Life Cycle Assessment of Residential Buildings Considering Photovoltaic Systems

by
Dhia Jabri

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Applied Science

in

Chemical Engineering

Waterloo, Ontario, Canada, 2018

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

Nowadays, energy consumption in the building sector is considered one of the main contributors to increased carbon dioxide (CO2) emissions, which is having an enormous negative environmental impact worldwide. Correspondingly, rising CO2 emissions have become a global environmental issue. Life Cycle Assessments (LCAs) have been deployed for evaluation of the ecological impact of the building sector will be used to analyze and assess ecological effects. Many studies utilize different LCA approaches to examine the building sector's energy consumption. Some of these studies aimed to decrease greenhouse gas (GHG) emissions from the building segment by the adoption of two new building structure categories in the Industrial Building System (IBS). However, but neglect to consider the integration of LCA and Photovoltaic (PV) systems added to the Heating, Ventilation, and Air Conditioning (HVAC) systems and the resulting impact on the load demand of the buildings. The primary objective of this research is to consider the different phases of life cycle energy and CO2 analysis of a PV system integrated residential building by designing geometry, spaces, and thermal zones in Sketch Up and simulating the building and calculating the energy load in EnergyPlus. For illustrative purposes, a single residential building in Toronto was simulated.

Moreover, carbon emissions of the residential building were calculated through LCA and compared with the case of added PV systems. Also, different life cycle phases of the residential building were employed to calculate the energy consumption using EnergyPlus. More significantly, the focus is on HVAC, lighting, and electronic equipment using the OpenStudio plug-in for the SketchUp modeling software. OpenStudio is used as an interface of the EnergyPlus modeling software, and the results are compared with those that include the PV system. As a result of the LCA of the building, it was found that there would be a significant

reduction in operating cost, energy cost, and CO_2 emissions. However, the capital cost would increase by integrating PV systems, but it would be less significant considering a higher carbon tax in the future.

Acknowledgements

First and foremost, all praise and thanks are due to Almighty Allah for providing me with the strength and patience to accomplish this work.

I am grateful to my Supervisor Professor Ali Elkamel and my advisor Dr. Lena Ahmadi , for their guidance, invaluable comments, patience, and encouragement throughout my study.

I owe my deepest gratitude to my family: my husband, my father , my mother my brothers, and my sisters for their support and encouragement, and unconditional love.

I would like also to acknowledge my country Libya and the Libyan Ministry of Higher Education for sponsoring me through this research work.

Dedication

My husband, who has supported me in following my dreams.

Table of Contents

AUTHOR'S DECLARATION……….. ii

Abstract………………………………………………………………………………………...iii

Acknowledgements………...v

Dedication………..vi

Table of Contents…….. vii

List of Figures……... ix

List of Tables……... x

List of Abbreviations…………………………………………………………………………..xi

CHAPTER 1: INTRODUCTION…….. 1

1.1 Life Cycle Assessment Process……..1

1.2 Photovoltaic System…. …………………………………………………………..3

1.2.1 Introduction ……………………………………………………………………...3

1.2.2 Life Cycle PV System………………………………………………………... 4

1.3 Literature Review…...5

1.3.1 Energy Consumption and Production...……………………………………………5

1.3.2 Life Cycle Assessment………………………………………………………....10

1.3.3 Energy Efficiency (Potential) …………………………………………………13

1.3.4 Optimization Analysis ……………………………………………………... 18

1.3.5 Building Performance (Structure, Commercial & Residential) ………………………18

1.3.6 Energy Simulation and Multivariate Regression ……………………………………...21

1.3.7 Strategy and Decision – Making Tools……………………………………………...22

1.4 Aims and Objectives...23

CHAPTER 2: Methodology... ………....25

2.1 Flowchart of Study Methodology..25

2.2 Simulation steps...26

2.3 EnergyPlus Software..27

2.3.1 Introduction ……………………………………………………………… 27

2.3.2 EnergyPlus Tools ………………………………………………………….29

2.3.3 Other Software are Used With EnergyPlus……………………………….. 29

2.4 Scenario...29

CHAPTER 3: Case Study.. 30

3.1 Building Information...30

3.2 Performance Compliance for Buildings..30

CHAPTER 4: RESULTS...33

4.1 Weather Variables and Effects on Energy Consumption..33

4.2 Energy Consumption and CO_2 Emission..34

4.3 Annual Emission...35

4.4 Life Cycle Energy Analysis..36

CHAPTER 5: CONCLUSION...37

REFERENCES...40

Appendix A. EnergyPlus Tools. ……………………………………………………...... 49

Appendix B. Building Geometry …………………………………………………….53

Appendix C. Number Exchange Rate ……………………………………………….54

List of Figures

Figure 1. Lifecycle Analysis (Process LCA)... 1

Figure 2. Lifecycle Methodology Steps ……………………………... 2

Figure 3. Canada in 2011 Installation………………………………………………………… 3

Figure 4. Life Cycle Diagram of PV system ……………………………………………………4

Figure 5. Flowchart of Study Methodology...25

Figure6.EnergyPlus Structure 1 ………………………………………………………….. 27

Figure 7. EnergyPlus Structure 2 ………………………………………………………..28

List of Tables

TABLE 1. Case Study Archetype Data 30

TABLE 2. Building Type Categories...30

TABLE 3. Space Function ………………………………………………………………...31

TABLE 4.Energy Consumption and CO_2 Emission by Considering Different Sources of Energy……………………………………………………………………………………34

TABLE 5. Annual CO2 Emission by Considering the Occupants... 35

TABLE 6. Life Cycle Energy Analysis (Use/ Cost) …………………………………………….36

TABLE 7. Life Cycle Renewable Energy Analysis……………………………………………..36

List of Abbreviations

Life Cycle Assessment	LCA
National Energy Efficiency Program	NEEP
King Abdulaziz City for Science and Technology	KACST
Kingdom of Saudi Arabia	KSA
Saudi Energy Efficiency Center	SEEC
Heating, Ventilation and Air Conditioning Systems	HVAC
Reinforced Concrete	RC
British Thermal Units	BTU
Photovoltaic	PV
Commercial Building Energy Consumption Survey	CBECS
Personalized Conditioning	PC
Phase-Change Material	PCM
Times of Local Use	TOLU
Building Cooling Heating & Power	BCHP
Climate Change Performance Index	CCPI
Industrial Building System	IBS
IBeacon-enabled indoor Positioning System	IPS
Dynamic Spatial Occupancy Distribution	DSOD
Computational Fluid Dynamics	CFD
Glued Laminated Timber	GLT
Laminated Veneer Lumber	LVL
Global Warming Potential	GWP
Demand-Controlled Ventilation system	DCV
Zero Energy Buildings	Nzeb
Greenhouse Gases	GHG
Megawatts Direct Current	MWDC
Giga Watt Hours	GWh
Carbon Dioxide Equivalent	CO_2eq
Kilowatt hours	KWh
GigaWatt Hours (GWh)	GWh
Megawatt	MW

CHAPTER 1: INTRODUCTION

1.1 Life Cycle Assessment Process

As the architecture and construction industries increasingly accentuate sustainability, more holistic approaches are underway, which were developed to assess and reduce the environmental effects caused by buildings. Life cycle assessment (LCA) appears to be one of the most widely accepted methodologies being used during the design process to evaluate the environmental impact of construction (Bayer et al., 2010). However, Life cycle assessment, also known as Life cycle analysis, is a technique for assessing the environmental effects associated with all phases of the life of the project from the extraction of raw materials through processing, distribution, use, repair, maintenance, disposal and/or recycling. Designers use this process to help critique their products (Ragheb, 2011). The next figure shows the life cycle analysis process.

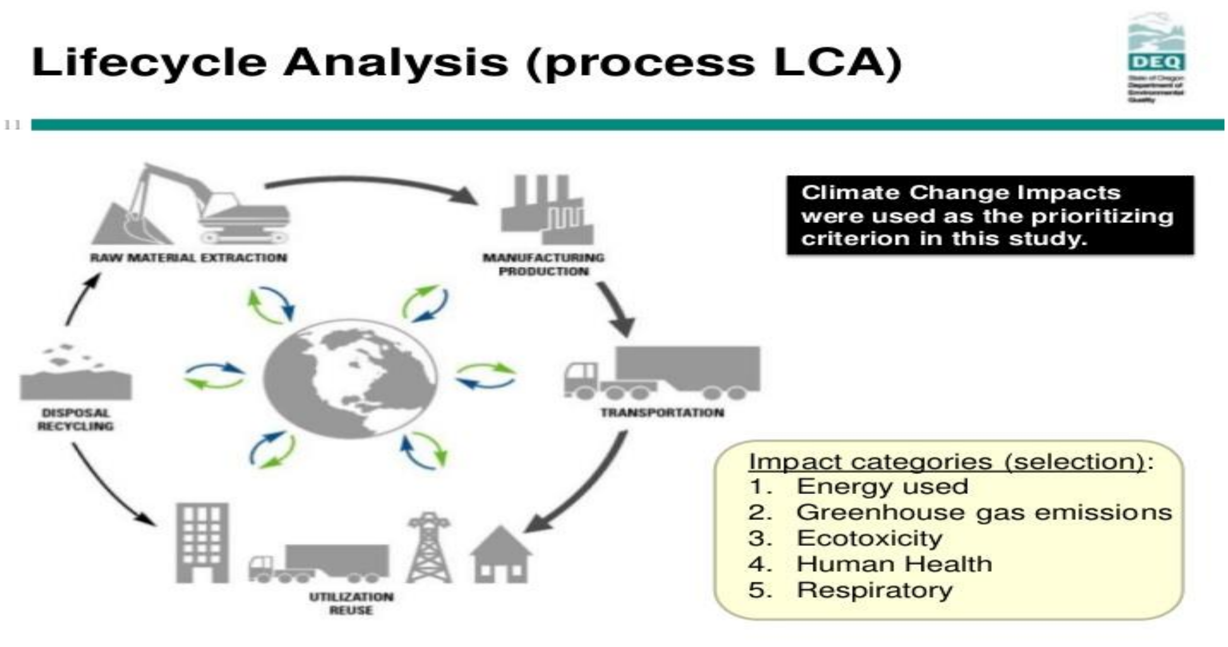


Figure 1: Life cycle Analysis Process (Jordan, 2012)

LCA consists of four stages, which are 1. Definition of goals and scope, 2. Inventory analysis, 3. Impact analysis and 4. Interpretation and results (Bayer et al., 2010). In the first stage, the definition of goals and scope is defined as the aim and a limitation of the study documented and explains how and to whom the results are reported. It is essential to consider the function unit in this step, for example, CO_2/ kg transported goods, CO_2/m^3 floor (Williams, 2009). Inventory analysis is the second stage which considers the data collection and data quality to quantify the input and output of products and energy; also, system boundaries and calculations are performed during this step (Bayer et al., 2010). The impact analysis presented in the third stage evaluates the potential environmental impacts, for example, resource depletion and the Global warming potential (Ragheb, 2011). Finally, the last scene is interpretation, assessment, and recommendation built on the results (Williams, 2009) Figure 2 shows the LCA steps.

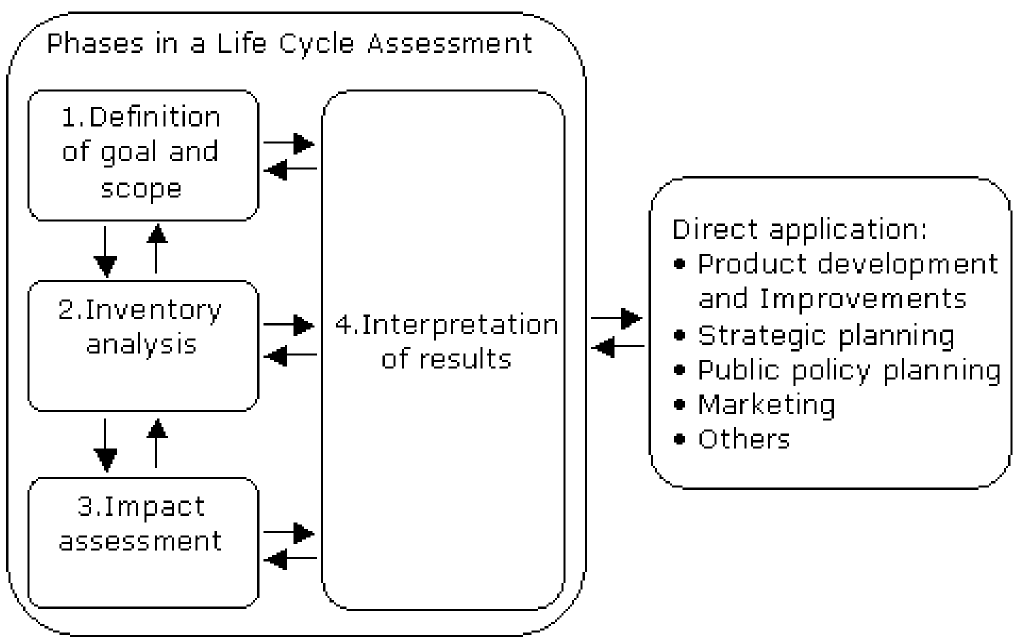


Figure 2: shows the LCA methodology steps (Bayer et al, 2010).

