Decision Support System for Value-Based Evaluation and Conditional Approval of Construction Submittals

by

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Author's Declaration

I hereby declare that I'm 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

To ensure compliance with specifications during construction, a formal review process, called the submittals process is typically implemented, whereby the contractor is required to submit proposals for materials, equipment, and processes for the owner's approval within a short period of time. This procedure can be a difficult task because of lack of time, lack of information in the submittal package, difficulty in retrieving related data, and lack of defined criteria for evaluation. This research introduces development of a framework for submittal evaluation that considers the operational impact of any minor variation in the required specifications. The evaluation mechanism uses the Multi-Attribute Utility Theory (MAUT) approach, which is adaptable to the varying requirements of organizations.

Through the process of analyzing the current submittal mechanism, a list of key submittals is defined and the top one (chiller) is selected to be the focus of the research. The governing criteria (evaluation parameters) are defined for the selected submittal item and categorized into two categories: inflexible and flexible. The inflexible parameters have been dealt with using checklists with predefined threshold that must be met without tolerance. Flexible parameters have been analyzed using utility functions that represent decision maker preferences and tolerance levels. Accordingly, the evaluation process considers multi-parameters to determine an overall utility for the submittal and the value-based condition for accepting it, incorporating LEED requirements. The investigation is based on data provided by three main organizations, as well as intensive meetings and interviews with experts from each participating organization. The outcome of this investigation is the development of evaluation criteria and checklist parameters that are used as the basis of a value-based evaluation, which is the core of the developed decision support system.

In summary, it has been demonstrated that a decision support system for the evaluation of construction submittals can be constructed and that it will provide numerous benefits: an expedited decision process, an audit trail for decisions, more consistent and objective decisions, risk identification, internal alignment of organizational values, and improved lifecycle asset performance. The benefits were validated by demonstration, and by experts' evaluations.

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*To the soul of my **father**, for his unforgettable support, guide, and love*

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Chapter 1
Introduction

1.1 General

Building design is the result of the combined efforts of architects and engineers. At the end of the design stage, the design package embodies the decisions and intentions of the designers; these are reflected directly in the lifecycle cost of the project (Figure 1-1) (Liescheidt 2003; Hegazy 2002). The builders use the decisions to finalize the project so that it meets the expected levels of performance and quality, and these characteristics should therefore be clearly documented in the drawings and specifications for the project (Liescheidt 2003; Rosen 1999).

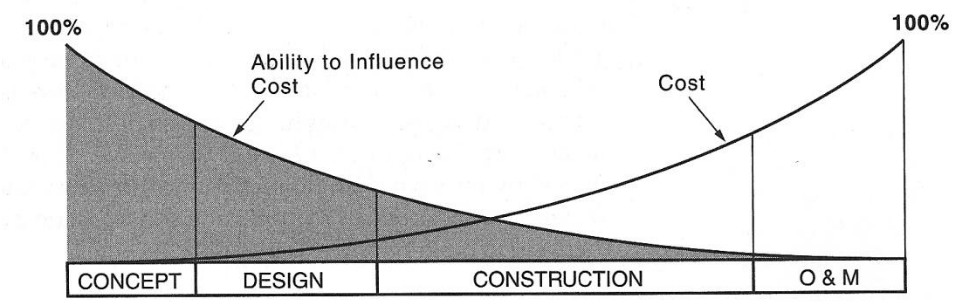


Figure 1-1: Impact of Decisions on Building LifeCycle Costs (Hegazy 2002)

Drawings and specifications, which are the two kinds of output during the design stage, have a decisive impact on the construction and operation stages. Josephson and Hammarlund (1999) have reported that design defects are responsible for approximately 30 % of all defects that arise during construction and for approximately 55 % of all defects that appear during in operation and maintenance (Figure 1-2). A study conducted in the UK reported that the majority of building failures are caused by design errors, with the second most frequent cause being construction defects (Parand and Bloomfield 1991).

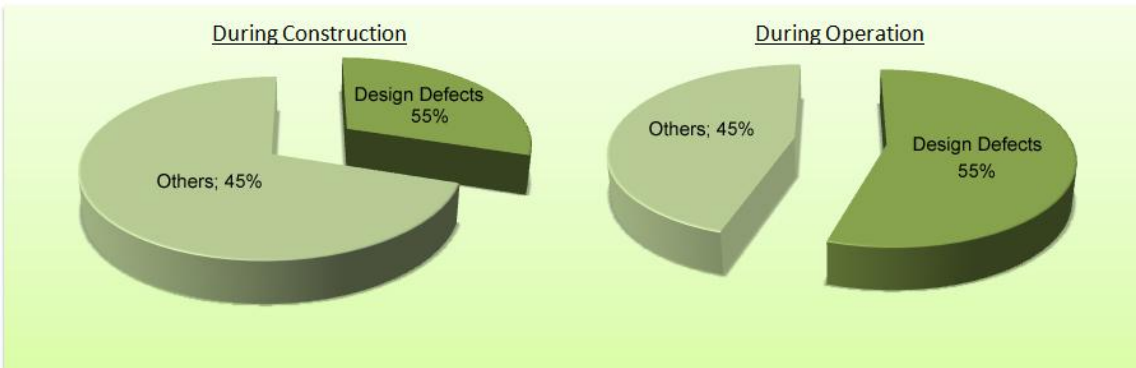


Figure 1-2: Impact of Design Defects During the Construction and Operational Phases (Josephson and Hammarlund 1999)

Drawings and specifications, which are both critical for all building phases, are subject to many changes and deviations during construction process. These changes have a direct effect on the quality of the building and the cost of operation (Boukamp 2006). Although both drawings and specifications are important in the construction process, specifications take legal priority over drawings (CI 2007; Rosen 1999), and are often one of the main causes of construction disputes (Jahren and Dammeier 1990). In contrast to the tools and technology for improving the accuracy of drawings, similar help is not as highly developed with respect to specifications, which have not received enough attention from engineers and designers and are therefore prone to error and are sometimes mismatches with the drawings. A UK study reported that the failure to provide accurate specifications accounted for more than 25 % of professional indemnity insurance claims (Rogers 1994). In another study, NBS (*National Building Specification*) (Gelder 2007) has analyzed specification-related problems and used the evidence presented in court cases in the United States (Nielson and Nielson 1981) in their analysis. The NBS study identified the following specification problems:

- Specifications are often poorly written, which can increase project time and price.
- Specifications are not enforced.
- The drawings often conflict with the specifications.
- The phrase "or equal" in specifications causes 25 % of all disputes.
- Specification ambiguity cases account for 12 % of disputes.
- Specifications that include inaccurate technical data are responsible for 12% of disputes.

To speed up the preparation of the specifications, designers often provide requirements for the final target based on limited details, on previous specifications, on readily available standards, and on experience (Emmitt 2001). Preparing specifications without the details simply postpones liability and problems to the construction stage (Kululanga and Price 2005), during which frequent changes in the specifications will occur. The final as-built specifications for many building components and their actual operational characteristics are therefore finalized only during the construction phase. Toole and Hallowell (2005) listed 24 building components whose specifications had not been determined until construction. In practice, many designers leave the final decision regarding how to achieve the required performance to the contractor, especially with respect to mechanical components, such as ventilation, heating, air conditioning, and structural steel connections (Friedlander 2000). This practice leaves the door open for updates and deviations from specifications because additional details must be added. Other reasons for the large number of changes in specifications during construction are pre-fabrication, the availability of materials, unknown site conditions, the discovery of better alternatives (Scott 1996), changes made by the owner, code updates, and design omissions and errors.

As part of the specification update process during construction, a formal review process, called the submittals process, requires the contractor to submit a proposal for materials, equipment, and processes, according to an established schedule, for the owner's approval before they can be used on site. These submittals must then be evaluated by the owner within a short period of time, which can be a difficult task because of time constraints, information missing from the submittal package (Atkins 2006; Liescheidt 2003; Scott 1996), problems in retrieving related information from text and CAD files (Wood 1996), and the lack of defined criteria for the evaluation. The last reason can be especially important when seemingly minor changes can affect performance and have implications not only for construction but also for the operation of the project. In practice, submittal evaluation has been based on experience, which has led to unsatisfactory decisions.

1.2 The Submittal Challenge

Rough specifications often include only general performance criteria and not details or specific characteristics, manufacturers' details, or operational data. With respect to HVAC specifications, for example, the following is an example of a description of a specification that was passed on for implementation at the construction stage: "Procure and install central HVAC system with minimum cooling capacity of 445 T.R. designed for 115 F with maximum sound level of 102 dBA that fits the designated mechanical room…" A rough specification such as this one is then used as a reference for selecting, submitting, processing, and approving a system (materials/equipment). During construction, however, the submittal process becomes essential for approving or rejecting the specific alternative items submitted by the contractor. As an example, a contractor, after investigating the market, may submit three brands to be considered for the HVAC system as tabulated in Table 1-1, which is extracted from a real-life submittal included in Appendix D-1. The bottom of the table indicates some of the additional construction and operational characteristics that were determined during the process of evaluating those three items.

Table 1-1: Three Brands Submitted for the HVAC System

	General	**Parameters**	**PETRA**	**LG**	**York**
Submitted by contractor		Number of Pieces	1	1	2 (Parallel)
		Cooling Capacity	454.3	449.7	230.5
		Design Ambient	115 F	115 F	115 F
	Compressors Data	Number of Compressor	3S	6	2x2
		Power Input (KW)	649.6	764.9	R 134a
	Cooler Data	Water Flow Rate (GPM)	685.5	764.9	(2x350)
		Water Pressure Drop (Psi)	4.3	2.82	3x2
		Number of Cooler	1	2	1x2
	Condenser cooling Data	Total Air Flow CFM	372615	285192	156000x2
		Total Face Area (sq. f.)	622.8	521.3	352x2
		Material Coil	Copper Tube	Copper Tube	Copper Tube
Determined during evaluation	**Construction related Constraints**	Procurement Time	Regular	Requires time	On shelf
		Initial Price	Cheaper	Per bid	More than bid
		Fitting within Mechanical Room	Fit	Fit	Needs space
	Operational related Constraints	Maintenance Lifecycle	7 years	10 years	8 years
		Technical Support Centre	Available	Per request	Available
		Training	Not included	Included	Included

Choosing the best value for the project therefore requires careful analysis. Based on the decisions made during the submittal process, the specification needs to be updated with new information, changes, and construction and operational details. Evaluating submitted materials, products, and equipment in order to arrive at a best-value decision is the most effective way to ensure that the intended performance and quality is achieved with respect to both the building and the selected item. A decision that seems to be reasonable during construction may produce undesirable effects during operation and may cost more money over the lifecycle of building. This thesis, therefore, considers the impact of changes in specifications on the operation and maintenance stage as an essential factor in submittal evaluation (Figure 1-3). The graph at the bottom of Figure 1-3 shows the expected effect on cost along the lifecycle of the project: a poor decision with respect to submitted items increases costs, especially during operation; a good decision either maintains or improves the intended operational performance.

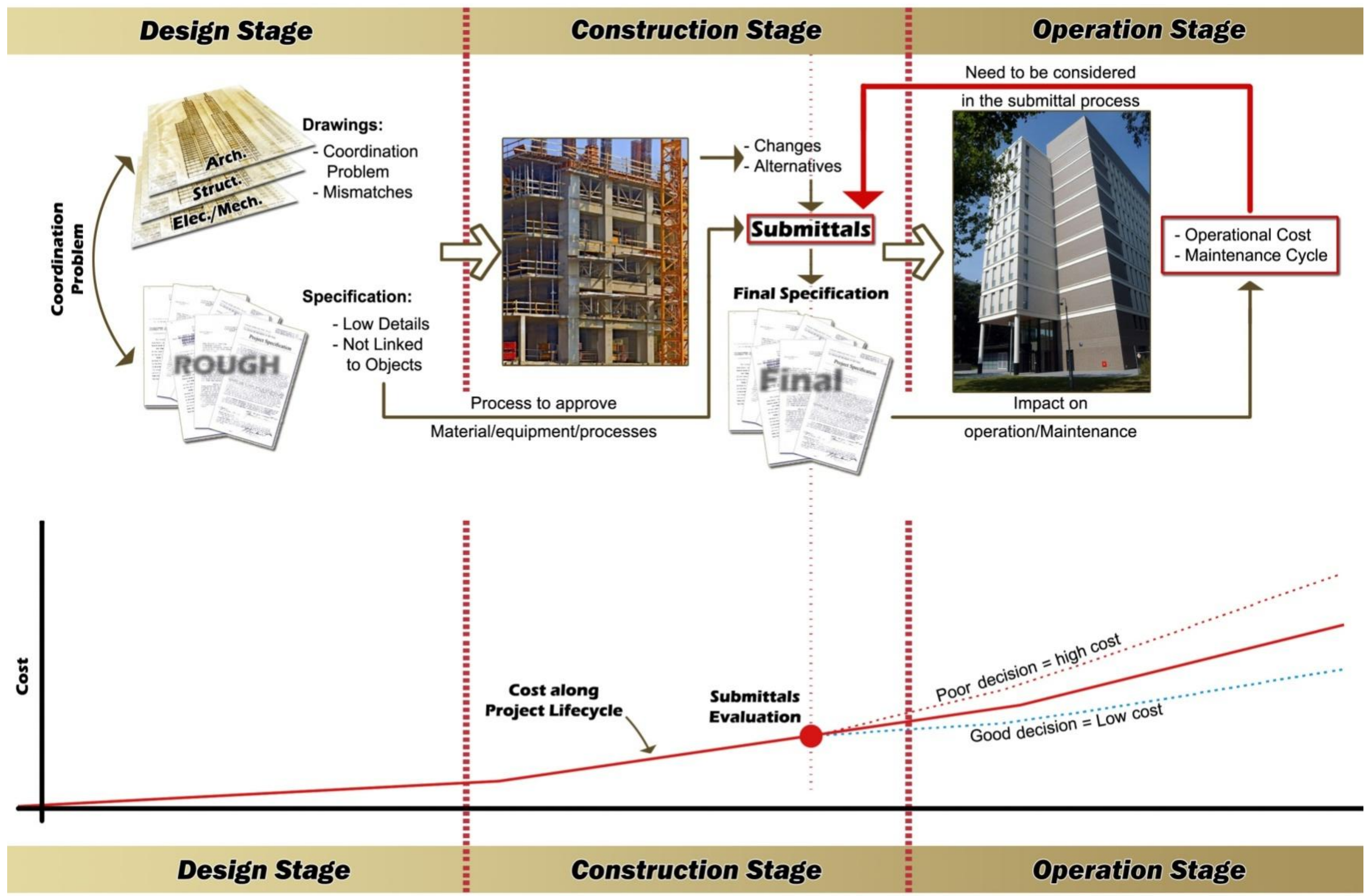


Figure 1-3: Impact of Submittals on Construction and Operation

1.3 Research Motivation

This research recommends changes to the evaluation of construction submittals in order to improve the quality and performance of construction projects. The research was motivated by the observations, discussed in the following subsections.

1.3.1 Specifications' Significant Impact on Operational Cost

Operation and maintenance management are meant to save money and energy by utilizing all systems, including electrical and mechanical, according to the finalized "as-built" drawings and specifications. Poorly written specifications that are not updated during construction compromise operational efficiency. More importantly, when designs are changed, it is necessary to approve the materials, equipment, and workmanship that provide the best value (Boukamp 2007; Wyatt 2006). Effective selection of items through the submittal process and timely updating of specifications according to the latest reliable information will therefore help contain operational costs.

1.3.2 Need to Consider Impact of Changes on Operation

The submittal process is intended to confirm compliance with specifications. This step is especially critical whenever the submitted information includes enhancement of or deviation from the original specifications, when the materials are critical, or when there are compatibility issues with new equipment (Williams 1997). In such cases, even a minor change in specifications affects operation and may even cause loss of life, higher expenses, and system failure. Elovitz (2002) described an architect who had been sued for approving submittals, including a change from 10- to 14-gauge steel for landing pads in a stairway, with the result that a stairway collapsed and two people were injured. Another example is a submittal that includes an alternative HVAC system that is less expensive initially but that requires a maintenance cycle that makes it more costly over the long run. Considering the operational impact of changes in the specifications can help control losses and prevent conflicts.

1.3.3 Need for Practical Decision Support for Evaluating Submittals

Evaluating submittals is a difficult, time-consuming, and costly process that involves many levels of engineers and administrators (Liescheidt 2003; Kilper 2002; Wood 1996). The likelihood of underestimating the impact of changes in the specifications is high, especially when there is pressure for speed in the construction process. In addition, in the absence of clear approval criteria, a reviewer is forced to make on-the-spot decisions based only on subjective judgment, experience, and short-term goals. The chance of error is therefore high and optimal decisions are not assured. Practical decision support is, therefore, needed so that the evaluation criteria can be defined and so that an optimal decision support methodology can provide a quantitative assessment of the submittals. A thorough and automated submittal evaluation process ensures the contractor understands and is in compliance with well-documented specifications so that any omissions or errors can be corrected. Such evaluation process should consider the best value for the project through integration of value analysis with decision alternatives. An example research of integrating value analysis and quality function was proposed by Cariaga et al. (2007). In addition, because some contractors deliberately use improper submittals in order to buy time, an automated or Web-based process can allow the contractor to evaluate items before making a formal submission, thus saving time and money. This helps expedite what often descends into a negotiation process.

1.4 Anticipated Benefits of the Framework

The anticipated benefits from the decision support system are as follows:

1. Expedited decision process,
2. An audit trail for decisions,
3. More consistent, potentially better, and objective decisions,
4. Risk identifications,
5. Internal alignment of organizational values, and

1.5 Research Objectives and Scope

The primary objective of this research was to develop a value-based framework that can support the evaluation of construction submittals and that takes into consideration the impact of changes in the specifications on the operational characteristics of a building. This study also had the following additional goals:

1. Study the submittal process and define the key building components that require rigorous submittal evaluation.
2. Study the construction requirements, operation-related criteria, and LEED requirements to be used in evaluating submittals for key building components.
3. Develop an automated submittal evaluation mechanism that uses a multiple-criteria utility-based method to determine the best-value condition for approving a submittal, considering its construction, operational, and LEED requirements.
4. Develop a prototype decision support system.
5. Validate the prototype using practical case studies.

This research also had the goal of automating the transfer of information from the construction to the operational stage of buildings within a framework for dynamic updates to specifications, considering the operational and functional impact. A further objective was to establish an automated decision support system for the value-based evaluation and approval of submittals.

1.6 Research Methodology

The proposed research methodology (Figure 1-4) was as follows:

1. Collect data about submittals from large building owners in the Toronto area, such as the Toronto District School Board (TDSB).
2. Analyze the submittal process, identify problems, and list solutions as suggested in the literature.
3. Investigate and identify the key building components that are frequently problematic with respect to submittal requests.
4. Investigate and identify construction- and operation-related criteria for evaluating the submittals for each component. Examine the propagation of changes in specifications with respect to the functional and spatial aspects of a project.
5. Develop a decision support system for facilitating a quantitative and speedy evaluation of submittals for the selected items, based on multi-criteria decision attributes for establishing weighting and scoring system for each selected item.
6. Develop a prototype of the proposed framework.
7. Apply the prototype to practical case studies for validation and to demonstrate its benefits.

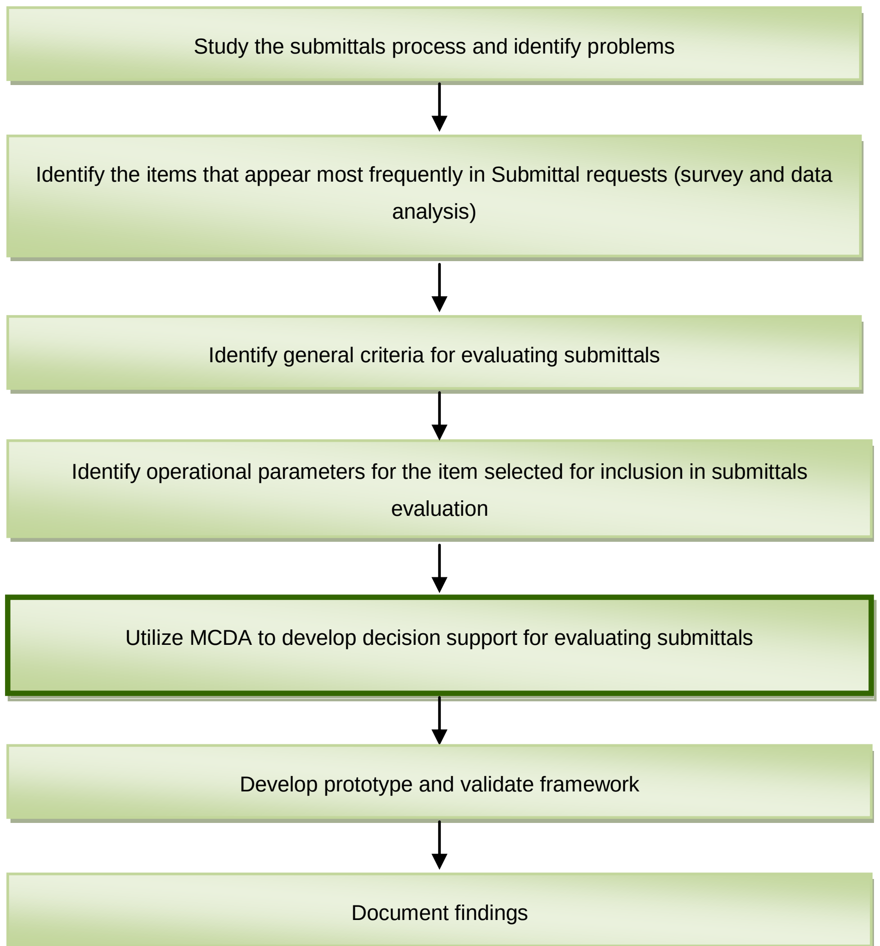


Figure 1-4: Research Methodology

1.7 Thesis Organization

The thesis is organized as follows:

Chapter 2 reviews previous work on the components of the research. It begins by describing the dilemma of interoperability in the construction industry and the efforts to resolve it. The chapter then presents the submittal as a means of communication in construction projects and the current process for evaluating submittals. Problem with submittals are summarized and solutions suggested. The chapter explores Multi-Criteria Decision Analysis (MCDA) techniques and the tools needed to improve the evaluation process and decision support for submittals.

Chapter 3 describes the process used to collect the study data from several sources, to analyze the data in order to identify a list of key submittals, and to select a key submittal for further evaluation.

Chapter 4 describes the evaluation mechanism conceptually and then presents an application of the mechanism with respect to a selected item. It also explains the interview process through which experts provided input about the selected item, which was then used to define the evaluation mechanism. The evaluation criteria are identified, and a utility function graph for value-based evaluation is presented.

Chapter 5 discusses the development of the submittal evaluation prototype and the evaluation process. The prototype is illustrated using a real-life case study, for which each step of the evaluation process is explained. A minimum acceptable threshold is also defined for use in evaluating the results of the case studies examined in this research.

Chapter 6 presents the validation and model sensitivity analysis of the overall system by detailing the processing of five case studies: four real-life cases and one hypothetical case. Three of the cases involved three alternatives. The real-life cases included both LEED and no-LEED scenarios, requirements and the results were compared with the organization's actual decision. The decision proposed by the system is also presented. The first case study was used to test the model against a single alternative with no-LEED requirements and with respect to its sensitivity to variations in the parameters. For the second real-life case, the requirements were set for the organization, and the alternatives were processed in parallel. For the third case, the requirements were set for the default mode, and the values of the alternative parameters from the second case were processed again. The results of the second and third cases are compared in order to identify the effect of the organizational requirements on the item's value and on the final decision. The LEED default requirements were included in the setup of the fourth case, which is also a real-life case. For the fifth case, a hypothetical one alternative was processed according to multiple scenarios in order to examine the behavior of the model relative to parameters variations with respect to LEED requirements. All of the results were shared with experts (project managers) in order to obtain feedback about the system and the results. This feedback and the details of all five case studies along with the results are presented in this chapter.

Chapter 7 summarizes the research, highlights its contributions, and presents recommendations for future work.

Chapter 2

Literature Review

2.1 Introduction

This chapter presents a detailed literature review of the components of the research, including current specification challenges, existing submittal problems, attempts to solve these problems, and the existing tools for managing submittals. LEED requirements for green construction are also presented in order to provide an understanding of their impact on the submittal approval process. The chapter then examines the multi-criteria decision analysis tools needed to improve evaluation and decision support for submittals.

2.2 Specifications

During the design process, architects and engineers should always convey accurate messages to contractors in order to ensure the intended quality and performance of the building. This objective is also the main reason for specifications that establish a baseline for all communications among the parties involved in the project. Specifications are classified by the American Institute of Architects as the part of the contract document (CI 2007) that falls under construction documents, which also includes the contract and the drawings (Rosen 1999). Specifications are the written description of the work required and the quality expected in addition to instructions and work guidelines that facilitate the construction process. They include all the details that can help the parties responsible for the construction to provide the required quality and performance, including procedure for submittals, testing, and inspections (Liescheidt 2003; Rosen 1999).

Specifications separate, organize, and classify the interconnected information from the drawings and provide all of the technical details. The quality and performance expected with respect to all materials, equipment, fixtures, and even the workmanship are divided into sections called divisions, which are listed in the specifications Master Format. The 1995 release included 16 divisions, which were expanded to 50 in 2004 with inclusion of facility lifecycle and maintenance information (Figure 2-1) (Gulledge et al. 2007).

SPECIFICATIONS GROUP

GENERAL REQUIREMENTS SUBGROUP

Division 01	General Requirements

FACILITY CONSTRUCTION SUBGROUP

Division 02	Existing Conditions
Division 03	Concrete
Division 04	Masonry
Division 05	Metals
Division 06	Wood, Plastics, and Composites
Division 07	Thermal and Moisture Protection
Division 08	Openings
Division 09	Finishes
Division 10	Specialties
Division 11	Equipment
Division 12	Furnishings
Division 13	Special Construction
Division 14	Conveying Equipment
Division 15	*Reserved*
Division 16	*Reserved*
Division 17	*Reserved*
Division 18	*Reserved*
Division 19	*Reserved*

FACILITY SERVICES SUBGROUP

Division 20	*Reserved*
Division 21	Fire Suppression
Division 22	Plumbing
Division 23	Heating, Ventilating, and Air Conditioning
Division 24	*Reserved*
Division 25	Integrated Automation
Division 26	Electrical
Division 27	Communications
Division 28	Electronic Safety and Security
Division 29	*Reserved*

SITE AND INFRASTRUCTURE SUBGROUP

Division 30	*Reserved*
Division 31	Earthwork
Division 32	Exterior Improvements
Division 33	Utilities
Division 34	Transportation
Division 35	Waterway and Marine Construction
Division 36	*Reserved*
Division 37	*Reserved*
Division 38	*Reserved*
Division 39	*Reserved*

PROCESS EQUIPMENT SUBGROUP

Division 40	Process Integration
Division 41	Material Processing and Handling Equipment
Division 42	Process Heating, Cooling, and Drying Equipment
Division 43	Process Gas and Liquid Handling, Purification, and Storage Equipment
Division 44	Pollution Control Equipment
Division 45	Industry-Specific Manufacturing Equipment
Division 46	*Reserved*
Division 47	*Reserved*
Division 48	Electrical Power Generation
Division 49	*Reserved*

Figure 2-1: Specification MasterFormat 2004 (CSI and CSC 2004)

2.3 Research Directed at Overcoming Difficulties with Specifications

The goal of many studies was to overcome the challenge of deficiencies with respect to specifications, and they have been focused on developing methods of writing, generating, and checking specifications. Kululanga (2005), for example, presented the principles behind the writing of specifications and the need for developing methods of evaluating that specific type of writing, which is one of the main challenges in the construction industry. Automation has been introduced in order to ensure that, when specifications are generated, a minimum amount of information is lost and the specifications match the drawings. An interesting online software program for automating the preparation, checking, and updating of specifications e-SPECS, has been introduced commercially (Figure 2-2). Integrated with a Building Information Model (BIM), e-SPECS works by linking the BIM building objects with master specifications and makes it possible to build specifications while working on a project. Information is also linked from the supplier and manufacturer to the specification (InterSpec 2007).

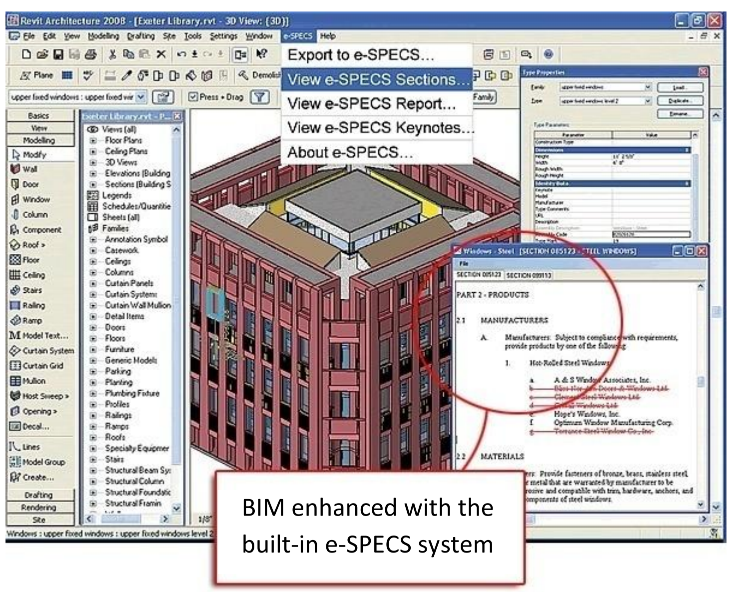


Figure 2-2: e-SPECS running with BIM (Revit) (e-specs 2008)

Automation has also been introduced to specification for evaluating compliance with building codes. The Extended Building Code (EBC), for example, has proposed a new framework that integrates code checking and performance analysis for a building envelope using decision tables. This framework compares specifications with the building codes through decision tables, and specifications either pass or fail according to a rules package (Tan et al., 2007). Horvat (2005) used the EBC to evaluate the performance of a light-frame building envelope using Microsoft Excel™. The assessment in the design stage follows an established scoring system based on the requirements of the National Housing Code of Canada 1998 as a benchmark for the study (Horvat, 2005). Notable studies have also been conducted in Singapore in the field of automated checking in construction, in which applications were based on 2D input data. Singapore's e-plan checking project, the Construction Real Estate Network (CORENET), allows Architecture/Engineering/Construction (AEC) professionals to submit project plans and documents online for review. CORENET is based on the checking of CAD drawings and was then extended to include the data model, Industry Foundation Class (IFC), which was developed by the International Alliance of Interoperability (IAI) (Khemlani, 2005). Boukamp's (2007) research enhanced and adjusted the checking to include the construction stage by using laser scan technology to identify deviations between as-built and as-designed information, thus facilitating the inspection process. Table 2-1 lists some of the automated systems designed to check specification and code compliance.

Table 2-1: Examples of Automated Checking Systems

	Some Efforts in Code Checking System	Reference
1	IFC-Based Framework for Evaluating Total Performance of Building Envelopes	(Fazio et al. 2007)
2	Automated Processing of Construction Specifications to Support Inspection and Quality Control	(Boukamp et al. 2007)
3	Automated Code Compliance Checking of Building Envelope Performance	(Tan et al. 2007)
4	An integrated Building Plan and Services (IBP/IBS) Checking System	(Yang and Xu 2004)
5	Design Knowledge modeling and Software for Building Code Compliance Checking	(Yang and Xu 2004)
6	CORENET e-PlanCheck	(Khemlani 2005)
7	Speeding-up Building Plan Approval	(Liebich et al. 2002)
8	Knowledge-Based Approach to Building Envelope Design	(Fazio 1989)
9	Automated Processing of Design Standards	(Cronembold and Law 1988)
10	SICAD: A Prototype Knowledge Based System for Conformance Checking and Design	(Lopez 1984)

In addition to the studies mentioned, the goal of improving building performance has also been addressed by significant research directed at optimizing the selection of materials and design alternatives. Examples include the work of Ashby (2005) on material selection, which used a scatter chart; Farag (2002), which applied the weighted sum method; Sefair (2009), which utilized the optimal scoring method; and Cariaga et al. (2007), which incorporated value analysis and quality function.

Another research area that emphasizes the current difficulties related to specifications is the work directed at enhancing the design document and process. The two primary research streams in this area are the representation of the intent of the design (e.g., Ganeshan 1994) and the coordination of the design team (e.g., Zaneldin 2000).

The overall goal of these studies collectively is generally to remedy current deficiencies in specifications, so that the intended design is carried through the construction process and then to the operation stage, in order to provide the owner with the desired building.

2.4 Administering Specifications through Submittals

The accuracy of specifications as source information is critical, especially when the specifications are rough. Despite efforts to optimize the material selection decisions during design, enhance specification quality, and clarify design intentions, it is essential to review product or item data prior to installation for the purpose of conformance to specification information and objectives (Drake 2002). Such a review is conducted through the submittal of detailed information about the product/item so that the owner can make a wise decision about the adequacy of the item in question (Hinze 1993). The submittal process connects the design requirements to the construction details that are needed for constructing the project by providing all information that becomes known only during construction stage and reflecting the manufacturer data (Schinnerer 2003; Drake 2002).

According to the procedure governing the contractor quality control (CQC), the contractor is responsible for performing the work in accordance with the specifications. Conformance is demonstrated when the contractor presents a submittal prior to installation, which is then reviewed by a consultant who check the detailed specifications of the materials or equipment submitted. During the review process, the consultant should ensure that the item submitted meets the required performance parameters identified in the specification (East 2007; Liescheidt 2003). The importance of the submittal, in addition to being a quality control process (East 2007; Poles 1995) is that it is also the last opportunity for the consultant to avoid or correct any shortages or mistakes in design (McDaniel 2002). The data approved in the submittal will also be a new reference values for the commissioning and testing procedure, which, as a result, may require modification before the project is turned over to the operation team (Turkaslan-Bulbul 2006). Fabricated items or other items that require the user to make a choice can easily generate multiple submittals, depending on the complexity and details involved. Up to eleven different types of submittals are in general used in the construction industry, as listed in Table 2-2 (East 2007).

Table 2-2: Submittal Types (East 2007)

	Submittal Types
01	Preconstruction Submittals
02	Shop Drawings
03	Product Data
04	Samples
05	Design Data
06	Test Reports
07	Certificates
08	Manufacturer's Instructions
09	Manufacturer's Field Reports
10	Operation and Maintenance
11	Closeout Submittals

Submittals may also be grouped into five categories: (1) extensions to the design, (2) critical materials, (3) deviations from original specifications, (4) compatibility issues, and (5) operation/maintenance manuals. Extensions to the design include special systems like fire alarms and sprinklers, and prefabricated building items that are defined only during construction. Critical materials represent all materials according to defined criteria and quality that are required; changing their specifications affects other systems or building operation such as in the case of high-pressure pipe specifications (Williams 1997). Deviations from the original specifications, which include substitutions, include situations in which the same product is distinguished from one another by verification of the manufacturers' specifications. Changing the manufacturer may mean different product information, which may affect operation (Elovitz 2002). With respect to equipment, a pre-installation check is required to ensure a match with existing systems; such a check can be performed only through submittals (Williams 1997). Looking at submittals from the perspective of these five categories makes it clear that submittals contain the most updated data regarding building components and items. A critical issue is therefore the decision process involved in determining the final product details that may impact the quality of construction and operation (Schinnerer 2003).

2.4.1 Submittal Procedure/Process

The American Institute of Architects (AIA), the Engineers Joint Contract Documents Committee (EJCDC), and the Associated General Contractors of America (AGC) mandate that a submittals process be provided and that requirements be within general project conditions. The requirements and process should be clearly defined in order to effectively regulate the timely flow of submittals (AIA 1997; William 1997; NAVFAC 2006).

To initiate the submittals process, a designer should identify and transfer the list of building components that must be submitted before they are procured and installed during construction. Such a list is called a submittals log (register) (NAVFAC 2006; East 2007) (Appendix B). The submittal register should then be integrated with the contractor's critical path activities as approved by the consultant. Tracking submittals during construction occurs through the submittal register, which records all related activities, such as dates of submission and recipients (Schinnerer 2003; RTKL 2002; NAVFAC 2006; Simpson et al. 1995; Poles 1995; East 2007).

Each submittal proceeds in a loop from the contractor to the owner for approval, and then back to the contractor for procurement and execution (Figure 2-3) (Mead 2001). Initiating the submittal is the responsibility of the general contractor; it is prepared either by the general contractor or by the involved subcontractor, supplier, or manufacturer. Once the product or component data is ready for consultant review, it is attached to a transmittal form, called submittal form (Appendix A) that records the reference information about the project and subsequently the consultant's decision, at which the transmittal form becomes very important to the whole process (Atkins 2006; McGreevy 2002; NAVFAC 2009; RTKL 2002; Mead 2001).

