Study #3), was found to have the least total embodied energy and total embodied GWP of all the buildings. This was due in large part to the high degree of material optimization that is inherent to these types of buildings.

The standing seam steel roof performed significantly better after 50 years than the asphalt-based, PVC, and EPDM roofs. Standing seam steel roofs have significantly less recurring embodied energy and recurring embodied GWP and show great promise in comparison to other roof coverings with higher recurring embodied effects. If a standing seam steel roof was to replace the 4-ply built-up asphalt roof in the predominately timber retail building (Case Study #5), then this building would have the least total embodied energy and total embodied GWP of all five buildings. The typical hot-rolled steel structure retail building (Case Study #1) was found to have the highest total embodied energy and total embodied GWP of all five buildings.

LCA Results for Individual Building Components

In general, a strong correlation was observed between the thermal resistance of the exterior infill walls in this study and the Δ total energy and Δ total GWP compared to the baseline datum. In fact, it was found that an increase in total energy and total GWP corresponded in general to a decrease in the thermal resistance of the exterior infill walls. In almost every case there were far more significant energy and GWP savings to be had because of savings in operating effects than from savings in embodied effects for the various exterior infill walls examined in this study.

For the case of the roof enclosures examined in this study, the magnitude of the embodied effects outweighed the operating effects in many instances. This result suggests that for the roof enclosures, the building materials have a more significant affect on the Δ total energy and Δ total GWP than was observed for the exterior infill walls. However, there was still a correlation between a decrease in the thermal resistance of the roof enclosures and an increase in the total energy and total GWP of the roofs. The results also indicate that significant savings could be achieved in terms of the total energy and total GWP if a green roof or a steel roof covering were used as opposed to an asphalt-based roof covering.

The choice of structural system, floor assembly, or interior partition wall type did not have any impact on the operating energy and operating GWP of the baseline building at all. Therefore, the Δ total energy and Δ total GWP compared to the baseline datum were minimal in these types of building components. The differences between the various options for these types of building components were solely a result of the differences in embodied effects.

The results of this study found a strong correlation between decreasing thermal resistance of the windows and increasing total energy and total GWP. Therefore, high performance glazing (argon filled, low-E coating) outperformed the corresponding windows with typical glazing (air filled, no low-E coating). The results also found that per m^2 of enclosure, windows actually have a relatively large total energy and total GWP compared to the exterior infill walls and roofs. A larger sample of doors must be examined before conclusive remarks can be made about the Δ total energy and Δ total GWP of different types of doors.

The best performing foundation components in this study were the ones that used less material. Therefore, smaller concrete footings, piers, foundation walls, and thinner slab-on-grades generally performed better in the LCA calculations. Also, higher percentages of flyash in the concrete mix resulted in greater energy and GWP savings. The best performing slab-on-grades were the ones where under slab insulation was specified, as significant savings in operating effects resulted.

8.2 Recommendations for Future Work

Based on the findings of this study, the following recommendations for future work have been compiled:

1. Determine how the relationships between embodied energy, embodied GWP, operating energy, and operating GWP change for a different building lifespan (5, 25, 100 years for example).

2. Determine how the results of this study would differ if the retail building were located elsewhere in Canada or in the United States.

3. Further investigate the LCA of pre-engineered steel buildings since they showed great promise in this study as an effective system to use in low-energy building applications due to their high degree of material optimization. For example, the savings in construction energy that would result from using a pre-engineered steel building system compared to other conventional systems might be significant due to shorter construction times and pre-fabrication benefits.

4. Compare the LCA results for a single-storey retail building to a multi-storey retail building in order to determine which building components have the most impact on the total life-cycle energy and GWP.

5. Calculate the embodied energy and embodied GWP that is associated with the mechanical, electrical, and plumbing components of a building. The operating effects of these components have been included in this study, but their embodied energy and embodied GWP has not been calculated here.

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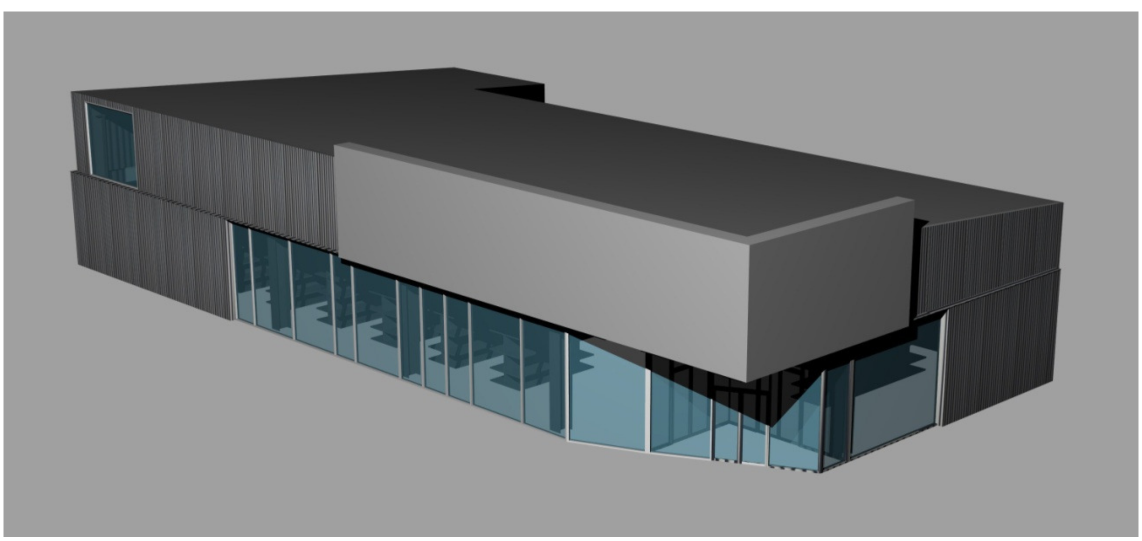
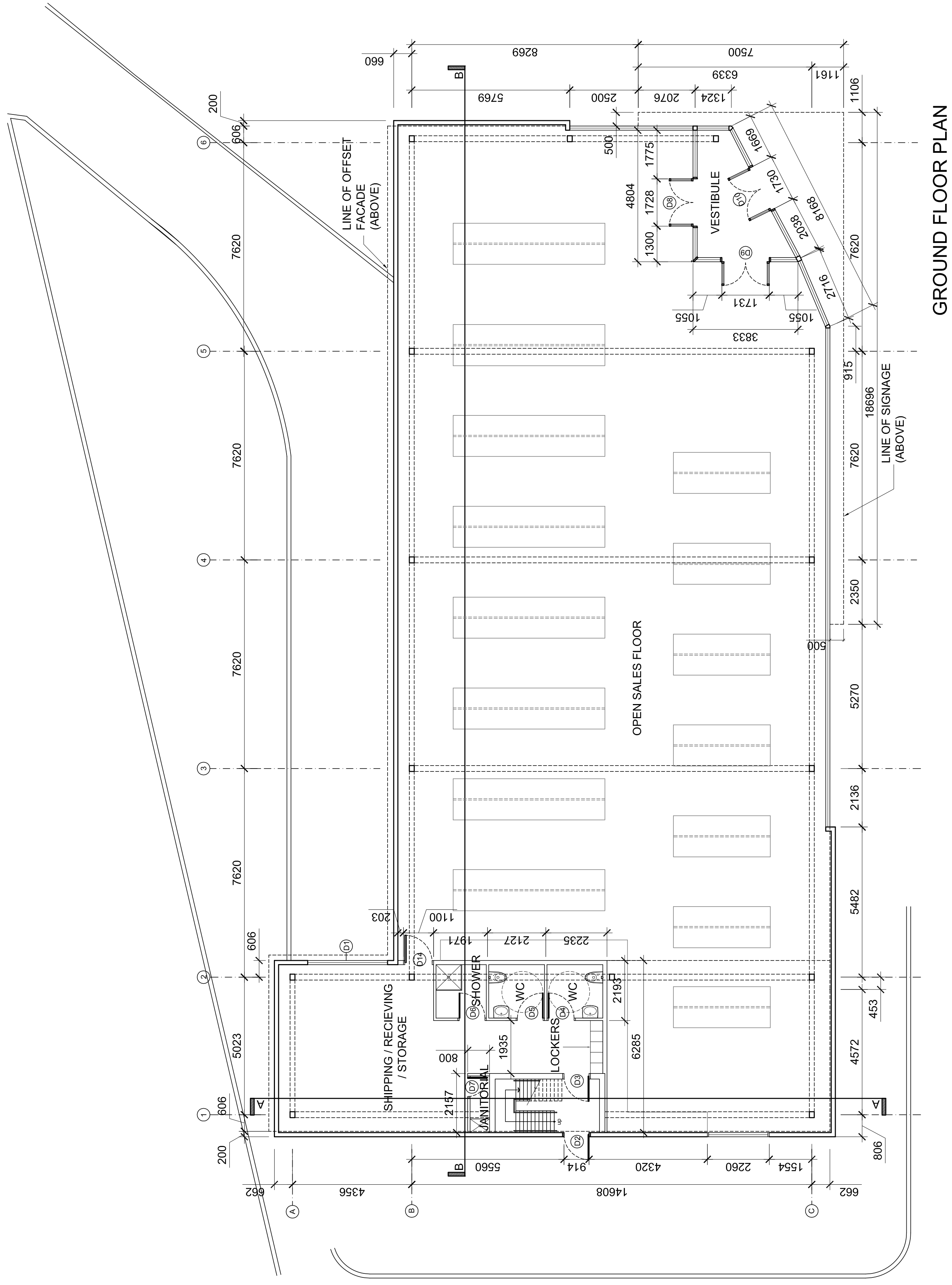
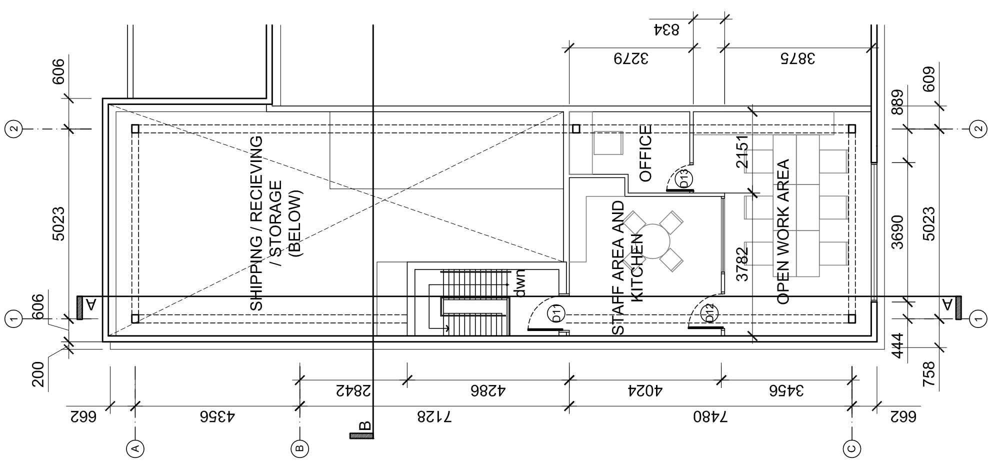
Appendix A

Description of Baseline Retail Building (Case Study #1)

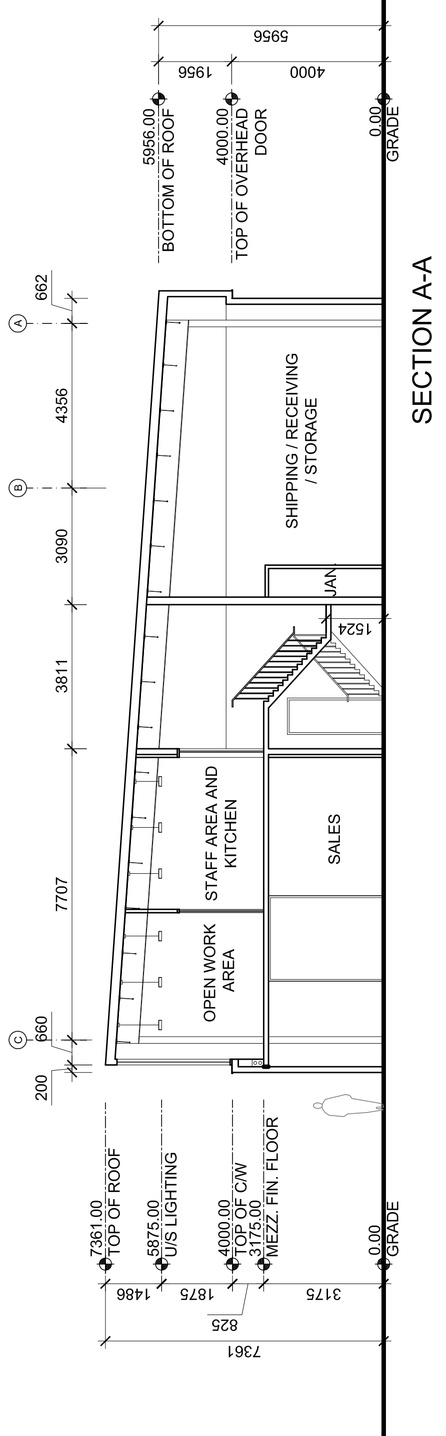
Appendix A provides a detailed description of the baseline retail building (Case Study #1 – Typical Hot-Rolled Steel Structure Retail Building) that was used in this study. This includes drawings of the floor plans, sections, building elevations, structural drawings, as well as a detailed list of building descriptors that were used for the energy modeling. Where noted, Appendix B should be consulted for a more complete description of certain building components.

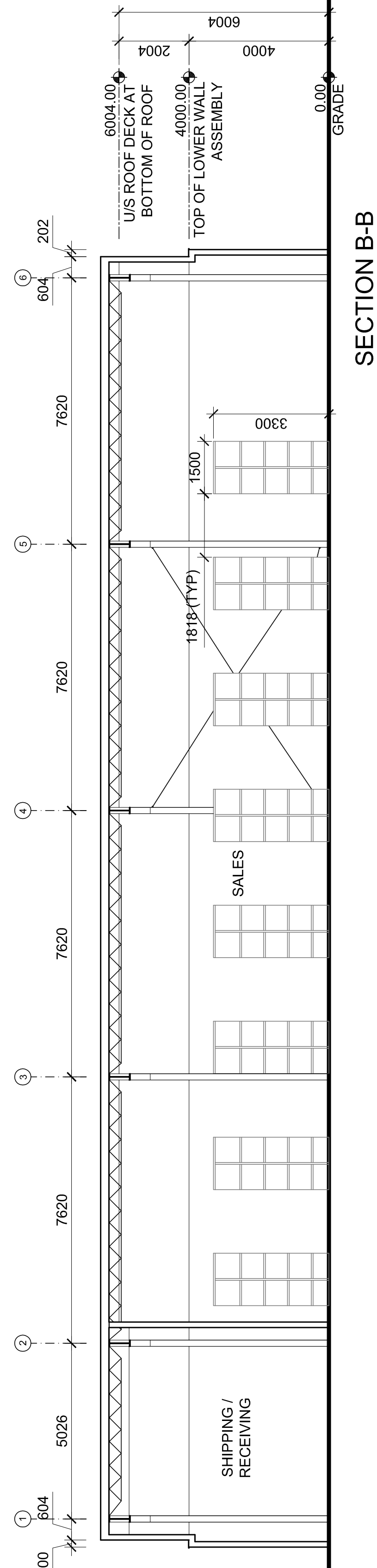


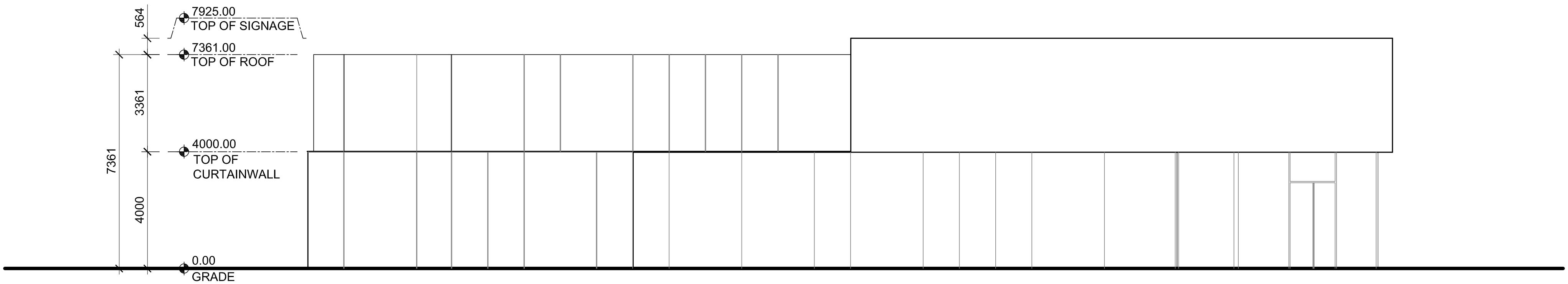

GROUND FLOOR PLAN
LINE OF OFFSET FACADE (ABOVE)
VESTIBULE
OPEN SALES FLOOR
LINE OF SIGNAGE (ABOVE)
SHIPPING / RECIEVING / STORAGE
SHOWER
WC
WC
LOCKERS
JANITORIAL



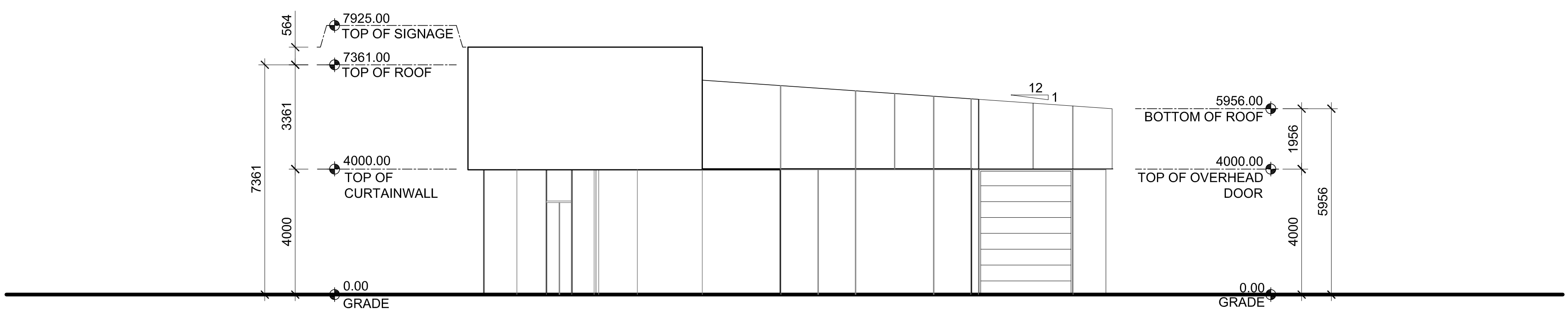
MEZZANINE PLAN


SECTION A-A
5956.00
BOTTOM OF ROOF
4000.00
TOP OF OVERHEAD DOOR
0.00
GRADE
5956
1956
4000
662
4356
3090
3811
7707
660
200
A
B
C
SHIPPING / RECEIVING / STORAGE
JAN
1524
STAFF AREA AND KITCHEN
SALES
OPEN WORK AREA
7361.00
TOP OF ROOF
5875.00
U/S LIGHTING
4000.00
TOP OF C/W
3175.00
MEZZ. FIN. FLOOR
0.00
GRADE
1486
1875
825
3175
7361

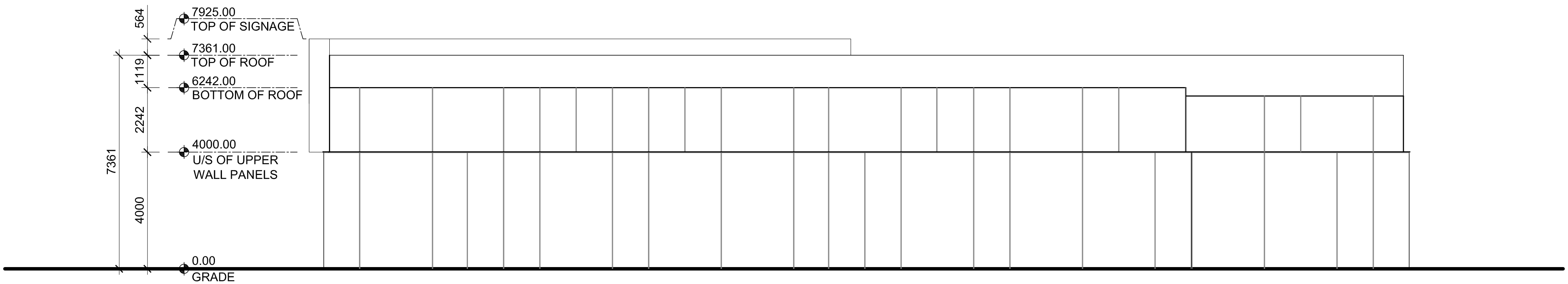

SECTION B-B
6004.00
U/S ROOF DECK AT BOTTOM OF ROOF
4000.00
TOP OF LOWER WALL ASSEMBLY
0.00
GRADE
6004
2004
4000
202
604
7620
7620
7620
7620
5026
604
200
1
2
3
4
5
6
3300
1500
1818 (TYP)
SALES
SHIPPING / RECEIVING



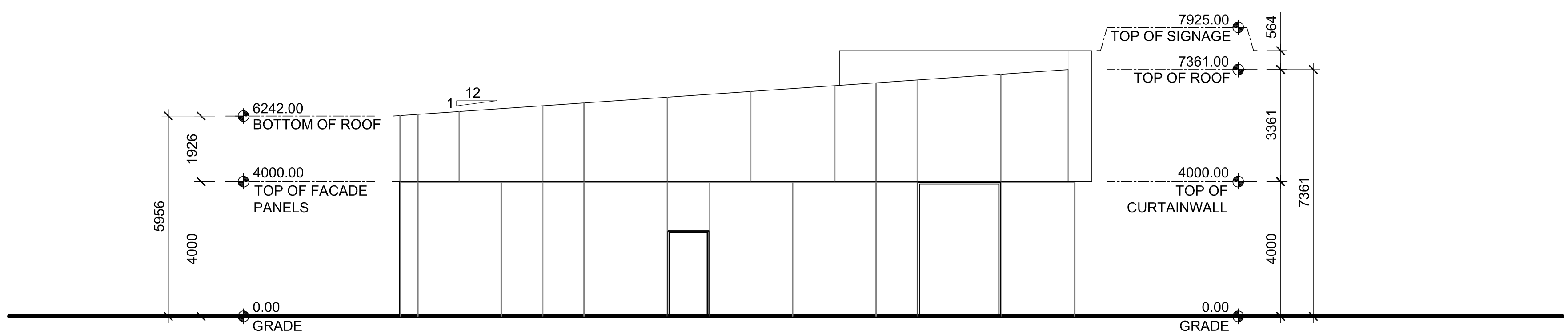
SOUTH ELEVATION



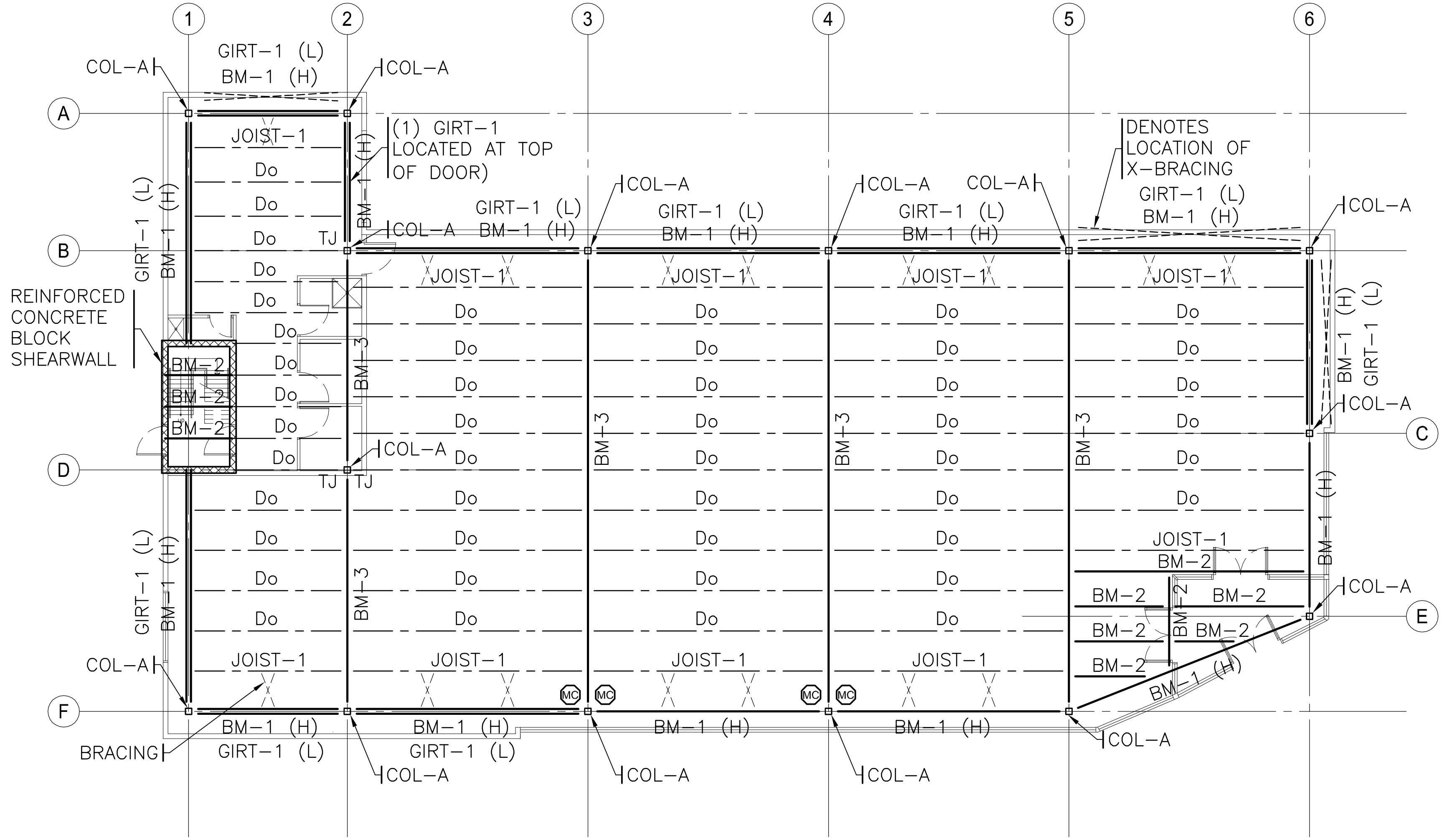
EAST ELEVATION



NORTH ELEVATION



WEST ELEVATION



ROOF FRAMING PLAN

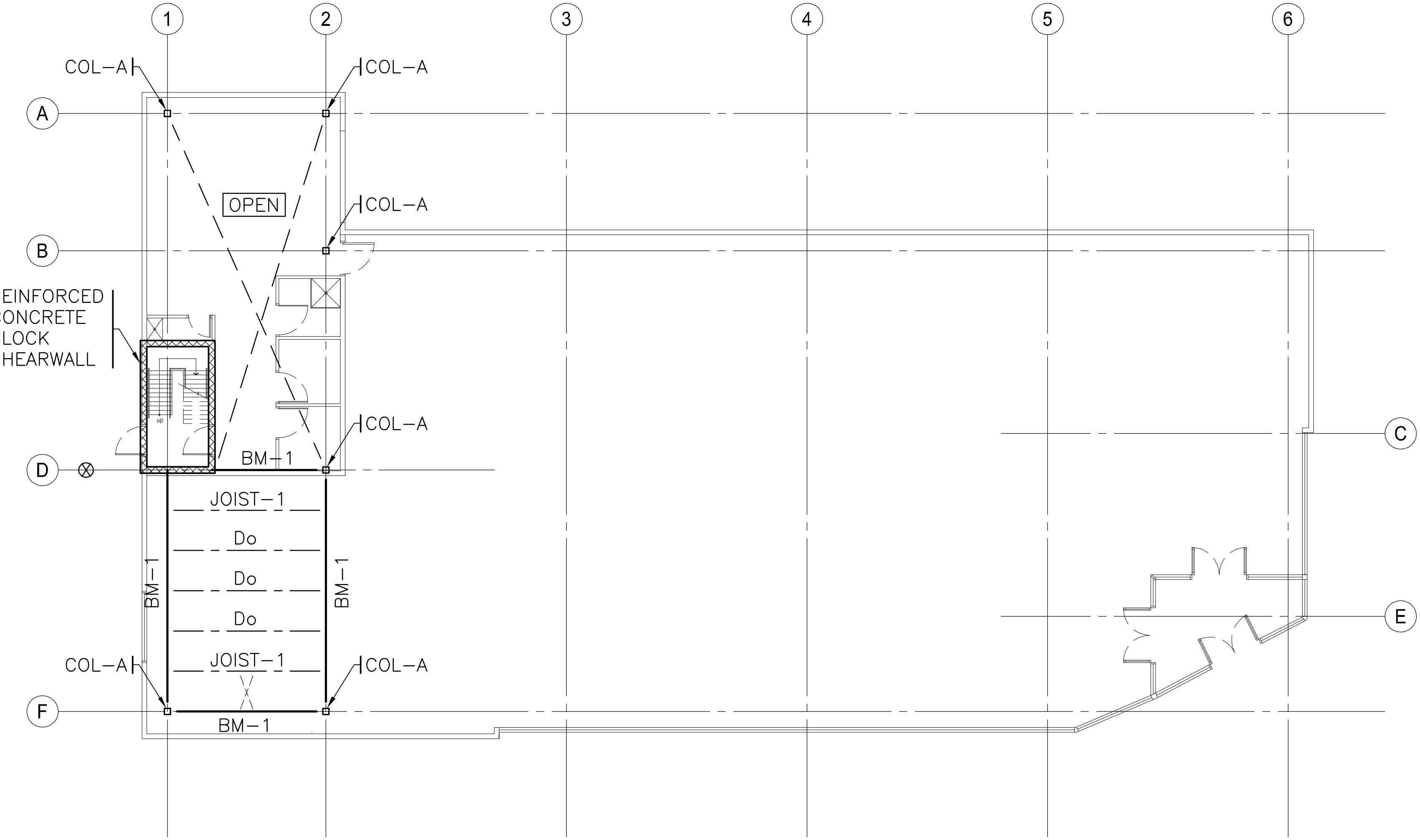
- / S1

SCALE: 1:200

Member Sizes		
Member ID	Hot-Rolled Steel Building	Heavy Timber Building
COL-A	H.S.S. 178x178x6.4mm	265x304mm D-FIR-L
BM-1	W310x21	80x494mm D-FIR-L
BM-2	W200x15	80x342mm D-FIR-L
BM-3	W610x92	265x874mm D-FIR-L
JOIST-1	350mm OWSJ @ 1200mm o/c	80x418mm D-FIR-L @ 1800mm o/c
GIRT-1	H.S.S. 178x127x6.4mm (2 in total, eq. spacing vertically)	175x304mm D-FIR-L (2 in total, eq. spacing vertically)

NOTES:

1. ROOF SPECIFIED DESIGN LOADS:
   DL = 1.5kPa
   LL = 1.1kPa



- S2 MEZZANINE FRAMING PLAN

SCALE: 1:200

Member Sizes		
Member ID	Hot-Rolled Steel Building	Heavy Timber Building
COL-A	H.S.S. 178x178x6.4mm	265x304mm D-FIR-L
BM-1	W310x21	80x494mm D-FIR-L
BM-2	W200x15	80x342mm D-FIR-L
BM-3	W610x92	265x874mm D-FIR-L
JOIST-1	350mm OWSJ @ 1200mm o/c	80x418mm D-FIR-L @ 1800mm o/c
GIRT-1	H.S.S. 178x127x6.4mm (2 in total, eq. spacing vertically)	175x304mm D-FIR-L (2 in total, eq. spacing vertically)

NOTES:

1. MEZZANINE SPECIFIED DESIGN LOADS:
   DL = 3.6kPa
   LL = 4.8kPa

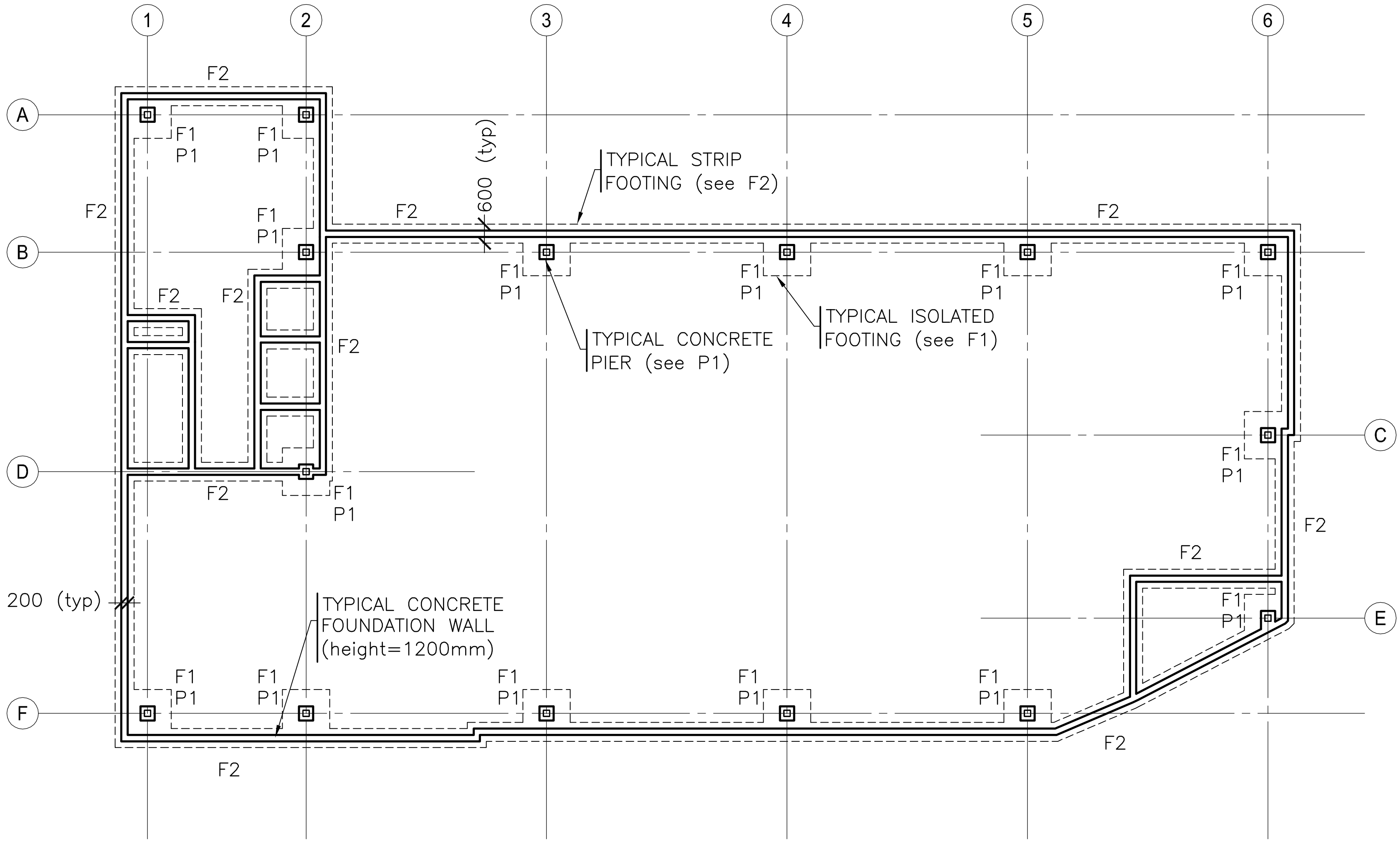
NOTES:

1. ENTIRE FLOOR TO BE 150mm CONCRETE SLAB–ON–GRADE ON 10mil POLY VAPOUR BARRIER, ON 150mm GRAN 'A' COMPACTED BASE

2. FOUNDATIONS DESIGNED FOR NATURAL UNDISTURBED SOIL HAVING A MINIMUM BEARING PRESSURE AS FOLLOWS:

   ALLOWABLE (SLS) = 3,000psf (150kPa)

   ULTIMATE (ULS) = 4,500psf (225kPa)



- / S3 FOUNDATION PLAN

SCALE: 1:200

Footing Schedule		
Mark	Size (mm)	Thickness (mm)
F1 (Isolated Ftg.)	1200 x 1200	350
F2 (Strip Ftg.)	600	200

Pier Schedule		
Mark	Size (mm)	Height (mm)
P1	450 x 450	1200

General Descriptors	
Building Type	▪ Stand alone retail
Location	▪ Toronto, Ontario, Canada
Number of Stories	▪ 1 storey with mezzanine for offices
Gross Floor Area	▪ 586 m^2 (6,300 ft^2)
Gross Dimensions	▪ Length x width (not including shipping and receiving area): 36.8 m x 15.8 m (120.7 ft x 51.8 ft) ▪ Mid-height of roof: 6.7 m (22.0 ft) ▪ Floor to ceiling height: 5.6 m (18.4 ft)
Hours of Occupancy	▪ Monday to Saturday 8am to 9pm ▪ Sunday 9am to 6pm ▪ Closed during statutory holidays
Building Orientation	▪ Long dimension aligned along E-W axis
Roof Slope	▪ Mono-slope roof with 1:12 pitch
Percentage of Gross Floor Area by Activity Type	▪ Retail sales and wholesale showroom: 64% ▪ Exhibit display area: 15% ▪ Conditioned storage: 6% ▪ Office: 8% ▪ Restrooms: 5% ▪ Mechanical and electrical room: 2%
Design Maximum Occupancy by Activity Type	▪ Retail sales and wholesale showroom: 27.9 m^2/person (300 ft^2/person) ▪ Exhibit display area: 4.6 m^2/person (50 ft^2/person) ▪ Conditioned storage: 46.5 m^2/person (500 ft^2/person) ▪ Office: 18.6 m^2/person (200 ft^2/person) ▪ Restrooms: 27.9 m^2/person (300 ft^2/person) ▪ Mechanical and electrical room: 185.9 m^2/person (2,000 ft^2/person)
Infiltration (Shell Air Tightness)	▪ Core zone: 5.08 x 10^{-6} m^3/s /m^2 (0.001cfm/ft^2) ▪ Perimeter zone: 1.93 x 10^{-4} m^3/s /m^2 (0.038 cfm/ft^2)
Limitations	▪ Shelving, furniture, and retail merchandise not accounted for in models ▪ Mechanical equipment not accounted for in embodied energy (and GWP) calculations

Structural Design Assumptions	
Structural Loads	▪ NBCC 2005 ▪ Ss = 0.9 kPa ▪ Sr = 0.4 kPa ▪ q (1/10) = 0.39 kPa ▪ q (1/50) = 0.52 kPa ▪ LL = 1.0 kPa (roof) and 4.8 kPa (mezzanine) ▪ DL = see Appendix B for DL of building components ▪ Earthquake loads not considered. Assumed that wind loads govern lateral force resisting system
Building Codes	▪ Hot-Rolled Steel: CAN/CSA S16-01 9^{th} ed. ▪ Cold-Formed Steel: CSA S136-07 ▪ Timber: CAN/CSA-086-01 ▪ Concrete: CSA Standard A23.9-04
Deflections	▪ Max allowable roof deflection: L/240 ▪ Max allowable horizontal deflection of building: 64 mm (2.5 in)

Structural Design Assumptions (Cont.)	
Columns	▪ Height = 7.4 m (24.3 ft) ▪ Pin-pin connections assumed ▪ Bearing not considered ▪ Columns selected based on axial loads, lateral bending moments, deflections, minimum connection widths, typical practice, and least weight per m
Beams	▪ Length = varies (see drawings) ▪ Simply supported pin-pin connections assumed ▪ Beams selected based on bending moments, deflections, minimum connection widths, typical practice, and least weight per m
Lateral Force Resisting System	▪ Combination of reinforced concrete masonry unit stair tower and 300W steel rod x-bracing (i.e. braced frame system)

Description of Building Components	
Exterior Infill Walls	▪ [BASE-W] – CFS *studs @ 400 mm o/c with EIFS (see Appendix B)*
Roofs	▪ [BASE-R] – *OWSJ @ 1,200 mm o/c and metal deck with continuous polyisocyanurate insulation and 4-ply built-up asphalt roof assembly (see Appendix B)* ▪ No roof overhang assumed
Structure	▪ [S-1] – *Conventional braced steel frame (H.S.S. columns and W-section beams) (see Appendix B)*
Mezzanine Floor	▪ Mezzanine includes office space (not modeled in eQUEST) ▪ [FL-3] – *OWSJ @ 1,200 mm o/c and metal deck with concrete topping, vinyl floor tile finish, and drywall ceiling (see Appendix B)*
Windows	▪ [W-1] – *Aluminum window frame with thermal break, typical double glazing unit with airspace, no low-E coating, no argon, fixed (see Appendix B)* ▪ [W-9] - *self-supported aluminum curtainwall system with thermal break, double glazing unit with airspace, no low-E coating, no argon (see Appendix B)* ▪ Window-to-wall ratio: 17% ▪ Typical window overhang = 0.3 m (1.0 ft) ▪ No window blinds or drapes to provide shade
Doors	▪ [D-2] – *Insulated steel exterior door with no glazing (see Appendix B)* ▪ [D-3] – *Uninsulated aluminum exterior door with 80% glazing (see Appendix B)* ▪ [D-4] – *Insulated sectional overhead steel door with no glazing (see Appendix B)* ▪ [D-6] – *Steel interior door with no glazing (see Appendix B)*
Interior Partitions	▪ [CMU-P1] for stair tower – *Reinforced 200 mm concrete masonry unit wall (see Appendix B)* ▪ [SS-P2] elsewhere – *CFS studs @ 600 mm o/c with two layers of drywall (see Appendix B)*

Description of Building Components (Cont.)	
Foundations	▪ Assume natural undisturbed soil with minimum bearing pressure of: - Allowable (SLS) = 150 kPa (3,000 psf) - Ultimate (ULS) = 215 kPa (4,500 psf) ▪ Design load for isolated footings = 150 kN (34 kips) ▪ All isolated footings assumed to be the same size for simplicity ▪ [SOG-5] – *200 mm thick concrete slab, 30 MPa, average flyash content, 10 mil poly vapor barrier, earth contact (see Appendix B)* ▪ [IF-1] – *1,200 mm x 1,200 mm x 350 mm isolated footing with 450 mm x 450 mm x 1,200 mm concrete pier, 20 MPa, average flyash content (see Appendix B)* ▪ [PF-5] – *600 mm x 200 mm strip footing with 1,200 mm x 200 mm concrete foundation wall, 20 MPa, average flyash content (see Appendix B)*
Finish Materials	▪ As per building components in Appendix B

Mechanical Systems	
Hours of Operation	▪ Mechanical systems operate 1 hour before and 1 hour after hours of occupancy ▪ Off during statutory holidays
HVAC	
Cooling Equipment	▪ Direct expansion (DX) coils (electric)
Heating Equipment	▪ Combustion furnace (natural gas)
System Type	▪ Packaged single zone DX with furnace (central packaged single zone air conditioner with combustion furnace) ▪ Ducted return air
Thermostat Set-Points	▪ Occupied spaces: Cool to 24.4°C (76.0°F), Heat to 21.1°C (70.0°F) ▪ Unoccupied spaces: Cool to 27.8°C (82.0°F), Heat to 17.8°C (64.0°F)
Air Flow	▪ Minimum design air flow: 2.54×10^{-3} m^3/s /m^2 (0.50 cfm/ft^2)
Zoning	▪ 0% core zone ▪ 100% perimeter zone
Hot Water	
DHW Equipment	▪ Heater fuel: natural gas ▪ Heater type: storage ▪ Hot water use: 1.9 L/person/day (0.50 gal/person/day) ▪ Supply water temperature: 57.2°C (135.0°F) ▪ Inlet water temperature: equal to ground temperature

Load Profiles by Space				
Space	Interior Lighting W/m^2 (W/ft^2)	Office Equipment W/m^2 (W/ft^2)	Misc. Electric Loads W/m^2 (W/ft^2)	Misc. Natural Gas Loads W/m^2 ($Btuh/ft^2$)
Retail sales and wholesale showroom	25.60 (2.38)	-	2.69 (0.25)	-
Exhibit display area	11.08 (1.03)	-	2.69 (0.25)	-
Conditioned storage	12.80 (1.19)	-	0.00 (0.00)	-
Office	13.34 (1.24)	5.0 (0.46)	8.07 (0.75)	-
Restrooms	8.28 (0.77)	-	1.08 (0.10)	-
Mechanical and electrical room	8.71 (0.81)	-	1.08 (0.10)	-
Additional Loads/Notes				
Building Occupants	▪ Average occupant heat gain of 132 W/person			
Exterior Lighting	▪ Not considered in models			
Daylight Controls	▪ No daylighting controls			

Appendix B

Life-Cycle Assessment Data for Building Components

This Appendix contains detailed LCA data for the 220 different building components that were examined in this study. For each building component, there is a detailed description of the assembly, a summary of the important LCA data, as well as a detailed list of the material quantities that were assumed.

Appendix B is divided into the following sub-sections:

For each building component group in this Appendix, there is a brief introduction as well as a graph that summaries the embodied energy and embodied GWP of the relevant building components. When reading this Appendix, it may be useful to reference the table below, which lists common thickness and gauges.

Common Thicknesses and Gauges

Gauge	Nominal Thickness (mm)	Nominal Thickness (in)
8	4.176	0.164
10	3.416	0.135
12	2.657	0.105
14	1.897	0.075
16	1.591	0.060
18	1.214	0.048

Gauge	Nominal Thickness (mm)	Nominal Thickness (in)
20	0.912	0.036
22	0.759	0.030
24	0.607	0.024
25	0.531	0.021
26	0.455	0.018
28	0.378	0.015
29	0.343	0.014

Appendix B-1

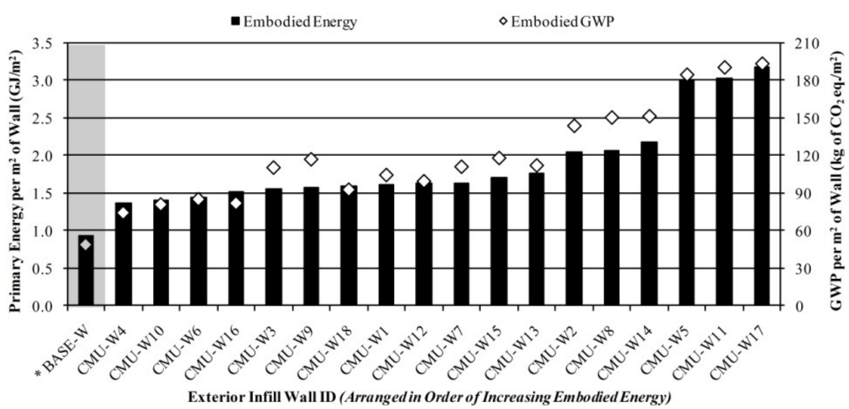
LCA Data for Exterior Infill Walls

LCA Data for Concrete Masonry Unit Walls

This section contains a detailed description of each concrete masonry unit (CMU) exterior infill wall that was examined in this study (18 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

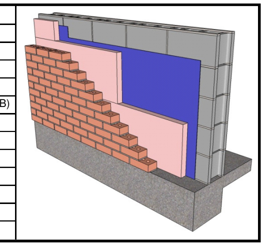
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various walls in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Concrete Masonry Unit Wall #1 (CMU-W1)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
Brief Description:	Concrete masonry unit wall with typical exterior rigid insulation and standard clay brick cladding	***Outside***
		Ontario (standard) clay brick cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 11.9 RSI-Value: 2.1	Latex paint
THERM 5.2:	R-Value: 13.3 RSI-Value: 2.3	***Inside***
Wall Thickness:	355 mm	
Total Embodied Energy:	1,607 MJ/m^2	
Total Embodied GWP:	105 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	74,638	452	75,090	685	1,902	2,587	0	0	0	0	0	0	77,677	1,525	-	-
50	74,638	452	75,090	685	1,902	2,587	3,099	10	3,110	75	951	1,027	81,813	1,607	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,223	1	5,224	48	4	51	0	0	0	0	0	0	5,275	104	-	-
50	5,223	1	5,224	48	4	51	44	0	44	5	2	7	5,325	105	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Cold Rolled Sheet	10.3	kg
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	104.3	m2 (25mm)
Modified Bitumen membrane	68.2	kg
Mortar	3.5	m3
Nails	3.1	kg
Ontario (Standard) Brick	53.5	m2
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

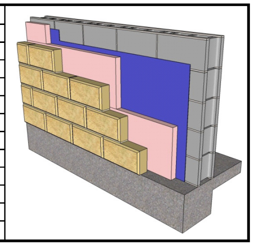
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #2 (CMU-W2)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with typical exterior rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 11.9 RSI-Value: 2.1	Latex paint
THERM 5.2:	R-Value: 13.2 RSI-Value: 2.3	***Inside***
Wall Thickness:	355 mm	
Total Embodied Energy:	2,037 MJ/m^2	
Total Embodied GWP:	144 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	93,666	1,015	94,681	685	2,713	3,397	0	0	0	0	0	0	98,078	1,926	-	-
50	93,666	1,015	94,681	685	2,713	3,397	3,099	10	3,110	76	2,477	2,553	103,741	2,037	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	7,209	2	7,210	48	5	53	0	0	0	0	0	0	7,263	143	-	-
50	7,209	2	7,210	48	5	53	44	0	44	5	5	10	7,317	144	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Cold Rolled Sheet	10.3	kg
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	104.3	m2 (25mm)
Modified Bitumen membrane	401.5	kg
Mortar	6.4	m3
Nails	3.1	kg
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

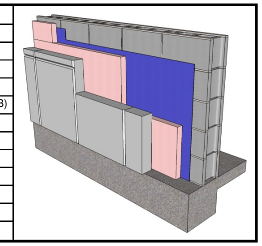
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #3 (CMU-W3)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with typical exterior rigid insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 11.9 RSI-Value: 2.1	Latex paint
THERM 5.2:	R-Value: 13.3 RSI-Value: 2.3	***Inside***
Wall Thickness:	390 mm	
Total Embodied Energy:	1,553 MJ/m^2	
Total Embodied GWP:	110 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	71,325	1,043	72,368	685	1,842	2,526	0	0	0	0	0	0	74,894	1,471	-	-
50	71,325	1,043	72,368	685	1,842	2,526	3,099	10	3,110	76	984	1,060	79,064	1,553	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,523	2	5,525	48	4	51	0	0	0	0	0	0	5,576	110	-	-
50	5,523	2	5,525	48	4	51	44	0	44	5	2	7	5,626	110	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Concrete 30 MPa (flyash avg.)	6.7	m3
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	104.3	m2 (25mm)
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	3.1	kg
Rebar, Rod, Light Sections	1,496.8	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

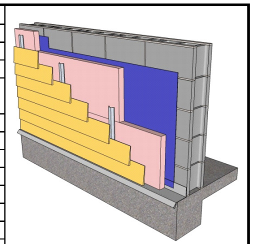
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #4 (CMU-W4)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with typical exterior rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		200mm standard weight concrete block
ASHRAE Standard 90.1:	R-Value: 11.9 RSI-Value: 2.1	*(includes #15M bars @ 400mm o/c with grout)*
THERM 5.2:	R-Value: 13.9 RSI-Value: 2.4	Latex paint
Wall Thickness:	290 mm	*Inside*
Total Embodied Energy:	1,365 MJ/m²	
Total Embodied GWP:	75 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	63,370	470	63,840	685	1,252	1,936	0	0	0	0	0	0	65,776	1,292	-	-
50	63,370	470	63,840	685	1,252	1,936	3,099	10	3,110	75	541	616	69,501	1,365	200,000	344

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	3,698	1	3,699	48	2	50	0	0	0	0	0	0	3,749	74	-	-
50	3,698	1	3,699	48	2	50	44	0	44	5	1	6	3,798	75	30,000	52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	106.1	kg
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	4.5	kg
Pine Wood Bevel Siding	160.4	m2
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

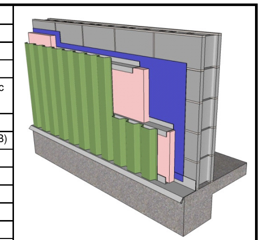
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Masonry Unit Wall #5 (CMU-W5)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with typical exterior rigid insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 64mm Z-girts @ 600mm o/c (self-weight: 1.1 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		200mm standard weight concrete block
ASHRAE Standard 90.1:	R-Value: 8.4 RSI-Value: 1.5	*(includes #15M bars @ 400mm o/c with grout)*
THERM 5.2:	R-Value: 9.7 RSI-Value: 1.7	Latex paint
Wall Thickness:	292 mm	*Inside*
Total Embodied Energy:	3,009 MJ/m²	
Total Embodied GWP:	184 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	147,220	422	147,642	685	1,152	1,836	0	0	0	0	0	0	149,478	2,936	-	-
50	147,220	422	147,642	685	1,152	1,836	3,099	10	3,110	75	535	610	153,197	3,009	1,800,000	3,098

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	9,284	1	9,285	48	2	50	0	0	0	0	0	0	9,335	183	-	-
50	9,284	1	9,285	48	2	50	44	0	44	5	1	6	9,384	184	120,000	207

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	101.0	kg
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	3.1	kg
Rebar, Rod, Light Sections	1,092.8	kg
Screws Nuts & Bolts	1.3	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