1.2 Photovoltaic System (PV).

1.2.1 Introduction

Advanced photovoltaic (PV) technology yields excellent potential for the removal of carbon dioxide emissions from the electricity industry because direct solar energy is in abundance compared to other energy resources (Arvizu et al., 2011). The integration of PV systems in buildings has several advantages over conventional photovoltaic power plants in open fields. The main benefits include land use and surfaces that are already used for other purposes, saving building materials needed for PV module support structures, the substitution of building envelope materials and the possibility of recovery of a significant fraction of the thermal energy dissipated by the photovoltaic panels (Frankl et al., 1998). Most industrialized countries are using a PV system as a source of electricity to reduce CO_2 emissions. According to Sector profile for solar photovoltaic in Canada in 2011 approximately of 289 Megawatts, direct current (MWDC) of solar PV representing more than 335-gigawatt hours (GWh) of electricity generation on an annual basis was installed. This level of activity generated $584 million of direct economic output and employed about 5,100 full-time employees directly on a yearly basis. Figure 3 illustrates PV installations in Canada in 2011, the majority of which are in Ontario.

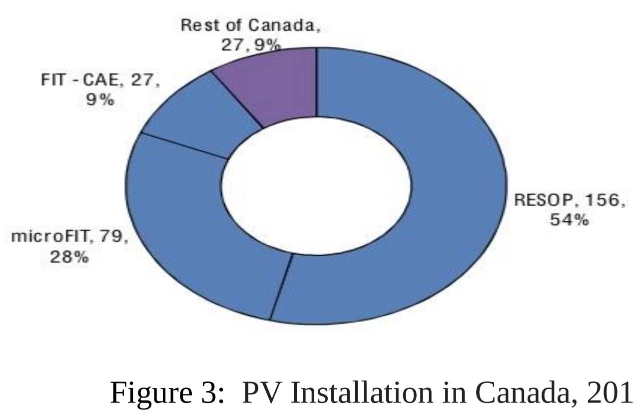


Figure 3: PV Installation in Canada, 2011

1.2.2 Life Cycle of PV system

The environmental life cycle assessment of an energy technology considers the impact analysis of all stages of production from “cradle to grave,” that is, from fuel production to decommissioning (Figure 4). The manufacturing of PV system is not included in the current study, as the carbon footprint for PV manufacturing can be high. In the case of PV energy, the stages shown in Figure 4 are simplified because no fuel needs to be prepared; no waste results from the conversion of sunlight into electricity and little maintenance are required during operation. The impacts are thus associated mainly with plant construction (raw materials, PV module and balance of system manufacturing, transportation, and plant manufacturing) and, to some extent, with decommissioning and recycling at the end of the PV system lifespan, which is typically 30 years (Vandeligt et al., 2012 & IEA, 2009).

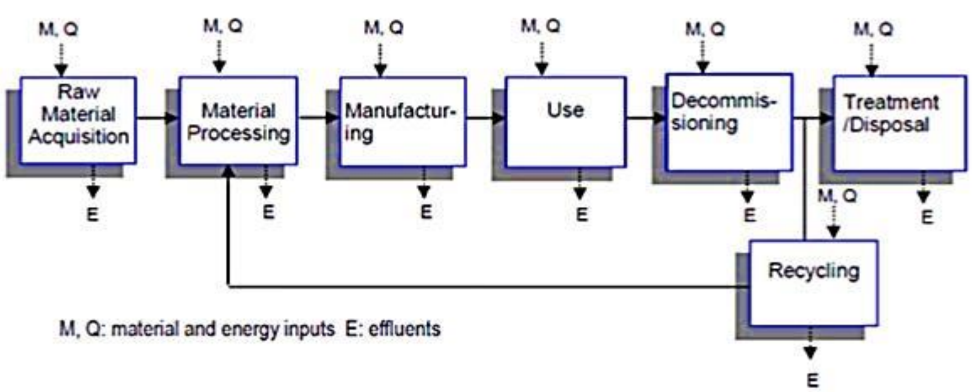


Figure 4: Life Cycle diagram of PV system (Frishknecht et al., 2012)

1.3 Literature Review

1.3.1 Energy Consumption and Production (Heating, Ventilation and Air Conditioning (HVAC) systems)

Kim et al. (2017) predicted that world energy consumption would grow 33% between 2010-2030 (Abdelaziz et al., 2011). In industrialized countries, total energy consumption in buildings represents about 20-40%. For example, in 2010 the United States consumed more than 40% of total primary energy in the building segment (DOE, 2011). With the growth of 82%, the major source of primary energy consumption is fossil fuels (EIA, 2011). These (non-renewable) energy resources are limited and also contribute significantly to CO2 emissions, which increased by more than 2% annually (DOE, 2011). In 2010, universal CO2 emissions surpassed more than 30 billion metric tons, with the U.S. contributing more than 4 billion metric tons (EIA, 2011). Due to increased energy consumption and inefficient use of energy, CO2 emissions continue to rise (Abdelaziz et al., 2011). Improving energy efficiency in complex buildings has significant potential to decrease energy consumption and related negative environmental impact. The related negative environmental impacts of greenhouse gas (GHG) emissions have been associated with global warming (Kessel, 2000) and the increased risk of natural disasters (Van Aalst, 2006). Energy efficiency in buildings has focused on improving energy consumption in air conditioning and lighting systems. More than 0.5% of energy consumption in buildings is due to Heating, Ventilation and Air Conditioning (HVAC) systems (Vali et al., 2009). More than 0.2% of total building energy is consumed by artificial lighting (Kozminski et al., 2006). HVAC and lighting systems have more than of 20% of potential energy savings. However, research thus has not provided energy-saving strategies for a complex manufacturing building. Therefore, this article focuses on the energy-saving technologies of the biotechnology manufacturing building such as laboratories and hospitals because this complex type of building requires health and safety regulations that consume far more energy consumption than a typical commercial building. The results identify that more than 13% of total energy cost savings resulting from energy-saving technologies. The savings were achieved by using high-efficiency HVAC equipment and advanced fluorescent lighting systems. When utilized to comparable types of buildings, the energy saving strategies considered will grow the economic and environmental benefits to homeowners. Also, the process energy consumes 67% of the building's total energy, almost double the energy consumed by air handling units (AHU), chillers, and lighting systems. Also, the annual energy savings estimate for air handling units, chillers, and lighting systems are 1,245,234 kilowatt hours (kWh); 869,202 kWh; and 1,122,165 kWh, respectively. The corresponding savings in dollars are $161,880; $112,996; and $145,881, respectively. The AHU contributes to the highest annual saving in energy costs, followed by lighting and then chillers. Based on the US Environmental Protection Agency (EPA) carbon equivalent emission factor of 7×10-4 metric tons CO2/kWh (EPA, 2012), the annual estimate of CO2eq, or carbon dioxide equivalent, savings in metric tons for AHU, coolers, and lighting is 878.57 tons, 613.27 tons, and 791.74 tons, respectively. The annual estimate of total energy savings for the three systems is 3,236,601 kWh, or $ 420,758. The total annual saving in CO2 equivalent is 2283.58 metric tons. These energy savings reduce greenhouse gas emissions by 2,283.58 metric tons of carbon dioxide equivalent.

Chel et al. (2017) pointed out that by developing more than 30% of the world's overall universal essential resources, the building sector is overgrowing. After the industrial area and agriculture, modern buildings have become the largest consumers of fossil energy. Within the framework of the sustainable environment program, there is an enhanced integration of renewable energy technologies installed with the building into several applications such as electricity generation, water heating, and heating/cooling (Feist et al., 2005). Sources put the amount of energy consumed in the building segment in Europe more than 40% of total energy consumption; about 0.66% of the amount as mentioned above is used in commercial buildings (Zografakis et al., 2000). Other sources claim that energy consumption in buildings in industrialization countries is responsible for 50 percent of CO_2 emissions (Loveday et al., 2002& Yannas et al., 1994). In this article, the four main strategies for energy efficiency in a building are studied with their economic and environmental impacts. The first is associated with the previous design before the construction of passive solar building techniques adapted all over the world not only for passive heating/cooling but also for daylight buildings. The second strategy is to take advantage of low-energy building materials. The third strategy considers the maintenance of operational energy using energy-saving equipment within the building. Finally, the building should benefit from integrated renewable hot water systems. Thus, the integration of passive solar features in buildings leads to a reduction in the energy consumption of buildings, thereby reducing carbon dioxide emissions and contributing to sustainable development. Another significant contribution to sustainability is the use of low internal energy and building materials available locally, to avoid the introduction of enormous energy requirement in the construction of the building, and thus reduce CO_2 emissions. Therefore, as a viable alternative, the focus is on the promotion of renewable energy technologies to meet the energy demands of buildings. When the energy of the building is fully satisfied with renewable energy systems, it is known as high-efficiency green buildings or zero emissions. Total mitigation of CO_2 emissions due to both heating and cooling energy saving potential capacity is identified as 5.2 metric ton per year (Arvind et al., 2009). The mitigation of carbon dioxide emissions was set at 58 metric tons due to the construction of a renovated mud house with an area of about 94 square meters compared to the reinforced concrete [RC] building house (Arvind et al., 2009). The carbon credits earned were set at $678 due to mitigation of CO2 emissions from mud house construction rather than RC structure building (Assuming 10 Euro/metric ton of CO2 reduction) (Arvind et al., 2009). Hence, the total building energy can be significantly reduced when using alternative energy systems included low energy building materials.

Radwan et al. (2016) indicated that Egypt has significant energy production, but because of the substantial increase in domestic consumption and investment in the energy sector declined, Egypt became dependent on hydrocarbon imports. Egypt’s dependency on hydrocarbon imports resulted in adverse impacts on the economic balance of trade and the national budget. Therefore, the Egyptian government is spurring energy-saving research. More than 55% of total energy in buildings is consumed by the air conditioning system (Fink, 2011, Aldossary et al., 2013). The future energy consumption of heating, ventilation and air conditioning (HVAC) will rise further due to increasing population growth, rapid expansion, and advocacy of new residential and commercial buildings and due to climate change and global warming. A hospital was selected in Alexandria, Egypt, as a case study because the hospital consumes a lot of energy because of 24-hour availability, medical equipment, and monitoring requirements for disease control and clean air requirements. In this study, an energy-efficient saving technology was developed to reduce energy consumption, which will provide specific methodologies and recommendations for energy-efficient operation. Improvements were made to the hospital to help both the hospital managers and designers begin the energy management program and create some "energy gains" to provide more energy saving for other purposes. The new system selected using the new cooling hospital loads was compared to the current system and a great deal of energy saving

(7,068,178 kWh/year) was found. Also, the simulation showed potential annual electricity savings of 41% on the baseline scenario when applied the demand-controlled ventilation system (DCV) controls the amount of fresh outdoor air, based on the amount of CO2 in a building compared to the external door reading. DCV facilitates ventilation and improves indoor air quality while saving energy.

Wang et al. (2017) concluded that the commercial and residential buildings had become the largest consumers of energy in all sectors, and energy efficient building has attracted increasing attention in recent years. Several studies indicate that occupancy detection is critical to enhancing energy efficiency in buildings because it is based on the idea of avoiding unnecessary waste while providing adequate service. In this paper, the proposed integration of an IBeacon-enabled indoor positioning system (IPS) and a variable air ventilation system, \as well as the air conditioning system (HVAC) is to optimize the control system and provide high-resolution power detection occupancy for saving energy. The proposed system aims to harmonize thermal service with the spatial distribution of occupancy and redefine occupancy as a matrix of dynamic spatial occupancy distribution (DSOD). This paper proposes spatial occupancy measurement by linking large areas of indoor patches and zones, using a synthetic artificial neural network algorithm with specific characteristics to set the spatial IPS to signal patterns. After obtaining detailed spatial distribution, also developed a ventilation control mechanism based on the occupancy distribution. To verify the proposed control mechanism, compare it with other conventional controllers in the on-site experiment and by simulation using computational fluid dynamics (CFD). The results suggest that 20% of energy savings can be achieved when the proposed approach is implemented correctly.

.

1.3.2 Life Cycle Assessment

I. The Life Cycle Assessment Tool (LCA) Simapro.8

Balasbaneh et al. (2017) investigated that a major worldwide concern is climate change, and the building sector and construction is the best place to mitigate the effects of these changes. The building sector accounts for more than 29 percent of total annual greenhouse gas emissions to the atmosphere (UNEP, 2009). According to the Climate Change Performance Index (CCPI), in 2015 (Jan Burck et al. 2015) Malaysia was ranked 52th out of 58 countries, performing "quite bad" at controlling CO2 emissions. Since there are several benefits such as efficiency, productivity, and cost, the Malaysian government recommended the builders utilize the Industrial Building System (IBS) technique in construction. The purpose of the study was to decrease greenhouse gas (GHG) emissions from the building segment by including two new buildings in IBS structure categories. The Life Cycle Assessment Tool (LCA) Simapro.8 was used to classify the environmental performance of cradle to grave buildings. The full life cycle assessment has been conducted to evaluate six diverse kinds of pre-fabricated buildings, four of which are presently identified, and the other two systems have been designed through recent research. The preliminary findings indicate that wood prefabrication is the preferred option due to reduced emissions, lessening the impacts of climate change on building construction. However, wood houses are seldom built because of flaws in their materials and structure over time. The rate of wood application in the construction industry in Malaysia has dropped from about 60% in the last 40 years. Hence, this study proposes the introduction of two new composites, which not only have significantly less global warming potential (GWP) than prefabricated concrete structure or steel framing system but can be replaced rather than the abandoned were considered. The first composite is glued laminated timber (GLT) with steel studs and the second composite is a combination of laminated veneer lumber (LVL) with steel studs. Therefore, six new composites may be suggested to house builders who will facilitate the decision-making process present in the block work system (R1), the precast concrete framing (R2), steel framework system (R3), the prefabricated timber system (beam and prefabricated poles) (R4), a new scheme GLT namely glued laminated timber & steel with timber wall (R5), new LVL scheme laminated veneer lumber & steel with timber wall (R6). (R6) emitted 6.27 E+ 03 less kg CO2 equivalent (CO2eq) emission compared to (R2), 2.6 6E+04 kg CO2eq less than (R1) and 1.83 E+04 kg CO2eq less than (R3). The result also shows that a new scheme GLT namely glued laminated timber & steel with timber wall (R5) has released up to 5.85 E+03 kg CO2eq less emission compared to R2, 2.62 E+04 kg CO2eq less than R1 and 1.79E+04 kg CO2eq less than R3. Therefore, R1 R2, R3, and (R4) can be replaced by other building blocks (R5, R6) in the construction industry. A comparison of these two new packages shows that although both schemes have a low atmospheric impact, the R6 laminate veneer timber composite is more environmentally friendly than R5, as the R6 produced 7% less CO2eq emission than R5. The application of a new structure or a new composite beam could encourage many stakeholders to use this alternative without the need for military replacement of residential buildings in Malaysia.