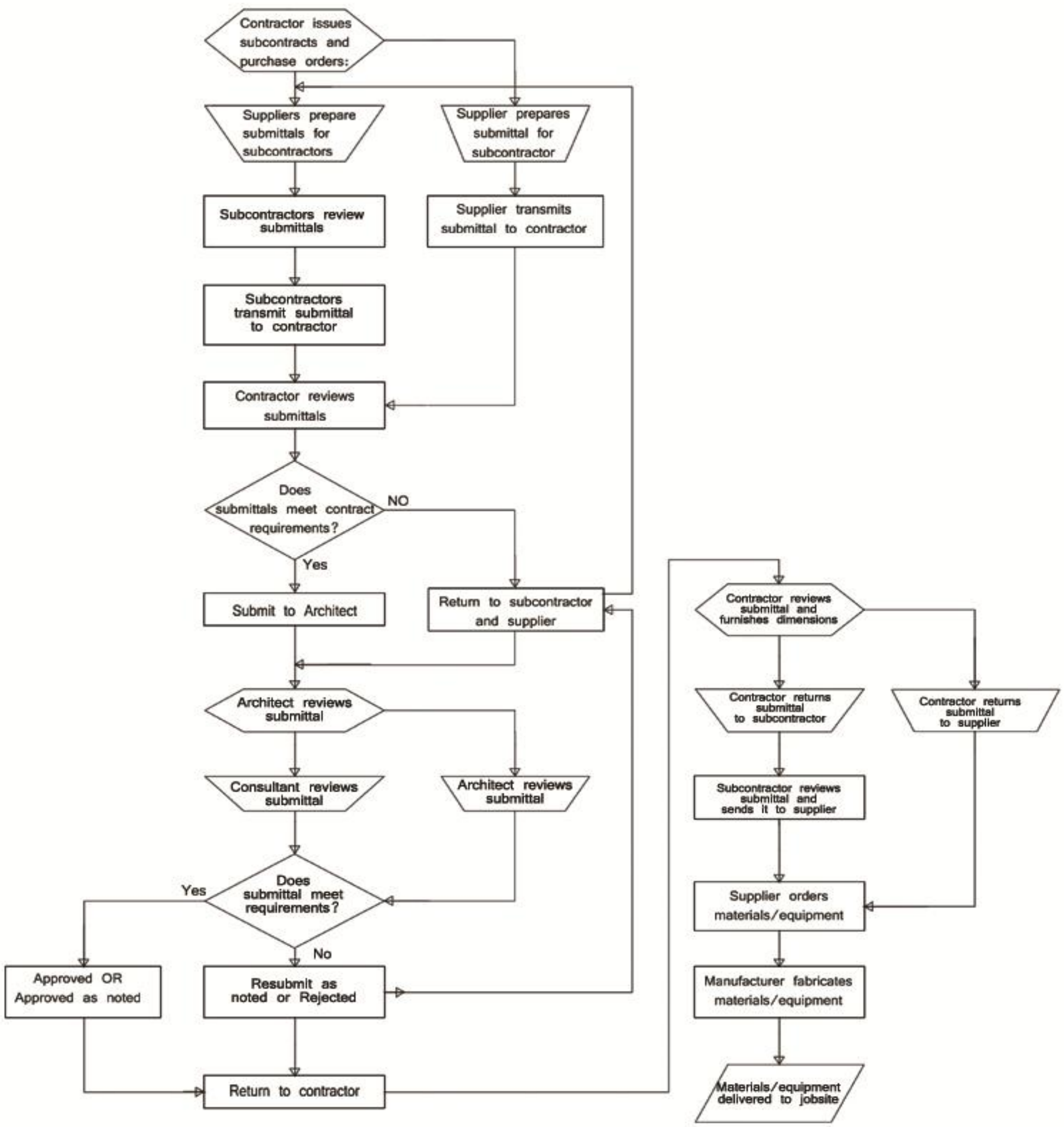


Figure 2-3: Submittal Process Flow Chart (Mincks and Johnson 1998)

The consultant decides whether the submitted product information is satisfactory. This process is then concluded when the consultant determines that the submittal falls into one of five categories: "approved,” "approved as noted,” "approved as noted resubmitting is required,” "disapproved" or "no action" (McGreevy 2002). The submittal is then handled by the contractor, who follows up on the decision through procurement or resubmission (Mead 2001). In summary, the submittal process is time consuming and critical to project performance.

Developing an efficient submittal evaluation process leads to better use of administrative time and enhances the efforts of all parties in the project. Such a process limits errors during the design and bidding phases and documents all installed materials, equipment, and systems. According to Wyatt (1997), an efficient submittal evaluation process can be established through six steps: (1) thoughtfully edit the submittal requirement; (2) state the submittal requirement in understandable language; (3) publish a master list of the submittals required for the firm's projects; (4) improve record keeping; (5) reject improper submittals; and (6) promptly route, receive, and return submittals. These steps will result in a practical submittal evaluation process that increases the productivity of all parties and adds value to the project.

2.4.2 Challenges with Submittals

As a process, managing and reviewing submittals are overwhelming and risky part of the construction phase of project, and involve numerous activities (Ingold 2010; Atkins 2006). The typical problems associated with the process are late submittals, incomplete submittals, submittals that do not comply with specifications, and missing submittals (Ingold 2010; Schinnerer 2003). Such problems interrupt the construction process and may lead to construction delays (Atkins 2006), which can be the reason of late completion, lost in productivity, and cost increase (Arditi 2006).

Table 2-3 indicates some of the problems associated with submittals and the solutions suggested in the literature.

Table 2-3: Submittal Problems and Solutions Suggested in the Literature

Reference	**Submittal Problem**	**Solution Suggested in the Literature**
Friedlander 2000; Atkins 2006	Inadequate submittal time in contract	Set fixed review time (14 -19 days).
Ingold 2010; Atkins 2006; Rickert 2002	Late submittals/procrastination	Notify contractor to follow schedule.
Ingold 2010; Atkins 2006	Forced substitutions in submittals within a limited time	Reject submittal/request enough processing time.
Atkins 2006	Perform non approved work	Write to contractor that it is required by contract.
Ingold 2010: Atkins 2006	No submittal schedule	Suspend submittal until schedule is provided.
Schinnerer 2003	Deviation from schedule	No solution suggested.
Wyatt 1997	Lengthy process	Minimize number of items that require submittals.
Wyatt 1997	Quality process not maintained	Give enough time to reviewer and have multiple reviewers.
Elovitz 2002	Inefficient decision	Provide detailed information and shop-drawings
Schinnerer 2003	Submittal that is not required	No solution suggested.
Wyatt 1997	Undefined process	Review process in pre-construction conference.
Wood 1996; Schinnerer 2003; Piccolo 2007	Inadequate information/ Incompleteness/lack of preparation	Insist to have contractor "reviewed" stamp before submitting submittals.
Friedlander 2000	What is approved when submittal is "Approved"	Use another phrase like "no exceptions".
Rickert 2002	Submittals are trivial	Eliminate by appropriate specifications.
Rickert 2002	Over delegation	Expert awareness of importance of review
Rickert 2002	Lack of support from owner	Disapproved should be based on specifications and owner preferences.
Kilper 2002	Lack of compliance with documents	No solution suggested.
Kilper 2002	Lack of coordination with related submittals	No solution suggested.
Piccolo 2007	Project delays	Give reviewers the needed information.
Wyatt 1997	Improper record of submittal	No solution suggested.
Ingold 2010; Schinnerer 2003; Friedlander 2000	Submittal not reviewed by contractor	No solution suggested.

2.4.3 Existing Commercial Tools for Managing Submittals

Managing submittals is a critical task that can overwhelm a construction team (Ingold 2010). Once they are received from the contractor, submittals need to be tracked with respect to when they have been received, who received them, and to whom they have been forwarded for review. Traditionally, managing submittals involves three components. The first is a spreadsheet used to record and track each submittal (submittal register). Each new submittal requires extensive data entry work. The file can have up to 10,000 pieces of information that are not linked and that must be entered manually. Microsoft Office Word™, as the second component, is used for transmittal forms that are filed manually and to save important information separately from the spreadsheet. Filing these submittals as hardcopy or digital files without links between them adds another task for construction team. The third component is the correspondence pertaining to submittal tasks such as letters, e-mails, or minutes of meetings (Rice 2007).

The increasing effort in the industry to control submittals has become apparent. Several computerized systems are available independently or as a part of construction document management systems. SUBMIT, for example, is a computer system designed to manage only construction submittal. It works with different files for storing active and non-active submittals. SUBMIT facilitates follow-up with respect to the work affected by a submittal by producing reports such as the jobs, supplier submittals, past due submittals, and closeout reports (Tavakoli 1990). More recently, Harris's (2006) patented construction project submittal management tool is another case in which managing submittals is based on networking all material specifications from professionals and suppliers. A contractor then can use the online system to send in a submittal and receive a decision from the architect. Figure 2-4 shows Harris's patented flow chart for the construction project submittal management system.

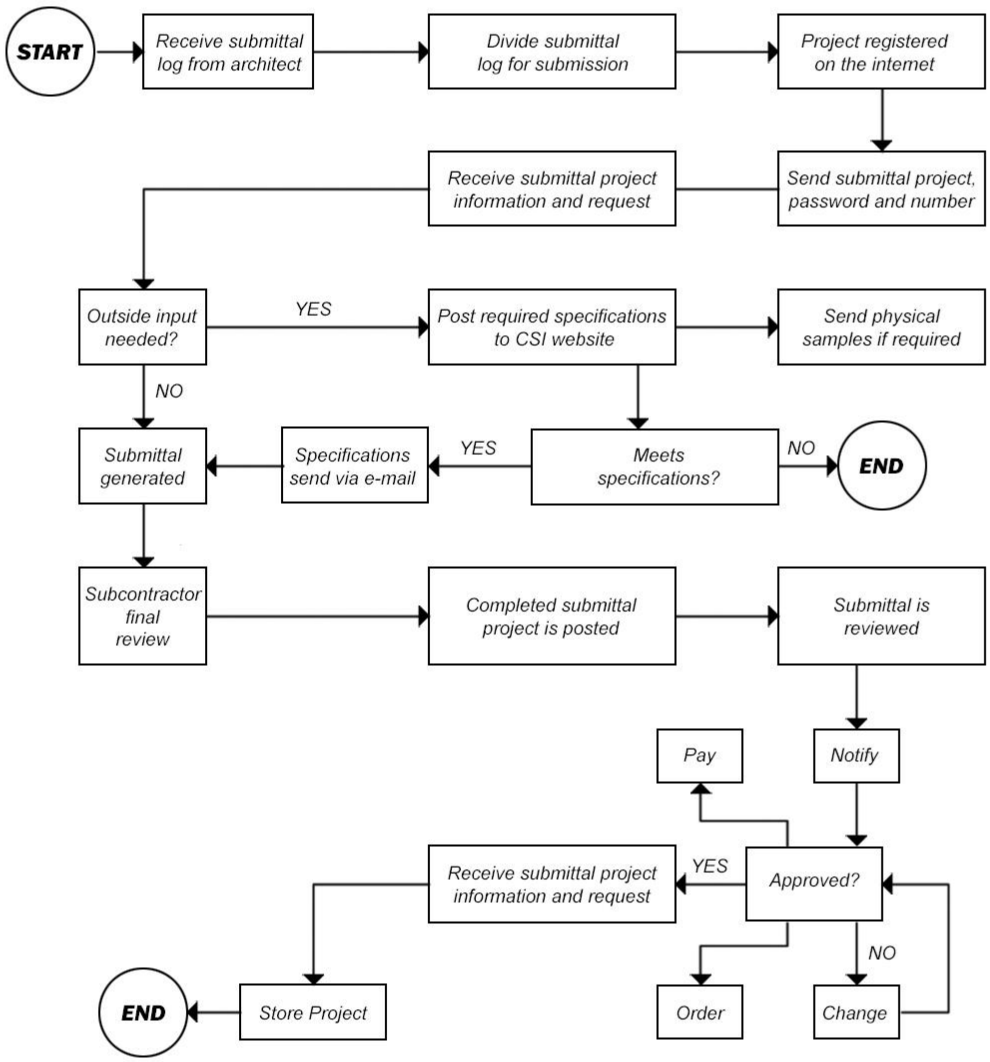


Figure 2-4: Flow Chart of Submittal Management System (Harris 2006)

Newforma Project Center™ is another example of software that centralizes the tasks related to submittals in a single system. Tracking and retrieving information related to these submittals is electronically possible using Newforma, through which it is possible to generate output reports in formats such as a mechanical submittals list or past due submittals (Rice 2007, Khemlani 2009). Newforma manages project documents as a whole and simplifies the review and evaluation of shop-drawings and submittals images can be captured from BIM files and used to write notes and comments. Decisions then can be forwarded to other parties with the click of a button. This scenario is applicable to many other online software programs. The latest addition to Newforma enhances the collaboration mechanism in the project team in order to provide better tracing of information and follow-up. The system also provides enhancements to the checking of design changes through systematic comparisons of new and previous drawings. Project Information Management (PIM), manufactured by Newforma, manages project files via corporation servers while other software programs that manage documents are web-based. Attolist™ was introduced at the American Institute of Architects 2008 National Convention. It has been enhanced since 2008 to include document management and the automation of workflow (Khemlani 2009).

Furman's (2005) patent developed a system and method for generating submittal packages using an expert logic engine. The system uses the internet so that parties to the project can communicate submittal data and decisions and so that submittals can be compiled based on pre-established documents (Furman et al. 2005). The methodology of the electronic submittal system developed by Rockey (2005) involves linear levels of review within the project team in which the submittal uploaded to the system by the manufacturer's representative is the first level, the next levels are review by the subcontractor and then general contractor, and review and approved by the engineers is the last level (Figure 2-5). Such a system centralizes communication on the internet and categorizes the reviewers at each level in order to control the linear process. Another submittal management system that has been developed in order to facilitate the exchange of submittal data electronically was published by Ostanik (2007). His system is based on the concept of establishing an online system to be a focal point for sharing the data among three parties.

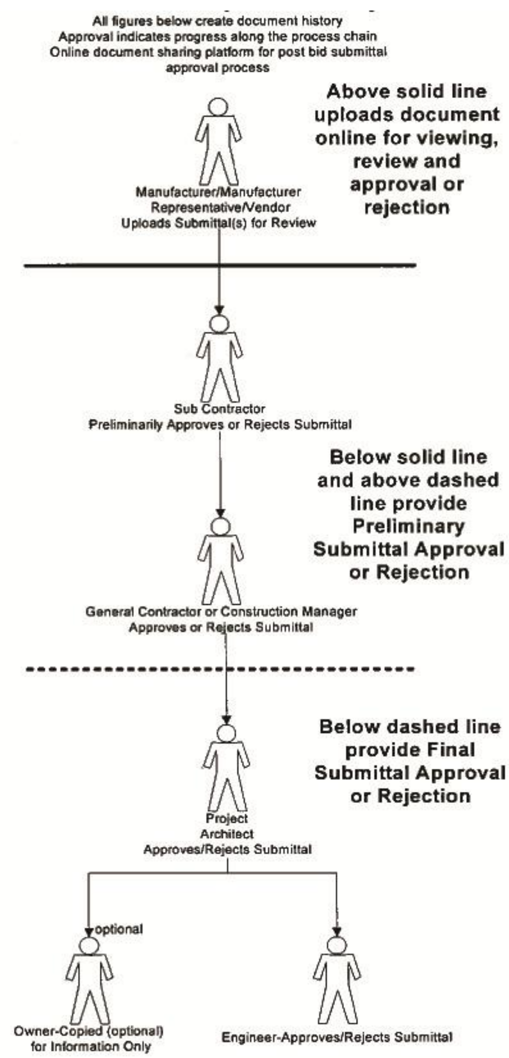


Figure 2-5: Electronic Submittal System (Rockey 2005)

Construction communicator™ is an online software program that was developed by Richard Sampson Associates, Inc. All submittals are submitted online and received digitally by the architect to comment on and send back with a decision. Each submittal and resubmittal is tagged with the vendor's reference or submittal title, and all data are stored on the main server for the service provider. Submittals are linked to all related electronic documents, such as cut sheets and PDF files, and retrieving details and tracking status can be performed online by authorized personnel at any location (Fremont 2007).

BuildSite™ is another online system that automates submittal preparation during construction, including ones related to LEED. Such automation tends to reduce the time for submittal preparation: BuildSite reduces submittal preparation time to one quarter (BuildSite 2007). AccuBuild™ has also released a "project management module" that can manage all project documentation. The new module has a search-engine for finding and tracking submittal information on a submittal log in addition to customized forms for initiating submittals, (Request For Information) RFIs, and change orders (AccuBuild 2007).

In Ontario, Canada, Software Innovation Inc. developed Coreworx™ software as a collaboration solution for contractors, owner/operators and others involved in planning, design, construction and operation. Using an online environment, engineering documents that include 2D and 3D drawings, emails, faxes, specifications, RFIs, (Request For Proposal) RFPs, submittals, and change orders are captured, reviewed, revised, approved, and distributed (Coreworx 2007). Submittals Exchange™ software focuses on managing construction communication that is reflected mainly in submittals and RFIs. It reduces errors that are made in traditional paperwork by controlling the submittal process. Submittal review and evaluation is performed as markups and notes on an electronic copy of the submittal (Submittal Exchange 2008).

SpecsIntact™ is an electrical construction submittal registrar that is used by the National Aeronautics and Space Administration (NASA), the U.S. Naval Facilities Engineering Command (NAVFAC), and the U.S. Army Corps of Engineers (USACE) to assure quality control for project specifications. It automates the development of standard design specifications and creates a data exchange format for exchanging, tracking, and reviewing information about submittals (NASA 2008).

Virtual Construction™ (VICO) online software has introduced six modules for project management using BIM technology. Submittal management takes place within the resource and construction management module where submittals are developed based on the embedded BIM data (VICO 2008).

These computerized systems manage a submittal register by tracking each submittal automatically and replacing the extensive labour required for data entry, follow-up, and note writing on scanned images or snapshots from CAD or/and BIM models. Such systems, however, lack decision support for submittal evaluation that takes into consideration the impact on operation and construction-related criteria.

2.4.4 Standards Related Efforts to Manage Submittals

Collaborative effort among the National Institute of Building Science's (NIBS) Facility Maintenance and Operation Committee, the Facility Information Council (FIC), the International Alliance for Interoperability (IAI), and the National Building Information Model Standard (NBIMS), has initiated the Construction Operation Building Information Exchange (COBIE) project for facilitating data exchange between the construction and operation stages. The main objective of

COBIE is to enhance the capturing of information during the design and construction stages and then transfer it for operation and maintenance purposes. COBIE addresses the lack of definition of open-source, interoperable requirements for the exchange of information between the construction and operations phase. COBIE provides a standardized data structure for submittals. The COBIE format is based on the Industry Foundation Class (IFC) standard as an open-source platform (Brodt 2006; East 2007), which is not currently available as an operational system or an independent software product.

A submittal for COBIE is the natural way of collecting updated data about equipment, products, and materials; the approved submittal reflects the final data. COBIE defines the specific data needed in order to create a submittal register. The "RegisterItemType," for example, refers to one of the 11 submittal types, while the "RegisterItemReview" refers to the submittal reviewer (decision maker) (East 2007).

Creating the register is the first step in the submittal process: the register should be transferred to the contractor once it has been approved by the consultant. The submittal review process is not accepted unless the schedule has been approved by the consultant. The submittal log is then moved between the consultant and contractor in order to manage and control the flow of submittals. The contractor prepares the submittal package after compiling the necessary information from the supplier and/or manufacturer. Support processing and evaluating of submittals by COBIE required the provision of specific data before the transmission. These data are related to the assigned reviewers. The submittal data are in Portable Document Format (PDF) files (East 2007). Tracking submittals is then a major task, especially when revisions and resubmits are necessary. By creating a data field requirement, COBIE keeps track of submittal versions (East 2007).

With COBIE, the initial submittal type determines the method of evaluation, according to which submittals are divided into three categories of items: engineered items, manufacturer-described items (material, equipment, and products), and physical sample submittals. Engineered items should be reviewed and approved by an A/E firm while the approval of any material, product, or equipment that has manufacturer's data is based on two sources: the file-based format that collects the information about the manufacturer’s requirements for the item and the attributes describing the characteristics of item performance (East 2007).

COBIE has six action types with respect to submittals, as shown in Table 2-4. These “Action Types” indicate the status of the submittal evaluation after review (East 2007). COBIE standards thus include a set of actions that provided a guideline for development of this research in order to maintain consistency with COBIE and to facilitate future integration with BIM.

Table 2-4: COBIE Action Types

No.	Action Type
1	Approved
2	Approved with comment
3	Approved, resubmittal required
4	Denied, resubmittal required
5	Receipt acknowledge
6	Information Only

2.5 Sustainability, Green Building, and Leadership in Energy and Environmental Design (LEED)

Whenever a process of evaluating and selecting building components is initiated, the impact of the decision should be the major concern and should determine the selection. Consideration of the impact can extend to effects on the environment such as threats to human health and existence from direct consumption of natural resources and negative effect on climate. The implications of these effects might not be well recognized by this generation, but the next generations will definitely suffer if the consumption of resources is not controlled, which introduces concern about sustainability (CICA 2007). The principle is that if the current generation consumes more than it needs to support the life, then the next generation will have a shortage of the resources needed to sustain life. This concept defines sustainability, according to the World Commission on Environment and Development (Parkin 2000). Buildings are a major consumer of resources. As reported by the U.S. Green Building Council (2009), they consume 40 % of total energy and 13% of potable water (USGBC 2009a). Almost the same percentage (38.9 %) was presented by the Environmental Information Administration (2008) for energy consumption by buildings, who also indicated that they account for 72 % of the electricity consumed in the United States (EIA 2008).

As a result of this information, many studies have been initiated to introduce sustainability into the design, construction, and operation of the buildings, all of which is known as "green building". Historically, consuming natural resources and overwhelming the ecosystem were not issues for a builder until modern inventions were introduced into building construction, such as air-conditioning systems, steel structures, and reflective glass. Energy consumption become massive and building designs were totally dependent on the availability of cheap fossil fuels for cooling and heating (MIA 2008).

After three years of celebrating Earth Day, in 1970, oil prices reached a peak, oil production was limited by OPEC in 1973, and as a consequence, a major drive was initiated in order to find an alternative for petroleum energy. This background was the main motivation for the growing interest in green buildings. When the OPEC problem was resolved, the iterative faded and lost support, but some figures in the construction industry kept the momentum going, led research initiatives, and provided examples of building designed for energy conservation and reduced effect on nature. The currently increasing pace of green building research has led to government support that resulted in the conversion of the White House to a green building in 1992 (completed 1996). The annual saving reached $300,000 US and provided an excellent example for other governmental agencies (MIA 2008). At the same time, the United States Green Building Council (USGBC) was established in 1993 in order to educate the public about design and construction methods that are more environmentally friendly and energy efficient. To cover the need for practitioner accreditation, an independent party was established in 2007 to administer a credentialing program. As a partner of the USGBC, the Green Building Certification Institute (GBCI) was formed to manage an accreditation program (USGBC 2009a). To recognize green buildings and to help decision makers chose green projects, the USGBC established the Leadership in Energy and Environment Design (LEED) rating tool (Syal 2007). Today, a LEED rating is a reference and objective for most energy-efficient buildings, and membership includes more than 18,000 organizations (USGBC 2009a).

2.5.1 LEED Rating and Topics

The USGBC formed a working team to develop a measuring system for identifying a green building based on specific guidelines and references. Their first pilot project was undertaken in 1998. The ratings became part of a formal measuring system with the release of the LEED Green

Building Rating System Version 2.0 (USGBC 2009a), followed by the LEED for New Construction Rating System (USGBC 2009b). As this rating system has developed, it has been enhanced by guidelines and ratings for specific building types, such as LEED for schools, healthcare, home, and retail buildings. Using the rating system, the USGBC awards certifications that are divided into four levels based on the points collected (USGBC 2009c):

1. Certified 40-49 points
2. Silver 50-59 points
3. Gold 60-79 points
4. Platinum 80 points and above

Because this study deals with new construction, the research included an investigation of LEED 2009 for New Construction and Major Renovations (USGBC 2009b). Seven relevant topics are addressed in that version of LEED: sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), material and resources (MR), indoor environmental quality (IEQ), innovation design (ED), and regional priorities (RP). Each of these topics represents an area in which a project can earn points by maintaining the minimum requirements that are always based on intent. For the SS topic, for example, it is possible to collect 26 points distributed among eight credits. Each credit in a topic explains the corresponding intent and then states the requirements which can sometimes also refer to a reference or standard. Another example is the EA topic, according to which 19 points can be gained through only one credit: Credit 1, which is the optimization of energy performance. Gaining points in the EA topic is possible only after a project includes the minimum prerequisite, that is, a 10 % improvement of the baseline based on ASHRAE standard 90.1-2007. Additional options are available for maintaining the required and minimum levels for each prerequisite and credit. After the 10 % minimum improvement is achieved, more points can be gained, starting with one point for a 12 % improvement and one point additional for each 2% increment therefore. Certification is awarded based on the total points collected according to the levels previously mentioned (USGBC 2009b).

2.5.2 Research Related to the Integration of LEED and Submittal Management

Many studies have been undertaken with the goals of enhancing green building practices and of developing the LEED rating standards. With reference to LEED-NC, Oberle (2007) discusses and demonstrates a model for developing a decision matrix that balances sustainability and antiterrorism. The antiterrorism aspect is provided as complement to sustainability because of the high demand for security in some specific buildings. The model provides system support for decision makers by including both aspects, which, it is assumed are independent. The matrix compiles the weights according to the proposal from the project engineer, and a total is obtained for both aspects (Oberle 2007).

Syal (2007) categorizes the LEED-NC credits according to three levels: major, moderate, and some. Depending on the role of the contractor in earning the credit, generally, the objective is to enhance the involvement of the contractor in green construction so that he can identify the colour-coded credit; know which level it is; and obtain the references, requirements, and appropriate database (Syle 2007).

LEED was integrated with BIM in the optimization tool developed by Barnes (2009). The tool is in the form of a toolbar linked directly to BIM software. It simply clarifies whether the proposed design or contractor-submitted material complies with LEED requirements. Using a pseudo-code calculation, the tool calculates the credit achieved and communicates it to the designer (Barnes 2009). The carbon "footprint" of a building, on the other hand, is the focus of the Autodesk Green Building Studio, which evaluates designs using Revit software as BIM. The Green Building Studio is a plug-in for Revit that became more widely used after it was certified by the U.S. Department of Energy in 2007. Today, registered web users number 7000, with more than 1000 active projects (Rundell 2008).

Given the influence LEED has had on industry values and practice, as described above, LEED requirements and thresholds were considered when the acceptable ranges of the item evaluation criteria were determined for the evaluation procedures that are presented in this research. After the criteria were defined for a selected submittal item, for each criterion, LEED certification was investigated in order to identify the requirements related to the criteria.

2.6 Multi-Criteria Decision Analysis (MCDA)

Submittal evaluation involves the analysis of several alternatives and the consideration of multiple criteria, and the process therefore falls into the category of Multi-Criteria Decision Analysis (MCDA) (Zeleny 1981). MCDA tools and techniques can consider criteria that are either quantitative and can be measured, such as material thickness, or subjective and difficult to measure, such as color and aesthetics (Kassab 2007). Submittals often include both types of criteria. Window specifications, for example, can list a thickness of 1.8 mm as a quantitative criterion, and “light brown color-coated” as a qualitative criterion.

MCDA techniques are distinguishable from one another principally in terms of how they process basic information. Some of the MCDA techniques that are most relevant to the evaluation of submittals are linear additive models, the analytical hierarchy process (Ababutain 2002), and the multiple attribute utility theory. Discussion of other approaches to solving problems associated with MCDA can be found in many other studies, such as Belton and Stewart (2001), Hipel (1992), Hipel et al. (1993; 1999), Hobbs and Meier (2000), Roy (1996) and Saaty (1980; 2001).

With respect to commercial decision analysis software, a summary of a survey conducted by the *OR/MS Today*, the journal published by the institute for Operation Research and the Management Sciences, is shown in Table 2-4. The study found that 19 companies produce 28 different packages. Many of the vendors of multiple packages have developed very robust interfaces between their products. These features allow a user to implement a particular package for its intended purpose and then efficiently share the required information with another specialized product. The three techniques that are related to submittal evaluation are discussed briefly in the following subsection.

Table 2-5: Decision Analysis Software Survey Based on Maxwell (2002)

	Applications									
	Trade-offs among multiple objectives	Analysis of uncertainty	Probabilistic dependencies	Risk aversion	Sequential decision making	Multiple stakeholders	All of the above in one model	Number of alternatives?	Number of levels in value or decision tree?	Number of states of a node in a tree?
Analytica	y	y	y	y	y	y	y	y	y	y
cdpGEO 1.0	y	y	n	y	n	y	n	n	n	n
Criterium DecisionPlus (CDP) 3.0	y	y	n	y	n	y	n	n	n	n
Crystal Ball 2000	n	y	y	n	n	n	n	n	n	n
DATA 4.0	y	y	y	y	y	y	y	y	y	y
Decision Explorer	y	y	n	y	y	y	-	y	-	y
Decision Programming Language (DPL)	y	y	y	y	y	n	y	y	n	y
DecisionPro 4.0	y	y	y	y	y	y	y	n	n	n
The DecisionTools Suite	y	y	y	y	y	n	n	-	y	y
EQUITY	y	y	n	n	n	y	y	y	n	n
Expert Choice 2000, 2nd Edition	y	y	y	y	-	y	n	n	n	n
Frontier Analyst	y	n	n	n	n	n	-	-	-	-
HIVIEW	y	y	n	n	n	y	y	n	n	n
Hi Priority	y	n	n	y	n	y	y	n	y	n
Impact Explorer	y	y	n	y	y	y	-	y	-	-
Joint Gains	y	n	n	n	n	y	y	n	n	n
Logical Decisions for Windows 5.1	y	y	n	y	n	y	y	n	n	-
Netica	y	y	y	y	y	y	y	n	n	n
NoRegrets	y	n	n	y	n	y	y	n	y	n
OB Run	y	n	n	y	n	n	y	y	y	n
OnBalance	y	n	n	y	n	y	y	n	y	n
Opinions-Online	n	n	n	n	n	y	y	n	n	n
PRIME Decisions	y	y	n	n	n	n	y	n	n	n
Risk Detective	y	y	y	y	y	y	y	n	n	y
TreePlan	n	y	y	y	y	n	n	-	-	-
WINPRE	y	y	n	n	n	y	y	y	y	n
Web-HIPRE	y	n	n	n	n	y	y	n	n	n

2.6.1 The Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) was developed by Thomas L. Saaty (1980; 1990) in the 1970s. It is one of the most popular methods for making a decision when multiple alternatives and criteria are involved (Zahedi 1986; Golden et al. 1989; Shim 1989). AHP uses procedures for deriving the weights and the scores achieved by alternatives, which are based, respectively, on pairwise comparisons of criteria and of alternatives. Thus, for example, in assessing weights, the Decision Maker (DM) is posed a series of questions, each of which asks how important one particular criterion is relative to another for the specific decision being addressed.

The strengths and weaknesses of the AHP have been the subject of substantial debate among specialists in MCDA (Zahedi, 1986; Golden et al., 1989; Shim, 1989; Goodwin and Wright, 1998; and French 1988). More recently, Saaty (2001) has developed the Analytic Network Process (ANP), which is a generalization of AHP.

2.6.2 Linear Additive Model

A linear additive model is used when the criteria are independent of one another and when uncertainty is not formally built into the MCDA model. The linear model shows how an alternative's values that are based on many criteria can be combined into one overall value. The value score for each criterion is multiplied by the weight of that criterion, and then the weighted scores are added together. However, this simple arithmetic is appropriate only if the criteria are mutually independent. In linear additive models, MCDA is commonly applied in two stages:

- Scoring: The expected consequences of each alternative are assigned numerical values.

- Weighting: For each criterion, a numerical weight is assigned that defines its relative contribution to the final decision. The overall preference score, or value, for each alternative is simply the weighted summation of its values for all the criteria. Letting the preference value for alternative *i* on criterion *j* be represented by V_{ij} and the weight for each criterion be W_i, then for q criteria, the overall score, v_i^j for the i^{th} alternative, can be calculated as follows:

$$V_i = V_{i1}W_1 + V_{i2}W_2 + V_{i3}W_3 + \ldots\ldots + V_{iq}W_q = \sum_{j=1}^{q} V_{iq}W_q \qquad (2\text{-}1)$$

Thus, scoring and weighting are the most challenging aspects of MCDA techniques. The above method is suitable if all data can be expressed quantitatively. For some decision problems, criteria or alternatives are difficult to express entirely in a quantitative form, or they are not feasible in some situations. It is then recommended that the elimination method be used, which has the advantage of allowing the alternatives to be ranked without using quantitative weights.

2.6.3 Multiple Attribute Utility Theory

The breakthrough in multiple attribute utility theory (MAUT) is the work of Keeney and Raiffa (1976). They developed MAUT, in which a set of procedures allows DMs to evaluate alternatives against multiple criteria. Their procedure establishes a utility function for each criterion, as a representation of a pre agreed-upon satisfaction level associated with different values for that criterion. A sample utility function is provided in Figure 2-6, which shows the utility values of 1.0, 0.9, 0.5, and 0.0 associated with a contractor’s bid price (criterion) of 2.6, 2.7, 2.8, and 3.0 million dollars, respectively. In this case, the utility value u (0 to 1.0) on the vertical axis represents the pre-agreed-upon level of satisfaction for the criterion values. The benefit of determining a pre-set utility function, therefore, is to remove bias decision process and to facilitate the automation of the evaluation of possible decisions.

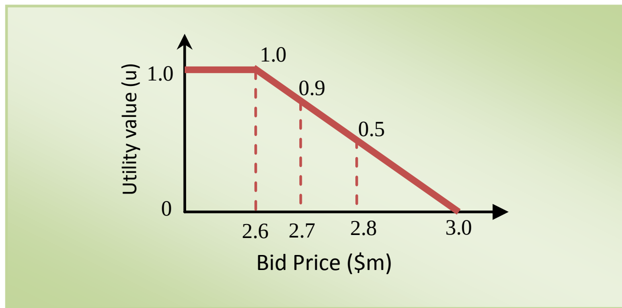


Figure 2-6: Utility Function for the "Bid Price" Criterion

In the case of decisions that involve multiple criteria, the alternative that maximizes the total expected utility, considering the criteria weights, is selected (Kilgour 2007). In other words, when utility analysis is used and the criteria are known to the contractors before they submit the material, they will try to maximize the item's utility in order to speed up the approval process and avoid any cost implications.

A critical step in MAUT analysis is the determination of a suitable utility function form for each criterion. With this goal, several studies have been carried out, such as those by Du and Chen (2007), Halter and Dean (1971), Musser et al. (1984), Keeney and Raiffa (1976), Pena-Mora and Wang (1998), Mumpower (1988), Darling and Mumpower (1990), Zuhair et al. (1992), Lin et al. (1974), Kersten (2001), Lin and Chang (1978), and Zeleznikow et al. (2007). In this research, the form of a utility function depends on the preferences and criteria values of the consultant and his/her organizational objectives. The general form of a utility function can be expressed mathematically as follows:

$$f(x) = a_n x^n + a_{n-1}x^{n-1} + \ldots + a_1 x + a_0 \tag{2-2}$$

Polynomial function: $f(x) = a_n x^n + a_{n-1}x^{n-1} + \ldots + a_1 x + a_0$ (2-2)

where $f(x)$ is the utility function, x is an input variable, n is the power of the function, and a is a real number coefficient. However, among MAUT's benefits is the fact that utility functions can be determined differently to reflect the risk attitude (or tolerance) of the decision maker with respect to various criterion values. Figure 2-7 shows three utility functions that represent three types of risk attitudes: risk-averse, risk-seeking, and risk-indifferent. When each criterion has been presented with one of these utility functions and the relative weights of the criteria are known, the analysis process becomes dynamic, responsive to the preferences of decision makers (DMs), and simple to automate. Such benefits make MAUT analysis suitable for developing a decision support system (DSS) for submittals evaluation.

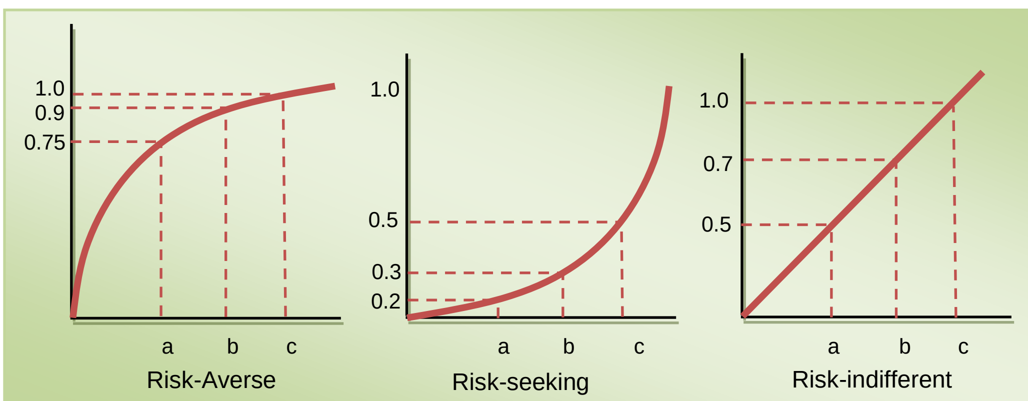


Figure 2-7: Different Utility Functions with Different Risk Attitudes (Moore 2001)

For this research the MAUT was used in order to develop a decision support system for determining the best-value condition for approving a promising submittal, considering construction- and operation-related criteria. Utility functions were established for each criterion in order to reflect the technical parameters and organizational preferences. A detailed discussion of the MAUT is included in Chapter 4.

2.7 Conclusion

This chapter has reviewed the literature related to specifications and construction submittals. A number of computerized systems are available for managing submittals, all of which work well as registers and document management subsystems for tracking each submittal. None of these systems, however, provides decision support regarding the acceptance or rejection of submittals that takes conditional acceptance and the operational impact into consideration.

Chapter 3
Analysis of Building Submittals

3.1 Introduction

Underestimating the impacts of critical submittals due to limited evaluation time may cause interruptions in the construction process, increased operational costs, and changes in the planned maintenance schedule. Critical submittals are ones that contain data about critical items. Critical items are defined as those items that primarily determine the performance and operational cost of the building in addition to user and owner satisfaction. Furthermore, they have a direct impact on the use of resources (energy/water) and the maintenance schedule. Such concerns have a direct relationship with one of the objectives of the concept of green building, which calls for efficient use of resources such as energy and water. This chapter presents details about the data collection process and the analysis that was carried out in order to identify key building submittals and to select one for further investigation.

3.2 Data Collection Process

The data collection process for this research involved several steps that were repeated in cycles. Figure 3-1 is a diagram of the general process of collecting data about submittals. The process began with the contacting of initial sources in order to determine their willingness to provide data. Three organizations were approached and asked for data in a variety of forms such as drawings and documents. Interviews with experts at the organizations were essential as well, since the drawings and documents were not detailed enough to describe the process of evaluating submittals. The interviews also confirmed the results of the analysis at this stage of the research.