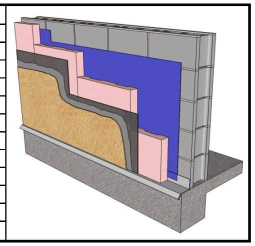
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Masonry Unit Wall #6 (CMU-W6)

Building Component Description:

Category:	Exterior Walls	
Brief Description:	Concrete masonry unit wall with typical exterior rigid insulation and EFIS cladding	
Quick Numbers:		
ASHRAE Standard 90.1:	R-Value: 11.9	RSI-Value: 2.1
THERM 5.2:	R-Value: 13.0	RSI-Value: 2.3
Wall Thickness:	278 mm	
Total Embodied Energy:	1,448 MJ/m^2	
Total Embodied GWP:	85 kg of CO_2 eq./m^2	

Assembly Layers
Outside
EFIS coating over metal mesh
50mm extruded polystyrene rigid insulation
Vertical drainage channels in insulation
Self-adhesive membrane with primer (AB, VB, WB)
200mm standard weight concrete block
(includes #15M bars @ 400mm o/c with grout)
Latex paint
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	67,237	477	67,714	685	1,244	1,929	0	0	0	0	0	0	69,643	1,368	-	-
50	67,237	477	67,714	685	1,244	1,929	3,099	10	3,110	75	890	965	73,718	1,448	500,000	861

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	4,243	1	4,244	48	2	50	0	0	0	0	0	0	4,295	84	-	-
50	4,243	1	4,244	48	2	50	44	0	44	5	2	7	4,345	85	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = *50.9* m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = *581.0* m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	4.6	kg
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

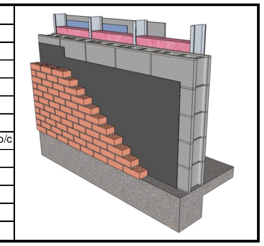
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #7 (CMU-W7)

Building Component Description:

Category:	Exterior Walls	
Brief Description:	Concrete masonry unit wall with typical batt insulation installed between drywall studs and standard clay brick cladding	
Quick Numbers:		
ASHRAE Standard 90.1:	R-Value: 11.1	RSI-Value: 2.0
THERM 5.2:	R-Value: 12.9	RSI-Value: 2.3
Wall Thickness:	473 mm	
Total Embodied Energy:	1,637 MJ/m^2	
Total Embodied GWP:	111 kg of CO_2 eq./m^2	

Assembly Layers
Outside
Ontario (standard) clay brick cladding
25mm air gap
#15 organic felt (WB)
200mm standard weight concrete block
(includes #15M bars @ 400mm o/c with grout)
39mm x 152mm 0.53mm steel studs @ 600mm o/c
140mm fiberglass batt insulation
6mil poly (AB, VB)
Regular 16mm gypsum board
Latex paint
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	77,793	520	78,313	844	2,084	2,928	0	0	0	0	0	0	81,241	1,595	-	-
50	77,793	520	78,313	844	2,084	2,928	1,047	10	1,057	75	1,008	1,083	83,381	1,637	500,000	861

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	5,572	1	5,573	58	4	62	0	0	0	0	0	0	5,635	111	-	-
50	5,572	1	5,573	58	4	62	18	0	18	5	2	7	5,660	111	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = *50.9* m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = *581.0* m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	51.9	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Concrete Blocks	648.0	Blocks
Galvanized Studs	138.3	kg
Joint Compound	55.9	kg
Mortar	3.5	m3
Nails	3.7	kg
Ontario (Standard) Brick	53.5	m2
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	1,092.8	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

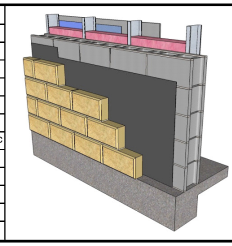
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #8 (CMU-W8)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with typical batt insulation installed between drywall studs and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		#15 organic felt (WB)
		200mm standard weight concrete block
Quick Numbers:		*(includes #15M bars @ 400mm o/c with grout)*
		39mm x 152mm 0.53mm steel studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 11.1 RSI-Value: 2.0	140mm fiberglass batt insulation
THERM 5.2:	R-Value: 12.8 RSI-Value: 2.3	6mil poly (AB, VB)
Wall Thickness:	473 mm	Regular 16mm gypsum board
Total Embodied Energy:	2,068 MJ/m^2	Latex paint
Total Embodied GWP:	150 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	96,821	1,083	97,904	844	2,894	3,738	0	0	0	0	0	0	101,643	1,996	-	-
50	96,821	1,083	97,904	844	2,894	3,738	1,047	10	1,057	76	2,534	2,610	105,309	2,068	600,000	1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	7,558	2	7,560	58	6	64	0	0	0	0	0	0	7,624	150	-	-
50	7,558	2	7,560	58	6	64	18	0	18	5	5	10	7,652	150	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	51.9	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Concrete Blocks	648.0	Blocks
Galvanized Studs	138.3	kg
Joint Compound	55.9	kg
Modified Bitumen membrane	333.3	kg
Mortar	6.4	m3
Nails	3.7	kg
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	1,092.8	kg
Screws Nuts & Bolts	2.6	kg
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

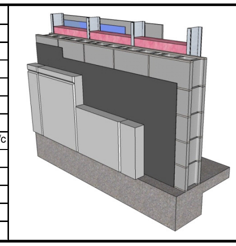
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #9 (CMU-W9)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with typical batt insulation installed between drywall studs and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		#15 organic felt (WB)
		200mm standard weight concrete block
Quick Numbers:		*(includes #15M bars @ 400mm o/c with grout)*
		39mm x 152mm 0.53mm steel studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 11.1 RSI-Value: 2.0	140mm fiberglass batt insulation
THERM 5.2:	R-Value: 12.9 RSI-Value: 2.3	6mil poly (AB, VB)
Wall Thickness:	508 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,584 MJ/m^2	Latex paint
Total Embodied GWP:	117 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	74,480	1,111	75,591	844	2,023	2,867	0	0	0	0	0	0	78,458	1,541	-	-
50	74,480	1,111	75,591	844	2,023	2,867	1,047	10	1,057	76	1,041	1,117	80,632	1,584	500,000	861

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,872	2	5,874	58	4	62	0	0	0	0	0	0	5,936	117	-	-
50	5,872	2	5,874	58	4	62	18	0	18	5	2	7	5,961	117	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	51.9	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Concrete 30 MPa (flyash avg.)	6.7	m3
Concrete Blocks	648.0	Blocks
Galvanized Studs	138.3	kg
Joint Compound	55.9	kg
Mortar	2.1	m3
Nails	3.7	kg
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	1,496.8	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

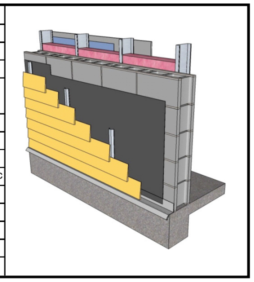
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #10 (CMU-W10)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Concrete masonry unit wall with typical batt insulation installed between drywall studs and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		#15 organic felt (WB)
		200mm standard weight concrete block
ASHRAE Standard 90.1:	R-Value: 11.1 RSI-Value: 2.0	*(includes #15M bars @ 400mm o/c with grout)*
THERM 5.2:	R-Value: 13.4 RSI-Value: 2.4	39mm x 152mm 0.53mm steel studs @ 600mm o/c
Wall Thickness:	408 mm	140mm fiberglass batt insulation
Total Embodied Energy:	1,396 MJ/m^2	6mil poly (AB, VB)
Total Embodied GWP:	81 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	66,525	538	67,063	844	1,433	2,277	0	0	0	0	0	0	69,340	1,362	-	-
50	66,525	538	67,063	844	1,433	2,277	1,047	10	1,057	75	598	673	71,070	1,396	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,047	1	4,048	58	3	61	0	0	0	0	0	0	4,109	81	-	-
50	4,047	1	4,048	58	3	61	18	0	18	5	1	6	4,133	81	30,000	52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	51.9	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Concrete Blocks	648.0	Blocks
Galvanized Sheet	106.1	kg
Galvanized Studs	138.3	kg
Joint Compound	55.9	kg
Mortar	2.1	m3
Nails	5.0	kg
Paper Tape	0.6	kg
Pine Wood Bevel Siding	160.4	m2
Rebar, Rod, Light Sections	1,092.8	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

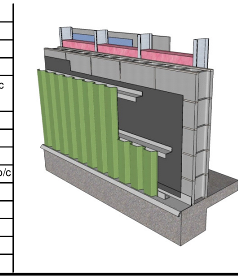
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #11 (CMU-W11)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Concrete masonry unit wall with typical batt insulation installed between drywall studs and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Quick Numbers:		#15 organic felt (WB)
		200mm standard weight concrete block
ASHRAE Standard 90.1:	R-Value: 11.1 RSI-Value: 2.0	*(includes #15M bars @ 400mm o/c with grout)*
THERM 5.2:	R-Value: 12.3 RSI-Value: 2.2	39mm x 152mm 0.53mm steel studs @ 600mm o/c
Wall Thickness:	434 mm	140mm fiberglass batt insulation
Total Embodied Energy:	3,030 MJ/m^2	6mil poly (AB, VB)
Total Embodied GWP:	190 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	149,893	490	150,383	844	1,331	2,175	0	0	0	0	0	0	152,558	2,996	-	-
50	149,893	490	150,383	844	1,331	2,175	1,047	10	1,057	75	591	666	154,280	3,030	800,000	1,377

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	9,594	1	9,595	58	3	61	0	0	0	0	0	0	9,656	190	-	-
50	9,594	1	9,595	58	3	61	18	0	18	5	1	6	9,680	190	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	51.9	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Commercial 0.46mm Steel Cladding	168.0	m2
Concrete Blocks	648.0	Blocks
Galvanized Studs	219.1	kg
Joint Compound	55.9	kg
Mortar	2.1	m3
Nails	3.7	kg
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	1,092.8	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

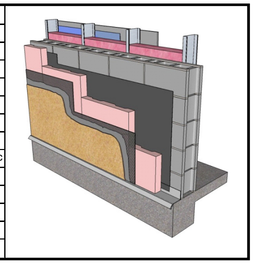
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #12 (CMU-W12)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with typical batt insulation installed between drywall studs and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		#15 organic felt (WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 21.0 RSI-Value: 3.7	39mm x 152mm 0.53mm steel studs @ 600mm o/c
THERM 5.2:	R-Value: 22.4 RSI-Value: 3.9	140mm fiberglass batt insulation
Wall Thickness:	446 mm	6mil poly (AB, VB)
Total Embodied Energy:	1,630 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	100 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	78,065	546	78,612	844	1,438	2,282	0	0	0	0	0	0	80,894	1,589	-	-
50	78,065	546	78,612	844	1,438	2,282	1,047	10	1,057	75	957	1,032	82,983	1,630	-1,500,000	-2,582

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,985	1	4,986	58	3	61	0	0	0	0	0	0	5,047	99	-	-
50	4,985	1	4,986	58	3	61	18	0	18	5	2	7	5,072	100	-70,000	-120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	271.3	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	138.3	kg
Joint Compound	55.9	kg
Mortar	2.1	m3
Nails	8.3	kg
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	1,092.8	kg
Screws Nuts & Bolts	2.6	kg
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

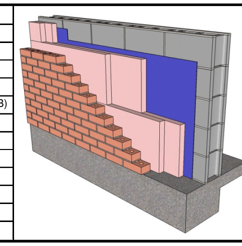
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #13 (CMU-W13)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with two layers of exterior rigid insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 21.9 RSI-Value: 3.9	Latex paint
THERM 5.2:	R-Value: 23.1 RSI-Value: 4.1	*Inside*
Wall Thickness:	405 mm	
Total Embodied Energy:	1,756 MJ/m^2	
Total Embodied GWP:	112 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	82,221	452	82,673	685	1,915	2,599	0	0	0	0	0	0	85,272	1,675	-	-
50	82,221	452	82,673	685	1,915	2,599	3,099	10	3,110	75	961	1,036	89,418	1,756	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,610	1	5,611	48	4	51	0	0	0	0	0	0	5,663	111	-	-
50	5,610	1	5,611	48	4	51	44	0	44	5	2	7	5,713	112	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Cold Rolled Sheet	10.3	kg
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	208.6	m2 (25mm)
Modified Bitumen membrane	68.2	kg
Mortar	3.5	m3
Nails	3.1	kg
Ontario (Standard) Brick	53.5	m2
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

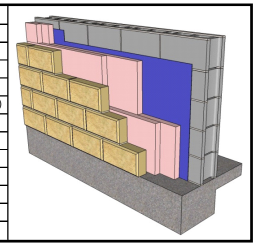
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Masonry Unit Wall #14 (CMU-W14)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with two layers of exterior rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 21.9 RSI-Value: 3.9	Latex paint
THERM 5.2:	R-Value: 23.1 RSI-Value: 4.1	***Inside***
Wall Thickness:	405 mm	
Total Embodied Energy:	2,187 MJ/m²	
Total Embodied GWP:	151 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	101,249	1,016	102,264	685	2,725	3,409	0	0	0	0	0	0	105,674	2,075	-	-
50	101,249	1,016	102,264	685	2,725	3,409	3,099	10	3,110	76	2,487	2,563	111,346	2,187	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	7,596	2	7,598	48	5	53	0	0	0	0	0	0	7,651	150	-	-
50	7,596	2	7,598	48	5	53	44	0	44	5	5	10	7,704	151	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Cold Rolled Sheet	10.3	kg
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	208.6	m2 (25mm)
Modified Bitumen membrane	401.5	kg
Mortar	6.4	m3
Nails	3.1	kg
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

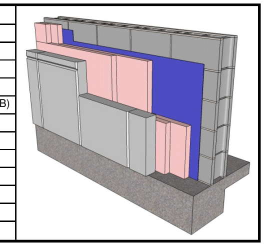
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Masonry Unit Wall #15 (CMU-W15)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with two layers of exterior rigid insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 21.9 RSI-Value: 3.9	Latex paint
THERM 5.2:	R-Value: 23.1 RSI-Value: 4.1	***Inside***
Wall Thickness:	440 mm	
Total Embodied Energy:	1,702 MJ/m²	
Total Embodied GWP:	118 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	78,908	1,043	79,951	685	1,854	2,538	0	0	0	0	0	0	82,489	1,620	-	-
50	78,908	1,043	79,951	685	1,854	2,538	3,099	10	3,110	76	994	1,070	86,669	1,702	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,910	2	5,912	48	4	51	0	0	0	0	0	0	5,964	117	-	-
50	5,910	2	5,912	48	4	51	44	0	44	5	2	7	6,014	118	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Concrete 30 MPa (flyash avg.)	6.7	m3
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	208.6	m2 (25mm)
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	3.1	kg
Rebar, Rod, Light Sections	1,496.8	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

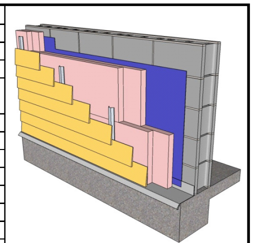
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Masonry Unit Wall #16 (CMU-W16)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Concrete masonry unit wall with two layers of exterior rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		200mm standard weight concrete block
ASHRAE Standard 90.1:	R-Value: 21.9 RSI-Value: 3.9	*(includes #15M bars @ 400mm o/c with grout)*
THERM 5.2:	R-Value: 23.7 RSI-Value: 4.2	Latex paint
Wall Thickness:	340 mm	***Inside***
Total Embodied Energy:	1,514 MJ/m²	
Total Embodied GWP:	82 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	70,953	470	71,423	685	1,264	1,948	0	0	0	0	0	0	73,371	1,441	-	-
50	70,953	470	71,423	685	1,264	1,948	3,099	10	3,110	75	551	626	77,107	1,514	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,085	1	4,086	48	2	50	0	0	0	0	0	0	4,136	81	-	-
50	4,085	1	4,086	48	2	50	44	0	44	5	1	6	4,186	82	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	106.1	kg
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	4.5	kg
Pine Wood Bevel Siding	160.4	m2
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

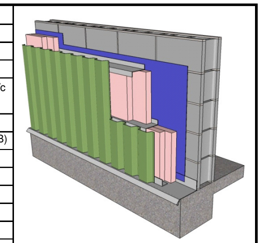
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Masonry Unit Wall #17 (CMU-W17)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Concrete masonry unit wall with two layers of exterior rigid insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 100mm Z-girts @ 600mm o/c (self-weight: 1.5 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		200mm standard weight concrete block
ASHRAE Standard 90.1:	R-Value: 10.9 RSI-Value: 1.9	*(includes #15M bars @ 400mm o/c with grout)*
THERM 5.2:	R-Value: 12.1 RSI-Value: 2.1	Latex paint
Wall Thickness:	328 mm	***Inside***
Total Embodied Energy:	3,172 MJ/m²	
Total Embodied GWP:	193 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	155,526	424	155,950	685	1,167	1,852	0	0	0	0	0	0	157,802	3,099	-	-
50	155,526	424	155,950	685	1,167	1,852	3,099	10	3,110	75	545	620	161,532	3,172	800,000	1,377

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	9,731	1	9,731	48	2	50	0	0	0	0	0	0	9,781	192	-	-
50	9,731	1	9,731	48	2	50	44	0	44	5	1	6	9,831	193	60,000	103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	131.3	kg
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	3.1	kg
Rebar, Rod, Light Sections	1,092.8	kg
Screws Nuts & Bolts	1.3	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

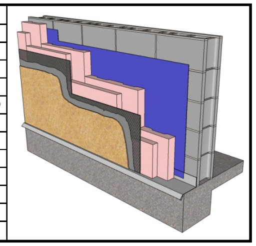
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Masonry Unit Wall #18 (CMU-W18)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete masonry unit wall with two layers of exterior rigid insulation and EFIS cladding	EFIS coating over metal mesh
		100mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 21.9 RSI-Value: 3.9	Latex paint
THERM 5.2:	R-Value: 22.7 RSI-Value: 4.0	*Inside*
Wall Thickness:	328 mm	
Total Embodied Energy:	1,597 MJ/m^2	
Total Embodied GWP:	93 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	74,820	478	75,298	685	1,256	1,941	0	0	0	0	0	0	77,239	1,517	-	-
50	74,820	478	75,298	685	1,256	1,941	3,099	10	3,110	75	900	975	81,323	1,597	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,631	1	4,632	48	2	50	0	0	0	0	0	0	4,682	92	-	-
50	4,631	1	4,632	48	2	50	44	0	44	5	2	7	4,732	93	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
Concrete Blocks	648.0	Blocks
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	51.4	kg
Modified Bitumen membrane	68.2	kg
Mortar	2.1	m3
Nails	4.6	kg
Rebar, Rod, Light Sections	1,092.8	kg
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

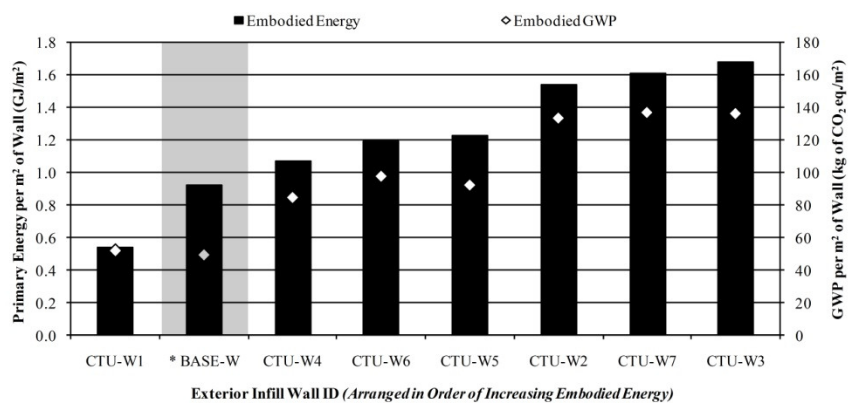
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Concrete Tilt-Up Walls

This section contains a detailed description of each concrete tilt-up (CTU) exterior infill wall that was examined in this study (7 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

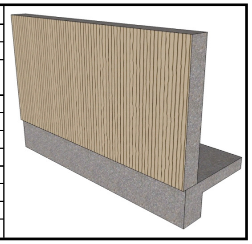
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various walls in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Concrete Tilt-Up Wall #1 (CTU-W1)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete tilt-up wall with no insulation	Alkyd based paint
		150mm concrete tilt-up wall (30MPa, 9% flyash) (AB, VR, WB)
		(includes 8m of #15M per m² and steel angles)
Quick Numbers:		Alkyd based paint
		Inside
ASHRAE Standard 90.1:	R-Value: 1.2 RSI-Value: 0.2	
THERM 5.2:	R-Value: 1.3 RSI-Value: 0.2	
Wall Thickness:	150 mm	
Total Embodied Energy:	542 MJ/m²	
Total Embodied GWP:	52 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)															Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²			
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	26,093	924	27,017	0	0	0	0	0	0	0	0	0	27,017	531	-	-
50	26,093	924	27,017	0	0	0	0	0	0	1	582	583	27,601	542	2.58E+07	44,406

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	2,636	2	2,638	0	0	0	0	0	0	0	0	0	2,638	52	-	-
50	2,636	2	2,638	0	0	0	0	0	0	0	1	1	2,639	52	1,420,000	2,444

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 30 MPa (flyash av)	8.0	m3
Rebar, Rod, Light Sections	347.6	kg
Solvent Based Alkyd Paint	116.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

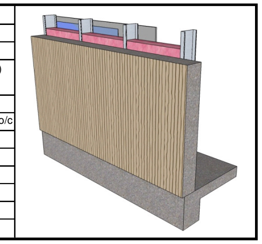
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Tilt-Up Wall #2 (CTU-W2)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete tilt-up wall with typical batt insulation installed between drywall studs and gypsum board interior finish	Alkyd based paint
		150mm concrete tilt-up wall (30MPa, 9% flyash) (WB)
		(includes 8m of #15M per m² and steel angles)
Quick Numbers:		39mm x 152mm 0.53mm steel studs @ 600mm o/c
		140mm fiberglass batt insulation
ASHRAE Standard 90.1:	R-Value: 10.5 RSI-Value: 1.9	6mil poly (AB, VB)
THERM 5.2:	R-Value: 10.7 RSI-Value: 1.9	Regular 16mm gypsum board
Wall Thickness:	318 mm	
Total Embodied Energy:	1,543 MJ/m²	
Total Embodied GWP:	133 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)															Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²			
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	73,841	1,973	75,814	160	1,288	1,448	0	0	0	0	0	0	77,262	1,517	-	-
50	73,841	1,973	75,814	160	1,288	1,448	0	0	0	2	1,301	1,303	78,565	1,543	1,600,000	2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	6,758	4	6,761	10	2	13	0	0	0	0	0	0	6,774	133	-	-
50	6,758	4	6,761	10	2	13	0	0	0	0	3	3	6,777	133	90,000	155

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Concrete 30 MPa (flyash av)	8.0	m3
Galvanized Studs	138.3	kg
Joint Compound	55.9	kg
Nails	3.7	kg
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	347.6	kg
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	58.3	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

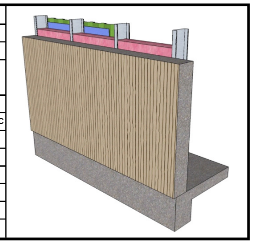
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Tilt-Up Wall #3 (CTU-W3)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Concrete tilt-up wall with typical batt insulation installed between drywall studs and steel cladding interior finish	Alkyd based paint
		150mm concrete tilt-up wall (30MPa, 9% flyash) (WB)
		(includes 8m of #15M per m² and steel angles)
Quick Numbers:		39mm x 152mm 0.53mm steel studs @ 600mm o/c
		140mm fiberglass batt insulation
ASHRAE Standard 90.1:	R-Value: 10.1 RSI-Value: 1.8	6mil poly (AB, VB)
THERM 5.2:	R-Value: 10.3 RSI-Value: 1.8	0.46mm galvanized commercial steel cladding
Wall Thickness:	340 mm	
Total Embodied Energy:	1,677 MJ/m²	
Total Embodied GWP:	136 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total EE	⁴ Total EE per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	80,800	1,906	82,705	160	1,147	1,307	0	0	0	0	0	0	84,012	1,650	-	-
50	80,800	1,906	82,705	160	1,147	1,307	161	1	162	2	1,207	1,209	85,384	1,677	1,800,000	3,098

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total GWP	⁴ Total GWP per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	6,896	4	6,900	10	2	13	0	0	0	0	0	0	6,913	136	-	-
50	6,896	4	6,900	10	2	13	3	0	3	0	2	2	6,918	136	100,000	172

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Concrete 30 MPa (flyash av)	8.0	m3
Galvanized Sheet	262.6	kg
Galvanized Studs	138.3	kg
Nails	3.1	kg
Rebar, Rod, Light Sections	347.6	kg
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	58.3	L
Water Based Latex Paint	6.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

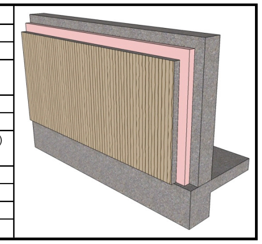
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Tilt-Up Wall #4 (CTU-W4)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Tilt-up insulated concrete sandwich panel wall with 50mm insulation	Alkyd based paint
		50mm concrete front wythe (30MPa, 9% flyash) (WB)
		(includes 8m of #15M per m²)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		150mm concrete back wythe (30MPa, 9% flyash) (AB, VR)
ASHRAE Standard 90.1:	R-Value: 11.2 RSI-Value: 2.0	
THERM 5.2:	R-Value: 11.2 RSI-Value: 2.0	*(includes 8m of #15M per m² and steel angles)*
Wall Thickness:	250 mm	
Total Embodied Energy:	1,074 MJ/m²	
Total Embodied GWP:	84 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total EE	⁴ Total EE per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	52,188	1,315	53,503	0	390	390	0	0	0	0	0	0	53,892	1,058	-	-
50	52,188	1,315	53,503	0	390	390	0	0	0	2	800	801	54,694	1,074	1,000,000	1,721

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total GWP	⁴ Total GWP per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	4,294	3	4,296	0	1	1	0	0	0	0	0	0	4,297	84	-	-
50	4,294	3	4,296	0	1	1	0	0	0	0	2	2	4,299	84	80,000	138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 30 MPa (flyash av)	10.7	m3
Extruded Polystyrene	104.3	m2 (25mm)
Nails	3.1	kg
Rebar, Rod, Light Sections	994.0	kg
Solvent Based Alkyd Paint	116.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

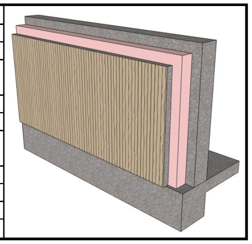
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Tilt-Up Wall #5 (CTU-W5)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Tilt-up insulated concrete sandwich panel wall with 100mm insulation	Alkyd based paint
		50mm concrete front wythe (30MPa, 9% flyash) (WB)
		(includes 8m of #15M per m²)
Quick Numbers:		100mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 21.0 RSI-Value: 3.7	150mm concrete back wythe (30MPa, 9% flyash) (AB, VR)
THERM 5.2:	R-Value: 21.0 RSI-Value: 3.7	*(includes 8m of #15M per m² and steel angles)*
Wall Thickness:	300 mm	
Total Embodied Energy:	1,223 MJ/m²	
Total Embodied GWP:	92 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	59,771	1,315	61,086	0	390	390	0	0	0	0	0	0	61,476	1,207	-	-
50	59,771	1,315	61,086	0	390	390	0	0	0	2	810	811	62,287	1,223	-1,100,000	-1,893

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,682	3	4,684	0	1	1	0	0	0	0	0	0	4,685	92	-	-
50	4,682	3	4,684	0	1	1	0	0	0	0	2	2	4,686	92	-40,000	-69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 30 MPa (flyash av)	10.7	m3
Extruded Polystyrene	208.6	m2 (25mm)
Nails	3.1	kg
Rebar, Rod, Light Sections	994.0	kg
Solvent Based Alkyd Paint	116.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

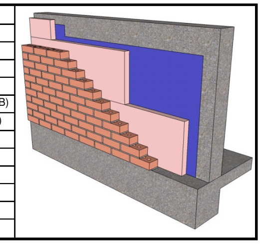
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Tilt-Up Wall #6 (CTU-W6)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Concrete tilt-up wall with 50mm insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		150mm concrete tilt-up wall (30MPa, 9% flyash)
		(includes 8m of #15M per m² and steel angles)
ASHRAE Standard 90.1:	R-Value: 11.1 RSI-Value: 2.0	Alkyd based paint
THERM 5.2:	R-Value: 12.3 RSI-Value: 2.2	***Inside***
Wall Thickness:	315 mm	
Total Embodied Energy:	1,195 MJ/m²	
Total Embodied GWP:	97 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	55,622	1,084	56,706	0	7	7	0	0	0	0	0	0	56,713	1,114	-	-
50	55,622	1,084	56,706	0	7	7	3,099	10	3,110	1	1,040	1,042	60,864	1,195	600,000	1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,914	2	4,916	0	0	0	0	0	0	0	0	0	4,916	97	-	-
50	4,914	2	4,916	0	0	0	44	0	44	0	2	2	4,962	97	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Cold Rolled Sheet	10.3	kg
Concrete 30 MPa (flyash av)	8.0	m3
Extruded Polystyrene	104.3	m2 (25mm)
Modified Bitumen membrane	68.2	kg
Mortar	1.5	m3
Nails	3.1	kg
Ontario (Standard) Brick	53.5	m2
Rebar, Rod, Light Sections	347.6	kg
Solvent Based Alkyd Paint	77.9	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

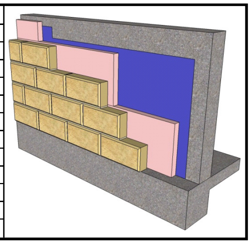
[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Tilt-Up Wall #7 (CTU-W7)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**	
		Outside	
Brief Description:	Concrete tilt-up wall with 50mm insulation and split-faced concrete block cladding	Split-faced concrete block cladding	
		25mm air gap	
		50mm extruded polystyrene rigid insulation	
		Self-adhesive membrane with primer (AB, VB, WB)	
Quick Numbers:		150mm concrete tilt-up wall (30MPa, 9% flyash)	
		(includes 8m of #15M per m^2 and steel angles)	
ASHRAE Standard 90.1:	R-Value: 11.1 RSI-Value: 2.0	Alkyd based paint	
THERM 5.2:	R-Value: 12.2 RSI-Value: 2.1	***Inside***	
Wall Thickness:	315 mm		
Total Embodied Energy:	1,610 MJ/m^2		
Total Embodied GWP:	137 kg of CO_2 eq./m^2		

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	74,650	1,647	76,297	0	7	7	0	0	0	0	0	0	76,304	1,499	-	-
50	74,650	1,647	76,297	0	7	7	3,099	10	3,110	2	2,566	2,568	81,981	1,610	600,000	1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	6,900	3	6,903	0	0	0	0	0	0	0	0	0	6,903	136	-	-
50	6,900	3	6,903	0	0	0	44	0	44	0	5	5	6,952	137	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
Cold Rolled Sheet	10.3	kg
Concrete 30 MPa (flyash av)	8.0	m3
Extruded Polystyrene	104.3	m2 (25mm)
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	3.1	kg
Rebar, Rod, Light Sections	347.6	kg
Solvent Based Alkyd Paint	77.9	L
Split-faced Concrete Block	1,238.2	Blocks

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

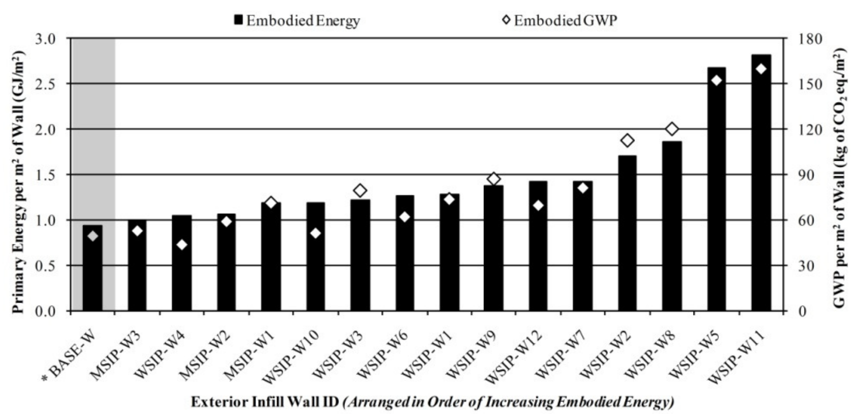
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Wood Structural Insulated Panel Walls

This section contains a detailed description of each wood structural insulated panel (WSIP) exterior infill wall that was examined in this study (12 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

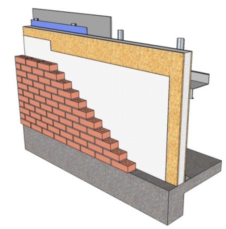
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various WSIP walls in this section and the metal structural insulated panel (MSIP) exterior infill walls from the next section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Wood Structural Insulated Panel Wall #1 (WSIP-W1)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	124mm (5in) wood SIP wall with standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		Building wrap (WB)
		12mm OSB
Quick Numbers:		100mm extruded polystyrene insulation
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	6mil poly (AB, VB)
THERM 5.2:	R-Value: 24.6 RSI-Value: 4.3	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Wall Thickness:	280 mm (excluding Z-girt)	
Total Embodied Energy:	1,278 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	73 kg of CO_2 eq./m²	Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	62,680	502	63,182	160	1,203	1,363	0	0	0	0	0	0	64,545	1,268	-	-
50	62,680	502	63,182	160	1,203	1,363	0	0	0	1	535	536	65,081	1,278	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	3,727	1	3,728	10	2	13	0	0	0	0	0	0	3,740	73	-	-
50	3,727	1	3,728	10	2	13	0	0	0	0	1	1	3,742	73	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Mortar	1.5	m3
Nails	3.7	kg
Ontario (Standard) Brick	53.5	m2
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

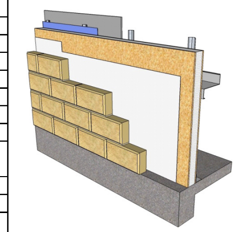
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Wall #2 (WSIP-W2)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	124mm (5in) wood SIP wall with split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		Building wrap (WB)
		12mm OSB
Quick Numbers:		100mm extruded polystyrene insulation
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	6mil poly (AB, VB)
THERM 5.2:	R-Value: 24.5 RSI-Value: 4.3	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Wall Thickness:	280 mm (excluding Z-girt)	
Total Embodied Energy:	1,709 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	113 kg of CO_2 eq./m²	Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	81,708	1,065	82,773	160	2,013	2,173	0	0	0	0	0	0	84,946	1,668	-	-
50	81,708	1,065	82,773	160	2,013	2,173	0	0	0	1	2,061	2,062	87,008	1,709	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,713	2	5,715	10	4	14	0	0	0	0	0	0	5,729	113	-	-
50	5,713	2	5,715	10	4	14	0	0	0	0	4	4	5,733	113	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Modified Bitumen membrane	333.3	kg
Mortar	4.3	m3
Nails	3.7	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	2.6	kg
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

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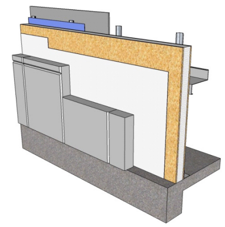
Wood Structural Insulated Panel Wall #3 (WSIP-W3)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	124mm (5in) wood SIP wall with concrete pre-cast cladding	125mm concrete pre-cast cladding
		25mm air gap
		Building wrap (WB)
		12mm OSB
Quick Numbers:		100mm extruded polystyrene insulation
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	6mil poly (AB, VB)
THERM 5.2:	R-Value: 24.5 RSI-Value: 4.3	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Wall Thickness:	315 mm (excluding Z-girt)	
Total Embodied Energy:	1,224 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	79 kg of CO_2 eq./m^2	Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	59,367	1,093	60,460	160	1,142	1,302	0	0	0	0	0	0	61,762	1,213	-	-
50	59,367	1,093	60,460	160	1,142	1,302	0	0	0	2	568	570	62,332	1,224	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,027	2	4,029	10	2	13	0	0	0	0	0	0	4,042	79	-	-
50	4,027	2	4,029	10	2	13	0	0	0	0	1	1	4,043	79	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Concrete 30 MPa (flyash av)	6.7	m3
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Nails	3.7	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	404.0	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

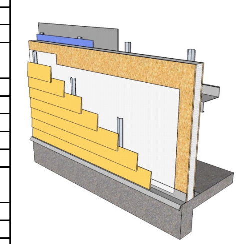
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Structural Insulated Panel Wall #4 (WSIP-W4)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	124mm (5in) wood SIP wall with pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		Building wrap (WB)
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	100mm extruded polystyrene insulation
THERM 5.2:	R-Value: 25.1 RSI-Value: 4.4	12mm OSB
Wall Thickness:	215 mm (excluding Z-girt)	6mil poly (AB, VB)
Total Embodied Energy:	1,037 MJ/m^2	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Total Embodied GWP:	44 kg of CO_2 eq./m^2	
		Regular 16mm gypsum board
		Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	51,431	520	51,951	160	552	712	0	0	0	0	0	0	52,663	1,034	-	-
50	51,431	520	51,951	160	552	712	0	0	0	1	125	126	52,789	1,037	-1,400,000	-2,410

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,202	1	2,203	10	1	11	0	0	0	0	0	0	2,215	43	-	-
50	2,202	1	2,203	10	1	11	0	0	0	0	0	0	2,215	44	-70,000	-120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	136.4	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Nails	5.0	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

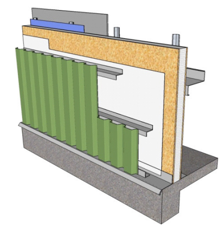
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Structural Insulated Panel Wall #5 (WSIP-W5)

Building Component Description:

Category:	Exterior Walls
Brief Description:	124mm (5in) wood SIP wall with commercial steel cladding
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A
THERM 5.2:	R-Value: 24.1 RSI-Value: 4.2
Wall Thickness:	241 mm (excluding Z-girt)
Total Embodied Energy:	2,670 MJ/m²
Total Embodied GWP:	152 kg of CO_2 eq./m²

Assembly Layers
Outside
Latex paint
0.46mm galvanized commercial steel cladding
1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Building wrap (WB)
12mm OSB
100mm extruded polystyrene insulation
12mm OSB
6mil poly (AB, VB)
0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Regular 16mm gypsum board
Latex paint
1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	134,780	471	135,251	160	450	610	0	0	0	0	0	0	135,861	2,668	-	-
50	134,780	471	135,251	160	450	610	0	0	0	1	117	118	135,979	2,670	-1,200,000	-2,065

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	7,749	1	7,750	10	1	11	0	0	0	0	0	0	7,761	152	-	-
50	7,749	1	7,750	10	1	11	0	0	0	0	0	0	7,761	152	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	368.7	kg
Joint Compound	55.9	kg
Nails	3.7	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	132.5	L

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

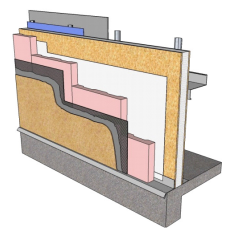
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Wall #6 (WSIP-W6)

Building Component Description:

Category:	Exterior Walls
Brief Description:	124mm (5in) wood SIP wall with EFIS cladding
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A
THERM 5.2:	R-Value: 34.0 RSI-Value: 6.0
Wall Thickness:	253 mm (excluding Z-girt)
Total Embodied Energy:	1,270 MJ/m²
Total Embodied GWP:	62 kg of CO_2 eq./m²

Assembly Layers
Outside
EFIS coating over metal mesh
50mm extruded polystyrene rigid insulation
Vertical drainage channels in insulation
Building wrap (WB)
12mm OSB
100mm extruded polystyrene insulation
12mm OSB
6mil poly (AB, VB)
0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Regular 16mm gypsum board
Latex paint
1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	62,953	528	63,480	160	557	717	0	0	0	0	0	0	64,197	1,261	-	-
50	62,953	528	63,480	160	557	717	0	0	0	1	484	485	64,682	1,270	-2,100,000	-3,614

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	3,140	1	3,141	10	1	11	0	0	0	0	0	0	3,152	62	-	-
50	3,140	1	3,141	10	1	11	0	0	0	0	1	1	3,153	62	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Extruded Polystyrene	313.0	m2 (25mm)
Galvanized Sheet	81.4	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Nails	8.3	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	2.6	kg
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

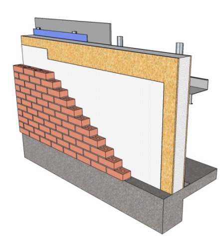
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Wall #7 (WSIP-W7)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	174mm (7in) wood SIP wall with standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		Building wrap (WB)
		12mm OSB
Quick Numbers:		150mm extruded polystyrene insulation
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	6mil poly (AB, VB)
THERM 5.2:	R-Value: 34.4 RSI-Value: 6.1	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Wall Thickness:	330 mm (excluding Z-girt)	
Total Embodied Energy:	1,427 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	81 kg of CO_2 eq./m^2	Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	70,263	502	70,765	160	1,215	1,375	0	0	0	0	0	0	72,140	1,417	-	-
50	70,263	502	70,765	160	1,215	1,375	0	0	0	1	545	546	72,686	1,427	-2,200,000	-3,787

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	4,114	1	4,115	10	2	13	0	0	0	0	0	0	4,128	81	-	-
50	4,114	1	4,115	10	2	13	0	0	0	0	1	1	4,129	81	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	313.0	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Mortar	1.5	m3
Nails	3.7	kg
Ontario (Standard) Brick	53.5	m2
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	66.3	L

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

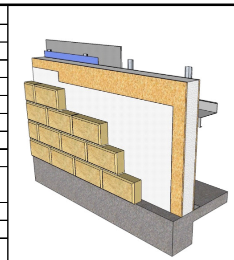
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Structural Insulated Panel Wall #8 (WSIP-W8)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	174mm (7in) wood SIP wall with split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		Building wrap (WB)
		12mm OSB
Quick Numbers:		150mm extruded polystyrene insulation
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	6mil poly (AB, VB)
THERM 5.2:	R-Value: 34.0 RSI-Value: 6.0	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Wall Thickness:	330 mm (excluding Z-girt)	
Total Embodied Energy:	1,858 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	120 kg of CO_2 eq./m^2	Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	89,291	1,065	90,356	160	2,025	2,185	0	0	0	0	0	0	92,542	1,817	-	-
50	89,291	1,065	90,356	160	2,025	2,185	0	0	0	1	2,071	2,072	94,614	1,858	-2,200,000	-3,787

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	6,100	2	6,102	10	4	14	0	0	0	0	0	0	6,117	120	-	-
50	6,100	2	6,102	10	4	14	0	0	0	0	4	4	6,121	120	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	313.0	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Modified Bitumen membrane	333.3	kg
Mortar	4.3	m3
Nails	3.7	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	2.6	kg
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

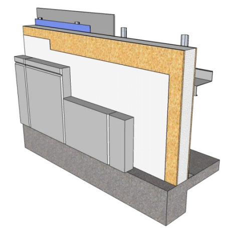
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Structural Insulated Panel Wall #9 (WSIP-W9)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	174mm (7in) wood SIP wall with concrete pre-cast cladding	125mm concrete pre-cast cladding
		25mm air gap
		Building wrap (WB)
		12mm OSB
Quick Numbers:		150mm extruded polystyrene insulation
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	6mil poly (AB, VB)
THERM 5.2:	R-Value: 34.2 RSI-Value: 6.0	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Wall Thickness:	365 mm (excluding Z-girt)	
Total Embodied Energy:	1,373 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	87 kg of CO_2 eq./m²	Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	66,950	1,093	68,043	160	1,154	1,314	0	0	0	0	0	0	69,357	1,362	-	-
50	66,950	1,093	68,043	160	1,154	1,314	0	0	0	2	578	580	69,937	1,373	-2,200,000	-3,787

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	4,414	2	4,417	10	2	13	0	0	0	0	0	0	4,429	87	-	-
50	4,414	2	4,417	10	2	13	0	0	0	0	1	1	4,430	87	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Concrete 30 MPa (flyash av)	6.7	m3
Extruded Polystyrene	313.0	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Nails	3.7	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Rebar, Rod, Light Sections	404.0	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

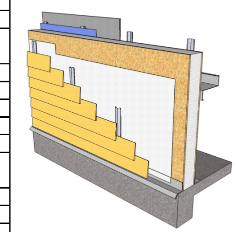
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Wall #10 (WSIP-W10)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	174mm (7in) wood SIP wall with pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		Building wrap (WB)
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	150mm extruded polystyrene insulation
THERM 5.2:	R-Value: 34.8 RSI-Value: 6.1	12mm OSB
Wall Thickness:	268 mm (excluding Z-girt)	6mil poly (AB, VB)
Total Embodied Energy:	1,186 MJ/m²	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Total Embodied GWP:	51 kg of CO_2 eq./m²	
		Regular 16mm gypsum board
		Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	59,015	520	59,535	160	564	724	0	0	0	0	0	0	60,259	1,183	-	-
50	59,015	520	59,535	160	564	724	0	0	0	1	134	135	60,394	1,186	-2,200,000	-3,787

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	2,590	1	2,591	10	1	11	0	0	0	0	0	0	2,603	51	-	-
50	2,590	1	2,591	10	1	11	0	0	0	0	0	0	2,603	51	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Extruded Polystyrene	313.0	m2 (25mm)
Galvanized Sheet	136.4	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Nails	5.0	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

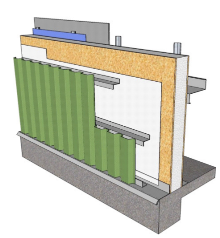
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Wall #11 (WSIP-W11)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	174mm (7in) wood SIP wall with commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Quick Numbers:		Building wrap (WB)
		12mm OSB
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	150mm extruded polystyrene insulation
THERM 5.2:	R-Value: 33.8 RSI-Value: 6.0	12mm OSB
Wall Thickness:	291 mm (excluding Z-girt)	6mil poly (AB, VB)
Total Embodied Energy:	2,820 MJ/m^2	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Total Embodied GWP:	160 kg of CO_2 eq./m^2	
		Regular 16mm gypsum board
		Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	142,363	472	142,835	160	462	622	0	0	0	0	0	0	143,457	2,817	-	-
50	142,363	472	142,835	160	462	622	0	0	0	1	127	128	143,585	2,820	-2,100,000	-3,614

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	8,137	1	8,138	10	1	11	0	0	0	0	0	0	8,149	160	-	-
50	8,137	1	8,138	10	1	11	0	0	0	0	0	0	8,149	160	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	313.0	m2 (25mm)
Galvanized Sheet	30.0	kg
Galvanized Studs	368.7	kg
Joint Compound	55.9	kg
Nails	3.7	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

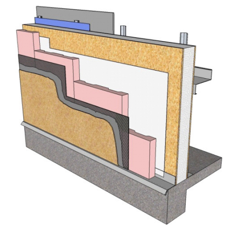
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Structural Insulated Panel Wall #12 (WSIP-W12)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	174mm (7in) wood SIP wall with EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Building wrap (WB)
Quick Numbers:		12mm OSB
		150mm extruded polystyrene insulation
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	12mm OSB
THERM 5.2:	R-Value: 43.7 RSI-Value: 7.7	6mil poly (AB, VB)
Wall Thickness:	303 mm (excluding Z-girt)	0.53mm galvanized steel furring channels @ 600mm o/c (self-weight: 0.35 kg/m)
Total Embodied Energy:	1,420 MJ/m^2	
Total Embodied GWP:	70 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	70,536	528	71,064	160	569	729	0	0	0	0	0	0	71,793	1,410	-	-
50	70,536	528	71,064	160	569	729	0	0	0	1	494	494	72,287	1,420	-2,500,000	-4,303

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,527	1	3,528	10	1	12	0	0	0	0	0	0	3,540	70	-	-
50	3,527	1	3,528	10	1	12	0	0	0	0	1	1	3,541	70	-130,000	-224

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Extruded Polystyrene	417.3	m2 (25mm)
Galvanized Sheet	81.4	kg
Galvanized Studs	287.9	kg
Joint Compound	55.9	kg
Nails	8.3	kg
Oriented Strand Board	145.8	m2 (9mm)
Paper Tape	0.6	kg
Screws Nuts & Bolts	2.6	kg
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

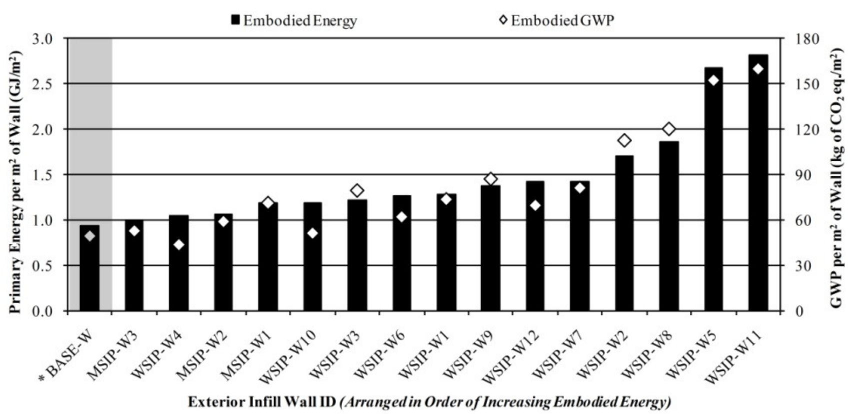
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Metal Structural Insulated Panel Walls

This section contains a detailed description of each metal structural insulated panel (MSIP) exterior infill wall that was examined in this study (3 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various walls in this section as well as the WSIP walls from the previous section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.