II. Calculation of the Carbon emissions for residential buildings basis of a life cycle assessment (LCA)

Hu et al. (2015) showed that the emission of greenhouse gases had become a common concern of the global societies. The building industry has caused a strain on the environment because of the emissions generated by the production of building materials and operation of the building system. Carbon emissions for residential buildings are calculated by a life cycle assessment (LCA). Impact factors, such as insulation thickness, air conditioning form and service life are analyzed. A typical energy-efficient residential building was chosen to calculate carbon emissions under several conditions. In this case, when the insulation thickness is 100mm, the carbon emission life cycle is minimal. In other words, each residential building has the optimum insulation thickness. As the building service is extended life, emissions will drop. As for air conditioning forms, the results appearance that residential buildings with split air conditioning have fewer carbon emissions than central air conditioning.

Lotteau et al. (2017) indicated that in 2015, almost 55% of the population lived in world's local areas (Habitat et al., 2016), and the sector is the hotspot for the environmental effects and source usage. For example, about 20% of the whole energy consumed worldwide is accounted for in the building segment (US El, 2014). The concluding energy consumption in developed countries accounts for about 42% in the building segment, almost 36% of greenhouse gas emissions and more than 50% of all removed material (European Commission, 2011). Analysis of the environmental effects of the constructed environment lectured through a diversity of methodologies depended on the gauge of study. At the building construction materials and the scale of individual buildings, life cycle assessment (LCA) is the accepted logical methodology for the quantitative evaluation of materials/buildings over their entire lifespan, taking into account upstream effects. LCA in the construction industry had been the topic of many studies. These reviews all point to the fact that case studies in the literature are difficult to compare because of their specificities such as resident regulations, building type, climate, cosiness requirements, and so on. Heating and cooling, and increasing the energy-sharing value of building materials in the context of low power buildings (Trigaux et al., 2014 & Lotteau et al. 2015). (Lotteau al., 2017) Propose a simplified model of assessment of the embodied power of buildings and embodied carbon concerning the urban planners' design levers. The model is based on the decomposition of buildings into functional elements to be sensitive to the shape of buildings. In detailed sensitivity analysis and contribution analysis, the model is conducted on two types of generic building forms to study influence meters binding to shape on the embodied power and carbon of the building. Sensitivity analysis shows that shape-related parameters (such as building size) have a more significant influence on energy and number of buildings per square meter than those for the elements themselves (such as wall thickness). Contribution analysis carbon proof of the relationship between the compactness factor, the CO_2 embodied, and the building embodied.

1.3.3 Energy Efficiency (Potential)

Krarti et al. (2017) discussed that several energy systems efficiency standards and programs had been introduced in the Saudi building sector to reduce energy consumption. In particular, the National Energy Efficiency Program (NEEP) was established at King Abdulaziz City for Science and Technology (KACST) to support research activities and provide recommendations to achieve reasonable consumption goals of the energy of the country. Explicitly, the Kingdom of Saudi Arabia (KSA) is committed under its Vision 2030 to reduce its carbon emissions by 130 million tons by 2030 compared to the status quo by promoting energy efficiency and technologies (Mitchell et al., 2016). Besides, the KSA government established the Saudi Energy Efficiency Center (SEEC) in 2010 to promote energy efficiency for all sectors, including buildings. The primary goal of SEEC is to reduce energy demand through audits, load management, regulation, and education. However, in this paper, a bottom-up evaluation of several energy efficiency programs for new and existing buildings is explicitly conducted to assess the potential for reducing energy consumption, peak demand and carbon emissions associated with KSA the energy sector buildings. First, energy efficiency policies for current buildings in Saudi Arabia are described. Next, the analysis approach for evaluating the impact of various energy efficiency programs is briefly described. Finally, the results of the analysis are presented and discussed. In particular, the energy consumed by residential and commercial buildings has increased significantly over the last five years, with an annual growth rate of almost 10%. As a result, this growth has meaningfully amplified the KSA's power generation requirements to meet national needs, particularly in the growing residential sector. Indeed, the building sector accounts for 76% of total electricity demand in the Kingdom. The primary results of the analysis presented in this paper indicate that energy efficient developments in the KSA housing stock has several advantages along with the reduction of electricity use and associated primary fuel consumption, advanced electric power demand and the development of new energy generation, which is associated with the nation's essential carbon emissions and improving environmental conditions, as well as creating a significant number of job opportunities. More specifically, a level 1 energy efficiency update program targeting only the current residential stock of building is reduced by 10,054-gigawatt hours (GWh) /year and peak demand by 2,290 megawatts (MW) and carbon emissions by 7.611 million tons.

Simona et al. (2017) investigated that current environmental issues require intensive research on energy efficiency and energy saving in buildings to decrease conventional fuel exhaust and carbon dioxide emissions that generate greenhouse effect (Santamaraa et al., 2017& Perez et al .,2016). For example, according to the European Union, the total energy consumption in the building segment accounts for more than 40% of demand and is therefore responsible for the very high emissions of pollutants, which embodies the region with the highest potential for interference (Tabrizi et al., 2017 & Kass et a., 2017). The Energy Package published by the European Commission to decrease greenhouse gas emissions by 20%, to upsurge the production of renewable energy to 20% and improve energy efficiency by 20% by 2020. Reducing energy demand for buildings is an essential objective of building construction and building occupancy significantly to emissions of universal CO2, accounting for nearly 0.25 % of global CO2 emissions (Miezis et al., 2016 & Fortuna et al., 2017). The primary factor affecting energy consumption depends on the building's energy consumption structure and the thermal performance of the building. For example, the energy consumption of heating or cooling can be reduced by thermally insulated walls (Adityaal et al., 2017& Schuchhardt et al., 2016). To reduce energy consumption for heating or cooling by increasing the thermal resistance of the building envelope is the primary purpose of mounting insulating material in the building. A relevant study of external and internal thermal insulation systems has been conducted to make residential buildings more energy efficient. Internal and external thermal insulation meaningfully decreases overall energy demands but provides different benefits regarding wall protection and mold formation, and the installation of thermal insulation is more suitable for outdoors. As expected, the heating energy demand is significantly reduced when external or internal insulation is applied. Once an insulation layer is installed, it prohibits the outer walls from cooling out during the night, in the case of non-insulation of the wall; indoor air and outdoor air have a high rate of intensive heat transfer, resulting in a significant decline in the temperature of the wall. This article presents the results of a study on increasing energy efficiency in collective residential buildings, as well as an analysis of the freezing point movement in the exterior wall structure when applying extra insulation on the outside surface of the wall.

Song et al. (2017) concluded that it is broadly recognized that global warming is highly probable due to the increased concentration of greenhouse gases due to human activities such as the use of fossil fuels and deforestation (IPCC, 2007). China's average surface temperature rises rapidly to 0.38°C per decade, well above the average global warming of the past 50 years. Mitigation and adaptation to climate change are possible methods of reducing the effects of global warming

(Kongsager et al., 2016). Mitigation of climate change aims at reducing greenhouse gas emissions and reducing global warming pressure. Energy consumption in buildings in China contributes about 30% of total greenhouse gas emissions, and hence climate change. At the same time, climate change will also affect overall energy consumption and greenhouse gas emissions in the residential sector. This study examined the potential impact of climate change on total energy consumption and related greenhouse gas emissions in housing in southern China. The potential pathways for existing and new residential buildings to adapt to climate change have been implemented. The results show that ambient temperatures in the 2020s, 2050s, and 2080s will increase by 0.82°C, 1.91°C and 3.41°C accordingly. Total energy use in heating and cooling is expected to grow from 3.5 and 5.5 stars of buildings by 25% and 20% respectively with global warming of 1.0°C. However, the use of energy-efficient appliances and retrofitting the house to 6.5 stars or higher are significant measures to maintain the same or lower level of the current level of total greenhouse gas emissions and energy consumption. Climate adaptations that focus on improving energy efficiency in Envelope Buildings, the application of renewable energy and the transition to low greenhouse gas emissions are desirable solutions.

Heidarinejad et al. (2017) suggested that improving energy efficiency in the building segment is the most effective strategy for mitigating the impact on the environment and adopting energy and electricity production to demand. Residential, commercial buildings represent 41% of the source energy in the United States. (Commercial Building Energy Consumption Survey (CBECS), 2012)) Commercial and residential buildings account for 9.9% and 5.4% of global GHG emissions, respectively (Shen, 2017). The United States accounts for 21% of global carbon dioxide emissions and 98% of US emissions from energy consumption (Atari et al., 2010). Recent studies have considered the severe side effects of carbon dioxide emissions on national economies because of climate change and global warming (Chang, 2015). If the warming trend continues during the next period, the average air temperature is expected to reach 1.3°C (Davies et al., 2010). This study analyzes the impact of Personalized Conditioning (PC) systems on potential savings of energy, carbon dioxide emissions, and cost of commercial buildings across the US cities. This analysis describes the potential benefits of deploying computer systems of PC during cooling times to peak shifting. PC systems implemented in coordination with central air conditioning systems in buildings can have a large-scale effect of portable PC systems that specifically use phase-change material (PCM) heat rejection, which allows the absorption of heat during the discharge of working heat during non-working hours, usually coinciding with off-peak (necessary) service rates when hours and the commercial building are generally vacant. However, there are limited energy factors for cost and the potential energy savings with the use of PC systems. Therefore, this study evaluates the use of PC systems in addition to the existing air conditioning system in buildings during cooling seasons. The evaluation involves potential energy savings in seven significant cities placed in different geographic climate zones of the US. Also, the study calculates potential cost savings based on differences in peak rates and the value of electricity at different times of local use (TOLU) program. This assessment provides the simulated of local utility programs and building systems the possibility of different regional being shown reducing energy footprint emissions in the city. The analysis shows the midrise apartments are a type of buildings better than office buildings to deploy PC systems during the cooling season. The cash savings per person for the deployments of the PC system midrise apartments are $62/year, $40/year, and $37 /year for Honolulu, NY City, and Phoenix, respectively. The simulation also presented that the use of the extended specific temperatures can reduce CO_2 emissions by up to 21.45 per year.

1.3.4. Optimization Analysis

Krarti et al. (2017) studied the benefits of large-scale energy efficiency programs for original and current buildings in Oman. In particular, the analysis of the energy productivity of these programs is carried out to include their overall impact on the economy of Oman. More than 75% of the total electricity consumed in Oman is allocated to buildings by 50% because of the household. First, a complete optimization analysis is performed using building energy simulation to determine the best energy efficiency measures suitable to develop the energy performance of buildings. The environmental and economic benefits of a range of energy efficiency technologies are then evaluated. In particular, the impacts of different levels of energy efficiency retrofit in existing buildings are estimates of energy productivity indicators for the building sector in Oman. The results of the analysis indicate that the imposition of a large-scale government-funded rehabilitation program for the existing residential building stock is very profitable. The result showed that a significant plan of massive energy efficiency change could reduce 957 GWh in annual electricity consumption also 214 MW well as more than 660,000 ton per year of carbon emissions. Also, a large-scale energy retrofit program for residential buildings can create significant employment in Oman up to 41,376 full-time job-years. More than 143,633 job-years are estimated if all the housing stock is redeveloped.

1.3.5. Building performance (structure, commercial & residential)

I .Integrated PV System Simulation to NZEB

Albadry et al. (2017) indicated that rising energy consumption and associated greenhouse gas emissions are among the world's most significant concerns recently. Total energy sold in Egypt for 2014 was about 120 terra watts per hour at a yearly growth rate of 5.2% (Eehc, 2015). The building sector alone - including all types of buildings - accounts more than 39% of total energy consumption and one-third of global greenhouse gas emissions, and figures are higher in Egypt, accounting for 51% of total energy sold in 2014. Existing residential buildings in Egypt suffer from low levels of insulation, which increases the energy consumed to achieve thermal comfort inside the building. One possible solution to this problem is to convert existing buildings into net-zero energy buildings (nZEB). The study suggested guidelines for following up on this outcome and the implementation of the instructions for the building of a case study in Cairo. The results of the study indicate that an existing residential building can be converted into an nZEB using the proposed guidelines. The cost analysis carried out in the study reveals the exact costs of the retrofit - using materials in the market - and the installation of PV panels that are considered cost-effective. The proposed renovation would reduce electricity consumption by 22,000 kilowatt-hours per year (kW/year), which would boost energy performance in the building as the first step to nZEB reach. The size of the PV system that will be used to transport the rest of the consumed electricity is 24 kW/year stations. After the retrofit, the annual electricity consumption reduced to 44,000 kWh instead of 66,000 kWh in the current case. These show the impact of the retrofit technologies used and provide a basis for the design of the PV system on which to work. Solar gains from external windows have decreased from 108 MW to 11 MW, which is almost the original value of about 10%, which justifies the significant reduction in electricity consumption as a result of increased insulation of the building. The amount of energy saved per 100 square meters of recycled glass reduced by energy-saving films and reduces the building's energy needs by up to 10,600 kWh per year, equivalent to reducing carbon dioxide emissions by about 9500 kg (IQue, 2015 & Films, 2015).