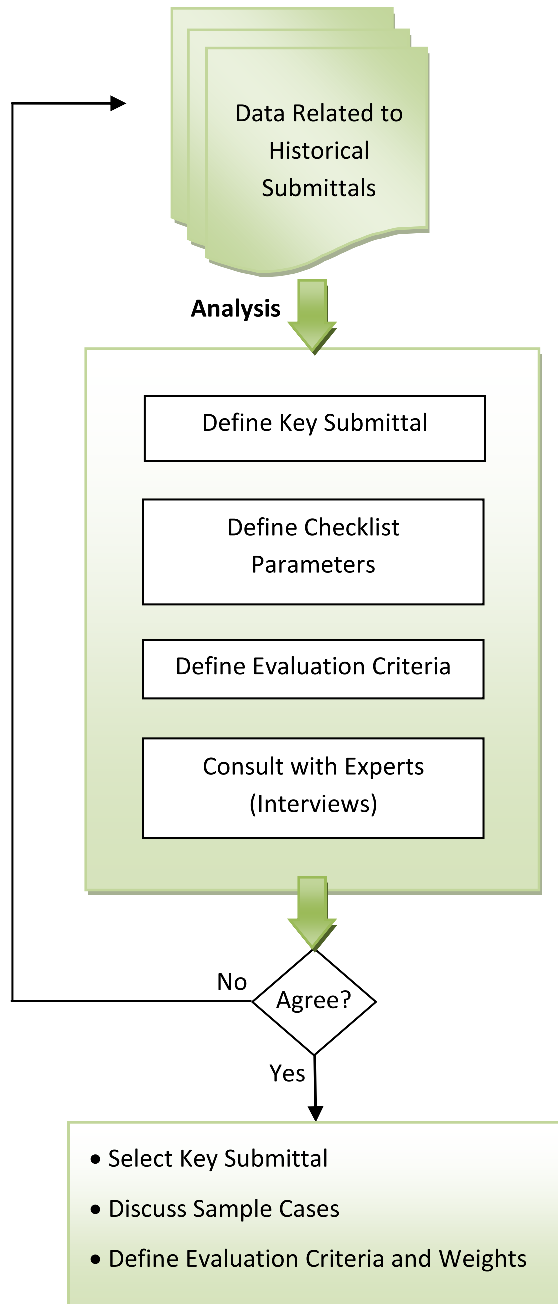


Figure 3-1: Data Collection Process

3.3 Sources of Data

Public organizations were the preferred data source because they administer many projects and may be expected to conduct structured evaluation of submittals. It was also necessary to collect data from organizations who deal with projects not only during construction but also often after they are operational.

Three public organizations were consulted for this study: the Toronto District School Board (TDSB), the University of Waterloo (UW) facilities and maintenance office (www.uwaterloo.ca), and the King Fahd University of Petroleum and Minerals (KFUPM) in Saudi Arabia (www.kfupm.edu.sa). As well, the consulting firm Zuhair Fayz Partnership Consultant Company, (ZFP) (http://www.zfp.com/) also provided data. The TDSB monitors the construction of its more than 550 schools, which requires frequent procurement of a large amount of building equipment. KFUPM and UW are large institutions that supervise many on-and off-campus academic activities. ZFP, on the other hand, operates as a governmental consultant for public projects and has extensive experience in submittal evaluation. Each of the participating experts from these organizations has at least 15 years of experience in project management, and they are all in charge of reviewing submittals and directing the approval process during construction. The three public organizations and the consulting office were contacted several times via e-mail, phone calls, and site visits. They extended their full cooperation, provided access to their files, and devoted time for meetings and reviews. Table 3-1 lists these experts and their organizations. Their names have been withheld for privacy reasons.

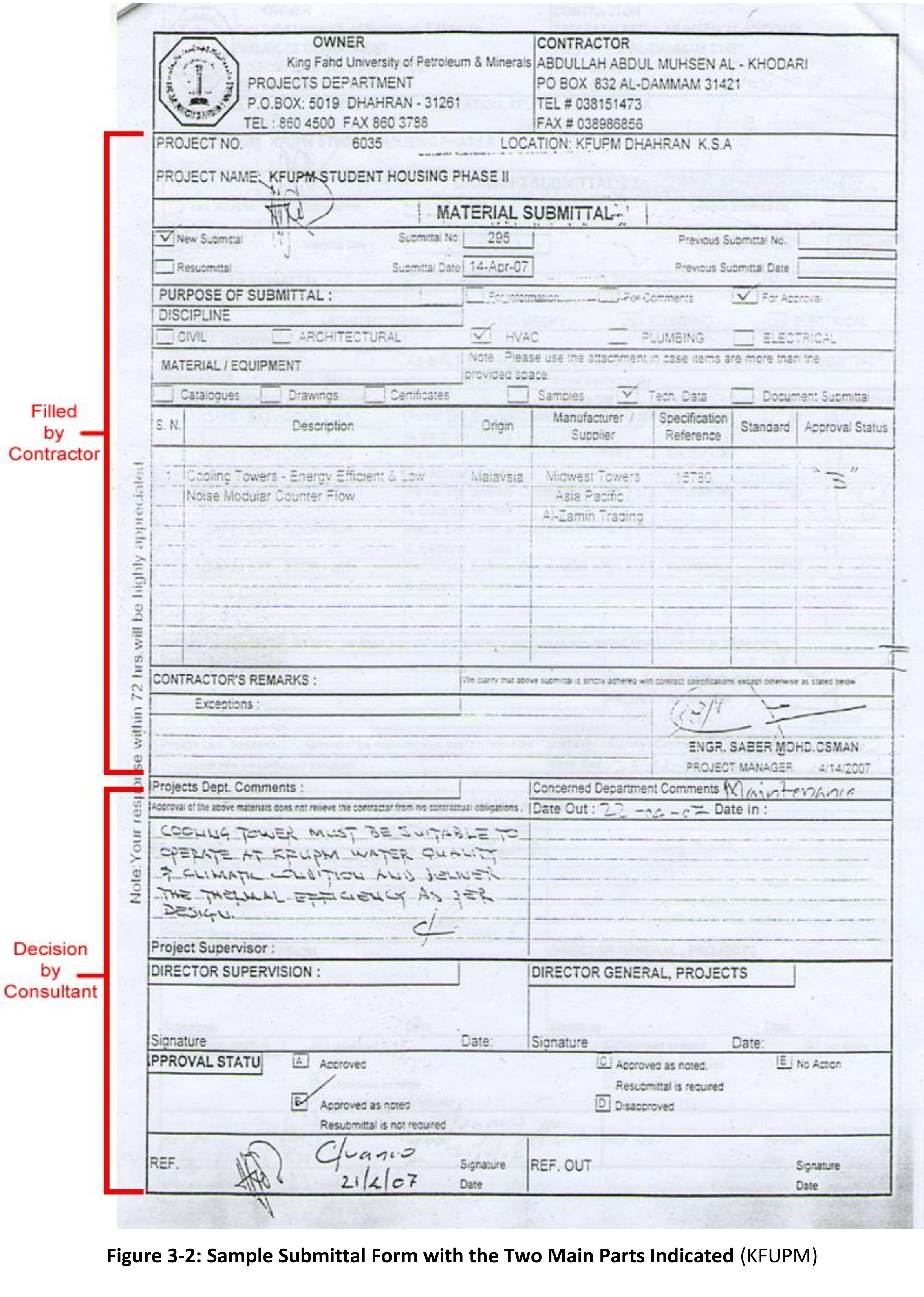
Table 3-1: Experts who participated in the research

Experts initial	*Specialization*	*Organization*	*Department*
Eng. M	Architect	Zuhair Fayz Partnership	Project Supervision
Eng. Y	Mechanical Engineer	King Fahd University of Petroleum and Minerals (KFUPM)	Project
Eng. W	Civil Engineer	King Fahd University of Petroleum and Minerals (KFUPM)	Maintenance
Eng. E	Civil Engineer	Toronto District School Board (TDSB)	Projects Management
Eng. A	Mechanical Engineer	Toronto District School Board (TDSB)	Projects/Mechanical
Eng. R	Mechanical Engineer	University of Waterloo (UW)	Maintenance and utility

3.4 Collected Data

Three types of data were collected for this research: historical submittal packages, historical submittal logs, and general specification guidelines. As presented in the following subsection, these types of data were analyzed in detail in order to define the key submittals. The appendix includes some of the raw data collected.

Submittal forms, a sample of which is shown in Figure 3-2, are the main documents produced by the contractor to initiate the submittal process; other samples are included in Appendix A. As noted in Figure 3-2, the form is divided into two parts: one for the contractor's descriptions of the submitted material/item, and the other for the consultant's decision. In the contractor's section, the contractor defines the type of submittal and provides a short description of the item submitted, such as the manufacturer and/or supplier, in addition to references to the specifications and standards. The submittal-related discipline is indicated by the contractor on the submittal form. Once the submittal package is completed, it is sent to the consultant/evaluator.



OWNER
King Fahd University of Petroleum & Minerals
PROJECTS DEPARTMENT
P.O.BOX: 5019 DHAHRAN - 31261
TEL : 860 4500 FAX 860 3788

CONTRACTOR
ABDULLAH ABDUL MUHSEN AL - KHODARI
PO BOX 832 AL-DAMMAM 31421
TEL # 038151473
FAX # 038986856

PROJECT NO. 6035 LOCATION: KFUPM DHAHRAN K.S.A

PROJECT NAME: KFUPM STUDENT HOUSING PHASE II

MATERIAL SUBMITTAL

☑ New Submittal — Submittal No. 295 — Previous Submittal No.

☐ Resubmittal — Submittal Date 14-Apr-07 — Previous Submittal Date

PURPOSE OF SUBMITTAL : ☐ For Information ☐ For Comments ☑ For Approval

DISCIPLINE

☐ CIVIL ☐ ARCHITECTURAL ☑ HVAC ☐ PLUMBING ☐ ELECTRICAL

MATERIAL / EQUIPMENT — Note: Please use the attachment in case items are more than the provided space.

☐ Catalogues ☐ Drawings ☐ Certificates ☐ Samples ☑ Tech. Data ☐ Document Submittal

S. N.	Description	Origin	Manufacturer / Supplier	Specification Reference	Standard	Approval Status
1	Cooling Towers - Energy Efficient & Low Noise Modular Counter Flow	Malaysia	Midwest Towers Asia Pacific Al-Zamin Trading	15780		

CONTRACTOR'S REMARKS :

Exceptions :

We certify that above submittal is strictly adhered with contract specifications except otherwise as stated below

ENGR. SABER MOHD.OSMAN
PROJECT MANAGER 4/14/2007

Note: Your response within 72 hrs will be highly appreciated

Projects Dept. Comments :

Approval of the above materials does not relieve the contractor from his contractual obligations.

COOLING TOWER MUST BE SUITABLE TO OPERATE AT KFUPM WATER QUALITY & CLIMATIC CONDITION AND DELIVER THE THERMAL EFFICIENCY AS PER DESIGN.

Concerned Department Comments Maintenance

Date Out : 22-04-07 Date In :

Project Supervisor :

DIRECTOR SUPERVISION :

DIRECTOR GENERAL, PROJECTS

Signature Date:

Signature Date:

APPROVAL STATUS

☐ A Approved

☑ B Approved as noted. Resubmittal is not required

☐ C Approved as noted. Resubmittal is required

☐ D Disapproved

☐ E No Action

REF. 21/4/07 Signature Date

REF. OUT Signature Date

Figure 3-2: Sample Submittal Form with the Two Main Parts Indicated (KFUPM)

The second part of the submittal form (Figure 3-2) provides space for recording the decision of the consultant/evaluator. The form lists five possible decisions: A) approved, B) approved as noted (resubmittal is not required), C) approved as noted (resubmittal is required), D) disapproved, or E) no action. One submittal form can be used to evaluate more than one alternative for a single item, in which case, the decision for each alternative is recorded in the appropriate row in the approval status column where the contractor has suggested alternatives (Appendix A-6)

A variety of submittal packages (Figure 3-3) from all disciplines were collected from the sources in Table 3-1 and 653 were analyzed. A summary of those submittals is provided in Table 3-2. As shown, the electrical submittals are divided almost equally between shop-drawings and material/equipment.

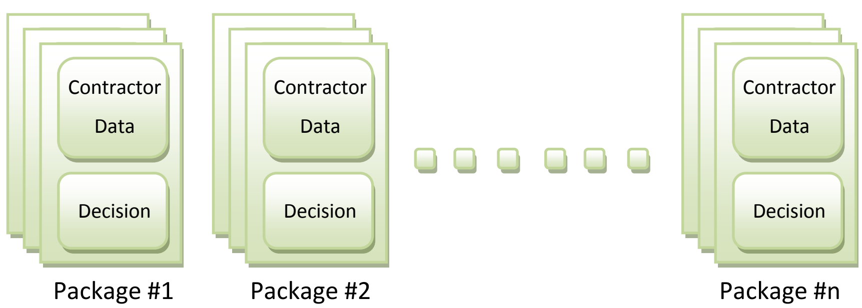


Figure 3-3: Historical Submittal Packages Diagram

Table 3-2: Summary of the Analysis of the Submittal Packages

Submittal Type	Total Submittal Packages	Submittal Packages by Discipline						
		Mechanical	Electrical	Structural	HVAC	Civil	Architecture	Fire System
Material/Equipment	327	101	52	0	75	25	58	16
Shop-Drawings	326	53	66	51	12	31	102	11
Total Packages	653	154	118	51	87	56	160	27
Approved in 1st Round	397	89	86	31	36	41	93	21
Require Resubmittal	256	65	32	20	51	15	67	6
% Resubmitted/Rejected	39%	42%	27%	39%	59%	27%	42%	22%

As an indication of the process of evaluating submittals, the bottom part of Table 3-2 shows for each category, the number of submittals that were approved in the first round. For example, out of the 154 mechanical submittals, 89 were approved during the first round while 65 were rejected or required resubmitting. It can be seen that the HVAC system exhibits the highest number of rejected/resubmitted items (59%). Within the submittal packages, it is noted that a comment from a consultant indicates that the approval of some of the submittals was based solely on the approval of the item for a previous project and that no detailed analysis was conducted.

Submittal logs are the second type of data collected from the TDSB, from UW, and from KFUPM. These logs are mainly an indication of the date IN and OUT for the submittals and the action that was taken for each one. The TDSB log (Figure 3-4) is unique in that it has additional columns for the specification sections, the expected submittal date, and the actual submittal date. TDSB then considers four possible actions, which are listed in the logs: (1) Reviewed (R); (2) Reviewed As

Modified (RM); (3) Revised Re-submit (RR); and (4) Not Reviewed (NR). The last column of the TDSB submittal log is the priority. Appendix B includes some of the samples of submittal logs/registers collected.

25-Apr-07

PROJECT: BROOKSIDE PUBLIC SCHOOL
SHOP DRAWING SUBMITTAL CONTROL SHEETS

ARCHITECTURAL SHOP DRAWINGS:
CONSULTANT [redacted]
ADMINISTRATOR: [redacted]

NOTE: 6 copies to be submitted

PLEASE FORWARD TRANSMITTAL TO SCHOOL BOARD

ACTION TAKEN LEGEND:
1. Reviewed (R)
2. Reviewed As Modified (RM)
3. Revised Re-submit (RR)
4. Not Reviewed (NR)

Section // Article	Specification Section Title	Sub-Contractor	Tnd Drg's Rec'd	S.D. Expected	# of Copies/ Description	Date Rec'd From Contractor	Date Sent To Consultant	Date Rec'd From Consultant	Date Ret'd To Contractor	Action Taken	Copies Ret'd	Notes:	PRIORITY:
8110	Metal Doors and Frames	[redacted]	yes		[illegible] sets (1 to 21)	29-Aug-06	29-Aug-06	13-Sep-06	13-Sep-06	RM	3 copies		
8710	Finish Hardware	[redacted]			5 copies	12-Oct-06	via site	1-Nov-06	1-Nov-06	RR			
	""""""""RESUBMISSION""""""""				1 copy email	18-Dec-06	18-Dec-06	15-Jan-07	15-Jan-07	RM			
	Hardware	CATALOGUE CUTS			5 copies	19-Oct-06	19-Oct-06	1-Nov-06	1-Nov-06	R	5 copies		
14240	Hydraulic Elevators	[redacted]	yes		5 copies (incl color chart	14-Sep-06	via site	25-Sep-06	25-Sep-06	RM	3 copies	[redacted]	
08440/ 08800/8620	Alum Framed glazing sys/ /glass	[redacted]	Yes	18-Dec-06	3 sets	20-Dec-06	via site	25-Jan-07	25-Jan-07	RM/RR		RESUBMIT for Record Purposes	
""""""""""""""""	""""""""RESUBMISSION""""""""	""""""""""""""""	emailed										
8450	Trans Panel System	[redacted]	Yes	21-Sep-06	4 sets (1 to 7)	24-Oct-06	24-Oct-06	15-Jan-07	17-Jan-07	RM	3 sets		
					3 copies panel analysis								
8620	Domed Skyllights	[redacted]			5 copies	11-Oct-06	via site	26-Oct-06	26-Oct-06	RM	4 copies		
5500	Metal Fabrications	[redacted]	Yes	LM	8 sets	5-Jan-07	5-Jan-07	2-Mar-07	2-Mar-07	RM	7 sets		
10665	Gym Dividers	[redacted]	with gym equipment		8 sets	13-Nov-06	13-Nov-06	7-Mar-07	7-Mar-07	RM	5 copies		
7425	Metal Cladding	Commercia [redacted]	yes	31-Jan-07	4 sets (P1 to P21)	31-Jan-07	31-Jan-07	19-Feb-07	21-Feb-07	RM	3 sets		
	""""""""RESUBMISSION	P1,P9,P10,P21""""""""			4 sets	6-Feb-07	6-Feb-07	13-Mar-07	13-Mar-07	RM	3 sets		
7427	Zinc cladding & Flashing												
11010	Fall Arrest Anchors	[redacted]			6 prints	7-Sep-06	7-Sep-06	14-Sep-06	14-Sep-06	RM		[redacted]	

Figure 3-4: Sample of Submittal Log Provided by the TDSB

The TDSB provided a log for North Toronto Collegiate Institute as of February 18, 2009, which contains data for 136 submittals. The log is organized by number of the specification section, and the items are then listed in numerical sequence. The Date Rec'd From Contractor and Date Ret'd To Contractor for each registered submittal gives an indication of the processing time. The average processing time for the first round was calculated to be about 34 days for this particular project. It was expected that the second round (resubmission processing) would take less processing time, but the average for the second round was almost the same as for the first.

Another interesting submittal log received from ZFP and entitled "Long Lead Material Submittal Schedule" log, was used to track the long lead material and equipments (Appendix B-6). A unique log such as this one gives an indication of the process used for critical material/equipment items in construction. A review of this log shows that it covers only three disciplines: architecture, mechanical, and electrical (Table 3-3). The majority of items are architectural (63%), while the mechanical items represent only 25%, and the electrical items make up the remaining 12%. Within the mechanical category, 75% of the items are HVAC components.

The third type of data collected is the general specification guidelines, which include many pages of standard details. A chiller specification example collected from the TDSB includes about 113 pages of text. There is an extremely wide range of design aspects and building components associated with standards, and the data of these standards are dynamic (Garrett 1992); therefore, the specification writer should always ensure the compatibility of the standards' current data with the requirements of the organization. While these details are important, the large volume of information makes the submittal evaluation complex and time consuming, particularly when the evaluation criteria are not defined. Appendix C-1 and C-2 presents sample pages for chiller specification.

Table 3-3: Long Lead Material/equipment Submittals (ZFP)

Discipline	No.	Description
Architecture	1	Specialty stone supplier
	2	Mild steel balustrade and turnstiles
	3	Gratings
	4	Laboratory Casework
	5	General fitments – pegboards
	6	Waterproofing
	7	Wood doors
	8	Storefronts (glazed)
	9	Door (metal frame)
	10	Door hardware
	11	Louvered ceiling
	12	Metal faceted ceiling
	13	Tack board
	14	Louver (sand trap)
	15	Lockers
	16	Toilets and bath accessories
	17	Projection screen
	18	Unit kitchen
	19	Laboratory hoods
	20	Auditorium seating
	21	Walk-in cold room
Mechanical	22	Hydraulic elevator
	23	Acid waste pipes
	24	Chillers
	25	Air-handling unit
	26	Fan coil units
	27	Package unit
	28	Roof exhaust fan
	29	Fume extraction system
Electrical	30	Building automation system
	31	Fire alarm and detection system
	32	LV distribution switch gear
	33	Motor control centre

3.5 Indentifying Key Submittal Items

To identify the key submittals, interviews with experts were conducted in order to discuss the list of long lead material submittals, as well as the initial analysis of the submittal packages and the submittal logs collected. The objective was to identify the top 10 key submittals. Figure 3-5 illustrates the process that was followed:

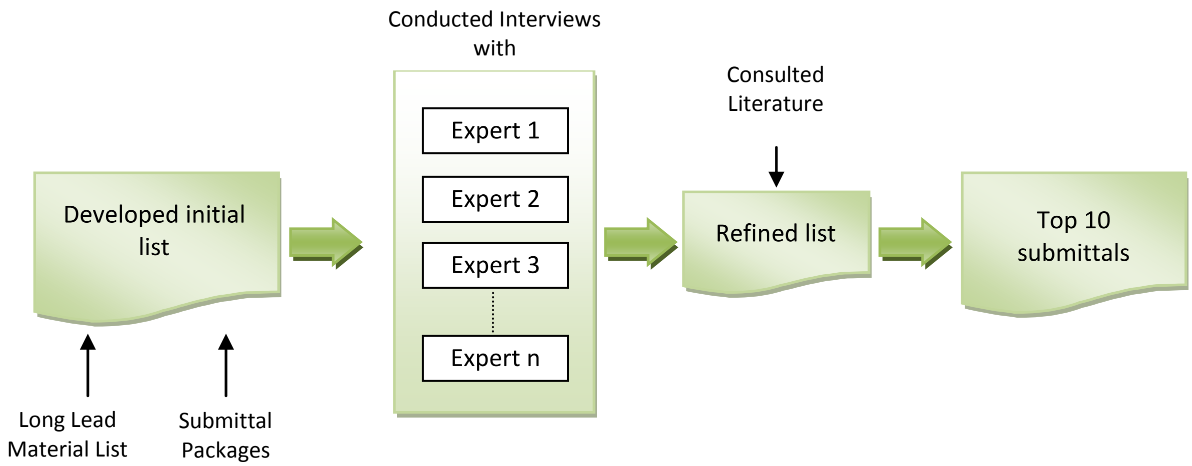


Figure 3-5: Process for Identifying Key Submittals

Interviews were conducted with the experts related to the participating organizations. During the interviews, criticality considerations were discussed, and it was concluded that an item can be considered critical when at least one of the following conditions apply:

1. It is manufactured away from the project site (overseas).
2. It requires customization by a specialized party.
3. Dealership/product support is located at a distance from the project location, which affects repair time.
4. It requires a designated space and installation process.
5. It has many successors in the construction schedule.

Criticality considerations thus seem to be construction-related, apply most to major building equipment, and affect the time needed for evaluating submittals. The discussion with the experts revealed that the most time-consuming items during a submittal review are the boiler and the chiller. This equipment involves technical drawings that must be reviewed, items that must be outsourced and procured, customization, dedicated space, an installation process, and testing and commissioning. In addition to these construction-related aspects, all the interviewees agreed that this equipment has a significant impact on the building operation as well. Of the HVAC items, for example, the chiller has the greatest impact on the operational costs of the building. Based on the interviews, the evaluation of a chiller submittal is time consuming and should be approved early in the project in order to ensure its procurement. After the interviews with the experts were concluded and analyzed, an initial list of key submittals was developed, as shown in Table 3-4.

Table 3-4: Initial Key Submittal Items

No.	***Critical item***
1	Chiller
2	Boiler
3	Electrical Panel Board
4	Fan Coil Unit
5	Package Unit
6	Fume Extraction System
7	Air Handling Unit
8	Exhaust and Ventilation Fans
9	Motor Control Centre
10	Building Automation System
11	Security/Access system
12	Lighting Fixtures
13	Sound/Address System
14	Pump
15	Cooling Tower

This list was then ranked by the experts during several rounds of interviews. The ranks assigned are shown in Table 3-5:

Table 3-5: Assigned and Average Ranks for Key Submittal items

	Key Submittals	***Expert M Rank***	***Expert R Rank***	***Expert Y Rank***	***Expert A Rank***	***Average Rank***
1	Chiller	1	1	1	1	1
2	Boiler	2	2	1	5	2.5
3	Electrical Panel Board	5	*15	15	15	12.5
4	Fan Coil Unit	15	4	3	3	6.25
5	Package Unit	15	15	15	15	15
6	Fume Extract System	15	15	15	15	15
7	Air-Handling Unit	3	4	3	3	3.3
8	Exhaustion/Ventilation Fans	4	7	6	3	5
9	Motor control centre	6	6	5	6	5.8
10	Building Automation System	7	15	7	15	11
11	Security/Access System	9	15	10	15	12.25
12	Lighting Fixtures/Type	8	9	8	10	8.8
13	Sound Address System	10	15	11	15	12.75
14	Pump	11	5	4	4	6
15	Cooling Tower	15	3	2	2	5.5

* 15 is replacing the 0 given rank by experts to reflect the least choice

According to Table 3-5, the 10 top key submittals are listed in the following Table (Table 3-6)

Table 3-6: Assigned and Average Ranks for Key Submittal items

Rank	**Key Submittals**	**Average Rank as Given in Table3-5**
1	Chiller	1
2	Boiler	2.5
3	Air-Handling Unit	3.3
4	Exhaust/Ventilation Fans	5
5	Cooling Tower	5.5
6	Motor Control Centre	5.8
7	Pump	6
8	Fan Coil Unit	6.3
9	Lighting Fixtures/Types	8.8
10	Building Automation System	11

It should be noted that the literature contains an interesting study by the Federal Energy Management Program (FEMP) in which they explored 10 items that are essential for operation and maintenance (O&M): air compressors, boilers, the building automation system, the chiller, the cooling tower, fans, lighting, motors, pumps, and steam traps (U.S. Department of Energy 2009). A comparison of these items to those in the final key submittal list shows eight items in common. Based on data for a typical office building of 60,000 ft^2, HVAC consumes about 30 % of the annual building energy cost in a northern climate and about 50 % of the building's energy in a warm, humid climate (Marriott 2006). In the United States, cooling a building requires one of every five kilowatt hours consumed. Not only does air conditioning consume 18 % of the electricity, it also contributes to global warming by releasing refrigerants into the atmosphere (Watts, 2008). The lighting system consumes 17 % of the electricity, as indicated by the U.S. Environmental Protection Agency (EPA) green building working group, who also include it in the critical list.

The following is a summary of other points that were discussed during the interviews:

- For some items such as the proposed security/access system and sound/address system criticality is related to the function of the building. These items are sometimes called application based items.

- Because water is a very important resource, controlling water consumption is mandatory. The main components that determine water consumption are the faucets, flushing, and showers. According to the LEED requirements in LEED-NC credit 3, water use can be reduced by maintaining the right fittings. LEED therefore provides baselines for faucets, flushing systems, and showerheads so that they can be regulated. They also provide the additional water consumption incentive of giving LEED points for reducing consumption below the baseline (USGBC 2009c). Water consumed in buildings ranges between 13.6 % and 16 % of the total use of potable water in the U.S., or 15 trillion gallons per year (USGBC 2009a and USGS 2000).

- Based on his experience, Eng. R, during an interview on Thursday, November 5, 2009, indicated that "faucets, flushing, and showers" should not be included in the list but that the "control and insulation valve" should be considered instead.
- Light fixtures as an item was emphasized by all interviewees as a critical electrical item that has a major impact on energy consumption.
- Disagreement arose with respect to the building automation system/building management system (BMS). Eng. E considers its characteristics to be different from those of other items. For him, such a system is not an item; it is system that controls and regulates the work of other items. The same point was raised by Eng R, who supports not including the building automation system in the list as an item. However, all agreed on its positive impact on power consumption.

3.6 Selecting a Key Submittal for Further Analysis

Since the chiller is the top-ranked submittal item identified in this research, it was further analyzed in order to develop a decision support system that would facilitate the evaluation of this key submittal item. To enable the evaluation, a clear understanding of the parameters that govern the performance of the chiller was required, as explained in this section. It was also determined that designers should clearly define the requirements for all the parameters in their specifications.

A chiller is the greatest consumer of energy in the HVAC system. The refrigerant gas that harms the atmosphere is contained in the chiller. It also includes minor components such as the compressor, condenser, expansion valve, and heat exchanger. Altering the parameters of these components can affect operation in terms of energy consumption and human comfort and may also harm the environment (Sofronis and Arampatizs 2005). Jayamaha (2006) presents a chart with respect to typical end-user consumption, which also indicates that the chiller is the greatest consumer at 42 % (Figure 3-6). It represents the largest electrical load on the system and can normally adds hundreds of thousands of dollars to operating costs for a typical office building (Grenz 2004).

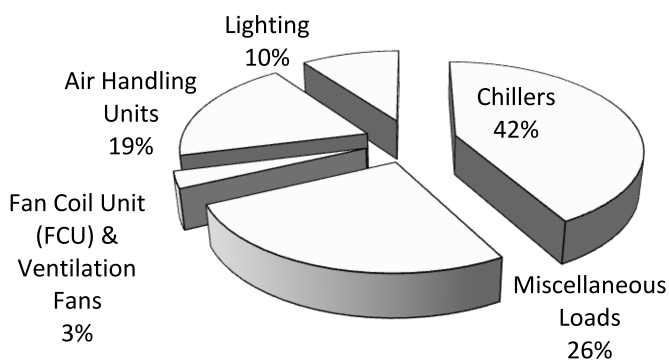


Figure 3-6: Typical End User Consumption (Jayamaha 2006)

The diagram developed by Marriott (2006) illustrates the energy consumption of a typical 60,000 ft^2 office building: it presents the chiller as the greatest consumer of, at with 33 % in a warm, humid climate and at 12% in a northern climate (Marriott 2006) (Figure 3-7).

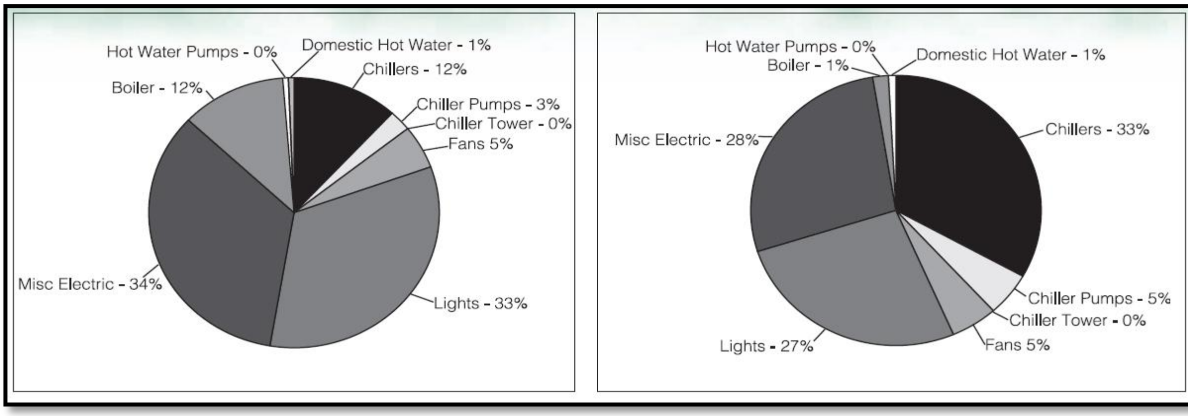


Figure 3-7: Energy Consumption of a 60,000 ft^2 Office Building in a Northern and in a Warm, Humid Climate

(Marriott 2006)

It can be concluded from such information that this item requires an in-depth evaluation and that is should be considered the most critical item. A chiller can be either an air- or water-cooled system. A study by Naguib (2009) compared the lifecycle cost of these two types of systems over a 20-years lifecycle, including initial, energy, and maintenance costs. The study concluded that a water-cooled chiller is more costly over its lifecycle. The study examined a variety of capacities from 100 to 500 tons, and covered six climatic zones in the United States. In addition to being costly, with respect to initial expenses, energy consumption, and maintenance, its expected lifecycle is longer than that of an air cooled machine (Naguib 2009). A water-cooled chiller has a range of capacities, depending on the type of compressor. These ranges can be divided into five categories, as shown in Table 3-7 (SHRAE SI 2000).

Table 3-7: Chiller Capacities for Different Types of Compressors

Compressor types	**Capacity range**
Reciprocating or Scroll	up to 90 KW
Screw, Reciprocating, or Scroll	90 to 280 KW
Screw, Reciprocating, or Centrifugal	280 to 1600 KW
Screw or Centrifugal	1600 to 3500 KW
Centrifugal	3500 KW

The compressor, along with the condenser, evaporator, and expansion device, are the four main components of a chiller. The compressor is the main part of the chiller and determines the workability of the machine. Based on the working mechanism, compressors can be divided into two groups: positive-displacement, which includes reciprocating, scroll, screw, and trochoidal, and dynamic, which represents a centrifugal compressor. The measure of performance of the chiller is derived from the compressor and is indicated by the power input value. An evaluation of a chiller submittal is based on data that should be provided by the contractor and is determined by the predefined criteria and parameters. These parameters and criteria are developed according to the data (such as document) collected from the field that is presenting the chiller parameters for evaluation, and they are required for all stages of the design, construction, and operation of the project. For this study, data were extracted from submittal packages and through interviews with the project engineers in order to provide the parameters shown in Table 3-8.

Table 3-8: Chiller parameters

No.	Parameter	No.	Parameter
1	Company	28	Fan Type
2	Model Number	29	Number of Fans
3	Country of Origin	30	Condenser Tubes
4	Number of Pieces (Chiller)	31	Condenser Fans Size (mm)
5	Cooling Capacity (T.R.) (ton)	32	Cooler Tubes
6	Power Consumption (kW/T.R.)	33	Fans Horse Power
7	EER (MBH/kW)	34	Evaporator Entering Fluid Temperature
8	IPLV/NPLV	35	Evaporator Leaving Fluid Temperature
9	Compressor Power Supply	36	Evaporator Gallons per Minute
10	Design Ambient	37	Evaporator Pressure Drop
11	Compressor Type	38	Evaporator Fouling Factor
12	Number of Compressors	39	Sound Power Level (dBA)
13	Refrigerant Type	40	Sound Pressure Level
14	Condenser Entering Fluid Temp	41	Casing Material
15	Condenser Leaving Fluid Temp	42	Casing Finish
16	Condenser Gallons per Minute	43	Lifecycle
17	Condenser Fouling Factor	44	Face Velocity
18	Condenser Pressure Drop	45	Total Face Area Ft^2
19	Condenser Water Box	46	Total Air Flow CFM
20	Condenser Fan Power Input (kW)	47	Test Pressure (Psi)
21	Condenser Motor Insulation	48	VFD Cooling
22	Control Type	49	Technical Support
23	Starter Type	50	Training
24	Number of Coolers	51	Dimension L x W x H
25	Circuiting	52	Weight
26	Number of Circuits	53	ARI Certificate
27	Motor Cooling Means	54	UL (Safety Standard)

Some mandatory parameters can be different in value and approval tolerance for different chiller sizes. For example, a small-capacity chiller has only one starter type while large machines typically involve choices. The type of chiller selected for the investigation and that will be used as the critical item for evaluation is a centrifugal chiller, which is representative of large-capacity chillers.

3.7 Conclusion

This chapter has presented the process of data collection and has defined key building submittals. The list of key building submittal includes 10 different items related to mechanical and electrical equipment and materials. According to both experts and the literature, in an HVAC system, the chiller consumes the most power. Its parameters were extracted and compiled from the submittal packages collected to be used as the basis for developing evaluation criteria, as described in the next chapter. All data analyzed indicates a need for a decision support system for submittal evaluation. The centrifugal chiller was selected for further investigation with the goal of developing an evaluation mechanism that can consider the impact of the submittal evaluation on building operation and maintenance and on project performance.

Chapter 4

Proposed Submittal Evaluation Mechanism

4.1 Introduction

Chapter 3 presented a process of defining key submittals with the help of experts from a number of organizations. It concluded with the selection of an item for investigation and the presentation of the parameters of that item. These steps represent the initial phase in the proposed process that enables an organization to determine critical items and to define their submittal evaluation mechanism. This chapter describes the development of the framework for the general evaluation of submittals. It presents the mechanism whereby any organization can generate and establish a submittal evaluation system and the process of setting up the system based on organizational requirements, including the acceptance checklist, criteria, weights, and utility functions. The critical item selected as explained in the previous chapter (centrifugal chillers) was used as an application for developing the framework, and throughout the development process, feedback was obtained through interviews with engineers from the participating organizations. The application and the development process are also described in this chapter.

4.2 Proposed Evaluation Mechanism

The purpose of a submittal evaluation is to examine all types of material and equipment in order to evaluate their compliance with specifications. This mechanism ensures that all project submittals provide a high enough level of value for the project that the building will perform as desired. As a component of the quality control procedure, submittal evaluation is a generic process that is part of all types of contracts and projects. It provides the opportunity for designers and consultants to recover any shortages that have been incorporated during the design process. The submittal process is typically initiated by the contractor for the owner to compare with the specifications. It therefore applies to every contract in which the owner and the contractor are separate parties (lump-sum, unit price, turnkey, etc.) However, even in a case in which the owner (operator of the building) and the contractor are one entity, a submittal evaluation still plays a critical role in ensuring quality. The typical submittal evaluation process for all types of projects is illustrated in Figure 4-1. As shown, the evaluation process is primarily subjective and results in a yes/no decision, based on the assumption that a rejected submittal provides no value to the project. Because of the lengthy and subjective process involved, it is impossible to provide an assessment of a marginally rejected submittal with respect to areas in which cost-effective changes to the submittal could improve its value for the project. The evaluation process is thus comprised of multiple cycles of costly and time-consuming evaluation.