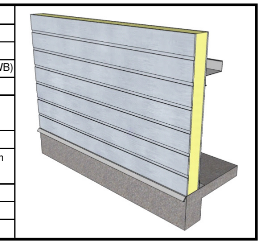


Metal Structural Insulated Panel Wall #1 (MSIP-W1)

Building Component Description:

Category:	Exterior Walls	
Brief Description:	150mm (6in) metal SIP wall with standard clay brick cladding	
Quick Numbers:		
ASHRAE Standard 90.1:	R-Value: N/A	RSI-Value: N/A
THERM 5.2:	R-Value: 36.4	RSI-Value: 6.4
Wall Thickness:	150	mm (excluding Z-girt)
Total Embodied Energy:	1,180	MJ/m^2
Total Embodied GWP:	71	kg of CO_2 eq./m^2

Assembly Layers
Outside
Latex paint
0.46mm galvanized commercial steel cladding (WB)
150mm polyurethane foam insulation
0.46mm galvanized commercial steel cladding (AB, VB)
Latex paint
1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	59,330	70	59,401	160	155	315	0	0	0	0	0	0	59,716	1,173	-	-
50	59,330	70	59,401	160	155	315	321	3	324	0	53	53	60,094	1,180	-2,000,000	-3,442

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,601	0	3,601	10	0	11	0	0	0	0	0	0	3,612	71	-	-
50	3,601	0	3,601	10	0	11	6	0	6	0	0	0	3,618	71	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Foam Polyisocyanurate	313.8	m2 (25mm)
Galvanized Sheet	529.2	kg
Galvanized Studs	287.9	kg
Nails	3.1	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	13.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

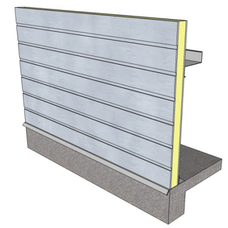
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Metal Structural Insulated Panel Wall #2 (MSIP-W2)

Building Component Description:

Category:	Exterior Walls		Assembly Layers
Brief Description:	100mm (4in) metal SIP wall with standard clay brick cladding		*Outside*
			Latex paint
			0.46mm galvanized commercial steel cladding (WB)
			100mm polyurethane foam insulation
			0.46mm galvanized commercial steel cladding (AB, VB)
Quick Numbers:			Latex paint
ASHRAE Standard 90.1:	R-Value: N/A	RSI-Value: N/A	1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
THERM 5.2:	R-Value: 24.5	RSI-Value: 4.3	
Wall Thickness:	100	mm (excluding Z-girt)	*Inside*
Total Embodied Energy:	1,059	MJ/m^2	
Total Embodied GWP:	59	kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	53,208	67	53,275	160	135	295	0	0	0	0	0	0	53,569	1,052	-	-
50	53,208	67	53,275	160	135	295	321	3	324	0	46	46	53,940	1,059	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,977	0	2,977	10	0	11	0	0	0	0	0	0	2,987	59	-	-
50	2,977	0	2,977	10	0	11	6	0	6	0	0	0	2,994	59	-70,000	-120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Foam Polyisocyanurate	209.2	m2 (25mm)
Galvanized Sheet	529.2	kg
Galvanized Studs	287.9	kg
Nails	3.1	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	13.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

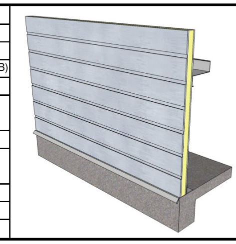
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Metal Structural Insulated Panel Wall #3 (MSIP-W3)

Building Component Description:

Category:	Exterior Walls		Assembly Layers
Brief Description:	75mm (3in) metal SIP wall with standard clay brick cladding		*Outside*
			Latex paint
			0.46mm galvanized commercial steel cladding (WB)
			75mm polyurethane foam insulation
			0.46mm galvanized commercial steel cladding (AB, VB)
Quick Numbers:			Latex paint
ASHRAE Standard 90.1:	R-Value: N/A	RSI-Value: N/A	1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
THERM 5.2:	R-Value: 18.6	RSI-Value: 3.3	
Wall Thickness:	75	mm (excluding Z-girt)	*Inside*
Total Embodied Energy:	999	MJ/m^2	
Total Embodied GWP:	53	kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	50,147	65	50,212	160	124	284	0	0	0	0	0	0	50,496	992	-	-
50	50,147	65	50,212	160	124	284	321	3	324	0	42	43	50,863	999	-600,000	-1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,664	0	2,664	10	0	11	0	0	0	0	0	0	2,675	53	-	-
50	2,664	0	2,664	10	0	11	6	0	6	0	0	0	2,682	53	-30,000	-52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Foam Polyisocyanurate	156.9	m2 (25mm)
Galvanized Sheet	529.2	kg
Galvanized Studs	287.9	kg
Nails	3.1	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	13.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

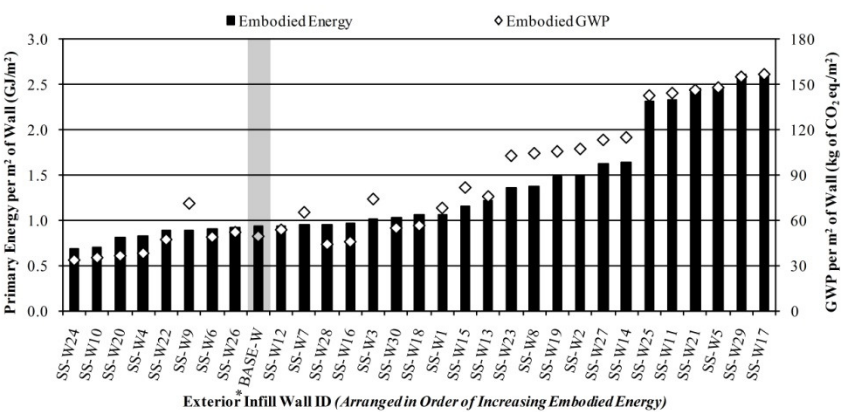
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Cold-Formed Steel Stud Walls

This section contains a detailed description of each cold-formed steel stud (SS) exterior infill wall that was examined in this study (31 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

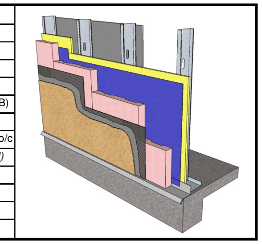
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various walls in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Baseline Retail Building Wall (BASE-W)

Building Component Description:

Category:	Exterior Walls		**Assembly Layers**
			Outside
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical exterior rigid insulation and EFIS cladding		EFIS coating over metal mesh
			64mm extruded polystyrene rigid insulation
			Vertical drainage channels in insulation
			Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:			16mm non paper-faced gypsum sheathing
			39mm x 152mm 1.52mm steel studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 15.6	RSI-Value: 2.8	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 16.5	RSI-Value: 2.9	*(also includes top and bottom steel tracks)*
Wall Thickness:	272	mm	Regular 16mm gypsum board
Total Embodied Energy:	927	MJ/m^2	Latex paint
Total Embodied GWP:	49	kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	42,405	299	42,704	160	715	875	0	0	0	0	0	0	43,579	856	-	-
50	42,405	299	42,704	160	715	875	3,099	10	3,110	0	520	520	47,208	927	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,450	1	2,451	10	1	12	0	0	0	0	0	0	2,462	48	-	-
50	2,450	1	2,451	10	1	12	44	0	44	0	1	1	2,507	49	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	133.5	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.7	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

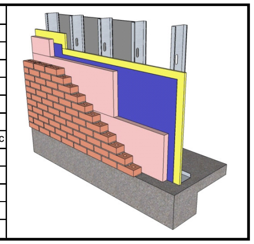
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #1 (SS-W1)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical exterior rigid insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 12.7 RSI-Value: 2.2	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 14.2 RSI-Value: 2.5	*(also includes top and bottom steel tracks)*
Wall Thickness:	349 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,065 MJ/m^2	Latex paint
Total Embodied GWP:	68 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	48,729	275	49,004	160	1,375	1,535	0	0	0	0	0	0	50,539	993	-	-
50	48,729	275	49,004	160	1,375	1,535	3,099	10	3,110	0	580	580	54,228	1,065	300,000	516

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,405	1	3,405	10	3	13	0	0	0	0	0	0	3,418	67	-	-
50	3,405	1	3,405	10	3	13	44	0	44	0	1	1	3,463	68	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Mortar	1.5	m3
Nails	4.2	kg
Ontario (Standard) Brick	53.5	m2
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

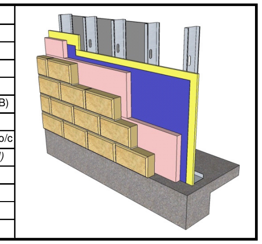
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #2 (SS-W2)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical exterior rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 12.7 RSI-Value: 2.2	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 14.1 RSI-Value: 2.5	*(also includes top and bottom steel tracks)*
Wall Thickness:	349 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,496 MJ/m^2	Latex paint
Total Embodied GWP:	107 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	67,757	839	68,595	160	2,185	2,345	0	0	0	0	0	0	70,940	1,393	-	-
50	67,757	839	68,595	160	2,185	2,345	3,099	10	3,110	1	2,106	2,106	76,156	1,496	300,000	516

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,390	2	5,392	10	4	15	0	0	0	0	0	0	5,407	106	-	-
50	5,390	2	5,392	10	4	15	44	0	44	0	4	4	5,454	107	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

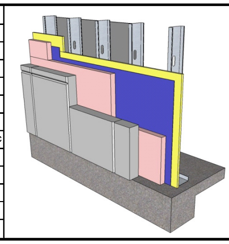
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #3 (SS-W3)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical exterior rigid insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 12.7 RSI-Value: 2.2	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 14.1 RSI-Value: 2.5	*(also includes top and bottom steel tracks)*
Wall Thickness:	384 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,011 MJ/m^2	Latex paint
Total Embodied GWP:	74 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	45,416	866	46,282	160	1,314	1,474	0	0	0	0	0	0	47,756	938	-	-
50	45,416	866	46,282	160	1,314	1,474	3,099	10	3,110	1	613	614	51,479	1,011	300,000	516

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,705	2	3,706	10	3	13	0	0	0	0	0	0	3,719	73	-	-
50	3,705	2	3,706	10	3	13	44	0	44	0	1	1	3,764	74	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Concrete 30 MPa (flyash av)	6.7	m3
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Rebar, Rod, Light Sections	404.0	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

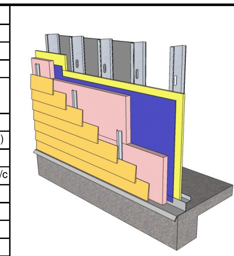
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #4 (SS-W4)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical exterior rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 12.7 RSI-Value: 2.2	39mm x 152mm 1.21mm steel studs @ 400mm o/c
THERM 5.2:	R-Value: 14.7 RSI-Value: 2.6	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	284 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	823 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	38 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	37,461	293	37,754	160	724	884	0	0	0	0	0	0	38,638	759	-	-
50	37,461	293	37,754	160	724	884	3,099	10	3,110	0	169	169	41,917	823	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,880	1	1,880	10	1	12	0	0	0	0	0	0	1,892	37	-	-
50	1,880	1	1,880	10	1	12	44	0	44	0	0	0	1,936	38	30,000	52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	106.1	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.5	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

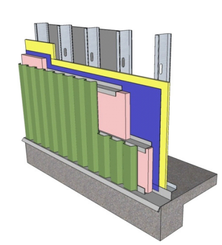
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #5 (SS-W5)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical exterior rigid insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 64mm Z-girts @ 600mm o/c (self-weight: 1.1 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 9.4 RSI-Value: 1.7	39mm x 152mm 1.21mm steel studs @ 400mm o/c
THERM 5.2:	R-Value: 10.5 RSI-Value: 1.9	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	286 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	2,467 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	148 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	121,311	246	121,556	160	624	784	0	0	0	0	0	0	122,340	2,403	-	-
50	121,311	246	121,556	160	624	784	3,099	10	3,110	0	163	163	125,613	2,467	1,900,000	3,270

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	7,466	0	7,466	10	1	12	0	0	0	0	0	0	7,478	147	-	-
50	7,466	0	7,466	10	1	12	44	0	44	0	0	0	7,522	148	110,000	189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	443.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails		kg
Paper Tape	4.2	kg
Screws Nuts & Bolts	1.3	kg
Solvent Based Alkyd Paint	5.2	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

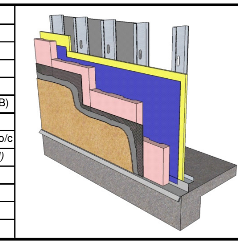
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #6 (SS-W6)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical exterior rigid insulation and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 12.7 RSI-Value: 2.2	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 13.8 RSI-Value: 2.4	*(also includes top and bottom steel tracks)*
Wall Thickness:	272 mm	Regular 16mm gypsum board
Total Embodied Energy:	906 MJ/m^2	Latex paint
Total Embodied GWP:	49 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	41,328	301	41,628	160	717	876	0	0	0	0	0	0	42,505	835	-	-
50	41,328	301	41,628	160	717	876	3,099	10	3,110	0	519	519	46,133	906	600,000	1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	2,425	1	2,426	10	1	12	0	0	0	0	0	0	2,438	48	-	-
50	2,425	1	2,426	10	1	12	44	0	44	0	1	1	2,482	49	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.7	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

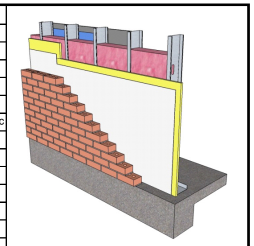
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #7 (SS-W7)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical batt insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
Quick Numbers:		39mm x 152mm 1.21mm steel studs @ 400mm o/c
		(includes 0.2kg of screws and fasteners per stud)
ASHRAE Standard 90.1:	R-Value: 9.3 RSI-Value: 1.6	*(also includes top and bottom steel tracks)*
THERM 5.2:	R-Value: 10.6 RSI-Value: 1.9	140mm fiberglass batt insulation
Wall Thickness:	299 mm	6mil poly (AB, VB)
Total Embodied Energy:	942 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	65 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	45,549	301	45,850	160	1,373	1,533	0	0	0	0	0	0	47,383	931	-	-
50	45,549	301	45,850	160	1,373	1,533	0	0	0	0	583	583	47,967	942	1,500,000	2,582

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,301	1	3,302	10	3	13	0	0	0	0	0	0	3,315	65	-	-
50	3,301	1	3,302	10	3	13	0	0	0	0	1	1	3,316	65	90,000	155

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Mortar	1.5	m3
Nails	4.2	kg
Ontario (Standard) Brick	53.5	m2
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

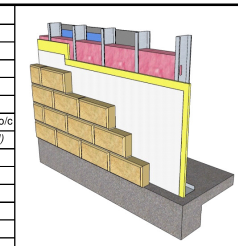
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #8 (SS-W8)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical batt insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
Quick Numbers:		39mm x 152mm 1.21mm steel studs @ 400mm o/c
		(includes 0.2kg of screws and fasteners per stud)
ASHRAE Standard 90.1:	R-Value: 9.3 RSI-Value: 1.6	*(also includes top and bottom steel tracks)*
THERM 5.2:	R-Value: 10.4 RSI-Value: 1.8	140mm fiberglass batt insulation
Wall Thickness:	299 mm	6mil poly (AB, VB)
Total Embodied Energy:	1,373 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	104 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	64,577	864	65,441	160	2,184	2,343	0	0	0	0	0	0	67,785	1,331	-	-
50	64,577	864	65,441	160	2,184	2,343	0	0	0	1	2,109	2,110	69,894	1,373	1,500,000	2,582

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,287	2	5,289	10	4	15	0	0	0	0	0	0	5,303	104	-	-
50	5,287	2	5,289	10	4	15	0	0	0	0	4	4	5,308	104	90,000	155

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	333.3	kg
Mortar	4.3	m3
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

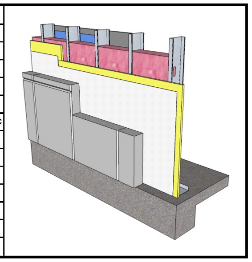
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #9 (SS-W9)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical batt insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
Quick Numbers:		39mm x 152mm 1.21mm steel studs @ 400mm o/c
		(includes 0.2kg of screws and fasteners per stud)
ASHRAE Standard 90.1:	R-Value: 9.3 RSI-Value: 1.6	*(also includes top and bottom steel tracks)*
THERM 5.2:	R-Value: 10.5 RSI-Value: 1.9	140mm fiberglass batt insulation
Wall Thickness:	334 mm	6mil poly (AB, VB)
Total Embodied Energy:	888 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	71 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	42,236	892	43,128	160	1,313	1,472	0	0	0	0	0	0	44,600	876	-	-
50	42,236	892	43,128	160	1,313	1,472	0	0	0	1	616	617	45,217	888	1,500,000	2,582

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,601	2	3,603	10	3	13	0	0	0	0	0	0	3,616	71	-	-
50	3,601	2	3,603	10	3	13	0	0	0	0	1	1	3,617	71	90,000	155

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Concrete 30 MPa (flyash av)	6.7	m3
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Rebar, Rod, Light Sections	404.0	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

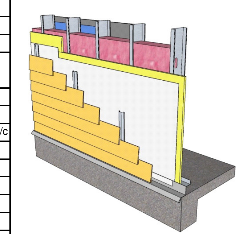
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #10 (SS-W10)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical batt insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 9.3 RSI-Value: 1.6	39mm x 152mm 1.21mm steel studs @ 400mm o/c
THERM 5.2:	R-Value: 11.1 RSI-Value: 2.0	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	234 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	700 MJ/m^2	140mm fiberglass batt insulation
Total Embodied GWP:	35 kg of CO_2 eq./m^2	6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	34,281	319	34,600	160	723	882	0	0	0	0	0	0	35,482	697	-	-
50	34,281	319	34,600	160	723	882	0	0	0	0	172	173	35,655	700	1,500,000	2,582

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,776	1	1,777	10	1	12	0	0	0	0	0	0	1,789	35	-	-
50	1,776	1	1,777	10	1	12	0	0	0	0	0	0	1,789	35	90,000	155

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Galvanized Sheet	106.1	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Nails	5.5	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

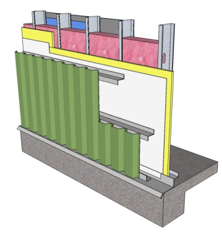
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #11 (SS-W11)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical batt insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Quick Numbers:		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 9.3 RSI-Value: 1.6	39mm x 152mm 1.21mm steel studs @ 400mm o/c
THERM 5.2:	R-Value: 10.0 RSI-Value: 1.8	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	260 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	2,334 MJ/m^2	140mm fiberglass batt insulation
Total Embodied GWP:	144 kg of CO_2 eq./m^2	6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	117,649	270	117,920	160	620	780	0	0	0	0	0	0	118,700	2,331	-	-
50	117,649	270	117,920	160	620	780	0	0	0	0	165	165	118,865	2,334	2,100,000	3,614

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	7,324	0	7,324	10	1	12	0	0	0	0	0	0	7,336	144	-	-
50	7,324	0	7,324	10	1	12	0	0	0	0	0	0	7,336	144	120,000	207

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Commercial 0.46mm Steel Cladding	168.0	m2
Galvanized Studs	423.3	kg
Joint Compound	111.8	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	5.2	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

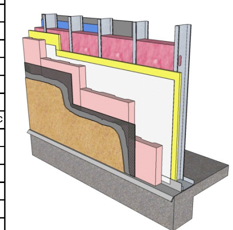
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #12 (SS-W12)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with typical batt insulation and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Building wrap (WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 19.2 RSI-Value: 3.4	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 19.1 RSI-Value: 3.4	*(also includes top and bottom steel tracks)*
Wall Thickness:	272 mm	140mm fiberglass batt insulation
Total Embodied Energy:	934 MJ/m^2	6mil poly (AB, VB)
Total Embodied GWP:	54 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	45,822	327	46,149	160	728	887	0	0	0	0	0	0	47,036	924	-	-
50	45,822	327	46,149	160	728	887	0	0	0	0	532	532	47,568	934	-800,000	-1,377

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,714	1	2,715	10	1	12	0	0	0	0	0	0	2,727	54	-	-
50	2,714	1	2,715	10	1	12	0	0	0	0	1	1	2,728	54	-40,000	-69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Nails	8.8	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

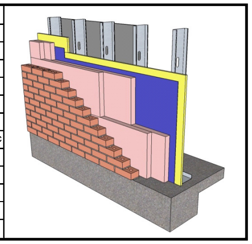
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #13 (SS-W13)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with two layers of rigid insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 24.0 RSI-Value: 4.2	*(also includes top and bottom steel tracks)*
Wall Thickness:	399 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,214 MJ/m²	Latex paint
Total Embodied GWP:	76 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	56,312	276	56,588	160	1,387	1,547	0	0	0	0	0	0	58,134	1,142	-	-
50	56,312	276	56,588	160	1,387	1,547	3,099	10	3,110	0	589	590	61,834	1,214	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	3,792	1	3,793	10	3	13	0	0	0	0	0	0	3,806	75	-	-
50	3,792	1	3,793	10	3	13	44	0	44	0	1	1	3,851	76	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Mortar	1.5	m3
Nails	4.2	kg
Ontario (Standard) Brick	53.5	m2
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

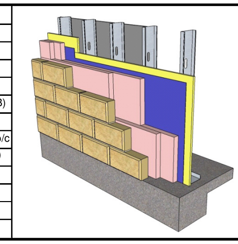
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #14 (SS-W14)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with two layers of rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 23.9 RSI-Value: 4.2	*(also includes top and bottom steel tracks)*
Wall Thickness:	399 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,645 MJ/m²	Latex paint
Total Embodied GWP:	115 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	75,340	839	76,179	160	2,197	2,357	0	0	0	0	0	0	78,536	1,542	-	-
50	75,340	839	76,179	160	2,197	2,357	3,099	10	3,110	1	2,115	2,116	83,761	1,645	-1,500,000	-2,582

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,778	2	5,780	10	4	15	0	0	0	0	0	0	5,794	114	-	-
50	5,778	2	5,780	10	4	15	44	0	44	0	4	4	5,842	115	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

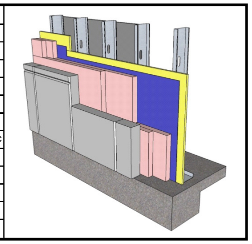
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #15 (SS-W15)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Structural steel curtainwall studs (400mm o/c) with two layers of rigid insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 24.0 RSI-Value: 4.2	*(also includes top and bottom steel tracks)*
Wall Thickness:	434 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,160 MJ/m^2	Latex paint
Total Embodied GWP:	82 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	52,999	866	53,865	160	1,326	1,486	0	0	0	0	0	0	55,351	1,087	-	-
50	52,999	866	53,865	160	1,326	1,486	3,099	10	3,110	1	622	623	59,084	1,160	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,092	2	4,094	10	3	13	0	0	0	0	0	0	4,107	81	-	-
50	4,092	2	4,094	10	3	13	44	0	44	0	1	1	4,152	82	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Concrete 30 MPa (flyash av)	6.7	m3
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Rebar, Rod, Light Sections	404.0	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

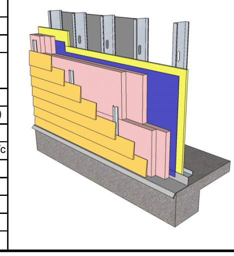
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #16 (SS-W16)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Structural steel curtainwall studs (400mm o/c) with two layers of rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	39mm x 152mm 1.21mm steel studs @ 400mm o/c
THERM 5.2:	R-Value: 24.6 RSI-Value: 4.3	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	334 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	973 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	46 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	45,044	293	45,337	160	736	896	0	0	0	0	0	0	46,233	908	-	-
50	45,044	293	45,337	160	736	896	3,099	10	3,110	0	179	179	49,522	973	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,267	1	2,268	10	1	12	0	0	0	0	0	0	2,280	45	-	-
50	2,267	1	2,268	10	1	12	44	0	44	0	0	0	2,324	46	-70,000	-120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	106.1	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.5	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

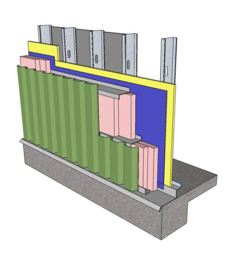
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #17 (SS-W17)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with two layers of rigid insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 100mm Z-girts @ 600mm o/c (self-weight: 1.5 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 11.9 RSI-Value: 2.1	39mm x 152mm 1.21mm steel studs @ 400mm o/c
THERM 5.2:	R-Value: 13.0 RSI-Value: 2.3	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	322 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	2,631 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	156 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	129,617	247	129,864	160	639	799	0	0	0	0	0	0	130,664	2,566	-	-
50	129,617	247	129,864	160	639	799	3,099	10	3,110	0	174	174	133,947	2,631	900,000	1,549

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	7,912	0	7,913	10	1	12	0	0	0	0	0	0	7,924	156	-	-
50	7,912	0	7,913	10	1	12	44	0	44	0	0	0	7,968	156	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	473.8	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	5.2	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

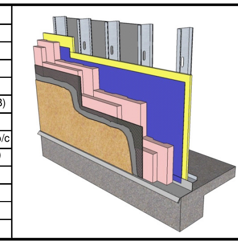
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #18 (SS-W18)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (400mm o/c) with two layers of rigid insulation and EFIS cladding	EFIS coating over metal mesh
		100mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.21mm steel studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 23.6 RSI-Value: 4.1	*(also includes top and bottom steel tracks)*
Wall Thickness:	322 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,055 MJ/m²	Latex paint
Total Embodied GWP:	56 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	48,911	301	49,212	160	729	889	0	0	0	0	0	0	50,100	984	-	-
50	48,911	301	49,212	160	729	889	3,099	10	3,110	0	528	528	53,738	1,055	-1,200,000	-2,065

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	2,813	1	2,814	10	1	12	0	0	0	0	0	0	2,825	55	-	-
50	2,813	1	2,814	10	1	12	44	0	44	0	1	1	2,870	56	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	342.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.7	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

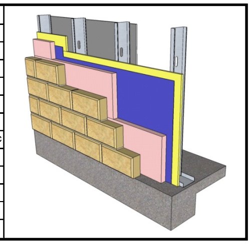
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #19 (SS-W19)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical exterior rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.52mm steel studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 12.8 RSI-Value: 2.3	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 14.0 RSI-Value: 2.5	*(also includes top and bottom steel tracks)*
Wall Thickness:	349 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,475 MJ/m²	Latex paint
Total Embodied GWP:	105 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	66,710	837	67,547	160	2,180	2,340	0	0	0	0	0	0	69,887	1,372	-	-
50	66,710	837	67,547	160	2,180	2,340	3,099	10	3,110	1	2,104	2,105	75,101	1,475	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	5,307	2	5,308	10	4	15	0	0	0	0	0	0	5,323	105	-	-
50	5,307	2	5,308	10	4	15	44	0	44	0	4	4	5,370	105	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 *m²* *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 *m²*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

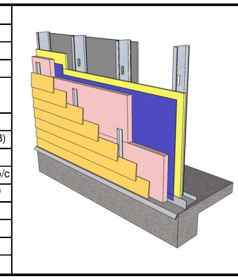
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #20 (SS-W20)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical exterior rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 600mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 12.8 RSI-Value: 2.3	39mm x 152mm 1.52mm steel studs @ 600mm o/c
THERM 5.2:	R-Value: 14.7 RSI-Value: 2.6	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	284 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	802 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	36 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	36,414	291	36,706	160	719	879	0	0	0	0	0	0	37,585	738	-	-
50	36,414	291	36,706	160	719	879	3,099	10	3,110	0	168	168	40,862	802	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	1,796	1	1,796	10	1	12	0	0	0	0	0	0	1,808	36	-	-
50	1,796	1	1,796	10	1	12	44	0	44	0	0	0	1,852	36	30,000	52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 *m²* *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 *m²*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	106.1	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.5	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

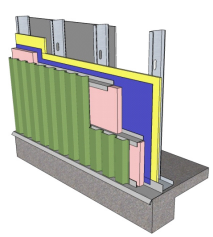
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #21 (SS-W21)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical exterior rigid insulation and commercial steel cladding	Latex paint 0.46mm galvanized commercial steel cladding 1.21mm galvanized 64mm Z-girts @ 600mm o/c (self-weight: 1.1 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 9.5 RSI-Value: 1.7	39mm x 152mm 1.52mm steel studs @ 600mm o/c
THERM 5.2:	R-Value: 10.5 RSI-Value: 1.8	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	286 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	2,446 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	146 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	120,264	244	120,508	160	619	779	0	0	0	0	0	0	121,287	2,382	-	-
50	120,264	244	120,508	160	619	779	3,099	10	3,110	0	161	161	124,558	2,446	1,900,000	3,270

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	7,382	0	7,383	10	1	12	0	0	0	0	0	0	7,394	145	-	-
50	7,382	0	7,383	10	1	12	44	0	44	0	0	0	7,438	146	110,000	189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	401.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

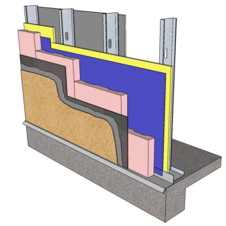
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #22 (SS-W22)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
		Outside
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical exterior rigid insulation and EFIS cladding	EFIS coating over metal mesh 50mm extruded polystyrene rigid insulation Vertical drainage channels in insulation Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing 39mm x 152mm 1.52mm steel studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 12.8 RSI-Value: 2.3	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 13.7 RSI-Value: 2.4	*(also includes top and bottom steel tracks)*
Wall Thickness:	272 mm	Regular 16mm gypsum board
Total Embodied Energy:	885 MJ/m²	Latex paint
Total Embodied GWP:	47 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	40,281	299	40,580	160	712	872	0	0	0	0	0	0	41,452	814	-	-
50	40,281	299	40,580	160	712	872	3,099	10	3,110	0	517	517	45,079	885	600,000	1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	2,342	1	2,342	10	1	12	0	0	0	0	0	0	2,354	46	-	-
50	2,342	1	2,342	10	1	12	44	0	44	0	1	1	2,398	47	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.7	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

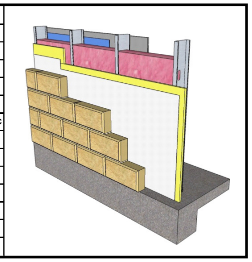
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #23 (SS-W23)

Building Component Description:

Category:	Exterior Walls
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical batt insulation and split-faced concrete block cladding
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: 11.0 RSI-Value: 1.9
THERM 5.2:	R-Value: 12.1 RSI-Value: 2.1
Wall Thickness:	299 mm
Total Embodied Energy:	1,352 MJ/m²
Total Embodied GWP:	103 kg of CO_2 eq./m²

Assembly Layers
Outside
Split-faced concrete block cladding
25mm air gap
Building wrap (WB)
16mm non paper-faced gypsum sheathing
39mm x 152mm 1.52mm steel studs @ 600mm o/c
(includes 0.2kg of screws and fasteners per stud)
(also includes top and bottom steel tracks)
140mm fiberglass batt insulation
6mil poly (AB, VB)
Regular 16mm gypsum board
Latex paint
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	63,531	862	64,393	160	2,179	2,339	0	0	0	0	0	0	66,732	1,311	-	-
50	63,531	862	64,393	160	2,179	2,339	0	0	0	1	2,107	2,108	68,840	1,352	900,000	1,549

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,203	2	5,205	10	4	15	0	0	0	0	0	0	5,220	103	-	-
50	5,203	2	5,205	10	4	15	0	0	0	0	4	4	5,224	103	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	333.3	kg
Mortar	4.3	m3
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	2.6	kg
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

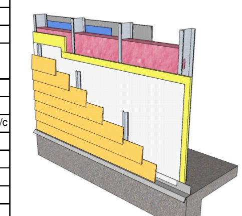
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #24 (SS-W24)

Building Component Description:

Category:	Exterior Walls
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical batt insulation and pine wood bevel siding
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: 11.0 RSI-Value: 1.9
THERM 5.2:	R-Value: 12.7 RSI-Value: 2.2
Wall Thickness:	234 mm
Total Embodied Energy:	680 MJ/m²
Total Embodied GWP:	33 kg of CO_2 eq./m²

Assembly Layers
Outside
Latex paint
Pine wood bevel siding
1.21mm heavy-duty galvanized steel furring channels @ 600mm o/c (self-weight: 0.82 kg/m)
Building wrap (WB)
16mm non paper-faced gypsum sheathing
39mm x 152mm 1.52mm steel studs @ 600mm o/c
(includes 0.2kg of screws and fasteners per stud)
(also includes top and bottom steel tracks)
140mm fiberglass batt insulation
6mil poly (AB, VB)
Regular 16mm gypsum board
Latex paint
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	33,235	317	33,552	160	718	878	0	0	0	0	0	0	34,429	676	-	-
50	33,235	317	33,552	160	718	878	0	0	0	0	171	171	34,600	680	900,000	1,549

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	1,693	1	1,693	10	1	12	0	0	0	0	0	0	1,705	33	-	-
50	1,693	1	1,693	10	1	12	0	0	0	0	0	0	1,705	33	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Galvanized Sheet	106.1	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Nails	5.5	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

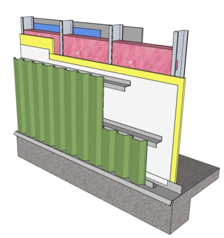
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Stud Wall #25 (SS-W25)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical batt insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Quick Numbers:		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 11.0 RSI-Value: 1.9	39mm x 152mm 1.52mm steel studs @ 600mm o/c
THERM 5.2:	R-Value: 11.7 RSI-Value: 2.1	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	260 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	2,314 MJ/m^2	140mm fiberglass batt insulation
Total Embodied GWP:	142 kg of CO_2 eq./m^2	6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	116,603	269	116,872	160	615	775	0	0	0	0	0	0	117,647	2,310	-	-
50	116,603	269	116,872	160	615	775	0	0	0	0	164	164	117,811	2,314	1,300,000	2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	7,240	0	7,240	10	1	12	0	0	0	0	0	0	7,252	142	-	-
50	7,240	0	7,240	10	1	12	0	0	0	0	0	0	7,252	142	70,000	120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Commercial 0.46mm Steel Cladding	168.0	m2
Galvanized Studs	381.3	kg
Joint Compound	111.8	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

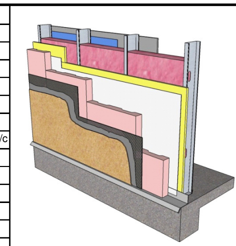
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #26 (SS-W26)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Structural steel curtainwall studs (600mm o/c) with typical batt insulation and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Building wrap (WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.52mm steel studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 20.4 RSI-Value: 3.6	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 20.6 RSI-Value: 3.6	*(also includes top and bottom steel tracks)*
Wall Thickness:	272 mm	140mm fiberglass batt insulation
Total Embodied Energy:	913 MJ/m^2	6mil poly (AB, VB)
Total Embodied GWP:	52 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	44,776	325	45,101	160	723	883	0	0	0	0	0	0	45,983	903	-	-
50	44,776	325	45,101	160	723	883	0	0	0	0	530	530	46,513	913	-1,000,000	-1,721

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,631	1	2,631	10	1	12	0	0	0	0	0	0	2,643	52	-	-
50	2,631	1	2,631	10	1	12	0	0	0	0	1	1	2,644	52	-50,000	-86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Nails	8.8	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	2.6	kg
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

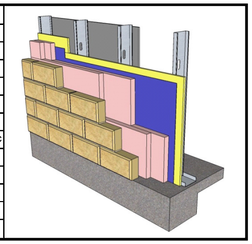
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #27 (SS-W27)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Structural steel curtainwall studs (600mm o/c) with two layers of rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		39mm x 152mm 1.52mm steel studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	*(includes 0.2kg of screws and fasteners per stud)*
THERM 5.2:	R-Value: 23.9 RSI-Value: 4.2	*(also includes top and bottom steel tracks)*
Wall Thickness:	399 mm	Regular 16mm gypsum board
Total Embodied Energy:	1,624 MJ/m^2	Latex paint
Total Embodied GWP:	113 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	74,294	837	75,131	160	2,192	2,352	0	0	0	0	0	0	77,483	1,522	-	-
50	74,294	837	75,131	160	2,192	2,352	3,099	10	3,110	1	2,114	2,114	82,707	1,624	-1,500,000	-2,582

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,694	2	5,696	10	4	15	0	0	0	0	0	0	5,710	112	-	-
50	5,694	2	5,696	10	4	15	44	0	44	0	4	4	5,758	113	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

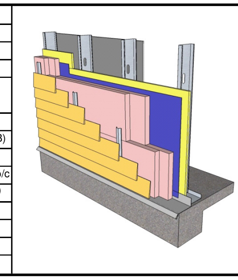
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #28 (SS-W28)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Structural steel curtainwall studs (600mm o/c) with two layers of rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 600mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	39mm x 152mm 1.52mm steel studs @ 600mm o/c
THERM 5.2:	R-Value: 24.5 RSI-Value: 4.3	*(includes 0.2kg of screws and fasteners per stud)*
Wall Thickness:	334 mm	*(also includes top and bottom steel tracks)*
Total Embodied Energy:	952 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	44 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	43,998	292	44,289	160	731	891	0	0	0	0	0	0	45,180	887	-	-
50	43,998	292	44,289	160	731	891	3,099	10	3,110	0	177	177	48,467	952	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,183	1	2,184	10	1	12	0	0	0	0	0	0	2,196	43	-	-
50	2,183	1	2,184	10	1	12	44	0	44	0	0	0	2,240	44	-70,000	-120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	106.1	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.5	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

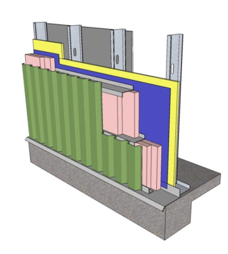
[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #29 (SS-W29)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**	
		Outside	
Brief Description:	Structural steel curtainwall studs (600mm o/c) with two layers of rigid insulation and commercial steel cladding	Latex paint	
		0.46mm galvanized commercial steel cladding	
		1.21mm galvanized 100mm Z-girts @ 600mm o/c (self-weight: 1.5 kg/m)	
Quick Numbers:		100mm extruded polystyrene rigid insulation	
		Self-adhesive membrane with primer (AB, VB, WB)	
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing	
ASHRAE Standard 90.1:	R-Value: 11.9 RSI-Value: 2.1	39mm x 152mm 1.52mm steel studs @ 600mm o/c	
THERM 5.2:	R-Value: 13.0 RSI-Value: 2.3	*(includes 0.2kg of screws and fasteners per stud)*	
Wall Thickness:	322 mm	*(also includes top and bottom steel tracks)*	
Total Embodied Energy:	2,610 MJ/m^2	Regular 16mm gypsum board	
Total Embodied GWP:	155 kg of CO_2 eq./m^2	Latex paint	
		Inside	

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	128,571	245	128,816	160	635	794	0	0	0	0	0	0	129,611	2,545	-	-
50	128,571	245	128,816	160	635	794	3,099	10	3,110	0	172	172	132,892	2,610	900,000	1,549

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	7,829	0	7,829	10	1	12	0	0	0	0	0	0	7,841	154	-	-
50	7,829	0	7,829	10	1	12	44	0	44	0	0	0	7,885	155	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	431.8	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	4.2	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	3.9	kg
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

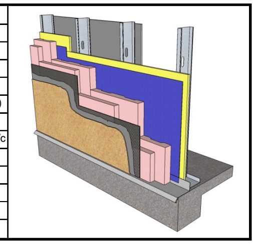
[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Wall #30 (SS-W30)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**	
		Outside	
Brief Description:	Structural steel curtainwall studs (600mm o/c) with two layers of rigid insulation and EFIS cladding	EFIS coating over metal mesh	
		100mm extruded polystyrene rigid insulation	
		Vertical drainage channels in insulation	
		Self-adhesive membrane with primer (AB, VB, WB)	
Quick Numbers:		16mm non paper-faced gypsum sheathing	
		39mm x 152mm 1.52mm steel studs @ 600mm o/c	
ASHRAE Standard 90.1:	R-Value: 22.2 RSI-Value: 3.9	*(includes 0.2kg of screws and fasteners per stud)*	
THERM 5.2:	R-Value: 23.6 RSI-Value: 4.1	*(also includes top and bottom steel tracks)*	
Wall Thickness:	322 mm	Regular 16mm gypsum board	
Total Embodied Energy:	1,035 MJ/m^2	Latex paint	
Total Embodied GWP:	55 kg of CO_2 eq./m^2	***Inside***	

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	47,865	299	48,164	160	724	884	0	0	0	0	0	0	49,048	963	-	-
50	47,865	299	48,164	160	724	884	3,099	10	3,110	0	527	527	52,684	1,035	-1,200,000	-2,065

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	2,729	1	2,730	10	1	12	0	0	0	0	0	0	2,742	54	-	-
50	2,729	1	2,730	10	1	12	44	0	44	0	1	1	2,786	55	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	51.4	kg
Galvanized Studs	300.5	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	5.7	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	2.6	kg
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

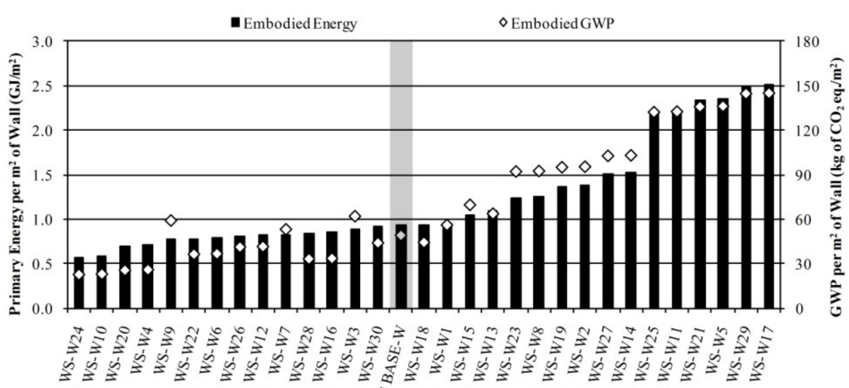
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Wood Stud Walls

This section contains a detailed description of wood stud (WS) exterior infill wall that was examined in this study (30 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various walls in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.

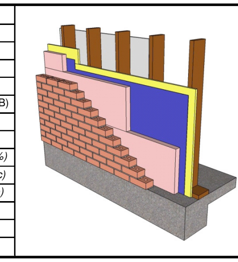


Exterior Infill Wall ID *(Arranged in Order of Increasing Embodied Energy)*

Wood Stud Wall #1 (WS-W1)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with typical exterior rigid insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 13.5 RSI-Value: 2.4	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 14.4 RSI-Value: 2.5	*(also includes 110g/m² steel nails @ 400mm o/c)*
Wall Thickness:	337 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	948 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	56 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	42,503	353	42,856	209	1,490	1,699	0	0	0	0	0	0	44,555	875	-	-
50	42,503	353	42,856	209	1,490	1,699	3,099	10	3,110	0	582	583	48,248	948	300,000	516

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	2,797	1	2,798	13	3	16	0	0	0	0	0	0	2,814	55	-	-
50	2,797	1	2,798	13	3	16	44	0	44	0	1	1	2,859	56	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	104.3	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Mortar	1.5	m3
Nails	9.0	kg
Ontario (Standard) Brick	53.5	m2
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

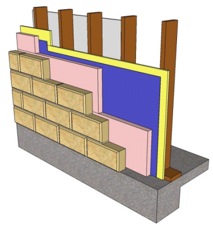
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #2 (WS-W2)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with typical exterior rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 13.5 RSI-Value: 2.4	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 14.2 RSI-Value: 2.5	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Wall Thickness:	337 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	1,378 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	95 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	61,531	916	62,447	209	2,300	2,509	0	0	0	0	0	0	64,957	1,276	-	-
50	61,531	916	62,447	209	2,300	2,509	3,099	10	3,110	1	2,108	2,109	70,175	1,378	300,000	516

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,783	2	4,785	13	4	18	0	0	0	0	0	0	4,803	94	-	-
50	4,783	2	4,785	13	4	18	44	0	44	0	4	4	4,851	95	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	104.3	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	9.0	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

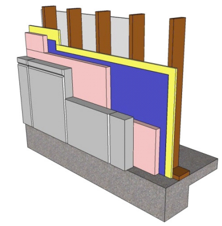
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #3 (WS-W3)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with typical exterior rigid insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 13.5 RSI-Value: 2.4	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 14.3 RSI-Value: 2.5	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Wall Thickness:	372 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	894 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	62 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	39,190	944	40,134	209	1,429	1,638	0	0	0	0	0	0	41,772	820	-	-
50	39,190	944	40,134	209	1,429	1,638	3,099	10	3,110	1	615	617	45,498	894	300,000	516

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,097	2	3,099	13	3	16	0	0	0	0	0	0	3,115	61	-	-
50	3,097	2	3,099	13	3	16	44	0	44	0	1	1	3,160	62	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Concrete 30 MPa (flyash av)	6.7	m3
Extruded Polystyrene	104.3	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	9.0	kg
Paper Tape	1.3	kg
Rebar, Rod, Light Sections	404.0	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

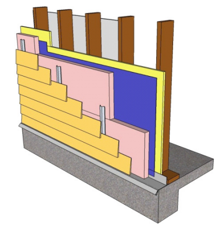
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #4 (WS-W4)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with typical exterior rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 13.5 RSI-Value: 2.4	38mm x 140mm wood studs @ 400mm o/c
THERM 5.2:	R-Value: 14.9 RSI-Value: 2.6	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	272 mm	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Total Embodied Energy:	706 MJ/m^2	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	26 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	31,235	371	31,606	209	839	1,048	0	0	0	0	0	0	32,654	641	-	-
50	31,235	371	31,606	209	839	1,048	3,099	10	3,110	0	172	172	35,936	706	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,272	1	1,273	13	2	15	0	0	0	0	0	0	1,288	25	-	-
50	1,272	1	1,273	13	2	15	44	0	44	0	0	0	1,332	26	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	106.1	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	10.3	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

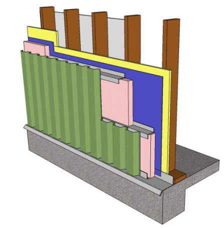
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #5 (WS-W5)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with typical exterior rigid insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 64mm Z-girts @ 600mm o/c (self-weight: 1.1 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 10.2 RSI-Value: 1.8	38mm x 140mm wood studs @ 400mm o/c
THERM 5.2:	R-Value: 10.7 RSI-Value: 1.9	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	274 mm	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Total Embodied Energy:	2,349 MJ/m^2	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	136 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	115,085	324	115,409	209	739	948	0	0	0	0	0	0	116,357	2,285	-	-
50	115,085	324	115,409	209	739	948	3,099	10	3,110	0	165	166	119,632	2,349	1,800,000	3,098

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	6,859	1	6,859	13	1	15	0	0	0	0	0	0	6,874	135	-	-
50	6,859	1	6,859	13	1	15	44	0	44	0	0	0	6,918	136	100,000	172

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	101.0	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	9.0	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

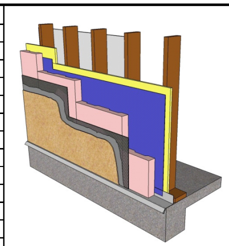
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #6 (WS-W6)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with typical exterior rigid insulation and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 13.5 RSI-Value: 2.4	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 14.0 RSI-Value: 2.5	*(also includes 110g/m² steel nails @ 400mm o/c)*
Wall Thickness:	260 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	789 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	37 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	35,102	378	35,481	209	831	1,041	0	0	0	0	0	0	36,521	717	-	-
50	35,102	378	35,481	209	831	1,041	3,099	10	3,110	0	521	522	40,153	789	600,000	1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	1,818	1	1,819	13	2	15	0	0	0	0	0	0	1,834	36	-	-
50	1,818	1	1,819	13	2	15	44	0	44	0	1	1	1,879	37	30,000	52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	10.5	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

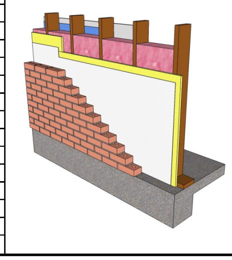
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #7 (WS-W7)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with typical batt insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
Quick Numbers:		38mm x 140mm wood studs @ 400mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
ASHRAE Standard 90.1:	R-Value: 15.9 RSI-Value: 2.8	*(also includes 110g/m² steel nails @ 400mm o/c)*
THERM 5.2:	R-Value: 19.0 RSI-Value: 3.3	*(also includes double top plate and one sil plate)*
Wall Thickness:	287 mm	140mm fiberglass batt insulation
Total Embodied Energy:	825 MJ/m²	6mil poly (AB, VB)
Total Embodied GWP:	53 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	39,324	378	39,702	209	1,488	1,698	0	0	0	0	0	0	41,400	813	-	-
50	39,324	378	39,702	209	1,488	1,698	0	0	0	0	586	586	41,986	825	-1,000,000	-1,721

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	2,694	1	2,695	13	3	16	0	0	0	0	0	0	2,711	53	-	-
50	2,694	1	2,695	13	3	16	0	0	0	0	1	1	2,712	53	-50,000	-86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Joint Compound	111.8	kg
Mortar	1.5	m3
Nails	9.0	kg
Ontario (Standard) Brick	53.5	m2
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

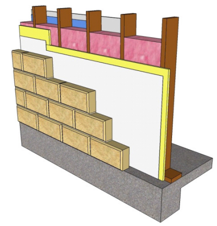
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #8 (WS-W8)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with typical batt insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
Quick Numbers:		38mm x 140mm wood studs @ 400mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
ASHRAE Standard 90.1:	R-Value: 15.9 RSI-Value: 2.8	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
THERM 5.2:	R-Value: 18.9 RSI-Value: 3.3	*(also includes double top plate and one sil plate)*
Wall Thickness:	287 mm	140mm fiberglass batt insulation
Total Embodied Energy:	1,255 MJ/m^2	6mil poly (AB, VB)
Total Embodied GWP:	92 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	58,352	942	59,293	209	2,298	2,508	0	0	0	0	0	0	61,801	1,214	-	-
50	58,352	942	59,293	209	2,298	2,508	0	0	0	1	2,112	2,112	63,914	1,255	-1,000,000	-1,721

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,680	2	4,682	13	4	18	0	0	0	0	0	0	4,700	92	-	-
50	4,680	2	4,682	13	4	18	0	0	0	0	4	4	4,704	92	-50,000	-86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	333.3	kg
Mortar	4.3	m3
Nails	9.0	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

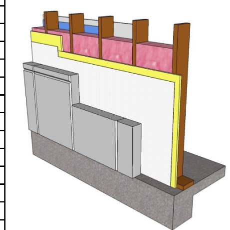
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #9 (WS-W9)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with typical batt insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
Quick Numbers:		38mm x 140mm wood studs @ 400mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
ASHRAE Standard 90.1:	R-Value: 15.9 RSI-Value: 2.8	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
THERM 5.2:	R-Value: 19.0 RSI-Value: 3.3	*(also includes double top plate and one sil plate)*
Wall Thickness:	322 mm	140mm fiberglass batt insulation
Total Embodied Energy:	771 MJ/m^2	6mil poly (AB, VB)
Total Embodied GWP:	59 kg of CO_2 eq./m^2	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	36,011	969	36,980	209	1,427	1,637	0	0	0	0	0	0	38,617	758	-	-
50	36,011	969	36,980	209	1,427	1,637	0	0	0	1	619	620	39,237	771	-1,000,000	-1,721

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,994	2	2,996	13	3	16	0	0	0	0	0	0	3,012	59	-	-
50	2,994	2	2,996	13	3	16	0	0	0	0	1	1	3,014	59	-50,000	-86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Concrete 30 MPa (flyash av)	6.7	m3
Joint Compound	111.8	kg
Nails	9.0	kg
Paper Tape	1.3	kg
Rebar, Rod, Light Sections	404.0	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

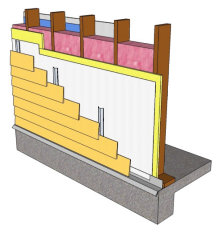
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #10 (WS-W10)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with typical batt insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 15.9 RSI-Value: 2.8	38mm x 140mm wood studs @ 400mm o/c
THERM 5.2:	R-Value: 19.6 RSI-Value: 3.4	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	222 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	583 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	23 kg of CO_2 eq./m²	140mm fiberglass batt insulation
		6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	28,056	396	28,452	209	837	1,047	0	0	0	0	0	0	29,499	579	-	-
50	28,056	396	28,452	209	837	1,047	0	0	0	0	175	176	29,674	583	-800,000	-1,377

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	1,169	1	1,170	13	2	15	0	0	0	0	0	0	1,185	23	-	-
50	1,169	1	1,170	13	2	15	0	0	0	0	0	0	1,185	23	-40,000	-69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Galvanized Sheet	106.1	kg
Joint Compound	111.8	kg
Nails	10.3	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

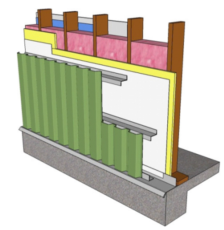
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #11 (WS-W11)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with typical batt insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Quick Numbers:		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 15.9 RSI-Value: 2.8	38mm x 140mm wood studs @ 400mm o/c
THERM 5.2:	R-Value: 18.4 RSI-Value: 3.2	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	248 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	2,217 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	132 kg of CO_2 eq./m²	140mm fiberglass batt insulation
		6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	111,424	348	111,772	209	735	945	0	0	0	0	0	0	112,716	2,214	-	-
50	111,424	348	111,772	209	735	945	0	0	0	0	168	168	112,885	2,217	-600,000	-1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	6,717	1	6,717	13	1	15	0	0	0	0	0	0	6,732	132	-	-
50	6,717	1	6,717	13	1	15	0	0	0	0	0	0	6,732	132	-30,000	-52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Commercial 0.46mm Steel Cladding	168.0	m2
Galvanized Studs	80.8	kg
Joint Compound	111.8	kg
Nails	9.0	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

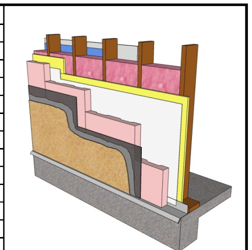
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #12 (WS-W12)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with typical batt insulation and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Building wrap (WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 27.8 RSI-Value: 4.9	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 28.5 RSI-Value: 5.0	*(also includes 110g/m² steel nails @ 400mm o/c)*
Wall Thickness:	260 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	817 MJ/m²	140mm fiberglass batt insulation
Total Embodied GWP:	42 kg of CO_2 eq./m²	6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²	[5] Total	[6] per m²
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	39,596	404	40,001	209	842	1,052	0	0	0	0	0	0	41,053	806	-	-
50	39,596	404	40,001	209	842	1,052	0	0	0	0	534	535	41,587	817	-1,900,000	-3,270

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²	[5] Total	[6] per m²
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	2,107	1	2,108	13	2	15	0	0	0	0	0	0	2,123	42	-	-
50	2,107	1	2,108	13	2	15	0	0	0	0	1	1	2,124	42	-100,000	-172

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Joint Compound	111.8	kg
Nails	13.6	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

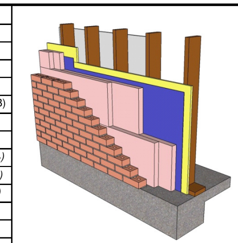
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #13 (WS-W13)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with two layers of rigid insulation and standard clay brick cladding	Ontario (standard) clay brick cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 24.2 RSI-Value: 4.3	*(also includes 110g/m² steel nails @ 400mm o/c)*
Wall Thickness:	387 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	1,097 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	64 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²	[5] Total	[6] per m²
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	50,086	353	50,440	209	1,502	1,711	0	0	0	0	0	0	52,151	1,024	-	-
50	50,086	353	50,440	209	1,502	1,711	3,099	10	3,110	0	592	592	55,853	1,097	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²	[5] Total	[6] per m²
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	3,185	1	3,186	13	3	16	0	0	0	0	0	0	3,202	63	-	-
50	3,185	1	3,186	13	3	16	44	0	44	0	1	1	3,247	64	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Mortar	1.5	m3
Nails	9.0	kg
Ontario (Standard) Brick	53.5	m2
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

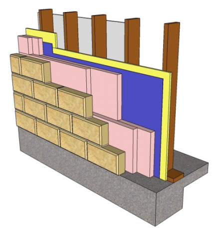
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #14 (WS-W14)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with two layers of rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 24.1 RSI-Value: 4.2	*(also includes 110g/m² steel nails @ 400mm o/c)*
Wall Thickness:	387 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	1,528 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	103 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	69,114	917	70,031	209	2,312	2,521	0	0	0	0	0	0	72,552	1,425	-	-
50	69,114	917	70,031	209	2,312	2,521	3,099	10	3,110	1	2,118	2,119	77,781	1,528	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,171	2	5,173	13	4	18	0	0	0	0	0	0	5,191	102	-	-
50	5,171	2	5,173	13	4	18	44	0	44	0	4	4	5,238	103	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	9.0	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