II. Microgrid Systems

Wu et al. (2016) found that in order to promote the low-carbon transformation of Shanghai's urban energy system, there is a need to re-examine the current energy supply system and to come up with new ideas and new methods for cities' energy carbon emissions. Application of the BCHP (Building Cooling Heating & Power) can provide powerful support for this transformation and the achievement of the long-term strategic objective (Hao et al., 2007 & Wang et al., 2013). Overall performance evaluation of BCHP systems will be under several designs, and organization options for residential buildings in Shanghai (GU Et Al., 2012). In this article, while considering the relationship between the BCHP system and the macro gird as well as its operating strategies, three scenarios were assumed for the evaluation of the technical potential of BCHP systems for commercial buildings located in Shanghai, China. According to the results, scenario 1 (grid connection with heat tracking mode), the largest application potential is in the sports building, followed by the hotel and the hospital, while store building faced the lowest application capacity of only 0.8 watts/m2. On the other hand, concerning optimum capacity with maximum energy saving ratio, under scenario 1, sports building has the greatest capacity, followed by the hotel and the hospital. However, as for energy saving, the hotel has the highest value of 19%, followed by the hospital (12.7%), while the corresponding value of the store building is only 0.52%. As for scenario 2, the sports building had the greatest potential, followed by theaters and hospitals. The hotel and hospital enjoy the maximum benefits of energy, which is 22% 16.1%, respectively. Moreover, for scenario 3, the optimum capacity of the sports building is still greater, followed by the theater and the office building. On the other hand, hotels and hospitals have the largest energy savings, 29%, and 21.9% respectively. Also, concerning the CO2 reduction rate, the hotel has the greatest benefits, at 42.3%, 47.6%, and 57.4%, respectively, of three scenarios. Under scenario 3, all buildings can enjoy the satisfactory environmental performance with the CO_2 reduction rate of more than 30%. The introduction of building cooling heating and power systems in commercial buildings in Shanghai for the assumed scenarios could reduce the annual carbon dioxide emissions of 8.9 million tons, 12.8 million tons and 15.1 million tons, respectively.

1.3.6 Energy simulation and multivariate regression

Zhao et al. (2017) found that in the past period, buildings become a large part of energy consumption and carbon emissions, the United States government and industry initiatives have stimulated green building technologies to improve energy efficiency in buildings. By 2025, the United States aims to decrease by more than 30% of energy use for air conditioning and water heating in residential buildings. However, in 2015 the commercial and residential buildings consume about 40%, $416 billion US dollars of the total US energy. Therefore, it is important for researchers to rethink the strategies adopted for years in the United States, with a strong focus on research and development of products and advanced building systems, and buildings provide a complex social and technical system that connects society (Gulbians et al., 2014). Nearly 90% of people live in a commercial or residential building. The connection between building performance, environment, and human behaviour could be noted from all around us (Keefe et al., 2014). This study presents an empirical study aimed at determining the association between building technology and resident behaviour and the combined impacts on energy consumption in residential buildings. The researchers collected behavioural and technical data from more than 300 residential units and using energy simulation and multivariate regression for analyzing the data that determined the results interaction between building and resident techniques. Behaviour, as well as quantitative evidence, supported the hypothesis that building technology and resident behaviours interact with each other and ultimately affect household energy consumption. The results point to four important resident behaviours that directly correlate to energy consumption, two of which indirectly linked to energy consumption, and that only 42 % of technological advances directly contribute to home energy efficiency, indicating that the possible effect on energy savings depends on both technical progress and behaviour. Also, the results indicate that technological advances in building systems contribute directly to 42% of energy efficiency. In other words, passenger habits have not been able to take advantage of more than 49% of the energy efficiency potential of a green building. This result explains, to a certain extent, the reason for the continued use of energy in buildings as it has been for years, given the technological advances in architectural, mechanical and electrical systems. From the systems perspective, the home is a small social and technical system Zhao et al., 2016) where energy savings require the collective efforts of humans, management, technology, and the environment. Thus, technical progress and plasticity behaviour have possible effects on energy efficiency in buildings.

1.3.7 Strategy and decision-making tools

Ahmed et al. (2017) stipulated that energy consumption provide a convenient and usable build environment accounts more than 34% of total GHG emissions and about 40% of total energy consumption in Europe (Directive 2010/31 / EU). With a large proportion of existing buildings constructed at a time when there are no effective energy-efficient components in the relevant building codes, most of the old buildings reach the end of their productive lives. Substantial environmental cost and impact will be needed to replace these buildings with new construction, accounting for about 1.5% of the building's stock each year (Baker, 2009). The goal of the project is to bring strategy and decision-making tools and advanced building fabric manufacturers to collaborate and progress building performance through low-impact rehabilitation interventions to decrease the energy consumption of the building order of 50%. This article aims to estimate the process of low energy renovation and the selection and estimation of low energy technologies for renovation. Specifically, the paper looks at the decision-making procedure for selecting advanced construction of buildings and technologies for high-performance energy retrofitting, using the fields of the University of Coventry as a case study. The article reviews innovative technologies and uses analytical methods to investigate the benefits of these potential technologies applied to obtain case study buildings at the University of Coventry. The interconnectivity of these buildings in the urban environment in which they installed also assessed. The results of Richard Crossman's modeling shows a significant decrease in total energy consumption for the entire buildings in the region by 49%, which corresponds to the initial goal of the 50% reduction project of the energy. The modeling shows an increase in electricity consumption in the retrofit system due to an increase in air conditioning in areas that were otherwise naturally ventilated. Although there is a slight increase in electricity consumption, this will offset by the 75 kW solar photovoltaic (PV) systems that integrated into the buildings. Also, the 3D model of the JL building refers to the location of the techniques installed on the facade of the building. Since the strategy in this building is to test the techniques in some parts of the structure, modeling also focuses on the performance of individual spaces that have technological interventions. There is no significant change in electricity consumption, but there is an 11.8% decrease in the boiler and natural gas consumption resulting in a total reduction of 10.58% and 9.67% for energy and carbon emissions respectively

1.4 Aim and Objective.

Many studies have worked on decreasing GHG emissions from the building segment by the adoption of two new building in Industrial Building System (IBS) structure categories. However, none of them considered the integration of LCA and Photovoltaic (PV) systems added to the Heating, Ventilation, and Air Conditioning (HVAC) systems and the impact on the load demand of the buildings. The primary objective of this research is to consider the different phases of life cycle assessment including carbon management of a PV system integrated residential building.

CHAPTER 2: METHODOLOGY

2.1 Flowchart of Study Methodology.

The methodology steps for this study are presented in the flowchart below.

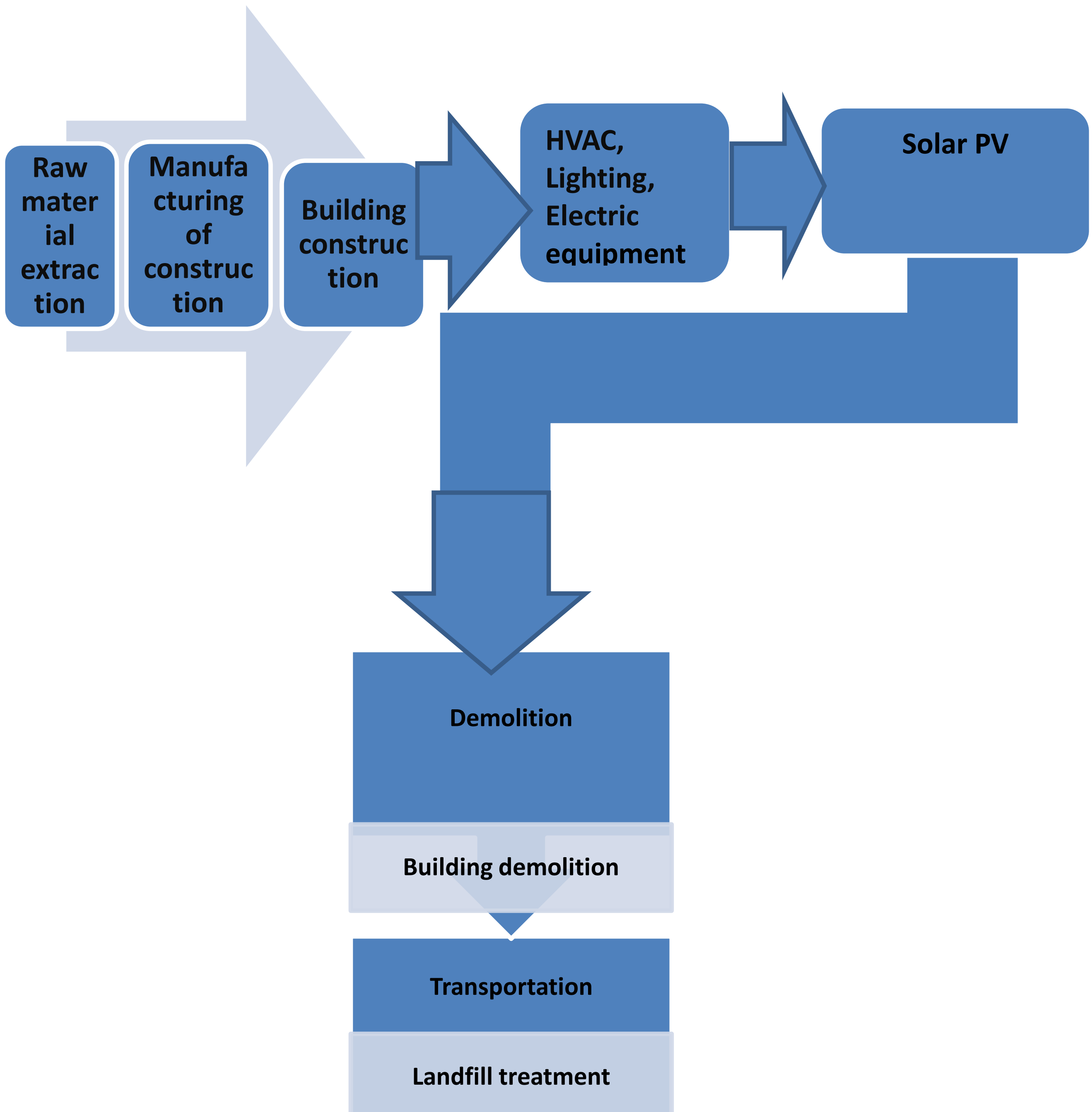


Figure 5: Flowchart of Study Methodology.

2.2 Simulation Steps

Three steps presented in this study:

1. Design geometry, spaces, and thermal zones in Sketch Up

The process of energy modeling begins with build geometry as Figures B1 and B2, space definition, and thermal zones. The Sketch Up software was used to model the building envelops. To create the envelope of the building, the Space Diagram tool was used to draw a floor plan. The surface matching tool was used to set boundary conditions after selecting the building envelope. The single thermostat used in a thermal zone where the thermal area represented an equal volume of air. It is important to note that the thermostat must be selected before running the EnergyPlus simulations with connected HVAC systems.

2. Simulate the building and calculate the energy load in EnergyPlus. After designing the geometry, space, and thermal zones in SketchUp, the Open Studio software was used to create the (IDF) file. To complete the building simulation and calculate the energy load, Energy Plus applied in three steps: the first step choose the IDF file as the input file and the second step choose the weather file for the building place. Finally, running to simulate the building to show the results select the text output file.

3. Calculate carbon emissions of the residential building through LCA and compare with the case of added PV systems, the carbon emissions of the residential building through LCA can be mathematically determined from the following:

From the view of LCA, energy consumption in the life cycle of a single residential building can be mathematically represented.

$$\mathbf{EW} = \sum_{i=1}^{5} \mathbf{Ei} \text{ (Gong \& Song, 2015)}$$

Where EW represents the life cycle energy consumption of a single residential building in

Toronto and Ei represents the energy consumption of the building sectors during the phase i of the life cycle.

CO2 “Ew¨K (Gong & Song,’ 2015)

Where EW¨is the building energy consumption from different phases of the life cycle building was calculated in EnergyPlus in the previous step.

K is the carbon emission coefficient. After getting the results from the above equation will compare the results with the case of added PV systems.

2.3 EnergyPlus Software.

2.3.1 Introduction

EnergyPlus is a program for energy analysis and thermal load.

User description of the building from the perspective of the physical installation of the building, the associated mechanical systems, etc. the heating and cooling loads, thermal control points, HVAC system, file loads, and power all of which can be calculated by using EnergyPlus. Also, the energy consumption of the essential plant equipment, as well as many other necessary simulation details, verify that the simulation performs as the actual building will work. Figures 6 and 7 illustrate the EnergyPlus structure.