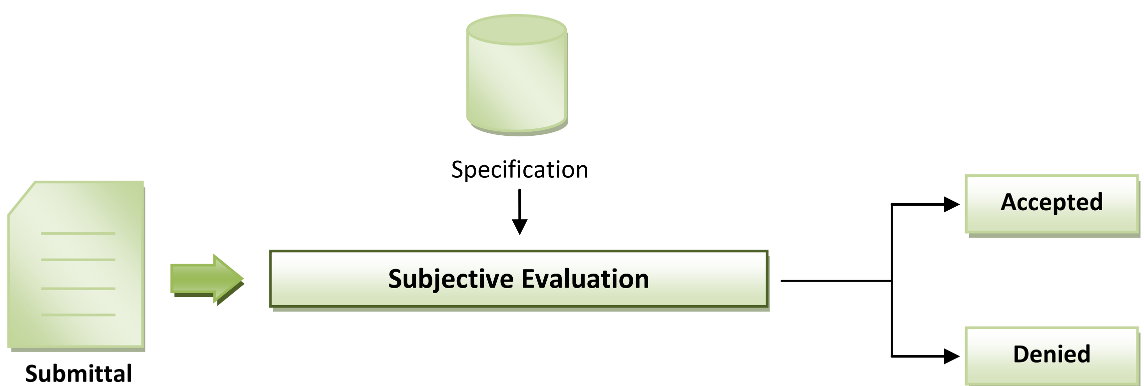


Figure 4-1: Traditional Submittal Evaluation Process

To overcome the difficulties in submittal evaluation and to avoid the subjectivity inherent in the traditional evaluation process, a new evaluation mechanism has been developed, as shown in Figure 4-2.

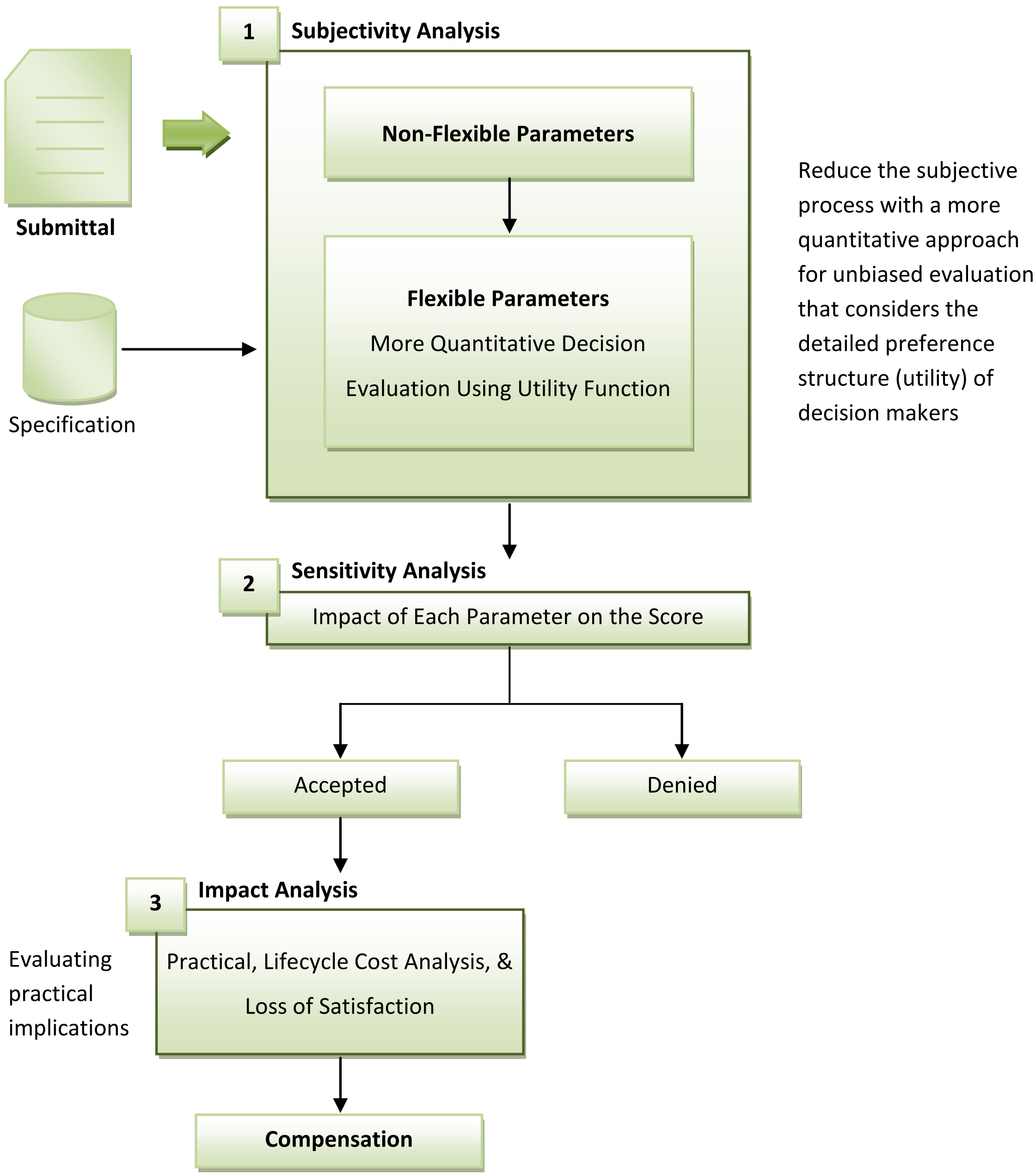


Figure 4-2: Conceptual Representation of the Developed Framework

Conceptually, the process has been designed to achieve three main objectives:

1. Transform the current subjective process into a quantitative approach that avoids bias and explicitly models the preferences of decision makers through an automated evaluation system.
2. Evaluate the short-term (during construction) and long-term (during operation) implications of the submittal and introduce a mechanism that can offset any negative impact.
3. Provide an understanding of how changes to a submittal can affect its acceptability, that is, its value for the project.

Meeting these three objectives will not only improve the speed and accuracy of the evaluation of submittals but will also serve as a mechanism that can provide an understanding of the specification requirements and that can update the project with accurate as-built data, which will be useful at the operational stage.

In the developed framework, the steps shown in Figure 4-2 are the steps that required consideration during the development of a decision support system that would be effective for any type of submittal: subjectivity analysis, sensitivity analysis, and impact analysis.

4.2.1 Analysis of Subjectivity

In the traditional process (Figure 4-1), the subjective evaluation of submittals is the result of the subjectivity in the submittal parameters provided in specifications. The subjectivity involved in the parameters should therefore be closely examined to enable better decision making. In this research, low-subjectivity parameters are thus identified as non-flexible parameters while high-subjectivity parameters, which are characterized by wide ranges of acceptability, are identified as flexible parameters, as illustrated in the top part of Figure 4-2.

The subjectivity level (represented by the extent of the acceptability range) is generally affected by the specific characteristics of the project and the organization. In a hot, dry climate, for example, the UV (ultra-violate) protection of window glass is identified as a parameter that has a narrow acceptability range (subjectivity). The same parameter, however, can have a wide range of subjectivity in a cold, humid environment. Project characteristics, such as climate and project type, a limited budget, and site location can have a variety of effects on the subjectivity associated with a parameter. These characteristics should be evaluated during the parameter analysis stage by experts and engineers who have experience in reviewing similar submittals. If available, the history of an organization's submittal packages should be reviewed in order to identify the consequences of and justification for previous decisions.

Since non-flexible parameters mean no tolerance with respect to acceptance, their specified values must be met by the contractor for submittal to be approved. If the submittal satisfies these non-flexible parameters, the next step is to consider other parameters that have a wider range of acceptability (the flexible parameters section in Figure 4-2). These flexible parameters can serve as criteria for an evaluation that incorporates the decision makers' preferences. Modeling these preferences in an automated system that has no bias requires the use of structured decision analysis technology, such as the multi-attribute utility theory (MAUT). MAUT is capable of transforming the subjectivity in the evaluation of flexible parameters using precise values that define the overall organizational preferences. Because the utility function can be developed even before the project begins, it avoids bias. Such a pre-modeling of decision makers' preferences enables automation and facilitates speedy decisions. MAUT is therefore well suited for this application. The results of the utility function analysis are presented in the form of a score for the submittal, which must be higher than a pre-defined organizational threshold in order for the submittal to be approved.

To develop the utility function, surveys and interviews were conducted in the field, and an attempt was made to minimize biased judgment. Several research studies have discussed data collection problems and ways to increase the absence of bias in the data. The problems include myside bias, the recency effect, the Von Restorff effect, the collective unconscious, the contrast effect, and dominance. An effort was made to avoid these data collection problems in this research.

4.2.2 Analysis of Sensitivity

Sensitivity analysis is considered to be important in examining the effect of variations in the preferences of the organization on the overall evaluation of the submittal. It is also important to examine the influence of each variation in a parameter on the overall submittal value. Such analysis can provide a full understanding of the contribution of each parameter to the overall submittal evaluation and can provide guidance for the consultant with respect to determining the specific parameter that needs to be changed in order to improve the acceptability of the submittal.

4.2.3 Analysis of Impact

The intent of this research is not to provide a "Yes" or "No" answer for the submitted proposal but to provide both a condition under which the submittal can be approved and also an assessment of possible changes that can improve the value of the submittal for the project. In this regard, it is important that any implication of the submittal for construction, operation, and the level of satisfaction be considered. In the short term, the impact on construction includes any extra cost introduced by a design modification, space allocation, storage or transportation requirements, or the consequences of interrupting the progress of the work during construction. The additional operational impact over the long term can be directly assessed through the calculation of any added running cost over the lifecycle of the component, including maintenance, fuel, and electricity. As well as the short-term and long-term implications, it is also important that loss of satisfaction be evaluated (i.e., the amount by which the submittal score differs from 100) as part of the impact of the submittal.

4.3 Proposed Evaluation Procedure

For the model to be adaptable to organizational requirements, the overall mechanism of submittal evaluation has been divided into two essential stages (Figure 4-3): system setup and system use. The system setup is the process whereby the organizational/owner preferences and requirements are set for each item so that the evaluation mechanism can be configured even before construction starts. The process begins with the updating of the list of key submittals so that they correspond to the needs of the organization. As an example, for some buildings, the sound address system may be considered a key submittal, according to the requirements of that specific project. The two-stage approach is especially useful for organizations that have building programs, so that the systems can be set up once and used for multiple projects. An example of such an organization is the TDSB.

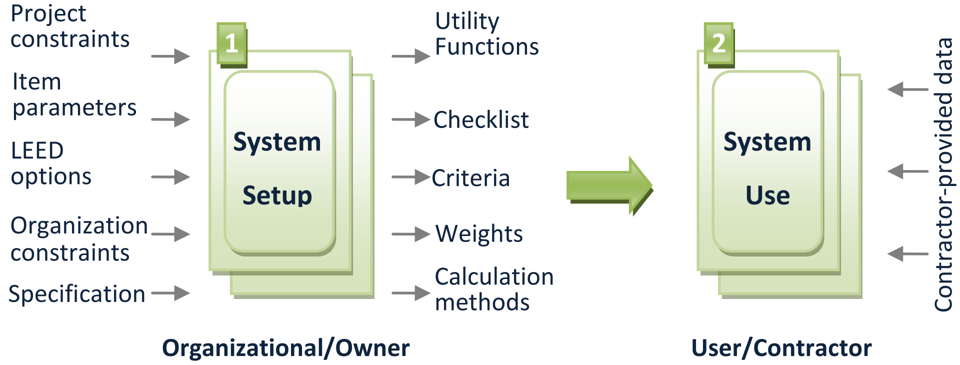


Figure 4-3: Two Main Components of Submittal Evaluation

At the system setup level, the data required include organizational and project constraints, specifications, decision parameters, and LEED considerations, if applicable. Using this data for each item, the evaluation criteria were developed and the submittal evaluation system was configured. The functions included in this stage of the system setup stage were as follows (Figure 4-4):

- Compliance Checklist
- Evaluation Criteria:
    - Acceptability Range
    - Weights
- Utility Function
- Calculation Method

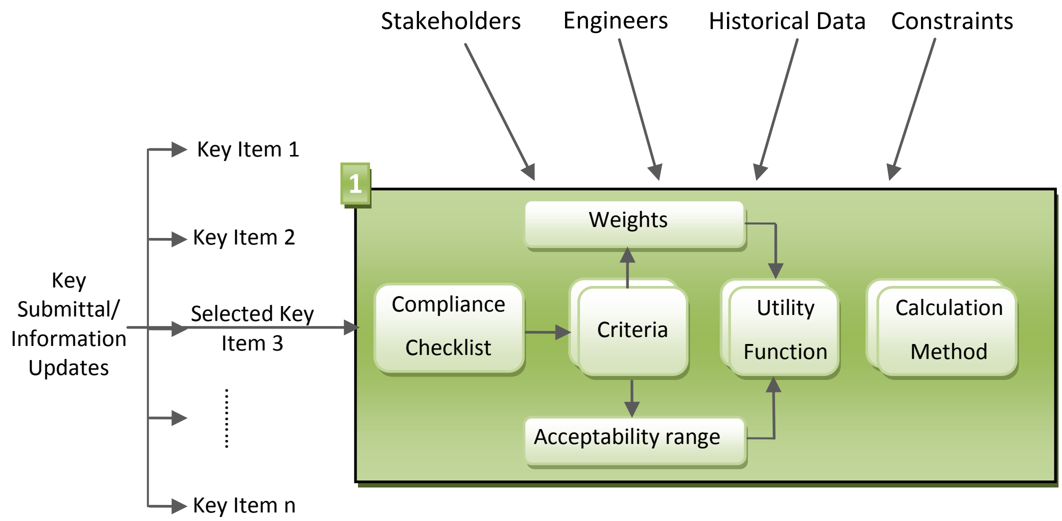


Figure 4-4: System Setup

4.4 Application of the proposed Mechanism

Starting from this section, the system setup is explained in detail, as it was applied to the selected item (centrifugal chiller), and considering the various requirements of the three collaborating organizations. In this way, a default evaluation system was established, which can be customized to suit the needs of a variety of organizations.

Because organizational and project requirements are different, it is important first to update the default key submittals list presented in Table 3-6 in Chapter 3. Based on the selection of "chiller" as the sample key item for this study, the following subsections include the steps necessary for building a submittal evaluation system.

4.4.1 Parameters Analysis

To set up the evaluation system to correspond to the preferences of the organization, an understanding of all parameters that affect the item selected was required. An analysis of the chiller parameters presented in Table 3-8 revealed the two sets of classifications: flexible and non-flexible. An example of a non-flexible parameter is the type of chiller. If a centrifugal chiller is specified, then the evaluation process has no flexibility to accept other types. The non-flexible parameters therefore require the submitted item to match the requirements exactly; otherwise, the item will be denied. The non-flexible parameters thus lend themselves to a checklist type of speedy evaluation for compliance with requirements. Any violation of the checklist requirements means rejection of the item. As an example of the use of the compliance checklist, Figure 4-3 shows a contractor's submittal that includes three types of chillers. If the "starter type" is a non-flexible parameter, the second chiller type does not comply with the required Variable Frequency Drive (VFD) type, and can therefore be immediately eliminated from the evaluation process. This result shows that the proposed approach of using non-flexible parameters as a pre-screening checklist simplifies the evaluation process and enables contractors to self-evaluate their submittals so that they will not include any rejected options.

The second set of parameters are flexible parameters, that is, ones with a range of acceptable values or selections. It is possible to receive submittal items with different values that are all acceptable but that offer different degrees of satisfying the requirements. Different submittals also might have different levels of effect on building performance, other equipment and/or resources, energy consumption, construction needs, or operation. Establishing the values of some of these parameters for a particular submittal item may require feedback from a consultant, or the performance of the item with respect to a parameter could be evaluated based on experience.

NF

Non-Flexible Parameter

Description of Parameter	KFUPM Specs / Requirements	Supplier Name: Carrier	Trane	York
Chiller Capacity in Ton of Refrigeration	600 Tons	678, Comply better	630, Comply better	600
Type of Chiller	Hermetic / Open	Hermetic	Hermetic	Open
Motor Cooling Means	Refrigerant / Air	Refrigerant	Refrigerant	Air
VFD Cooling	Refrigerant / Cooling Water	Refrigerant	Not Applicable	Cooling Water
Starter Type	VFD	VFD	Y-Delta,	VFD
Chiller Country of Origin	USA	USA	China	USA
Chilled Water Supply Temperature, Deg. C.	6.0 Deg C	5.0, Comply	6.2	6
Chilled Water Return Temperature, Deg. C.	12.0 Deg C	12.18 Comply	12.22	12
Chilled Water Flow rate	90.85	92	90.85	84.12
Cooling Water Supply Temperature, Deg. C.	35	35, Comply	35, Comply	35
Cooling Water Return Temperature, Deg. C.	41	41, Comply	41, Comply	41
Cooling Water Flow rate	114	115.5	106.7	100.9
Electrical Power	480 / 3/ 60	480 / 3/ 60	480 / 3 / 60	460 / 3 / 60
Condenser tube, Inch	.035 thick, enhanced copper	Comply	0.035"	0.035"
Cooler tube, Inch	.025" thick, enhanced copper	0.028" better	0.025"	.0.028", better
Condenser Water Boxes	Marine	Marine, better	Marine	Marine
Cooler Water Boxes	NIH	Marine, better	ine	Marine
Power Consumption	Energy Efficient, lower side	0.751	0.716	0.748
NPLV, KW/Ton	Energy Efficient	Not Provided	0.556	0.42
Services Isolation Valve	Required	Comply	Comply	Comply
Separate Pumpdown unit with storage tank	Required	Comply	Comply	not mentioned
Spare Sensors	Required	Comply	Comply	not mentioned
Sound Isolation Kit	Required	Comply	not mentioned	not mentioned
Discharge Line Sound Reduction Kit	Required	Comply	Comply	not mentioned
Training	Required	Comply, better	not mentioned	Comply
Guarantee	12 months	24 months	12 months	2 Years
Added benefit	Required	PM with 6 visits	none	none
After Sale service	Past Experience	Excellent	Good	Good
Response to services call	Past Experience	Excellent	Good	Good
Spare parts availability	Past Experience	Excellent	Good	Good

Figure 4-5: Example of a Non-flexible (NF) Chiller Parameter

Based on this discussion, the first step in the setup level is to update the list of parameters and to define which are flexible and which are non-flexible. This step is discussed in more detail in the following subsections.

4.4.2 Setting the Compliance Checklist with the Non-Flexible Parameters

For a centrifugal chiller, a compliance checklist was developed based on interviews with experts from the collaborating organizations. The process required several rounds of review that began with the development of the initial checklist. The chiller submittal packages collected were investigated and discussed with Eng. M, the project manager at ZFP. The results of the discussion provided an initial list of parameters (Table 4-1), which are considered to be a draft checklist of parameters to be used to develop the primer/default list with the help of the other experts from all three organizations.

Table 4-1: Draft Checklist

No.	Initial Checklist Parameters
1	Starter Type
2	Control System/Monitoring
3	Diagnostic and Trouble-shooting Capabilities
4	Water Box Type
5	Storage Bank
6	Pump Down Unit
7	Service Isolation Valve

The applicability of each parameter listed in Table 4-1 as a checklist item and the addition of any other parameters were discussed with all the participating experts during meetings and interviews. Their feedback was documented and tabulated, as shown in Table 4-2.

Table 4-2: Professional Feedback about Non-Flexible Checklist Parameters

	S	*Checklist Parameters*	*KFUPM*	*U W*	*TDSB*
Draft Checklist Parameters	1	Starter Type	☑	☐ Required Only when remote starter is submitted to ensure 3' clearance	☑
	2	Control System/Monitoring	☐ Default in the chiller	☐ Default in the chiller	☐ Default in the chiller
	3	Diagnostic and Troubleshooting Capabilities	☐ Included	☐ Included	☐ Included
	4	Water Box Type	☐ Potential to be criterion	☐ Potential to be criterion	☐
	5	Storage Tank	☑ Combined with parameter (6) as one.	☐ Should be called "Unit Services" and include parameters 6 & 7 Considered only if chiller does not have built-in service ability	☑ Should be as one package with parameters 6 & 7
	6	Pump Down Unit	☑ Should be as one package with parameters 5 & 7	☐ Should be within "Unit Services" parameter	☑ Should be as one package with parameters 5 & 7
	7	Service Isolation Valve	☑	☐ Should be within "Unit Services" parameter	☑ Should be as one package with parameters 5 &6
Experts' Added Parameters	8	Compressor Type	☑	☑ Possible to change between types when load is < 300 tons	☑
	9	Chiller Type	☑	☑ Possible to change between types when load is < 300 tons	☑
	10	Motor Type	☑	☐	☑
	11	Water In/Outlet Temperature	☑	☑ The outlet temperature is the only required parameter	☑
	12	Dimension/Weight	☑ With tolerance of 15%	☑ As suggested by the Mechanical Engineer	☑ As suggested by the Mechanical Engineer
	13	Flow Rate (GPM)	☑	☑	☑

☑ = Necessary ☐ = Unnecessary

The feedback shows minor differences among the experts with respect to the selection of checklist parameters. A default checklist (Table 4-3) was therefore determined based on their feedback. This list will always be initially available in the evaluation system, and any organization can modify it to suit specific needs. The default checklist was then ready for pre-screening stage.

Table 4-3: Default Checklist for Non-Flexible Parameters

S	Parameters	Acceptability
1	Compressor Type	Same as specification
2	Chiller Type	Same as specification
3	Motor Type	Same as specification
4	Flow Rate (GPM)	Same as specification
5	Starter Type	Same as specification
6	Service Requirement	No additional equipment
7	Water Inlet Temperature	Same as specification
8	Water Outlet Temperature	Same as specification
9	Dimension/Weight	As in shop drawing
10	Pressure Drop	< Pump Capacity

For a submittal or alternative i to pass the prescreening stage, every parameter V_{ij} must receive a "pass" at this stage.

4.3.3 Evaluation Criteria for Flexible Chiller Parameters

Once a submittal passes the pre-screening stage (checklist), it then undergoes a detailed evaluation based on a set of flexible parameters. These flexible parameters are the evaluation criteria for the selected item. To develop the criteria, a draft list of criteria was used as a reference for experts in each organization to consider. Figure 4-6 illustrates the development process, whereby each organization was approached independently in order to develop the criteria and weights. The constraints that each organization may have with respect to a project determine their decision in regard to any minor change in the values. Examples of these constraints are LEED considerations and compatibility issues (if available) that definitively set different ranges of acceptability for each criterion. For this study, defining the default criteria was used as baseline for presenting the mechanism of the evaluation, and then a variety of scenarios that organizational constraints may create are discussed. The utility function was the first step in providing quantitative values for changes. The utility function was developed for each criterion of the default list before the overall calculation methods were set. The total cost was used as the approval condition for a submitted item.

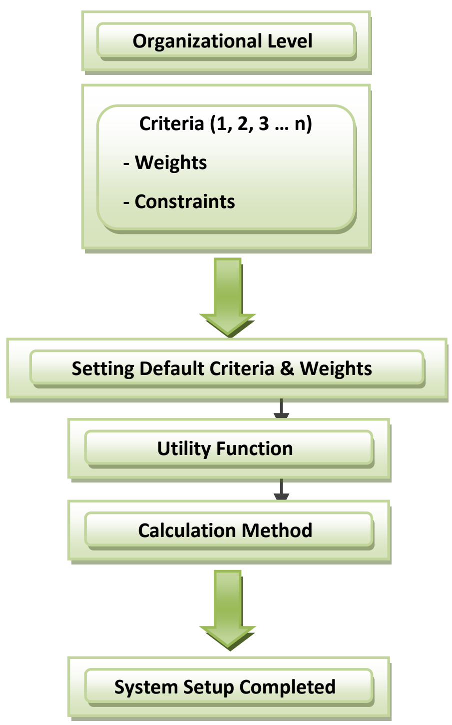


Figure 4-6: Process for the Development Flexible Parameters

A centrifugal chiller was investigated further in order to define the evaluation criteria according to experts from the three organizations. Table 4-4 presents the draft list of flexible criteria that were proposed during the meeting with Eng. M. These criteria were then presented to all the professionals in the three organizations for their feedback with respect to their applicability as criteria, acceptable ranges, constraints in regard to the criteria, and their weights.

Table 4-4: Draft List of Flexible Chiller Evaluation Criteria

No.	Criteria
1	Energy Efficiency Ratio (EER)
2	Condenser Tube Thickness and Material
3	Chiller Control Type
4	Technical Support Capabilities
5	Additional Features
6	Coefficient Of Performance (COP)
7	Climatic Condition of Application and Elevation
8	Refrigerant Type

Their feedback was tabulated and is shown in Table 4-5 which presents the feedback related to the applicability of the criteria and any additional criteria proposed. The basis for rating criteria was the impact of the change on resource consumption, on the maintenance schedule, and on the user productivity.

Table 4-5: Expert Feedback about the Draft List of Flexible Criteria

	S	Criterion	KFUPM	U W	TDSB
Draft Criteria	1	Energy Efficiency Ratio (EER)	☐ Only for small load units	☐ Only for small load units	☐ Only for small load units
	2	Condenser Tube Thickness and Material	☑ Affects maintenance schedule	☐ Considered with the power input	☑ Affects maintenance schedule
	3	Chiller Control Type	☐	☐	☐
	4	Technical Capabilities	☑ High priority criterion	☑ As a low priority criterion	☑
	5	Additional Features	☐	☐	☐
	6	Coefficient Of Performance (COP)	☐ Only for small load units Equivalent to EER	☐ Only for small load units Equivalent to EER	☐ Only for small load units Equivalent to EER
	7	Climatic Condition of Application and Elevation	☐ Design factor	☐ Design factor	☐ Design factor
	8	Refrigerant Type	☑	☑	☑
Criteria added by Experts	9	Power Input (KW/ton)	☑ Replace EER & COP	☑ Replace EER & COP	☑ Replace EER & COP
	10	Condenser Water Box Type	☑ Affect maintenance schedule	☑ Affects maintenance schedule	☐
	11	Water Pressure Drop	☑ Affect the power and the pump	☑ Affect the power and the pump	☑ Affect the power and the pump
	12	Sound Level	☑ Affects user satisfaction and building structure	☑ Affects user satisfaction and building structure	☑ Affects user satisfaction and building structure

☑ = Necessary ☐ = Unnecessary

Based on the feedback, changes were made to the list of criteria. Some criteria were removed and others were added. The default list shown in Table 4-6 includes all criteria that were considered necessary by at least two organizations, with the exception of water pressure drop, which has an impact on the pump capacity and was therefore included as item 10 in the checklist shown in Table 4-3.

Table 4-6: Default List of Flexible Criteria

No.	Parameters
1	Power Consumption
2	Technical Support
3	Refrigerant Type
4	Condenser Water-Box Type
5	Condenser Tubes Thickness and Material
6	Sound Level

The interview with the experts was extended in order to assign weights to these criteria that would reflect the importance of each one for the organization. Table 4-7 presents these weights listed by organization. The only criterion that experts from all organizations agreed upon is power consumption, and it was given the highest weight. All other criteria were weighted differently for each organization. Technical support, for example, was a given 23 % weight by the KFUPM expert, while it was rated as low as 8 % and 7 % by the experts from the other organizations. Such differences in values are acceptable because of the variations these organizations in locations. The same applied to sound level, which was given the second highest weight by UW experts while it was placed at the end of the list for the other organizations (Table 4-7).

Table 4-7: Weights Assigned to Criteria by Participating Experts

No.	Criteria	KFUPM	UW	TDSB	Average Weight
		Weights (∑ = 100%)	Weights (∑ = 100%)	Weights (∑ = 100%)	(∑ = 100%)
1	Power Consumption	32	55	41	42 %
2	Technical Support	23	7	8	13 %
3	Refrigerant Type	15	13	29	19 %
4	Condenser Water-Box Type	11	8	NA	6 %
5	Condenser Tubes Thickness and Material	11	NA	18	10 %
6	Sound Level	8	17	4	10 %

The default weight for each criterion was taken as the average of the weights given by the experts from each organization. Based on these weights, the criteria were ranked from most highest to least important (Table 4-8).

Table 4-8: Criteria Default Ranking Based on Weight

Default Rank	Criteria
1	Power Consumption
2	Refrigerant Type
3	Technical Support
4	Condenser Tubes Thickness and Material
4	Sound Level
5	Condenser Water-Box Type

4.3.4 Utility Functions and Calculation Methods

Evaluating a submitted item means, in fact, evaluating specific criteria within that item. The overall score and calculation method for a criterion provides a quantitative measure of any minor change in the submittal. Such measures can reflect the impact on operation (energy), maintenance costs, and owner/organization satisfaction. To establish quantitative measures, multiple attribute utility functions (MAUT) theory was used for the value-based criteria evaluation. The acceptability of the values submitted in the MAUT is limited to a specific range that can be changed based on the requirements of the organization or owner. The utility value of each parameter submitted for a criterion can vary from one organization to another and is limited to their approved range of acceptability. For each default criterion, the organizational constraints are used, and the most general values are considered as the default. The values for multiple intervals within the criterion generate a utility function graph. The values in between these intervals are determined mathematically and automatically based on the contractor input at the time of submittal and based on their position on the developed graph. The shape of the graph, that is, whether it is risk-seeking, risk-adverse, or risk-indifferent, is also determined based on the organizational constraints. The default is always risk indifferent. The score for each criterion j is the utility value U_j of the contractor-submitted value multiplied by the weight W_j. The overall score value for the submittal or alternative i, S_i, reflects the owner satisfaction and is the sum of all criteria scores, given by

$$S_i = \sum_{i=1}^{n} W_j U_j \qquad i = 1, 2, 3, \ldots, n \tag{4-1}$$

Such a score has a minimum accptable value that is determined by the organization based on the project criticality. A submittal or alternative is rejected when its score is less than that required.

In addition to calculating the overall score S_i for submittal alternative i, it is also important to calculate the cost A_i of using this i^{th} submittal. This cost includes the operational cost, the maintenance cost, the additional construction cost, and any other cost related to the submittal. These can be evaluated by evaluating the criteria one by one and calculating any related cost. For example, criterion 1 (power consumption) requires calculation of C_{i1}, which is the operational cost. Criterion 2 (refrigerant type) may lead to construction changes, and their cost C_{i2} should also be determined. Accordingly, the cost of using submittal A_i then becomes

$$A_i = \sum_{i=1}^{n} C_{ij} - R_i \qquad i = 1, 2, 3, \dots, n \tag{4-2}$$

where C_{ij} is the cost of submittal i in criterion j, and R_i is the cost of the original required item with respect to the same criteria. This A_i cost, therefore, should be considered as a condition for reducing the price of the item by this value. In addition, a total compensation P_i is calculated by adding any reduction in the satisfaction of the evaluation criteria, as follows:

$$Total\ Compensation\ P_i = A_i + (100 - S_i) * A_i/100 \tag{4-3}$$

As presented in the following subsections, the default criteria were investigated one by one both in the literature and at the organizational level in order to set up the default method for calculating the extra cost and for developing a utility functions for each criterion.

4.3.4.1 Power Consumption (KW/Ton) Criterion

The chiller is a major consumer of power in a building, accounting for about 33 % of the total power usage in warm regions and about 12 % in cold regions (Marriott 2006). Ongoing research with respect to predicting and calculating the power consumption of chillers shows the criticality of chillers as energy consumers. In 1977, a model was developed using BLAST software, to calculate the power consumption of the chiller. The model considered two chiller types: reciprocating and centrifugal (Hittle 1977). Data from chiller manufacturers were the basis of the model developed by Stoecker (1982) for studying the energy consumption of compressors. Strand (1994) considered the condensation temperature of ice storage chillers in his proposal for the energy analysis of chillers at full load. Table 4-9 summarizes some of the research directed at analyzing and calculating the power consumption of chillers. These studies confirm both the choice of the chiller as the key submittal item for this research, and the validity of the maximum weighting allotted to the chiller by the experts in the participating organizations, as indicated in Table 4-7.

Table 4-9: Research Related to Optimizing the Power Consumption of Chillers

No.	Description	Researcher
1	BLAST software for modeling the calculation of power consumption during the operation of reciprocating and centrifugal chillers	Hittle 1977
2	Model of power consumption of compressors by deriving regression coefficient of manufacturers data	Stoecker 1982
3	Energy analysis model for an ice storage system with a chiller at full load	Strand 1994
4	Rating method for chiller performance considering off-design conditions	Hubbard 1999
5	Power consumption model for a screw chiller using ASHRAE Toolkit software and manufacturers operating data	Solati 2003
6	Using regression analysis to formulate a relationship and obtain power consumption results for chillers and cooling towers	Chen 2004
7	TRNSYS program to model power consumption for air-cooled chillers	Chen 2004
8	Model for determining the accurate power consumption of chiller by investigating ASHRAE guideline 14	Tai 2006
9	Evaluation of the power consumption of a chiller using a Grey prediction	Chan 2009

The LEED requirements for New Construction (LEED-NC), with the intention to maintain minimum energy performance at the EA Prerequisite 2, mention that the minimum prerequisite is to provide a 10 % saving above the baseline performance of the building. Such an improvement is for the energy of the whole building, and the baseline is calculated according to ASHRAE standard 90.1-2007 (USGBC 2009b). LEED-NC also considers the Advanced Building Benchmark as an alternative for simulating the energy of the whole building (Marriott 2009), which also presents the baseline requirements for chiller power input. Table 4-10 is extracted from the Advanced Building Benchmark, which summarizes the power input baseline for an electrical chiller and shows the power required for a centrifugal chiller as 0.55 KW/ton (Johnson 2005).

Table 4-10: Required Baseline Consumption at Full Load (Johnson 2005)

S	**Chiller Type**	**Size**	**Required Efficiencies (Power Input) (KW/ton)**
1	Air-cooled with condenser	All	1.2
2	Air-cooled without condenser	All	1.08
3	Water-cooled – reciprocating	All	0.84
4	Water-cooled – screw and scroll	< 100 tons	0.78
		≥ 100 tons & < 150 tons	0.73
		≥ 150 tons & ≤ 300 tons	0.61
		> 300 tons	0.60
5	Water-cooled – centrifugal	< 150 tons	0.61
		≥ 150 tons & ≤ 300 tons	0.59
		> 300 tons & ≤ 600 tons	0.57
		> 600 tons	0.55

UW is geared towards LEED performance only while other organizations are interested in acquiring LEED points. In its energy and atmosphere category, "Credit 1" for LEED, "optimize energy performance," LEED-NC provides a table that presents the percentage of energy savings required in order to achieve LEED points. Table 4-11 presents a partial listing of the number of points and the required savings. The table shows that every 2 % of savings after 10 % above the baseline provides 1 LEED point, up to 19 points. The baseline is calculated according to *ANSI/ASHRAE/IESNA Standard 90.1-2007* (USGBC 2009b).

Table 4-11: Required Percentage Savings for the whole Building Each Point (USGBC 2009b)

Saving above the baseline	Number of Points
12 %	1
14 %	2
16 %	3
18 %	4
20 %	5

Considering 33 % as share for the chiller in whole building power consumption according to Marriott (2006) study, Table 4-12 lists possible points for the contribution of the chiller to the energy saving in the building. Four points are considered to be the maximum since the percentage savings is high.

Table 4-12: Proposed LEED Points for Chiller Savings

Number of Points per LEED	Save for whole building		Proposed LEED points for an efficient chiller	Saving based on the chiller as 33 %
0	10 %		1	30 %
1	12 %		2	36 %
2	14 %		3	42 %
3	16 %		4	48 %

In the LEED setup, the system provides the opportunity for the organization or owner to select a specific number of points to be obtained through the power efficiency of the chiller. The current LEED regulation gives one point for efficiency in general while the scenario developed in the research would obtain the first point for efficiency by providing saving of 30 % to the baseline. The other points would be obtained based on the required savings shown in Table 4-12. Based on this discussion, the baseline is the maximum acceptable for the default LEED. The 100% default for LEED is the value of the power with 30 % saving above the baseline that should also provide one LEED point for the efficiency.

On the other hand, the Interview with the UW expert with regard to acceptable power input revealed that their target level is the LEED baseline. His organization focuses more on efficiency and considers the 0.55 KW/ton for a centrifugal chiller as the maximum acceptable value, which is supported by LEED and which may provide the organization with one point toward LEED efficiency certification. KFUPM and TDSB consider 0.55 KW/ton to be an ideal power input that is sometimes difficult to achieve. The reasonable for them is 0.7 KW/ton while the 0.8 KW/ton represents low value for such a large machine, with a maximum accepted value of 1 KW/ton. According to the discussion with the experts, Table 4-13 was developed indicating the satisfactions of each discussed point in order to develop the default utility function graph.

Table 4-13: Power Input Value Satisfactions

Power Input (KW/ton)	Satisfaction %
0.55	100
0.7	90
0.8	40
1.0	0

Accordingly, the utility function graphs for both defaults, LEED and No-LEED, are presented in Figure 4-7.

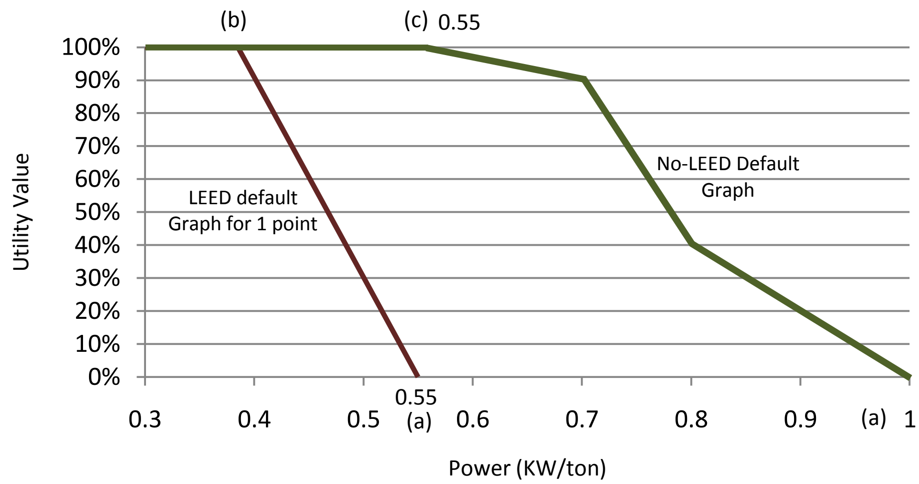


Figure 4-7: The Default LEED and No-LEED Power Utility Function Graphs

To customize the graph in both cases (LEED and No-LEED), the following questions must be answered:

1. What is the minimum acceptable power consumption (0.55, 0.7, 1, etc.)? point (a) at Figure 4-7
2. For LEED, how many LEED points are desired (1, 2, or 3)? (point (b) at Figure 4-5)
3. For NO-LEED, what is the required power input (KW/ton)? (point (c) at Figure 4-5)
4. For both cases, what is satisfaction value for each interval if available? (Table 4-13)

The curve will be customized accordingly. For the default utility function, the utility value (U_{ij}) for any submitted power value (E_i) that falls between the baseline (the minimum acceptable) (E_b) (0%) and the Required Power (E_r) (100 %) or between two intervals is generated using equation 4-4.

$$(U_{i1})\,(E_r\,) + \,(1 - U_{i1})(E_b) = E_i \qquad \textit{(4-3)}$$

$$U_{i1} = {}^{(E_i\ - E_b)}\!\big/_{(E_r\ -\ E_b)} \qquad \textit{(4-4)}$$

The score value for the criterion (S_{i1}) is given by multiplying U_{i1} by the weight of the criterion (W_1):

$$S_{i1} = U_{i1} * W_1 \qquad (4\text{-}5)$$

While deviating from the required power value within the acceptable range is approved by the system, the additional cost introduced by new power input should be taken into consideration when a decision is made. Such cost is in relation to the condition for approval (compensation) at the time of the decision. A discussion of the energy consumption of a chiller requires an understanding of many terms related to efficiency. The Energy Efficiency Ratio (EER) (Btu/Wh) is the ratio between the cooling capacity (Btu/Hr) and the input power (W). It is used to define cooling efficiency: when the efficiency of a chiller is equal to 1 KW/ton, the EER is equal to 12 Btu/Wh. The EER is also equal to 3.412 of the Coefficient Of Performance (COP), which is another term or parameter used to indicate efficiency of a chiller. Higher EERs and COPs mean more efficient systems. Both of these terms were discussed with the experts during the process of developing the criteria, and they explained that the parameter commonly used for large chillers is the power input (KW/ton).