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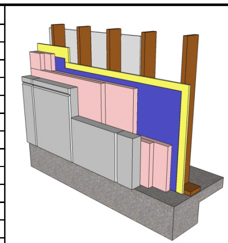
Wood Stud Wall #15 (WS-W15)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (400mm o/c) with two layers of rigid insulation and pre-cast concrete cladding	125mm concrete pre-cast cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 24.2 RSI-Value: 4.3	*(also includes 110g/m² steel nails @ 400mm o/c)*
Wall Thickness:	422 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	1,043 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	70 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	46,773	944	47,718	209	1,441	1,650	0	0	0	0	0	0	49,368	970	-	-
50	46,773	944	47,718	209	1,441	1,650	3,099	10	3,110	1	625	626	53,104	1,043	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	3,485	2	3,487	13	3	16	0	0	0	0	0	0	3,503	69	-	-
50	3,485	2	3,487	13	3	16	44	0	44	0	1	1	3,548	70	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Concrete 30 MPa (flyash av)	6.7	m3
Extruded Polystyrene	208.6	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	9.0	kg
Paper Tape	1.3	kg
Rebar, Rod, Light Sections	404.0	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

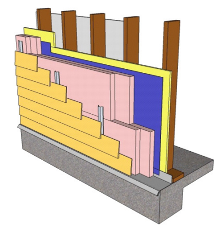
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #16 (WS-W16)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
Brief Description:	Wood stud wall (400mm o/c) with two layers of rigid insulation and pine wood bevel siding	***Outside***
		Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 400mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	38mm x 140mm wood studs @ 400mm o/c
THERM 5.2:	R-Value: 24.8 RSI-Value: 4.4	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	322 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	855 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	34 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	38,818	371	39,189	209	851	1,060	0	0	0	0	0	0	40,250	790	-	-
50	38,818	371	39,189	209	851	1,060	3,099	10	3,110	0	182	182	43,541	855	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	1,660	1	1,661	13	2	15	0	0	0	0	0	0	1,676	33	-	-
50	1,660	1	1,661	13	2	15	44	0	44	0	0	0	1,720	34	-70,000	-120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	106.1	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	10.3	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

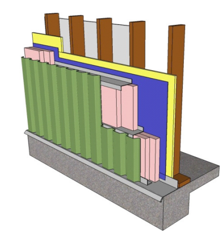
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #17 (WS-W17)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
Brief Description:	Wood stud wall (400mm o/c) with two layers of rigid insulation and commercial steel cladding	***Outside***
		Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 100mm Z-girts @ 600mm o/c (self-weight: 1.5 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 12.7 RSI-Value: 2.2	38mm x 140mm wood studs @ 400mm o/c
THERM 5.2:	R-Value: 13.2 RSI-Value: 2.3	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	310 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	2,513 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	145 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	123,392	325	123,716	209	754	964	0	0	0	0	0	0	124,680	2,449	-	-
50	123,392	325	123,716	209	754	964	3,099	10	3,110	0	176	177	127,967	2,513	900,000	1,549

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	7,305	1	7,306	13	1	15	0	0	0	0	0	0	7,321	144	-	-
50	7,305	1	7,306	13	1	15	44	0	44	0	0	0	7,365	145	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	131.3	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	9.0	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

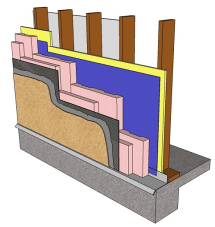
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #18 (WS-W18)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (400mm o/c) with two layers of rigid insulation and EFIS cladding	EFIS coating over metal mesh
		100mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 400mm o/c
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 23.8 RSI-Value: 4.2	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Wall Thickness:	310 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	938 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	45 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	42,686	379	43,064	209	844	1,053	0	0	0	0	0	0	44,117	866	-	-
50	42,686	379	43,064	209	844	1,053	3,099	10	3,110	0	531	531	47,758	938	-1,200,000	-2,065

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,206	1	2,207	13	2	15	0	0	0	0	0	0	2,222	44	-	-
50	2,206	1	2,207	13	2	15	44	0	44	0	1	1	2,266	45	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	51.4	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	10.5	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

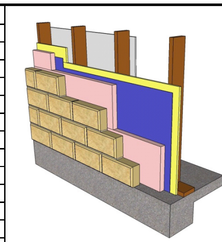
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #19 (WS-W19)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with typical exterior rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 13.3 RSI-Value: 2.3	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 14.1 RSI-Value: 2.5	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Wall Thickness:	337 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	1,366 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	95 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	60,972	892	61,864	209	2,259	2,468	0	0	0	0	0	0	64,333	1,263	-	-
50	60,972	892	61,864	209	2,259	2,468	3,099	10	3,110	1	2,104	2,105	69,547	1,366	300,000	516

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,766	2	4,768	13	4	18	0	0	0	0	0	0	4,785	94	-	-
50	4,766	2	4,768	13	4	18	44	0	44	0	4	4	4,833	95	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	104.3	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	7.4	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

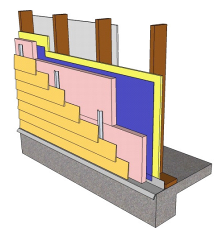
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #20 (WS-W20)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with typical exterior rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 600mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 13.3 RSI-Value: 2.3	38mm x 140mm wood studs @ 600mm o/c
THERM 5.2:	R-Value: 14.8 RSI-Value: 2.6	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	272 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	693 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	26 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total EE	⁴ Total EE per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	30,676	347	31,023	209	798	1,007	0	0	0	0	0	0	32,030	629	-	-
50	30,676	347	31,023	209	798	1,007	3,099	10	3,110	0	168	168	35,308	693	400,000	688

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total GWP	⁴ Total GWP per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	1,255	1	1,256	13	2	15	0	0	0	0	0	0	1,271	25	-	-
50	1,255	1	1,256	13	2	15	44	0	44	0	0	0	1,315	26	20,000	34

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	106.1	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	8.7	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

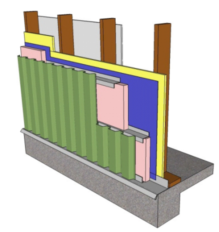
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #21 (WS-W21)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with typical exterior rigid insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 64mm Z-girts @ 600mm o/c (self-weight: 1.1 kg/m)
Quick Numbers:		50mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 10.1 RSI-Value: 1.8	38mm x 140mm wood studs @ 600mm o/c
THERM 5.2:	R-Value: 10.6 RSI-Value: 1.9	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	274 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	2,337 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	136 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total EE	⁴ Total EE per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	114,526	299	114,825	209	698	907	0	0	0	0	0	0	115,733	2,273	-	-
50	114,526	299	114,825	209	698	907	3,099	10	3,110	0	161	161	119,004	2,337	1,800,000	3,098

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			³ Total GWP	⁴ Total GWP per m²		
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total			⁵ Total	⁶ per m²
¹ Initial	6,842	0	6,842	13	1	15	0	0	0	0	0	0	6,857	135	-	-
50	6,842	0	6,842	13	1	15	44	0	44	0	0	0	6,901	136	100,000	172

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Studs	101.0	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	7.4	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

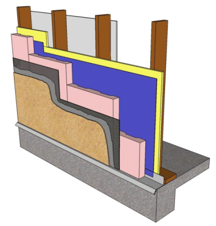
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #22 (WS-W22)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (600mm o/c) with typical exterior rigid insulation and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 13.3 RSI-Value: 2.3	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 13.8 RSI-Value: 2.4	*(also includes 110g/m² steel nails @ 400mm o/c)*
Wall Thickness:	260 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	776 MJ/m²	Regular 16mm gypsum board
Total Embodied GWP:	37 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	34,543	354	34,897	209	791	1,000	0	0	0	0	0	0	35,897	705	-	-
50	34,543	354	34,897	209	791	1,000	3,099	10	3,110	0	517	517	39,524	776	600,000	1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	1,801	1	1,802	13	1	15	0	0	0	0	0	0	1,817	36	-	-
50	1,801	1	1,802	13	1	15	44	0	44	0	1	1	1,861	37	40,000	69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	8.9	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

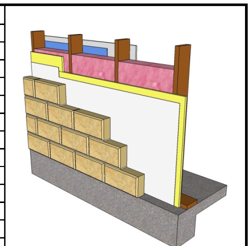
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #23 (WS-W23)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (600mm o/c) with typical batt insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
Quick Numbers:		38mm x 140mm wood studs @ 600mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
ASHRAE Standard 90.1:	R-Value: 16.7 RSI-Value: 2.9	*(also includes 110g/m² steel nails @ 400mm o/c)*
THERM 5.2:	R-Value: 19.8 RSI-Value: 3.5	*(also includes double top plate and one sil plate)*
Wall Thickness:	287 mm	140mm fiberglass batt insulation
Total Embodied Energy:	1,243 MJ/m²	6mil poly (AB, VB)
Total Embodied GWP:	92 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	57,793	918	58,710	209	2,258	2,467	0	0	0	0	0	0	61,177	1,201	-	-
50	57,793	918	58,710	209	2,258	2,467	0	0	0	1	2,107	2,108	63,285	1,243	-1,100,000	-1,893

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,663	2	4,665	13	4	18	0	0	0	0	0	0	4,682	92	-	-
50	4,663	2	4,665	13	4	18	0	0	0	0	4	4	4,686	92	-50,000	-86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Cold Rolled Sheet	10.3	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	333.3	kg
Mortar	4.3	m3
Nails	7.4	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

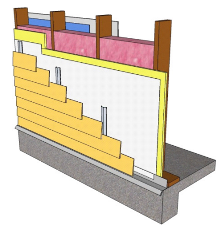
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #24 (WS-W24)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with typical batt insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 600mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 16.7 RSI-Value: 2.9	38mm x 140mm wood studs @ 600mm o/c
THERM 5.2:	R-Value: 19.9 RSI-Value: 3.5	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	222 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	570 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	23 kg of CO_2 eq./m²	140mm fiberglass batt insulation
		6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	27,497	372	27,869	209	797	1,006	0	0	0	0	0	0	28,875	567	-	-
50	27,497	372	27,869	209	797	1,006	0	0	0	0	171	171	29,046	570	-800,000	-1,377

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	1,152	1	1,153	13	2	15	0	0	0	0	0	0	1,168	23	-	-
50	1,152	1	1,153	13	2	15	0	0	0	0	0	0	1,168	23	-40,000	-69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Galvanized Sheet	106.1	kg
Joint Compound	111.8	kg
Nails	8.7	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

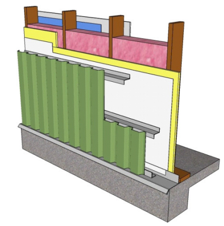
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #25 (WS-W25)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with typical batt insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Quick Numbers:		Building wrap (WB)
		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 16.7 RSI-Value: 2.9	38mm x 140mm wood studs @ 600mm o/c
THERM 5.2:	R-Value: 19.4 RSI-Value: 3.4	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	248 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	2,205 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	132 kg of CO_2 eq./m²	140mm fiberglass batt insulation
		6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	110,865	324	111,189	209	694	904	0	0	0	0	0	0	112,092	2,201	-	-
50	110,865	324	111,189	209	694	904	0	0	0	0	164	164	112,256	2,205	-700,000	-1,205

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	6,699	1	6,700	13	1	15	0	0	0	0	0	0	6,715	132	-	-
50	6,699	1	6,700	13	1	15	0	0	0	0	0	0	6,715	132	-40,000	-69

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m²)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Commercial 0.46mm Steel Cladding	168.0	m2
Galvanized Studs	80.8	kg
Joint Compound	111.8	kg
Nails	7.4	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

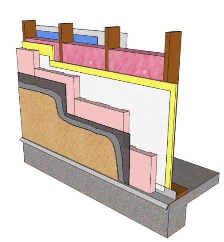
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #26 (WS-W26)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with typical batt insulation and EFIS cladding	EFIS coating over metal mesh
		50mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Building wrap (WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 27.8 RSI-Value: 4.9	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 29.4 RSI-Value: 5.2	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Wall Thickness:	260 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	804 MJ/m^2	140mm fiberglass batt insulation
Total Embodied GWP:	41 kg of CO_2 eq./m^2	6mil poly (AB, VB)
		Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	39,037	380	39,417	209	802	1,011	0	0	0	0	0	0	40,429	794	-	-
50	39,037	380	39,417	209	802	1,011	0	0	0	0	530	530	40,959	804	-1,900,000	-3,270

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,090	1	2,091	13	2	15	0	0	0	0	0	0	2,106	41	-	-
50	2,090	1	2,091	13	2	15	0	0	0	0	1	1	2,107	41	-100,000	-172

Embodied energy (and GWP) numbers are based on an area of wall = *50.9* *m^2* *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = *581.0* *m^2*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
6 mil Polyethylene	108.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Extruded Polystyrene	104.3	m2 (25mm)
Galvanized Sheet	51.4	kg
Joint Compound	111.8	kg
Nails	12.0	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

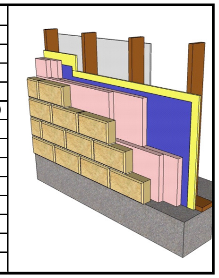
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #27 (WS-W27)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with two layers of rigid insulation and split-faced concrete block cladding	Split-faced concrete block cladding
		25mm air gap
		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 24.0 RSI-Value: 4.2	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Wall Thickness:	387 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	1,515 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	103 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	68,555	892	69,448	209	2,271	2,481	0	0	0	0	0	0	71,928	1,413	-	-
50	68,555	892	69,448	209	2,271	2,481	3,099	10	3,110	1	2,114	2,115	77,152	1,515	-1,600,000	-2,754

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,154	2	5,155	13	4	18	0	0	0	0	0	0	5,173	102	-	-
50	5,154	2	5,155	13	4	18	44	0	44	0	4	4	5,221	103	-80,000	-138

Embodied energy (and GWP) numbers are based on an area of wall = *50.9* *m^2* *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = *581.0* *m^2*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Cold Rolled Sheet	10.3	kg
Extruded Polystyrene	208.6	m2 (25mm)
Joint Compound	111.8	kg
Modified Bitumen membrane	401.5	kg
Mortar	4.3	m3
Nails	7.4	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Split-faced Concrete Block	1,238.2	Blocks
Water Based Latex Paint	66.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

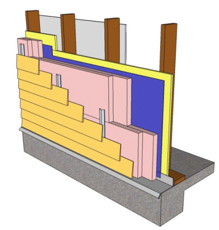
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Wall #28 (WS-W28)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with two layers of rigid insulation and pine wood bevel siding	Latex paint
		Pine wood bevel siding
		1.21mm heavy-duty galvanized steel furring channels @ 600mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
No Significant Thermal Bridge Through Exterior Insulation:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	38mm x 140mm wood studs @ 600mm o/c
THERM 5.2:	R-Value: 24.7 RSI-Value: 4.3	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	322 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	843 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	33 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	38,259	347	38,606	209	810	1,020	0	0	0	0	0	0	39,626	778	-	-
50	38,259	347	38,606	209	810	1,020	3,099	10	3,110	0	177	178	42,913	843	-1,300,000	-2,238

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	1,643	1	1,643	13	2	15	0	0	0	0	0	0	1,658	33	-	-
50	1,643	1	1,643	13	2	15	44	0	44	0	0	0	1,702	33	-70,000	-120

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	106.1	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	8.7	kg
Paper Tape	1.3	kg
Pine Wood Bevel Siding	160.4	m2
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

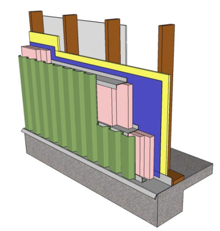
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #29 (WS-W29)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Wood stud wall (600mm o/c) with two layers of rigid insulation and commercial steel cladding	Latex paint
		0.46mm galvanized commercial steel cladding
		1.21mm galvanized 100mm Z-girts @ 600mm o/c (self-weight: 1.5 kg/m)
Quick Numbers:		100mm extruded polystyrene rigid insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Continuous Thermal Bridge Through Exterior Insulation @ 600mm o/c:		16mm non paper-faced gypsum sheathing
ASHRAE Standard 90.1:	R-Value: 12.7 RSI-Value: 2.2	38mm x 140mm wood studs @ 600mm o/c
THERM 5.2:	R-Value: 13.1 RSI-Value: 2.3	*(wood studs are kiln-dried to a MC of at least 19%)*
Wall Thickness:	310 mm	*(also includes 110g/m² steel nails @ 400mm o/c)*
Total Embodied Energy:	2,501 MJ/m²	*(also includes double top plate and one sil plate)*
Total Embodied GWP:	144 kg of CO_2 eq./m²	Regular 16mm gypsum board
		Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	122,833	301	123,133	209	714	923	0	0	0	0	0	0	124,056	2,436	-	-
50	122,833	301	123,133	209	714	923	3,099	10	3,110	0	172	172	127,338	2,501	900,000	1,549

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	7,288	0	7,288	13	1	15	0	0	0	0	0	0	7,303	143	-	-
50	7,288	0	7,288	13	1	15	44	0	44	0	0	0	7,347	144	50,000	86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Commercial 0.46mm Steel Cladding	168.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Studs	131.3	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	7.4	kg
Paper Tape	1.3	kg
Screws Nuts & Bolts	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

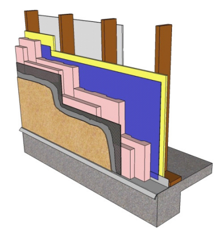
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Wall #30 (WS-W30)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Wood stud wall (600mm o/c) with two layers of rigid insulation and EFIS cladding	EFIS coating over metal mesh
		100mm extruded polystyrene rigid insulation
		Vertical drainage channels in insulation
		Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:		16mm non paper-faced gypsum sheathing
		38mm x 140mm wood studs @ 600mm o/c
ASHRAE Standard 90.1:	R-Value: 23.3 RSI-Value: 4.1	*(wood studs are kiln-dried to a MC of at least 19%)*
THERM 5.2:	R-Value: 23.7 RSI-Value: 4.2	*(also includes 110g/m^2 steel nails @ 400mm o/c)*
Wall Thickness:	310 mm	*(also includes double top plate and one sil plate)*
Total Embodied Energy:	926 MJ/m^2	Regular 16mm gypsum board
Total Embodied GWP:	44 kg of CO_2 eq./m^2	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	42,126	355	42,481	209	803	1,012	0	0	0	0	0	0	43,493	854	-	-
50	42,126	355	42,481	209	803	1,012	3,099	10	3,110	0	527	527	47,130	926	-1,200,000	-2,065

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,189	1	2,189	13	2	15	0	0	0	0	0	0	2,204	43	-	-
50	2,189	1	2,189	13	2	15	44	0	44	0	1	1	2,249	44	-60,000	-103

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 *(Length x Height = 7.6m x 6.7m = 50.9m^2)*

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	219.4	m2
3 mil Polyethylene	54.0	m2
16mm Moisture Resistant Gypsum Board	56.0	m2
16mm Regular Gypsum Board	56.0	m2
Extruded Polystyrene	208.6	m2 (25mm)
Galvanized Sheet	51.4	kg
Joint Compound	111.8	kg
Modified Bitumen membrane	68.2	kg
Nails	8.9	kg
Paper Tape	1.3	kg
Small Dimension Softwood Lumber, kiln-dried	0.7	m3
Solvent Based Alkyd Paint	19.6	L
Stucco over metal mesh	136.0	m2
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

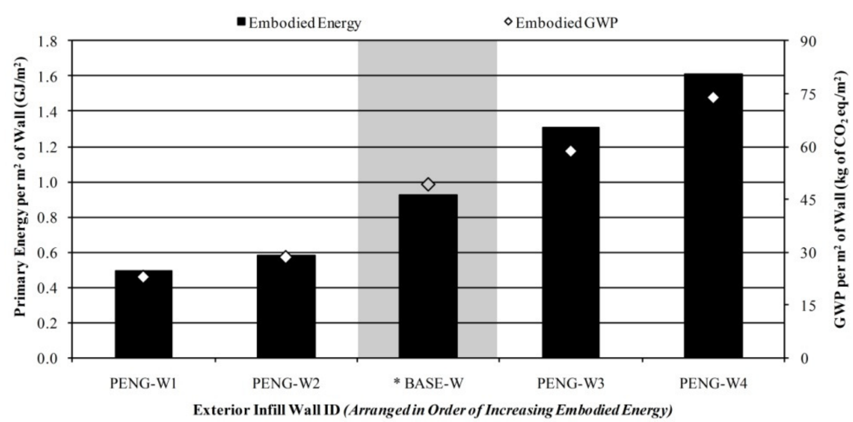
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Pre-Engineered Steel Building Exterior Walls

This section contains a detailed description of each pre-engineered steel building (PENG) exterior infill wall that was examined in this study (4 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

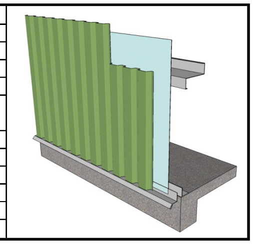
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various walls in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Pre-Engineered Steel Building Exterior Wall #1 (PENG-W1)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
Brief Description:	Pre-engineered steel building exterior enclosure wall with exterior steel cladding and no insulation (not typical pre-eng. enclosure)	***Outside*** Latex paint 0.46mm galvanized commercial steel cladding 6mil poly (AB, VB) 1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m) ***Inside***
Quick Numbers:		
ASHRAE Standard 90.1:	R-Value: 0.8 RSI-Value: 0.1	
THERM 5.2:	R-Value: 0.9 RSI-Value: 0.1	
Wall Thickness:	38 mm (excluding Z-girt)	
Total Embodied Energy:	491 MJ/m^2	
Total Embodied GWP:	23 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	24,579	35	24,614	160	64	223	0	0	0	0	0	0	24,837	488	-	-
50	24,579	35	24,614	160	64	223	161	1	162	0	22	22	25,021	491	* N/A	* N/A

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,154	0	1,154	10	0	11	0	0	0	0	0	0	1,165	23	-	-
50	1,154	0	1,154	10	0	11	3	0	3	0	0	0	1,168	23	* N/A	* N/A

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

** Thermal resistance and thermal mass of wall was too low to get an accurate evaluation of operating energy from computer simulations*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	54.0	m2
Galvanized Sheet	264.6	kg
Galvanized Studs	287.9	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	6.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

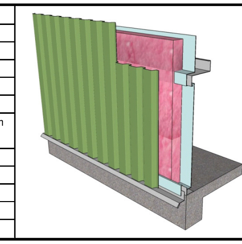
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Pre-Engineered Steel Building Exterior Wall #2 (PENG-W2)

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**
Brief Description:	Typical pre-engineered steel building exterior enclosure wall with exterior steel cladding and batt insulation (typical pre-eng. enclosure)	***Outside*** Latex paint 0.46mm galvanized commercial steel cladding 140mm fiberglass batt insulation 6mil poly (AB, VB) 1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m) ***Inside***
Quick Numbers:		
ASHRAE Standard 90.1:	R-Value: 17.2 RSI-Value: 3.0	
THERM 5.2:	R-Value: 17.9 RSI-Value: 3.2	
Wall Thickness:	178 mm (excluding Z-girt)	
Total Embodied Energy:	580 MJ/m^2	
Total Embodied GWP:	29 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	29,031	62	29,093	160	81	241	0	0	0	0	0	0	29,333	576	-	-
50	29,031	62	29,093	160	81	241	161	1	162	0	36	36	29,531	580	-600,000	-1,033

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,439	0	1,439	10	0	11	0	0	0	0	0	0	1,450	28	-	-
50	1,439	0	1,439	10	0	11	3	0	3	0	0	0	1,453	29	-30,000	-52

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	54.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Galvanized Sheet	264.6	kg
Galvanized Studs	287.9	kg
Nails	3.1	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	6.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Pre-Engineered Steel Building Exterior Wall #3 (PENG-W3)

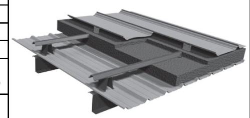
Building Component Description:

Category:	Exterior Walls
Brief Description:	Pre-engineered steel building exterior enclosure wall with exterior steel cladding, 150mm rigid insulation, and interior steel liner sheet (advanced pre-eng. enclosure)

Quick Numbers:

ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A
BEHLEN Industries LP:	R-Value: 21.0 RSI-Value: 3.7
Wall Thickness:	226 mm (excluding Z-girt)
Total Embodied Energy:	1,312 MJ/m^2
Total Embodied GWP:	59 kg of CO_2 eq./m^2

Assembly Layers
Outside
Latex paint
0.46mm galvanized commercial steel cladding
150mm extruded polystyrene rigid insulation
1.21mm heavy-duty galvanized steel furring channels @ 1,200mm o/c (self-weight: 0.82 kg/m)
0.46mm galvanized commercial steel cladding (AB, VB)
Latex paint
1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
Inside



Rendering & R-value courtesy of BEHLEN Industries LP *http://www.behlen.ca/*

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	66,041	64	66,105	160	134	294	0	0	0	0	0	0	66,399	1,304	-	-
50	66,041	64	66,105	160	134	294	321	3	324	0	62	62	66,785	1,312	-900,000	-1,549

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	2,970	0	2,971	10	0	11	0	0	0	0	0	0	2,981	59	-	-
50	2,970	0	2,971	10	0	11	6	0	6	0	0	0	2,988	59	-50,000	-86

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Extruded Polystyrene	313.0	m2 (25mm)
Galvanized Sheet	565.6	kg
Galvanized Studs	287.9	kg
Nails	3.1	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	13.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Pre-Engineered Steel Building Exterior Wall #4 (PENG-W4)

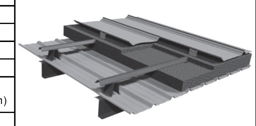
Building Component Description:

Category:	Exterior Walls
Brief Description:	Pre-engineered steel building exterior enclosure wall with exterior steel cladding, 250mm rigid insulation, and interior steel liner sheet (advanced pre-eng. enclosure)

Quick Numbers:

ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A
BEHLEN Industries LP:	R-Value: 35.0 RSI-Value: 6.2
Wall Thickness:	326 mm (excluding Z-girt)
Total Embodied Energy:	1,610 MJ/m^2
Total Embodied GWP:	74 kg of CO_2 eq./m^2

Assembly Layers
Outside
Latex paint
0.46mm galvanized commercial steel cladding
250mm extruded polystyrene rigid insulation
1.21mm heavy-duty galvanized steel furring channels @ 1,200mm o/c (self-weight: 0.82 kg/m)
0.46mm galvanized commercial steel cladding (AB, VB)
Latex paint
1.90mm galvanized 200mm Z-girts @ 1,200mm o/c (self-weight: 6.3 kg/m)
Inside



Rendering & R-value courtesy of BEHLEN Industries LP *http://www.behlen.ca/*

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	81,208	64	81,272	160	158	318	0	0	0	0	0	0	81,590	1,602	-	-
50	81,208	64	81,272	160	158	318	321	3	324	0	81	82	81,996	1,610	-2,000,000	-3,442

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	3,746	0	3,746	10	0	11	0	0	0	0	0	0	3,757	74	-	-
50	3,746	0	3,746	10	0	11	6	0	6	0	0	0	3,763	74	-110,000	-189

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Extruded Polystyrene	521.6	m2 (25mm)
Galvanized Sheet	565.6	kg
Galvanized Studs	287.9	kg
Nails	3.1	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	13.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

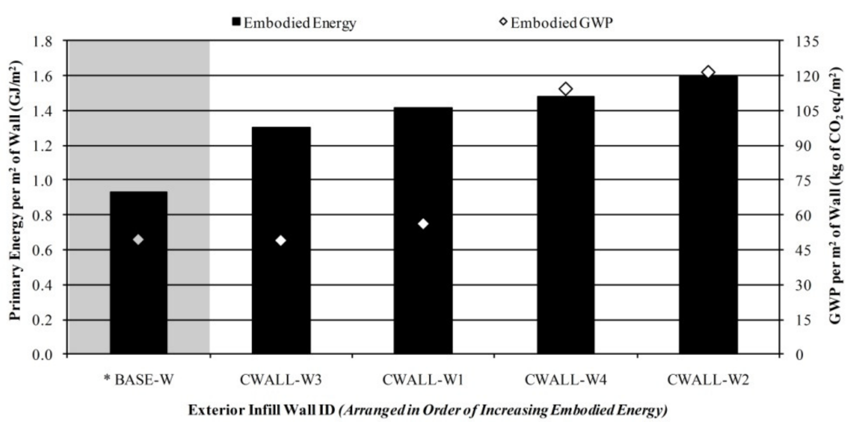
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Opaque Curtainwall Enclosures

This section contains a detailed description of each opaque curtainwall enclosure (CWALL) that was examined in this study (4 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

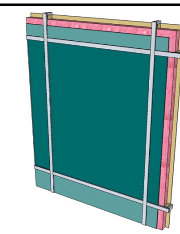
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various walls in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Opaque Curtainwall Enclosure #1 (CWALL-W1)

Building Component Description:

		Assembly Layers
Category:	Exterior Walls	***Outside***
Brief Description:	Self-supported aluminum curtainwall with painted metal spandrel panel and insulated metal backpan	Painted metal spandrel panel (WB)
		Self-supporting aluminum curtainwall grid system with thermal break
		(100mm deep mullions spaced 2m o/c vertically and 1.5m o/c horizontally)
Quick Numbers:		90mm high density fiberglass insulation
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 6.3 RSI-Value: 1.1	Metal backpan (AB, VB)
		Inside
Wall Thickness:	100 mm	
Total Embodied Energy:	1,414 MJ/m^2	
Total Embodied GWP:	56 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	70,306	575	70,881	0	1,039	1,039	0	0	0	0	0	0	71,920	1,412	-	-
50	70,306	575	70,881	0	1,039	1,039	0	0	0	0	67	67	71,987	1,414	4,900,000	8,434

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,851	1	2,852	0	2	2	0	0	0	0	0	0	2,854	56	-	-
50	2,851	1	2,852	0	2	2	0	0	0	0	0	0	2,854	56	270,000	465

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	850.4	kg
Batt. Fiberglass	378.9	m2 (25mm)
EPDM membrane	36.4	kg
Galvanized Sheet	346.6	kg
Screws Nuts & Bolts	22.0	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

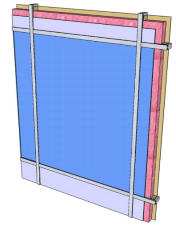
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Opaque Curtainwall Enclosure #2 (CWALL-W2)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Self-supported aluminum curtainwall with opaque glazing spandrel panel and insulated metal backpan	Opaque glazing spandrel panel (WB)
		(one pane of 6mm glazing)
		Self-supporting aluminum curtainwall grid system with thermal break
Quick Numbers:		*(100mm deep mullions spaced 2m o/c vertically and 1.5m o/c horizontally)*
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 6.3 RSI-Value: 1.1	90mm high density fiberglass insulation
		Metal backpan (AB, VB)
Wall Thickness:	100 mm	*Inside*
Total Embodied Energy:	1,590 MJ/m^2	
Total Embodied GWP:	122 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)															Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	78,205	810	79,016	0	1,718	1,718	0	0	0	0	0	0	80,734	1,586	-	-
50	78,205	810	79,016	0	1,718	1,718	0	0	0	0	205	205	80,939	1,590	4,900,000	8,434

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	6,189	1	6,190	0	3	3	0	0	0	0	0	0	6,193	122	-	-
50	6,189	1	6,190	0	3	3	0	0	0	0	0	0	6,194	122	270,000	465

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	621.2	kg
Batt. Fiberglass	378.9	m2 (25mm)
EPDM membrane	36.4	kg
Galvanized Sheet	225.3	kg
Glazing Panel	1,997.9	kg
Screws Nuts & Bolts	22.0	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

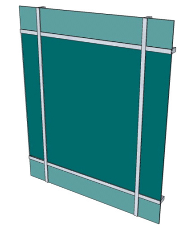
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Opaque Curtainwall Enclosure #3 (CWALL-W3)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Self-supported aluminum curtainwall with painted metal spandrel panel and no insulated metal backpan	Painted metal spandrel panel (AB, VB, WB)
		Self-supporting aluminum curtainwall grid system with thermal break
Quick Numbers:		*(100mm deep mullions spaced 2m o/c vertically and 1.5m o/c horizontally)*
		Inside
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 0.9 RSI-Value: 0.2	
Wall Thickness:	100 mm	
Total Embodied Energy:	1,300 MJ/m^2	
Total Embodied GWP:	49 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	64,602	541	65,143	0	1,017	1,017	0	0	0	0	0	0	66,160	1,299	-	-
50	64,602	541	65,143	0	1,017	1,017	0	0	0	0	49	49	66,209	1,300	* N/A	* N/A

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,483	1	2,484	0	2	2	0	0	0	0	0	0	2,486	49	-	-
50	2,483	1	2,484	0	2	2	0	0	0	0	0	0	2,486	49	* N/A	* N/A

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

** Thermal resistance and thermal mass of wall was too low to get an accurate evaluation of operating energy from computer simulations*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	850.4	kg
EPDM membrane	36.4	kg
Galvanized Sheet	346.6	kg
Screws Nuts & Bolts	22.0	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

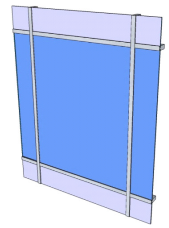
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Opaque Curtainwall Enclosure #4 (CWALL-W4)

Building Component Description:

Category:	Exterior Walls	Assembly Layers
		Outside
Brief Description:	Self-supported aluminum curtainwall with opaque glazing spandrel panel and no insulated metal backpan	Opaque glazing spandrel panel (AB, VB, WB)
		(one pane of 6mm glazing)
		Self-supporting aluminum curtainwall grid system with thermal break
Quick Numbers:		*(100mm deep mullions spaced 2m o/c vertically and 1.5m o/c horizontally)*
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 1.0 RSI-Value: 0.2	***Inside***
Wall Thickness:	100 mm	
Total Embodied Energy:	1,476 MJ/m^2	
Total Embodied GWP:	114 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	72,502	776	73,277	0	1,696	1,696	0	0	0	0	0	0	74,973	1,472	-	-
50	72,502	776	73,277	0	1,696	1,696	0	0	0	0	187	187	75,160	1,476	* N/A	* N/A

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,821	1	5,823	0	3	3	0	0	0	0	0	0	5,826	114	-	-
50	5,821	1	5,823	0	3	3	0	0	0	0	0	0	5,826	114	* N/A	* N/A

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Net wall area of baseline retail building (gross wall area - openings) = 581.0 m^2

** Thermal resistance and thermal mass of wall was too low to get an accurate evaluation of operating energy from computer simulations*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	621.2	kg
EPDM membrane	36.4	kg
Galvanized Sheet	225.3	kg
Glazing Panel	1,997.9	kg
Screws Nuts & Bolts	22.0	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Appendix B-2

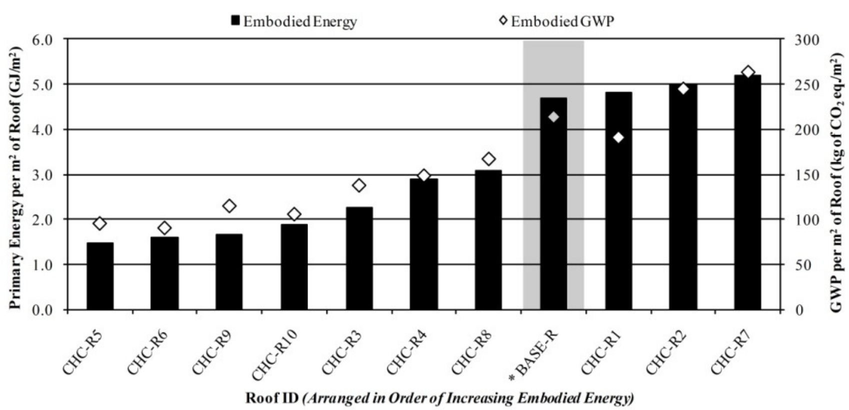
LCA Data for Roofs

LCA Data for Concrete Hollow Core Roofs

This section contains a detailed description of each concrete hollow core (CHC) roof that was examined in this study (10 in total). The assembly layers are listed for each roof, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each roof is also included. In each case, the results were calculated for an area of roof equal to 57.8 m^2, which represents a typical bay size for a single-storey retail building with this type of roof system. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

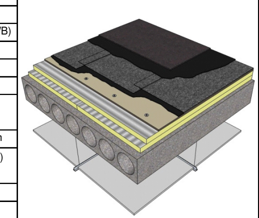
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various roofs in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Concrete Hollow Core Roof #1 (CHC-R1)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Concrete hollow core roof slab with continuous 75mm polyisocyanurate insulation and SBS modified bitumen membrane roof assembly	SBS modified bitumen membrane cap sheet (WB)
		Roofing asphalt
		Basesheet (modeled as #15 organic felt)
		Roofing asphalt
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 22.6 RSI-Value: 4.0	200mm concrete hollow core roof slab (AB, VR) (9% flyash, 45+ MPa, typical reinforcement)
Roof Thickness:	300 mm (excluding drop ceiling)	
Span:	Range: 3 m to 14 m Design: 7.6 m	16mm suspended acoustical ceiling
Specified Design Loads:	DL 3.4 kPa SL 1.1 kPa	Misc. fasteners, nails, and galvanized sheet
Total Embodied Energy:	4,803 MJ/m^2	*Inside*
Total Embodied GWP:	190 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	122,304	1,134	123,438	933	2,046	2,979	0	0	0	0	0	0	126,417	2,189	-	-
50	122,304	1,134	123,438	933	2,046	2,979	149,882	306	150,188	1	836	838	277,443	4,803	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	6,939	2	6,941	65	3	69	0	0	0	0	0	0	7,010	121	-	-
50	6,939	2	6,941	65	3	69	3,988	1	3,989	0	2	2	11,000	190	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	521.6	m2
13mm Moisture Resistant Gypsum Board	63.5	m2
16mm Gypsum Fibre Gypsum Board	63.5	m2
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Galvanized Sheet	155.7	kg
Isocyanurate	179.2	m2 (25mm)
Joint Compound	63.4	kg
Modified Bitumen membrane	2,101.2	kg
Nails	30.3	kg
Paper Tape	0.7	kg
Rebar, Rod, Light Sections	197.2	kg
Roofing Asphalt	1,060.2	kg
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

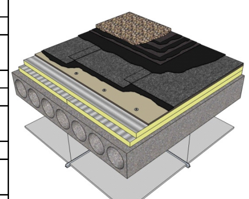
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #2 (CHC-R2)

Building Component Description:

Category:	Roofs
Brief Description:	Concrete hollow core roof slab with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7
THERM 5.2:	R-Value: 22.8 RSI-Value: 4.0
Roof Thickness:	325 mm (excluding drop ceiling)
Span:	Range: 3 m to 14 m Design: 7.6 m
Specified Design Loads:	DL 3.8 kPa SL 1.1 kPa
Total Embodied Energy:	5,002 MJ/m^2
Total Embodied GWP:	244 kg of CO_2 eq./m^2

Assembly Layers
Outside
Ballast (aggregate stone)
4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
Basesheet (modeled as #15 organic felt)
Roofing asphalt
12mm coverboard *(modeled as moisture resistant gypsum)*
Continuous 75mm polyisocyanurate insulation
200mm concrete hollow core roof slab (AB, VR) (9% flyash, 45+ MPa, typical reinforcement)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	141,750	1,178	142,928	933	1,956	2,889	0	0	0	0	0	0	145,817	2,525	-	-
50	141,750	1,178	142,928	933	1,956	2,889	141,720	490	142,210	1	873	874	288,901	5,002	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	8,399	2	8,401	65	3	69	0	0	0	0	0	0	8,469	147	-	-
50	8,399	2	8,401	65	3	69	5,635	1	5,636	0	2	2	14,107	244	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	521.6	m2
13mm Moisture Resistant Gypsum Board	63.5	m2
16mm Gypsum Fibre Gypsum Board	63.5	m2
Ballast (aggregate stone)	4,993.0	kg
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Galvanized Sheet	203.2	kg
Isocyanurate	179.2	m2 (25mm)
Joint Compound	63.4	kg
Nails	30.3	kg
Paper Tape	0.7	kg
Rebar, Rod, Light Sections	197.2	kg
Roofing Asphalt	1,927.6	kg
Type III Glass Felt	1,043.2	m2
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

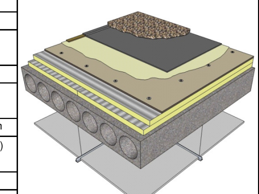
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #3 (CHC-R3)

Building Component Description:

Category:	Roofs
Brief Description:	Concrete hollow core roof slab with continuous 75mm polyisocyanurate insulation and EPDM roof assembly
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7
THERM 5.2:	R-Value: 22.8 RSI-Value: 4.0
Roof Thickness:	325 mm (excluding drop ceiling)
Span:	Range: 3 m to 14 m Design: 7.6 m
Specified Design Loads:	DL 3.8 kPa SL 1.1 kPa
Total Embodied Energy:	2,255 MJ/m^2
Total Embodied GWP:	137 kg of CO_2 eq./m^2

Assembly Layers
Outside
Ballast (aggregate stone)
EPDM cap sheet (WB) (includes wood nailing strips)
Bonding agent (modeled as 6mil poly)
12mm coverboard *(modeled as moisture resistant gypsum)*
Continuous 75mm polyisocyanurate insulation
200mm concrete hollow core roof slab (AB, VR) (9% flyash, 45+ MPa, typical reinforcement)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	66,358	1,178	67,537	933	2,235	3,167	0	0	0	0	0	0	70,704	1,224	-	-
50	66,358	1,178	67,537	933	2,235	3,167	57,921	689	58,610	1	910	911	130,226	2,255	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,299	2	5,302	65	4	69	0	0	0	0	0	0	5,371	93	-	-
50	5,299	2	5,302	65	4	69	2,560	1	2,562	0	2	2	7,934	137	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	63.5	m2
16mm Gypsum Fibre Gypsum Board	63.5	m2
6 mil Polyethylene	58.9	m2
Ballast (aggregate stone)	14,978.9	kg
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
EPDM membrane	541.6	kg
Galvanized Sheet	159.4	kg
Isocyanurate	179.2	m2 (25mm)
Joint Compound	126.8	kg
Nails	5.9	kg
Paper Tape	1.5	kg
Rebar, Rod, Light Sections	197.2	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	1.2	m2 (9mm)
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

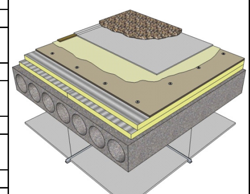
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #4 (CHC-R4)

Building Component Description:

Category:	Roofs	**Assembly Layers**
		Outside
Brief Description:	Concrete hollow core roof slab with continuous 75mm polyisocyanurate insulation and PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 22.8 RSI-Value: 4.0	200mm concrete hollow core roof slab (AB, VR) (9% flyash, 45+ MPa, typical reinforcement)
Roof Thickness:	325 mm (excluding drop ceiling)	16mm suspended acoustical ceiling
Span:	Range: 3 m to 14 m Design: 7.6 m	Misc. fasteners, nails, and galvanized sheet
Specified Design Loads:	DL 3.8 kPa SL 1.1 kPa	***Inside***
Total Embodied Energy:	2,889 MJ/m^2	
Total Embodied GWP:	148 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	73,412	1,208	74,620	933	2,381	3,314	0	0	0	0	0	0	77,934	1,349	-	-
50	73,412	1,208	74,620	933	2,381	3,314	87,120	860	87,981	1	924	925	166,840	2,889	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,415	2	5,418	65	4	69	0	0	0	0	0	0	5,487	95	-	-
50	5,415	2	5,418	65	4	69	3,063	2	3,065	0	2	2	8,554	148	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	63.5	m2
16mm Gypsum Fibre Gypsum Board	63.5	m2
6 mil Polyethylene	58.9	m2
Ballast (aggregate stone)	14,978.9	kg
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Galvanized Sheet	153.5	kg
Isocyanurate	179.2	m2 (25mm)
Joint Compound	126.8	kg
Nails	7.1	kg
Paper Tape	1.5	kg
PVC membrane	1,442.2	kg
Rebar, Rod, Light Sections	197.2	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	1.2	m2 (9mm)
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

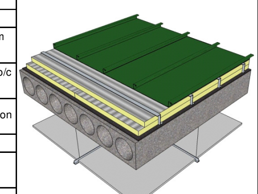
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #5 (CHC-R5)

Building Component Description:

Category:	Roofs	**Assembly Layers**
		Outside
Brief Description:	Concrete hollow core roof slab with non-continuous 75mm polyisocyanurate insulation and standing seam steel roof assembly	Alkyd based paint
		Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
		1.21mm galvanized 92mm Z-girts @ 1,200mm o/c (self-weight: 1.4 kg/m)
Quick Numbers:		Non-continuous 75mm polyisocyanurate insulation
ASHRAE Standard 90.1:	R-Value: 17.9 RSI-Value: 3.1	
THERM 5.2:	R-Value: 19.2 RSI-Value: 3.4	Modified bitumen membrane (AB, VB)
Roof Thickness:	330 mm (excluding drop ceiling)	200mm concrete hollow core roof slab (9% flyash, 45+ MPa, typical reinforcement)
Span:	Range: 3 m to 14 m Design: 7.6 m	
Specified Design Loads:	DL 3.3 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	1,477 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	95 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	71,609	1,087	72,696	933	1,779	2,711	0	0	0	0	0	0	75,407	1,306	-	-
50	71,609	1,087	72,696	933	1,779	2,711	9,162	29	9,191	1	731	733	85,331	1,477	100,000	171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,297	2	5,299	65	3	68	0	0	0	0	0	0	5,367	93	-	-
50	5,297	2	5,299	65	3	68	127	0	127	0	1	1	5,496	95	10,000	17

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	63.5	m2
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Foam Polyisocyanurate	178.0	m2 (25mm)
Galvanized Sheet	472.7	kg
Galvanized Studs	70.7	kg
Joint Compound	63.4	kg
Modified Bitumen membrane	203.3	kg
Nails	4.2	kg
Paper Tape	0.7	kg
Rebar, Rod, Light Sections	197.2	kg
Screws Nuts & Bolts	0.6	kg
Solvent Based Alkyd Paint	48.4	L
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

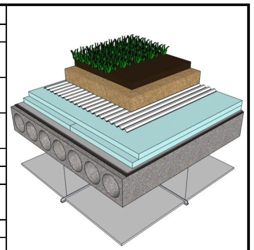
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #6 (CHC-R6)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Concrete hollow core roof slab with continuous 100mm extruded polystyrene rigid insulation and green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Continuous 100mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Protection barrier (modeled as 6mil poly)
THERM 5.2:	R-Value: 22.4 RSI-Value: 3.9	Modified bitumen membrane (AB, VB)
Roof Thickness:	475 mm (excluding drop ceiling)	200mm concrete hollow core roof slab (9% flyash, 45+ MPa, typical reinforcement)
Span:	Range: 3 m to 14 m Design: 7.6 m	
Specified Design Loads:	DL 5.0 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	1,583 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	90 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	60,558	1,054	61,613	933	1,786	2,718	0	0	0	0	0	0	64,331	1,114	-	-
50	60,558	1,054	61,613	933	1,786	2,718	26,300	72	26,372	1	734	735	91,438	1,583	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,407	2	4,409	65	3	68	0	0	0	0	0	0	4,477	78	-	-
50	4,407	2	4,409	65	3	68	731	0	732	0	1	1	5,210	90	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	63.5	m2
6 mil Polyethylene	61.3	m2
Ballast (aggregate stone)	249.6	kg
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Extruded Polystyrene	236.7	m2 (25mm)
Galvanized Sheet	134.3	kg
Joint Compound	63.4	kg
Modified Bitumen membrane	244.9	kg
Nails	4.2	kg
Paper Tape	0.7	kg
PVC membrane	294.3	kg
Rebar, Rod, Light Sections	197.2	kg
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

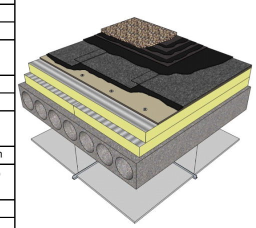
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #7 (CHC-R7)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Concrete hollow core roof slab with continuous 150mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 42.1 RSI-Value: 7.4	Continuous 150mm polyisocyanurate insulation
Roof Thickness:	400 mm (excluding drop ceiling)	200mm concrete hollow core roof slab (AB, VR) (9% flyash, 45+ MPa, typical reinforcement)
Span:	Range: 3 m to 14 m Design: 7.6 m	
Specified Design Loads:	DL 3.8 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	5,184 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	263 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	152,239	1,184	153,423	933	1,991	2,924	0	0	0	0	0	0	156,347	2,707	-	-
50	152,239	1,184	153,423	933	1,991	2,924	141,720	490	142,210	1	886	887	299,444	5,184	-1,200,000	-2,048

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	9,468	2	9,471	65	3	69	0	0	0	0	0	0	9,539	165	-	-
50	9,468	2	9,471	65	3	69	5,635	1	5,636	0	2	2	15,177	263	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	521.6	m2
13mm Moisture Resistant Gypsum Board	63.5	m2
16mm Gypsum Fibre Gypsum Board	63.5	m2
Ballast (aggregate stone)	4,993.0	kg
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Galvanized Sheet	203.2	kg
Isocyanurate	358.4	m2 (25mm)
Joint Compound	63.4	kg
Nails	30.3	kg
Paper Tape	0.7	kg
Rebar, Rod, Light Sections	197.2	kg
Roofing Asphalt	1,927.6	kg
Type III Glass Felt	1,043.2	m2
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

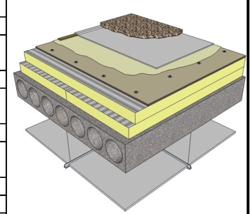
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #8 (CHC-R8)

Building Component Description:

Category:	Roofs
Brief Description:	Concrete hollow core roof slab with continuous 150mm polyisocyanurate insulation and PVC roof assembly
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9
THERM 5.2:	R-Value: 42.1 RSI-Value: 7.4
Roof Thickness:	400 mm (excluding drop ceiling)
Span:	Range: 3 m to 14 m Design: 7.6 m
Specified Design Loads:	DL 3.8 kPa SL 1.1 kPa
Total Embodied Energy:	3,071 MJ/m^2
Total Embodied GWP:	167 kg of CO_2 eq./m^2

Assembly Layers
Outside
Ballast (aggregate stone)
PVC membrane cap sheet (WB) (includes wood nailing strips)
Bonding agent (modeled as 6mil poly)
12mm coverboard *(modeled as moisture resistant gypsum)*
Continuous 150mm polyisocyanurate insulation
200mm concrete hollow core roof slab (AB, VR) (9% flyash, 45+ MPa, typical reinforcement)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	83,901	1,214	85,115	933	2,417	3,350	0	0	0	0	0	0	88,465	1,532	-	-
50	83,901	1,214	85,115	933	2,417	3,350	87,120	860	87,981	1	936	938	177,383	3,071	-1,200,000	-2,048

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	6,485	2	6,488	65	4	69	0	0	0	0	0	0	6,557	114	-	-
50	6,485	2	6,488	65	4	69	3,063	2	3,065	0	2	2	9,624	167	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = *57.8* m^2 *(Span x Width = 7.6m x 7.6m = 57.8m^2)*

Net roof area of baseline retail building (gross roof area - openings) = *586.0* m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	63.5	m2
16mm Gypsum Fibre Gypsum Board	63.5	m2
6 mil Polyethylene	58.9	m2
Ballast (aggregate stone)	14,978.9	kg
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Galvanized Sheet	153.5	kg
Isocyanurate	358.4	m2 (25mm)
Joint Compound	126.8	kg
Nails	7.1	kg
Paper Tape	1.5	kg
PVC membrane	1,442.2	kg
Rebar, Rod, Light Sections	197.2	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	1.2	m2 (9mm)
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

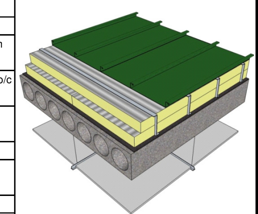
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #9 (CHC-R9)

Building Component Description:

Category:	Roofs
Brief Description:	Concrete hollow core roof slab with non-continuous 150mm polyisocyanurate insulation and standing seam steel roof assembly
Quick Numbers:	
ASHRAE Standard 90.1:	R-Value: 29.4 RSI-Value: 5.2
THERM 5.2:	R-Value: 30.9 RSI-Value: 5.4
Roof Thickness:	388 mm (excluding drop ceiling)
Span:	Range: 3 m to 14 m Design: 7.6 m
Specified Design Loads:	DL 3.3 kPa SL 1.1 kPa
Total Embodied Energy:	1,671 MJ/m^2
Total Embodied GWP:	115 kg of CO_2 eq./m^2

Assembly Layers
Outside
Alkyd based paint
Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
1.21mm galvanized 150mm Z-girts @ 1,200mm o/c (self-weight: 2.0 kg/m)
Non-continuous 150mm polyisocyanurate insulation
Modified bitumen membrane (AB, VB)
200mm concrete hollow core roof slab (9% flyash, 45+ MPa, typical reinforcement)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	82,750	1,094	83,843	933	1,817	2,750	0	0	0	0	0	0	86,594	1,499	-	-
50	82,750	1,094	83,843	933	1,817	2,750	9,162	29	9,191	1	745	746	96,530	1,671	-800,000	-1,365

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	6,418	2	6,420	65	3	68	0	0	0	0	0	0	6,488	112	-	-
50	6,418	2	6,420	65	3	68	127	0	127	0	1	2	6,617	115	-40,000	-68

Embodied energy (and GWP) numbers are based on an area of roof = *57.8* m^2 *(Span x Width = 7.6m x 7.6m = 57.8m^2)*

Net roof area of baseline retail building (gross roof area - openings) = *586.0* m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	63.5	m2
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Foam Polyisocyanurate	356.0	m2 (25mm)
Galvanized Sheet	472.7	kg
Galvanized Studs	101.0	kg
Joint Compound	63.4	kg
Modified Bitumen membrane	203.3	kg
Nails	4.2	kg
Paper Tape	0.7	kg
Rebar, Rod, Light Sections	197.2	kg
Screws Nuts & Bolts	0.6	kg
Solvent Based Alkyd Paint	48.4	L
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