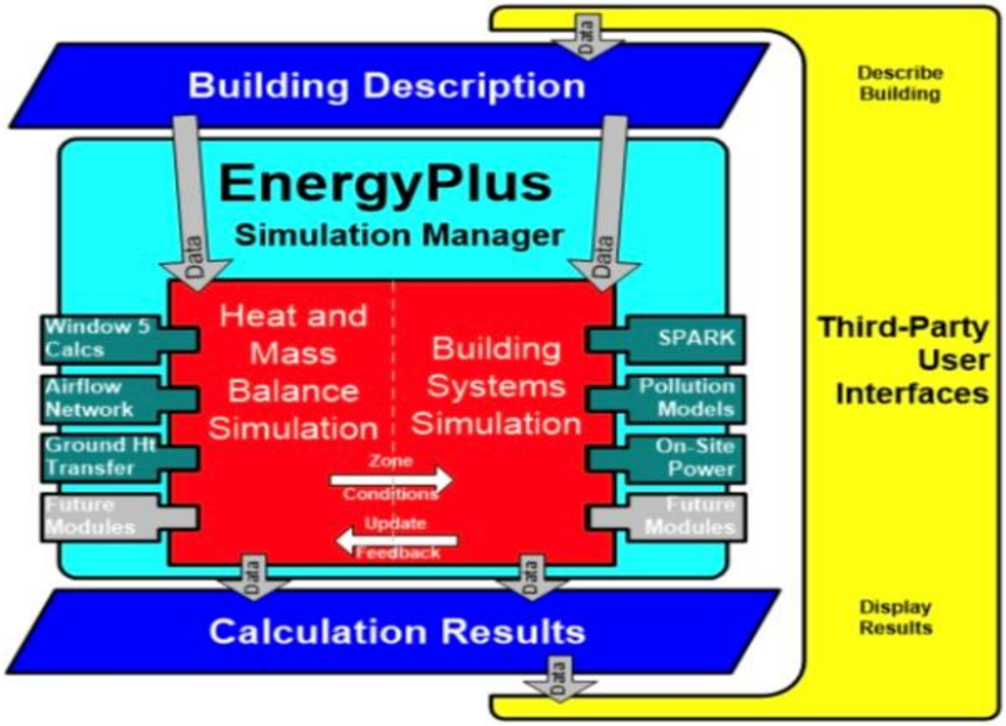


Figure 6: Energyplus Structure 1.

https://www.researchgate.net/figure/The-EnergyPlus-Structure-1_fig1_262725304

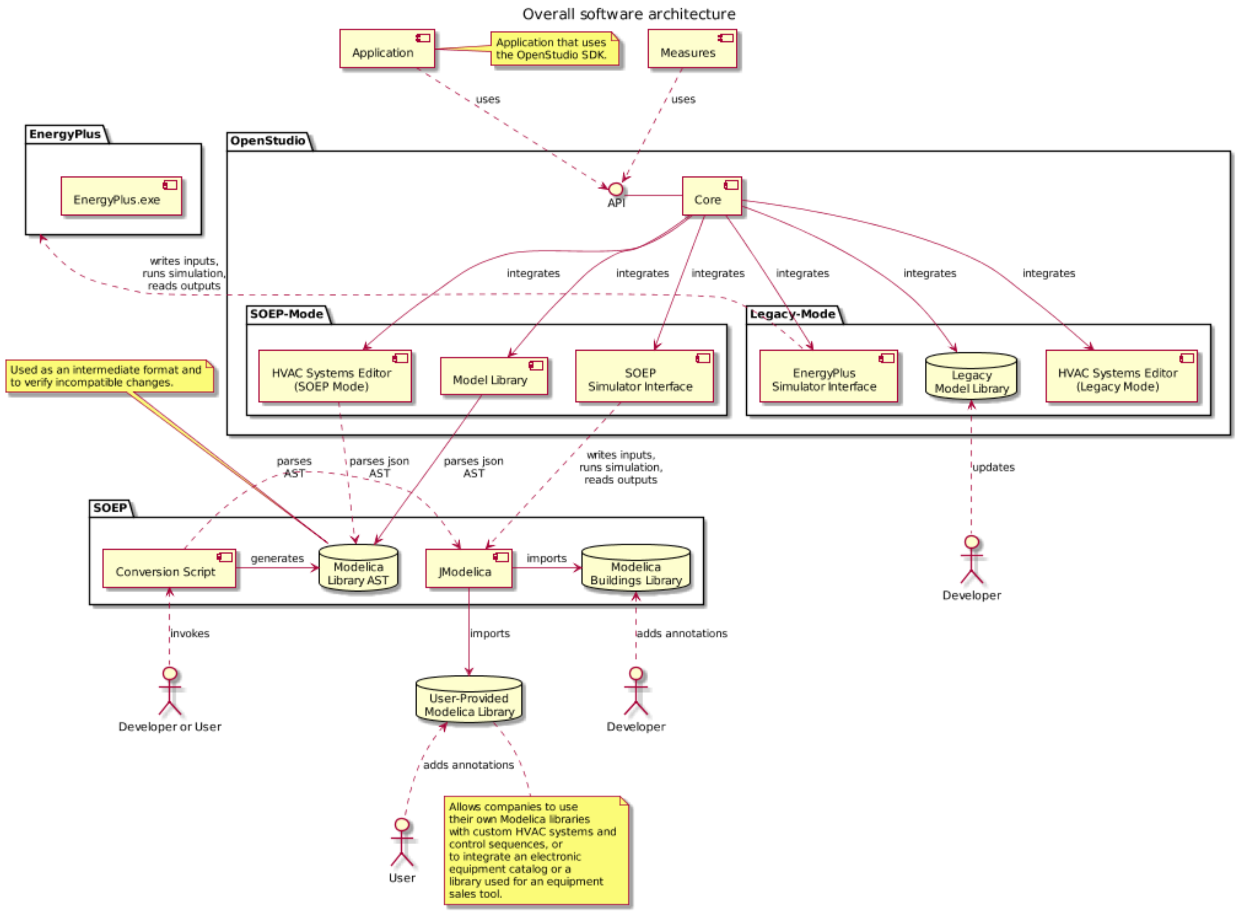


Figure 7**:** Energyplus Structure 2

https://www.researchgate.net/figure/The-EnergyPlus-Structure-1_fig1_262725304

2.3.2 EnergyPlus Tools

Here are a few simple tools helping you to get started with Energy Plus:

1. EP-Launch: It is a tool used to support the simulation running as figure A1 & A2.
2. IDF- Editor: it is a tool used to help create or look at input file as figure A3.
3. Simulation Results: It is a tool used to help to view the results as figure A4.

2.3.3 Other software with EnergyPlus.

1. SketchUp Software.

It is 3D molding software used to design different objects such as buildings. Architects widely use it. In this study, SketchUp was used to design the building envelope.

2. Open Studio Software.

The OpenStudio used as an interface of the EnergyPlus modeling software. In this study was used to create the (ID) input file.

2.4 Scenario

The four scenarios were used in this study.

1. Life Cycle Analysis of SRB: Business as Usual
2. Life Cycle Analysis of SRB Integrated with PV system (Low Efficiency)
3. Life Cycle Analysis of SRB Integrated with PV system (Medium Efficiency)
4. Life Cycle Analysis of SRB Integrated with PV system (High Efficiency)

CHAPTER 3: CASESTUDY

3.1 Building Information

The single residential building located at Toronto used in this study.

Single Residential Building (SRB)
Location: Toronto
Year of construction: 2008
Floor area: 200 m^2
Planned life time: 50 years
Height: 2.4 m
Number of floors: 1
Number of rooms: 5
Occupation: 2 Adults with 2 children

Table 1: Case Study Archetype Data

3.2. Performance **Compliance for Buildings** (this information were taken from Canadian Commission on Building and Fire Codes).

Building Type	Occupant Density (m^2/person)	Receptacle Power(W/m^2)	Service Water Heating (W-person)	Minimum O.A. ($L/s/m^2$)	Lighting Power Density (W/m^2)
Office	25	7.5	90	0.4	18
Restaurant	10	1	115	1.25	15
Retail	30	2.5	40	1.0	30

Mall/Concourse/ Altria	**30**	**2.5**	**40**	**1.0**	**16**
School	**8**	**5**	**60**	**1.0**	**19**
Service Establishment	**30**	**2.5**	**80**	**1.0**	**22**
Warehouse	**1500**	**1**	**300**	**1.0**	**6**
Hot/motel	**25**	**2.5**	**500**	**0.25**	**15**
Multifamily residential	**60**	**5**	**500**	**1.7**	**9**

Table 2: Building Type Categories

Space Function	**Occupant Density (m^2/ person)**	**Receptacle Power(W/m^2)**	**Service Water Heating (W-person)**	**Minimum O.A. ($L/s/m^2$)**	**Lighting Power Density (W/m^2)**
Office					
Category 1: enclosed office, all open plans without partitions.	**20**	**7.5**	**90**	**0.5**	**19.4**
Category 2: open plan office larger with partitions	**20**	**7.5**	**90**	**0.5**	**20.4**

Computer/ Office Equipment	**20**	**7.5**	**90**	**0.5**	**22.6**
Laundry					
Washing	**20**	**20**	**60**	**0.6**	**9.7**
Ironing and Sorting	**20**	**20**	**60**	**0.5**	**14.0**

Table 3: Space Function

CHAPTER 4: RESULTS

4.1: Weather Variables and Effects on Energy Consumption

The energy consumption of a single residential building was affected by many weather variables.

1. Temperature: the changes in atmospheric temperature lead to using more or less HVAC. Also, using low or high energy convention and infiltration lead to using more or less electronic equipment through the building.

2. Humidity: the humidity in the atmosphere affected the energy consumption of building as well. It leads to using more or less HVAC and using low or high energy convention and infiltration lead to using more or less electronic equipment through the building.

3. Solar irradiance: the changes in radiant amount produced lead to more or less energy through the windows, where the windows are low or high radiation energy. These gains can affect HVAC and electronic equipment; in this case, the solar plan has to be concerned too.

4. Sunshine duration: the changes in sunlight produced an amount in specific time affected the energy consumption of the building as well. It leads more or less energy through the windows, where the windows are low or high radiation energy. These gains can affect the HVAC and electronic equipment; in this case, the solar plan has to be concerned too.

5. Sky conditions: when the sky is overcast with possibilities of rain, this can increase/decrease the energy when the use of internal lightning may be required. Also, the energy coming from solar energy plates can be significantly affected.

6. Precipitation: snow and rain lead to using more or less of HVAC and electronic equipment due to moisture on external surfaces is low or high power connection.

4.2 Energy Consumption and CO_2 Emissions.

The second section in this study quantifies the energy consumption and CO_2 emission by considering different sources of energy as pointed in the table below.

Energy Source	**Unit**	**Energy Consumption**	**CO_2 Factor (Kg- co_2/Unit)**	**CO_2 emission (Kg- co_2)**
Propane	**Kg**	**10.8**	**2.890**	**1,248**
City Gas	**Nm^3**	**275**	**2.200**	**24,510**
Electricity	**Kwh**	**7600**	**0.495**	**150,440**
Heat Energy	**Mcal**	**18,800**	**0.213**	**161,200**
Hot Water	**Mcal**	**150**	**0.213**	**1,280**
Total				**338,678**

Table 4: Energy Consumption and CO_2 Emission by Considering Different Sources of Energy.

The results in this section show that the heat energy consumes about 18,800 Mcal of energy. This amount of energy consumption considered as the most significant amount of energy compared to other energy sources. On other hand, when using the propane as an energy source, the energy consumption was 10.8 kg. This amount represents the lowest value of energy consumption compared to other energy sources. Much energy consumption leads to increased CO_2 emissions. Where the heat energy caused about 161,200 Kg of CO_2, that represents the largest amount of CO_2 emissions compared to other sources of energy. Besides, propane represents the lowest amount of CO_2 emissions compared to other sources of energy around 1,248 Kg of CO_2. However, the total results of CO_2 emission for all energy sources of S RB was 338,674.3 Kg of CO_2.

Annual CO_2 Emissions

The third section in this study quantifies the annual CO_2 emissions by considering the occupants and the energy impacts of some electronic equipment and some places of SRB as pointed in the table below.

Energy impacts	CO_2 emission (kg)
Thermal control	600
Hot water	2,550
Refrigeration	900
Lighting	800
Kitchen	606
Laundry & bathroom	550
Entertainment	1,500
Car park Ventilation	510

Table5: Annual CO_2 Emission by Considering the Occupants.

The results in this section reveal that hot water uses a significant amount of electricity compared to other equipment in the building, and this leads to increasing carbon dioxide emissions that cause around 2,550 kg of CO_2 emissions each year. Also, car park ventilation represents the lowest amount of CO_2 emissions each year compared to other impact energy sources about 510 kg of CO_2 emissions. The range of the rest of the impact source emission was between 550 - 1,500 kg of CO_2 emission.

4.4 Life Cycle Energy Analysis.

The last section in this study quantifies life cycle energy analysis considering use and cost and life cycle renewable energy analysis as pointed in the tables below.