KW/ton is the unit of Integrated Part Load Value/Non-standard Part Load Value (IPLV/NPLV) that is used by Air-Conditioning and Refrigeration Institute (ARI 550/590) for standard water-chilling packages in order to rate chiller energy. The IPLV/NPLV is based on the measurement of the EER at four different loads (25 % of full load, 50 % of full load, 75 % of full load, and full load). The efficiency (KW/ton) obtained by the IPLV/NPLV is more seasonal than a single rated condition. For this study, the KW/ton is used for a single rated condition that is at full operational load. The calculation of the compensation considers the operation of the unit at full load for 10 % of the unit's lifecycle. It is also assumed that the difference in the operating cost of the condenser and the evaporator is neglected compared to the total consumption of the chiller during its lifecycle. The KW/ton given is converted first to KW, and then the time factor, that is the hour, is added. The power in (KW) is a result of multiplying the power input (KW/ton) by the cooling capacity (ton). Given that the power input is p and the cooling capacity load is L, the power P (Kw) is given by

$$P(Kw) = \frac{(PI)Kw}{ton}(L)\ ton \tag{4-6}$$

Since the cost of power consumption should be obtained over the lifetime of the machine, Kilowatts should take into account the time Kilowatts-hours by incorporating the annual operation time T_i. Accordingly, it is essential to input number of operating hours per day for the building under evaluation, which is determined by the building function. The time T_i = Operating hours/day x number of working days/month x number of working months/year. Given that the annual time is T_i , the power P (Kwh) is given by

$$P\ (Kwh) = \left(\frac{(PI)Kw}{ton}\right) L\ (ton)\ T_i \tag{4-7}$$

The cost of electricity for every kilowatt-hour consumed over the unit's lifecycle is dependent on the location of the project (city and province). If the electrical retail price C_e is provided, the annual operating cost at full load C_o can be given by

$$C_o = C_e\ \left(\frac{cents}{Kwh}\right) P(Kwh) \tag{4-8}$$

The overall operating cost for power is the sum of the annual cost of all years over the lifecycle of the machine from the present. The present worth value (PC_{i1}) for the annual power consumption cost over a lifespan of n years, considering an interest rate i, is given by

$$PC_{i1} = C_o \frac{(1+i)^n - 1}{i(1+i)^n} \tag{4-9}$$

Based on the discussion with the experts, the assumption is that the unit works at full load for a maximum of 10 % of the operating time. The cost C_{i1} thus considers only 10% of the operating cost at full load, as follows:

$$C_{i1} = PC_{i1} * (10\%)/100 \qquad \textit{(4-10)}$$

The extra cost a_{i1} that the contractor introduces into the project by providing this submittal is calculated as the difference between the value of the submitted item *(C_{i1})* and the cost of the required item (R_1), as follows:

$$a_{i1} = C_{i1} - R_1 \qquad \textit{(4-11)}$$

Whenever LEED is indicated as an evaluation level for the project, other requirements become mandatory in order to fulfill the LEED requirements for energy efficiency. The system updates the LEED (pre-screening) checklist with the requirements that are listed in Table 4-14, as extracted from the Advance Building Benchmark Manual (Johnson 2005).

Table 4-14: Requirements for Chillers when LEED is Indicated (Johnson 2005)

	Chiller Requirement
☑	Single chiller system requires adjustable speed drive (ASD)
☑	Chiller must have variable air volume
☑	Trend-logging acceptance testing should be performed

4.3.4.2 Refrigerant Type Criterion

The refrigerant, which is considered the second default criterion with a weight of 19 %, is a core component in the refrigeration system. It is the fluid that absorbs heat from the system in order to release it. The selection of a refrigerant for a chiller is based on a number of factors, such as the permanency of the chemical, its cost, availability, efficiency, compatibility with the compressor, environmental consequences, safety, latent heat, and suitability to the operating conditions (ASHREA 2007). Of these factors, environmental consequences have become the top consideration. The refrigerant can be very destructive to the ozone layer if it contains the halogenated compounds such as chlorofluorocarbons (CFCs). Ozone protects the Earth from ultraviolet – B radiation from the sun, which can be very harmful to all living species, including humans. The refrigerant should have the least possible ozone depletion potential (ODP), which is the potential for a single molecule of the refrigerant to destroy the ozone layer. Chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) contain chlorine and bromine molecules that diffuse in the atmosphere and destroy the ozone. Refrigerants also contribute to global warming, which can spread disease and raise the sea to dangerous heights. The global warming potential (GWP), which is a measurement of the amount of effect of a given refrigerant on global warming should also be considered when a refrigerant is selected. The lower the value of the ODP and the GWP, the better the refrigerant is for the environment (ASHRAE 2001; Calm 2002).

In 1987, the international Montreal Protocol was signed. It forbids the production of CFC refrigerants and requires the phasing out of HCFC refrigerants so that stratospheric ozone can be preserved (Green Building and LEED Core Concepts Guide, 1st ed.; ASHRAE 2001; Calm 2002). LEED-NC supports the protocol and their Environment and Atmosphere category (EA-prerequisite 3) requires the use of the most efficient with a low ODP. The refrigerants most commonly used for a centrifugal chiller, R-123 and R-134a (Calm 2002), vary in their impact as determined per LEED considerations. In general, R-134a earns more LEED points than R-123, which is given only one point. R-123 contains chlorine, which increases the potential for ozone depletion. The Montreal

Protocol therefore includes R-123 as a refrigerant to be phased out by 2020, while LEED provides only one point for energy efficiency when R-123 is used. Table 4-15 presents a comparison of R-123 and R-134a based on LEED considerations.

Table 4-15: Comparison of R-123 and R-134a per LEED Considerations

Refrigerant	ODP	GWP	Efficiency	Pressure	CO2	Phased out	LEED points	LEED points justification
R-123	1.2 %	1	Higher by 10-12%	Low	Lower	2020	1	For efficiency
R-134a	0 %	17	Meets standard	Medium	Higher	Not	2	For ODP For no chlorine

The discussion of refrigerant as a criterion with the participated experts revealed variations in the handling of this issue among organizations. For UW, for example, compatibility and organizational considerations take preference over LEED because they give priority to using R-123 over R-134a, while the TDSB offers only one choice and approve only R-134a, because R-123 is being phased out within 10 years. The TDSB approach is supported by Crowther (2004) in his comments about the "Interim Report on the Treatment by LEED," in which he also calls for an end to the use of R-123 (Crowther 2004). Table 4-16 presents the feedback from each organization with respect to commonly used refrigerants.

Table 4-16: Feedback about Refrigerants by Organization

Organization	Refrigerant	Comment/Feedback
KFUPM	R-123	Environmentally better: leakage controlled, minimum material wastage, & more efficient
	R-134a	Material escapes when leaked, requires ventilation, and has longer maintenance time
UW	R-123	Preferred by the organization, leaks as R-134a, low pressure, requires a gas monitor, not possible to replace it with R-134a
	R-134a	LEED recommended, has potential of full-time operator, medium pressure, possible to replace it with R-123 with some design and construction modifications for ventilation and gas monitor
TDSB	R-123	To be phased out soon and should not be in use, should not be approved
	R-134a	Best available for the centrifugal chiller

The feedback indicates variations in organizational requirements and values for each refrigerant type, which offers different satisfaction values. The default satisfaction values along with the organizational values are presented in Table 4-17.

Table 4-17: Default Utility Values for Refrigerants Based on Feedback

Refrigerant	KFUPM	U of W	TDSB	Average satisfaction	Default NO-LEED Satisfaction	Default LEED Satisfaction
R-123	100%	100%	0%	67%	90%	50%
R-134a	50%	70%	100%	73%	100%	100%

The LEED default utility values were built based on the number of points attached to each refrigerant. Based on the previous discussion, the utility graph for the refrigerants was developed with consideration for both the LEED and the No-LEED defaults (Figure 4-8).

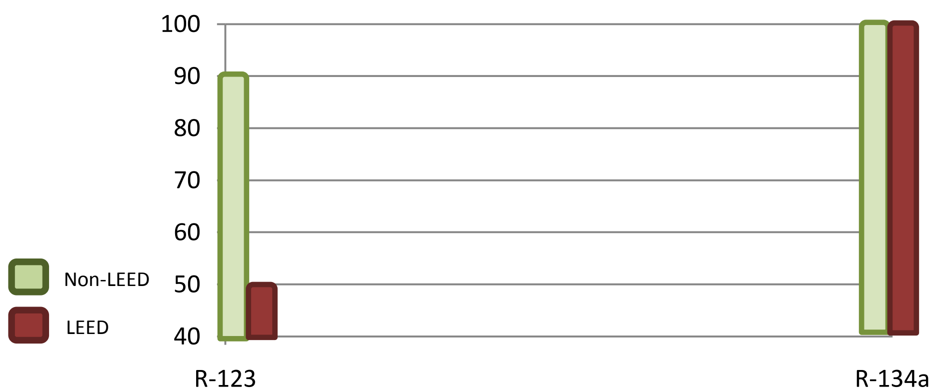


Figure 4-8: The Default Utility Function for Refrigerant (LEED/No-LEED)

Establishing the cost of altering the refrigerant was based on discussion with the experts. Changing from R-134a to R-123 involves additional construction costs for room ventilation and gas monitoring devices, while changing from R-123 to R-134a has the potential of requiring a full-time monitor for the unit during operation. These potential costs are determined by a consultant and will not render the change impossible, but notification of such a potential and consultant approval are required.

A difference in utility value between the LEED and No-LEED default occurs when it is proposed that R-123 replace R-134a. The energy impact of selecting a refrigerant type is already reflected in the power input submitted within the alternative parameters. The default cost for criterion 2, a_{i2}= fixed value, is the cost of changing from R-134a to R-123 covering construction modifications. Such a cost can always be updated by the organization during the setup period while the default will be considered as $50,000 as proposed by experts. The score value S_{i2} is the result of the utility value U_{i2} of the selection made multiplied by the criterion weight W_2, as follows:

$$S_{i2} = U_{i2} * W_2 \qquad \textit{(4-12)}$$

4.3.4.3 Technical Support Capability Criterion

The technical support capabilities criterion represents the after-sale support provided by the company or supplier. This criterion is an evaluation of factors such as adherence to the maintenance schedule, response to service calls, and the availability and delivery of spare parts. Discussing this criterion with experts revealed differing viewpoints. For Eng. Y (KFUPM), this criterion is based mainly on historical data and previous experience with a particular company or supplier. He considers after-sale services as the second most important criterion, immediately after the power consumption. Eng. E and Eng. A (TDSB) support this opinion and consider it essential for the organization to have a predefined company's index. Eng. R (UW), on the other hand, assesses after-sale services based on the availability of spare parts and on delivery time. This concept relates to the organization's strategy of dealing with a single company. The historical experiences/indexes are not considered for UW evaluation during the submittal that is never guarantee services support for the next project. According to UW, this criterion should be evaluated based mainly on the availability of the spare part whenever it is needed. It can be determined by the location of the nearest spare parts store and the ability to deliver the parts within an acceptable time frame. The distance to the store by car should be considered, so that in case spare/parts are needed, the supplier can ensure that they will be delivered within a maximum of one day. Being reachable by car enables the maintenance department to control an emergency by sending an agent to obtain the parts when the supplier's deliveryman is busy. A 100% satisfaction level can be achieved by delivering the parts within one day. A maximum of one week represents 0 % satisfaction. Table 4-18 summarizes the approaches of three organizations.

Table 4-18: Approaches to Technical Support by Organization

Organization name	Approach
KFUPM	Company's index (Previous experience)
UW	Delivery time and spare part availability
TDSB	Company's index (Previous experience)

The default approach for this criterion is based on historical data and previous experience. Whenever a new company or supplier is introduced in a submittal, the qualification document should be reviewed and then the rate given for the company during the setup process. For this study, a list of companies was prepared and given to the participating experts for rating. The experts' ratings of the list of companies were tabulated as shown in Table 4-19. The original list provided to the experts included six companies but feedback was received for the three with whom the participants had previous experience. It should be noted that none of the companies received a rating of 100 % satisfaction. For privacy reasons, the companies' names have not been provided.

Table 4-19: Company Index for the Default Technical Support Criterion

Company Name	Expert 1	Expert 2	Default Value
Company 1	90	90	90 %
Company 2	90	70	80 %
Company 3	80	80	80 %

The default utility function graph that resulted from this feedback is illustrated in Figure 4-9. It includes values only for the three companies for which feedback was obtained from the experts. The utility graph that was developed reflects the approach of two of the three organizations.

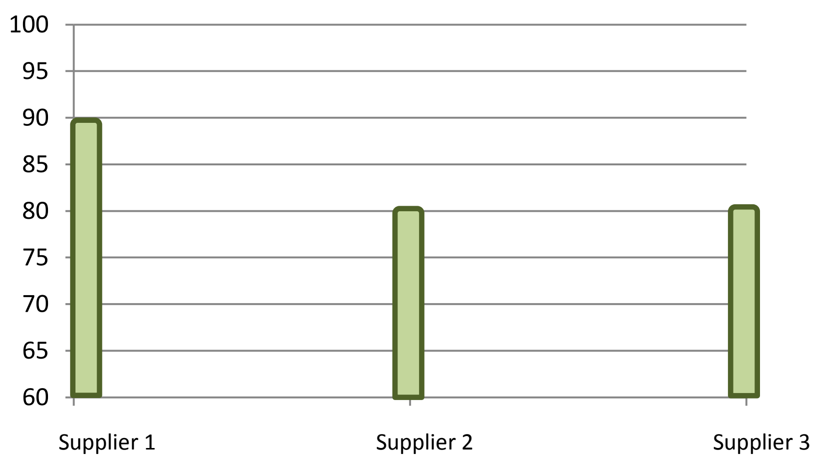


Figure 4-9: Default Technical Capability Utility Function Graph

To represent the approach of UW, each day in a week was given a distance value in km and a satisfaction value, which was obtained from the expert. The maximum distance that can be approved is 999 km. Table 4-20 shows the days, distances, and the satisfaction level provided.

Table 4-20: Delivery Time and Distance

Number of Days	Distance (KM)	% Satisfaction
1	100	100
2	200	80
3	400	60
4	600	40
5	800	20
6	1000 +	0

These values were plotted in the utility function graph shown in Figure 4-10.

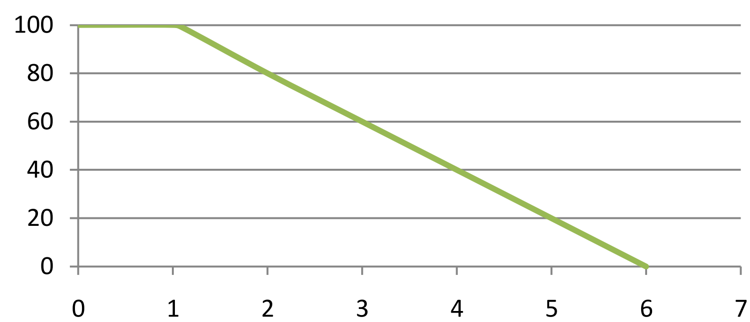


Figure 4-10: Delivery Time Frame Utility Function Graph

There is no extra cost associated with this criterion**.** The score S_{i3} is given by

$$S_{i3} = U_{i3} * W_3 \quad (4\text{-}14)$$

4.3.4.4 Condenser Tube Thickness and Material Criterion

Sludge, mud, and contaminants in condenser tubes affect the performance of the chiller, the maintenance process, and the productivity of the building user. Regular and frequent sessions of cleaning of these tubes are required to be included in the maintenance procedure of the chiller, as recommended by the manufacturer. Graham (2004) lists tube cleaning as the second most important step for an efficient chiller. When this criterion was discussed with the experts, unique evaluation considerations were discovered such as the characteristics of the tubes: thickness and material. The criterion was also considered to be affected by the type of condenser water-box selected. The participating experts provided information about three thicknesses and four materials. The thicknesses available are 0.035", 0.028", and 0.025", and the materials are pure copper or (90/10) copper/nickel, (70/30) copper/nickel, or titanium. According to the experts, a cleaning session, which involves one technician and two labourers, consumes 20 to 60 working hours or 40 hours on average. The frequency with which the cleaning session is required is affected by the surrounding area and the characteristics of the tube (thickness and material). The impact of changing the required tube characteristics is reflected in the maintenance schedule. As the interviewees indicated, the failure of these tubes normally starts after 10 years of machine life. As a result of the discussion, Table 4-21 was developed in order represent types of materials, available thicknesses, and the expected number of visits per year. The best selection is the one with the minimum number of visits; based on Table 4-21, the default selections were listed and the utility value for each selection was developed according to the number of maintenance visits.

Table 4-21: Condenser Tube Characteristics With Utility Values

No.	Types	Cleaning Sessions/year	% Satisfaction
1	Titanium	0.8	100%
2	Copper 0.035"	1	83.3%
3	Copper /Nickel *0.028"*	1.7	66.7%
4	Copper 0.028"	2	56.7%
5	Copper /Nickel *0.025"*	2.5	33.3%
6	Copper 0.025"	3	26.7%

Based on Table 4-21, default utility function graph was developed, as shown in Figure 4-11.

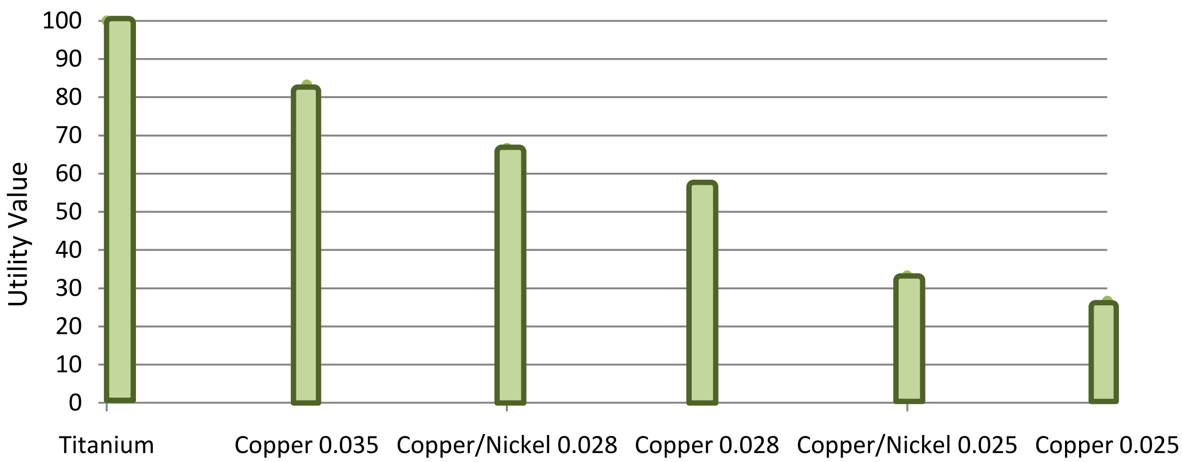


Figure 4-11: Default Condenser Tube Thickness and Material Utility Function Graph

To obtain the extra cost of altering the type of tube a_{i4}, a cost estimate of tube cleaning session should be obtained. Based on their experience, the organization should estimate the average time for each session to be able to calculate the overall cost. The considered average time by hours is M_t . The total time for tube maintenance (M_v) includes the effect on time of the type of water-box selected (B_i) for each submittal i. The total cleaning session time M_v is thus given by

$$M_v = M_t + B_i \quad (4\text{-}15)$$

The cost of the cleaning session is the compensation for the total working hours of the technicians and the labourers who perform the work in addition to the cost of any material or equipment. The cost of materials and equipment is considered to be an extra percentage beyond the total cost of the technicians and labourers, as revealed through experts' discussion. The overall percentage for the materials and equipment was determined to be 10 % of the total cost. If the hourly rate for an HVAC technician is T_r, the hourly rate a labourer is L_r, the number of HVAC technicians is (X), the number of labourers is (Y), and the percentage for the materials and equipment used is ME, the cost of the tube cleaning session C_t can be calculated as follows:

$$C_t = M_v\ (X * T_r +\ Y *\ L_r) * ((^{ME}/_{100}) + 1) \quad (4\text{-}16)$$

For each selection, the number of visits per year is determined according to Table 4-21. If the number of cleaning sessions per year is M_i, the annual cost C_a is then

$$C_a = C_t * M_i \quad (4\text{-}17)$$

The present worth value C_{i4} of the annual tube cleaning session cost over the chiller lifecycle n, considering the interest rate to be i, can be calculated as follows:

$$C_{i4} = C_a \frac{(1+i)^n - 1}{i(1+i)^n} \quad (4\text{-}18)$$

The extra cost for the condenser tube characteristics criterion a_{i4} is the difference between the present values for the submitted item (C_{i4}) and the required (R_4) cost, and it can be calculated as

$$a_{i4} = C_{i4} - R_4 \quad (4\text{-}19)$$

The criterion score value S_{i4} is then obtained as follows:

$$S_{i4}\ = U_{i4} * W_4 \quad (4\text{-}20)$$

4.3.4.5 Sound Level (dBA) Criterion

As a major source of noise, the HVAC equipment has a direct influence on the interior acoustical environment of a building. The process of selecting HVAC equipment requires consideration of an acceptable noise level. This consideration is also extended to the vibration caused by the operation of the equipment, which contributes to the noise. In any building, noise can be controlled by assessing three components: the source of the noise, the transmittal baths, and the receiver. The sources are the machines themselves such as pumps and chillers, the transmittal baths are the media through which the sound is transmitted, and the receivers are the users of the building (ASHRAE 2007).

The significant amount of tonal and broadband noise that is produced by a chiller makes it a major source of noise in an HVAC system. The flow of liquid within the chiller causes broadband noise, while the tonal is normally produced by the compressor, the motor, and the rotation of the fan (ASHRAE 2007). The impact of chiller noise on the surrounding environment is significant regardless of whether it is installed indoors or outdoors. Chiller design therefore always requires consideration of an acceptable range of noise. Based on ASHRAE, Table 4-22 was developed to show the different pathways of chiller noise transmittal in a building as well as the method recommended for reducing this noise.

Table 4-22: Transmission of Chiller Noise and Vibration, and Reduction Methods

No.	Noise/Vibration Transmission Paths	Noise Reduction Method
1	*Noise:* through equipment room walls and floors to adjacent rooms	Locate equipment room away from critical areas; use masonry blocks or concrete for mechanical room walls.
2	*Vibration:* via building structure to adjacent walls and ceiling	Mount all machines on properly designed vibration isolators; design mechanical room for dynamic load; balance the machine.
3	*Vibration:* along pipes and duct walls	Isolate ducts and pipes from structure with neoprene or spring hangers; install flexible connectors between pipes, ducts, and vibrating machines.

The tonal noise of the compressor is normally dominant, and each type of compressor produces a different noise level. Table 4-23 shows different types of compressors, their method of producing noise, the strength of the noise, and the ranking developed based on the strength of the noise. Based on ASHRAE (2007), the table shows that the screw compressor has the strongest noise and that the lowest noise level is produced by a scroll compressor.

Table 4-23: Types of Compressors and the Source and Strength of the Noise Produced

S	Compressor Type	Source of Noise	Strength of Noise	Noise Ranking
1	Centrifugal	Rotation of the impeller and gears	Not very strong	4
2	Reciprocating	Swing motion of the pistons	High	3
3	Absorption	The flow of steam in associated with pump and valves	Significantly high	2
4	Scroll	---	Weak	5
5	Screw (Helical Rotor/Rotary)	Condenser and evaporator shells	Very strong	1

Based on the Air-Conditioning and Refrigeration Institute (ARI) standards (ARI 575 and ARI 370) that require the measurement of the sound power level of a machine, ASHRAE provides different graphs for the maximum and minimum values of sound levels for both indoor and outdoor chillers. For the water-cooled centrifugal compressors, a graph of typical indoor minimum and maximum values is presented in Figure 4-12, and a graph of the outdoor values is presented in Figure 4-13. The range of values presented is divided into eight frequencies: 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz (ASHRAE 2007).

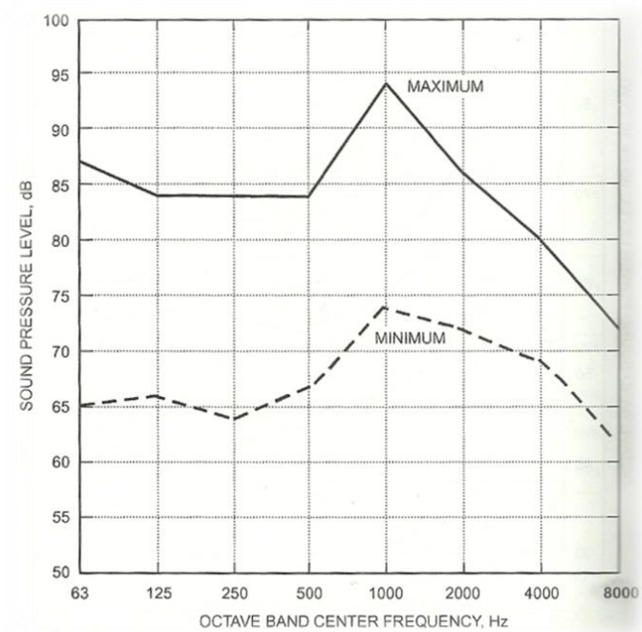


Figure 4-12: Typical Minimum and Maximum ARI 575 *Lp* Values for Centrifugal Chiller (ASHRAE 2007)

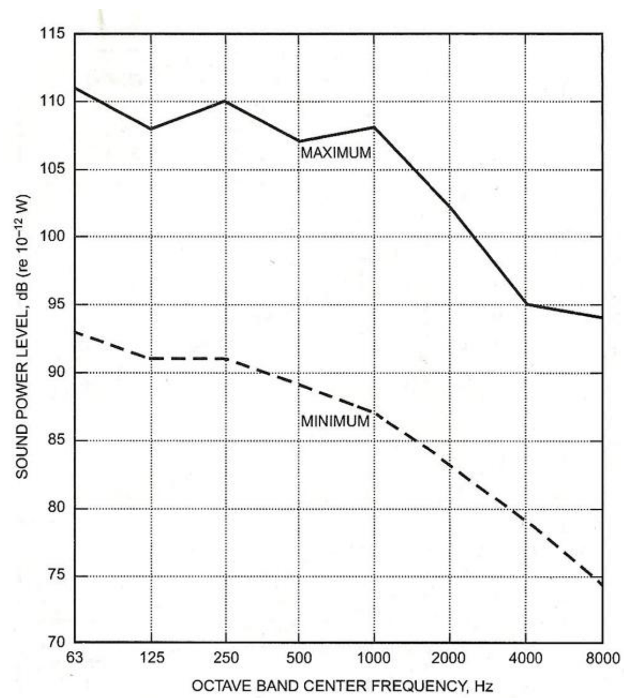


Figure 4-13: Typical ARI 370 L_w Values for Outdoor Chillers (70 to 1300) (ASHRAE 2007)

Table 4-24 presents the maximum and minimum value points as extracted from Figures 4-12 and 4-13 along with the desired satisfaction percentage for each set of values.

Table 4-24: Values for Minimum and Maximum Sound Levels per ARI 575 and ARI 370

Type of Chiller	Range Values	Frequency Bands								Satisfaction
		1	2	3	4	5	6	7	8	
Indoor Chiller	Maximum Value (dB)	87	84	84	84	94	86	80	72.5	0 %
	Minimum Value or less (dB)	65	66	64	67	74	72	69	62	100 %
Outdoor Chiller	Maximum Value (dB)	111	108	110	107	107.5	102.5	95	94	0 %
	Minimum Value or less (dB)	92.5	91	91	89	87	82.5	79	74.5	100 %

Using the ASHRAE graph, the system determines the total utility value for each chiller submittal, the minimum and lower value to be 100%. The submitted sound level (dB) values are compared to the minimum and maximum values for each frequency band by plotting the values submitted in the related graph. The new curve developed based on the value submitted indicates whether the values fall within the acceptable range. In the case of sound, the utility value is the average of the sum of frequencies' dB values. To calculate the utility value, each frequency's dB value (V_f) should first be obtained from the difference between the maximum dB value of the frequency band $(Max.L_{pi})$ and the submitted dB value (SL_{pi}). V_f for each alternative/submittal i, can be calculated as follows:

$$V_{fi} = ((Max.L_{pi} - SL_{pi})\ x\ 100)/(Max.L_{pi} - MinL_{pi}) \quad (4\text{-}21)$$

The average of the sum of all n frequency's dB values (V_{fi}) is the utility value for the submitted sound level (U_{i5}):

$$U_{i5} = {\sum_{i=1}^{n}(V_{fi})}/{n} \tag{4-22}$$

If the utility value for the sound pressure level is U_{i5}, the score S_{i5} for the criterion can be calculated as follows:

$$S_{i5} = U_{i5} * W_5 \tag{4-23}$$

Figure 4-14 shows a plotted set of submitted sound level values that falls in between the maximum and minimum established by ARI 575. The example is a screen shot from the developed prototype that will be explained in detail in the next chapter. There is no extra cost attached to this criterion.

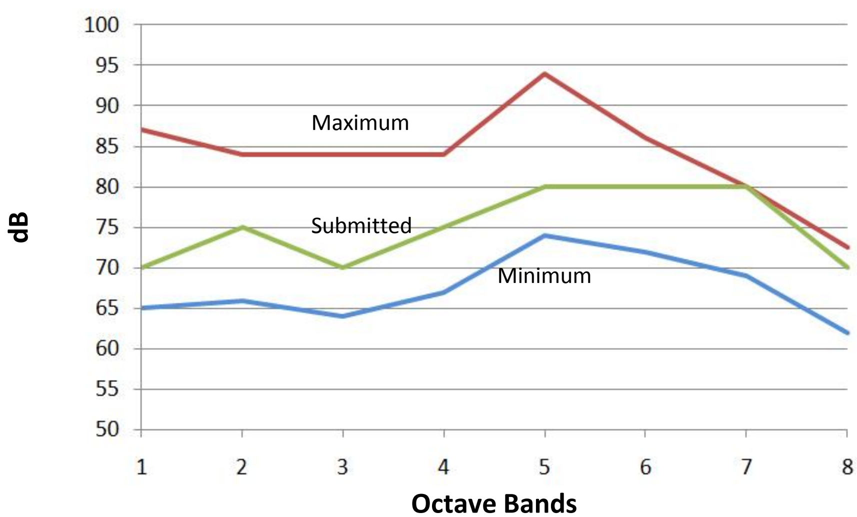


Figure 4-14: Example of the Sound Level Submittal Value Plotted in an EXCEL Spreadsheet

4.3.4.6 Water-box Types Criterion

To clean the condenser tubes that were evaluated as criterion 4, the maintenance team can access them through the water box. Discussion with the experts revealed that there are two main types of water box: Nussle In Hall (NIH) standard and marine. To access the condenser pipes, the water box must be opened; with the marine, the tubes can be accessed while the pipes in place, but with the NIH, the connective piping must be removed and the cover lifted by means of a small crane or chain. The heavy lifting of the cover of the NIH is time-consuming and adds risk to the process, which means that the cost increases as well. An investigation of the literature uncovered a third alternative, the Auto-Brush Cleaning System (Sehgal 1997). According to the experts, the Auto-Brush Cleaning System is not yet in common use. The NIH, which is the standard option, provides only a 70 % satisfaction level for both of the engineers consulted while the marine is considered to provide 100 % satisfaction for them. Table 4-25 shows the satisfactions as given by the experts.

Table 4-25: Water Box Type Satisfaction Levels

	Water Box	Satisfaction
1	Marine	100%
2	Nussle In Hall (NIH)	70%

The default utility function graph was developed based on Table 4-25 and is presented in Figure 4-15. It also includes the Auto-Brush Cleaning System as a third selection, which is also given a 100 % satisfaction value.

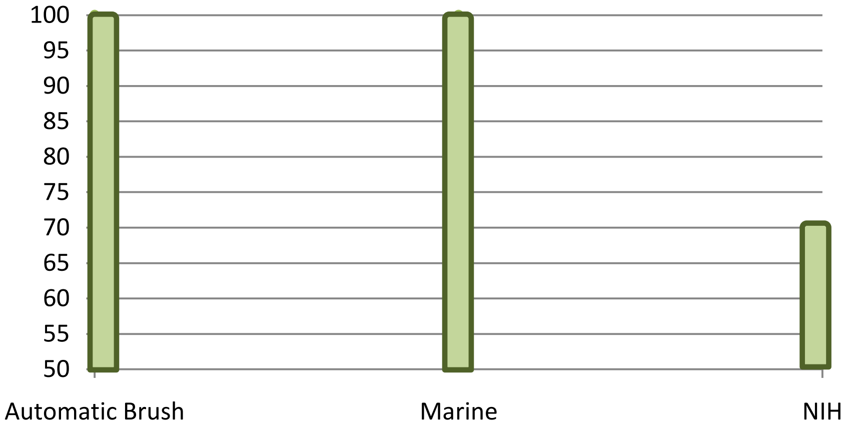


Figure 4-15: The Default Utility Function Graph for the Water Box

Table 4-26 shows a comparison of the two main types of condenser water boxes. It shows that the main difference between the types is in the number of working hours required for maintenance. With the same number of workers the number of working hours required is four times greater for the NIH box than for the marine box.

Table 4-26: Water Box Direct Cost

		Maintenance Direct Cost				
	Water Box Type	Number of technicians	Number of labourers	Number of working hours (B_i)	Additional Equipment needed	% Satisfaction level
1	Marine	1	2	1	None	100%
2	Nussle In Hall (NIH)	1	2	4	Crane/Chain	70%
Direct Cost Considerations		0	0	3	Fix Cost	0

The selection of the type of water box determines the total working hours (B_i) that is used into equation 4-15 in order to obtain the total time for the tube cleaning session, which includes the maintenance and cleaning of water box. This time affects the total cost of the tube cleaning session in addition to the fixed extra cost for any additional equipment, such as the crane that is required for the NIH water box, all of which is used to formulate a_{i6}.

$$a_{i6} = Additional\ equipment\ cost \tag{4-26}$$

Based on the type of water-box selected, the utility value for the criterion is obtained, and the score is calculated as follows:

$$S_{i6} = U_{i6} * W_6 \tag{4-27}$$

When the score and the cost of the water box have been obtained, the evaluation process is concluded, and the system is ready to provide a recommendation with the respect to approval.

4.5 Conclusion

This chapter has described the process of developing the overall evaluation mechanism for building materials, equipment, and/or components in general. The process has been explained in detail through its application to the selected item (the chiller). The participating organizations were mainly institutional/academic organizations; the general data collected and also these related to the chiller are based on their preferences and experience. Accordingly, the default requirements and acceptability range may be reflective of this type of building. Applying the evaluation mechanism for another type of building requires defining the criteria and checklist using an organization's historical data and experience to evaluate the selected items.

The setup level has been explored in detail and has included consideration of all participating organizations in order to develop a default setup for the system, the steps for which are listed in Table 4-27.

Table 4-27: Summary of the Setup Module

Setup Module
Set Requirements/Specification
Define Non-Flexible Parameters
Establish Acceptable Value for Each Non Flexible Parameter
Define Flexible Parameters
Establish Acceptable Range for Each Flexible Parameter
Define the Minimum Acceptable Score

The main two stages in the evaluation module, the pre-screening (checklist) and the criteria evaluation levels were defined following an investigation of the chiller with the help of participating experts. Based on this investigation, checklist parameters and criteria with assigned weight were defined in the preparation for the evaluation process. Table 4-28 summarizes the checklist evaluation process within the evaluation module.

Table 4-28: Summary for the Evaluation Module: Checklist Evaluation

Evaluation Module							
Checklist Evaluation		Submittal for *n* alternatives					
		Alternative 1		Alternative 2		Alternative *n*	
Parameters	Required Value	Submitted Value	Result	Submitted Value	Result	Submitted Value	Result
Parameter 1	V_{i1}	V_{s1}	$*P/F$	V_{s1}	P/F	V_{s1}	P/F
Parameter 2	V_{i2}	V_{s2}	P/F	V_{s2}	P/F	V_{s2}	P/F
Parameter 3	V_{i3}	V_{s3}	P/F	V_{s3}	P/F	V_{s3}	P/F
Parameter n	V_{in}	V_{sn}	P/F	V_{sn}	P/F	V_{sn}	P/F
****Alternative Result**			P/F		P/F		P/F

*P/F = Pass/Fail　　** Only Pass Alternative(s) go on for Value-Based Evaluation

The framework has been completed, with the development of the utility functions and the method of calculation for each criterion that will be used in the system for evaluation. The final recommended decision for each alternative/submittal is based on a consideration of the total score, which should be higher than the required score value. The process for the value-based evaluation and the formulation of the final condition are summarized in Table 4-29.