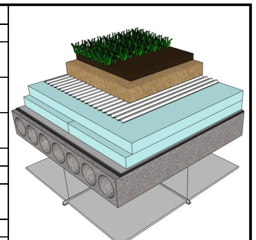
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Hollow Core Roof #10 (CHC-R10)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Concrete hollow core roof slab with continuous 200mm extruded polystyrene rigid insulation and green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Continuous 200mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	Protection barrier (modeled as 6mil poly)
THERM 5.2:	R-Value: 42.1 RSI-Value: 7.4	Modified bitumen membrane (AB, VB)
Roof Thickness:	575 mm (excluding drop ceiling)	200mm concrete hollow core roof slab (9% flyash, 45+ MPa, typical reinforcement)
Span:	Range: 3 m to 14 m Design: 7.6 m	
Specified Design Loads:	DL 5.0 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	1,882 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	105 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	77,762	1,055	78,817	933	1,813	2,746	0	0	0	0	0	0	81,563	1,412	-	-
50	77,762	1,055	78,817	933	1,813	2,746	26,300	72	26,372	1	756	757	108,692	1,882	-1,200,000	-2,048

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	5,286	2	5,288	65	3	68	0	0	0	0	0	0	5,357	93	-	-
50	5,286	2	5,288	65	3	68	731	0	732	0	1	2	6,090	105	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	63.5	m2
6 mil Polyethylene	61.3	m2
Ballast (aggregate stone)	249.6	kg
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Extruded Polystyrene	473.3	m2 (25mm)
Galvanized Sheet	134.3	kg
Joint Compound	63.4	kg
Modified Bitumen membrane	244.9	kg
Nails	4.2	kg
Paper Tape	0.7	kg
PVC membrane	294.3	kg
Rebar, Rod, Light Sections	197.2	kg
Welded Wire Mesh / Ladder Wire	88.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

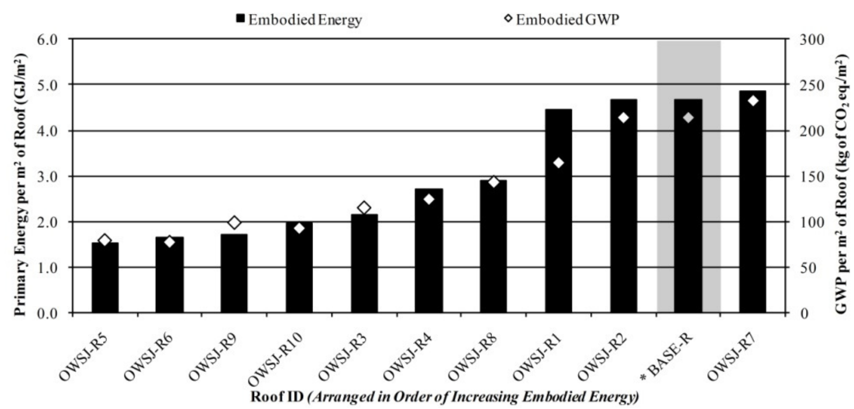
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Open Web Steel Joist Roofs

This section contains a detailed description of each open web steel joist (OWSJ) roof that was examined in this study (11 in total). The assembly layers are listed for each roof, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each roof is also included. In each case, the results were calculated for an area of roof equal to 69.2 m^2, which represents a typical bay size for a single-storey retail building with this type of roof system. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various roofs in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Baseline Retail Building Roof (BASE-R)

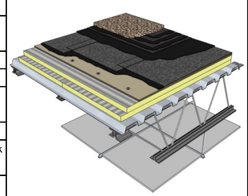
Building Component Description:

Category:	Roofs
Brief Description:	OWSJ and metal deck with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly

Quick Numbers:

ASHRAE Standard 90.1:	R-Value: 20.8	RSI-Value: 3.7
THERM 5.2:	R-Value: 21.5	RSI-Value: 3.8
Roof Thickness:	713 mm (excluding drop ceiling)	
Span:	Range: 3 m to 46 m	Design: 9.1 m
Specified Design Loads:	DL 1.5 kPa	SL 1.1 kPa
Total Embodied Energy:	4,684 MJ/m²	
Total Embodied GWP:	213 kg of CO_2 eq./m²	

Assembly Layers
Outside
Ballast (aggregate stone)
4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
Basesheet (modeled as #15 organic felt)
Roofing asphalt
12mm coverboard (modeled as moisture resistant gypsum)
Continuous 75mm polyisocyanurate insulation
39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	177,710	413	178,123	631	1,051	1,683	0	0	0	0	0	0	179,805	2,600	-	-
50	177,710	413	178,123	631	1,051	1,683	143,295	495	143,790	1	336	336	323,932	4,684	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	9,005	1	9,006	41	1	43	0	0	0	0	0	0	9,049	131	-	-
50	9,005	1	9,006	41	1	43	5,698	1	5,699	0	1	1	14,748	213	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.9	m2
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
Ballast (aggregate stone)	5,274.4	kg
Galvanized Decking	684.5	kg
Galvanized Sheet	243.0	kg
Isocyanurate	214.6	m2 (25mm)
Joint Compound	75.9	kg
Nails	36.3	kg
Open Web Joists	596.4	kg
Paper Tape	0.9	kg
Roofing Asphalt	2,093.8	kg
Type III Glass Felt	1,103.8	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Open Web Steel Joist Roof #1 (OWSJ-R1)

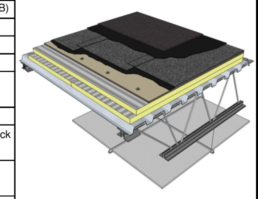
Building Component Description:

Category:	Roofs
Brief Description:	OWSJ and metal deck with continuous 75mm polyisocyanurate insulation and SBS modified bitumen membrane roof assembly

Quick Numbers:

ASHRAE Standard 90.1:	R-Value: 20.8	RSI-Value: 3.7
THERM 5.2:	R-Value: 21.3	RSI-Value: 3.7
Roof Thickness:	688 mm (excluding drop ceiling)	
Span:	Range: 3 m to 46 m	Design: 9.1 m
Specified Design Loads:	DL 1.1 kPa	SL 1.1 kPa
Total Embodied Energy:	4,464 MJ/m²	
Total Embodied GWP:	164 kg of CO_2 eq./m²	

Assembly Layers
Outside
SBS modified bitumen membrane cap sheet (WB)
Roofing asphalt
Basesheet (modeled as #15 organic felt)
Roofing asphalt
12mm coverboard (modeled as moisture resistant gypsum)
Continuous 75mm polyisocyanurate insulation
39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	154,426	360	154,786	631	1,160	1,791	0	0	0	0	0	0	156,577	2,264	-	-
50	154,426	360	154,786	631	1,160	1,791	151,547	309	151,856	0	292	292	308,726	4,464	-100,000	-171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	7,258	1	7,259	41	1	43	0	0	0	0	0	0	7,301	106	-	-
50	7,258	1	7,259	41	1	43	4,032	1	4,033	0	1	1	11,335	164	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.9	m2
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
Galvanized Decking	684.5	kg
Galvanized Sheet	186.2	kg
Isocyanurate	214.6	m2 (25mm)
Joint Compound	75.9	kg
Modified Bitumen membrane	2,219.6	kg
Nails	36.3	kg
Open Web Joists	596.4	kg
Paper Tape	0.9	kg
Roofing Asphalt	1,151.6	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

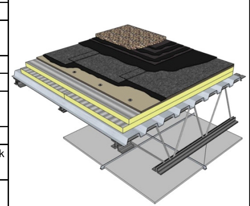
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Open Web Steel Joist Roof #2 (OWSJ-R2)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
		Ballast (aggregate stone)
Brief Description:	OWSJ and metal deck with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
		Roofing asphalt
Quick Numbers:		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 21.5 RSI-Value: 3.8	Continuous 75mm polyisocyanurate insulation
Roof Thickness:	713 mm (excluding drop ceiling)	39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
Span:	Range: 3 m to 46 m Design: 9.1 m	
Specified Design Loads:	DL 1.5 kPa SL 1.1 kPa	550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
Total Embodied Energy:	4,684 MJ/m^2	
Total Embodied GWP:	213 kg of CO_2 eq./m^2	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	177,710	413	178,123	631	1,051	1,683	0	0	0	0	0	0	179,805	2,600	-	-
50	177,710	413	178,123	631	1,051	1,683	143,295	495	143,790	1	336	336	323,932	4,684	-100,000	-171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	9,005	1	9,006	41	1	43	0	0	0	0	0	0	9,049	131	-	-
50	9,005	1	9,006	41	1	43	5,698	1	5,699	0	1	1	14,748	213	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.9	m2
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
Ballast (aggregate stone)	5,274.4	kg
Galvanized Decking	684.5	kg
Galvanized Sheet	243.0	kg
Isocyanurate	214.6	m2 (25mm)
Joint Compound	75.9	kg
Nails	36.3	kg
Open Web Joists	596.4	kg
Paper Tape	0.9	kg
Roofing Asphalt	2,093.8	kg
Type III Glass Felt	1,103.8	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

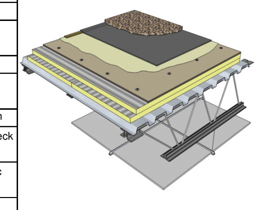
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Open Web Steel Joist Roof #3 (OWSJ-R3)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
		Ballast (aggregate stone)
Brief Description:	OWSJ and metal deck with continuous 75mm polyisocyanurate insulation and EPDM roof assembly	EPDM cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 21.5 RSI-Value: 3.8	39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
Roof Thickness:	713 mm (excluding drop ceiling)	
Span:	Range: 3 m to 46 m Design: 9.1 m	550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
Specified Design Loads:	DL 1.5 kPa SL 1.1 kPa	
Total Embodied Energy:	2,162 MJ/m^2	16mm suspended acoustical ceiling
Total Embodied GWP:	115 kg of CO_2 eq./m^2	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	87,438	413	87,852	631	1,385	2,016	0	0	0	0	0	0	89,868	1,299	-	-
50	87,438	413	87,852	631	1,385	2,016	58,565	696	59,261	1	380	381	149,510	2,162	-100,000	-171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,294	1	5,295	41	2	43	0	0	0	0	0	0	5,338	77	-	-
50	5,294	1	5,295	41	2	43	2,589	1	2,590	0	1	1	7,929	115	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	70.5	m2
Ballast (aggregate stone)	15,823.1	kg
EPDM membrane	568.0	kg
Galvanized Decking	684.5	kg
Galvanized Sheet	190.6	kg
Isocyanurate	214.6	m2 (25mm)
Joint Compound	151.9	kg
Nails	7.1	kg
Open Web Joists	596.4	kg
Paper Tape	1.7	kg
Small Dimension Softwood Lumber, kiln-dried	0.2	m3
Softwood Plywood	1.4	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

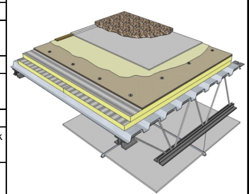
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Open Web Steel Joist Roof #4 (OWSJ-R4)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	OWSJ and metal deck with continuous 75mm polyisocyanurate insulation and PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 21.5 RSI-Value: 3.8	39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
Roof Thickness:	713 mm (excluding drop ceiling)	
Span:	Range: 3 m to 46 m Design: 9.1 m	550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
Specified Design Loads:	DL 1.5 kPa SL 1.1 kPa	
Total Embodied Energy:	2,717 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	124 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)															Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²			
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	95,885	448	96,333	631	1,561	2,192	0	0	0	0	0	0	98,525	1,425	-	-
50	95,885	448	96,333	631	1,561	2,192	88,088	870	88,958	1	397	397	187,880	2,717	-100,000	-171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,433	1	5,434	41	2	44	0	0	0	0	0	0	5,478	79	-	-
50	5,433	1	5,434	41	2	44	3,097	2	3,099	0	1	1	8,577	124	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	70.5	m2
Ballast (aggregate stone)	15,823.1	kg
Galvanized Decking	684.5	kg
Galvanized Sheet	183.5	kg
Isocyanurate	214.6	m2 (25mm)
Joint Compound	151.9	kg
Nails	8.5	kg
Open Web Joists	596.4	kg
Paper Tape	1.7	kg
PVC membrane	1,512.6	kg
Small Dimension Softwood Lumber, kiln-dried	0.2	m3
Softwood Plywood	1.4	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

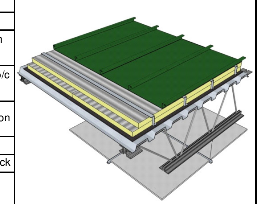
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Open Web Steel Joist Roof #5 (OWSJ-R5)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	OWSJ and metal deck with non-continuous75mm polyisocyanurate insulation and standing seam steel roof assembly	Alkyd based paint
		Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
		1.21mm galvanized 92mm Z-girts @ 1,200mm o/c (self-weight: 1.4 kg/m)
Quick Numbers:		Non-continuous 75mm polyisocyanurate insulation
ASHRAE Standard 90.1:	R-Value: 17.9 RSI-Value: 3.1	
THERM 5.2:	R-Value: 17.8 RSI-Value: 3.1	Modified bitumen membrane (AB, VB)
Roof Thickness:	718 mm (excluding drop ceiling)	39mm x 0.76mm galvanized corrugated metal deck
Span:	Range: 3 m to 46 m Design: 9.1 m	550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
Specified Design Loads:	DL 1.0 kPa SL 1.1 kPa	
Total Embodied Energy:	1,516 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	79 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	93,634	303	93,937	631	839	1,470	0	0	0	0	0	0	95,407	1,380	-	-
50	93,634	303	93,937	631	839	1,470	9,263	29	9,293	1	166	167	104,866	1,516	300,000	512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,284	1	5,285	41	1	42	0	0	0	0	0	0	5,327	77	-	-
50	5,284	1	5,285	41	1	42	129	0	129	0	0	0	5,456	79	20,000	34

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	76.1	m2
Foam Polyisocyanurate	213.1	m2 (25mm)
Galvanized Decking	684.5	kg
Galvanized Sheet	565.7	kg
Galvanized Studs	80.8	kg
Joint Compound	75.9	kg
Modified Bitumen membrane	214.7	kg
Nails	5.0	kg
Open Web Joists	596.4	kg
Paper Tape	0.9	kg
Screws Nuts & Bolts	0.7	kg
Solvent Based Alkyd Paint	49.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

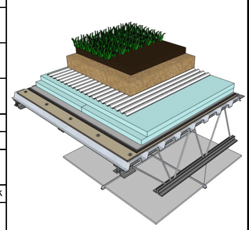
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Open Web Steel Joist Roof #6 (OWSJ-R6)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	OWSJ and metal deck with continuous 100mm extruded polystyrene rigid insulation and green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Continuous 100mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Protection barrier (modeled as 6mil poly)
THERM 5.2:	R-Value: 21.7 RSI-Value: 3.8	Modified bitumen membrane (AB, VB)
Roof Thickness:	875 mm (excluding drop ceiling)	12mm coverboard
Span:	Range: 3 m to 46 m Design: 9.1 m	*(modeled as moisture resistant gypsum)*
Specified Design Loads:	DL 2.7 kPa SL 1.1 kPa	39mm x 0.76mm galvanized corrugated metal deck
Total Embodied Energy:	1,660 MJ/m^2	550mm open web steel joists @ 1,200mm o/c (self-weight: 11.4 kg/m)
Total Embodied GWP:	77 kg of CO_2 eq./m^2	
		16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	85,939	318	86,257	631	1,059	1,690	0	0	0	0	0	0	87,947	1,272	-	-
50	85,939	318	86,257	631	1,059	1,690	26,592	73	26,665	0	227	228	114,840	1,660	-100,000	-171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,544	1	4,544	41	1	43	0	0	0	0	0	0	4,587	66	-	-
50	4,544	1	4,544	41	1	43	740	0	740	0	0	0	5,327	77	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	73.4	m2
Ballast (aggregate stone)	263.7	kg
Extruded Polystyrene	283.4	m2 (25mm)
Galvanized Decking	684.5	kg
Galvanized Sheet	160.6	kg
Joint Compound	151.9	kg
Modified Bitumen membrane	258.7	kg
Nails	5.7	kg
Open Web Joists	657.6	kg
Paper Tape	1.7	kg
PVC membrane	308.7	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

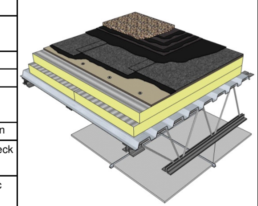
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Open Web Steel Joist Roof #7 (OWSJ-R7)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	OWSJ and metal deck with continuous 150mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 40.8 RSI-Value: 7.2	Continuous 150mm polyisocyanurate insulation
Roof Thickness:	788 mm (excluding drop ceiling)	39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
Span:	Range: 3 m to 46 m Design: 9.1 m	
Specified Design Loads:	DL 1.5 kPa SL 1.1 kPa	550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
Total Embodied Energy:	4,866 MJ/m^2	
Total Embodied GWP:	232 kg of CO_2 eq./m^2	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	190,269	420	190,689	631	1,094	1,725	0	0	0	0	0	0	192,414	2,782	-	-
50	190,269	420	190,689	631	1,094	1,725	143,295	495	143,790	1	351	351	336,556	4,866	-1,100,000	-1,877

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	10,286	1	10,287	41	1	43	0	0	0	0	0	0	10,330	149	-	-
50	10,286	1	10,287	41	1	43	5,698	1	5,699	0	1	1	16,029	232	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.9	m2
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
Ballast (aggregate stone)	5,274.4	kg
Galvanized Decking	684.5	kg
Galvanized Sheet	243.0	kg
Isocyanurate	429.2	m2 (25mm)
Joint Compound	75.9	kg
Nails	36.3	kg
Open Web Joists	596.4	kg
Paper Tape	0.9	kg
Roofing Asphalt	2,093.8	kg
Type III Glass Felt	1,103.8	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

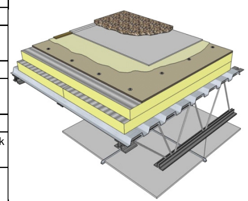
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Open Web Steel Joist Roof #8 (OWSJ-R8)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	OWSJ and metal deck with continuous 150mm polyisocyanurate insulation and PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	Continuous 150mm polyisocyanurate insulation
THERM 5.2:	R-Value: 40.8 RSI-Value: 7.2	39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
Roof Thickness:	788 mm (excluding drop ceiling)	550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
Span:	Range: 3 m to 46 m Design: 9.1 m	
Specified Design Loads:	DL 1.5 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	2,899 MJ/m^2	
Total Embodied GWP:	143 kg of CO_2 eq./m^2	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	108,444	455	108,899	631	1,603	2,235	0	0	0	0	0	0	111,134	1,607	-	-
50	108,444	455	108,899	631	1,603	2,235	88,088	870	88,958	1	412	412	200,504	2,899	-1,100,000	-1,877

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	6,714	1	6,715	41	2	44	0	0	0	0	0	0	6,759	98	-	-
50	6,714	1	6,715	41	2	44	3,097	2	3,099	0	1	1	9,858	143	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	70.5	m2
Ballast (aggregate stone)	15,823.1	kg
Galvanized Decking	684.5	kg
Galvanized Sheet	183.5	kg
Isocyanurate	429.2	m2 (25mm)
Joint Compound	151.9	kg
Nails	8.5	kg
Open Web Joists	596.4	kg
Paper Tape	1.7	kg
PVC membrane	1,512.6	kg
Small Dimension Softwood Lumber, kiln-dried	0.2	m3
Softwood Plywood	1.4	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

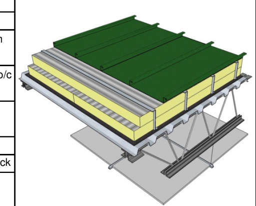
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Open Web Steel Joist Roof #9 (OWSJ-R9)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	OWSJ and metal deck with non-continuous 150mm polyisocyanurate insulation and standing seam steel roof assembly	Alkyd based paint
		Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
		1.21mm galvanized 150mm Z-girts @ 1,200mm o/c (self-weight: 2.0 kg/m)
Quick Numbers:		Non-continuous 150mm polyisocyanurate insulation
ASHRAE Standard 90.1:	R-Value: 29.4 RSI-Value: 5.2	
THERM 5.2:	R-Value: 29.4 RSI-Value: 5.2	Modified bitumen membrane (AB, VB)
Roof Thickness:	776 mm (excluding drop ceiling)	39mm x 0.76mm galvanized corrugated metal deck
Span:	Range: 3 m to 46 m Design: 9.1 m	550mm open web steel joists @ 1,200mm o/c (self-weight: 10.3 kg/m)
Specified Design Loads:	DL 1.0 kPa SL 1.1 kPa	
Total Embodied Energy:	1,712 MJ/m^2	16mm suspended acoustical ceiling
Total Embodied GWP:	98 kg of CO_2 eq./m^2	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	107,071	312	107,383	631	885	1,517	0	0	0	0	0	0	108,900	1,575	-	-
50	107,071	312	107,383	631	885	1,517	9,263	29	9,293	1	182	183	118,376	1,712	-700,000	-1,195

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	6,635	1	6,635	41	1	42	0	0	0	0	0	0	6,677	97	-	-
50	6,635	1	6,635	41	1	42	129	0	129	0	0	0	6,807	98	-30,000	-51

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	76.1	m2
Foam Polyisocyanurate	426.2	m2 (25mm)
Galvanized Decking	684.5	kg
Galvanized Sheet	565.7	kg
Galvanized Studs	121.2	kg
Joint Compound	75.9	kg
Modified Bitumen membrane	214.7	kg
Nails	5.0	kg
Open Web Joists	596.4	kg
Paper Tape	0.9	kg
Screws Nuts & Bolts	0.7	kg
Solvent Based Alkyd Paint	49.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

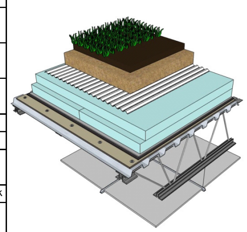
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Open Web Steel Joist Roof #10 (OWSJ-R10)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	OWSJ and metal deck with continuous 200mm extruded polystyrene rigid insulation and green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Continuous 200mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	Protection barrier (modeled as 6mil poly)
THERM 5.2:	R-Value: 41.1 RSI-Value: 7.2	Modified bitumen membrane (AB, VB)
Roof Thickness:	975 mm (excluding drop ceiling)	12mm coverboard
Span:	Range: 3 m to 46 m Design: 9.1 m	*(modeled as moisture resistant gypsum)*
Specified Design Loads:	DL 2.7 kPa SL 1.1 kPa	39mm x 0.76mm galvanized corrugated metal deck
Total Embodied Energy:	1,959 MJ/m²	550mm open web steel joists @ 1,200mm o/c (self-weight: 11.4 kg/m)
Total Embodied GWP:	92 kg of CO_2 eq./m²	
		16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	106,538	318	106,857	631	1,092	1,723	0	0	0	0	0	0	108,580	1,570	-	-
50	106,538	318	106,857	631	1,092	1,723	26,592	73	26,665	0	254	254	135,499	1,959	-1,100,000	-1,877

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,597	1	5,597	41	1	43	0	0	0	0	0	0	5,640	82	-	-
50	5,597	1	5,597	41	1	43	740	0	740	0	0	1	6,380	92	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² *(Span x Width = 9.1m x 7.6m = 69.2m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	73.4	m2
Ballast (aggregate stone)	263.7	kg
Extruded Polystyrene	566.8	m2 (25mm)
Galvanized Decking	684.5	kg
Galvanized Sheet	160.6	kg
Joint Compound	151.9	kg
Modified Bitumen membrane	258.7	kg
Nails	5.7	kg
Open Web Joists	657.6	kg
Paper Tape	1.7	kg
PVC membrane	308.7	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

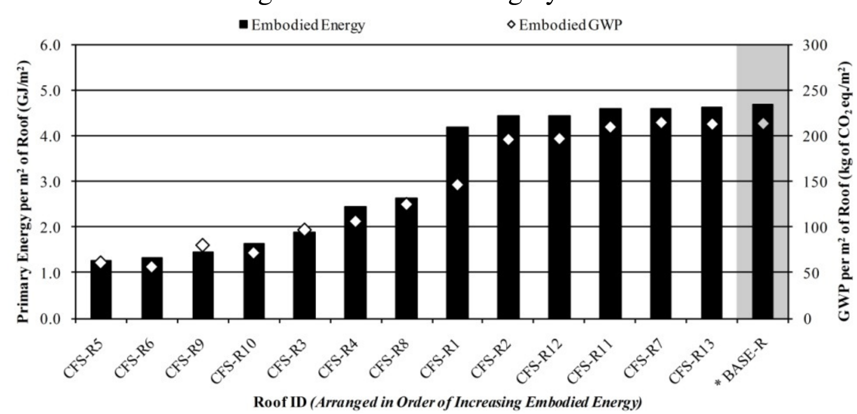
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

LCA Data for Cold-Formed Steel Roofs

This section contains a detailed description of each cold-formed steel (CFS) roof that was examined in this study (13 in total). The assembly layers are listed for each roof, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each roof is also included. In general, the results were calculated for an area of roof equal to 38.0 m², which represents a typical bay size for a single-storey retail building with this type of roof system (with the exception of the double joist system and the cold-formed steel truss systems which were calculated for 57.8 m² and 69.2 m² respectfully). The results are also expressed on a per m² basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

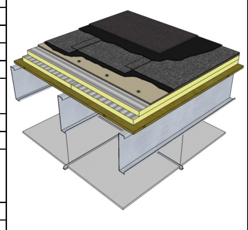
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various roofs in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Cold-Formed Steel Roof #1 (CFS-R1)

Building Component Description:

		Assembly Layers
Category:	Roofs	*Outside*
Brief Description:	Cold-formed steel joists and plywood deck with continuous 75mm polyisocyanurate insulation and SBS modified bitumen membrane roof assembly	SBS modified bitumen membrane cap sheet (WB)
		Roofing asphalt
		Basesheet (modeled as #15 organic felt)
		Roofing asphalt
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 22.3 RSI-Value: 3.9	19mm plywood deck (AB, VR)
Roof Thickness:	364 mm (excluding drop ceiling)	39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
Span:	Range: 1 m to 6 m Design: 5 m	
Specified Design Loads:	DL 0.9 kPa SL 1.1 kPa	
Total Embodied Energy:	4,199 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	146 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	75,163	216	75,379	0	610	610	0	0	0	0	0	0	75,989	2,000	-	-
50	75,163	216	75,379	0	610	610	83,268	170	83,438	1	152	152	159,579	4,199	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	3,349	0	3,350	0	1	1	0	0	0	0	0	0	3,350	88	-	-
50	3,349	0	3,350	0	1	1	2,216	0	2,216	0	0	0	5,566	146	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m² *(Span x Width = 5.0m x 7.6m = 38.0m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	303.2	m2
13mm Moisture Resistant Gypsum Board	41.8	m2
16mm Gypsum Fibre Gypsum Board	41.8	m2
Galvanized Sheet	102.3	kg
Galvanized Studs	266.0	kg
Isocyanurate	117.9	m2 (25mm)
Joint Compound	41.7	kg
Modified Bitumen membrane	1,219.6	kg
Nails	20.0	kg
Paper Tape	0.5	kg
Roofing Asphalt	632.7	kg
Screws Nuts & Bolts	5.5	kg
Softwood Plywood	79.8	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

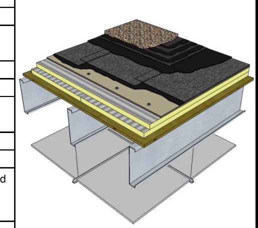
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Roof #2 (CFS-R2)

Building Component Description:

		Assembly Layers
Category:	Roofs	*Outside*
Brief Description:	Cold-formed steel joists and plywood deck with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 22.4 RSI-Value: 4.0	Continuous 75mm polyisocyanurate insulation
Roof Thickness:	389 mm (excluding drop ceiling)	19mm plywood deck (AB, VR)
Span:	Range: 1 m to 6 m Design: 5 m	39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	
Total Embodied Energy:	4,419 MJ/m²	
Total Embodied GWP:	196 kg of CO_2 eq./m²	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	87,956	245	88,201	0	551	551	0	0	0	0	0	0	88,752	2,336	-	-
50	87,956	245	88,201	0	551	551	78,734	272	79,006	1	176	176	167,934	4,419	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,309	0	4,310	0	1	1	0	0	0	0	0	0	4,310	113	-	-
50	4,309	0	4,310	0	1	1	3,131	1	3,131	0	0	0	7,442	196	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m² *(Span x Width = 5.0m x 7.6m = 38.0m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	303.2	m2
13mm Moisture Resistant Gypsum Board	41.8	m2
16mm Gypsum Fibre Gypsum Board	41.8	m2
Ballast (aggregate stone)	2,898.0	kg
Galvanized Sheet	133.6	kg
Galvanized Studs	266.0	kg
Isocyanurate	117.9	m2 (25mm)
Joint Compound	41.7	kg
Nails	20.0	kg
Paper Tape	0.5	kg
Roofing Asphalt	1,150.4	kg
Screws Nuts & Bolts	5.5	kg
Softwood Plywood	79.8	m2 (9mm)
Type III Glass Felt	606.5	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

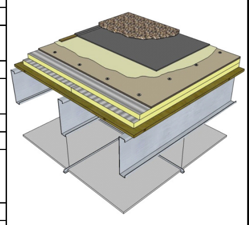
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Roof #3 (CFS-R3)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Cold-formed steel joists and plywood deck with continuous 75mm polyisocyanurate insulation and EPDM roof assembly	Ballast (aggregate stone)
		EPDM cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 22.4 RSI-Value: 4.0	19mm plywood deck (AB, VR)
Roof Thickness:	389 mm (excluding drop ceiling)	39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
Span:	Range: 1 m to 6 m Design: 5 m	
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	
Total Embodied Energy:	1,897 MJ/m^2	16mm suspended acoustical ceiling
Total Embodied GWP:	97 kg of CO_2 eq./m^2	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	38,357	245	38,602	0	734	734	0	0	0	0	0	0	39,336	1,035	-	-
50	38,357	245	38,602	0	734	734	32,178	383	32,561	1	200	201	72,097	1,897	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	2,270	0	2,271	0	1	1	0	0	0	0	0	0	2,272	60	-	-
50	2,270	0	2,271	0	1	1	1,422	1	1,423	0	0	0	3,695	97	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	41.8	m2
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	38.8	m2
Ballast (aggregate stone)	8,694.0	kg
EPDM membrane	312.1	kg
Galvanized Sheet	104.8	kg
Galvanized Studs	266.0	kg
Isocyanurate	117.9	m2 (25mm)
Joint Compound	83.4	kg
Nails	3.9	kg
Paper Tape	1.0	kg
Screws Nuts & Bolts	5.5	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	80.6	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

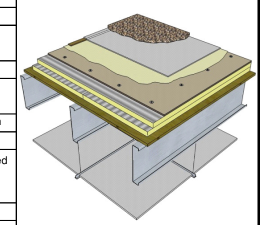
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #4 (CFS-R4)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Cold-formed steel joists and plywood deck with continuous 75mm polyisocyanurate insulation and PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 22.4 RSI-Value: 4.0	19mm plywood deck (AB, VR)
Roof Thickness:	389 mm (excluding drop ceiling)	39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
Span:	Range: 1 m to 6 m Design: 5 m	
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	
Total Embodied Energy:	2,452 MJ/m^2	16mm suspended acoustical ceiling
Total Embodied GWP:	107 kg of CO_2 eq./m^2	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	42,997	264	43,262	0	831	831	0	0	0	0	0	0	44,092	1,160	-	-
50	42,997	264	43,262	0	831	831	48,400	478	48,878	1	209	210	93,180	2,452	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	2,347	1	2,347	0	1	1	0	0	0	0	0	0	2,348	62	-	-
50	2,347	1	2,347	0	1	1	1,702	1	1,703	0	0	0	4,051	107	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	41.8	m2
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	38.8	m2
Ballast (aggregate stone)	8,694.0	kg
Galvanized Sheet	100.9	kg
Galvanized Studs	266.0	kg
Isocyanurate	117.9	m2 (25mm)
Joint Compound	83.4	kg
Nails	4.7	kg
Paper Tape	1.0	kg
PVC membrane	831.1	kg
Screws Nuts & Bolts	5.5	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	80.6	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

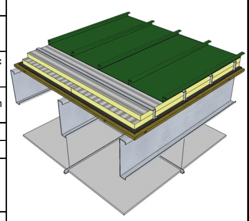
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #5 (CFS-R5)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Cold-formed steel joists and plywood deck with non-continuous 75mm polyisocyanurate insulation and standing seam steel roof assembly	Alkyd based paint
		Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
		1.21mm galvanized 92mm Z-girts @ 1,200mm o/c (self-weight: 1.4 kg/m)
Quick Numbers:		Non-continuous 75mm polyisocyanurate insulation
ASHRAE Standard 90.1:	R-Value: 17.9 RSI-Value: 3.1	
THERM 5.2:	R-Value: 18.8 RSI-Value: 3.3	Modified bitumen membrane (AB, VB)
Roof Thickness:	394 mm (excluding drop ceiling)	19mm plywood deck
Span:	Range: 1 m to 6 m Design: 5 m	39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
Specified Design Loads:	DL 0.9 kPa SL 1.1 kPa	
Total Embodied Energy:	1,252 MJ/m²	
Total Embodied GWP:	61 kg of CO_2 eq./m²	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	41,759	185	41,944	0	434	434	0	0	0	0	0	0	42,378	1,115	-	-
50	41,759	185	41,944	0	434	434	5,090	16	5,106	1	82	83	47,567	1,252	200,000	341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	2,265	0	2,265	0	0	0	0	0	0	0	0	0	2,265	60	-	-
50	2,265	0	2,265	0	0	0	71	0	71	0	0	0	2,336	61	20,000	34

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m² (Span x Width = 5.0m x 7.6m = 38.0m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
Foam Polyisocyanurate	117.1	m2 (25mm)
Galvanized Sheet	310.9	kg
Galvanized Studs	310.4	kg
Joint Compound	41.7	kg
Modified Bitumen membrane	118.0	kg
Nails	2.7	kg
Paper Tape	0.5	kg
Screws Nuts & Bolts	5.9	kg
Softwood Plywood	79.8	m2 (9mm)
Solvent Based Alkyd Paint	27.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

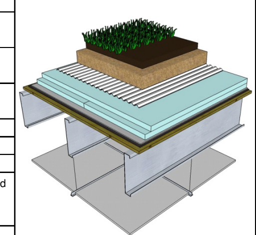
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Roof #6 (CFS-R6)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Cold-formed steel joists and plywood deck with continuous 100mm extruded polystyrene rigid insulation and green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Continuous 100mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Protection barrier (modeled as 6mil poly)
THERM 5.2:	R-Value: 22.0 RSI-Value: 3.9	Modified bitumen membrane (AB, VB)
Roof Thickness:	588 mm (excluding drop ceiling)	19mm plywood deck
Span:	Range: 1 m to 6 m Design: 5 m	39mm x 294mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.8 kg/m)
Specified Design Loads:	DL 2.6 kPa SL 1.1 kPa	
Total Embodied Energy:	1,337 MJ/m²	
Total Embodied GWP:	57 kg of CO_2 eq./m²	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	35,457	165	35,622	0	443	443	0	0	0	0	0	0	36,065	949	-	-
50	35,457	165	35,622	0	443	443	14,611	40	14,651	1	85	86	50,802	1,337	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	1,758	0	1,758	0	0	0	0	0	0	0	0	0	1,758	46	-	-
50	1,758	0	1,758	0	0	0	406	0	406	0	0	0	2,165	57	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m² (Span x Width = 5.0m x 7.6m = 38.0m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	40.3	m2
Ballast (aggregate stone)	144.9	kg
Extruded Polystyrene	155.7	m2 (25mm)
Galvanized Sheet	88.3	kg
Galvanized Studs	304.4	kg
Joint Compound	41.7	kg
Modified Bitumen membrane	142.1	kg
Nails	2.7	kg
Paper Tape	0.5	kg
PVC membrane	169.6	kg
Screws Nuts & Bolts	5.5	kg
Softwood Plywood	79.8	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

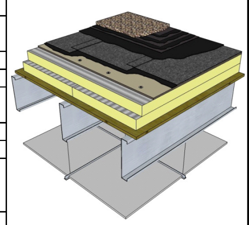
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Cold-Formed Steel Roof #7 (CFS-R7)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Cold-formed steel joists and plywood deck with continuous 150mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 41.8 RSI-Value: 7.4	Continuous 150mm polyisocyanurate insulation
Roof Thickness:	464 mm (excluding drop ceiling)	19mm plywood deck (AB, VR)
Span:	Range: 1 m to 6 m Design: 5 m	39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	
Total Embodied Energy:	4,602 MJ/m^2	
Total Embodied GWP:	214 kg of CO_2 eq./m^2	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	94,857	249	95,106	0	574	574	0	0	0	0	0	0	95,680	2,518	-	-
50	94,857	249	95,106	0	574	574	78,734	272	79,006	1	184	184	174,870	4,602	-1,100,000	-1,877

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	5,013	0	5,013	0	1	1	0	0	0	0	0	0	5,014	132	-	-
50	5,013	0	5,013	0	1	1	3,131	1	3,131	0	0	0	8,146	214	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	303.2	m2
13mm Moisture Resistant Gypsum Board	41.8	m2
16mm Gypsum Fibre Gypsum Board	41.8	m2
Ballast (aggregate stone)	2,898.0	kg
Galvanized Sheet	133.6	kg
Galvanized Studs	266.0	kg
Isocyanurate	235.8	m2 (25mm)
Joint Compound	41.7	kg
Nails	20.0	kg
Paper Tape	0.5	kg
Roofing Asphalt	1,150.4	kg
Screws Nuts & Bolts	5.5	kg
Softwood Plywood	79.8	m2 (9mm)
Type III Glass Felt	606.5	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

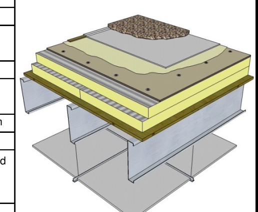
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #8 (CFS-R8)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Cold-formed steel joists and plywood deck with continuous 150mm polyisocyanurate insulation and PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	Continuous 150mm polyisocyanurate insulation
THERM 5.2:	R-Value: 41.8 RSI-Value: 7.4	19mm plywood deck (AB, VR)
Roof Thickness:	464 mm (excluding drop ceiling)	39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
Span:	Range: 1 m to 6 m Design: 5 m	
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	
Total Embodied Energy:	2,635 MJ/m^2	16mm suspended acoustical ceiling
Total Embodied GWP:	125 kg of CO_2 eq./m^2	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	49,898	268	50,166	0	854	854	0	0	0	0	0	0	51,020	1,343	-	-
50	49,898	268	50,166	0	854	854	48,400	478	48,878	1	217	218	100,116	2,635	-1,100,000	-1,877

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,050	1	3,051	0	1	1	0	0	0	0	0	0	3,052	80	-	-
50	3,050	1	3,051	0	1	1	1,702	1	1,703	0	0	0	4,755	125	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	41.8	m2
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	38.8	m2
Ballast (aggregate stone)	8,694.0	kg
Galvanized Sheet	100.9	kg
Galvanized Studs	266.0	kg
Isocyanurate	235.8	m2 (25mm)
Joint Compound	83.4	kg
Nails	4.7	kg
Paper Tape	1.0	kg
PVC membrane	831.1	kg
Screws Nuts & Bolts	5.5	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	80.6	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #9 (CFS-R9)

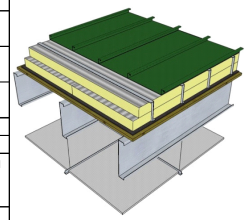
Building Component Description:

Category:	Roofs
Brief Description:	Cold-formed steel joists and plywood deck with non-continuous 150mm polyisocyanurate insulation and standing seam steel roof assembly

Quick Numbers:

ASHRAE Standard 90.1:	R-Value: 29.4 RSI-Value: 5.2
THERM 5.2:	R-Value: 30.5 RSI-Value: 5.4
Roof Thickness:	452 mm (excluding drop ceiling)
Span:	Range: 1 m to 6 m Design: 5 m
Specified Design Loads:	DL 0.9 kPa SL 1.1 kPa
Total Embodied Energy:	1,441 MJ/m^2
Total Embodied GWP:	81 kg of CO_2 eq./m^2

Assembly Layers
Outside
Alkyd based paint
Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
1.21mm galvanized 150mm Z-girts @ 1,200mm o/c (self-weight: 2.0 kg/m)
Non-continuous 150mm polyisocyanurate insulation
Modified bitumen membrane (AB, VB)
19mm plywood deck
39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.2 kg/m)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	48,926	189	49,115	0	458	458	0	0	0	0	0	0	49,574	1,305	-	-
50	48,926	189	49,115	0	458	458	5,090	16	5,106	1	91	92	54,771	1,441	-700,000	-1,195

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	2,989	0	2,989	0	0	0	0	0	0	0	0	0	2,990	79	-	-
50	2,989	0	2,989	0	0	0	71	0	71	0	0	0	3,061	81	-30,000	-51

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
Foam Polyisocyanurate	234.2	m2 (25mm)
Galvanized Sheet	310.9	kg
Galvanized Studs	323.5	kg
Joint Compound	41.7	kg
Modified Bitumen membrane	118.0	kg
Nails	2.7	kg
Paper Tape	0.5	kg
Screws Nuts & Bolts	5.9	kg
Softwood Plywood	79.8	m2 (9mm)
Solvent Based Alkyd Paint	27.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #10 (CFS-R10)

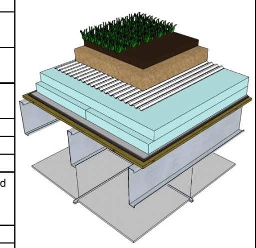
Building Component Description:

Category:	Roofs
Brief Description:	Cold-formed steel joists and plywood deck with continuous 200mm extruded polystyrene rigid insulation and green roof assembly

Quick Numbers:

ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9
THERM 5.2:	R-Value: 41.4 RSI-Value: 7.3
Roof Thickness:	688 mm (excluding drop ceiling)
Span:	Range: 1 m to 6 m Design: 5 m
Specified Design Loads:	DL 2.6 kPa SL 1.1 kPa
Total Embodied Energy:	1,636 MJ/m^2
Total Embodied GWP:	72 kg of CO_2 eq./m^2

Assembly Layers
Outside
Green roof assembly (150mm of soil and vegetation)
Drainage board (WB) (modeled as PVC membrane)
Continuous 200mm extruded polystyrene rigid insulation
Protection barrier (modeled as 6mil poly)
Modified bitumen membrane (AB, VB)
19mm plywood deck
39mm x 294mm 1.52mm galvanized cold-formed steel C-joists @ 600mm o/c (self-weight: 4.8 kg/m)
16mm suspended acoustical ceiling
Misc. fasteners, nails, and galvanized sheet
Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	46,775	165	46,940	0	461	461	0	0	0	0	0	0	47,401	1,247	-	-
50	46,775	165	46,940	0	461	461	14,611	40	14,651	1	100	100	62,153	1,636	-1,100,000	-1,877

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	2,336	0	2,336	0	0	0	0	0	0	0	0	0	2,337	61	-	-
50	2,336	0	2,336	0	0	0	406	0	406	0	0	0	2,744	72	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	40.3	m2
Ballast (aggregate stone)	144.9	kg
Extruded Polystyrene	311.4	m2 (25mm)
Galvanized Sheet	88.3	kg
Galvanized Studs	304.4	kg
Joint Compound	41.7	kg
Modified Bitumen membrane	142.1	kg
Nails	2.7	kg
Paper Tape	0.5	kg
PVC membrane	169.6	kg
Screws Nuts & Bolts	5.5	kg
Softwood Plywood	79.8	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

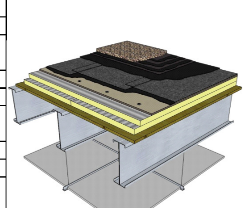
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #11 (CFS-R11)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Back-to-back cold-formed steel joists and plywood deck with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 22.4 RSI-Value: 4.0	Continuous 75mm polyisocyanurate insulation
Roof Thickness:	389 mm (excluding drop ceiling)	19mm plywood deck (AB, VR)
Span:	Range: 1 m to 7.6 m Design: 7.6 m	(2) - 39mm x 245mm 1.52mm galvanized cold-formed steel C-joists back-to-back @ 600mm o/c (self-weight: 8.4 kg/m)
Specified Design Loads:	DL 1.5 kPa SL 1.1 kPa	
Total Embodied Energy:	4,588 MJ/m^2	
Total Embodied GWP:	209 kg of CO_2 eq./m^2	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	143,368	387	143,755	0	883	883	0	0	0	0	0	0	144,638	2,504	-	-
50	143,368	387	143,755	0	883	883	119,654	414	120,068	1	282	283	264,990	4,588	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	7,336	1	7,336	0	1	1	0	0	0	0	0	0	7,337	127	-	-
50	7,336	1	7,336	0	1	1	4,758	1	4,759	0	1	1	12,097	209	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	460.9	m2
13mm Moisture Resistant Gypsum Board	63.5	m2
16mm Gypsum Fibre Gypsum Board	63.5	m2
Ballast (aggregate stone)	4,404.2	kg
Galvanized Sheet	203.1	kg
Galvanized Studs	810.1	kg
Isocyanurate	179.2	m2 (25mm)
Joint Compound	63.4	kg
Nails	30.3	kg
Paper Tape	0.7	kg
Roofing Asphalt	1,748.4	kg
Screws Nuts & Bolts	8.3	kg
Softwood Plywood	121.3	m2 (9mm)
Type III Glass Felt	921.7	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

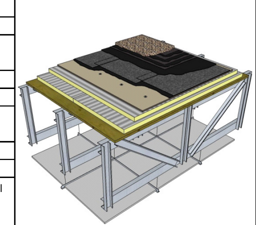
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #12 (1CFS-R12)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Cold-formed steel truss @ 600mm o/c and plywood deck with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 22.4 RSI-Value: 4.0	Continuous 75mm polyisocyanurate insulation
Roof Thickness:	744 mm (excluding drop ceiling)	19mm plywood deck (AB, VR)
Span:	Range: 1 m to 9.1 m Design: 9.1 m	9100mm long x 600mm deep cold-formed steel trusses spaced @ 600mm o/c (self-weight: 4.5 kg/m)
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	
Total Embodied Energy:	4,430 MJ/m^2	
Total Embodied GWP:	197 kg of CO_2 eq./m^2	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	160,867	447	161,314	0	1,006	1,006	0	0	0	0	0	0	162,320	2,347	-	-
50	160,867	447	161,314	0	1,006	1,006	143,243	495	143,738	1	321	322	306,380	4,430	-200,000	-341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	7,909	1	7,909	0	1	1	0	0	0	0	0	0	7,910	114	-	-
50	7,909	1	7,909	0	1	1	5,696	1	5,697	0	1	1	13,608	197	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.7	m2
13mm Moisture Resistant Gypsum Board	76.0	m2
16mm Gypsum Fibre Gypsum Board	76.0	m2
Ballast (aggregate stone)	5,272.5	kg
Galvanized Sheet	243.0	kg
Galvanized Studs	519.4	kg
Isocyanurate	214.5	m2 (25mm)
Joint Compound	75.9	kg
Nails	36.3	kg
Paper Tape	0.9	kg
Roofing Asphalt	2,093.0	kg
Screws Nuts & Bolts	10.0	kg
Softwood Plywood	145.2	m2 (9mm)
Type III Glass Felt	1,103.4	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

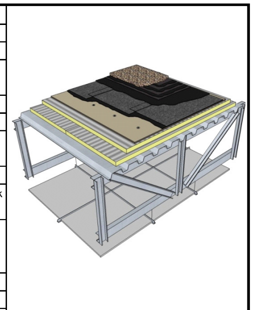
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Roof #13 (CFS-R13)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Cold-formed steel truss @ 1,200mm o/c and metal deck with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 21.5 RSI-Value: 3.8	Continuous 75mm polyisocyanurate insulation
Roof Thickness:	925 mm (excluding drop ceiling)	39mm x 0.76mm galvanized corrugated metal deck (AB, VB)
Span:	Range: 1 m to 9.1 m Design: 9.1 m	
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	9100mm long x 762mm deep cold-formed steel trusses spaced @ 1,200mm o/c (self-weight: 8.9 kg/m)
Total Embodied Energy:	4,615 MJ/m²	
Total Embodied GWP:	213 kg of CO_2 eq./m²	
		16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	173,625	367	173,992	0	1,076	1,076	0	0	0	0	0	0	175,068	2,531	-	-
50	173,625	367	173,992	0	1,076	1,076	143,243	495	143,738	0	346	347	319,153	4,615	-100,000	-171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	9,005	1	9,006	0	1	1	0	0	0	0	0	0	9,007	130	-	-
50	9,005	1	9,006	0	1	1	5,696	1	5,697	0	1	1	14,704	213	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.7	m2
13mm Moisture Resistant Gypsum Board	76.0	m2
16mm Gypsum Fibre Gypsum Board	76.0	m2
Ballast (aggregate stone)	5,272.5	kg
Galvanized Decking	684.8	kg
Galvanized Sheet	243.0	kg
Galvanized Studs	513.4	kg
Isocyanurate	214.5	m2 (25mm)
Joint Compound	75.9	kg
Nails	36.3	kg
Paper Tape	0.9	kg
Roofing Asphalt	2,093.0	kg
Screws Nuts & Bolts	10.0	kg
Type III Glass Felt	1,103.4	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

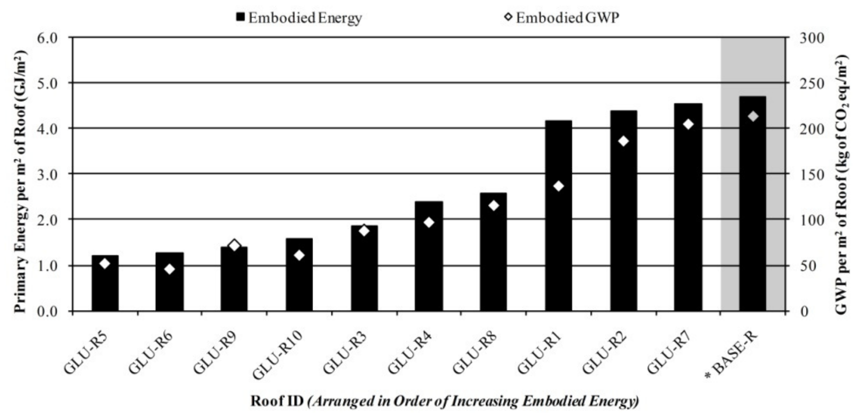
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

LCA Data for Glulam Joist Roofs

This section contains a detailed description of each glulam (GLU) roof that was examined in this study (10 in total). The assembly layers are listed for each roof, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each roof is also included. In each case, the results were calculated for an area of roof equal to 69.2 m², which represents a typical bay size for a single-storey retail building with this type of roof system. The results are also expressed on a per m² basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

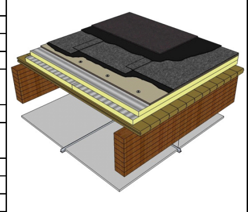
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various roofs in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Glulam Roof #1 (GLU-R1)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Glulam joists and wood plank deck with continuous 75mm polyisocyanurate insulation and SBS modified bitumen membrane roof assembly	SBS modified bitumen membrane cap sheet (WB)
		Roofing asphalt
		Basesheet (modeled as #15 organic felt)
		Roofing asphalt
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 22.9 RSI-Value: 4.0	38mm SPF tongue & groove solid wood plank decking (AB, VR)
Roof Thickness:	632 mm (excluding drop ceiling)	
Span:	Range: 2 m to 12 m Design: 9.1 m	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Specified Design Loads:	DL 1.2 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	4,149 MJ/m²	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	137 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	131,645	731	132,377	461	1,903	2,364	0	0	0	0	0	0	134,740	1,948	-	-
50	131,645	731	132,377	461	1,903	2,364	151,547	309	151,856	2	333	335	286,931	4,149	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	5,389	1	5,390	30	2	33	0	0	0	0	0	0	5,423	78	-	-
50	5,389	1	5,390	30	2	33	4,032	1	4,033	0	1	1	9,457	137	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.9	m2
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
Galvanized Sheet	186.2	kg
GluLam Sections	1.5	m3
Isocyanurate	214.6	m2 (25mm)
Joint Compound	75.9	kg
Modified Bitumen membrane	2,219.6	kg
Nails	49.2	kg
Paper Tape	0.9	kg
Roofing Asphalt	1,151.6	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

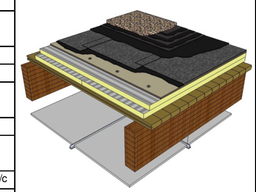
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Glulam Roof #2 (GLU-R2)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Glulam joists and wood plank deck with continuous 75mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 23.1 RSI-Value: 4.1	Continuous 75mm polyisocyanurate insulation
Roof Thickness:	657 mm (excluding drop ceiling)	38mm SPF tongue & groove solid wood plank decking (AB, VR)
Span:	Range: 2 m to 12 m Design: 9.1 m	
Specified Design Loads:	DL 1.7 kPa SL 1.1 kPa	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Total Embodied Energy:	4,369 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	186 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	154,929	785	155,713	461	1,795	2,255	0	0	0	0	0	0	157,969	2,284	-	-
50	154,929	785	155,713	461	1,795	2,255	143,295	495	143,790	2	377	378	302,138	4,369	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	7,136	1	7,138	30	2	33	0	0	0	0	0	0	7,170	104	-	-
50	7,136	1	7,138	30	2	33	5,698	1	5,699	0	1	1	12,870	186	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.9	m2
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
Ballast (aggregate stone)	5,274.4	kg
Galvanized Sheet	243.0	kg
GluLam Sections	1.5	m3
Isocyanurate	214.6	m2 (25mm)
Joint Compound	75.9	kg
Nails	49.2	kg
Paper Tape	0.9	kg
Roofing Asphalt	2,093.8	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3
Type III Glass Felt	1,103.8	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