Life Cycle Electricity Use	**102,453 kWh**
Life Cycle Fuel Use	**327,793 MJ**
Life Cycle Energy Use	**$ 8,316**
30-year life and 5.5% discount rate for costs	

Table 6: Life Cycle Energy Analysis (Use/Cost)

Integrated PV System (Low Efficiency)	**10,644 kWh/yr**
Integrated PV System (Medium Efficiency)	**21,288 kWh/yr**
Integrated PV System (High Efficiency)	**31,932 kWh/yr**

Table 7: Life Cycle Renewable Energy Analysis

The results of the life cycle energy analysis considering the use and cost show that the electricity consumption was about 102,453 kWh, fuel consumption approximately 327,793 MJ, and their costs are significantly lower. The discount rate for costs was 5.5%. However, the results of life cycle renewable energy analysis using PV system shows that the amount of energy consumption of integrated PV system (Low Efficiency), (Medium Efficiency), (High Efficiency) was 10,644 kWh/yr, 21,288 kWh/yr, 31,932 kWh/yr respectively. As a result of these, there would be a significant reduction in operating cost, energy cost, and CO_2 emissions. However, the capital cost would increase by integrating PV systems, but it would be less significant by a higher carbon tax in the future.

CHAPTER 5: CONCLUSION

In this study, the different phases of life cycle energy and CO_2 analysis of a PV system integrated residential building considered. We used the signal residential building located in Toronto in this study. EnergyPlus, SketchUp, and Open Studio were the software programs utilized for modeling the building. The benefit of this study is reduced energy consumption, higher energy efficiency and environmental benefits of CO_2 emission reduction. The life cycle analysis is an effective method to reduce energy consumption and CO_2 emissions.

The results show that the energy consumption of the single residential building was affected by many weather variables. High and low temperature and humidity in the air affect HVAC system usage, which affects energy consumption and related CO_2 emission levels. Besides, carbon dioxide emissions from space heating HVAC systems for a single residential building is higher than business as the usual electricity generation system. Moreover, hot water uses the largest amount of energy compared to other energy sources in SRB, which leads to increased carbon dioxide emissions. On other hand, propane water uses the lowest amount of energy compared to other energy sources in SRB, and it represents the smallest amount of CO_2 emissions compared to other sources.

In addition, the results quantify the annual CO_2 emissions by considering the occupants, the energy impacts of specific electronic equipment and some places of SRB pointed that car park ventilation represents the lowest amount of CO_2 emissions annually compared to other impact energy sources; hot water uses a significant amount of electricity compared to other equipment in the building, and this leads to increasing carbon dioxide emissions each year.

Finally, the results of the life cycle energy analysis show that there would be a significant reduction in operating cost, energy cost, and CO_2 emissions. However, the capital cost would increase by integrating PV systems, but it would be less significant than higher future carbon taxes.

REFRENCES

Krarti, M., & Dubey, K. (2017). Energy productivity evaluation of large scale building energy. efficiency programs for Oman. *Sustainable Cities and Society*, *29*, 12-22

Wu, Q., Ren, H., Zhou, J., Liu, S., & Yang, X. (2016). Feasibility and Potential Assessment of BCHP Systems for Commercial Buildings in Shanghai. *Energy Procedia*, *104*, 251-256.

75441 Paris CEDEX 09, France

Abdelaziz, E.A., Saidur, R., Mekhilef, S., 2011. A review on energy saving strategies in industrial sector. Renew. Sustain. Energy Rev. 15 (1), 150–168.i

Adityaa L, Mahliaa TMI, Rismanchic B, Nge HM, Hasane MH, Metselaare HSC, Oki M, Aditiyab HB. A review on insulation materials for energy conservation in buildings. Renewable and Sustainable Energy Reviews 2017; 73:1352–1365.

Ahmed, A., Mateo-Garcia, M., McGough, D., & Gaterell, M. (2017). Methodology for Evaluating Innovative Technologies for Low-Energy Retrofitting of Public Buildings. *Energy Procedia*, *112*, 166-175.

Albadry, S., Tarabieh, K., & Sewilam, H. (2017). Achieving Net Zero-Energy Buildings through Retrofitting Existing Residential Buildings Using PV Panels. *Energy Procedia*, *115*, 195-204.

Arvind Chel. G.N. Tiwari, Thermal performance and embodied energy analysis of a passive house case study of vault roof mud-house in India. Appl. Energy 8 (10) (2009) 1956-1969

Attari, Sz., DeKay, M.L, Davidson, CL, Bruine de Bruin, W. 2010. Public perceptions of energy consumption and savings. Proc. Natl. Acad. Sci. 107 (37) 16054-16059.

Arvizu, D., Balaya, P., Cabeza, L., Hollands, T., Jaeger-Waldau, A., Kondo, M., Konseibo, M., Meleshko, W., Stein, W., Tamaura, Y., Xu, H., Zilles, R., 2011. Direct Solar Energy, in: Special Report on Renewable Energy Sources and Climate Change Mitigation. Intergovernmental Panel on Climate Change (IPCC).

Baker NV. Handbook of Sustainable Refurbishment – Non Domestic Buildings. London: Earthscan; 2009.

Balasbaneh, A. T., & Marsono, A. K. B. (2017). Strategies for reducing greenhouse gas emissions from residential sector by proposing new building structures in hot and humid climatic conditions. *Building and Environment*, *124*, 357-368. *Buildings*, *154*, 1-11.

Bayer, C., Gamble, M., Gentry, R., & Joshi, S. (2010). AIA guide to building life cycle assessment in practice. *The American Institute of Architects*, *Washington DC*.

Canadian Commission on Building and Fire Codes, Performance Compliance for Building available on the internet http://nparc.nrc-cnrc.gc.ca/eng/view/fulltext/?id=b3c55fee-db1a-4ad3-adad-884209387011

Chang, M. C. 2015. Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves, Clean. Prod. 99, 140-151.

Chel, A., & Kaushik, G. (2017). Renewable energy technologies for sustainable development of energy efficient building. *Alexandria Engineering Journal*.

Commercial Building Consumption Survey (cBECs), 2012. us. Energy In- formation Administration (EIA), eia.gov/consumption/commercial

D. L. Loveday K.C. Parsons. A H. Taki, S.G. Hodder Displacement ventilation environments with chilled ceilings: thermal comfort design within the context of the BS EN ISO7730 versus adaptive debate, Energy Build. 34 (6) (2002) 573 579

D. Trigaux, K.Allaker, F. De Troyer, Model for the environmental impact assessment of neighbourhoods, 2014, http://dx doi, org/ 10.2495/eid140091

D. Zhao, A.P. McCoy, B.M. Kleiner, TL. Smith-Jackson, Sociotechnical systems of fatal electrical injuries in the construction industry, .Constr. Eng. Manage. 142 (1) (2016) 04015056 http://dx.doi.org/10.1061/(asce)co. 1943- 7862.0001036

Davis, SJ, Caldeira, K., Matthews, H.D.. 2010. Future CO2 emissions and climate change from existing energy infrastructure. Science 329 (5997) 1330.

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of buildings. Available on the internet: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

DOE, 2011. 2010 Buildings Energy Data Book. US Department of Energy.

DTIE, Sustainable Consumption & Production Branch, 2009, 15 Rue de Milan,

Eehc, "Annual Report 2013/2014." p. 56, 2015.

EIA, 2011. 2010 Annual Energy Review. U.S. Energy Information Administration.

Fortuna S, Mora TD, Peron F, Romagnoni P. Environmental Performances of a Timber-concrete Prefabricated Composite Wall System.Energy Procedia 2017;113:90–97.

Frankl, P., Masini, A., Gamberale, M., & Toccaceli, D. (1998). Simplified life-cycle analysis of PV systems in buildings: present situation and future trends. *Progress in Photovoltaics Research and Applications*, *6*(2), 137-146.

Fthenakis, V., Kim, H.C., Frishknecht, R., Raugei, M., Sinha, P., and Stucki, M. (2011b). Life

Cycle Inventories and Life Cycle Assessment of Photovoltaic Systems, PVPS Task 12, Report T12-02.(St-Ursen, Switzerland: International Energy Agency Photovoltaic Power Systems Program).

Gong, Y., & Song, D. (2015). Life Cycle building carbon emissions assessment and driving factors decomposition analysis based on LMDI—A case study of Wuhan City in China. *Sustainability*, *7*(12), 16670-16686.

Gu, Q., Ren, H., Gao, W., & Ren, J. (2012). Integrated assessment of combined cooling heating and power systems under different design and management options for residential buildings in Shanghai. *Energy and Buildings*, *51*, 143-152.

H.S. Fink, Promoting behavioral change towards lower energy consumption in the building sector, Eur. J. Soc. Sci. Res. 24 (1– 2) (2011) 7–26.

Hao x, hang G. Chen Y. Role of BCHP in energy and environmental sustainable development and its prospects in China. Renewable and Sustainable Energy Reviews 2007: 11(8): 1827-1842

Heidarinejad, M., Dalgo, D. A., Mattise, N. W., & Srebric, J. (2017). Personalized cooling as an energy efficiency technology for city energy footprint reduction. *Journal of Cleaner Production*

Hu, F., & Zheng, X. (2015). Carbon Emission of Energy Efficient Residential Building. *ProcediaEngineering*,*121*,10961102.IQue,“ttp://www.iquefilms.com/iQueProfile.aspx,”0 15.[Online].Available:http://www.iquefilms.com/iQueProfile.aspx. [Accessed: 01- Jan-2015].

International Energy Agency (IEA). (2009). Photovoltaic Power Systems Program (PVPS) Annual Report 2009 (St-Ursen, Switzerland: International Energy Agency Photovoltaic

Power Systems Program) http://iea-pvps.org/index.php?id=6 (accessed January10, 2012).

IPCC (Intergovernmental Panel on Climate Change). Climate change 2007: the physical science basis. Available from: http://www.ipcc.ch/publications

Jan Burck, Christoph Bals, Kathy Bohnenberge, The Climate Change Perfor- Kass K,Blumberga. A, Blumberga D, Zogla G, Kamenders A, Kamendere E. Pre-assessment Method for Historic Building Stock Renovation Evaluation. Energy Procedia 2017; 113:346–353

Jordan Palmeri, a Life Cycle Approach to Waste Prevention from the Oregon Residential Construction Sector. Available from: https: //www.slideshare.net/ORDEQ/a-life-cycle-approach-to-waste-prevention-from-the-oregon-residential-construction-sector (accessed August 16, 2012)

Kessel, D.G., 2000. Global warming—facts, assessment: countermeasures. J. Petrol. Sci. Eng. 26, 157–168. Vali, A., Simonson, C., Besant, R., Mahmood, G., 2009. Numerical model and effectiveness correlations for a run-around heat recovery system with combined counter and cross flow exchangers. Int. J. Heat Mass Transfer 52, 5827–5840.

Van Aalst, M.K., 2006. The impacts of climate change on the risk of natural disasters. Disasters 30 (1), 5–18.

Kim, J. J. (2017). Economic analysis on energy saving technologies for complex manufacturing building. *Resources, Conservation and Recycling*, *123*, 249-254.

Kongsager R, Locatelli B, Chazarin F. Addressing Climate Change Mitigation and Adaptation Together: A Global Assessment of Agriculture and Forestry Projects. Environmental Management 2016; 57(2); 271-282.

Kozminski, K., Lewis, S., Mathew, P., 2006. Efficient Electric Lighting in Laboratories. Laboratories for the 21st century best practice guide.

Krarti, M., Dubey, K., & Howarth, N. (2017). Evaluation of building energy efficiency investment options for the Kingdom of Saudi Arabia. *Energy*, *134*(C), 595-610.

Lotteau, M., Loubet, P., & Sonnemann, G. (2017). An analysis to understand how the shape of a concrete residential building influences its embodied energy and embodied carbon. *Energy*

M. Keefe, A. McCoy, D.Sanderford, D. Zhao, Adoption patterns of energy efficient housing technologies 2000-2010: builders as innovators, in: 2nd Annual Residential Building Design and Construction Conference (RBDCC Bethlehem, PA, 2014

M. Lotteau, P. Loubet. M. Pousse, E. Dufrasnes. G. Sonnemann, Critical of life cycle assessment (LCA) for the built environment at the neighborhood scale, Build, Environ. 93 (2015) 165-178, http://dx.doi.org/10.1016li buildenv 2015.06.029. mance Index Results, 2015. www.germanwatch.org..

Miezis M, Zvaigznitis K, Stancioff N, Soeftestad L. Climate Change and Buildings Energy Efficiency – the Key Role of Residents. Environmental and Climate Technologies 2016;17:30–43.

Mitchell J. Mitchell B. Paris Mismatches: the impact of the cop21 change negotiations on the oil and gas industries. Research Paper. London. UK: Chatham House: 2016.

N. Zografakis, Technologies for rational use and savings of energy in buildings. Energy 62 (November December) 2000) 112-114 (in Greek).

N.A. Aldossary, Y. Rezgui, A. Kwan, Domestic energy consumption patterns in a hot and humid climate: A multiple- case study analysis, Appl. Energ. 114 (2014) 353–365.

Perez JS, Rives JB, Gabarrell X. Environmental assessment of façade-building systems and thermal insulation materials for different climatic conditions. Journal of Cleaner Production 2016;113:102–113.

R. Gulbinas, J.E. Taylor, Effects of real-time eco-feedback and organizational network dynamics on energy efficient behavior in commercial buildings, Energy 493-500.

Radwan, A. F., Hanafy, A. A., Elhelw, M., & El-Sayed, A. E. H. A. (2016). Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt. *Alexandria Engineering Journal*, *55*(4), 3061-3071.

Ragheb, A. F. (2011). Towards Environmental Profiling for Office Buildings Using Life Cycle Assessment (LCA).