Table 4-29: Summary for the Evaluation Module: Value-Based Evaluation

Evaluation Module										
Value-Based Evaluation		Submittal for *n* alternatives								
		Alternative 1			Alternative 2			Alternative *n*		
Criterion	Weight	Utility Value	Score	Cost	Utility Value	Score	Cost	Utility Value	Score	Cost
Criterion 1	W_1	$*U_{i1}$	S_{i1}	a_{i1}	$*U_{i1}$	S_{i1}	a_{i1}	$*U_{i1}$	S_{i1}	a_{i1}
Criterion 2	W_2	U_{i2}	S_{i2}	a_{i2}	U_{i2}	S_{i2}	a_{i2}	U_{i2}	S_{i2}	a_{i2}
Criterion 3	W_3	U_{i3}	S_{i3}	a_{i3}	U_{i3}	S_{i3}	a_{i3}	U_{i3}	S_{i3}	a_{i3}
Criterion 4	W_4	U_{i4}	S_{i4}	a_{i4}	U_{i4}	S_{i4}	a_{i4}	U_{i4}	S_{i4}	a_{i4}
Criterion 5	W_5	U_{i5}	S_{i5}	a_{i5}	U_{i5}	S_{i5}	a_{i5}	U_{i5}	S_{i5}	a_{i5}
Criterion 6	W_6	U_{i6}	S_{i6}	a_{i6}	U_{i6}	S_{i6}	a_{i6}	U_{i6}	S_{i6}	a_{i6}
Total	100		$**S_1$	A_1		S_2	A_2		S_n	A_n

$*U_{ij}$ must fall within the criterion acceptable range

$**$ S_i must be > the minimum overall acceptable score value

Min. Accept. Score		<	$\boldsymbol{S_1}$	$\boldsymbol{A_1}$		$\boldsymbol{S_2}$	$\boldsymbol{A_2}$		$\boldsymbol{S_n}$	$\boldsymbol{A_n}$

If Yes

For every alternative, the compensation cost = $((\mathbf{100} - \boldsymbol{Si}) * \boldsymbol{C}) + \boldsymbol{C}$

The default setup defined for the selected item "chiller" in this chapter was used at the system use level, and the prototype was examined in detail using a real-life case study, as described in the next chapter.

Chapter 5

Decision Support Prototype for Submittal Evaluation

5.1 Introduction

This chapter describes the development of an automated submittal evaluation system that considers the specific requirements of an organization and is programmed to operate based on their defined criteria. The checklist, criteria, and MAUT calculations that are developed and that have been presented in the previous chapters were coded in an Excel spreadsheet in order to automate the generation of utility values and the submittal evaluation. These coded spreadsheets use VBA programming language to develop the main prototype, SUBMIT & EVALUATE (S&E), which considers any number of criteria and is coded to perform all necessary calculations and to generate reports. This chapter also presents the use of the prototype at the system through real-life case, which illustrates all the steps in the submittal evaluation process, including the default checklist and criteria.

5.2 Prototype Modules and Evaluation Process

The proposed prototype is composed of two main modules, as shown in Figure 5-1: system setup and use (evaluation). Initially, the default system setup consists of the criteria and checklist values that were presented in the previous chapter. The setup module contains these default data in addition to the specification parameters for the selected item. It is always possible to change these requirements to correspond to organizational requirements or specific project conditions. The evaluation module, on the other hand, deals with the process of evaluating the submittal. The criteria for the evaluation are the ones that have been saved in the setup module.

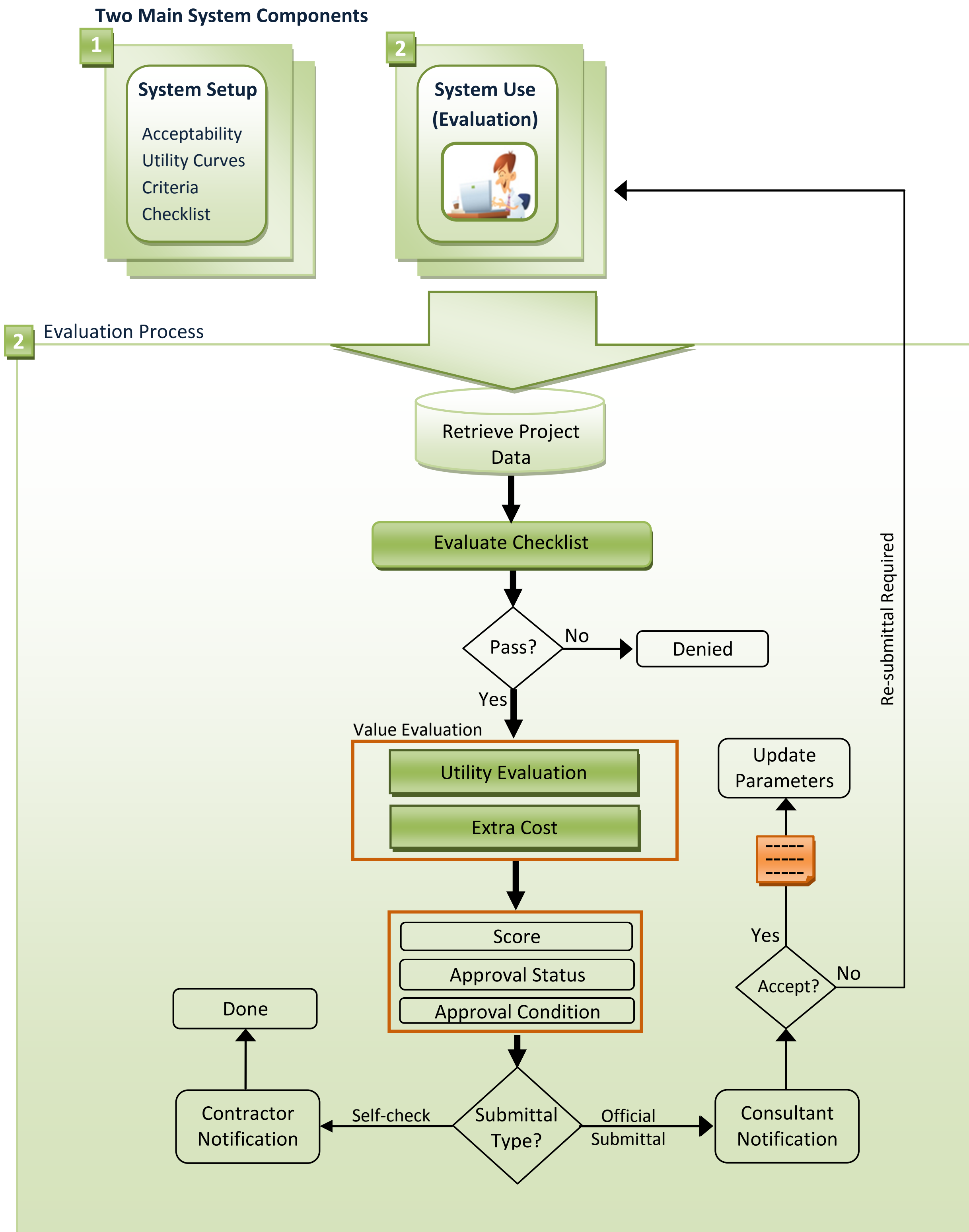


Figure 5-1: System Modules and Submittal Evaluation Process

The general evaluation process is set out in Figure 5-1, which shows that the evaluation process is initiated with the retrieval and consideration of project data. The evaluation starts by processing the non-flexible parameters from the checklist, comparing contractor-submitted data to the data recorded in the system. Only if all the data match will the submittal evaluation move to the next stage; otherwise, the submitted item or alternative is rejected and sent for resubmittal. The system always provides reasons for the rejection of a submittal or alternative at every level. The value-based evaluation then processes the flexible parameters (criteria). This stage of the evaluation considers the criteria utility values and cost calculations. The final result of the value-based evaluation falls into one of three categories: approved, approved with condition, or denied.

A submittal alternative can be denied for either of two reasons: it is out of the acceptability range for any criterion, or it has been allocated a total score less than the minimum pre-set score value. In the case of a deviation from the requirements, a conditional approval is recommended. The condition is then a proposed compensation that the contractor must pay in order for the submittal/alternative to be accepted. The system allows the contractor to process the submittal as an official submittal or just to submit it unofficially as a self-check alternative. A self-check submittal gives the contractor a clear idea of the status of a proposed alternative without involving a consultant, thereby saving reviewer time and productivity. If the contractor selects to process the submittal as an official one it indicates an acceptance of the proposed condition on the part of the contractor, and the submittal then moves to the stage of consultant involvement for confirmation and data update (Figure 5-1).

The prototype is controlled by access authorization, which determines the user's level of authority. Activating the setup module requires administrator authority, which is not given to the contractor (Figure 5-2). The setup and evaluation modules can be activated only after an item is selected for submittal.

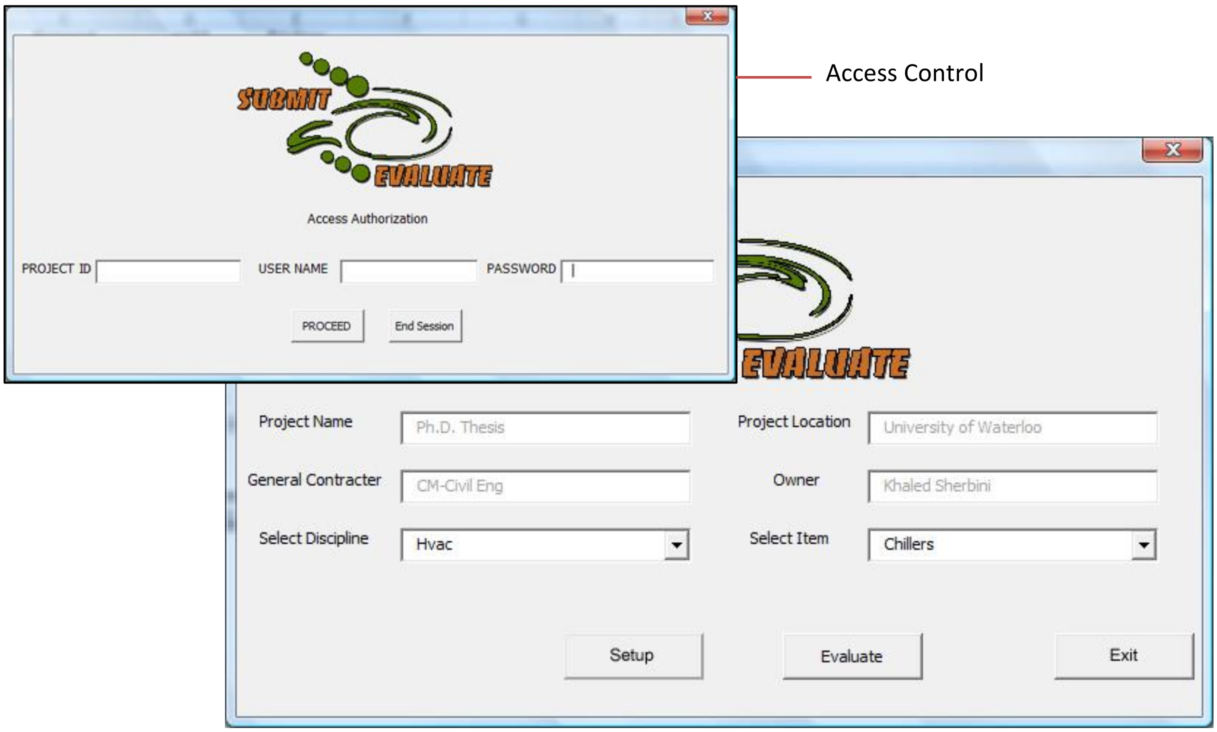
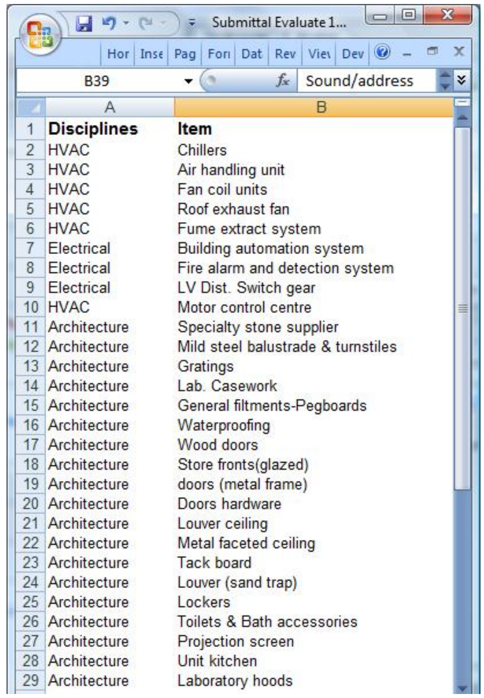


Figure 5-2: Main Prototype Interface

The prototype includes a range of items that relate to the selection of multiple disciplines in the building. These items essentially represent an enhanced list of critical submittals (Figure 5-3). In this case, the only item that is ready for evaluation is the key selected item: the chiller.



	A	B
1	**Disciplines**	**Item**
2	HVAC	Chillers
3	HVAC	Air handling unit
4	HVAC	Fan coil units
5	HVAC	Roof exhaust fan
6	HVAC	Fume extract system
7	Electrical	Building automation system
8	Electrical	Fire alarm and detection system
9	Electrical	LV Dist. Switch gear
10	HVAC	Motor control centre
11	Architecture	Specialty stone supplier
12	Architecture	Mild steel balustrade & turnstiles
13	Architecture	Gratings
14	Architecture	Lab. Casework
15	Architecture	General filtments-Pegboards
16	Architecture	Waterproofing
17	Architecture	Wood doors
18	Architecture	Store fronts(glazed)
19	Architecture	doors (metal frame)
20	Architecture	Doors hardware
21	Architecture	Louver ceiling
22	Architecture	Metal faceted ceiling
23	Architecture	Tack board
24	Architecture	Louver (sand trap)
25	Architecture	Lockers
26	Architecture	Toilets & Bath accessories
27	Architecture	Projection screen
28	Architecture	Unit kitchen
29	Architecture	Laboratory hoods

Figure 5-3: Sample of the Items Listed in the S&E System

5.3 Setup Module

Once the setup module is activated (Figure 5-2), it permits the user to change the requirements of the organization simply by entering new values. The setup offers several levels, from basic to advanced and then customized. Figure 5-4 is a screen shot of the basic level in which it is possible to configure the LEED or No-LEED default setup for the project. In the LEED setup, the consultant can set the desired LEED points that redefine the acceptability range of the power by selecting desire LEED points. The electricity rate and building operation hours are also available for update at this level (Figure 5-4).

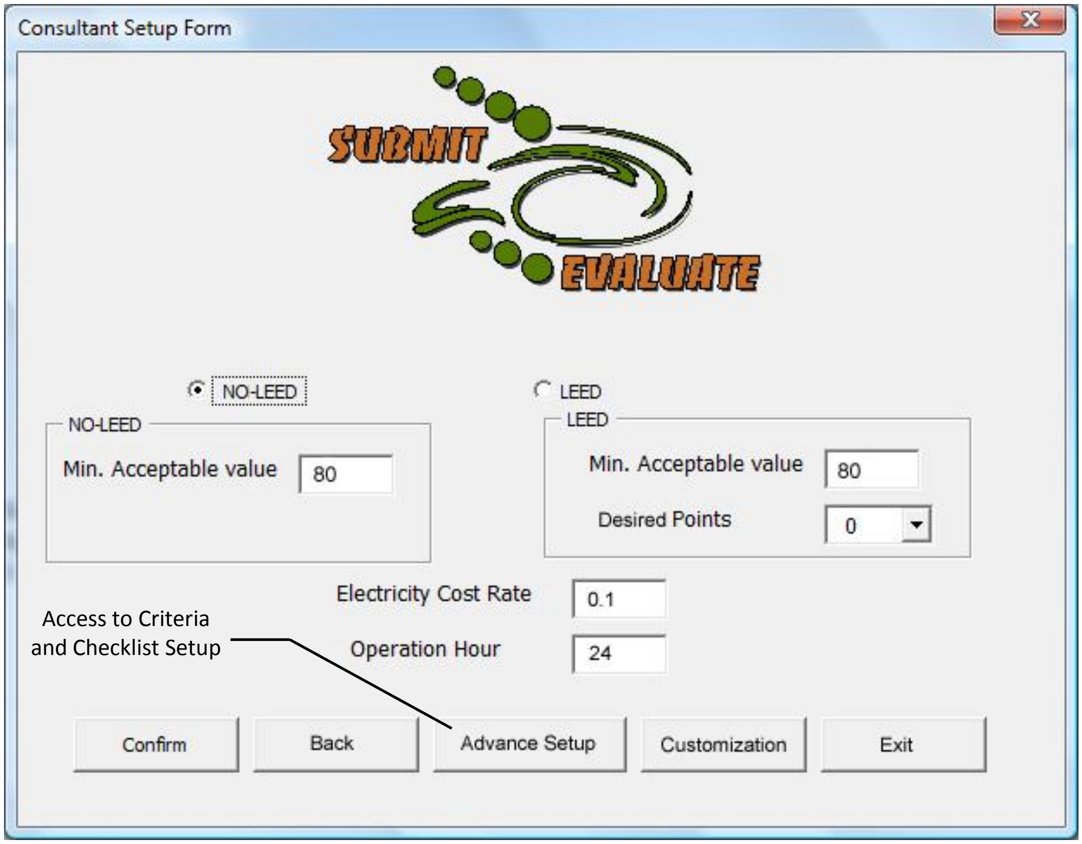


Figure 5-4: System Default Setup for LEED and No-LEED Category

The advanced setup (Figure 5-5) offers the opportunity to update the value for the criteria and checklist parameters.The values can be updated and new utility curves developed through the advanced setup only for the No-LEED parameters. LEED requirements must be updated through the customization setup.

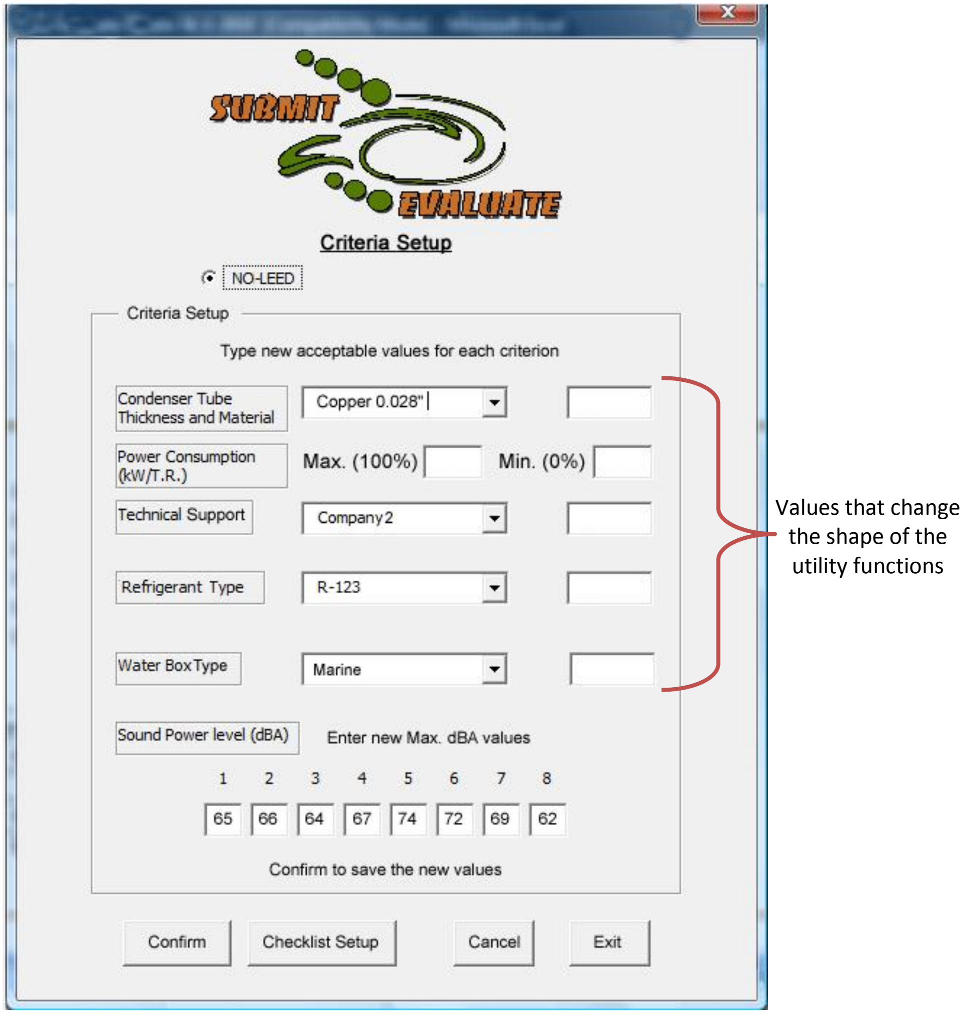


Figure 5-5: Advanced Setup for Criteria

Confirming the changes at any level of setup takes the user back to the main screen (Figure 5-2) and prepares the system for the evaluation.

5.4 Evaluation Module

To demonstrate how the evaluation module functions, a real-life case (submittal) collected from the University of Waterloo was processed. The submittal includes a 450-ton chiller. For privacy reasons, the project original requirements (specifications) were not supplied by UW. Some of the submittal data as provided in the submittal are shown partially in Figure 5-6; details are provided Appendices D-3 to D-6. The case used No-LEED default requirements for the value-based evaluation criteria, for which the acceptable power ranges from 0.55 to 0.8 KW/ton.

Performance Data - Centrifugal Water Chillers

Tags	CH-PH-02
Primary tons of refrigeration (tons)	450.00
Condenser entering fluid temp (F)	85.00
Condenser leaving fluid temp (F)	94.35
Condenser gallons per minute (gpm)	1350.00
Condenser pressure drop (ft H2O)	26.33
Condenser fouling factor (hr-sq ft-deg F/Btu)	0.00025
HCFC 123 refrigerant charge (lb)	750.0
Shipping weight (lb)	17740
Operating weight (lb)	20379
Heat rejected into equipment room (MBh)	4.33

Product Data - Centrifugal Water Chillers

Condenser shell size: 050 long
Condenser tube: 1.00 inch (25.4 mm) micro internally enhanced copper
Condenser tube wall: .028 inch (0.7 mm) thick
Condenser shell construction: Standard
Condenser fluid type: Water
Condenser waterbox type: 2 pass marine
Condenser waterbox construction: Standard
Condenser waterbox pressure: 150 psig (1034 kPa)
Condenser waterbox connection: Victaulic
Agency listing: U.L. listed unit includes energy efficiency verification
Factory performance test: Standard air run and vibration test
Factory tolerance test: Standard air run and vibration test
Complies with all versions of ASHRAE/IESNA 90.1
BACnet communication protocol on-board
With enhanced motor protection
Accessory: 2 Flow switches, 300 psi (2068 kPa) NEMA 1 (Fld)
Trane Supplied Refrigerant
Starter power connection: Circuit breaker
1st Year Parts and Labor Warranty Whole Unit with Trane Supplied Starter
2nd-5th Year Parts and Labor Warranty Motor/Compressor only
Davit Arms Both Ends Both Shells
Solid State Unit Mounted Starter with Circuit Breaker
Starter option: Lightning arrestor
Starter option: Ground fault protection
Right Hand piping connections

Figure 5-6: Selected Chiller Parameters as Provided in the Submittal (UW)

When the evaluation module is initiated for the selected item (Figure 5-7), the number of proposed alternatives is selected (Figure 5-8); in this case, one.

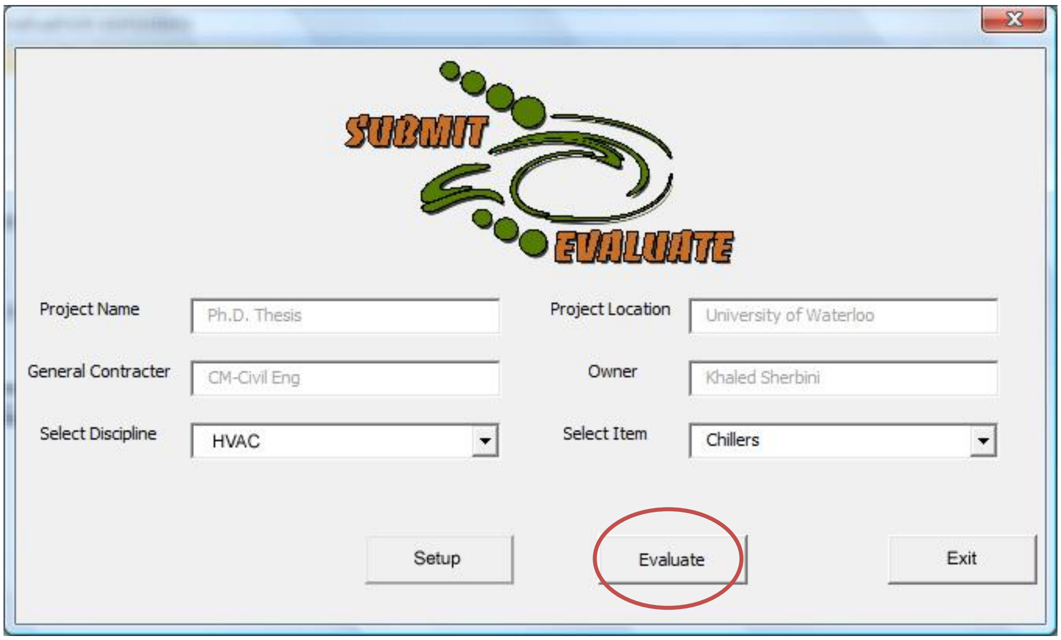


Figure 5-7: Access Screen for Item Evaluation

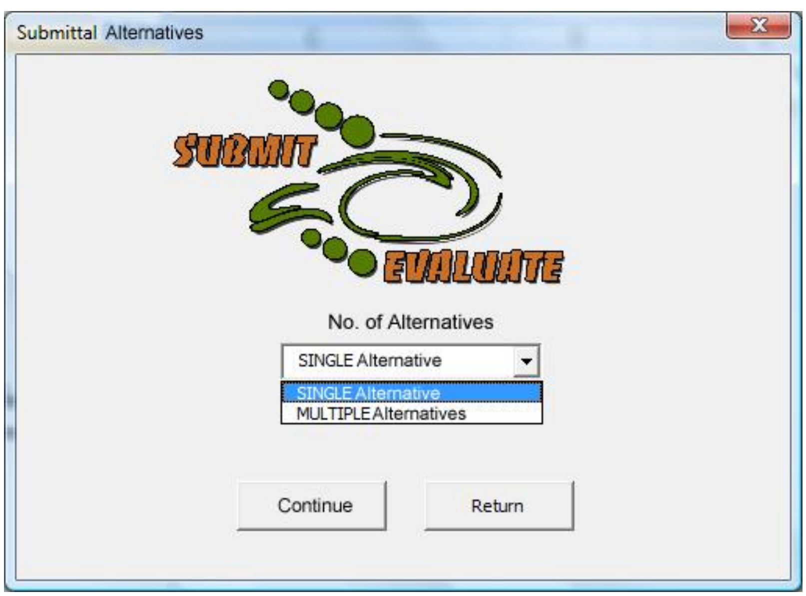


Figure 5-8: Number of Alternatives Selection Screen

It should be noted that the prototype can accommodate three alternatives in parallel as is the case in practice with respect to minimum requirements: additional alternatives can always be processed through another submittal. The system can be enhanced so that it can accommodate more alternatives. Once the number of alternatives is selected, the checklist form (Figure 5-9) is then available for contractor to input data.

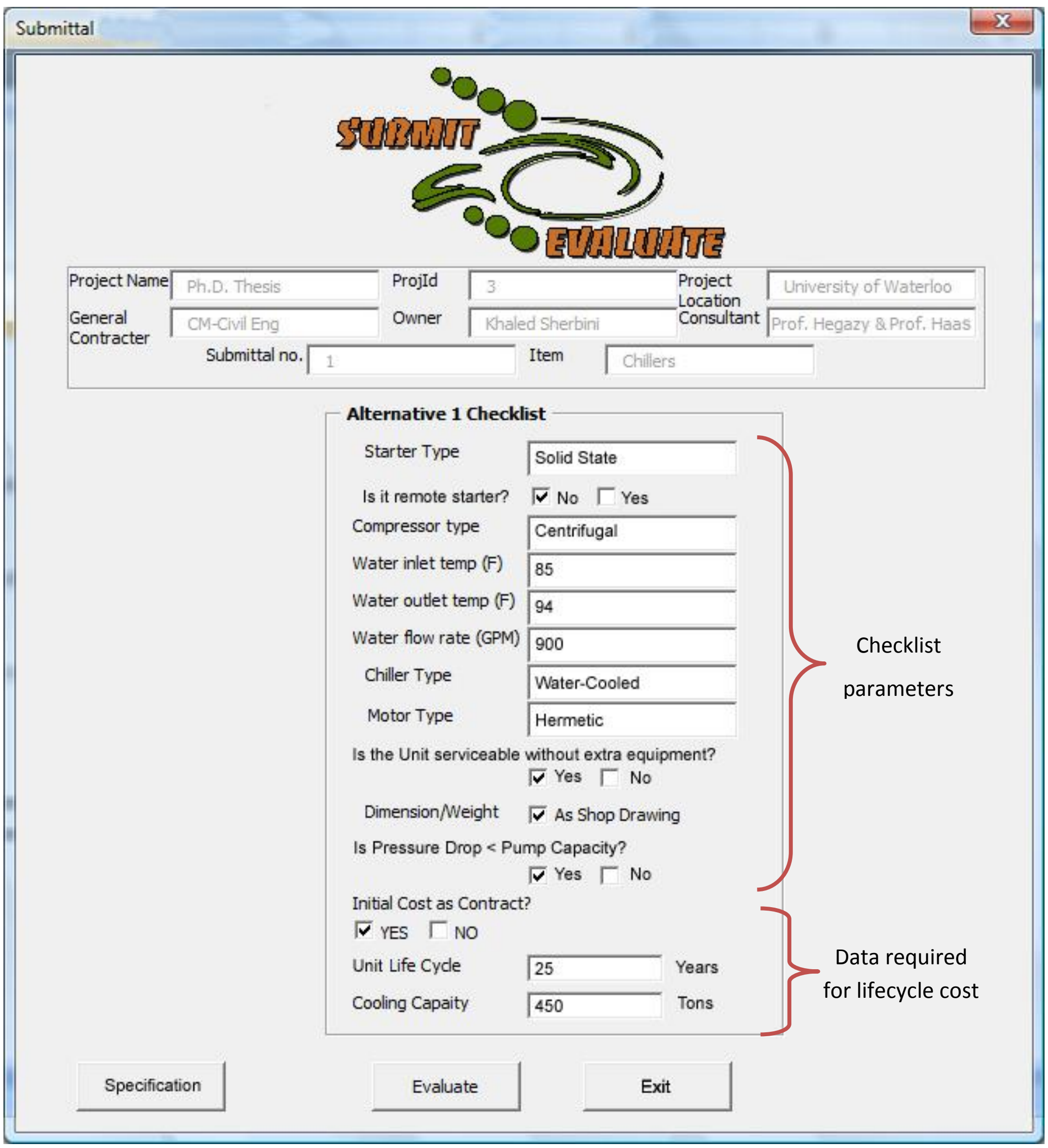


Figure 5-9: Checklist Completed with Sample Submittal Data

The contractor data populates the EXCEL spreadsheets based on which the actual evaluation process is performed (Figure 5-10). All parameters should match the checklist requirements for the alternative to be granted PASS status (Figure 5-11) and to be moved to the next evaluation stage: value-based evaluation (Figure 5-12).

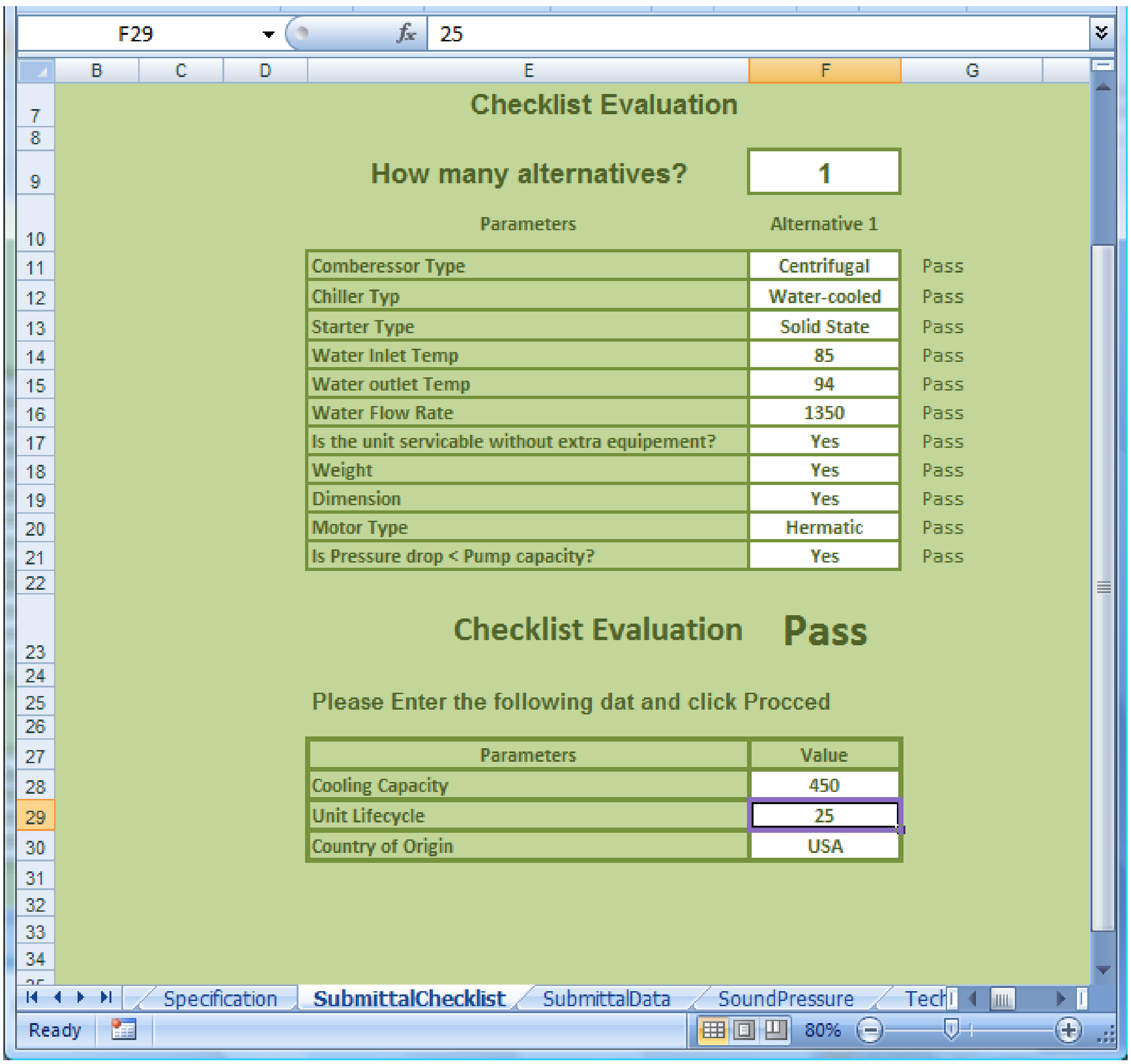


Figure 5-10: Excel Checklist Spreadsheet

Using the form shown in Figure 5-11, the contractor populates the EXCEL sheet (Figure 5-12) that is linked to all the criteria sheets from which the utility values, scores, and costs are obtained.