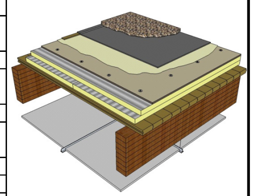
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Glulam Roof #3 (GLU-R3)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Glulam joists and wood plank deck with continuous 75mm polyisocyanurate insulation and EPDM roof assembly	Ballast (aggregate stone)
		EPDM cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 23.1 RSI-Value: 4.1	38mm SPF tongue & groove solid wood plank decking (AB, VR)
Roof Thickness:	657 mm (excluding drop ceiling)	
Span:	Range: 2 m to 12 m Design: 9.1 m	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Specified Design Loads:	DL 1.7 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	1,847 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	87 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	64,658	785	65,442	461	2,128	2,589	0	0	0	0	0	0	68,031	984	-	-
50	64,658	785	65,442	461	2,128	2,589	58,565	696	59,261	2	421	423	127,715	1,847	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,425	1	3,427	30	3	33	0	0	0	0	0	0	3,460	50	-	-
50	3,425	1	3,427	30	3	33	2,589	1	2,590	0	1	1	6,051	87	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	70.5	m2
Ballast (aggregate stone)	15,823.1	kg
EPDM membrane	568.0	kg
Galvanized Sheet	190.6	kg
GluLam Sections	1.5	m3
Isocyanurate	214.6	m2 (25mm)
Joint Compound	151.9	kg
Nails	19.9	kg
Paper Tape	1.7	kg
Small Dimension Softwood Lumber, kiln-dried	3.7	m3
Softwood Plywood	1.4	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

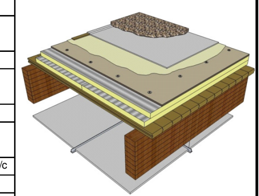
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Glulam Roof #4 (GLU-R4)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Glulam joists and wood plank deck with continuous 75mm polyisocyanurate insulation and PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard *(modeled as moisture resistant gypsum)*
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Continuous 75mm polyisocyanurate insulation
THERM 5.2:	R-Value: 23.1 RSI-Value: 4.1	38mm SPF tongue & groove solid wood plank decking (AB, VR)
Roof Thickness:	657 mm (excluding drop ceiling)	
Span:	Range: 2 m to 12 m Design: 9.1 m	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Specified Design Loads:	DL 1.7 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	2,401 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	97 kg of CO_2 eq./m^2	*Inside*



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	73,104	820	73,924	461	2,304	2,765	0	0	0	0	0	0	76,688	1,109	-	-
50	73,104	820	73,924	461	2,304	2,765	88,088	870	88,958	2	438	439	166,086	2,401	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,565	2	3,566	30	3	34	0	0	0	0	0	0	3,600	52	-	-
50	3,565	2	3,566	30	3	34	3,097	2	3,099	0	1	1	6,699	97	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	70.5	m2
Ballast (aggregate stone)	15,823.1	kg
Galvanized Sheet	183.5	kg
GluLam Sections	1.5	m3
Isocyanurate	214.6	m2 (25mm)
Joint Compound	151.9	kg
Nails	21.4	kg
Paper Tape	1.7	kg
PVC membrane	1,512.6	kg
Small Dimension Softwood Lumber, kiln-dried	3.7	m3
Softwood Plywood	1.4	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

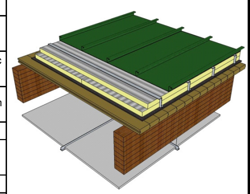
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Glulam Roof #5 (GLU-R5)

Building Component Description:

		Assembly Layers
Category:	Roofs	*Outside*
Brief Description:	Glulam joists and wood plank deck with non-continuous 75mm polyisocyanurate insulation and standing seam steel roof assembly	Alkyd based paint
		Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
		1.21mm galvanized 92mm Z-girts @ 1,200mm o/c (self-weight: 1.4 kg/m)
Quick Numbers:		Non-continuous 75mm polyisocyanurate insulation
ASHRAE Standard 90.1:	R-Value: 17.9 RSI-Value: 3.1	Modified bitumen membrane (AB, VB)
THERM 5.2:	R-Value: 19.4 RSI-Value: 3.4	38mm SPF tongue & groove solid wood plank decking
Roof Thickness:	662 mm (excluding drop ceiling)	
Span:	Range: 2 m to 12 m Design: 9.1 m	
Specified Design Loads:	DL 1.2 kPa SL 1.1 kPa	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Total Embodied Energy:	1,201 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	52 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE): Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE	Difference in Operating Energy from Baseline after Lifespan	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	70,853	675	71,528	461	1,582	2,042	0	0	0	0	0	0	73,570	1,064	-	-
50	70,853	675	71,528	461	1,582	2,042	9,263	29	9,293	2	207	209	83,072	1,201	100,000	171

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP): Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP	Difference in Operating GWP from Baseline after Lifespan	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	3,415	1	3,416	30	2	32	0	0	0	0	0	0	3,449	50	-	-
50	3,415	1	3,416	30	2	32	129	0	129	0	0	0	3,578	52	10,000	17

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	76.1	m2
Foam Polyisocyanurate	213.1	m2 (25mm)
Galvanized Sheet	0.6	kg
Galvanized Studs	80.8	kg
GluLam Sections	1.5	m3
Joint Compound	75.9	kg
Modified Bitumen membrane	214.7	kg
Nails	17.8	kg
Paper Tape	0.9	kg
Screws Nuts & Bolts	0.7	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3
Solvent Based Alkyd Paint	49.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

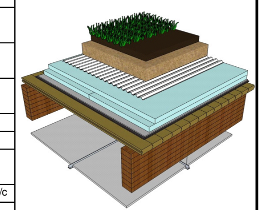
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Glulam Roof #6 (GLU-R6)

Building Component Description:

		Assembly Layers
Category:	Roofs	*Outside*
Brief Description:	Glulam joists and wood plank deck with continuous 100mm extruded polystyrene rigid insulation and green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Continuous 100mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 20.8 RSI-Value: 3.7	Protection barrier (modeled as 6mil poly)
THERM 5.2:	R-Value: 23.1 RSI-Value: 4.1	Modified bitumen membrane (AB, VB)
Roof Thickness:	883 mm (excluding drop ceiling)	38mm SPF tongue & groove solid wood plank decking
Span:	Range: 2 m to 12 m Design: 9.1 m	
Specified Design Loads:	DL 2.9 kPa SL 1.1 kPa	80mm x 570mm 24f-E glulam joists @ 1800m o/c
Total Embodied Energy:	1,271 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	46 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE): Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE	Difference in Operating Energy from Baseline after Lifespan	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	58,297	659	58,957	461	1,633	2,093	0	0	0	0	0	0	61,050	883	-	-
50	58,297	659	58,957	461	1,633	2,093	26,592	73	26,665	2	212	214	87,930	1,271	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP): Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP	Difference in Operating GWP from Baseline after Lifespan	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	2,382	1	2,383	30	2	32	0	0	0	0	0	0	2,416	35	-	-
50	2,382	1	2,383	30	2	32	740	0	740	0	0	1	3,156	46	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² (Span x Width = 9.1m x 7.6m = 69.2m²)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	73.4	m2
Ballast (aggregate stone)	263.7	kg
Extruded Polystyrene	283.4	m2 (25mm)
Galvanized Sheet	160.6	kg
GluLam Sections	1.8	m3
Joint Compound	75.9	kg
Modified Bitumen membrane	258.7	kg
Nails	17.8	kg
Paper Tape	0.9	kg
PVC membrane	308.7	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

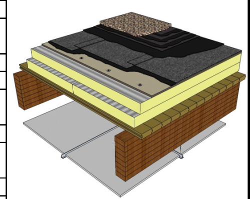
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Glulam Roof #7 (GLU-R7)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Glulam joists and wood plank deck with continuous 150mm polyisocyanurate insulation and 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm coverboard
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	*(modeled as moisture resistant gypsum)*
THERM 5.2:	R-Value: 42.7 RSI-Value: 7.5	Continuous 150mm polyisocyanurate insulation
Roof Thickness:	732 mm (excluding drop ceiling)	38mm SPF tongue & groove solid wood plank decking (AB, VR)
Span:	Range: 2 m to 12 m Design: 9.1 m	
Specified Design Loads:	DL 1.7 kPa SL 1.1 kPa	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Total Embodied Energy:	4,551 MJ/m^2	16mm suspended acoustical ceiling
Total Embodied GWP:	205 kg of CO_2 eq./m^2	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	167,488	792	168,280	461	1,837	2,298	0	0	0	0	0	0	170,577	2,466	-	-
50	167,488	792	168,280	461	1,837	2,298	143,295	495	143,790	2	392	393	314,761	4,551	-1,200,000	-2,048

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	8,417	2	8,419	30	2	33	0	0	0	0	0	0	8,451	122	-	-
50	8,417	2	8,419	30	2	33	5,698	1	5,699	0	1	1	14,151	205	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	551.9	m2
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
Ballast (aggregate stone)	5,274.4	kg
Galvanized Sheet	243.0	kg
GluLam Sections	1.5	m3
Isocyanurate	429.2	m2 (25mm)
Joint Compound	75.9	kg
Nails	49.2	kg
Paper Tape	0.9	kg
Roofing Asphalt	2,093.8	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3
Type III Glass Felt	1,103.8	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

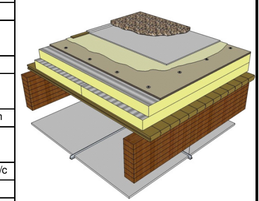
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Glulam Roof #8 (GLU-R8)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Glulam joists and wood plank deck with continuous 150mm polyisocyanurate insulation and PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm coverboard
		(modeled as moisture resistant gypsum)
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	Continuous 150mm polyisocyanurate insulation
THERM 5.2:	R-Value: 42.7 RSI-Value: 7.5	38mm SPF tongue & groove solid wood plank decking (AB, VR)
Roof Thickness:	732 mm (excluding drop ceiling)	
Span:	Range: 2 m to 12 m Design: 9.1 m	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Specified Design Loads:	DL 1.7 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	2,584 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	115 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	85,663	827	86,490	461	2,347	2,807	0	0	0	0	0	0	89,297	1,291	-	-
50	85,663	827	86,490	461	2,347	2,807	88,088	870	88,958	2	453	454	178,710	2,584	-1,200,000	-2,048

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	4,845	2	4,847	30	3	34	0	0	0	0	0	0	4,881	71	-	-
50	4,845	2	4,847	30	3	34	3,097	2	3,099	0	1	1	7,980	115	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m^2 (Span x Width = 9.1m x 7.6m = 69.2m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Moisture Resistant Gypsum Board	76.1	m2
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	70.5	m2
Ballast (aggregate stone)	15,823.1	kg
Galvanized Sheet	183.5	kg
GluLam Sections	1.5	m3
Isocyanurate	429.2	m2 (25mm)
Joint Compound	151.9	kg
Nails	21.4	kg
Paper Tape	1.7	kg
PVC membrane	1,512.6	kg
Small Dimension Softwood Lumber, kiln-dried	3.7	m3
Softwood Plywood	1.4	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

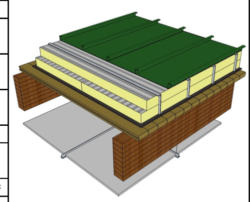
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Glulam Roof #9 (GLU-R9)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Glulam joists and wood plank deck with non-continuous 150mm polyisocyanurate insulation and standing seam steel roof assembly	Alkyd based paint
		Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
		1.21mm galvanized 150mm Z-girts @ 1,200mm o/c (self-weight: 2.0 kg/m)
Quick Numbers:		Non-continuous 150mm polyisocyanurate insulation
ASHRAE Standard 90.1:	R-Value: 29.4 RSI-Value: 5.2	
THERM 5.2:	R-Value: 31.0 RSI-Value: 5.5	Modified bitumen membrane (AB, VB)
Roof Thickness:	720 mm (excluding drop ceiling)	38mm SPF tongue & groove solid wood plank decking
Span:	Range: 2 m to 12 m Design: 9.1 m	
Specified Design Loads:	DL 1.2 kPa SL 1.1 kPa	80mm x 494mm 24f-E glulam joists @ 1800m o/c
Total Embodied Energy:	1,396 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	71 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	84,290	683	84,974	461	1,629	2,089	0	0	0	0	0	0	87,063	1,259	-	-
50	84,290	683	84,974	461	1,629	2,089	9,263	29	9,293	2	223	225	96,581	1,396	-700,000	-1,195

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,766	1	4,767	30	2	32	0	0	0	0	0	0	4,799	69	-	-
50	4,766	1	4,767	30	2	32	129	0	129	0	0	1	4,929	71	-30,000	-51

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² *(Span x Width = 9.1m x 7.6m = 69.2m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	76.1	m2
Foam Polyisocyanurate	426.2	m2 (25mm)
Galvanized Sheet	565.7	kg
Galvanized Studs	121.2	kg
GluLam Sections	1.5	m3
Joint Compound	75.9	kg
Modified Bitumen membrane	214.7	kg
Nails	17.8	kg
Paper Tape	0.9	kg
Screws Nuts & Bolts	0.7	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3
Solvent Based Alkyd Paint	49.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

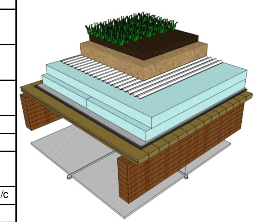
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Glulam Roof #10 (GLU-R10)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	Glulam joists and wood plank deck with continuous 200mm extruded polystyrene rigid insulation and green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Continuous 200mm extruded polystyrene rigid insulation
ASHRAE Standard 90.1:	R-Value: 39.1 RSI-Value: 6.9	Protection barrier (modeled as 6mil poly)
THERM 5.2:	R-Value: 42.4 RSI-Value: 7.5	Modified bitumen membrane (AB, VB)
Roof Thickness:	983 mm (excluding drop ceiling)	38mm SPF tongue & groove solid wood plank decking
Span:	Range: 2 m to 12 m Design: 9.1 m	
Specified Design Loads:	DL 2.9 kPa SL 1.1 kPa	80mm x 570mm 24f-E glulam joists @ 1800m o/c
Total Embodied Energy:	1,570 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	61 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	78,897	660	79,557	461	1,666	2,126	0	0	0	0	0	0	81,683	1,181	-	-
50	78,897	660	79,557	461	1,666	2,126	26,592	73	26,665	2	239	240	108,589	1,570	-1,200,000	-2,048

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	3,435	1	3,437	30	2	32	0	0	0	0	0	0	3,469	50	-	-
50	3,435	1	3,437	30	2	32	740	0	740	0	0	1	4,209	61	-60,000	-102

Embodied energy (and GWP) numbers are based on an area of roof = 69.2 m² *(Span x Width = 9.1m x 7.6m = 69.2m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	76.1	m2
6 mil Polyethylene	73.4	m2
Ballast (aggregate stone)	263.7	kg
Extruded Polystyrene	566.8	m2 (25mm)
Galvanized Sheet	160.6	kg
GluLam Sections	1.8	m3
Joint Compound	75.9	kg
Modified Bitumen membrane	258.7	kg
Nails	17.8	kg
Paper Tape	0.9	kg
PVC membrane	308.7	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

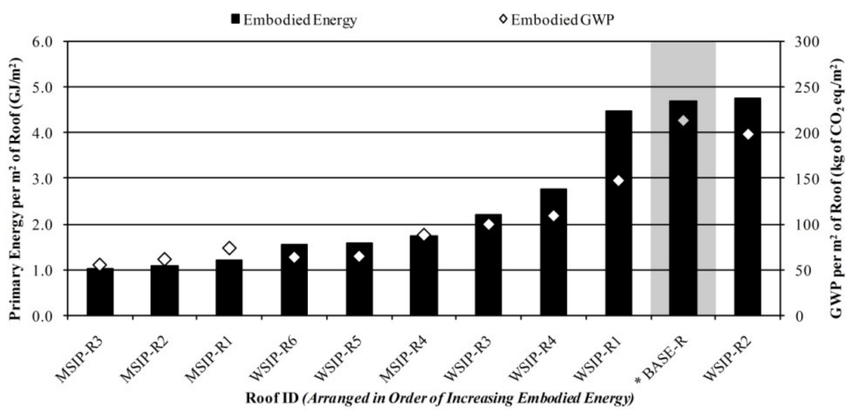
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

LCA Data for Wood Structural Insulated Panel Roofs

This section contains a detailed description of each wood structural insulated panel (WSIP) roof that was examined in this study (6 in total). The assembly layers are listed for each roof, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each roof is also included. In each case, the results were calculated for an area of roof equal to 38.0 m^2, which represents a typical bay size for a single-storey retail building with this type of roof system. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

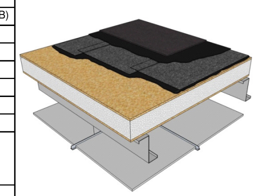
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various roofs in this section as well as the metal structural insulated panel (MSIP) roofs from the next section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Wood Structural Insulated Panel Roof #1 (WSIP-R1)

Building Component Description:

Category:	Roofs	Assembly Layers
Brief Description:	174mm (7in) wood SIP roof with SBS modified bitumen membrane roof assembly	***Outside***
		SBS modified bitumen membrane cap sheet (WB)
		Roofing asphalt
		Basesheet (modeled as #15 organic felt)
		Roofing asphalt
Quick Numbers:		12mm OSB
		150mm extruded polystyrene insulation
ASHRAE Standard 90.1:	R-Value: 30.3 RSI-Value: 5.3	12mm OSB (AB, VR)
THERM 5.2:	R-Value: 31.9 RSI-Value: 5.6	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
Roof Thickness:	416 mm (excluding drop ceiling)	
Span:	Range: 1 m to 10 m Design: 5 m	
Specified Design Loads:	DL 1.0 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	4,478 MJ/m^2	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	147 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	86,068	264	86,332	0	289	289	0	0	0	0	0	0	86,621	2,279	-	-
50	86,068	264	86,332	0	289	289	83,268	170	83,438	1	118	118	170,177	4,478	-800,000	-1,365

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	3,386	1	3,386	0	1	1	0	0	0	0	0	0	3,387	89	-	-
50	3,386	1	3,386	0	1	1	2,216	0	2,216	0	0	0	5,603	147	-40,000	-68

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	303.2	m2
13mm Moisture Resistant Gypsum Board	41.8	m2
Extruded Polystyrene	235.8	m2 (25mm)
Galvanized Sheet	102.3	kg
Galvanized Studs	262.9	kg
Modified Bitumen membrane	1,219.6	kg
Nails	19.6	kg
Oriented Strand Board	103.3	m2 (9mm)
Roofing Asphalt	632.7	kg
Screws Nuts & Bolts	5.5	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

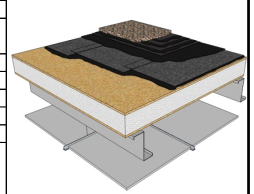
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Structural Insulated Panel Roof #2 (WSIP-R2)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	174mm (7in) wood SIP roof with 4-ply built-up asphalt roof assembly	Ballast (aggregate stone)
		4-ply built-up asphalt roof assembly (WB) (type III glass felt & roofing asphalt)
		Basesheet (modeled as #15 organic felt)
Quick Numbers:		Roofing asphalt
		12mm OSB
ASHRAE Standard 90.1:	R-Value: 30.3 RSI-Value: 5.3	150mm extruded polystyrene insulation
THERM 5.2:	R-Value: 32.1 RSI-Value: 5.6	12mm OSB (AB, VR)
Roof Thickness:	441 mm (excluding drop ceiling)	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
Span:	Range: 1 m to 10 m Design: 5 m	
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	
Total Embodied Energy:	4,735 MJ/m²	16mm suspended acoustical ceiling
Total Embodied GWP:	198 kg of CO_2 eq./m²	Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	99,943	333	100,276	0	484	484	0	0	0	0	0	0	100,760	2,652	-	-
50	99,943	333	100,276	0	484	484	78,734	272	79,006	1	161	162	179,928	4,735	-800,000	-1,365

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,397	1	4,397	0	0	0	0	0	0	0	0	0	4,398	116	-	-
50	4,397	1	4,397	0	0	0	3,131	1	3,131	0	0	0	7,529	198	-40,000	-68

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 *(Span x Width = 5.0m x 7.6m = 38.0m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
#15 Organic Felt	303.2	m2
16mm Gypsum Fibre Gypsum Board	41.8	m2
Ballast (aggregate stone)	2,898.0	kg
Extruded Polystyrene	235.8	m2 (25mm)
Galvanized Sheet	133.6	kg
Galvanized Studs	262.9	kg
Joint Compound	41.7	kg
Nails	20.0	kg
Oriented Strand Board	103.3	m2 (9mm)
Paper Tape	0.5	kg
Roofing Asphalt	1,150.4	kg
Screws Nuts & Bolts	5.5	kg
Type III Glass Felt	606.5	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

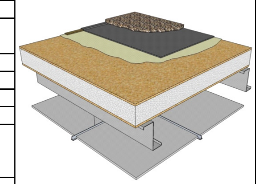
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Roof #3 (WSIP-R3)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	174mm (7in) wood SIP roof with EPDM roof assembly	Ballast (aggregate stone)
		EPDM cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm OSB
		150mm extruded polystyrene insulation
ASHRAE Standard 90.1:	R-Value: 30.3 RSI-Value: 5.3	12mm OSB (AB, VR)
THERM 5.2:	R-Value: 32.1 RSI-Value: 5.6	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
Roof Thickness:	441 mm (excluding drop ceiling)	
Span:	Range: 1 m to 10 m Design: 5 m	
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	2,211 MJ/m²	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	99 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	50,309	332	50,641	0	622	622	0	0	0	0	0	0	51,263	1,349	-	-
50	50,309	332	50,641	0	622	622	32,178	383	32,561	1	182	183	84,007	2,211	-800,000	-1,365

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	2,356	1	2,357	0	1	1	0	0	0	0	0	0	2,357	62	-	-
50	2,356	1	2,357	0	1	1	1,422	1	1,423	0	0	0	3,781	99	-40,000	-68

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 *(Span x Width = 5.0m x 7.6m = 38.0m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	38.8	m2
Ballast (aggregate stone)	8,694.0	kg
EPDM membrane	312.1	kg
Extruded Polystyrene	235.8	m2 (25mm)
Galvanized Sheet	104.8	kg
Galvanized Studs	262.9	kg
Joint Compound	41.7	kg
Nails	3.5	kg
Oriented Strand Board	103.3	m2 (9mm)
Paper Tape	0.5	kg
Screws Nuts & Bolts	5.5	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	0.8	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

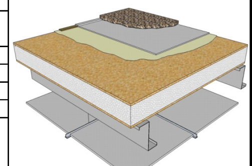
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Roof #4 (WSIP-R4)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	174mm (7in) wood SIP roof with PVC roof assembly	Ballast (aggregate stone)
		PVC membrane cap sheet (WB) (includes wood nailing strips)
		Bonding agent (modeled as 6mil poly)
Quick Numbers:		12mm OSB
		150mm extruded polystyrene insulation
ASHRAE Standard 90.1:	R-Value: 30.3 RSI-Value: 5.3	12mm OSB (AB, VR)
THERM 5.2:	R-Value: 32.1 RSI-Value: 5.6	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
Roof Thickness:	441 mm (excluding drop ceiling)	
Span:	Range: 1 m to 10 m Design: 5 m	
Specified Design Loads:	DL 1.4 kPa SL 1.1 kPa	16mm suspended acoustical ceiling
Total Embodied Energy:	2,766 MJ/m²	Misc. fasteners, nails, and galvanized sheet
Total Embodied GWP:	109 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	54,950	352	55,301	0	719	719	0	0	0	0	0	0	56,020	1,474	-	-
50	54,950	352	55,301	0	719	719	48,400	478	48,878	1	191	192	105,090	2,766	-800,000	-1,365

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	2,432	1	2,433	0	1	1	0	0	0	0	0	0	2,434	64	-	-
50	2,432	1	2,433	0	1	1	1,702	1	1,703	0	0	0	4,137	109	-40,000	-68

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 *(Span x Width = 5.0m x 7.6m = 38.0m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	38.8	m2
Ballast (aggregate stone)	8,694.0	kg
Extruded Polystyrene	235.8	m2 (25mm)
Galvanized Sheet	100.9	kg
Galvanized Studs	262.9	kg
Joint Compound	41.7	kg
Nails	4.3	kg
Oriented Strand Board	103.3	m2 (9mm)
Paper Tape	0.5	kg
PVC membrane	831.1	kg
Screws Nuts & Bolts	5.5	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Softwood Plywood	0.8	m2 (9mm)

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

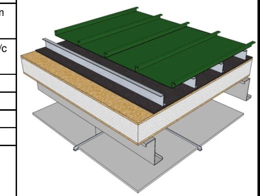
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Roof #5 (WSIP-R5)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	174mm (7in) wood SIP roof with standing seam steel roof assembly	Alkyd based paint
		Commercial 0.46mm galvanized standing seam steel roof (WB) (includes fasteners)
		1.21mm galvanized 38mm Z-girts @ 600mm o/c (self-weight: 0.9 kg/m)
Quick Numbers:		Modified bitumen membrane (AB)
ASHRAE Standard 90.1:	R-Value: 30.3 RSI-Value: 5.3	12mm OSB
THERM 5.2:	R-Value: 34.0 RSI-Value: 6.0	150mm extruded polystyrene insulation
Roof Thickness:	479 mm (excluding drop ceiling)	12mm OSB (VR)
Span:	Range: 1 m to 10 m Design: 5 m	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
Specified Design Loads:	DL 0.9 kPa SL 1.1 kPa	
Total Embodied Energy:	1,593 MJ/m²	
Total Embodied GWP:	64 kg of CO_2 eq./m²	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	54,592	296	54,888	0	431	431	0	0	0	0	0	0	55,319	1,456	-	-
50	54,592	296	54,888	0	431	431	5,090	16	5,106	1	94	95	60,520	1,593	-900,000	-1,536

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	2,378	1	2,379	0	0	0	0	0	0	0	0	0	2,379	63	-	-
50	2,378	1	2,379	0	0	0	71	0	71	0	0	0	2,450	64	-40,000	-68

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 *(Span x Width = 5.0m x 7.6m = 38.0m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
Extruded Polystyrene	233.6	m2 (25mm)
Galvanized Sheet	310.9	kg
Galvanized Studs	262.9	kg
Joint Compound	41.7	kg
Modified Bitumen membrane	118.0	kg
Nails	2.7	kg
Oriented Strand Board	103.3	m2 (9mm)
Paper Tape	0.5	kg
Screws Nuts & Bolts	5.9	kg
Solvent Based Alkyd Paint	27.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

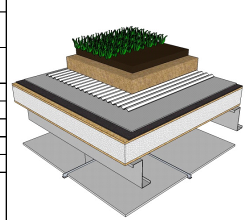
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Structural Insulated Panel Roof #6 (WSIP-R6)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	174mm (7in) wood SIP roof with green roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Protection barrier (modeled as 6mil poly)
		Modified bitumen membrane (AB)
ASHRAE Standard 90.1:	R-Value: 30.3 RSI-Value: 5.3	12mm OSB
THERM 5.2:	R-Value: 32.1 RSI-Value: 5.6	150mm extruded polystyrene insulation
Roof Thickness:	654 mm (excluding drop ceiling)	12mm OSB (VR)
Span:	Range: 1 m to 10 m Design: 5 m	1.90mm galvanized 305mm Z-shape purlin @ 1,200mm o/c (self-weight: 7.7 kg/m)
Specified Design Loads:	DL 2.6 kPa SL 1.1 kPa	
Total Embodied Energy:	1,564 MJ/m^2	
Total Embodied GWP:	63 kg of CO_2 eq./m^2	16mm suspended acoustical ceiling
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	43,967	280	44,247	0	446	446	0	0	0	0	0	0	44,693	1,176	-	-
50	43,967	280	44,247	0	446	446	14,611	40	14,651	1	91	92	59,436	1,564	-800,000	-1,365

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,003	1	2,004	0	0	0	0	0	0	0	0	0	2,004	53	-	-
50	2,003	1	2,004	0	0	0	406	0	406	0	0	0	2,411	63	-40,000	-68

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
16mm Gypsum Fibre Gypsum Board	41.8	m2
6 mil Polyethylene	40.3	m2
Ballast (aggregate stone)	144.9	kg
Extruded Polystyrene	233.6	m2 (25mm)
Galvanized Sheet	88.3	kg
Galvanized Studs	262.9	kg
Joint Compound	41.7	kg
Modified Bitumen membrane	142.1	kg
Nails	2.7	kg
Oriented Strand Board	103.3	m2 (9mm)
Paper Tape	0.5	kg
PVC membrane	169.6	kg
Screws Nuts & Bolts	5.5	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

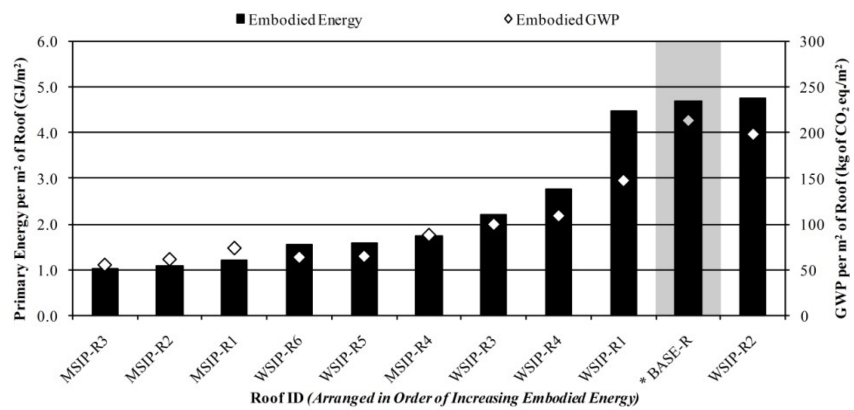
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Metal Structural Insulated Panel Roofs

This section contains a detailed description of each metal structural insulated panel (MSIP) roof that was examined in this study (4 in total). The assembly layers are listed for each roof, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each roof is also included. In each case, the results were calculated for an area of roof equal to 38.0 m^2, which represents a typical bay size for a single-storey retail building with this type of roof system. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

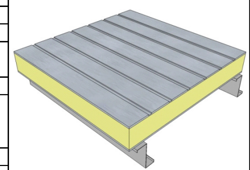
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various roofs in this section as well as the WSIP roofs from the previous section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Metal Structural Insulated Panel Roof #1 (MSIP-R1)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	150mm (6in) metal SIP roof with SBS modified bitumen membrane roof assembly	Latex based paint
		0.46mm galvanized commercial steel cladding
		150mm polyurethane foam insulation
		0.46mm galvanized commercial steel cladding (AB, VB)
Quick Numbers:		Latex based paint
ASHRAE Standard 90.1:	R-Value: 36.1 RSI-Value: 6.4	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
THERM 5.2:	R-Value: 36.2 RSI-Value: 6.4	
Roof Thickness:	379 mm	
Span:	Range: 1 m to 10 m Design: 5 m	Misc. fasteners, nails, and galvanized sheet
Specified Design Loads:	DL 0.6 kPa SL 1.1 kPa	*Inside*
Total Embodied Energy:	1,201 MJ/m^2	
Total Embodied GWP:	73 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	45,534	55	45,589	0	122	122	0	0	0	0	0	0	45,710	1,203	-	-
50	45,534	55	45,589	0	122	122	241	2	243	0	42	42	45,996	1,210	-1,000,000	-1,706

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	2,787	0	2,787	0	0	0	0	0	0	0	0	0	2,787	73	-	-
50	2,787	0	2,787	0	0	0	5	0	5	0	0	0	2,792	73	-50,000	-85

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 *(Span x Width = 5.0m x 7.6m = 38.0m^2)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Foam Polyisocyanurate	234.2	m2 (25mm)
Galvanized Sheet	394.9	kg
Galvanized Studs	262.9	kg
Nails	2.3	kg
Screws Nuts & Bolts	5.5	kg
Water Based Latex Paint	10.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

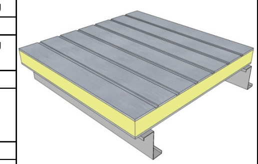
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Metal Structural Insulated Panel Roof #2 (MSIP-R2)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	100mm (4in) metal SIP roof with 4-ply built-up asphalt roof assembly	Latex based paint
		0.46mm galvanized commercial steel cladding
		100mm polyurethane foam insulation
		0.46mm galvanized commercial steel cladding (AB, VB)
Quick Numbers:		Latex based paint
ASHRAE Standard 90.1:	R-Value: 24.6 RSI-Value: 4.3	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
THERM 5.2:	R-Value: 24.5 RSI-Value: 4.3	
Roof Thickness:	329 mm	
Span:	Range: 1 m to 10 m Design: 5 m	Misc. fasteners, nails, and galvanized sheet
Specified Design Loads:	DL 0.6 kPa SL 1.1 kPa	*Inside*
Total Embodied Energy:	1,090 MJ/m^2	
Total Embodied GWP:	61 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	40,965	52	41,017	0	106	106	0	0	0	0	0	0	41,123	1,082	-	-
50	40,965	52	41,017	0	106	106	241	2	243	0	36	36	41,403	1,090	-300,000	-512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	2,321	0	2,321	0	0	0	0	0	0	0	0	0	2,321	61	-	-
50	2,321	0	2,321	0	0	0	5	0	5	0	0	0	2,326	61	-10,000	-17

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 *(Span x Width = 5.0m x 7.6m = 38.0m^2)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Foam Polyisocyanurate	156.1	m2 (25mm)
Galvanized Sheet	394.9	kg
Galvanized Studs	262.9	kg
Nails	2.3	kg
Screws Nuts & Bolts	5.5	kg
Water Based Latex Paint	10.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

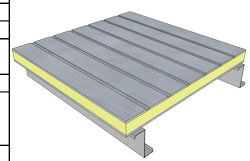
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Metal Structural Insulated Panel Roof #3 (MSIP-R3)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	75mm (3in) metal SIP roof with EPDM roof assembly	Latex based paint
		0.46mm galvanized commercial steel cladding
		75mm polyurethane foam insulation
		0.46mm galvanized commercial steel cladding (AB, VB)
Quick Numbers:		Latex based paint
ASHRAE Standard 90.1:	R-Value: 18.7 RSI-Value: 3.3	1.90mm galvanized 229mm Z-shape purlin @ 1,200mm o/c (self-weight: 6.6 kg/m)
THERM 5.2:	R-Value: 18.5 RSI-Value: 3.3	
Roof Thickness:	304 mm	
Span:	Range: 1 m to 10 m Design: 5 m	Misc. fasteners, nails, and galvanized sheet
Specified Design Loads:	DL 0.6 kPa SL 1.1 kPa	*Inside*
Total Embodied Energy:	1,029 MJ/m^2	
Total Embodied GWP:	55 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	38,681	51	38,732	0	98	98	0	0	0	0	0	0	38,830	1,022	-	-
50	38,681	51	38,732	0	98	98	241	2	243	0	34	34	39,107	1,029	200,000	341

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	2,088	0	2,088	0	0	0	0	0	0	0	0	0	2,088	55	-	-
50	2,088	0	2,088	0	0	0	5	0	5	0	0	0	2,093	55	20,000	34

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Foam Polyisocyanurate	117.1	m2 (25mm)
Galvanized Sheet	394.9	kg
Galvanized Studs	262.9	kg
Nails	2.3	kg
Screws Nuts & Bolts	5.5	kg
Water Based Latex Paint	10.1	L

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

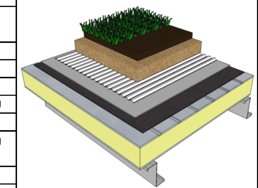
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Metal Structural Insulated Panel Roof #4 (MSIP-R4)

Building Component Description:

Category:	Roofs	Assembly Layers
		Outside
Brief Description:	150mm (6in) metal SIP roof with PVC roof assembly	Green roof assembly (150mm of soil and vegetation)
		Drainage board (WB) (modeled as PVC membrane)
Quick Numbers:		Protection barrier (modeled as 6mil poly)
		Modified bitumen membrane
ASHRAE Standard 90.1:	R-Value: 36.1 RSI-Value: 6.4	Latex based paint
THERM 5.2:	R-Value: 36.9 RSI-Value: 6.5	0.46mm galvanized commercial steel cladding
Roof Thickness:	630 mm	150mm polyurethane foam insulation
Span:	Range: 1 m to 10 m Design: 5 m	0.46mm galvanized commercial steel cladding (AB, VB)
Specified Design Loads:	DL 2.7 kPa SL 1.1 kPa	
Total Embodied Energy:	1,736 MJ/m^2	Latex based paint
Total Embodied GWP:	88 kg of CO_2 eq./m^2	1.90mm galvanized 305mm Z-shape purlin @ 1,200mm o/c (self-weight: 7.7 kg/m)
		Misc. fasteners, nails, and galvanized sheet
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	50,797	61	50,858	0	174	174	0	0	0	0	0	0	51,032	1,343	-	-
50	50,797	61	50,858	0	174	174	14,852	42	14,894	0	50	50	65,976	1,736	-1,000,000	-1,706

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m^2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m^2
1 Initial	2,922	0	2,922	0	0	0	0	0	0	0	0	0	2,922	77	-	-
50	2,922	0	2,922	0	0	0	411	0	411	0	0	0	3,333	88	-50,000	-85

Embodied energy (and GWP) numbers are based on an area of roof = 38.0 m^2 (Span x Width = 5.0m x 7.6m = 38.0m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	40.3	m2
Ballast (aggregate stone)	144.9	kg
Foam Polyisocyanurate	234.2	m2 (25mm)
Galvanized Sheet	394.9	kg
Galvanized Studs	262.9	kg
Modified Bitumen membrane	142.1	kg
Nails	2.3	kg
PVC membrane	169.6	kg
Screws Nuts & Bolts	5.5	kg
Water Based Latex Paint	10.1	L

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

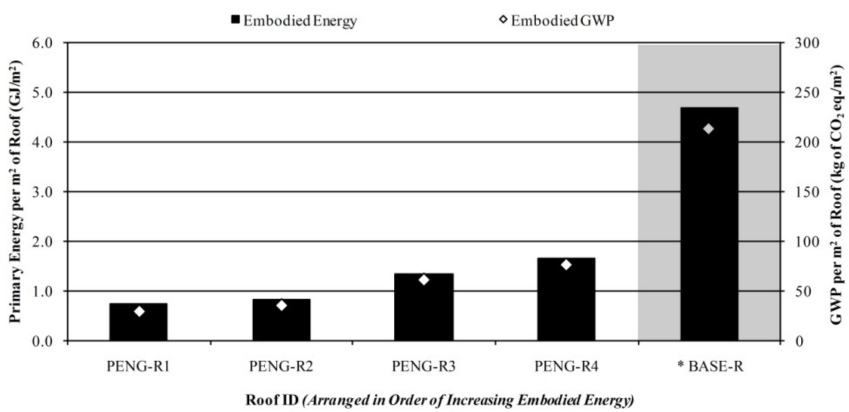
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Pre-Engineered Steel Building Roofs

This section contains a detailed description of each pre-engineered steel building (PENG) roof that was examined in this study (4 in total). The assembly layers are listed for each roof, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each roof is also included. In each case, the results were calculated for an area of roof equal to 57.8 m^2, which represents a typical bay size for a single-storey retail building with this type of roof system. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

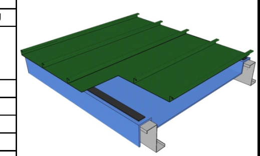
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various roofs in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Pre-Engineered Steel Building Roof #1 (PENG-R1)

Building Component Description:

Category:	Roofs	Assembly Layers
Brief Description:	Typical pre-engineered steel building roof with exterior steel cladding and no insulation (not typical pre-eng. roof)	***Outside***
		Alkyd based paint
		0.46mm galvanized commercial steel cladding
		1.52mm galvanized 200mm Z-shape purlin @ 1,200mm o/c with thermal block (self-weight: 5.1 kg/m)
Quick Numbers:		6mil poly (AB, VB)
ASHRAE Standard 90.1:	R-Value: 0.8 RSI-Value: 0.1	Misc. fasteners, nails, and galvanized sheet
THERM 5.2:	R-Value: 0.8 RSI-Value: 0.1	***Inside***
Roof Thickness:	238 mm	
Span:	Range: 1 m to 10 m Design: 7.6 m	
Specified Design Loads:	DL 0.4 kPa SL 1.1 kPa	
Total Embodied Energy:	738 MJ/m^2	
Total Embodied GWP:	29 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	34,703	49	34,752	0	104	104	0	0	0	0	0	0	34,856	603	-	-
50	34,703	49	34,752	0	104	104	7,735	25	7,760	0	33	33	42,649	738	* N/A	* N/A

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,577	0	1,577	0	0	0	0	0	0	0	0	0	1,577	27	-	-
50	1,577	0	1,577	0	0	0	108	0	108	0	0	0	1,685	29	* N/A	* N/A

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

** Thermal resistance and thermal mass of roof was too low to get an accurate evaluation of operating energy from computer simulations*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	61.3	m2
Galvanized Sheet	338.3	kg
Galvanized Studs	399.5	kg
Modified Bitumen membrane	179.3	kg
Screws Nuts & Bolts	8.9	kg
Solvent Based Alkyd Paint	41.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

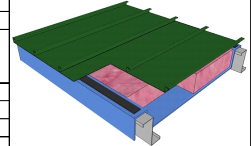
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Pre-Engineered Steel Building Roof #2 (PENG-R2)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Typical pre-engineered steel building roof with exterior steel cladding and batt insulation (typical pre-eng. roof)	Alkyd based paint 0.46mm galvanized commercial steel cladding 150mm fiberglass batt insulation
Quick Numbers:		1.52mm galvanized 200mm Z-shape purlin @ 1,200mm o/c with thermal block (self-weight: 5.1 kg/m)
ASHRAE Standard 90.1:	R-Value: 17.2 RSI-Value: 3.0	6mil poly (AB, VB)
THERM 5.2:	R-Value: 17.8 RSI-Value: 3.1	Misc. fasteners, nails, and galvanized sheet
Roof Thickness:	238 mm	***Inside***
Span:	Range: 1 m to 10 m Design: 7.6 m	
Specified Design Loads:	DL 0.4 kPa SL 1.1 kPa	
Total Embodied Energy:	833 MJ/m^2	
Total Embodied GWP:	35 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	40,106	81	40,187	0	124	124	0	0	0	0	0	0	40,312	698	-	-
50	40,106	81	40,187	0	124	124	7,735	25	7,760	0	50	50	48,121	833	300,000	512

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	1,923	0	1,923	0	0	0	0	0	0	0	0	0	1,923	33	-	-
50	1,923	0	1,923	0	0	0	108	0	108	0	0	0	2,031	35	20,000	34

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	61.3	m2
Batt. Fiberglass	352.1	m2 (25mm)
Galvanized Sheet	338.3	kg
Galvanized Studs	399.5	kg
Modified Bitumen membrane	179.3	kg
Nails	3.6	kg
Screws Nuts & Bolts	8.9	kg
Solvent Based Alkyd Paint	41.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

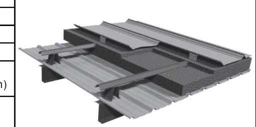
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Pre-Engineered Steel Building Roof #3 (PENG-R3)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Pre-engineered steel building roof with exterior steel cladding, 150mm rigid insulation, and interior steel liner sheet (advanced pre-eng. roof)	Alkyd based paint 0.46mm galvanized commercial steel cladding 150mm extruded polystyrene rigid insulation
Quick Numbers:		1.21mm heavy-duty galvanized steel furring channels @ 1,200mm o/c (self-weight: 0.82 kg/m)
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	0.46mm galvanized commercial steel cladding (AB, VB)
BEHLEN Industries LP:	R-Value: 21.0 RSI-Value: 3.7	Alkyd based paint
Roof Thickness:	426 mm	1.52mm galvanized 200mm Z-shape purlin @ 1,200mm o/c with thermal block (self-weight: 5.1 kg/m)
Span:	Range: 1 m to 10 m Design: 7.6 m	
Specified Design Loads:	DL 0.5 kPa SL 1.1 kPa	
Total Embodied Energy:	1,341 MJ/m^2	***Inside***
Total Embodied GWP:	61 kg of CO_2 eq./m^2	



Rendering & R-value courtesy of BEHLEN Industries LP *http://www.behlen.ca/*

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	76,510	75	76,585	0	160	160	0	0	0	0	0	0	76,745	1,329	-	-
50	76,510	75	76,585	0	160	160	621	4	626	0	73	73	77,444	1,341	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	3,509	0	3,509	0	0	0	0	0	0	0	0	0	3,509	61	-	-
50	3,509	0	3,509	0	0	0	11	0	11	0	0	0	3,520	61	0	0

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m^2 (Span x Width = 7.6m x 7.6m = 57.8m^2)

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Extruded Polystyrene	355.0	m2 (25mm)
Galvanized Sheet	636.3	kg
Galvanized Studs	399.5	kg
Nails	3.6	kg
Screws Nuts & Bolts	8.3	kg
Solvent Based Alkyd Paint	15.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

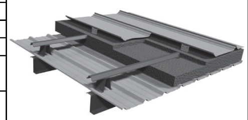
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Pre-Engineered Steel Building Roof #4 (PENG-R4)

Building Component Description:

		Assembly Layers
Category:	Roofs	***Outside***
Brief Description:	Pre-engineered steel building roof with exterior steel cladding, 250mm rigid insulation, and interior steel liner sheet (advanced pre-eng. roof)	Alkyd based paint 0.46mm galvanized commercial steel cladding 250mm extruded polystyrene rigid insulation 1.21mm heavy-duty galvanized steel furring channels @ 1,200mm o/c (self-weight: 0.82 kg/m)
Quick Numbers:		0.46mm galvanized commercial steel cladding (AB, VB)
ASHRAE Standard 90.1:	R-Value: N/A RSI-Value: N/A	
BEHLEN Industries LP:	R-Value: 35.0 RSI-Value: 6.2	Alkyd based paint
Roof Thickness:	526 mm	1.52mm galvanized 200mm Z-shape purlin @ 1,200mm o/c with thermal block (self-weight: 5.1 kg/m)
Span:	Range: 1 m to 10 m Design: 7.6 m	
Specified Design Loads:	DL 0.6 kPa SL 1.1 kPa	
Total Embodied Energy:	1,639 MJ/m²	***Inside***
Total Embodied GWP:	76 kg of CO_2 eq./m²	



Rendering & R-value courtesy of BEHLEN Industries LP
http://www.behlen.ca/

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	93,711	76	93,787	0	187	187	0	0	0	0	0	0	93,974	1,627	-	-
50	93,711	76	93,787	0	187	187	621	4	626	0	95	95	94,695	1,639	-900,000	-1,536

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	4,388	0	4,388	0	0	0	0	0	0	0	0	0	4,389	76	-	-
50	4,388	0	4,388	0	0	0	11	0	11	0	0	0	4,400	76	-50,000	-85

Embodied energy (and GWP) numbers are based on an area of roof = 57.8 m² *(Span x Width = 7.6m x 7.6m = 57.8m²)*

Net roof area of baseline retail building (gross roof area - openings) = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Extruded Polystyrene	591.6	m2 (25mm)
Galvanized Sheet	636.3	kg
Galvanized Studs	399.5	kg
Nails	3.6	kg
Screws Nuts & Bolts	8.3	kg
Solvent Based Alkyd Paint	15.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / net roof area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Appendix B-3

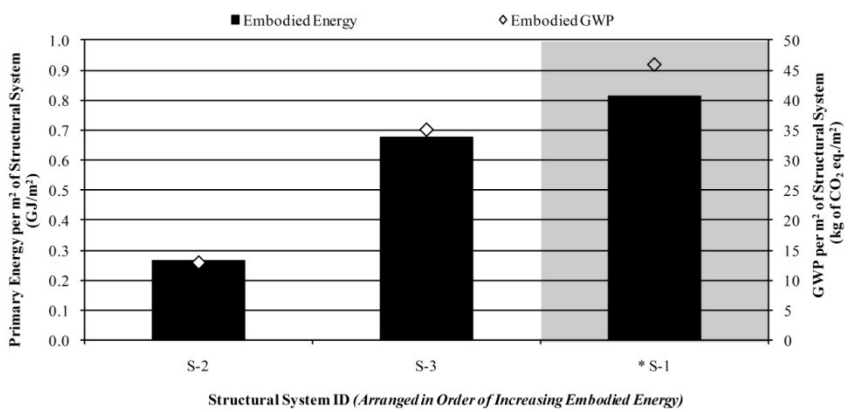
LCA Data for Structural Systems

LCA Data for Structural Systems

This section contains a detailed description of structural systems that were examined in this study (3 in total). A summary of the important elements of each system are listed, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each structural system is also included. In each case, the results were calculated for an entire retail building. The results are also expressed per m^2 of structural system in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

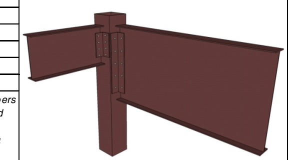
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various structural systems in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Structural System #1 (S-1)

Building Component Description:

		Summary of Structural Elements
Category:	Structure	***Beams***
		W-sections, 350MPa
Brief Description:	Conventional braced steel frame structural system with H.S.S. columns and W-section beams (Note: Floor joists and roof joists are included in floor and roof assemblies)	***Columns***
		Hollow Structural Steel sections, 350MPa
		Wind Girts
Quick Numbers:		Hollow Structural Steel sections, 350MPa
Total Embodied Energy:	813 MJ/m^2	*Note: The embodied energy (and GWP) numbers for this structural system were calculated based on Case Study #1 - Typical Hot-Rolled Steel Structure Retail Building. See Appendix D for a complete description of this structural system, including the member sizes, spans, and beam spacings that were assumed.*
Total Embodied GWP:	46 kg of CO_2 eq./m^2	
	Note: Embodied energy and embodied GWP numbers are per m^2 of structural system	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m^2)	([4] per m^2)
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	471,848	1,816	473,664	509	1,927	2,436	0	0	0	0	0	0	812	-
50	471,848	1,816	473,664	509	1,927	2,436	0	0	0	6	310	316	813	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m^2)	([4] per m^2)
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	26,830	4	26,833	33	4	37	0	0	0	0	0	0	46	-
50	26,830	4	26,833	33	4	37	0	0	0	0	1	1	46	0

Embodied energy (and GWP) numbers were calculated for the entire structural system for Case Study Building #1 - Typical Hot-Rolled Steel Structure

Floor area of Case Study Building #1 = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Hollow Structural Steel	3,307.4	kg
Hot Rolled Sheet	1,515.0	kg
Screws Nuts & Bolts	626.7	kg
Wide Flange Sections	11,822.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m^2** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects) / floor area of baseline building

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component / floor area of baseline building

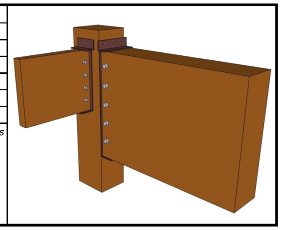
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Structural System #2 (S-2)

Building Component Description:

		Summary of Structural Elements
Category:	Structure	***Beams***
Brief Description:	Conventional braced heavy timber structural system with glulam columns and glulam beams (Note: Floor joists and roof joists are included in floor and roof assemblies)	20f-E Glulam, D-Fir-L
		Columns
		16c-E Glulam, D-Fir-L
		Wind Girts
Quick Numbers:		20f-E Glulam, D-Fir-L
Total Embodied Energy:	266 MJ/m²	*Note: The embodied energy (and GWP) numbers for this structural system were calculated based on Case Study #2 - Typical Heavy Timber Structure Retail Building. See Appendix D for a complete description of this structural system, including the member sizes, spans, and beam spacings that were assumed.*
Total Embodied GWP:	13 kg of CO_2 eq./m²	
	Note: Embodied energy and embodied GWP numbers are per m² of structural system	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m²)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m²)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	144,531	3,510	148,041	1,166	6,306	7,472	0	0	0	0	0	0	265	-
50	144,531	3,510	148,041	1,166	6,306	7,472	0	0	0	16	442	458	266	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m²)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m²)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	7,468	7	7,475	75	4	79	0	0	0	0	0	0	13	-
50	7,468	7	7,475	75	4	79	0	0	0	1	1	2	13	0

Embodied energy (and GWP) numbers were calculated for the entire structural system for Case Study Building #2 - Typical Heavy Timber Structure

Floor area of Case Study Building #2 = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
GluLam Sections	33.5	m3
Hollow Structural Steel	780.7	kg
Hot Rolled Sheet	1,515.0	kg
Screws Nuts & Bolts	206.0	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m²** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects) / floor area of baseline building

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component / floor area of baseline building

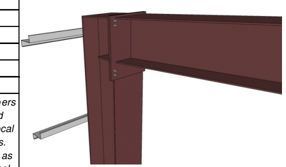
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Structural System #3 (S-3)

Building Component Description:

		Summary of Structural Elements
Category:	Structure	***Beams***
Brief Description:	Conventional pre-engineered steel building system with tapered W-section columns and tapered W-section beams (Note: Floor joists and roof joists are included in floor and roof assemblies)	Tapered W-section members, 350MPa
		Columns
		Tapered W-section members, 350MPa
		Wind Girts
Quick Numbers:		Cold-formed steel Z-sections
Total Embodied Energy:	674 MJ/m²	*Note: The embodied energy (and GWP) numbers for this structural system were calculated based on a detailed estimate of steel provided by a local manufacturer of pre-engineered steel buildings. The manufacturer provided material quantities as well as a set of construction drawings for a typical pre-engineered steel retail building.*
Total Embodied GWP:	35 kg of CO_2 eq./m²	
	Note: Embodied energy and embodied GWP numbers are per m² of structural system	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m²)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m²)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	390,970	1,701	392,671	509	1,521	2,030	0	0	0	0	0	0	674	-
50	390,970	1,701	392,671	509	1,521	2,030	0	0	0	4	222	226	674	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m²)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m²)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	20,477	3	20,481	33	3	36	0	0	0	0	0	0	35	-
50	20,477	3	20,481	33	3	36	0	0	0	0	0	1	35	0

Embodied energy (and GWP) numbers were calculated for the entire structural system for Case Study Building #3 - Typical Pre-Engineered Steel Building Structure

Floor area of Case Study Building #3 = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Screws Nuts & Bolts	626.7	kg
Wide Flange Sections	13,077.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m²** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects) / floor area of baseline building

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component / floor area of baseline building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Appendix B-4

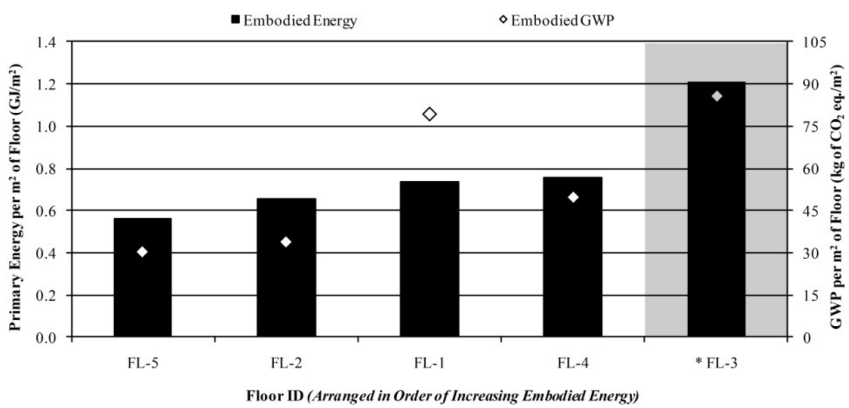
LCA Data for Floors

LCA Data for Floors

This section contains a detailed description of each floor (FL) assembly that was examined in this study (5 in total). The assembly layers are listed for each floor, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each floor is also included. In each case, the results were calculated for a different area of mezzanine floor, depending on the typical spans of each system. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

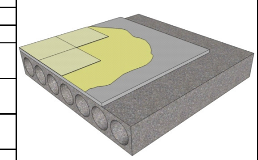
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various floors in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Floor #1 (FL-1)

Building Component Description:

Category:	Mezzanine Floors	**Assembly Layers**
		Top
Brief Description:	Floor assembly: 200mm concrete hollow core slab with vinyl tile finish	Vinyl floor tile
		Adhesive (modeled as alkyd based paint)
		50mm concrete topping (modeled as 50mm of mortar)
Quick Numbers:		*(concrete topping is reinforced with 150mm x 150mm #10M steel mesh @ 1.0 kg/m²)*
Floor Thickness:	256 mm	200mm concrete hollow core floor slab (9% flyash, 45+ MPa, typical reinforcement)
Span:	Range: 3 m to 14 m Design: 7.6 m	
Specified Design Loads:	DL 5.4 kPa LL 2.4 kPa	***Bottom***
Total Embodied Energy:	739 MJ/m²	
Total Embodied GWP:	79 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	31,616	1,058	32,674	933	1,425	2,358	0	0	0	0	0	0	35,031	607	-	-
50	31,616	1,058	32,674	933	1,425	2,358	6,833	38	6,871	1	760	762	42,664	739	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	4,016	2	4,018	65	3	68	0	0	0	0	0	0	4,086	71	-	-
50	4,016	2	4,018	65	3	68	498	0	498	0	1	2	4,586	79	0	0

Embodied energy (and GWP) numbers are based on a mezzanine floor area = 57.8 m² *(Length x Height = 7.6m x 7.6m = 57.8m²)*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 20 MPa (flyash av)	3.0	m3
Concrete 60 MPa (flyash av)	5.7	m3
Mortar	3.3	m3
Rebar, Rod, Light Sections	197.2	kg
Solvent Based Alkyd Paint	12.3	L
Vinyl Siding	119.5	m2
Welded Wire Mesh / Ladder Wire	98.6	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / floor area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Floor #2 (FL-2)

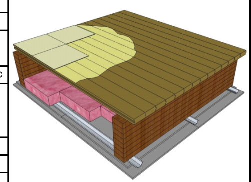
Building Component Description:

Category:	Mezzanine Floors
Brief Description:	Floor assembly: Glulam joists and wood plank deck with vinyl tile finish and drywall ceiling

Quick Numbers:

Floor Thickness:	651 mm
Span:	Range: 2 m to 12 m Design: 9.1 m
Specified Design Loads:	DL 2.8 kPa LL 2.4 kPa
Total Embodied Energy:	657 MJ/m^2
Total Embodied GWP:	34 kg of CO_2 eq./m^2

Assembly Layers
Top
Vinyl floor tile
Adhesive (modeled as alkyd based paint)
64mm SPF tongue & groove solid wood plank decking
80mm x 532mm 24f-E glulam joists @ 1,200m o/c
0.53mm galvanized steel resilient channels @ 600mm o/c (self-weight: 0.31 kg/m)
90mm fiberglass batt insulation
Two layers of regular 12mm gypsum board
Latex paint
Misc. fasteners, nails, and galvanized sheet
Bottom



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	32,233	738	32,971	343	1,504	1,847	0	0	0	0	0	0	34,818	503	-	-
50	32,233	738	32,971	343	1,504	1,847	10,312	64	10,377	2	219	221	45,415	657	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	1,685	1	1,686	22	2	25	0	0	0	0	0	0	1,711	25	-	-
50	1,685	1	1,686	22	2	25	638	0	638	0	0	1	2,349	34	0	0

Embodied energy (and GWP) numbers are based on a mezzanine floor area = 69.2 m^2 (Length x Height = 9.1m x 7.6m = 69.2m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	152.2	m2
Batt. Fiberglass	253.0	m2 (25mm)
Galvanized Studs	40.4	kg
GluLam Sections	2.8	m3
Joint Compound	151.9	kg
Nails	18.5	kg
Paper Tape	1.7	kg
Small Dimension Softwood Lumber, kiln-dried	3.5	m3
Solvent Based Alkyd Paint	14.6	L
Vinyl Siding	142.9	m2
Water Based Latex Paint	90.0	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / floor area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Floor #3 (FL-3)

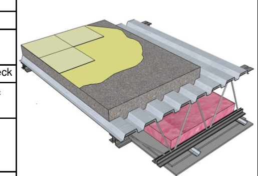
Building Component Description:

Category:	Mezzanine Floors
Brief Description:	Floor assembly: OWSJ and metal deck with concrete topping, vinyl tile finish, and drywall ceiling

Quick Numbers:

Floor Thickness:	732 mm
Span:	Range: 3 m to 46 m Design: 9.1 m
Specified Design Loads:	DL 4.4 kPa LL 2.4 kPa
Total Embodied Energy:	1,205 MJ/m^2
Total Embodied GWP:	86 kg of CO_2 eq./m^2

Assembly Layers
Top
Vinyl floor tile
Adhesive (modeled as alkyd based paint)
89mm concrete topping
(concrete topping is reinforced with 150mm x 150mm #10M steel mesh)
39mm x 0.76mm galvanized corrugated metal deck
550mm open web steel joists @ 1,200mm o/c (self-weight: 15.4 kg/m)
0.53mm galvanized steel resilient channels @ 600mm o/c (self-weight: 0.31 kg/m)
90mm fiberglass batt insulation
Two layers of regular 12mm gypsum board
Latex paint
Misc. fasteners, nails, and galvanized sheet
Bottom



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	69,423	852	70,275	669	1,398	2,066	0	0	0	0	0	0	72,341	1,046	-	-
50	69,423	852	70,275	669	1,398	2,066	10,312	64	10,377	1	621	622	83,339	1,205	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	5,245	2	5,247	44	3	46	0	0	0	0	0	0	5,293	77	-	-
50	5,245	2	5,247	44	3	46	638	0	638	0	1	1	5,932	86	0	0

Embodied energy (and GWP) numbers are based on a mezzanine floor area = 69.2 m^2 (Length x Height = 9.1m x 7.6m = 69.2m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	152.2	m2
Batt. Fiberglass	253.0	m2 (25mm)
Concrete 20 MPa (flyash av)	6.4	m3
Galvanized Decking	684.5	kg
Galvanized Studs	40.4	kg
Joint Compound	151.9	kg
Nails	5.7	kg
Open Web Joists	891.6	kg
Paper Tape	1.7	kg
Rebar, Rod, Light Sections	62.5	kg
Solvent Based Alkyd Paint	14.6	L
Vinyl Siding	142.9	m2
Water Based Latex Paint	90.0	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / floor area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

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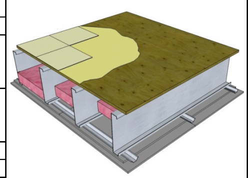
Floor #4 (FL-4)

Building Component Description:

Category:	Mezzanine Floors	Assembly Layers
		Top
Brief Description:	Floor assembly: Cold-formed steel joists and plywood deck with vinyl tile finish and drywall ceiling	Vinyl floor tile
		Adhesive (modeled as alkyd based paint)
		19mm plywood deck
		39mm x 245mm 1.52mm galvanized cold-formed steel C-joists @ 400mm o/c (self-weight: 4.2 kg/m)
Quick Numbers:		0.53mm galvanized steel resilient channels @ 600mm o/c (self-weight: 0.31 kg/m)
Floor Thickness:	319 mm	
Span:	Range: 1 m to 6 m Design: 5 m	
Specified Design Loads:	DL 2.2 kPa LL 2.4 kPa	90mm fiberglass batt insulation
Total Embodied Energy:	757 MJ/m^2	Two layers of regular 12mm gypsum board
Total Embodied GWP:	50 kg of CO_2 eq./m^2	Latex paint
		Misc. fasteners, nails, and galvanized sheet
		Bottom



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	22,541	157	22,698	0	284	284	0	0	0	0	0	0	22,982	605	-	-
50	22,541	157	22,698	0	284	284	5,680	35	5,715	1	87	88	28,785	757	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,542	0	1,542	0	1	1	0	0	0	0	0	0	1,543	41	-	-
50	1,542	0	1,542	0	1	1	351	0	351	0	0	0	1,895	50	0	0

Embodied energy (and GWP) numbers are based on a mezzanine floor area = 38.0 m^2 (Length x Height = 5.0m x 7.6m = 38.0m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	83.6	m2
Batt. Fiberglass	139.0	m2 (25mm)
Galvanized Studs	444.3	kg
Joint Compound	83.4	kg
Nails	3.1	kg
Paper Tape	1.0	kg
Screws Nuts & Bolts	5.5	kg
Softwood Plywood	79.8	m2 (9mm)
Solvent Based Alkyd Paint	8.1	L
Vinyl Siding	78.7	m2
Water Based Latex Paint	49.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / floor area of baseline retail building

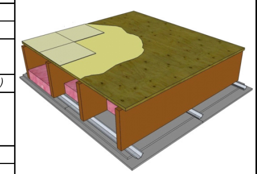
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Floor #5 (FL-5)

Building Component Description:

Category:	Mezzanine Floors	Assembly Layers
		Top
Brief Description:	Floor assembly: Traditional wood joists and plywood deck with vinyl tile finish and drywall ceiling	Vinyl floor tile
		Adhesive (modeled as alkyd based paint)
		19mm plywood deck
		38mm x 286mm SPF No. 1 / No. 2 solid wood joists @ 400mm o/c
Quick Numbers:		*(Includes solid lumber bridging at 2,000mm o/c)*
Floor Thickness:	360 mm	0.53mm galvanized steel resilient channels @ 600mm o/c (self-weight: 0.31 kg/m)
Span:	Range: 1 m to 6 m Design: 5 m	
Specified Design Loads:	DL 2.3 kPa LL 2.4 kPa	
Total Embodied Energy:	559 MJ/m^2	90mm fiberglass batt insulation
Total Embodied GWP:	30 kg of CO_2 eq./m^2	Two layers of regular 12mm gypsum board
		Latex paint
		Misc. fasteners, nails, and galvanized sheet
		Bottom



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	14,264	238	14,502	238	684	922	0	0	0	0	0	0	15,425	406	-	-
50	14,264	238	14,502	238	684	922	5,679	35	5,715	1	85	86	21,225	559	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	788	0	789	16	1	17	0	0	0	0	0	0	805	21	-	-
50	788	0	789	16	1	17	351	0	351	0	0	0	1,157	30	0	0

Embodied energy (and GWP) numbers are based on a mezzanine floor area = 38.0 m^2 (Length x Height = 5.0m x 7.6m = 38.0m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	83.6	m2
Batt. Fiberglass	138.9	m2 (25mm)
Galvanized Sheet	0.0	kg
Galvanized Studs	36.4	kg
Joint Compound	83.4	kg
Large Dimension Softwood Lumber, kiln-dried	0.9	m3
Nails	8.6	kg
Paper Tape	1.0	kg
Softwood Plywood	79.8	m2 (9mm)
Solvent Based Alkyd Paint	8.1	L
Vinyl Siding	78.7	m2
Water Based Latex Paint	49.4	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / floor area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Appendix B-5

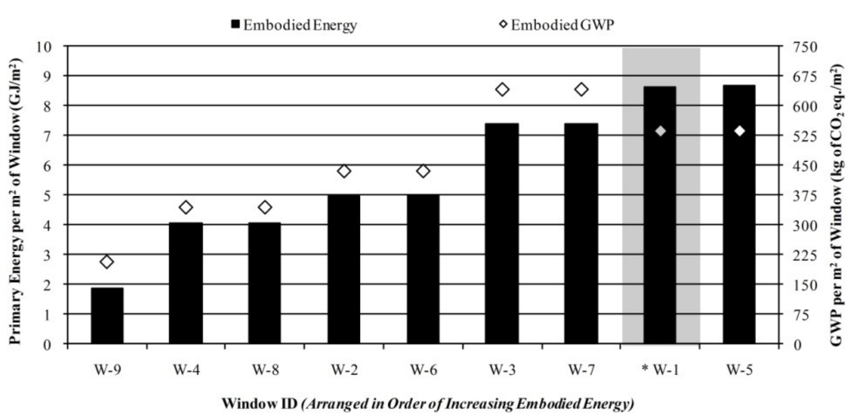
LCA Data for Windows and Doors

LCA Data for Windows

This section contains a detailed description of each window that was examined in this study (9 in total). The assembly layers are listed for each window, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each window is also included. In each case, the results were calculated for a window area equal to 2.9 m^2, which represents a typical window size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

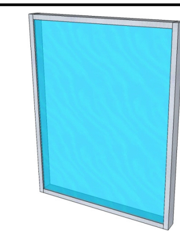
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various windows in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Window #1 (W-1)

Building Component Description:

Category:	Windows & Doors	**Assembly Layers**
Brief Description:	Aluminum window frame with typical double pane glazing unit	***Outside***
		Aluminum window frame with thermal break
		Typical sealed double pane glazing unit with 12.7mm airspace
		(No low-E coating. No argon between panes)
Quick Numbers:		*(Fixed window i.e. not operable)*
		Inside
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 1.8 RSI-Value: 0.3	
SHGC:	0.70	
Total Embodied Energy:	8,657 MJ/m^2	
Total Embodied GWP:	537 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	14,869	177	15,046	0	374	374	0	0	0	0	0	0	15,420	5,317	-	-
50	14,869	177	15,046	0	374	374	9,293	362	9,655	0	29	29	25,104	8,657	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	958	0	958	0	1	1	0	0	0	0	0	0	959	331	-	-
50	958	0	958	0	1	1	599	1	599	0	0	0	1,558	537	0	0

Embodied energy (and GWP) numbers are based on a window area = 2.9 m^2 (Length x Height = 1.2m x 2.4m = 2.9m^2)

Total window area of baseline retail building (total fenestration area) = 148.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	179.0	kg
EPDM membrane	11.8	kg
Nails	10.2	kg
Standard Glazing	12.7	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

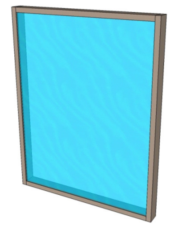
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Window #2 (W-2)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
		Outside
Brief Description:	PVC clad wood window frame with typical double pane glazing unit	PVC clad wood window frame with thermal break
		Typical sealed double pane glazing unit with 12.7mm airspace
		(No low-E coating. No argon between panes)
Quick Numbers:		*(Fixed window i.e. not operable)*
		Inside
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 2.0 RSI-Value: 0.4	
SHGC:	0.70	
Total Embodied Energy:	4,991 MJ/m^2	
Total Embodied GWP:	437 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	8,858	85	8,943	0	179	179	0	0	0	0	0	0	9,122	3,146	-	-
50	8,858	85	8,943	0	179	179	5,150	171	5,321	0	30	30	14,474	4,991	-200,000	-1,351

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	800	0	800	0	0	0	0	0	0	0	0	0	801	276	-	-
50	800	0	800	0	0	0	465	0	466	0	0	0	1,266	437	-10,000	-68

Embodied energy (and GWP) numbers are based on a window area = 2.9 m^2 (Length x Height = 1.2m x 2.4m = 2.9m^2)

Total window area of baseline retail building (total fenestration area) = 148.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Batt. Fiberglass	0.6	m2 (25mm)
EPDM membrane	10.3	kg
Nails	8.9	kg
Small Dimension Softwood Lumber, kiln-dried	0.3	m3
Standard Glazing	11.1	m2
Vinyl Siding	29.9	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

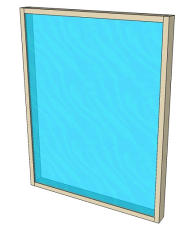
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Window #3 (W-3)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
		Outside
Brief Description:	PVC window frame with typical double pane glazing unit	PVC window frame with thermal break
		Typical sealed double pane glazing unit with 12.7mm airspace
		(No low-E coating. No argon between panes)
Quick Numbers:		*(Fixed window i.e. not operable)*
		Inside
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 2.0 RSI-Value: 0.4	
SHGC:	0.70	
Total Embodied Energy:	7,387 MJ/m^2	
Total Embodied GWP:	641 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	13,302	71	13,373	0	137	137	0	0	0	0	0	0	13,511	4,659	-	-
50	13,302	71	13,373	0	137	137	7,734	142	7,876	0	35	35	21,421	7,387	-200,000	-1,351

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2	[5] Total	[6] per m^2
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total				
[1] Initial	1,176	0	1,176	0	0	0	0	0	0	0	0	0	1,176	406	-	-
50	1,176	0	1,176	0	0	0	684	0	684	0	0	0	1,860	641	-10,000	-68

Embodied energy (and GWP) numbers are based on a window area = 2.9 m^2 (Length x Height = 1.2m x 2.4m = 2.9m^2)

Total window area of baseline retail building (total fenestration area) = 148.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Batt. Fiberglass	0.6	m2 (25mm)
EPDM membrane	10.3	kg
Nails	8.9	kg
Standard Glazing	11.1	m2
Vinyl Siding	74.9	m2

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

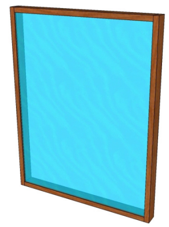
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Window #4 (W-4)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
Brief Description:	Wood window frame with typical double pane glazing unit	*Outside*
		Wood window frame with thermal break
		Typical sealed double pane glazing unit with 12.7mm airspace
		(No low-E coating. No argon between panes)
Quick Numbers:		*(Fixed window i.e. not operable)*
		Inside
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 2.0 RSI-Value: 0.4	
SHGC:	0.70	
Total Embodied Energy:	4,084 MJ/m²	
Total Embodied GWP:	346 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	7,025	94	7,119	0	213	213	0	0	0	0	0	0	7,331	2,528	-	-
50	7,025	94	7,119	0	213	213	4,284	203	4,487	0	27	27	11,844	4,084	-200,000	-1,351

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	622	0	623	0	0	0	0	0	0	0	0	0	623	215	-	-
50	622	0	623	0	0	0	379	0	380	0	0	0	1,003	346	-10,000	-68

Embodied energy (and GWP) numbers are based on a window area = 2.9 m² *(Length x Height = 1.2m x 2.4m = 2.9m²)*

Total window area of baseline retail building (total fenestration area) = 148.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	20.9	kg
Batt. Fiberglass	0.6	m2 (25mm)
EPDM membrane	11.2	kg
Nails	10.0	kg
Small Dimension Softwood Lumber, kiln-dried	0.3	m3
Standard Glazing	12.1	m2
Water Based Latex Paint	1.2	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

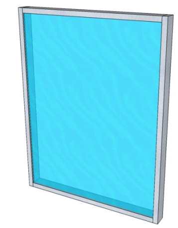
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Window #5 (W-5)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
Brief Description:	Aluminum window frame with argon filed double pane glazing unit and low-E coating	*Outside*
		Aluminum window frame with thermal break
		Sealed double pane glazing unit with 12.7mm argon space
		(Tin based low-E coating: e = 0.4)
Quick Numbers:		*(Argon gas between panes)*
		(Fixed window i.e. not operable)
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 2.2 RSI-Value: 0.4	*Inside*
SHGC:	0.73	
Total Embodied Energy:	8,661 MJ/m²	
Total Embodied GWP:	537 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	14,874	178	15,053	0	374	374	0	0	0	0	0	0	15,427	5,320	-	-
50	14,874	178	15,053	0	374	374	9,297	363	9,660	0	29	29	25,116	8,661	-1,900,000	-12,838

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	958	0	958	0	1	1	0	0	0	0	0	0	959	331	-	-
50	958	0	958	0	1	1	599	1	599	0	0	0	1,559	537	-100,000	-676

Embodied energy (and GWP) numbers are based on a window area = 2.9 m² *(Length x Height = 1.2m x 2.4m = 2.9m²)*

Total window area of baseline retail building (total fenestration area) = 148.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	179.0	kg
EPDM membrane	11.8	kg
Low E Tin Argon Filled Glazing	12.7	m2
Nails	10.2	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

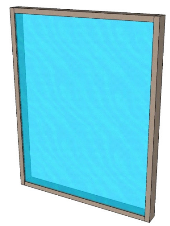
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Window #6 (W-6)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
		Outside
Brief Description:	PVC clad wood window frame with argon filed double pane glazing unit and low-E coating	PVC clad wood window frame with thermal break
		Sealed double pane glazing unit with 12.7mm argon space
		(Tin based low-E coating: e = 0.4)
Quick Numbers:		*(Argon gas between panes)*
		(Fixed window i.e. not operable)
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 2.5 RSI-Value: 0.4	*Inside*
SHGC:	0.73	
Total Embodied Energy:	4,995 MJ/m2	
Total Embodied GWP:	437 kg of CO_2 eq./m2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m2
1 Initial	8,863	86	8,949	0	179	179	0	0	0	0	0	0	9,129	3,148	-	-
50	8,863	86	8,949	0	179	179	5,153	172	5,325	0	30	30	14,484	4,995	-2,000,000	-13,514

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m2
1 Initial	801	0	801	0	0	0	0	0	0	0	0	0	801	276	-	-
50	801	0	801	0	0	0	465	0	466	0	0	0	1,267	437	-110,000	-743

Embodied energy (and GWP) numbers are based on a window area = 2.9 m^2 (Length x Height = 1.2m x 2.4m = 2.9m^2)

Total window area of baseline retail building (total fenestration area) = 148.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Batt. Fiberglass	0.6	m2 (25mm)
EPDM membrane	10.3	kg
Low E Tin Argon Filled Glazing	11.1	m2
Nails	8.9	kg
Small Dimension Softwood Lumber, kiln-dried	0.3	m3
Vinyl Siding	29.9	m2

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m2** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

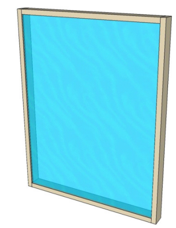
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m2/yr)*

Window #7 (W-7)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
		Outside
Brief Description:	PVC window frame with argon filed double pane glazing unit and low-E coating	PVC window frame with thermal break
		Sealed double pane glazing unit with 12.7mm argon space
		(Tin based low-E coating: e = 0.4)
Quick Numbers:		*(Argon gas between panes)*
		(Fixed window i.e. not operable)
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 2.5 RSI-Value: 0.4	*Inside*
SHGC:	0.73	
Total Embodied Energy:	7,390 MJ/m2	
Total Embodied GWP:	642 kg of CO_2 eq./m2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m2
1 Initial	13,307	73	13,380	0	137	137	0	0	0	0	0	0	13,518	4,661	-	-
50	13,307	73	13,380	0	137	137	7,737	142	7,879	0	35	35	21,432	7,390	-2,000,000	-13,514

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m2		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m2
1 Initial	1,176	0	1,176	0	0	0	0	0	0	0	0	0	1,177	406	-	-
50	1,176	0	1,176	0	0	0	684	0	684	0	0	0	1,861	642	-110,000	-743

Embodied energy (and GWP) numbers are based on a window area = 2.9 m^2 (Length x Height = 1.2m x 2.4m = 2.9m^2)

Total window area of baseline retail building (total fenestration area) = 148.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Batt. Fiberglass	0.6	m2 (25mm)
EPDM membrane	10.3	kg
Low E Tin Argon Filled Glazing	11.1	m2
Nails	8.9	kg
Vinyl Siding	74.9	m2

Notes:

1 **Initial** = Time '0' (i.e. at the completion of initial construction)

2 **Trans.** = Transportation

3 **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

4 **Total EE (or Total GWP) per m2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

5 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

6 **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m2** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

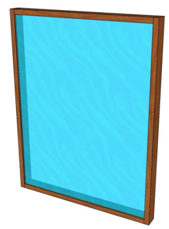
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m2/yr)*

Window #8 (W-8)

Building Component Description:

		Assembly Layers
Category:	Windows & Doors	*Outside*
Brief Description:	Wood window frame with argon filed double pane glazing unit and low-E coating	Wood window frame with thermal break
		Sealed double pane glazing unit with 12.7mm argon space
		(Tin based low-E coating: e = 0.4)
Quick Numbers:		*(Argon gas between panes)*
		(Fixed window i.e. not operable)
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 2.5 RSI-Value: 0.4	***Inside***
SHGC:	0.73	
Total Embodied Energy:	4,088 MJ/m^2	
Total Embodied GWP:	346 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	7,031	95	7,126	0	213	213	0	0	0	0	0	0	7,338	2,530	-	-
50	7,031	95	7,126	0	213	213	4,287	204	4,491	0	27	27	11,856	4,088	-2,000,000	-13,514

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	623	0	623	0	0	0	0	0	0	0	0	0	623	215	-	-
50	623	0	623	0	0	0	380	0	380	0	0	0	1,003	346	-110,000	-743

Embodied energy (and GWP) numbers are based on a window area = 2.9 m^2 (Length x Height = 1.2m x 2.4m = 2.9m^2)

Total window area of baseline retail building (total fenestration area) = 148.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	20.9	kg
Batt. Fiberglass	0.6	m2 (25mm)
EPDM membrane	11.2	kg
Low E Tin Argon Filled Glazing	12.1	m2
Nails	10.0	kg
Small Dimension Softwood Lumber, kiln-dried	0.3	m3
Water Based Latex Paint	1.2	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

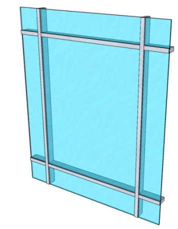
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Window #9 (W-9)

Building Component Description:

		Assembly Layers
Category:	Windows & Doors	*Outside*
Brief Description:	Self-supported aluminum curtainwall with viewable glazing unit	Two 6mm sealed viewable glazing panes with 12.7mm airspace
		(No low-E coating. No argon between panes)
		Self-supporting aluminum curtainwall grid system with thermal break
Quick Numbers:		*(100mm deep mullions spaced 2m o/c vertically and 1.5m o/c horizontally)*
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 1.8 RSI-Value: 0.3	*(Fixed curtainwall i.e. not operable)*
SHGC:	0.70	***Inside***
Total Embodied Energy:	1,895 MJ/m^2	
Total Embodied GWP:	209 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	5,234	72	5,306	0	166	166	0	0	0	0	0	0	5,473	1,887	-	-
50	5,234	72	5,306	0	166	166	0	0	0	0	22	22	5,494	1,895	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	606	0	606	0	0	0	0	0	0	0	0	0	606	209	-	-
50	606	0	606	0	0	0	0	0	0	0	0	0	606	209	0	0

Embodied energy (and GWP) numbers are based on a window area = 2.9 m^2 (Length x Height = 1.2m x 2.4m = 2.9m^2)

Total window area of baseline retail building (total fenestration area) = 148.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	35.1	kg
EPDM membrane	2.1	kg
Glazing Panel	265.1	kg
Screws Nuts & Bolts	1.2	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / window area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

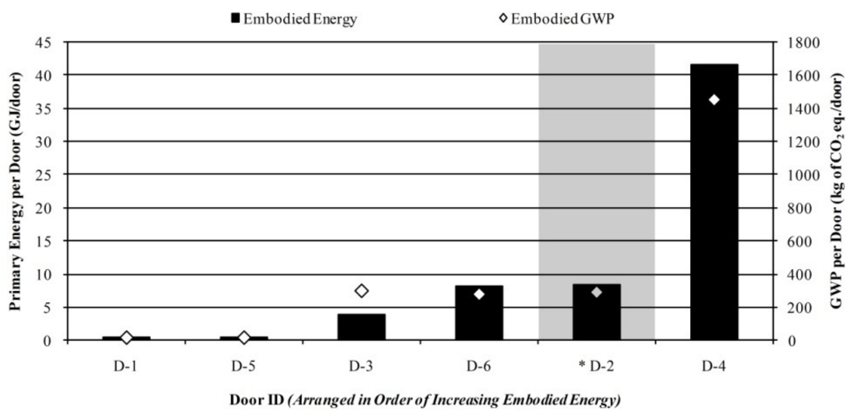
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Doors

This section contains a detailed description of each door that was examined in this study (6 in total). The assembly layers are listed for each door, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each door is also included. In each case, the results were calculated for a single door. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various doors in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Door #1 (D-1)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
		Outside
Brief Description:	Standard size solid wood exterior door with no glazing	Solid wood exterior door with no glazing
		(Includes latex paint)
		(Standard size: 813mm x 2134mm)
		Inside
Quick Numbers:		
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 1.8 RSI-Value: 0.3	
Total Embodied Energy:	539 MJ/unit	
Total Embodied GWP:	16 kg of CO_2 eq./unit	

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	492	17	509	0	28	28	0	0	0	0	0	0	536	-
50	492	17	509	0	28	28	0	0	0	0	3	3	539	-100,000

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	16	0	16	0	0	0	0	0	0	0	0	0	16	-
50	16	0	16	0	0	0	0	0	0	0	0	0	16	0

Note: Calculations are per individual door

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Nails	2.0	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Water Based Latex Paint	0.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

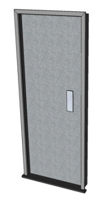
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Door #2 (D-2)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
Brief Description:	Insulated standard size steel exterior door with no glazing	***Outside***
		Insulated steel exterior door with no glazing
		(Includes alkyd based paint)
		(Standard size: 813mm x 2134mm)
		Inside
Quick Numbers:		
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 1.2 RSI-Value: 0.2	
Total Embodied Energy:	8,335 MJ/unit	
Total Embodied GWP:	290 kg of CO_2 eq./unit	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	8,303	12	8,315	0	15	15	0	0	0	0	0	0	8,330	-
50	8,303	12	8,315	0	15	15	0	0	0	0	5	5	8,335	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	290	0	290	0	0	0	0	0	0	0	0	0	290	-
50	290	0	290	0	0	0	0	0	0	0	0	0	290	0

Note : Calculations are per individual door

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Expanded Polystyrene	3.3	m2 (25mm)
Galvanized Sheet	61.9	kg
Nails	2.0	kg
Solvent Based Alkyd Paint	0.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

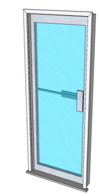
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Door #3 (D-3)

Building Component Description:

Category:	Windows & Doors	Assembly Layers
Brief Description:	Uninsulated standard size aluminum exterior door with 80% glazing	***Outside***
		Uninsulated aluminum exterior door with 80% glazing
		(Typical sealed double pane glazing unit)
		(No low-E coating. No argon between panes)
Quick Numbers:		*(Standard size: 813mm x 2134mm)*
		Inside
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 1.1 RSI-Value: 0.2	
SHGC:	0.76	
Total Embodied Energy:	3,806 MJ/unit	
Total Embodied GWP:	298 kg of CO_2 eq./unit	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	3,641	51	3,691	0	105	105	0	0	0	0	0	0	3,796	-
50	3,641	51	3,691	0	105	105	0	0	0	0	10	10	3,806	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	298	0	298	0	0	0	0	0	0	0	0	0	298	-
50	298	0	298	0	0	0	0	0	0	0	0	0	298	0

Note : Calculations are per individual door

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Aluminum	25.7	kg
Glazing Panel	50.7	kg
Nails	2.0	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Door #4 (D-4)

Building Component Description:

		Assembly Layers
Category:	Windows & Doors	***Outside***
Brief Description:	Insulated sectional overhead steel door with no glazing	Insulated sectional overhead steel door with no glazing
		(modeled in ATHENA as equivalent area of insulated steel exterior door with no glazing)
Quick Numbers:		*(50mm extruded polystyrene insulation assumed)*
ASHRAE Standard 90.1 - Fundamentals (SI):	R-Value: 1.2 RSI-Value: 0.2	*(Standard size: 3050mm x 3050mm)*
		Inside
Total Embodied Energy:	41,677 MJ/unit	
Total Embodied GWP:	1,448 kg of CO_2 eq./unit	

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	41,516	60	41,576	0	74	74	0	0	0	0	0	0	41,650	-
50	41,516	60	41,576	0	74	74	0	0	0	0	27	27	41,677	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	1,448	0	1,448	0	0	0	0	0	0	0	0	0	1,448	-
50	1,448	0	1,448	0	0	0	0	0	0	0	0	0	1,448	0

Note: Calculations are per individual door

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Expanded Polystyrene	16.3	m2 (25mm)
Galvanized Sheet	309.6	kg
Nails	9.8	kg
Solvent Based Alkyd Paint	1.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Door #5 (D-5)

Building Component Description:

		Assembly Layers
Category:	Windows & Doors	***Outside***
Brief Description:	Standard size solid wood interior door with no glazing	Solid wood interior door with no glazing
		(Includes latex paint)
		(Standard size: 813mm x 2134mm)
		Inside
Quick Numbers:		
Total Embodied Energy:	539 MJ/unit	
Total Embodied GWP:	16 kg of CO_2 eq./unit	

Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	492	17	509	0	28	28	0	0	0	0	0	0	536	-
50	492	17	509	0	28	28	0	0	0	0	3	3	539	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	16	0	16	0	0	0	0	0	0	0	0	0	16	-
50	16	0	16	0	0	0	0	0	0	0	0	0	16	0

Note: Calculations are per individual door

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Nails	2.0	kg
Small Dimension Softwood Lumber, kiln-dried	0.1	m3
Water Based Latex Paint	0.7	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

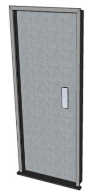
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Door #6 (D-6)

Building Component Description:

		Assembly Layers
Category:	Windows & Doors	***Outside***
Brief Description:	Standard size steel interior door with no glazing	Steel interior door with no glazing
		(Includes alkyd based paint)
		(Standard size: 813mm x 2134mm)
		Inside
Quick Numbers:		
Total Embodied Energy:	8,098 MJ/unit	
Total Embodied GWP:	277 kg of CO_2 eq./unit	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	8,067	12	8,079	0	14	14	0	0	0	0	0	0	8,093	-
50	8,067	12	8,079	0	14	14	0	0	0	0	5	5	8,098	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	277	0	277	0	0	0	0	0	0	0	0	0	277	-
50	277	0	277	0	0	0	0	0	0	0	0	0	277	0

Note: Calculations are per individual door

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Galvanized Sheet	61.9	kg
Nails	2.0	kg
Solvent Based Alkyd Paint	0.3	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Appendix B-6

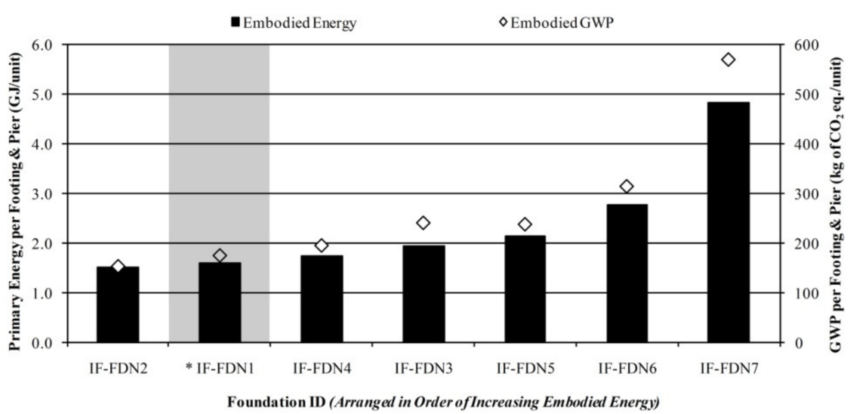
LCA Data for Foundations

LCA Data for Isolated Footings and Concrete Piers

This section contains a detailed description of each isolated footing and concrete pier combination that was examined in this study (7 in total). The assembly layers are listed for each case, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each footing and pier is also included. In each case, the results were calculated for one isolated footing with one concrete pier. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

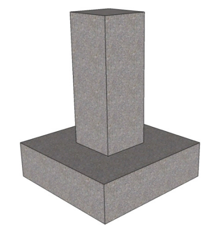
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various footing and pier combinations in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Isolated Concrete Footing and Pier #1 (IF-FDN1)

Building Component Description:

Category:	Foundations	**Assembly Layers**
Brief Description:	Isolated concrete footing (1,200mm x 1,200mm x 350mm) with concrete pier: 20MPa concrete strength and average flyash content	***Isolated Concrete Footing***
		20MPa concrete strength
		1,200mm x 1,200mm x 350mm
		20M bars @ 22kg of steel per m^3 of concrete
		9% (average) flyash content
Quick Numbers:		
		Concrete Pier
Total Embodied Energy:	1,609 MJ/unit	20MPa concrete strength
Total Embodied GWP:	175 kg of CO_2 eq./unit	450mm x 450mm x 1,200mm
		Equivalent of 15M bars @ 600mm o/c vert. & hor.
		Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
		9% (average) flyash content



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	1,292	72	1,364	84	104	189	0	0	0	0	0	0	1,553	-
50	1,292	72	1,364	84	104	189	0	0	0	0	56	56	1,609	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	168	0	168	6	0	6	0	0	0	0	0	0	174	-
50	168	0	168	6	0	6	0	0	0	0	0	0	175	0

Note: Calculations are for one isolated footing and one concrete pier combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 20 MPa (flyash av)	0.8	m3
Rebar, Rod, Light Sections	14.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

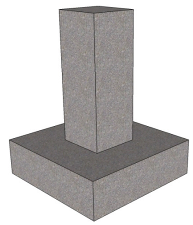
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Isolated Concrete Footing and Pier #2 (IF-FDN2)

Building Component Description:

Category:	Foundations	Assembly Layers
		Isolated Concrete Footing
Brief Description:	Isolated concrete footing (1,200mm x 1,200mm x 350mm) with concrete pier: 20MPa concrete strength and high flyash content	20MPa concrete strength
		1,200mm x 1,200mm x 350mm
		20M bars @ 22kg of steel per m^3 of concrete
		35% (high) flyash content
Quick Numbers:		
		Concrete Pier
Total Embodied Energy:	1,518 MJ/unit	20MPa concrete strength
Total Embodied GWP:	153 kg of CO_2 eq./unit	450mm x 450mm x 1,200mm
		Equivalent of 15M bars @ 600mm o/c vert. & hor.
		Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
		35% (high) flyash content



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			
[1] Initial	1,179	94	1,274	84	104	189	0	0	0	0	0	0	1,462		-
50	1,179	94	1,274	84	104	189	0	0	0	0	56	56	1,518		0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			
[1] Initial	146	0	147	6	0	6	0	0	0	0	0	0	153		-
50	146	0	147	6	0	6	0	0	0	0	0	0	153		0

Note: Calculations are for one isolated footing and one concrete pier combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 20 MPa (flyash 35%)	0.8	m3
Rebar, Rod, Light Sections	14.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

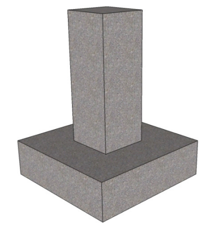
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Isolated Concrete Footing and Pier #3 (IF-FDN3)

Building Component Description:

Category:	Foundations	Assembly Layers
		Isolated Concrete Footing
Brief Description:	Isolated concrete footing (1,200mm x 1,200mm x 350mm) with concrete pier: 30MPa concrete strength and average flyash content	30MPa concrete strength
		1,200mm x 1,200mm x 350mm
		20M bars @ 22kg of steel per m^3 of concrete
		9% (average) flyash content
Quick Numbers:		
		Concrete Pier
Total Embodied Energy:	1,948 MJ/unit	30MPa concrete strength
Total Embodied GWP:	240 kg of CO_2 eq./unit	450mm x 450mm x 1,200mm
		Equivalent of 15M bars @ 600mm o/c vert. & hor.
		Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
		9% (average) flyash content



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			
[1] Initial	1,619	84	1,703	84	104	189	0	0	0	0	0	0	1,892		-
50	1,619	84	1,703	84	104	189	0	0	0	0	56	56	1,948		0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			
[1] Initial	234	0	234	6	0	6	0	0	0	0	0	0	240		-
50	234	0	234	6	0	6	0	0	0	0	0	0	240		0

Note: Calculations are for one isolated footing and one concrete pier combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 30 MPa (flyash av)	0.8	m3
Rebar, Rod, Light Sections	14.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

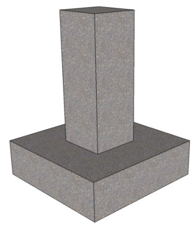
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Isolated Concrete Footing and Pier #4 (IF-FDN4)

Building Component Description:

Category:	Foundations	Assembly Layers
		Isolated Concrete Footing
Brief Description:	Isolated concrete footing (1,200mm x 1,200mm x 350mm) with concrete pier: 30MPa concrete strength and high flyash content	30MPa concrete strength
		1,200mm x 1,200mm x 350mm
		20M bars @ 22kg of steel per m^3 of concrete
		35% (high) flyash content
Quick Numbers:		
		Concrete Pier
Total Embodied Energy:	1,740 MJ/unit	30MPa concrete strength
Total Embodied GWP:	195 kg of CO_2 eq./unit	450mm x 450mm x 1,200mm
		Equivalent of 15M bars @ 600mm o/c vert. & hor.
		Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
		35% (high) flyash content



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	1,383	111	1,495	84	104	189	0	0	0	0	0	0	1,684	-
50	1,383	111	1,495	84	104	189	0	0	0	0	56	56	1,740	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	188	0	188	6	0	6	0	0	0	0	0	0	195	-
50	188	0	188	6	0	6	0	0	0	0	0	0	195	0

Note: Calculations are for one isolated footing and one concrete pier combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 30 MPa (flyash 35%)	0.8	m3
Rebar, Rod, Light Sections	14.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

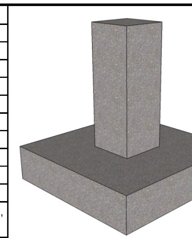
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Isolated Concrete Footing and Pier #5 (IF-FDN5)

Building Component Description:

Category:	Foundations	Assembly Layers
		Isolated Concrete Footing
Brief Description:	Isolated concrete footing (1500mm x 1500mm x 350mm) with concrete pier: 20MPa concrete strength and average flyash content	20MPa concrete strength
		1500mm x 1500mm x 350mm
		20M bars @ 22kg of steel per m^3 of concrete
		9% (average) flyash content
Quick Numbers:		
		Concrete Pier
Total Embodied Energy:	2,137 MJ/unit	20MPa concrete strength
Total Embodied GWP:	237 kg of CO_2 eq./unit	450mm x 450mm x 1,200mm
		Equivalent of 15M bars @ 600mm o/c vert. & hor.
		Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
		9% (average) flyash content



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	1,718	99	1,817	99	144	243	0	0	0	0	0	0	2,060	-
50	1,718	99	1,817	99	144	243	0	0	0	0	77	77	2,137	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	230	0	230	7	0	7	0	0	0	0	0	0	237	-
50	230	0	230	7	0	7	0	0	0	0	0	0	237	0

Note: Calculations are for one isolated footing and one concrete pier combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 20 MPa (flyash av)	1.1	m3
Rebar, Rod, Light Sections	16.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

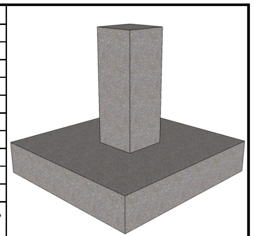
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Isolated Concrete Footing and Pier #6 (IF-FDN6)

Building Component Description:

Category:	Foundations	Assembly Layers
Brief Description:	Isolated concrete footing (1800mm x 1800mm x350mm) with concrete pier: 20MPa concrete strength and average flyash content	***Isolated Concrete Footing***
		20MPa concrete strength
		1800mm x 1800mm x 350mm
		20M bars @ 22kg of steel per m^3 of concrete
		9% (average) flyash content
Quick Numbers:		***Concrete Pier***
Total Embodied Energy:	2,770 MJ/unit	20MPa concrete strength
Total Embodied GWP:	313 kg of CO_2 eq./unit	450mm x 450mm x 1,200mm
		Equivalent of 15M bars @ 600mm o/c vert. & hor.
		Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
		9% (average) flyash content



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	2,227	131	2,358	117	192	309	0	0	0	0	0	0	2,667	-
50	2,227	131	2,358	117	192	309	0	0	0	0	102	103	2,770	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	304	0	305	8	0	8	0	0	0	0	0	0	313	-
50	304	0	305	8	0	8	0	0	0	0	0	0	313	0

Note: Calculations are for one isolated footing and one concrete pier combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 20 MPa (flyash av)	1.4	m3
Rebar, Rod, Light Sections	19.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

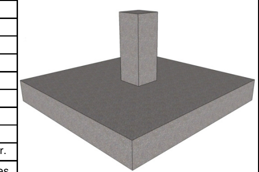
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Isolated Concrete Footing and Pier #7 (IF-FDN7)

Building Component Description:

Category:	Foundations	Assembly Layers
Brief Description:	Isolated concrete footing (2,400mm x 2,400mm x 400mm) with concrete pier: 20MPa concrete strength and average flyash content	***Isolated Concrete Footing***
		20MPa concrete strength
		2,400mm x 2,400mm x 400mm
		20M bars @ 22kg of steel per m^3 of concrete
		9% (average) flyash content
Quick Numbers:		***Concrete Pier***
Total Embodied Energy:	4,833 MJ/unit	20MPa concrete strength
Total Embodied GWP:	568 kg of CO_2 eq./unit	450mm x 450mm x 1,200mm
		Equivalent of 15M bars @ 600mm o/c vert. & hor.
		Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
		9% (average) flyash content



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	3,869	241	4,111	178	355	533	0	0	0	0	0	0	4,644	-
50	3,869	241	4,111	178	355	533	0	0	0	0	189	189	4,833	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per unit)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per unit)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	554	0	555	12	1	13	0	0	0	0	0	0	568	-
50	554	0	555	12	1	13	0	0	0	0	0	0	568	0

Note: Calculations are for one isolated footing and one concrete pier combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete 20 MPa (flyash av)	2.7	m3
Rebar, Rod, Light Sections	24.4	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per unit** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per unit** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

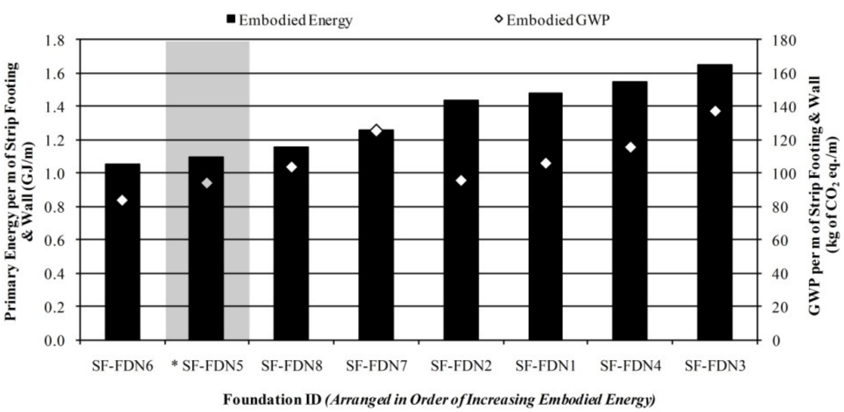
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Concrete Strip Footings and Foundation Walls

This section contains a detailed description of each concrete strip footing and concrete foundation wall combination that was examined in this study (8 in total). The assembly layers are listed for each case, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each footing and wall is also included. In each case, the results were calculated per linear meter of strip footing and foundation wall. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

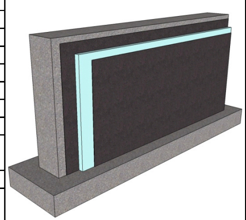
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various footing and wall combinations in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Concrete Strip Footing and Foundation Wall #1 (SF-FDN1)

Building Component Description:

		Assembly Layers
Category:	Foundations	***Concrete Strip Footing***
Brief Description:	Concrete strip footing with insulated concrete foundation wall: 20MPa concrete strength and average flyash content	20MPa concrete strength
		600mm x 200mm
		6.0kg of steel per linear m
		9% (average) flyash content
Quick Numbers:		***Concrete Foundation Wall***
		20MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 11.0 RSI-Value: 1.9	1,200mm x 200mm
THERM 5.2:	R-Value: 11.1 RSI-Value: 2.0	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,484 MJ/m	Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
Total Embodied GWP:	106 kg of CO_2 eq./m	
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	9% (average) flyash content
		60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m^2 of modified bitumen membrane and 6mil poly sheet with primer)
		50mm extruded polystyrene rigid insulation
		6.4mm asphalt protection board



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	1,076	37	1,113	70	52	122	0	0	0	0	0	0	1,235	-
50	1,076	37	1,113	70	52	122	219	2	221	0	28	28	1,484	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	98	0	98	5	0	5	0	0	0	0	0	0	103	-
50	98	0	98	5	0	5	3	0	3	0	0	0	106	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 20 MPa (flyash av)	0.4	m3
Extruded Polystyrene	2.5	m2 (25mm)
Modified Bitumen membrane	2.1	kg
Nails	0.1	kg
Organic Felt shingles 25yr	1.3	m2
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time ‘0’ (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

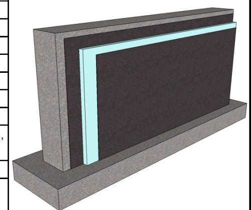
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Strip Footing and Foundation Wall #2 (SF-FDN2)

Building Component Description:

Category:	Foundations	Assembly Layers
Brief Description:	Concrete strip footing with insulated concrete foundation wall: 20MPa concrete strength and high flyash content	*Concrete Strip Footing*
		20MPa concrete strength
		600mm x 200mm
		6.0kg of steel per linear m
		35% (high) flyash content
Quick Numbers:		*Concrete Foundation Wall*
		20MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 11.0 RSI-Value: 1.9	1,200mm x 200mm
THERM 5.2:	R-Value: 11.1 RSI-Value: 2.0	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,440 MJ/m	Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
Total Embodied GWP:	96 kg of CO_2 eq./m	35% (high) flyash content
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m^2 of modified bitumen membrane and 6mil poly sheet with primer)
		50mm extruded polystyrene rigid insulation
		6.4mm asphalt protection board



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	1,022	47	1,069	70	52	122	0	0	0	0	0	0	1,191	-
50	1,022	47	1,069	70	52	122	219	2	221	0	28	28	1,440	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	87	0	88	5	0	5	0	0	0	0	0	0	92	-
50	87	0	88	5	0	5	3	0	3	0	0	0	96	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 20 MPa (flyash 35%)	0.4	m3
Extruded Polystyrene	2.5	m2 (25mm)
Modified Bitumen membrane	2.1	kg
Nails	0.1	kg
Organic Felt shingles 25yr	1.3	m2
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

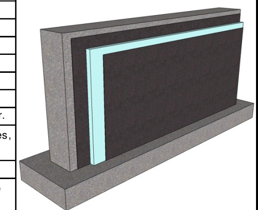
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Strip Footing and Foundation Wall #3 (SF-FDN3)

Building Component Description:

Category:	Foundations	Assembly Layers
Brief Description:	Concrete strip footing with insulated concrete foundation wall: 30MPa concrete strength and average flyash content	*Concrete Strip Footing*
		30MPa concrete strength
		600mm x 200mm
		6.0kg of steel per linear m
		9% (average) flyash content
Quick Numbers:		*Concrete Foundation Wall*
		30MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 11.0 RSI-Value: 1.9	1,200mm x 200mm
THERM 5.2:	R-Value: 11.1 RSI-Value: 2.0	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,647 MJ/m	Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
Total Embodied GWP:	138 kg of CO_2 eq./m	9% (average) flyash content
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m^2 of modified bitumen membrane and 6mil poly sheet with primer)
		50mm extruded polystyrene rigid insulation
		6.4mm asphalt protection board



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	1,233	43	1,276	70	52	122	0	0	0	0	0	0	1,398	-
50	1,233	43	1,276	70	52	122	219	2	221	0	28	28	1,647	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	130	0	130	5	0	5	0	0	0	0	0	0	135	-
50	130	0	130	5	0	5	3	0	3	0	0	0	138	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 30 MPa (flyash av)	0.4	m3
Extruded Polystyrene	2.5	m2 (25mm)
Modified Bitumen membrane	2.1	kg
Nails	0.1	kg
Organic Felt shingles 25yr	1.3	m2
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

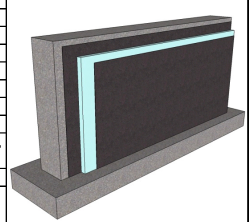
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Strip Footing and Foundation Wall #4 (SF-FDN4)

Building Component Description:

		Assembly Layers
Category:	Foundations	***Concrete Strip Footing***
Brief Description:	Concrete strip footing with insulated concrete foundation wall: 30MPa concrete strength and high flyash content	30MPa concrete strength
		600mm x 200mm
		6.0kg of steel per linear m
		35% (high) flyash content
Quick Numbers:		***Concrete Foundation Wall***
		30MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 11.0 RSI-Value: 1.9	1,200mm x 200mm
THERM 5.2:	R-Value: 11.1 RSI-Value: 2.0	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,547 MJ/m	Includes allowance for 0.425kg/m² of steel for ties, wire, etc.
Total Embodied GWP:	116 kg of CO_2 eq./m	35% (high) flyash content
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m² of modified bitumen membrane and 6mil poly sheet with primer)
		50mm extruded polystyrene rigid insulation
		6.4mm asphalt protection board



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan (⁴ per m)
	Manufacturing			Construction			Maintenance			End of Life			³ Total EE (per m)	
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total		
¹ Initial	1,120	56	1,176	70	52	122	0	0	0	0	0	0	1,298	-
50	1,120	56	1,176	70	52	122	219	2	221	0	28	28	1,547	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan (⁴ per m)
	Manufacturing			Construction			Maintenance			End of Life			³ Total GWP (per m)	
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total		
¹ Initial	108	0	108	5	0	5	0	0	0	0	0	0	113	-
50	108	0	108	5	0	5	3	0	3	0	0	0	116	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 30 MPa (flyash 35%)	0.4	m3
Extruded Polystyrene	2.5	m2 (25mm)
Modified Bitumen membrane	2.1	kg
Nails	0.1	kg
Organic Felt shingles 25yr	1.3	m2
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

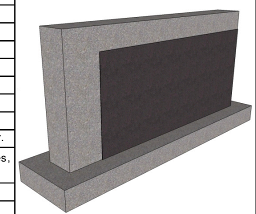
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Strip Footing and Foundation Wall #5 (SF-FDN5)

Building Component Description:

		Assembly Layers
Category:	Foundations	***Concrete Strip Footing***
Brief Description:	Concrete strip footing with uninsulated concrete foundation wall: 20MPa concrete strength and average flyash content	20MPa concrete strength
		600mm x 200mm
		6.0kg of steel per linear m
		9% (average) flyash content
Quick Numbers:		***Concrete Foundation Wall***
		20MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 1.3 RSI-Value: 0.2	1,200mm x 200mm
THERM 5.2:	R-Value: 1.3 RSI-Value: 0.2	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,097 MJ/m	Includes allowance for 0.425kg/m² of steel for ties, wire, etc.
Total Embodied GWP:	94 kg of CO_2 eq./m	9% (average) flyash content
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m² of modified bitumen membrane and 6mil poly sheet with primer)



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan (⁴ per m)
	Manufacturing			Construction			Maintenance			End of Life			³ Total EE (per m)	
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total		
¹ Initial	837	36	874	70	51	121	0	0	0	0	0	0	995	-
50	837	36	874	70	51	121	75	0	75	0	27	27	1,097	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan (⁴ per m)
	Manufacturing			Construction			Maintenance			End of Life			³ Total GWP (per m)	
	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total	Material	² Trans.	Total		
¹ Initial	88	0	88	5	0	5	0	0	0	0	0	0	93	-
50	88	0	88	5	0	5	1	0	1	0	0	0	94	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 20 MPa (flyash av)	0.4	m3
Modified Bitumen membrane	2.1	kg
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

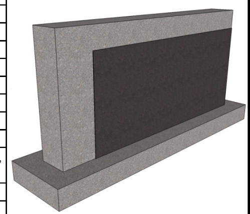
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Strip Footing and Foundation Wall #6 (SF-FDN6)

Building Component Description:

Category:	Foundations	Assembly Layers
		Concrete Strip Footing
Brief Description:	Concrete strip footing with uninsulated concrete foundation wall: 20MPa concrete strength and high flyash content	20MPa concrete strength
		600mm x 200mm
		6.0kg of steel per linear m
		35% (high) flyash content
Quick Numbers:		*Concrete Foundation Wall*
		20MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 1.3 RSI-Value: 0.2	1,200mm x 200mm
THERM 5.2:	R-Value: 1.3 RSI-Value: 0.2	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,053 MJ/m	Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
Total Embodied GWP:	83 kg of CO_2 eq./m	35% (high) flyash content
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m^2 of modified bitumen membrane and 6mil poly sheet with primer)



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	783	47	830	70	51	121	0	0	0	0	0	0	951	-
50	783	47	830	70	51	121	75	0	75	0	27	27	1,053	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	77	0	78	5	0	5	0	0	0	0	0	0	82	-
50	77	0	78	5	0	5	1	0	1	0	0	0	83	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 20 MPa (flyash 35%)	0.4	m3
Modified Bitumen membrane	2.1	kg
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

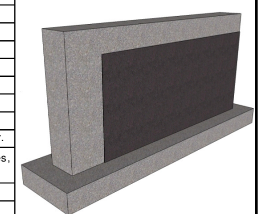
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Strip Footing and Foundation Wall #7 (SF-FDN7)

Building Component Description:

Category:	Foundations	Assembly Layers
		Concrete Strip Footing
Brief Description:	Concrete strip footing with uninsulated concrete foundation wall: 30MPa concrete strength and average flyash content	30MPa concrete strength
		600mm x 200mm
		6.0kg of steel per linear m
		9% (average) flyash content
Quick Numbers:		*Concrete Foundation Wall*
		30MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 1.3 RSI-Value: 0.2	1,200mm x 200mm
THERM 5.2:	R-Value: 1.3 RSI-Value: 0.2	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,260 MJ/m	Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
Total Embodied GWP:	126 kg of CO_2 eq./m	9% (average) flyash content
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m^2 of modified bitumen membrane and 6mil poly sheet with primer)



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	995	42	1,037	70	51	121	0	0	0	0	0	0	1,158	-
50	995	42	1,037	70	51	121	75	0	75	0	27	27	1,260	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	120	0	120	5	0	5	0	0	0	0	0	0	124	-
50	120	0	120	5	0	5	1	0	1	0	0	0	126	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 30 MPa (flyash av)	0.4	m3
Modified Bitumen membrane	2.1	kg
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

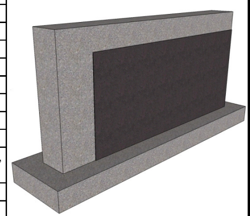
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Strip Footing and Foundation Wall #8 (SF-FDN8)

Building Component Description:

Category:	Foundations	**Assembly Layers**
Brief Description:	Concrete strip footing with uninsulated concrete foundation wall: 30MPa concrete strength and high flyash content	***Concrete Strip Footing*** 30MPa concrete strength 600mm x 200mm 6.0kg of steel per linear m 35% (high) flyash content
Quick Numbers:		***Concrete Foundation Wall*** 30MPa concrete strength
ASHRAE Standard 90.1:	R-Value: 1.3 RSI-Value: 0.2	1,200mm x 200mm
THERM 5.2:	R-Value: 1.3 RSI-Value: 0.2	Equivalent of 15M bars @ 600mm o/c vert. & hor.
Total Embodied Energy:	1,160 MJ/m	Includes allowance for 0.425kg/m^2 of steel for ties, wire, etc.
Total Embodied GWP:	104 kg of CO_2 eq./m	
	Note: Embodied energy and embodied GWP numbers are per horizontal meter of footing and wall	35% (high) flyash content
		60mil asphalt-based waterproofing membrane (modeled as 1.6kg/m^2 of modified bitumen membrane and 6mil poly sheet with primer)



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)													Difference in Operating Energy from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	881	55	937	70	51	121	0	0	0	0	0	0	1,058	-
50	881	55	937	70	51	121	75	0	75	0	27	27	1,160	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													Difference in Operating GWP from Baseline after Lifespan ([4] per m)
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP (per m)	
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	98	0	98	5	0	5	0	0	0	0	0	0	103	-
50	98	0	98	5	0	5	1	0	1	0	0	0	104	0

Note: Calculations are per linear meter of strip footing (600mm x 200m) and foundation wall (1200mm x 200mm) combination

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	1.3	m2
Concrete 30 MPa (flyash 35%)	0.4	m3
Modified Bitumen membrane	2.1	kg
Rebar, Rod, Light Sections	14.9	kg
Solvent Based Alkyd Paint	0.1	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans**. = Transportation

[3] **Total EE (or Total GWP) per m** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

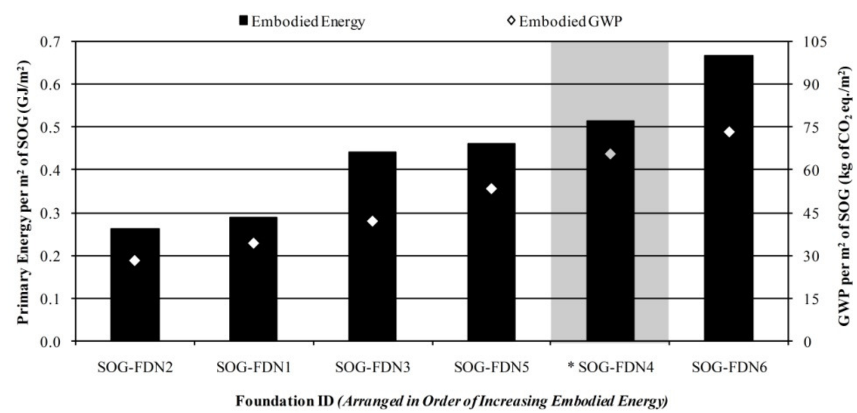
* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

LCA Data for Concrete Slab-on-Grades

This section contains a detailed description of each concrete slab-on-grade that was examined in this study (6 in total). The assembly layers are listed for each case, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each slab-on-grade is also included. In each case, the results were calculated for a slab-on-grade area of 610 m^2, which represents a typical size for a single-storey retail building. The results are also expressed per m^2 of slab-on-grade. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

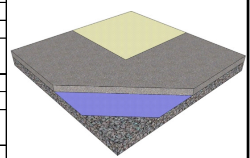
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various slab-on-grades in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Concrete Slab-On-Grade #1 (SOG-FDN1)

Building Component Description:

Category:	Foundations	Assembly Layers
Brief Description:	Concrete slab-on-grade: 100mm thick, average flyash content, no insulation	***Concrete Slab-On-Grade***
		30MPa concrete strength
		100mm thick concrete slab
		150mm x 150mm 3.42mm steel mesh reinforcement at 0.886kg/m^2
Quick Numbers:		9% (average) flyash content
		10mil poly
ASHRAE Standard 90.1:	F-Factor: 0.73 Btu/(hr·ft·°F)	Concrete sealant (modeled as alkyd based paint finish on concrete)
THERM 5.2:	R-Value: 1.9 RSI-Value: 0.3	
Slab Thickness:	100 mm (plus compacted sub-base)	
Total Embodied Energy:	289 MJ/m^2	
Total Embodied GWP:	34 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	137,399	6,664	144,063	16,495	8,507	25,002	0	0	0	0	0	0	169,065	277	-	-
50	137,399	6,664	144,063	16,495	8,507	25,002	2,740	20	2,760	8	4,524	4,532	176,357	289	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	19,766	13	19,778	1,071	16	1,088	0	0	0	0	0	0	20,866	34	-	-
50	19,766	13	19,778	1,071	16	1,088	47	0	47	0	9	9	20,922	34	10,000	17

Embodied energy (and GWP) numbers are based on an area of SOG = 610.0 m^2

Area of SOG in baseline retail building = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	645.4	m2
Concrete 30 MPa (flyash av)	63.9	m3
Solvent Based Alkyd Paint	67.3	L
Welded Wire Mesh / Ladder Wire	549.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / baseline retail building slab-on-grade area

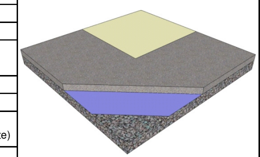
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Slab-On-Grade #2 (SOG-FDN2)

Building Component Description:

Category:	Foundations	Assembly Layers
Brief Description:	Concrete slab-on-grade: 100mm thick, high flyash content, no insulation	***Concrete Slab-On-Grade***
		30MPa concrete strength
		100mm thick concrete slab
		150mm x 150mm 3.42mm steel mesh reinforcement at 0.886kg/m^2
Quick Numbers:		35% (high) flyash content
		10mil poly
ASHRAE Standard 90.1:	F-Factor: 0.73 Btu/(hr·ft·°F)	Concrete sealant (modeled as alkyd based paint finish on concrete)
THERM 5.2:	R-Value: 1.9 RSI-Value: 0.3	
Slab Thickness:	100 mm (plus compacted sub-base)	
Total Embodied Energy:	261 MJ/m^2	
Total Embodied GWP:	28 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	118,196	8,905	127,100	16,495	8,507	25,002	0	0	0	0	0	0	152,103	249	-	-
50	118,196	8,905	127,100	16,495	8,507	25,002	2,740	20	2,760	8	4,524	4,532	159,395	261	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	16,064	17	16,081	1,071	16	1,088	0	0	0	0	0	0	17,169	28	-	-
50	16,064	17	16,081	1,071	16	1,088	47	0	47	0	9	9	17,225	28	10,000	17

Embodied energy (and GWP) numbers are based on an area of SOG = 610.0 m^2

Area of SOG in baseline retail building = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	645.4	m2
Concrete 30 MPa (flyash 35%)	63.9	m3
Solvent Based Alkyd Paint	67.3	L
Welded Wire Mesh / Ladder Wire	549.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / baseline retail building slab-on-grade area

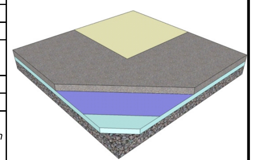
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Slab-On-Grade #3 (SOG-FDN3)

Building Component Description:

		Assembly Layers
Category:	Foundations	***Concrete Slab-On-Grade***
Brief Description:	Concrete slab-on-grade: 100mm thick, average flyash content, 50mm insulation	30MPa concrete strength
		100mm thick concrete slab
		150mm x 150mm 3.42mm steel mesh reinforcement at 0.886kg/m^2
Quick Numbers:		9% (average) flyash content
		10mil poly
ASHRAE Standard 90.1:	F-Factor: 0.36 Btu/(hr·ft·°F)	50mm extruded polystyrene rigid insulation *(R-value calculations are taken through section with full under slab insulation)*
THERM 5.2:	R-Value: 11.7 RSI-Value: 2.1	
Slab Thickness:	150 mm (plus compacted sub-base)	
Total Embodied Energy:	440 MJ/m^2	Concrete sealant (modeled as alkyd based paint finish on concrete)
Total Embodied GWP:	42 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	229,088	6,671	235,759	16,495	8,655	25,150	0	0	0	0	0	0	260,909	428	-	-
50	229,088	6,671	235,759	16,495	8,655	25,150	2,740	20	2,760	8	4,643	4,651	268,320	440	-1,700,000	-2,901

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	24,451	13	24,464	1,071	17	1,088	0	0	0	0	0	0	25,552	42	-	-
50	24,451	13	24,464	1,071	17	1,088	47	0	47	0	9	9	25,608	42	-100,000	-171

Embodied energy (and GWP) numbers are based on an area of SOG = 610.0 m^2

Area of SOG in baseline retail building = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	645.4	m2
Concrete 30 MPa (flyash av)	63.9	m3
Extruded Polystyrene	1,246.6	m2 (25mm)
Nails	37.6	kg
Solvent Based Alkyd Paint	67.3	L
Welded Wire Mesh / Ladder Wire	549.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / baseline retail building slab-on-grade area

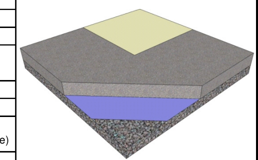
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Slab-On-Grade #4 (SOG-FDN4)

Building Component Description:

		Assembly Layers
Category:	Foundations	***Concrete Slab-On-Grade***
Brief Description:	Concrete slab-on-grade: 200mm thick, average flyash content, no insulation	30MPa concrete strength
		200mm thick concrete slab
		150mm x 150mm 3.42mm steel mesh reinforcement at 0.886kg/m^2
Quick Numbers:		9% (average) flyash content
		10mil poly
ASHRAE Standard 90.1:	F-Factor: 0.73 Btu/(hr·ft·°F)	Concrete sealant (modeled as alkyd based paint finish on concrete)
THERM 5.2:	R-Value: 2.2 RSI-Value: 0.4	
Slab Thickness:	200 mm (plus compacted sub-base)	
Total Embodied Energy:	515 MJ/m^2	
Total Embodied GWP:	65 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	243,853	13,299	257,152	28,420	16,945	45,365	0	0	0	0	0	0	302,517	496	-	-
50	243,853	13,299	257,152	28,420	16,945	45,365	2,740	20	2,760	15	9,024	9,039	314,316	515	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	37,878	25	37,903	1,915	33	1,948	0	0	0	0	0	0	39,851	65	-	-
50	37,878	25	37,903	1,915	33	1,948	47	0	47	1	17	18	39,916	65	0	0

Embodied energy (and GWP) numbers are based on an area of SOG = 610.0 m^2

Area of SOG in baseline retail building = 586.0 m^2

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	645.4	m2
Concrete 30 MPa (flyash av)	127.8	m3
Solvent Based Alkyd Paint	67.3	L
Welded Wire Mesh / Ladder Wire	549.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / baseline retail building slab-on-grade area

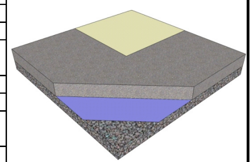
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Concrete Slab-On-Grade #5 (SOG-FDN5)

Building Component Description:

		Assembly Layers
Category:	Foundations	***Concrete Slab-On-Grade***
Brief Description:	Concrete slab-on-grade: 200mm thick, high flyash content, no insulation	30MPa concrete strength
		200mm thick concrete slab
		150mm x 150mm 3.42mm steel mesh reinforcement at 0.886kg/m²
Quick Numbers:		35% (high) flyash content
		10mil poly
ASHRAE Standard 90.1:	F-Factor: 0.73 Btu/(hr·ft·°F)	Concrete sealant (modeled as alkyd based paint finish on concrete)
THERM 5.2:	R-Value: 2.2 RSI-Value: 0.4	
Slab Thickness:	200 mm (plus compacted sub-base)	
Total Embodied Energy:	460 MJ/m²	
Total Embodied GWP:	53 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	205,447	17,781	223,228	28,420	16,945	45,365	0	0	0	0	0	0	268,593	440	-	-
50	205,447	17,781	223,228	28,420	16,945	45,365	2,740	20	2,760	15	9,024	9,039	280,392	460	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	30,474	34	30,508	1,915	33	1,948	0	0	0	0	0	0	32,456	53	-	-
50	30,474	34	30,508	1,915	33	1,948	47	0	47	1	17	18	32,521	53	0	0

Embodied energy (and GWP) numbers are based on an area of SOG = 610.0 m²

Area of SOG in baseline retail building = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	645.4	m2
Concrete 30 MPa (flyash 35%)	127.8	m3
Solvent Based Alkyd Paint	67.3	L
Welded Wire Mesh / Ladder Wire	549.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / baseline retail building slab-on-grade area

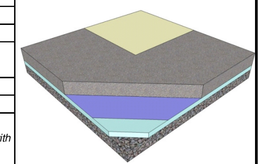
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Concrete Slab-On-Grade #6 (SOG-FDN6)

Building Component Description:

		Assembly Layers
Category:	Foundations	***Concrete Slab-On-Grade***
Brief Description:	Concrete slab-on-grade: 200mm thick, average flyash content, 50mm insulation	30MPa concrete strength
		200mm thick concrete slab
		150mm x 150mm 3.42mm steel mesh reinforcement at 0.886kg/m²
Quick Numbers:		9% (average) flyash content
		10mil poly
ASHRAE Standard 90.1:	F-Factor: 0.36 Btu/(hr·ft·°F)	50mm extruded polystyrene rigid insulation *(R-value calculations are taken through section with full under slab insulation)*
THERM 5.2:	R-Value: 12.0 RSI-Value: 2.1	
Slab Thickness:	250 mm (plus compacted sub-base)	
Total Embodied Energy:	666 MJ/m²	Concrete sealant (modeled as alkyd based paint finish on concrete)
Total Embodied GWP:	73 kg of CO_2 eq./m²	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total EE	4 Total EE per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	335,542	13,307	348,849	28,420	17,092	45,512	0	0	0	0	0	0	394,361	646	-	-
50	335,542	13,307	348,849	28,420	17,092	45,512	2,740	20	2,760	15	9,143	9,158	406,279	666	-1,500,000	-2,560

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			3 Total GWP	4 Total GWP per m²		
	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total	Material	2 Trans.	Total			5 Total	6 per m²
1 Initial	42,563	25	42,589	1,915	33	1,948	0	0	0	0	0	0	44,537	73	-	-
50	42,563	25	42,589	1,915	33	1,948	47	0	47	1	18	19	44,602	73	-90,000	-154

Embodied energy (and GWP) numbers are based on an area of SOG = 610.0 m²

Area of SOG in baseline retail building = 586.0 m²

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
6 mil Polyethylene	645.4	m2
Concrete 30 MPa (flyash av)	127.8	m3
Extruded Polystyrene	1,246.6	m2 (25mm)
Nails	37.6	kg
Solvent Based Alkyd Paint	67.3	L
Welded Wire Mesh / Ladder Wire	549.9	kg

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / baseline retail building slab-on-grade area

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Appendix B-7

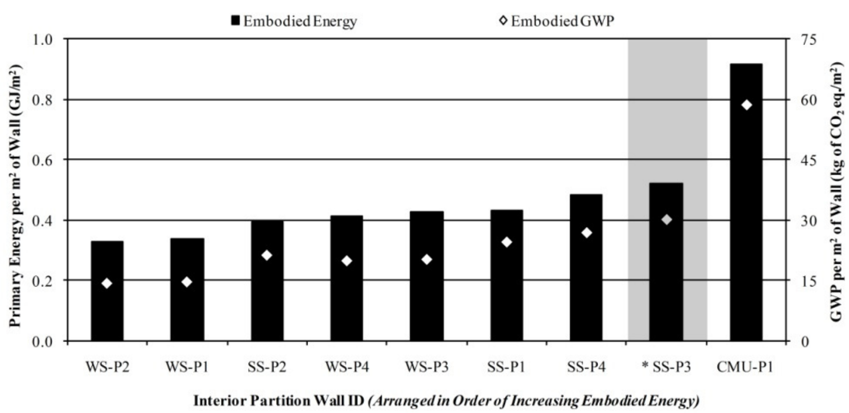
LCA Data for Interior Partitions

LCA Data for Interior Partition Walls

This section contains a detailed description of each interior partition wall that was examined in this study (9 in total). The assembly layers are listed for each wall, along with a detailed description of the material quantities from the ATHENA® Environmental Impact Estimator for Buildings.

A breakdown of the total primary energy consumption and the total global warming potential (GWP) for each wall is also included. In each case, the results were calculated for an area of partition wall equal to 50.9 m^2, which represents a typical bay size for a single-storey retail building. The results are also expressed on a per m^2 basis in each case. The data has been calculated for two different lifespans: at the completion of initial construction and after 50 years.

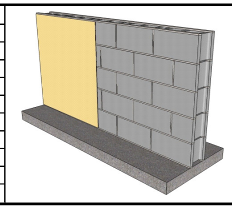
As a summary, the figure below illustrates a comparison of the total embodied energy (and GWP) after 50 years for the various interior partition walls in this section. For comparison purpose, the building component used in the baseline retail building has been shaded in grey.



Concrete Masonry Unit Interior Partition Wall #1 (CMU-P1)

Building Component Description:

Category:	Interior Partition Walls	Assembly Layers
Brief Description:	Concrete masonry unit interior partition wall with latex paint	***Outside***
		Latex paint
		200mm standard weight concrete block
		(includes #15M bars @ 400mm o/c with grout)
		Latex paint
Quick Numbers:		***Inside***
Wall Thickness:	190 mm	
Total Embodied Energy:	917 MJ/m^2	
Total Embodied GWP:	59 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	44,241	288	44,529	685	921	1,606	0	0	0	0	0	0	46,135	906	-	-
50	44,241	288	44,529	685	921	1,606	0	0	0	75	493	568	46,704	917	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	2,935	1	2,936	48	2	50	0	0	0	0	0	0	2,985	59	-	-
50	2,935	1	2,936	48	2	50	0	0	0	5	1	6	2,991	59	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
Concrete Blocks	648.0	Blocks
Mortar	2.1	m3
Rebar, Rod, Light Sections	1,092.8	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

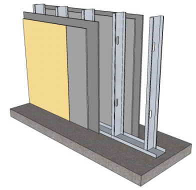
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Interior Partition Wall #1 (SS-P1)

Building Component Description:

Category:	Interior Partition Walls	Assembly Layers
		Outside
Brief Description:	Non-load bearing steel stud interior partition wall (400mm o/c) with gypsum board and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		39mm x 152mm 0.91mm steel studs @ 400mm o/c
		(includes 0.2kg of screws and fasteners per stud)
Quick Numbers:		*(also includes top and bottom steel tracks)*
		Two layers of regular 12mm gypsum board
Wall Thickness:	200 mm	Latex paint
Total Embodied Energy:	435 MJ/m^2	*Inside*
Total Embodied GWP:	25 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	21,037	146	21,183	160	616	776	0	0	0	0	0	0	21,960	431	-	-
50	21,037	146	21,183	160	616	776	0	0	0	0	173	173	22,132	435	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,240	0	1,241	10	1	12	0	0	0	0	0	0	1,252	25	-	-
50	1,240	0	1,241	10	1	12	0	0	0	0	0	0	1,253	25	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Galvanized Studs	290.4	kg
Joint Compound	223.6	kg
Nails	2.1	kg
Paper Tape	2.6	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

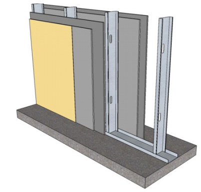
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Interior Partition Wall #2 (SS-P2)

Building Component Description:

Category:	Interior Partition Walls	Assembly Layers
		Outside
Brief Description:	Non-load bearing steel stud interior partition wall (600mm o/c) with gypsum board and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		39mm x 152mm 0.91mm steel studs @ 600mm o/c
		(includes 0.2kg of screws and fasteners per stud)
Quick Numbers:		*(also includes top and bottom steel tracks)*
		Two layers of regular 12mm gypsum board
Wall Thickness:	200 mm	Latex paint
Total Embodied Energy:	394 MJ/m^2	*Inside*
Total Embodied GWP:	21 kg of CO_2 eq./m^2	



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	18,969	143	19,111	160	607	767	0	0	0	0	0	0	19,878	390	-	-
50	18,969	143	19,111	160	607	767	0	0	0	0	169	170	20,048	394	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m^2		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m^2
[1] Initial	1,074	0	1,074	10	1	12	0	0	0	0	0	0	1,085	21	-	-
50	1,074	0	1,074	10	1	12	0	0	0	0	0	0	1,086	21	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Galvanized Studs	205.5	kg
Joint Compound	223.6	kg
Nails	2.1	kg
Paper Tape	2.6	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

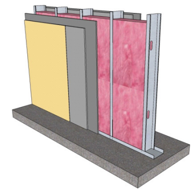
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 $MJ/m^2/yr$)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Interior Partition Wall #3 (SS-P3)

Building Component Description:

Category:	Interior Partition Walls	Assembly Layers
		Outside
Brief Description:	Non-load bearing steel stud interior partition wall (400mm o/c) with gypsum board, fiberglass batt insulation, and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		39mm x 152mm 0.91mm steel studs @ 400mm o/c
		(includes 0.2kg of screws and fasteners per stud)
Quick Numbers:		*(also includes top and bottom steel tracks)*
		140mm fiberglass batt insulation
Wall Thickness:	200 mm	Two layers of regular 12mm gypsum board
Total Embodied Energy:	523 MJ/m^2	Latex paint
Total Embodied GWP:	30 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	25,489	173	25,662	160	634	794	0	0	0	0	0	0	26,456	520	-	-
50	25,489	173	25,662	160	634	794	0	0	0	0	187	187	26,642	523	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	1,526	0	1,526	10	1	12	0	0	0	0	0	0	1,538	30	-	-
50	1,526	0	1,526	10	1	12	0	0	0	0	0	0	1,538	30	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Galvanized Studs	290.4	kg
Joint Compound	223.6	kg
Nails	5.2	kg
Paper Tape	2.6	kg
Screws Nuts & Bolts	3.9	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

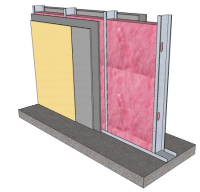
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Cold-Formed Steel Stud Interior Partition Wall #4 (SS-P4)

Building Component Description:

Category:	Interior Partition Walls	Assembly Layers
		Outside
Brief Description:	Non-load bearing steel stud interior partition wall (600mm o/c) with gypsum board, fiberglass batt insulation, and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		39mm x 152mm 0.91mm steel studs @ 600mm o/c
		(includes 0.2kg of screws and fasteners per stud)
Quick Numbers:		*(also includes top and bottom steel tracks)*
		140mm fiberglass batt insulation
Wall Thickness:	200 mm	Two layers of regular 12mm gypsum board
Total Embodied Energy:	482 MJ/m^2	Latex paint
Total Embodied GWP:	27 kg of CO_2 eq./m^2	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	23,420	170	23,590	160	624	784	0	0	0	0	0	0	24,374	479	-	-
50	23,420	170	23,590	160	624	784	0	0	0	0	183	183	24,557	482	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m^2	[5] Total	[6] per m^2
[1] Initial	1,359	0	1,359	10	1	12	0	0	0	0	0	0	1,371	27	-	-
50	1,359	0	1,359	10	1	12	0	0	0	0	0	0	1,371	27	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Galvanized Studs	205.5	kg
Joint Compound	223.6	kg
Nails	5.2	kg
Paper Tape	2.6	kg
Screws Nuts & Bolts	2.6	kg
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m^2** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m^2** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

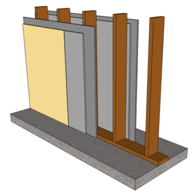
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m^2/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m^2/yr)*

Wood Stud Interior Partition Wall #1 (WS-P1)

Building Component Description:

		Assembly Layers
Category:	Interior Partition Walls	***Outside***
Brief Description:	Non-load bearing wood stud interior partition wall (400mm o/c) with gypsum board and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		38mm x 140mm wood studs @ 400mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
Quick Numbers:		*(also includes 110g/m² steel nails @ 400mm o/c)*
		(also includes double top plate and one sil plate)
Wall Thickness:	188 mm	Two layers of regular 12mm gypsum board
Total Embodied Energy:	340 MJ/m²	Latex paint
Total Embodied GWP:	15 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	15,964	222	16,185	209	730	939	0	0	0	0	0	0	17,125	336	-	-
50	15,964	222	16,185	209	730	939	0	0	0	0	177	177	17,301	340	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	732	0	732	13	1	15	0	0	0	0	0	0	747	15	-	-
50	732	0	732	13	1	15	0	0	0	0	0	0	747	15	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Joint Compound	223.6	kg
Nails	6.9	kg
Paper Tape	2.6	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

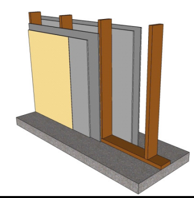
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Interior Partition Wall #2 (WS-P2)

Building Component Description:

		Assembly Layers
Category:	Interior Partition Walls	***Outside***
Brief Description:	Non-load bearing wood stud interior partition wall (600mm o/c) with gypsum board and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		38mm x 140mm wood studs @ 600mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
Quick Numbers:		*(also includes 110g/m² steel nails @ 400mm o/c)*
		(also includes double top plate and one sil plate)
Wall Thickness:	188 mm	Two layers of regular 12mm gypsum board
Total Embodied Energy:	327 MJ/m²	Latex paint
Total Embodied GWP:	14 kg of CO_2 eq./m²	***Inside***



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	15,404	197	15,602	209	689	899	0	0	0	0	0	0	16,501	324	-	-
50	15,404	197	15,602	209	689	899	0	0	0	0	172	173	16,673	327	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total			[5] Total	[6] per m²
[1] Initial	714	0	715	13	1	15	0	0	0	0	0	0	729	14	-	-
50	714	0	715	13	1	15	0	0	0	0	0	0	730	14	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Joint Compound	223.6	kg
Nails	5.3	kg
Paper Tape	2.6	kg
Small Dimension Softwood Lumber, kiln-dried	0.6	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

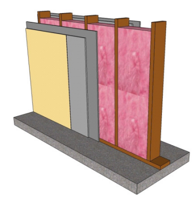
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Interior Partition Wall #3 (WS-P3)

Building Component Description:

		Assembly Layers
Category:	Interior Partition Walls	***Outside***
Brief Description:	Non-load bearing wood stud interior partition wall (400mm o/c) with gypsum board, fiberglass batt insulation, and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		38mm x 140mm wood studs @ 400mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
Quick Numbers:		*(also includes 110g/m² steel nails @ 400mm o/c)*
		(also includes double top plate and one sil plate)
Wall Thickness:	188 mm	140mm fiberglass batt insulation
Total Embodied Energy:	428 MJ/m²	Two layers of regular 12mm gypsum board
Total Embodied GWP:	20 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	20,416	248	20,664	209	747	957	0	0	0	0	0	0	21,620	425	-	-
50	20,416	248	20,664	209	747	957	0	0	0	0	191	191	21,811	428	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	1,017	0	1,017	13	1	15	0	0	0	0	0	0	1,032	20	-	-
50	1,017	0	1,017	13	1	15	0	0	0	0	0	0	1,033	20	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Joint Compound	223.6	kg
Nails	10.1	kg
Paper Tape	2.6	kg
Small Dimension Softwood Lumber, kiln-dried	0.9	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

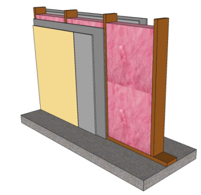
* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Wood Stud Interior Partition Wall #4 (WS-P4)

Building Component Description:

		Assembly Layers
Category:	Interior Partition Walls	***Outside***
Brief Description:	Non-load bearing wood stud interior partition wall (600mm o/c) with gypsum board, fiberglass batt insulation, and latex paint	Latex paint
		Two layers of regular 12mm gypsum board
		38mm x 140mm wood studs @ 600mm o/c
		(wood studs are kiln-dried to a MC of at least 19%)
Quick Numbers:		*(also includes 110g/m² steel nails @ 400mm o/c)*
		(also includes double top plate and one sil plate)
Wall Thickness:	188 mm	140mm fiberglass batt insulation
Total Embodied Energy:	416 MJ/m²	Two layers of regular 12mm gypsum board
Total Embodied GWP:	20 kg of CO_2 eq./m²	Latex paint
		Inside



Life-Cycle Assessment Results:

Primary Energy Consumption (MJ)

Lifespan (Years)	Embodied Energy (EE)														Difference in Operating Energy from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total EE	[4] Total EE		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	19,856	224	20,081	209	706	916	0	0	0	0	0	0	20,996	412	-	-
50	19,856	224	20,081	209	706	916	0	0	0	0	186	187	21,183	416	0	0

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)														Difference in Operating GWP from Baseline after Lifespan	
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP		
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		per m²	[5] Total	[6] per m²
[1] Initial	1,000	0	1,000	13	1	15	0	0	0	0	0	0	1,015	20	-	-
50	1,000	0	1,000	13	1	15	0	0	0	0	0	0	1,015	20	0	0

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² *(Length x Height = 7.6m x 6.7m = 50.9m²)*

ATHENA ® EIE Material List:

(Includes all materials after 50 years)

Material List	Quantities	Unit
13mm Regular Gypsum Board	224.0	m2
Batt. Fiberglass	289.8	m2 (25mm)
Joint Compound	223.6	kg
Nails	8.4	kg
Paper Tape	2.6	kg
Small Dimension Softwood Lumber, kiln-dried	0.6	m3
Water Based Latex Paint	132.5	L

Notes:

[1] **Initial** = Time '0' (i.e. at the completion of initial construction)

[2] **Trans.** = Transportation

[3] **Total EE (or Total GWP)** = Total embodied energy (or total embodied GWP) of building component after lifespan (i.e. total manufacturing + total construction + total maintenance + total end-of-life effects)

[4] **Total EE (or Total GWP) per m²** = Total EE (or Total GWP) of building component / area of building component that was modelled in ATHENA® EIE

[5] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan** = The difference in the total life-cycle operating energy (or GWP) from the baseline retail building after lifespan, due to using this building component instead of the baseline component

[6] **Total Difference in Operating Energy (or GWP) from Baseline after Lifespan per m²** = Total difference in operating energy (or GWP) from baseline after lifespan / interior partition wall area of baseline retail building

* *Total operating primary energy use of baseline retail building after 50 years = 50,700 GJ (1,745 MJ/m²/yr)*

* *Total operating GWP of baseline retail building after 50 years = 2,310 tonnes of CO_2 eq. (80 kg of CO_2 eq./m²/yr)*

Appendix C
Life-Cycle Assessment Results for Case Study Buildings

Appendix C contains a breakdown of the LCA results for the five case study buildings. This includes a summary of the various building components for each building, the estimated quantity of each component, and the corresponding life-cycle energy use and GWP.

Case Study #1: Typical Hot-Rolled Steel Structure Retail Building (Baseline Retail Building)

Total Life-Cycle Energy of Typical Hot-Rolled Steel Structure Retail Building after 50 Year Lifespan in Toronto (Case Study #1 a.k.a. Baseline Building)

Building Component	Building Component Quantities			Total Embodied Energy of Building Components after 50 Years (MJ)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	BASE-W	581.0	sq.m	535,776
Roof Enclosure (Includes Roof Joists, JOIST-1)	BASE-R	586.0	sq.m	2,728,802
Structural System - 350W Hot-Rolled Steel	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-1	11.8	tonnes	476,416
Columns (Includes COL-A)	S-1	3.3	tonnes	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m	57,882
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	242,560
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	65,378
Windows	W-1	20.3	sq.m	175,737
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	41,677
Exterior Doors - Opaque	D-2	1.0	doors	8,335
Exterior Doors - Glazing	D-3	6.0	doors	22,836
Interior Doors	D-6	9.0	doors	72,882
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	76,815
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	39,138
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	22,593
6mm Tempered Glass	N/A	5.7	sq.m	1,132
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	302,448
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	200,874
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	175,641
Total Embodied Energy of Entire Building (GJ)				**5,247**
Total Operating Energy of Entire Building (GJ)	**Annual = 1,014**			**50,700**
Total Energy of Entire Building (GJ)				**55,947**

Total Life-Cycle GWP of Typical Hot-Rolled Steel Structure Retail Building after 50 Year Lifespan in Toronto (Case Study #1 a.k.a. Baseline Building)

Building Component	Building Component Quantities			Total Embodied GWP of Building Components after 50 Years (kg of CO_2 eq.)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	BASE-W	581.0	sq.m	28,375
Roof Enclosure (Includes Roof Joists, JOIST-1)	BASE-R	586.0	sq.m	124,234
Structural System - 350W Hot-Rolled Steel	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-1	11.8	tonnes	26,872
Columns (Includes COL-A)	S-1	3.3	tonnes	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m	4,120
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	26,752
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	7,211
Windows	W-1	20.3	sq.m	10,901
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	1,448
Exterior Doors - Opaque	D-2	1.0	doors	290
Exterior Doors - Glazing	D-3	6.0	doors	1,788
Interior Doors	D-6	9.0	doors	2,493
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	4,919
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	2,256
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	1,279
6mm Tempered Glass	N/A	5.7	sq.m	172
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	38,410
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	25,291
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	15,033
Total Embodied GWP of Entire Building (tonnes of CO_2 eq.)				**322**
Total Operating GWP of Entire Building (tonnes of CO_2 eq.)	**Annual = 46**			**2,310**
Total GWP of Entire Building (tonnes of CO_2 eq.)				**2,632**

Case Study #2: Typical Heavy Timber Structure Retail Building

Total Life-Cycle Energy of Typical Heavy Timber Structure Retail Building after 50 Year Lifespan in Toronto (Case Study #2)

Building Component	Building Component Quantities			Total Embodied Energy of Building Components after 50 Years (MJ)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	BASE-W	581.0	sq.m	535,776
Roof Enclosure (Includes Roof Joists, JOIST-1)	BASE-R	586.0	sq.m	2,728,802
Structural System - 24f-E Glulam Timber	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-2	25.4	cu.m	155,972
Columns (Includes COL-A)	S-2	8.0	cu.m	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m	57,882
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	242,560
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	65,378
Windows	W-1	20.3	sq.m	175,737
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	41,677
Exterior Doors - Opaque	D-2	1.0	doors	8,335
Exterior Doors - Glazing	D-3	6.0	doors	22,836
Interior Doors	D-6	9.0	doors	72,882
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	76,815
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	39,138
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	22,593
6mm Tempered Glass	N/A	5.7	sq.m	1,132
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	302,448
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	200,874
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	175,641
Total Embodied Energy of Entire Building (GJ)				**4,926**
Total Operating Energy of Entire Building (GJ)	**Annual = 1,014**			**50,700**
Total Energy of Entire Building (GJ)				**55,626**

Total Life-Cycle GWP of Typical Heavy Timber Structure Retail Building after 50 Year Lifespan in Toronto (Case Study #2)

Building Component	Building Component Quantities			Total Embodied GWP of Building Components after 50 Years (kg of CO_2 eq.)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	BASE-W	581.0	sq.m	28,375
Roof Enclosure (Includes Roof Joists, JOIST-1)	BASE-R	586.0	sq.m	124,234
Structural System - 24f-E Glulam Timber	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-2	25.4	cu.m	7,556
Columns (Includes COL-A)	S-2	8.0	cu.m	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m	4,120
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	26,752
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	7,211
Windows	W-1	20.3	sq.m	10,901
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	1,448
Exterior Doors - Opaque	D-2	1.0	doors	290
Exterior Doors - Glazing	D-3	6.0	doors	1,788
Interior Doors	D-6	9.0	doors	2,493
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	4,919
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	2,256
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	1,279
6mm Tempered Glass	N/A	5.7	sq.m	172
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	38,410
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	25,291
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	15,033
Total Embodied GWP of Entire Building (tonnes of CO_2 eq.)				**303**
Total Operating GWP of Entire Building (tonnes of CO_2 eq.)	**Annual = 46**			**2,310**
Total GWP of Entire Building (tonnes of CO_2 eq.)				**2,613**

Case Study #3: Typical Pre-Engineered Steel Retail Building

Total Life-Cycle Energy of Typical Pre-Engineered Steel Retail Building after 50 Year Lifespan in Toronto (Case Study #3)

Building Component	Building Component Quantities			Total Embodied Energy of Building Components after 50 Years (MJ)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure (Includes Girts)	PENG-W2	581.0	sq.m	394,629
Roof Enclosure (Includes Roof Joists)	PENG-R2	586.0	sq.m	544,654
Structural System - Pre-Engineered Steel	-	-	-	-
Beams and Columns (Hot-Rolled Steel)	N/A	13.1	tonnes	394,927
Fasteners	N/A	0.2	tonnes	
Additional Hot-Rolled Steel	N/A	1.3	tonnes	36,549
(Including Hot-Rolled Steel Connection Plates)	N/A	1.2	tonnes	
Additional Cold-Formed Steel	N/A	1.8	tonnes	45,568
Mezzanine Floor (Includes Floor Joists)	N/A	48.0	sq.m	62,143
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	242,560
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	65,378
Windows	W-1	20.3	sq.m	175,737
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	41,677
Exterior Doors - Opaque	D-2	1.0	doors	8,335
Exterior Doors - Glazing	D-3	6.0	doors	22,836
Interior Doors	D-6	9.0	doors	72,882
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	76,815
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	39,138
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	22,593
6mm Tempered Glass	N/A	5.7	sq.m	1,132
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	302,448
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	200,874
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	175,641
Total Embodied Energy of Entire Building (GJ)				**2,927**
Total Operating Energy of Entire Building (GJ)	**Annual = 1,009**			**50,470**
Total Energy of Entire Building (GJ)				**53,396**

Total Life-Cycle GWP of Typical Pre-Engineered Steel Retail Building after 50 Year Lifespan in Toronto (Case Study #3)

Building Component	Building Component Quantities			Total Embodied GWP of Building Components after 50 Years (kg of CO_2 eq.)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure (Includes Girts)	PENG-W2	581.0	sq.m	18,406
Roof Enclosure (Includes Roof Joists)	PENG-R2	586.0	sq.m	22,498
Structural System - Pre-Engineered Steel	-	-	-	-
Beams and Columns (Hot-Rolled Steel)	N/A	13.1	tonnes	20,518
Fasteners	N/A	0.2	tonnes	
Additional Hot-Rolled Steel	N/A	1.3	tonnes	2,097
(Including Hot-Rolled Steel Connection Plates)	N/A	1.2	tonnes	
Additional Cold-Formed Steel	N/A	1.8	tonnes	3,034
Mezzanine Floor (Includes Floor Joists)	N/A	48.0	sq.m	3,285
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	26,752
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	7,211
Windows	W-1	20.3	sq.m	10,901
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	1,448
Exterior Doors - Opaque	D-2	1.0	doors	290
Exterior Doors - Glazing	D-3	6.0	doors	1,788
Interior Doors	D-6	9.0	doors	2,493
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	4,919
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	2,256
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	1,279
6mm Tempered Glass	N/A	5.7	sq.m	172
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	38,410
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	25,291
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	15,033
Total Embodied GWP of Entire Building (tonnes of CO_2 eq.)				**208**
Total Operating GWP of Entire Building (tonnes of CO_2 eq.)	**Annual = 46**			**2,300**
Total GWP of Entire Building (tonnes of CO_2 eq.)				**2,508**

Case Study #4: Predominately Steel Retail Building

Total Life-Cycle Energy of Predominately Steel Retail Building after 50 Year Lifespan in Toronto (Case Study #4)

Building Component	Building Component Quantities			Total Embodied Energy of Building Components after 50 Years (MJ)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	SS-W17	581.0	sq.m	1,525,301
Roof Enclosure (Includes Roof Joists, JOIST-1)	OWSJ-R5	586.0	sq.m	888,710
Structural System - 350W Hot-Rolled Steel	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-1	11.8	tonnes	476,416
Columns (Includes COL-A)	S-1	3.3	tonnes	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m	57,882
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	242,560
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	65,378
Windows	W-1	20.3	sq.m	175,737
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	41,677
Exterior Doors - Opaque	D-2	1.0	doors	8,335
Exterior Doors - Glazing	D-3	6.0	doors	22,836
Interior Doors	D-6	9.0	doors	72,882
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	76,815
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	39,138
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	22,593
6mm Tempered Glass	N/A	5.7	sq.m	1,132
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	302,448
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	200,874
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	175,641
Total Embodied Energy of Entire Building (GJ)				**4,396**
Total Operating Energy of Entire Building (GJ)	**Annual = 1,040**			**51,981**
Total Energy of Entire Building (GJ)				**56,377**

Total Life-Cycle GWP of Predominately Steel Retail Building after 50 Year Lifespan in Toronto (Case Study #4)

Building Component	Building Component Quantities			Total Embodied GWP of Building Components after 50 Years (kg of CO_2 eq.)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	SS-W17	581.0	sq.m	90,679
Roof Enclosure (Includes Roof Joists, JOIST-1)	OWSJ-R5	586.0	sq.m	46,236
Structural System - 350W Hot-Rolled Steel	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-1	11.8	tonnes	26,872
Columns (Includes COL-A)	S-1	3.3	tonnes	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-3	48.0	sq.m	4,120
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	26,752
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	7,211
Windows	W-1	20.3	sq.m	10,901
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	1,448
Exterior Doors - Opaque	D-2	1.0	doors	290
Exterior Doors - Glazing	D-3	6.0	doors	1,788
Interior Doors	D-6	9.0	doors	2,493
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	4,919
Insulated Interior Stud Wall Partition	SS-P3	75.0	sq.m	2,256
Uninsulated Interior Stud Wall Partition	SS-P1	52.0	sq.m	1,279
6mm Tempered Glass	N/A	5.7	sq.m	172
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	38,410
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	25,291
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	15,033
Total Embodied GWP of Entire Building (tonnes of CO_2 eq.)				**306**
Total Operating GWP of Entire Building (tonnes of CO_2 eq.)	**Annual = 48**			**2,381**
Total GWP of Entire Building (tonnes of CO_2 eq.)				**2,687**

Case Study #5: Predominately Timber Retail Building

Total Life-Cycle Energy of Predominately Timber Retail Building after 50 Year Lifespan in Toronto (Case Study #5)

Building Component	Building Component Quantities			Total Embodied Energy of Building Components after 50 Years (MJ)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	WS-W4	581.0	sq.m	410,119
Roof Enclosure (Includes Roof Joists, JOIST-1)	GLU-R2	586.0	sq.m	2,560,210
Structural System - 24f-E Glulam Timber	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-2	25.4	cu.m	155,972
Columns (Includes COL-A)	S-2	8.0	cu.m	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-2	48.0	sq.m	31,527
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	242,560
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	65,378
Windows	W-4	20.3	sq.m	82,905
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	41,677
Exterior Doors - Opaque	D-1	1.0	doors	539
Exterior Doors - Glazing	D-3	6.0	doors	22,836
Interior Doors	D-5	9.0	doors	4,851
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	76,815
Insulated Interior Stud Wall Partition	WS-P3	75.0	sq.m	32,143
Uninsulated Interior Stud Wall Partition	WS-P1	52.0	sq.m	17,666
6mm Tempered Glass	N/A	5.7	sq.m	1,132
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	302,448
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	200,874
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	175,641
Total Embodied Energy of Entire Building (GJ)				**4,425**
Total Operating Energy of Entire Building (GJ)	**Annual = 1,016**			**50,822**
Total Energy of Entire Building (GJ)				**55,247**

Total Life-Cycle GWP of Predominately Timber Retail Building after 50 Year Lifespan in Toronto (Case Study #5)

Building Component	Building Component Quantities			Total Embodied GWP of Building Components after 50 Years (kg of CO_2 eq.)
	ID	Estimated Quantity	Unit	
Exterior Infill Wall Enclosure	WS-W4	581.0	sq.m	15,202
Roof Enclosure (Includes Roof Joists, JOIST-1)	GLU-R2	586.0	sq.m	109,056
Structural System - 24f-E Glulam Timber	-	-	-	-
Beams (Includes BM-1, BM-2, BM-3, GIRT-1)	S-2	25.4	cu.m	7,556
Columns (Includes COL-A)	S-2	8.0	cu.m	
Hot-Rolled Steel Connection Plates	N/A	0.3	tonnes	
Fasteners	N/A	0.2	tonnes	
Miscellaneous Hot-Rolled Steel	N/A	1.2	tonnes	
Mezzanine Floor (Includes Floor Joists, JOIST-1)	FL-2	48.0	sq.m	1,633
Windows	-	-	-	-
Curtainwall (Façade)	W-9	128.0	sq.m	26,752
Curtainwall (Interior Vestibule)	W-9	34.5	sq.m	7,211
Windows	W-4	20.3	sq.m	7,024
Doors	-	-	-	-
Overhead Doors	D-4	1.0	doors	1,448
Exterior Doors - Opaque	D-1	1.0	doors	16
Exterior Doors - Glazing	D-3	6.0	doors	1,788
Interior Doors	D-5	9.0	doors	144
Interior Partitions	-	-	-	-
Fire Rated Stair Tower	CMU-P1	84.0	sq.m	4,919
Insulated Interior Stud Wall Partition	WS-P3	75.0	sq.m	1,522
Uninsulated Interior Stud Wall Partition	WS-P1	52.0	sq.m	763
6mm Tempered Glass	N/A	5.7	sq.m	172
Foundations	-	-	-	-
Slab-On-Grade	S0G-FDN4	586.0	sq.m	38,410
Isolated Footings with Concrete Piers	IF-FDN1	15.0	units	25,291
Strip Footings with Concrete Foundation Wall	SF-FDN5	160.0	m	15,033
Total Embodied GWP of Entire Building (tonnes of CO_2 eq.)				**264**
Total Operating GWP of Entire Building (tonnes of CO_2 eq.)	**Annual = 46**			**2,319**
Total GWP of Entire Building (tonnes of CO_2 eq.)				**2,583**