S. Yannas. Solar Energy and Housing Design, Principles Objectives. Guidelines, vol I, Architectural Association, London, 1994.

Santamaraa J, Campano MA, Giron S. Method for the economic profitability of energy rehabilitation operations: Application to residential dwellings in Seville. Procedia Computer Science 2016;83:742–749.

Schuchardt GK. Integration of Decentralized Thermal Storages Within District Heating (DH) Networks. Environmental and Climate Technologies 2016;18:5–16.

Sector profile for solar photovoltaic https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/2012-063-eng.pd

Sheen, P, 2017. Impacts of climate change on building energy use by using downscaled hourly future weather data. Energ Build. 134, 61-70.

Simona, P. L., Spiru, P., & Ion, I. V. (2017). Increasing the energy efficiency of buildings by thermal insulation. *Energy Procedia*, *128*, 393-399.

Song, X., & Ye, C. (2017). Climate Change Adaptation Pathways for Residential Buildings in Southern China. *Energy Procedia*, *105*, 3062-3067.

Tabrizi TB, Hill G, Aitchison M. The impact of different insulation options on the life cycle energy demands of a hypothetical residential building. Procedia Engineering 2017;180:128–135.

UNEP, Buildings and Climate Change e Summary for Decision- Makers, UNEP

UN-Habitat, World Cities Report 2016, Urbanization and Development-Emerging Futures, 2016 http://wcr.unhabitat.org/wp-content/ uploads/2017102/WCR-2016 Full-Report.pdf.

US El. Administration, International Energy outlook 2016, 2016, DOE/EIA-0484 (2014)

European Commission, Roadmap to a Ressource Efficient Europe, 2011

Us. Energy Information Administration, Electricity Data, 2016 (May 20) (2016)

Vandeligt, K., Pelland, S., & Poissant, Y. (2012). Assessment of the Environmental Performance of Solar Photovoltaic Technologies. *Environment Canada*.

W. Feist, J. Schnieders, V. Dor A. Haas, Reinventing air heating convenient and comfortable within the frame of the Passive House concept, Energy Build. 37 (1) (2005) 1186 1203

W. Films, "Energy costs," p. 313, 2015.

Wang J. Fu C. Yang K, Zhang x, Shi G, zhai J. Reliability and availa analysis of redundant 540 BCHP (building cooling, heating and power) system. Energy 2013: 61: 531-

Wang, W., Chen, J., Huang, G., & Lu, Y. (2017). Energy efficient HVAC control for an IPS-enabled large space in commercial buildings through dynamic spatial occupancy distribution. *Applied Energy*.

Williams, A. S. (2009). Life Cycle Analysis (LCA). TN Series (Illinois Sustainable Technology Center); 13098.

Zhao, D., McCoy, A. P., Du, J., Agee, P., & Lu, Y. (2017). Interaction effects of building technology and resident behavior on energy consumption in residential buildings. *Energy and Buildings*, *134*, 223-23