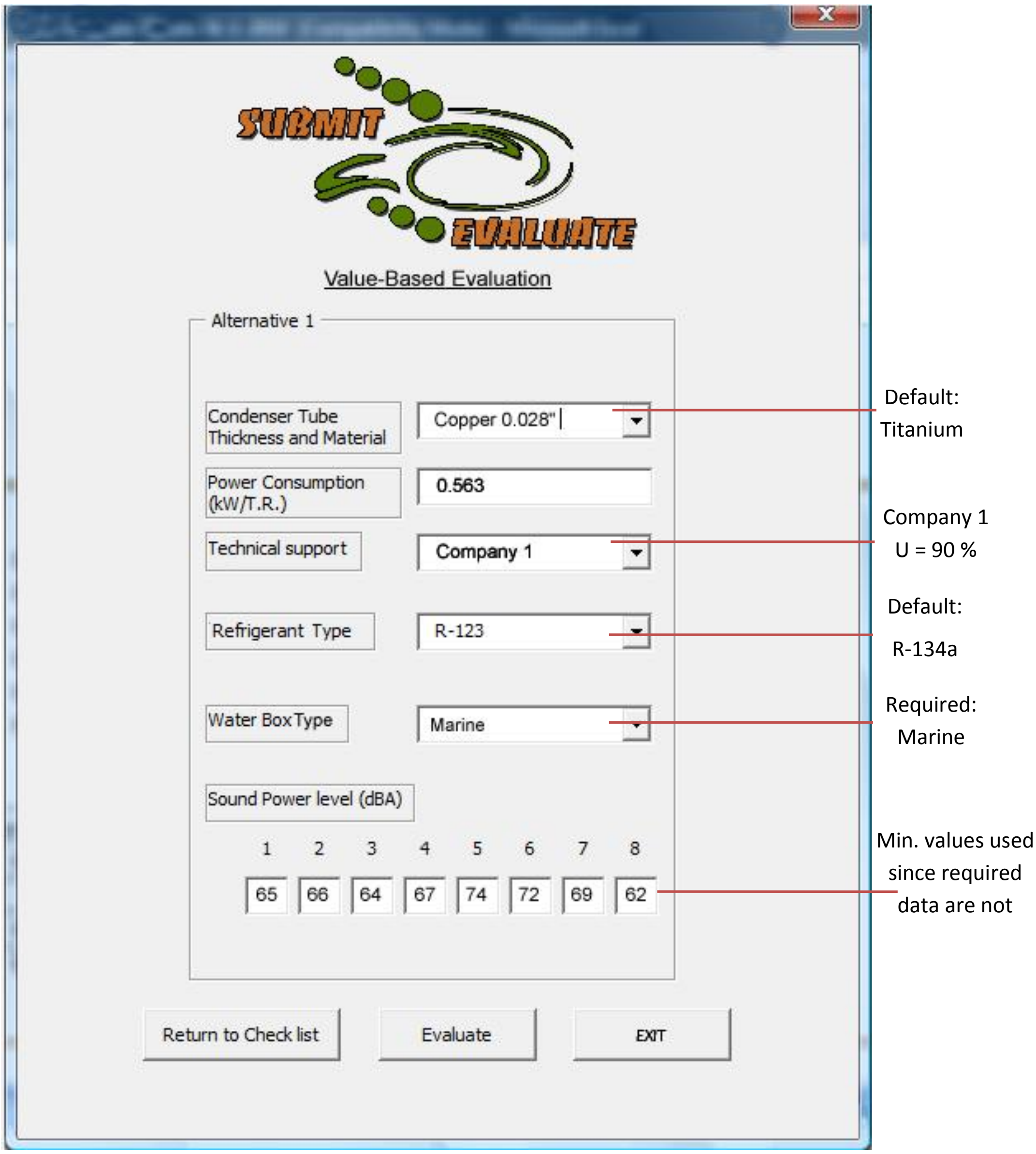


Figure 5-11: Evaluation Criteria for Case Study

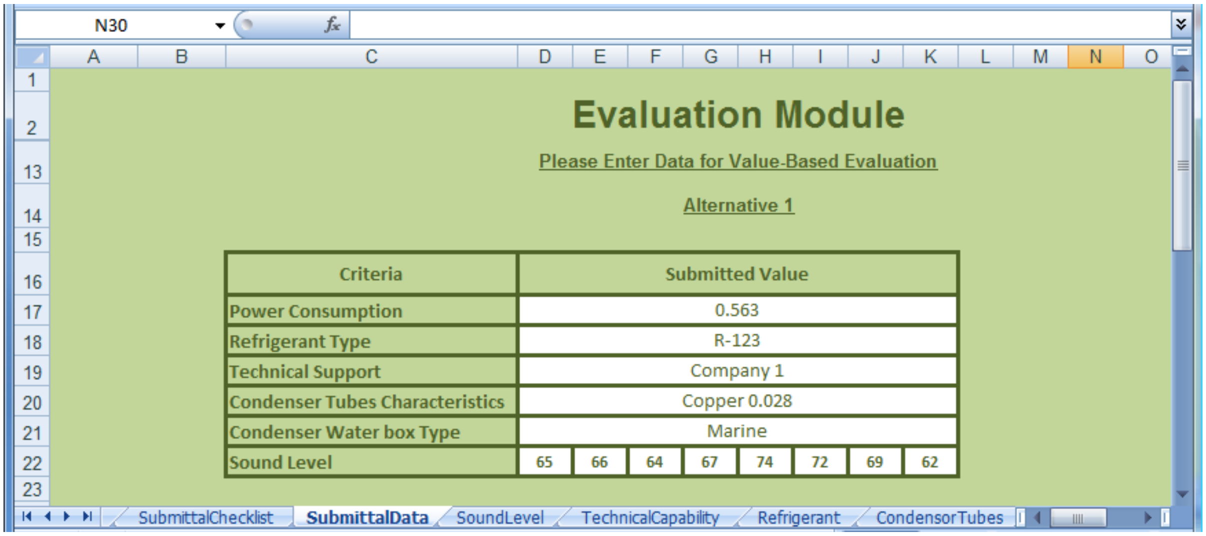


Figure 5-12: Evaluation Criteria for Case Study

The calculations are processed for each criterion using the built-in equations presented in Chapter 4 and the utility function graphs. In the following subsections, each criterion is explained in order to demonstrate the evaluation process.

5.4.1 Criterion 1: Power Consumption

The submitted power input value has been applied automatically to the utility function graph that generates the utility value. The score for the criterion is then derived from the multiplication of the utility value by the weight, as shown in Figure 5-13.

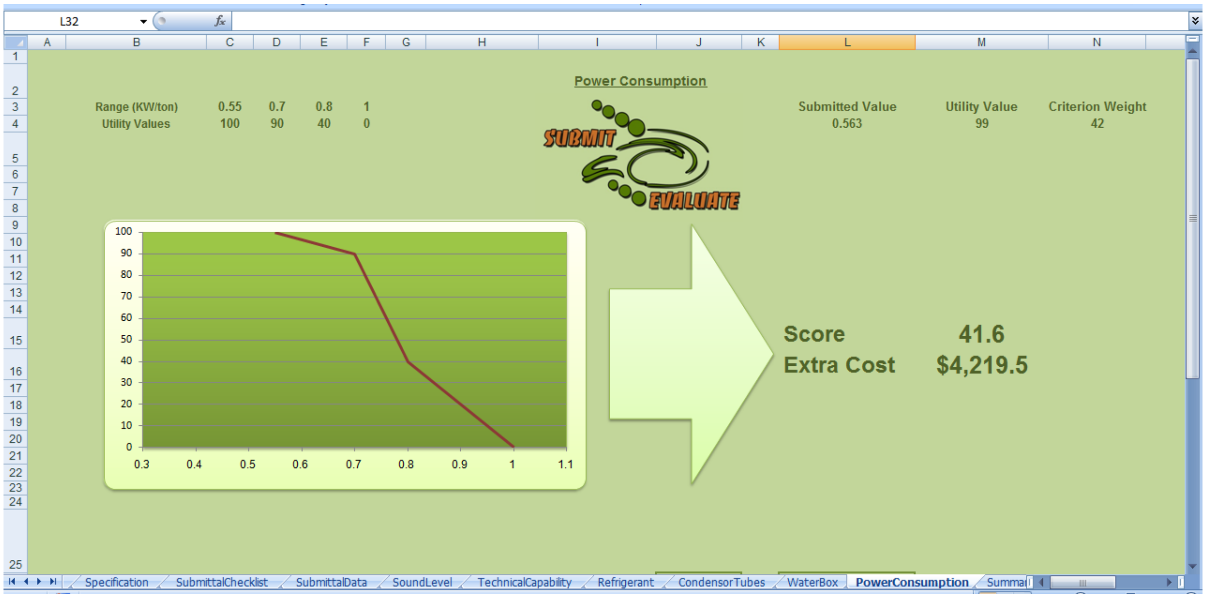
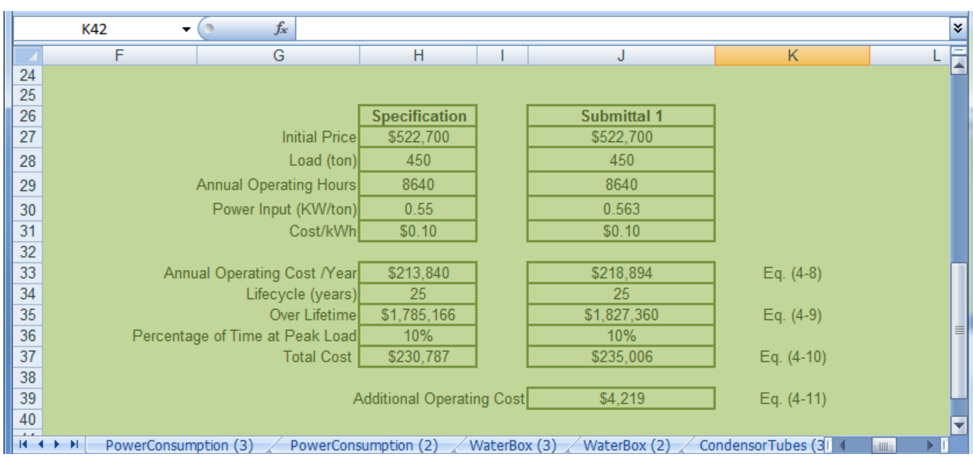


Figure 5-13: Power Consumption Calculation Page in the Prototype

The extra cost noted in Figure 5-13 is a result of the coded equations presented in Chapter 4, as shown in Figure 5-14. In addition to indicating the equations used to derive each value, Figure 5-14 also shows the data and parameters used to derive the cost. The two values that are then extracted for the power consumption criterion are the extra cost ($ 4,219.5) and the total score for the criterion (41.6).



	Specification	Submittal 1	
Initial Price	$522,700	$522,700	
Load (ton)	450	450	
Annual Operating Hours	8640	8640	
Power Input (KW/ton)	0.55	0.563	
Cost/kWh	$0.10	$0.10	
Annual Operating Cost /Year	$213,840	$218,894	Eq. (4-8)
Lifecycle (years)	25	25	
Over Lifetime	$1,785,166	$1,827,360	Eq. (4-9)
Percentage of Time at Peak Load	10%	10%	
Total Cost	$230,787	$235,006	Eq. (4-10)
Additional Operating Cost		$4,219	Eq. (4-11)

Figure 5-14: Power Consumption Calculations

5.4.2 Criterion 2: Refrigerant Type

The default refrigerant is R-134a; the submitted type is R-123, which is given a utility value of 70. According to the No-LEED default, changing from R-134a (100 %) to R-123 (90 %) costs a figure of $50,000. Based on the derived utility value, the final score for the criterion is 17 out of 19. Figure 5-15 shows the EXCEL sheet for refrigerant type, which presents the final score and the extra cost.

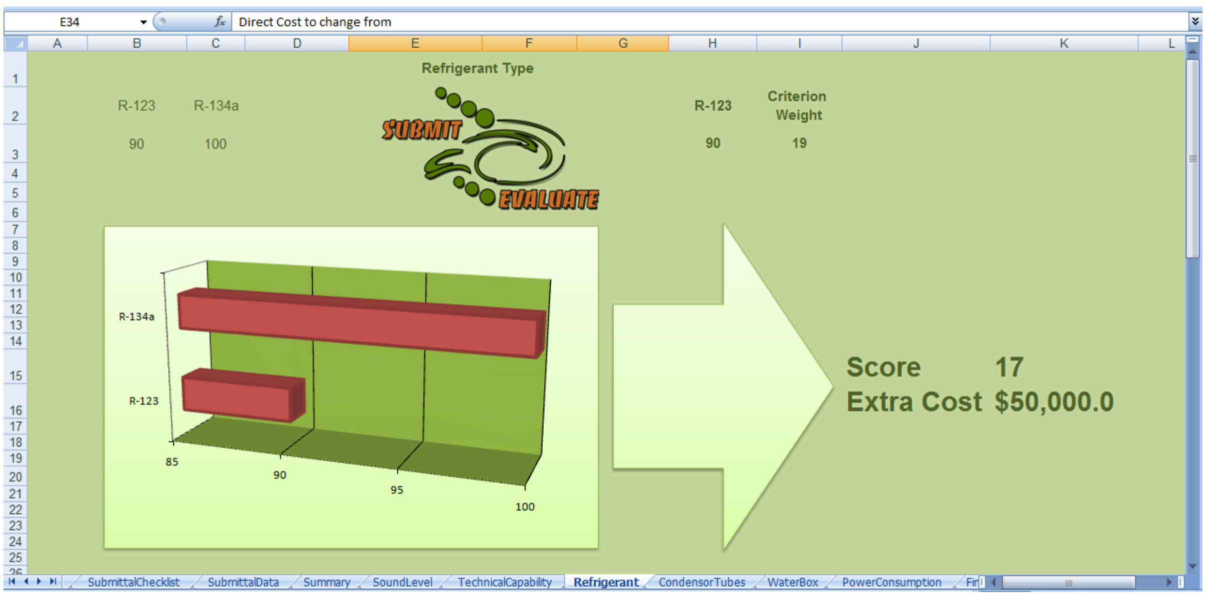


Figure 5-15: Refrigerant Type Page in the Prototype

5.4.3 Criterion 3: Technical Capabilities

The default for technical capabilities is company 1, with a given utility value of 90. It is considered that there is no change in the submittal value with regard to this criterion, so it receives the maximum possible score: 12 (Figure 5-16).

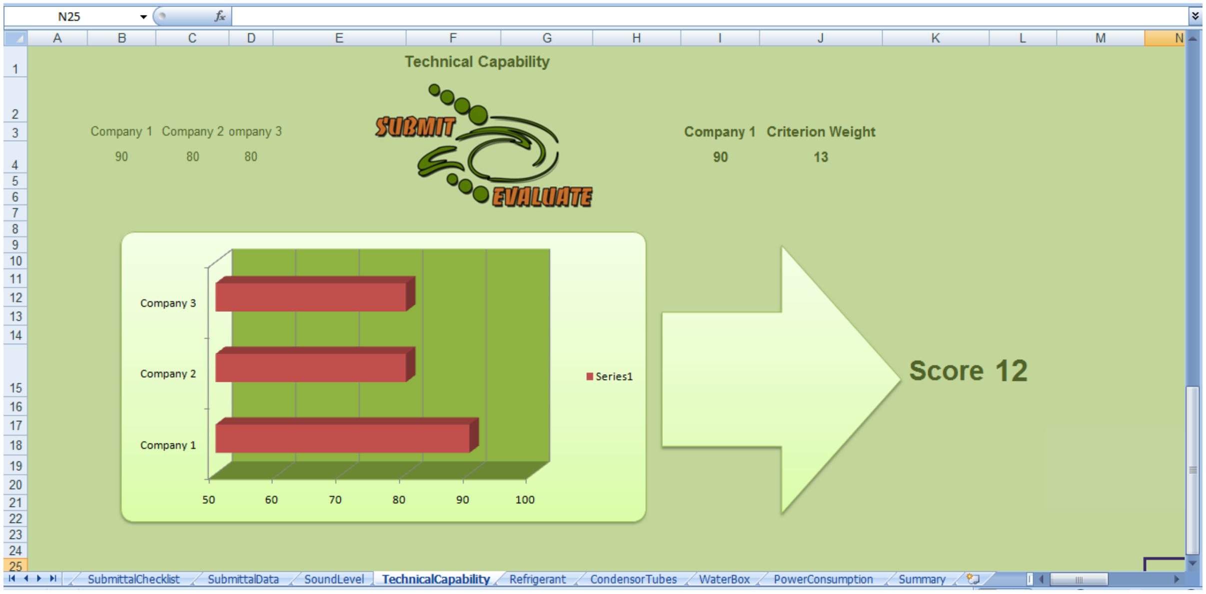


Figure 5-16: Technical Capabilities Page in the Prototype

5.4.4 Criterion 4: Condenser Tubes Thickness and Material

The default tube type is titanium while the submitted is copper tube with a thickness of 0.028", which is allocated a utility value of only 56.7, producing a total score of 6. Figure 5-17 shows the EXCEL sheet for this criterion, from which the utility value is generated. The calculation for each session for tube cleaning assumes having one HVAC technician and two HVAC assistant labourers to work an average of 40 hours in each session. Based on the website (www.indeed.com), the hourly rates used are $19/hour for the HVAC technician and $14/hour for the HVAC service technician. Using equation 4-16, as shown in Figure 5-18, the cost of each tube cleaning session came to $2,068.0. Using an interest rate of 11% and a lifecycle of 25 years, the extra cost is then $20,717. Figure 5-18 shows the cost generated and indicates all the equations used. It should be noted that the cost might change depending on the results of the water-box type selection, which is evaluated later.

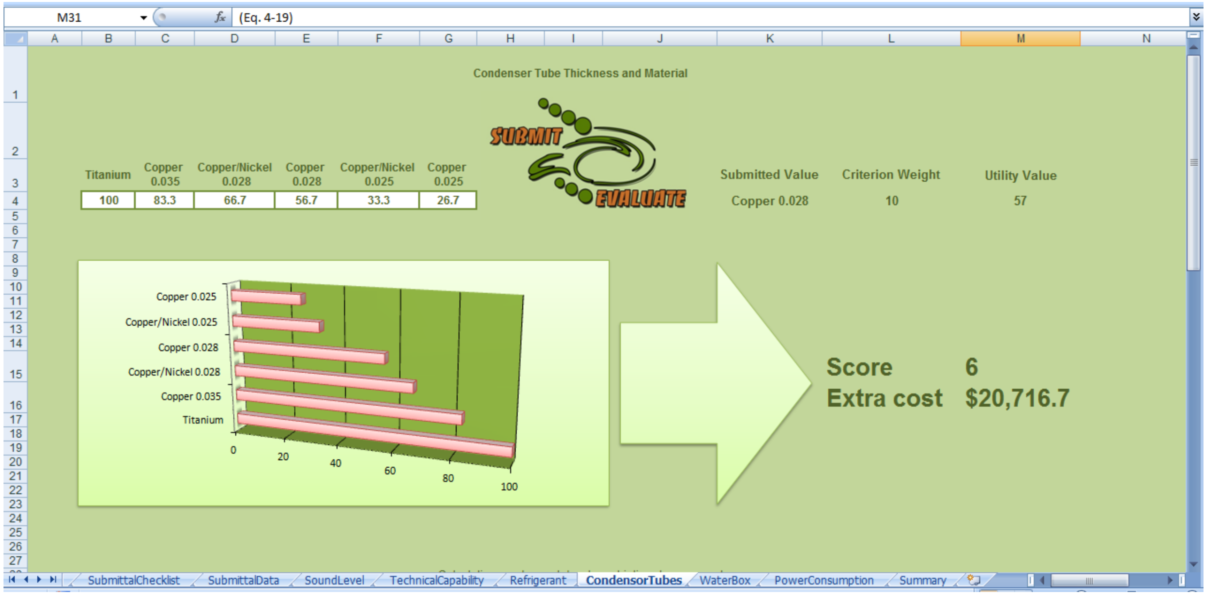
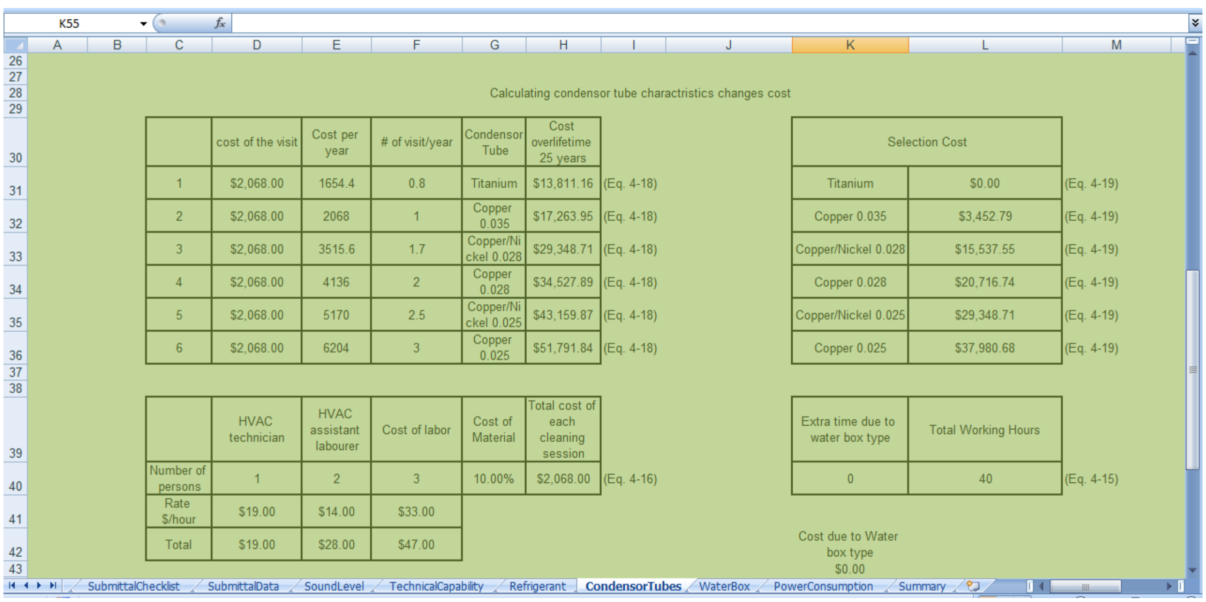


Figure 5-17: Condenser Tube Thickness and Material Utility Value Sheet


K55

Calculating condensor tube charactristics changes cost

	cost of the visit	Cost per year	# of visit/year	Condensor Tube	Cost overlifetime 25 years	
1	$2,068.00	1654.4	0.8	Titanium	$13,811.16	(Eq. 4-18)
2	$2,068.00	2068	1	Copper 0.035	$17,263.95	(Eq. 4-18)
3	$2,068.00	3515.6	1.7	Copper/Nickel 0.028	$29,348.71	(Eq. 4-18)
4	$2,068.00	4136	2	Copper 0.028	$34,527.89	(Eq. 4-18)
5	$2,068.00	5170	2.5	Copper/Nickel 0.025	$43,159.87	(Eq. 4-18)
6	$2,068.00	6204	3	Copper 0.025	$51,791.84	(Eq. 4-18)

Selection Cost		
Titanium	$0.00	(Eq. 4-19)
Copper 0.035	$3,452.79	(Eq. 4-19)
Copper/Nickel 0.028	$15,537.55	(Eq. 4-19)
Copper 0.028	$20,716.74	(Eq. 4-19)
Copper/Nickel 0.025	$29,348.71	(Eq. 4-19)
Copper 0.025	$37,980.68	(Eq. 4-19)

	HVAC technician	HVAC assistant labourer	Cost of labor	Cost of Material	Total cost of each cleaning session	
Number of persons	1	2	3	10.00%	$2,068.00	(Eq. 4-16)
Rate $/hour	$19.00	$14.00	$33.00			
Total	$19.00	$28.00	$47.00			

Extra time due to water box type	Total Working Hours	
0	40	(Eq. 4-15)

Cost due to Water box type
$0.00

SubmittalChecklist | SubmittalData | SoundLevel | TechnicalCapability | Refrigerant | CondensorTubes | WaterBox | PowerConsumption | Summary

Figure 5-18: Cost Calculation for Condenser Tubes Thickness and Material

5.4.5 Criterion 5: Sound Level

The submittal data do not include the Sound Pressure Level data because the manufacturer for the chiller was contacted, but there was no response. The value used for the submittal is therefore the minimum value according to the ARI 575 standard. As shown in Figure 5-19, the submitted and minimum curves are perfectly aligned, which reflects a 100% satisfaction level and results in a score of 10.

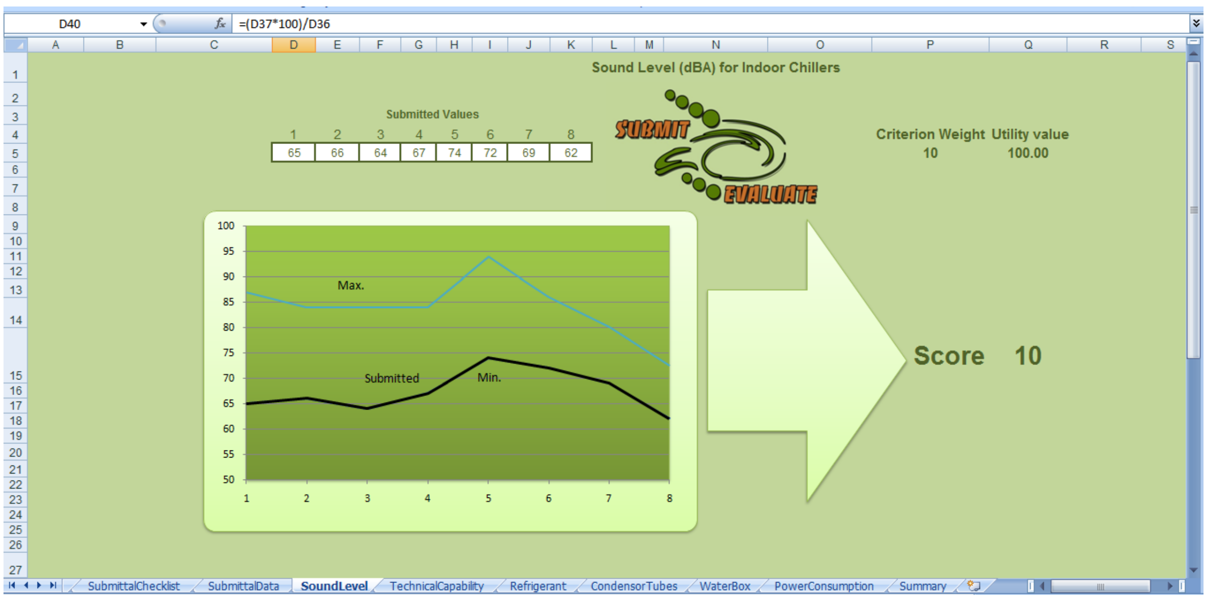
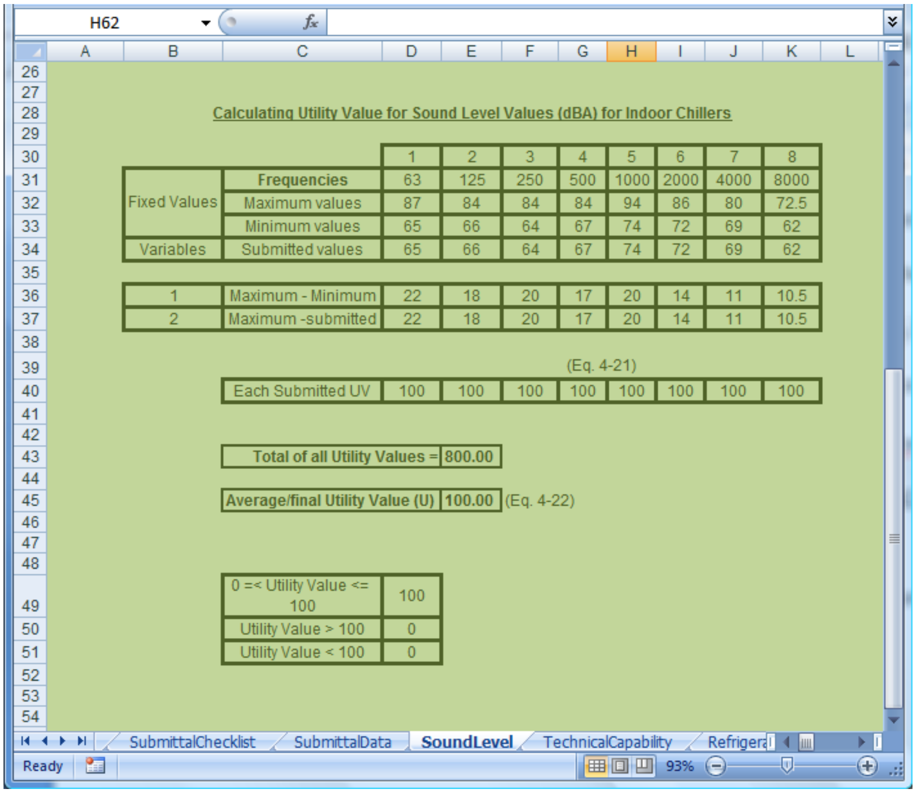


Figure 5-19: Sound Level Page within the Prototype

Figure 5-20 shows the Excel sheet, which indicates the equations used to derive each value and generate the final utility value.



Calculating Utility Value for Sound Level Values (dBA) for Indoor Chillers

		1	2	3	4	5	6	7	8
Fixed Values	**Frequencies**	63	125	250	500	1000	2000	4000	8000
	Maximum values	87	84	84	84	94	86	80	72.5
	Minimum values	65	66	64	67	74	72	69	62
Variables	Submitted values	65	66	64	67	74	72	69	62

1	Maximum - Minimum	22	18	20	17	20	14	11	10.5
2	Maximum -submitted	22	18	20	17	20	14	11	10.5

(Eq. 4-21)

Each Submitted UV	100	100	100	100	100	100	100	100

Total of all Utility Values =	**800.00**
Average/final Utility Value (U)	**100.00** (Eq. 4-22)

0 =< Utility Value <= 100	100
Utility Value > 100	0
Utility Value < 100	0

Figure 5-20: Utility Value Calculation for Sound Level

5.4.6 Criterion 6: Condenser Water-Box Type

The water-box parameter in the submittal data matches the 100% default option, which is the marine. Figure 5-21 presents the utility function graph for the three options available to the contractor. The utility value for the marine is 100 %, which results in a final score of 6, according to the criterion weight.

Figure 5-21: Condenser Water Box Type Utility Value, Score, and Cost

All scores and direct costs are then inserted automatically in the correct cell so that the final submittal score and conditions, if any, can be calculated. Figure 5-22 shows the EXCEL sheet with these data as compiled and calculated.

Summary for Alternative 1 Evaluation

Criterion	Original Weight	Utility Value	Score	Direct Cost
Power Consumption	42	99	42	$4,219.5
Refrigerant Type	19	90	17	$50,000
Technical Capabilities	13	90	12	$0
Condenser Tube Thickness and Material	10	57	6	$20,716.7
Sound Level	10	100	10	$0
Condenser Water Box Type	6	100	6	$0
Total				
Impact of score on cost =	$5,915.5		Total Direct Cost =	$74,936.2
		Total Score =	92.1	(Eq. 4-1)
		Approval Penalty =	$80,852	(Eq. 4-3)

Figure 5-22: Summary Sheet for the Case Study

The screen shot for the result as presented to the contractor is shown in Figure 5-23 along with the report indicating the details of the score and the direct cost. In this case, the final score for this alternative is 92.1 and the compensation cost is $80,851. The summation of the costs represented in the report shown in Figure 5-23 is reflecting the direct cost only while the reflection of the loose in satisfaction is hidden.

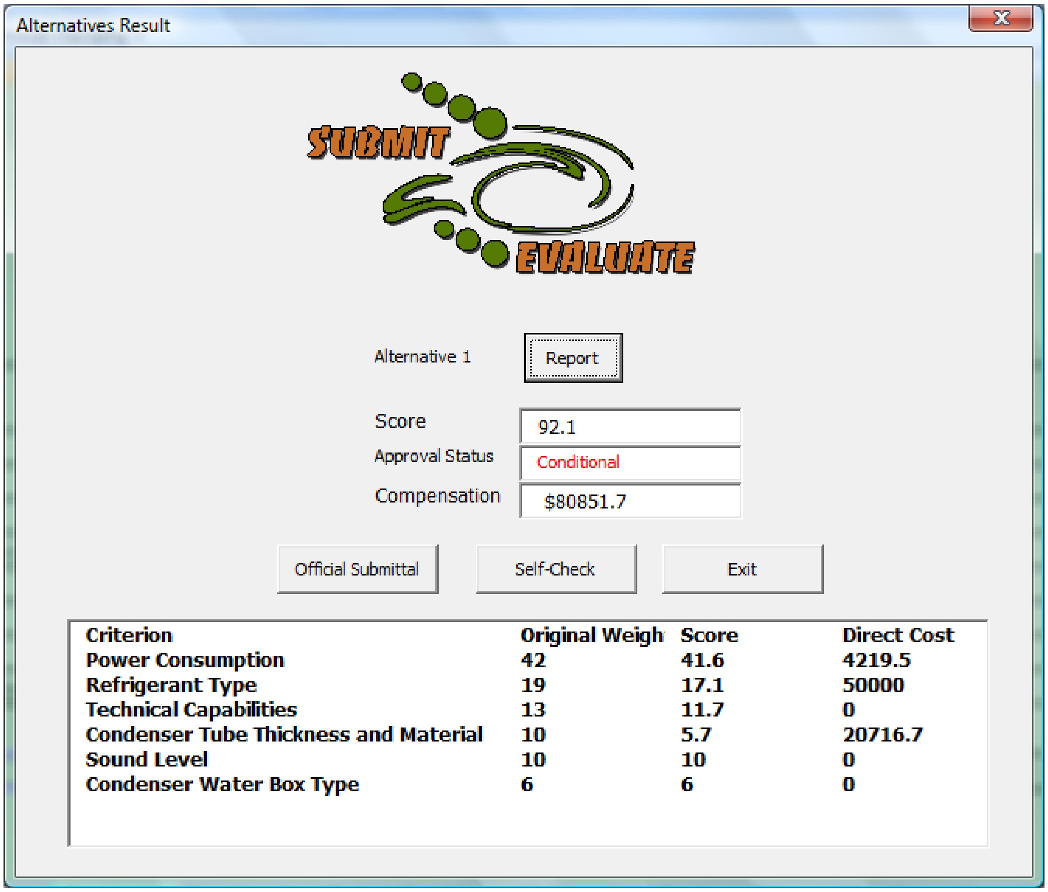


Figure 5-23: Results and Report of the Case Study

The alternative can then be finally approved or not depending on if that the score is above or below a minimum acceptable threshold (default) set by the organization.

To establish a reasonable threshold value for the minimum acceptable score to be used in this study, a simple analysis was carried out of a number of chillers that had already approved for actual construction project. In this analysis, each chiller was evaluated by the prototype system, and the final score was calculated. The results (Table 5-1) were then averaged to determine a minimum acceptable default score. The analysis revealed that 80 is a reasonable estimate, and this value was then used for evaluating the remaining of the case study results. This value is also a parameter that can be changed by the user to suit the specific preferences of an organization. Based on the threshold score, the process to determine the final evaluation decision is illustrated in Figure 5-24.

Table 5-1: Determining the Minimum Acceptable Threshold (Score)

Chiller 1 Score	Chiller 2 Score	Chiller 3 Score	Chiller 4 Score	Average Score
86	85	65	85.5	**80**

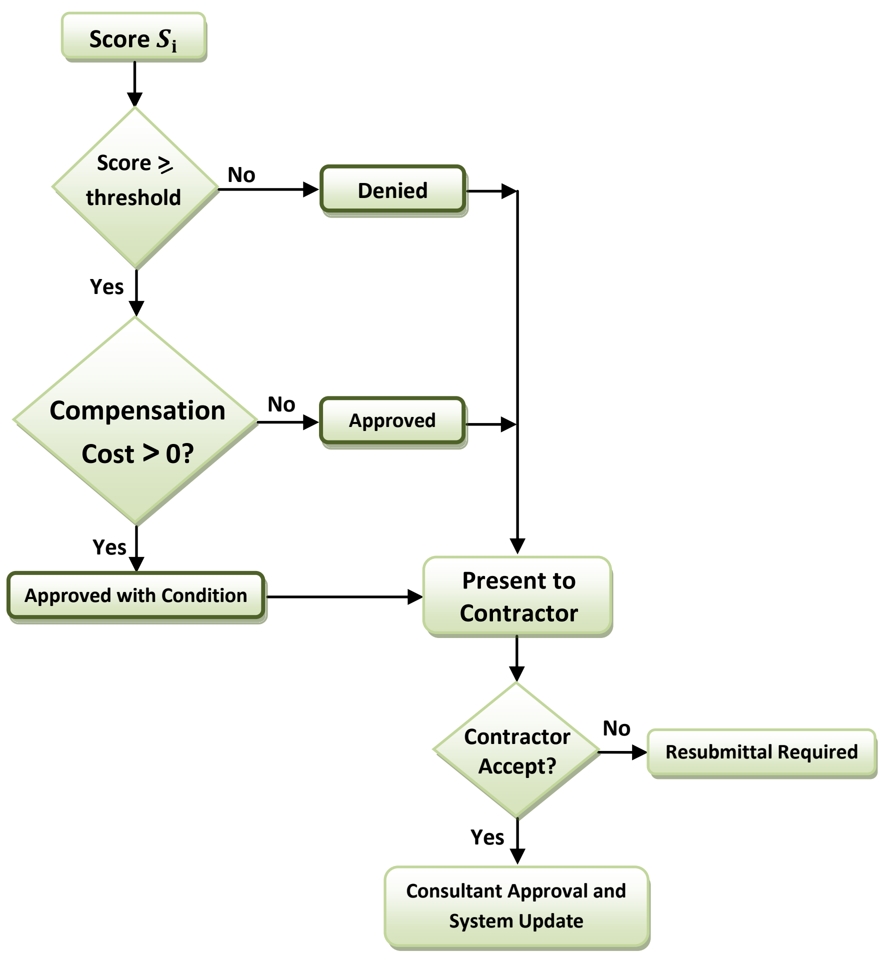


Figure 5-24: Process to Determine the System Final Evaluation Decision

5.5 Conclusion

This chapter presented the developed prototype for submittal evaluation. The value-based decision support system was explored using a case-study demonstration of the two developed modules: setup and evaluation. The case study used a real-life submittal that was collected from UW along with the system's default requirements. The system produced a score and a total compensation cost for the case, which indicate that the submittal was approved but that the approval was contingent on the condition that the contractor compensate the owner for the additional cost associated with this submittal. A minimum acceptable threshold has also been defined for evaluating the results of the case studies used in this research.

Chapter 6

Case Studies, Experiments, and Validation

6.1 Introduction

Chapter 5 described the use of the prototype for processing a real-life submittal in default mode for illustration purposes. This chapter presents the model sensitivity analysis and the validation of the system through the use of five different case studies with eleven scenarios. The first case study included three different scenarios in a real-life case received from the University of Waterloo (UW). These scenarios were used to examine the behavior of the developed model when the parameters are varied. The second case study was another real-life submittal that included three alternatives with known requirements. In the third case study, the system evaluated the same three alternatives from the second case, but this time against the default requirements in order to examine the value of the submitted items with respect to organizational preferences. The results of the second and third cases were compared in order to determine the effect of changing the requirements. The fourth case study was another real case in which the default LEED requirements were considered with respect to a single alternative. Two scenarios were included in the fourth case in order to examine the sensitivity of the model with respect to variations in the LEED requirements of the parameters. The fifth case study was a hypothetical case for multiple alternatives with respect to LEED requirements that were developed based on the data collected. The results of the five scenarios were shared with experts in order to obtain feedback about the specific decisions and about the system as whole.

Table 6-1: Summary of the Descriptions and Purposes of the Case Studies

Case Number	Description	Purpose
Case 1	- Real-life submittal from UW with one alternative - Evaluation against default requirements with no LEED	To show the benefits of sensitivity analysis in identifying simple options for enhancing the submittal value
Case 2	- Real-life submittal from KFUPM with 3 alternatives - Evaluation against organizational requirements with no LEED	To show submittal evaluation results relative to organizational requirements
Case 3	- Same as case # 2 - Evaluation against default requirements with No-LEED	To show the effects of changes in the organizational requirements on the submittal score
Case 4	- Real-life submittal from KFUPM with one alternative - Evaluation against default requirements with LEED	To show the importance of the opinions of experts in the final decision
Case 5	- Hypothetical submittal with 3 alternatives - Evaluation against default requirements with LEED	To show the benefits of sensitivity analysis in identifying changes to a rejected submittal in order to make it acceptable

6.2 Real-Life Case Study 1: (Single alternative against no-LEED default requirements)

The first case study is a real-life case in which a 300-ton chiller that was received by UW as part of a submittal that included two chillers (Appendix D-2 & D-3). Since the organizational requirements were not provided by UW, the case was processed against the default requirements based on the assumption that the same loading capacity was required: 300 tons. The known fact was that the organization had-already approved the chiller for the designated project. The result produced by the system was a conditional approval, with a total score of 91.9 and a compensation value of $81,370.00, as shown in Figure 6-1.