APPENDIX A. EnergyPlus Tools

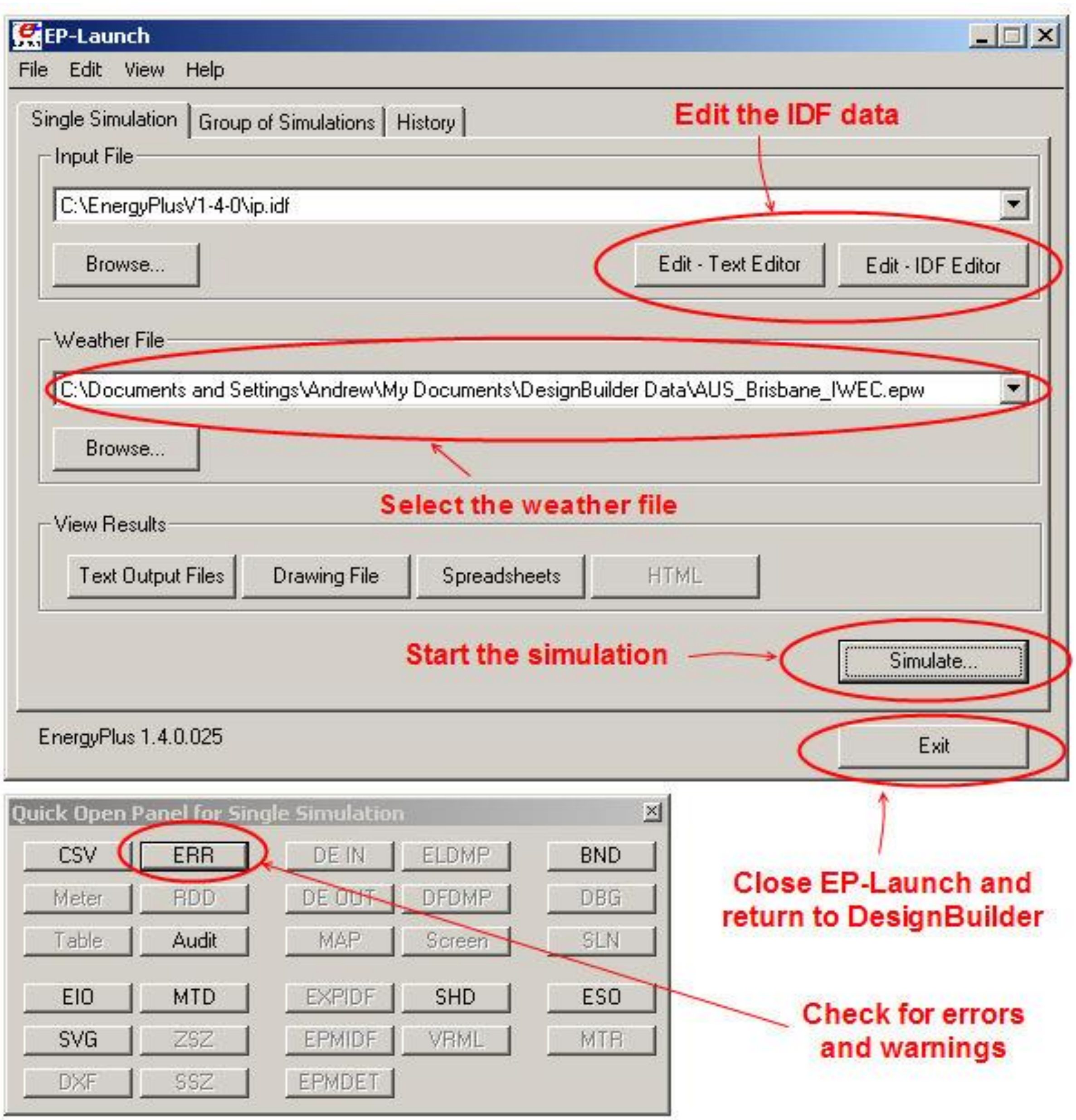


Figure A1: EP -lunch Tool

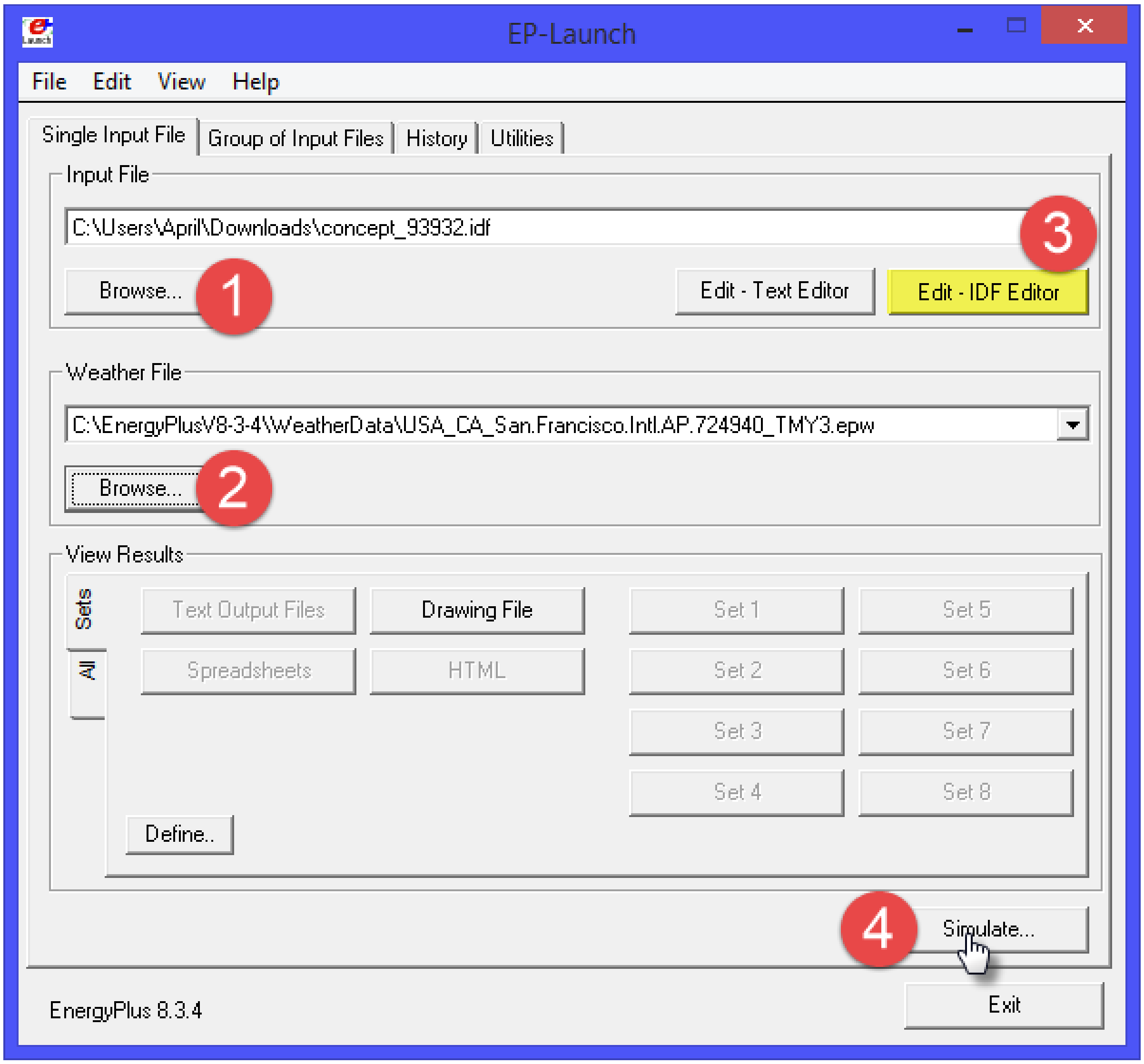


Figure A 2: EP –lunch Simulation Steps

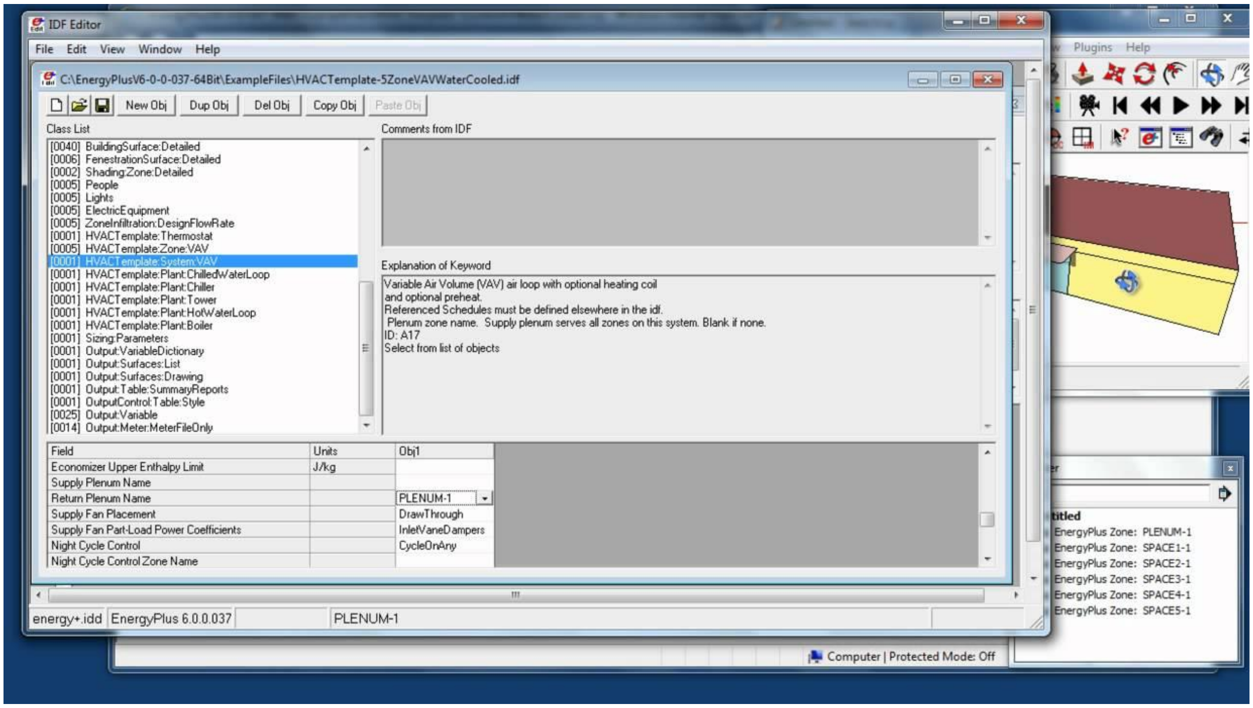
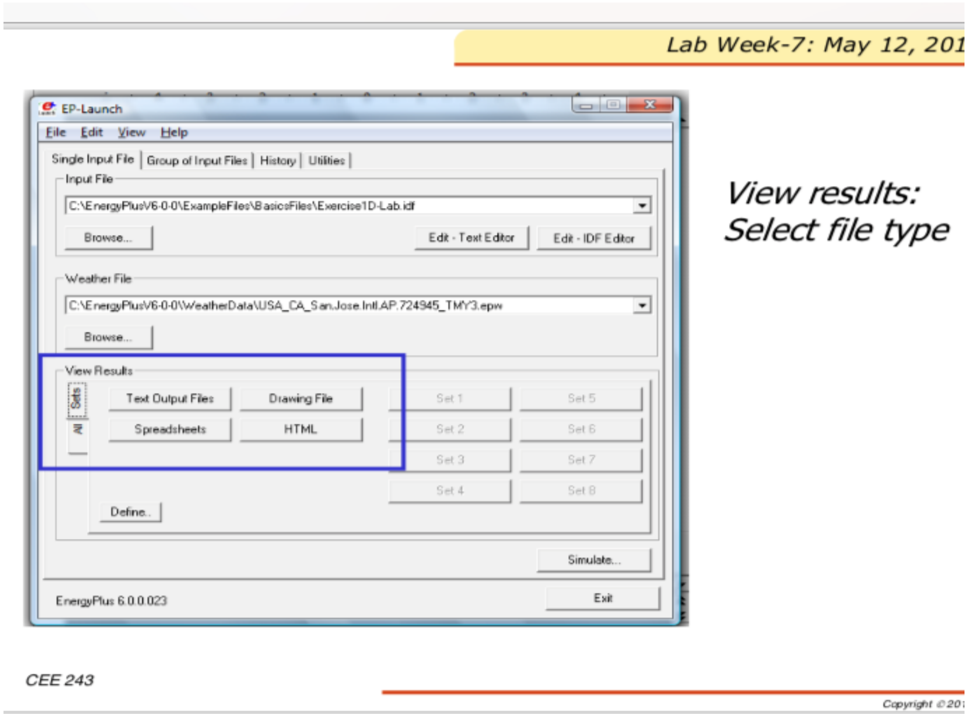
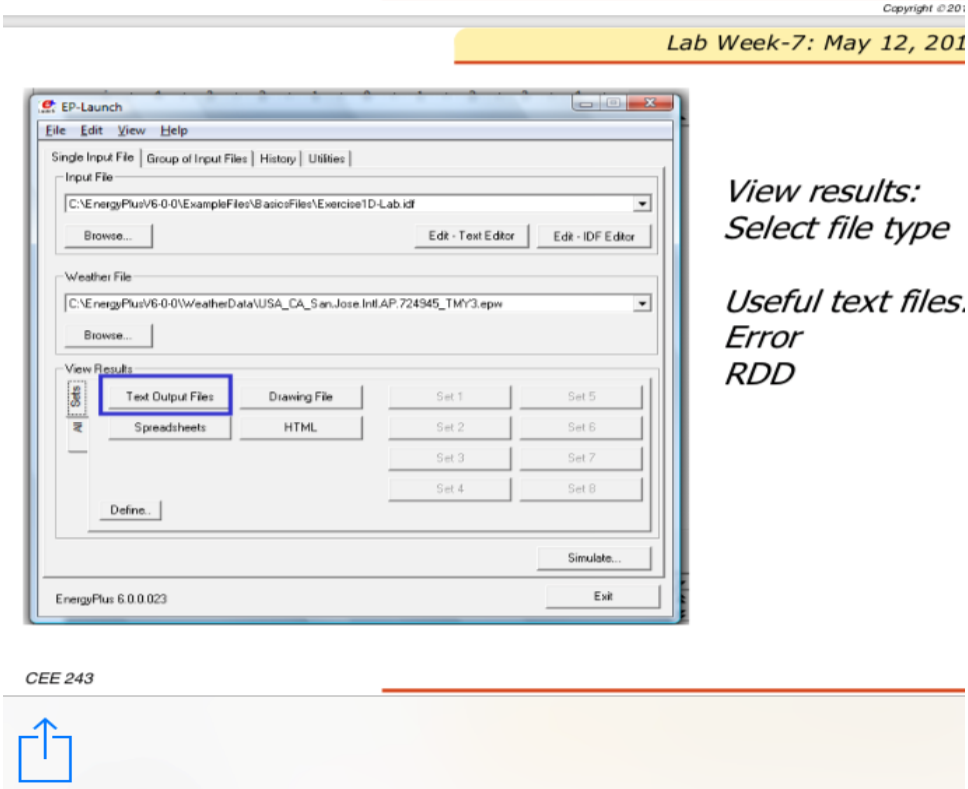


Figure A3: IDF-Editor





Figurer A4: View Results Tool

APPENDIX B. Building Geometry

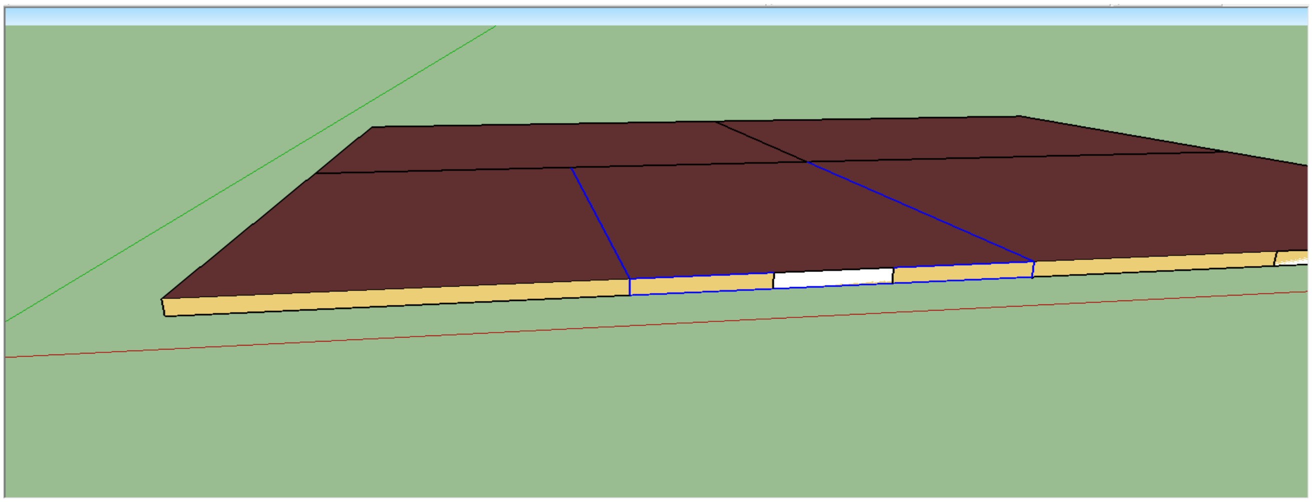


Figure B1: Building Geometry 1

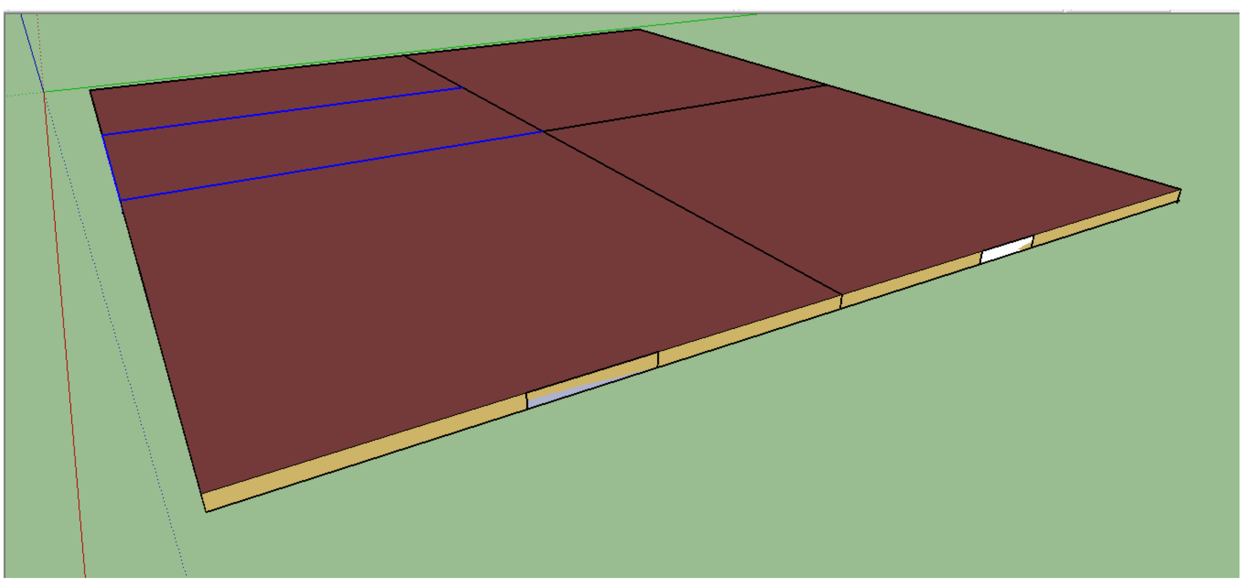


Figure B2: Building Geometry 2

APPENDIX C. Number Exchange Rate

Sauder School of Business
PACIFIC Exchange Rate Service

unch. | -0.2% | -0.1% | +0.2% | +0.2%

click on image for detailed information

Today's Exchange Rates: Tuesday, July 24, 2018

Code	Currency	fcu/CAD	CAD/fcu	fcu/USD	USD/fcu	fcu/EUR	EUR/fcu
AUD	Australian Dollars	1.0249	0.9757	1.3485	0.7416	1.5766	0.6343
BRL	Brazilian Reals	2.8490	0.3510	3.7484	0.2668	4.3826	0.2282
GBP	British Pounds	0.5785	1.7285	0.7612	1.3138	0.8900	1.1236
BGN	Bulgarian Lev*	1.2706	0.7870	1.6708	0.5985	1.9558	0.5113
CAD	Canadian Dollars	1.0000	1.0000	1.3157	0.7601	1.5383	0.6501
CNY	Chinese Renminbi	5.1626	0.1937	6.7925	0.1472	7.9417	0.1259
HRK	Croatian Kuna*	4.8058	0.2081	6.3194	0.1582	7.3975	0.1352
CZK	Czech Koruna*	16.736	0.0598	22.007	0.0454	25.761	0.0388
DKK	Danish Kroner*	4.8401	0.2066	6.3646	0.1571	7.4504	0.1342
EUR	European Euros	0.6501	1.5383	0.8553	1.1692	1.0000	1.0000
HKD	Hong Kong Dollars	5.9630	0.1677	7.8456	0.1275	9.1729	0.1090
HUF	Hungarian Forint*	212.20	0.0047	279.04	0.0036	326.64	0.0031
INR	Indian Rupees	52.411	0.0191	68.957	0.0145	80.624	0.0124
IDR	Indonesian Rupiah	10989	—	14458	—	16904	—
ILS	Israeli New Shekels*	2.7746	0.3604	3.6485	0.2741	4.2709	0.2341
JPY	Japanese Yen	84.460	0.0118	111.12	0.0090	129.92	0.0077
MYR	Malaysian Ringgit	3.0902	0.3236	4.0658	0.2460	4.7537	0.2104
MXN	Mexican Pesos	14.341	0.0697	18.868	0.0530	22.061	0.0453
NZD	New Zealand Dollars	1.1172	0.8951	1.4699	0.6803	1.7186	0.5819
NOK	Norwegian Kroner	6.2112	0.1610	8.1720	0.1224	9.5547	0.1047
PEN	Peruvian New Soles	2.4894	0.4017	3.2753	0.3053	3.8295	0.2611
PHP	Philippines Pesos*	40.516	0.0247	53.277	0.0188	62.366	0.0160
PLN	Polish Zloty*	2.8051	0.3565	3.6886	0.2711	4.3179	0.2316
RON	Romanian Leu*	3.0142	0.3318	3.9636	0.2523	4.6398	0.2155
RUB	Russian Rubles	47.847	0.0209	62.952	0.0159	73.603	0.0136
SGD	Singapore Dollars	1.0366	0.9647	1.3638	0.7332	1.5946	0.6271
ZAR	South African Rand	10.120	0.0988	13.315	0.0751	15.568	0.0642
KRW	South Korean Won	856.90	—	1127.4	—	1318.2	—
XDR	Special Drawing Rights	0.5412	1.8478	0.7120	1.4044	0.8325	1.2012
SEK	Swedish Krona	6.7069	0.1491	8.8243	0.1133	10.317	0.0969
CHF	Swiss Francs	0.7553	1.3240	0.9937	1.0063	1.1619	0.8607
TWD	Taiwanese Dollars	23.272	0.0430	30.619	0.0327	35.799	0.0279
THB	Thai Baht	25.361	0.0394	33.368	0.0300	39.013	0.0256
TRY	Turkish New Lira	3.7106	0.2695	4.8820	0.2048	5.7080	0.1752
USD	U.S. Dollars	0.7601	1.3157	1.0000	1.0000	1.1692	0.8553

http://fx.sauder.ubc.ca/today.html