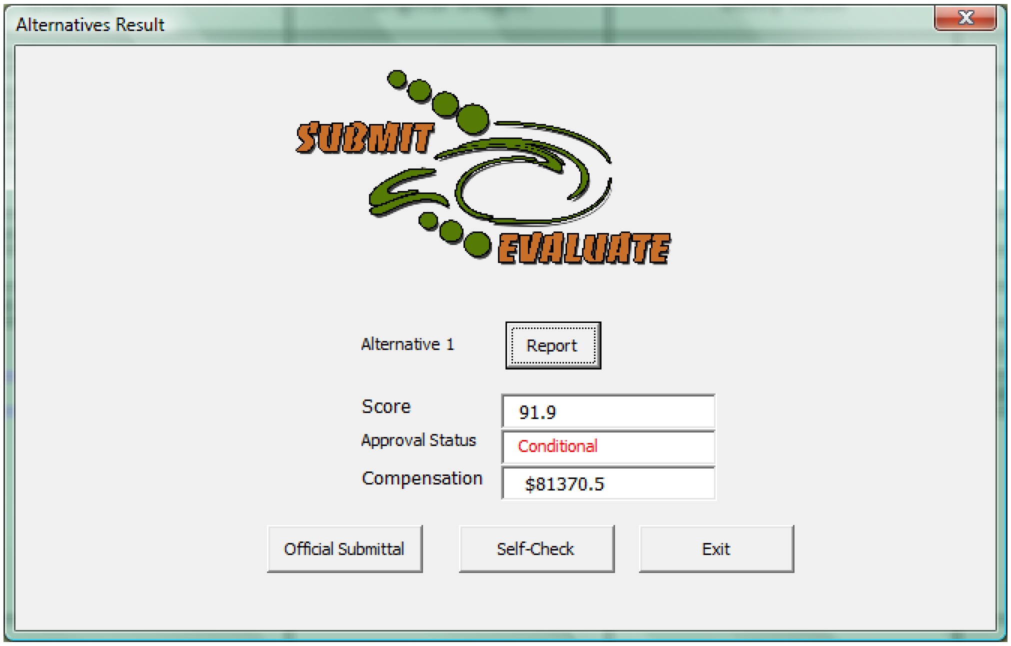


Figure 6-1: Results for Case 1, Original Submitted

It should be noted that the variation within the parameter values between the submitted and the required (the default) produced the low score and compensation value. The refrigerant type in the submittal, for example, is R-123, and the condenser tube is copper, with a thickness of 0.028 in., while the default refrigerant type is R-134a, and the condenser tube is titanium. For these parameters, the submitted values were lower than the required and had direct implications for the cost and level of satisfaction. To examine the sensitivity of the model against the parameters and to identify the effect of each parameter on the results, the case was processed several times after the parameters values were changed one by one, the results of which are shown in Table 6-2.

Table 6-2: Results Summary for three different Scenarios of Case 1,

	Criteria Number						Evaluation	
	*1	*2	*3	*4	*5	*6	Score	Compensation
Specification	**0.55**	**R-134a**	**1**	**Titanium**	**Min.**	**Marine**	**100**	**0**
Original Submitted	0.571	R-123	1	Copper 0.028"	Min.	Marine	**91.9**	**81,370**.00
Scenario 1: Power Input Changed	**0.55**	R-123	1	Copper 0.028"	Min.	Marine	**92.5**	**76,042**
Scenario 2: Refrigerant Changed	0.571	**R-134a**	1	Copper 0.028"	Min.	Marine	**93.8**	**26,832**
Scenario 3: Tube Changed	0.571	R-123	1	**Titanium**	Min.	Marine	**96.2**	**56,610**

*1 = Power Input *2 = Refrigerant Type *3 = After-Sale Capabilities *4 = Condenser Tube *5 = Sound Level *6 = Water-Box

In three different scenarios (Table 6-2), parameters 1, 2, and 4 were modified one by one to match the requirements while all other parameter values were kept as submitted. The results for the three scenarios show that every parameter can introduce different values for the submittal and the decision to improve one of them requires careful analysis of all of them. Changing each parameter provided an improvement in the value of the submittal, to different degrees. The owner can offer to reduce the compensation that the contractor should pay for the approval by modifying a specific parameter. Changing the submitted condenser tube type to be as specified can save the contractor about $25,000 while providing the owner with the best possible value. The owner can even offer a savings of more than $50,000 by asking the contractor to provide the specified refrigerant type, which would still provide better value for the owner. With traditional methods, such analysis is difficult and time consuming and lacks objective criteria, while the developed automated model offers a speedy process with a quantitative result. The new approach can help the owner to direct any negotiation with respect to improving the value of the submitted item based on knowledge of the most effective parameter.

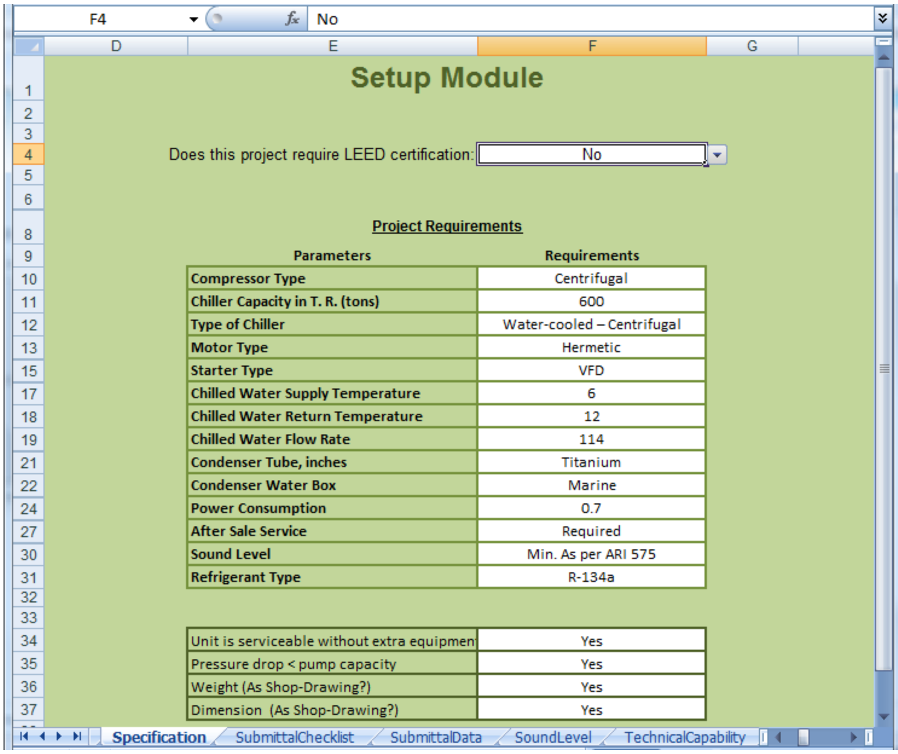
6.3 Case Study 2: (Multiple alternatives against no-LEED organizational requirements)

The second case study, provided by KFUPM, is another real-life submittal for a chiller. in this case, the organizational requirements, or specifications, were provided for the model to examine against three alternatives as provided by the contractor. The contractor claimed unavailability of the item according to the required parameter value during the project and provided multiple alternatives that had minor deviations. The project team considered these deviations acceptable for review although there was no defined range of acceptability.

A review of the original submittal revealed concerns about undefined parameter values for the alternatives, which were clarified based on input from the project engineer (Eng. Y). The acceptable range of power input for the organization was therefore set to (1 to 0.7 KW/ton). Table 6-3 summarizes the requirements and the data for the three alternative chillers in this submittal, and Figure 6-2 shows the specification requirements as populated in the prototype setup module.

Table 6-3: Requirements for Case 2

Parameter	Requirements	Alternative 1	Alternative 2	Alternative 3
Chiller Capacity in T. R. (tons)	600	678	630	600
Motor Type	Hermetic/Open	Hermetic	Hermetic	Open
Starter Type	VFD	VFD	Y-Delta	VFD
Water Supply Temperature	6.0 Deg. C	6.0	6.0	6.0
Water Return Temperature	12.0 Deg. C	12.0	12.0	12.0
Chilled Water Flow Rate	114	114	114	114
Condenser Tube (inches)	0.035" & Copper	Comply	0.035" & Copper	0.035" & Copper
Condenser Water Box	Marine	Marine	Marine	Marine
Power Consumption	0.7 – 1.0 KW/ton	0.751	0.716	0.748
After-Sale Service	Required	Excellent	Good	Good
Sound Level	Min. as per ARI 575	Comply	Comply	Comply
Refrigerant Type	R-134a	R-134a	R-134a	R-134a



Parameters	Requirements
Compressor Type	Centrifugal
Chiller Capacity in T. R. (tons)	600
Type of Chiller	Water-cooled – Centrifugal
Motor Type	Hermetic
Starter Type	VFD
Chilled Water Supply Temperature	6
Chilled Water Return Temperature	12
Chilled Water Flow Rate	114
Condenser Tube, inches	Titanium
Condenser Water Box	Marine
Power Consumption	0.7
After Sale Service	Required
Sound Level	Min. As per ARI 575
Refrigerant Type	R-134a

Unit is serviceable without extra equipmen	Yes
Pressure drop < pump capacity	Yes
Weight (As Shop-Drawing?)	Yes
Dimension (As Shop-Drawing?)	Yes

Figure 6-2: Specification Parameters as Shown in the Prototype

The three alternatives were processed in parallel through the pre-screening (checklist) evaluation. Figure 6-3 presents the user form for populating the spreadsheet (Figure 6-4) with data. Submitting a starter type that is different from that required causes alternative 2 to fail, as shown in Figure 6-5.

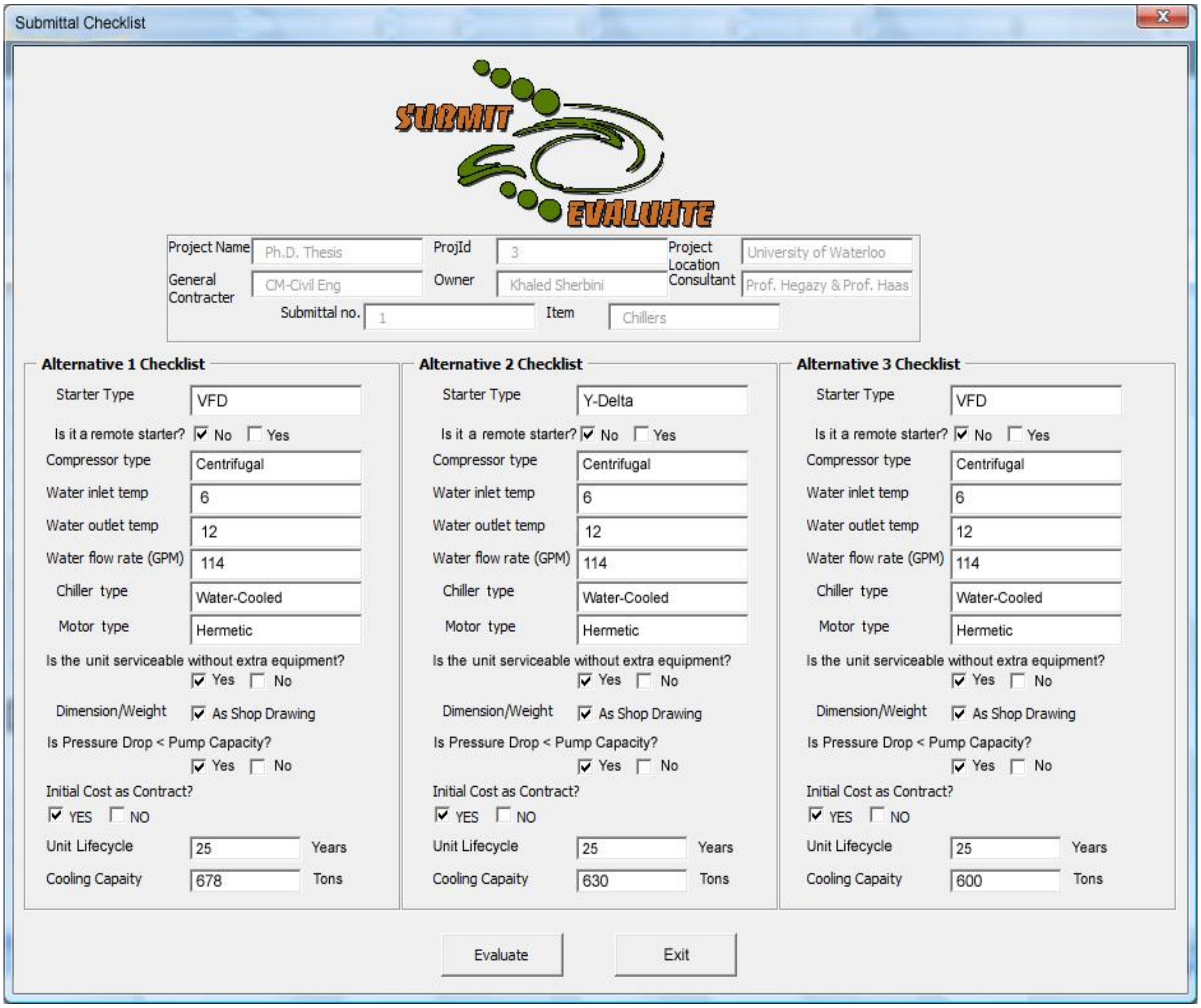


Figure 6-3: Processing the Checklist (User Form)

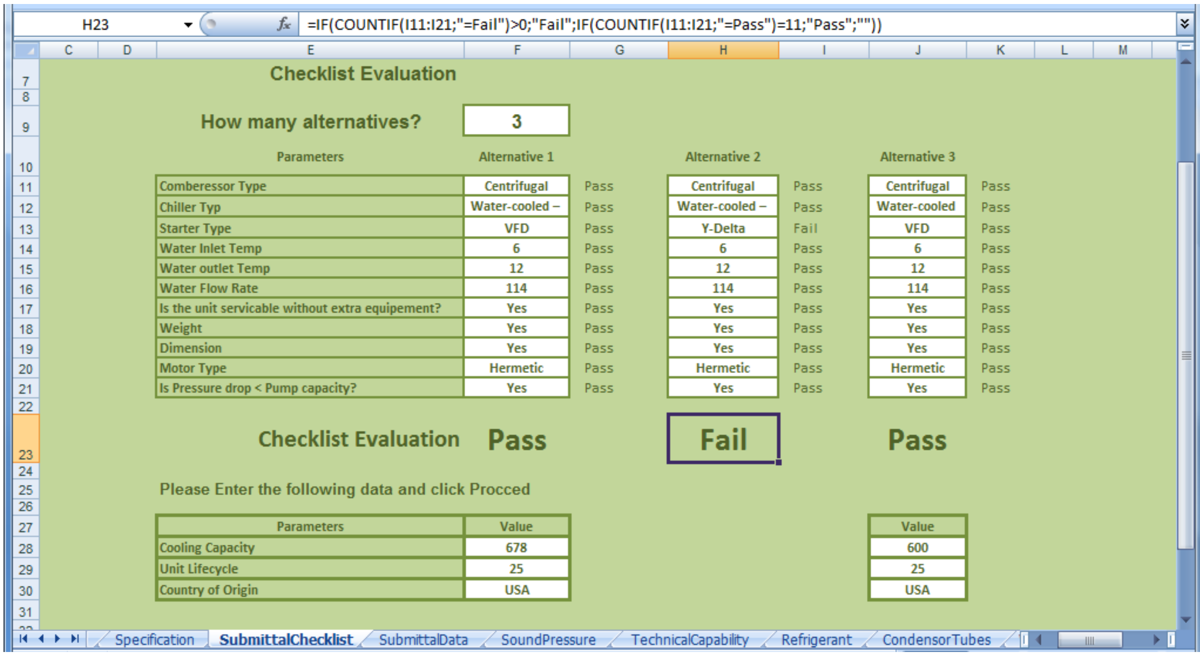


Figure 6-4: Checklist Evaluation (Excel Sheet)

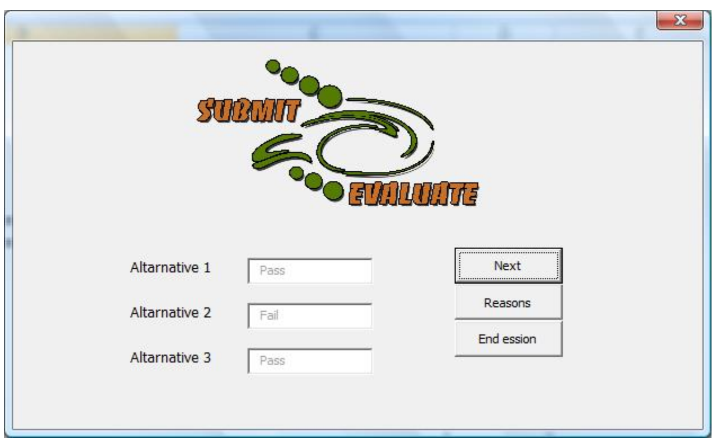


Figure 6-5: Checklist Evaluation Result as Presented to the User

The two alternatives that passed, 1 and 3, were moved to the next evaluation stage: the value-based evaluation. The process considered the defined criteria as explained in Chapter 4 and used the electricity rate of 0.1 cents/KWh for 24 hours of operation. Figure 6-6 shows the user form that populates the data to the Excel spreadsheet, which is shown in Figure 6-7.

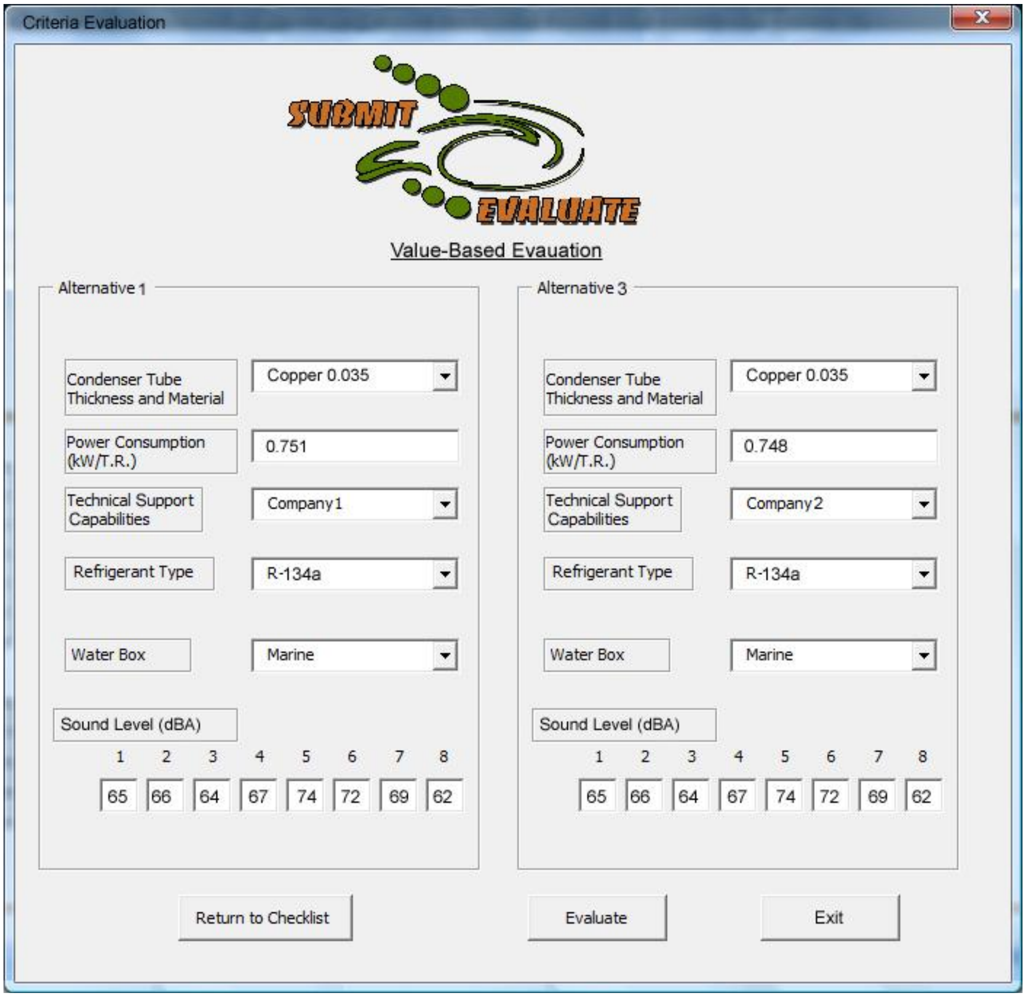


Figure 6-6: Value-Based Evaluation for Alternatives 1 & 3 (User Form)

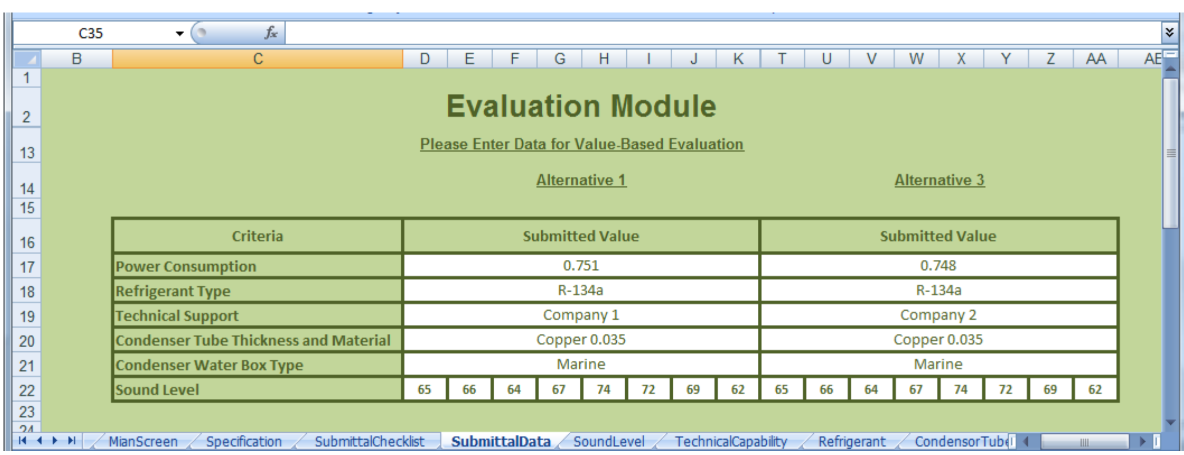


Figure 6-7: Value-Based Evaluation for Alternatives 1 & 3 (Spreadsheet)

For each of Figures 6-8 to 6-13, criterion Excel spreadsheet for alternative 1 is shown indicating the scores and extra costs.

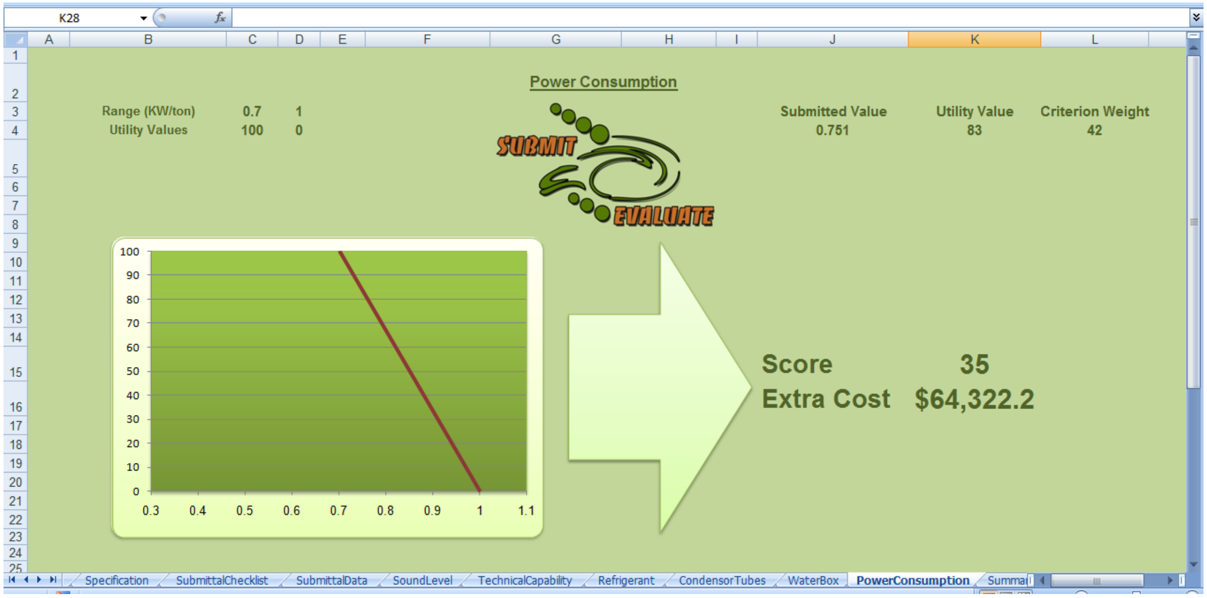


Figure 6-8: Power Consumption Score and Extra Cost Spreadsheet

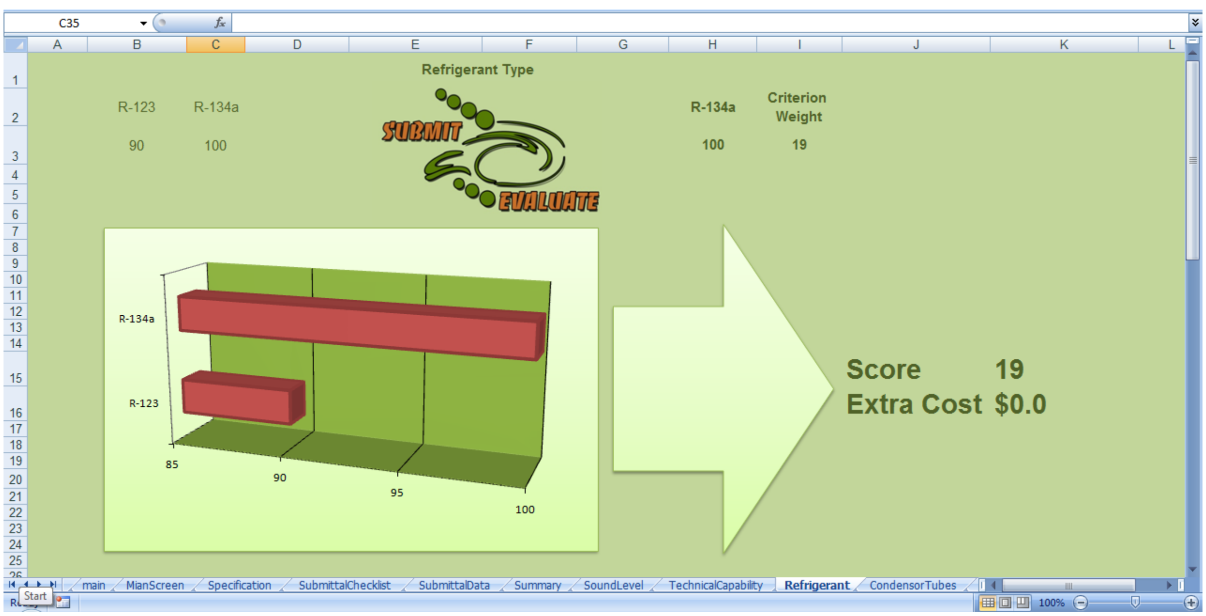


Figure 6-9: Refrigerant Type Score and Extra Cost Spreadsheet

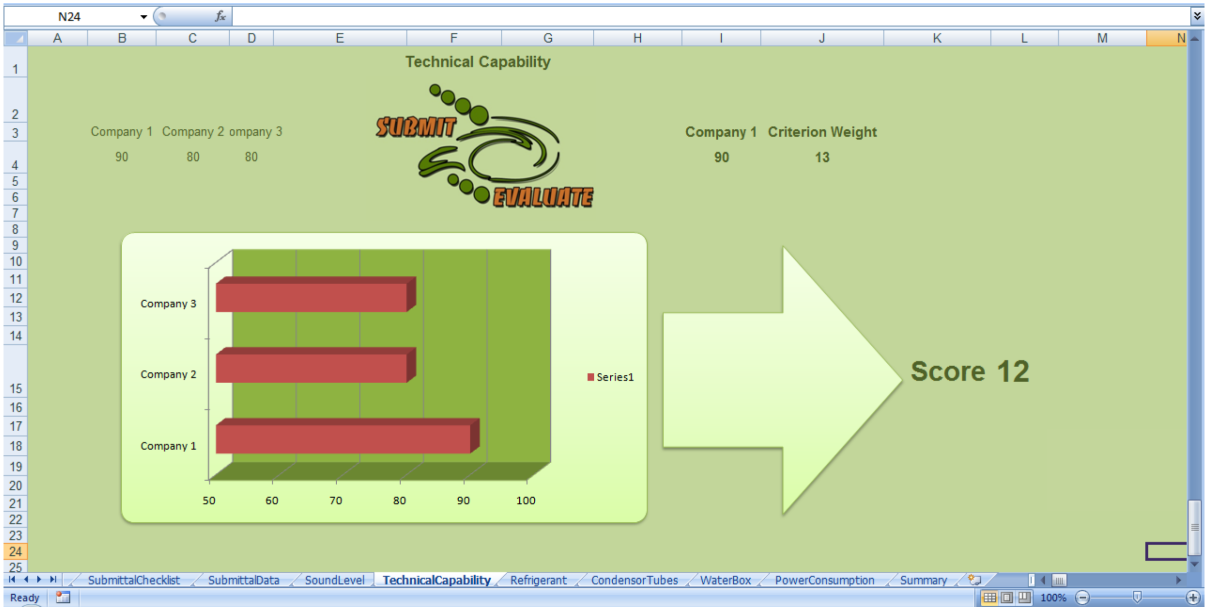


Figure 6-10: Technical Capability Score Spreadsheet

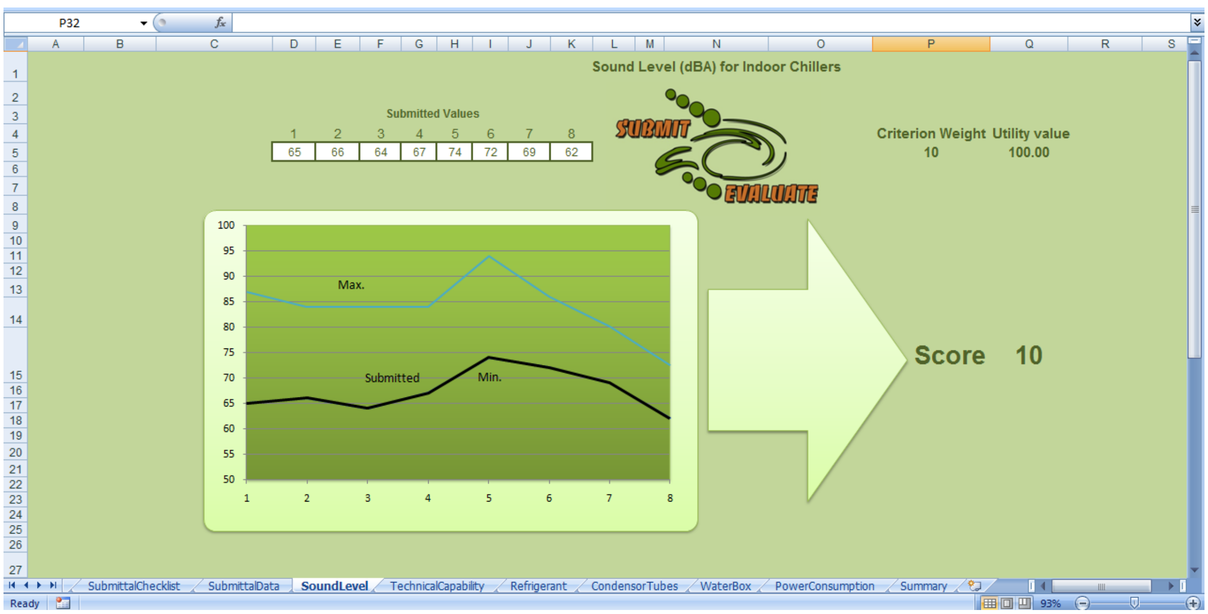


Figure 6-11: Sound Level Score Spreadsheet

It should be noted that the condenser tube thickness and material was shifted to copper 0.035" to meet the organization's requirements, which is reflected in the change to a value of 100% (Figure 6-12).

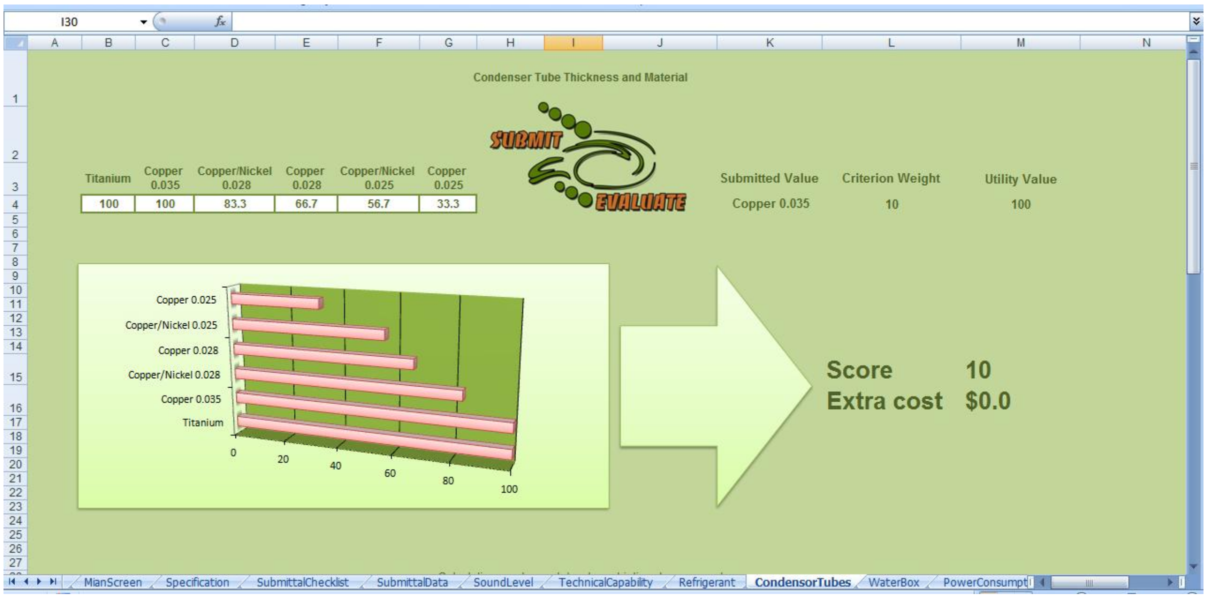


Figure 6-12: Condenser Tube Thickness and Material Score and Extra Cost Spreadsheet

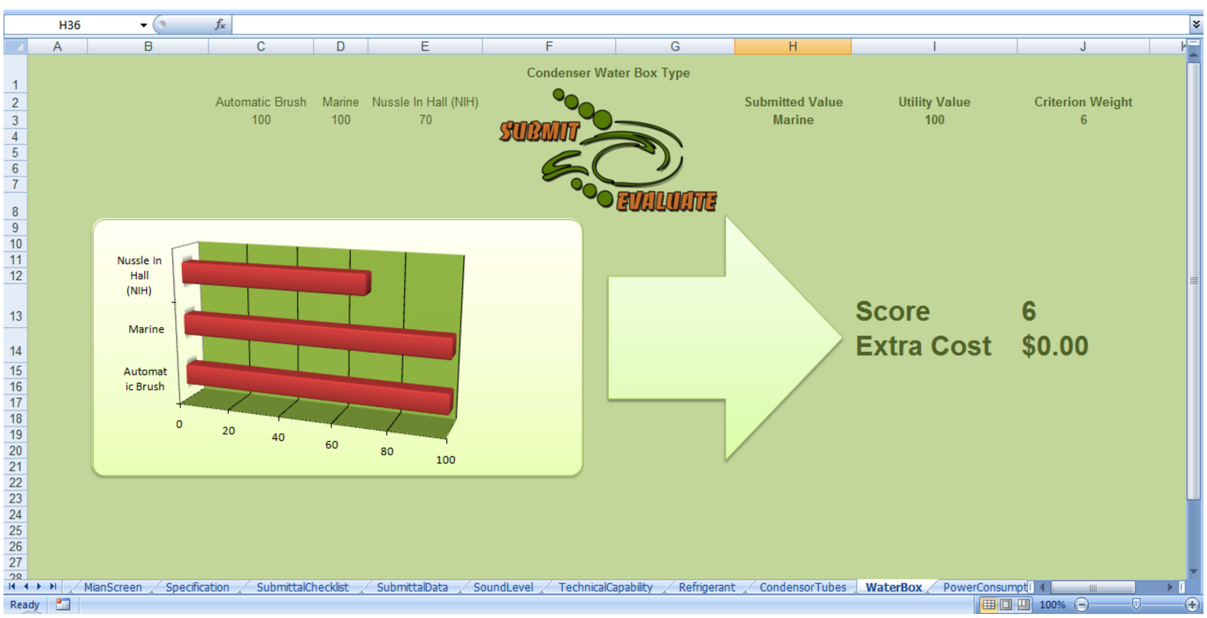


Figure 6-13: Water Box Type Score and Extra Cost in the Spreadsheet

The alternatives processed received relatively high scores (Figure 6-14). Alternative 1, the highest-scoring alternative that is 91.6, has the highest compensation cost. Alternative 2 was denied early in the process because it did not meet the checklist requirements. Table 6-4 summarizes the results of the processed alternatives.

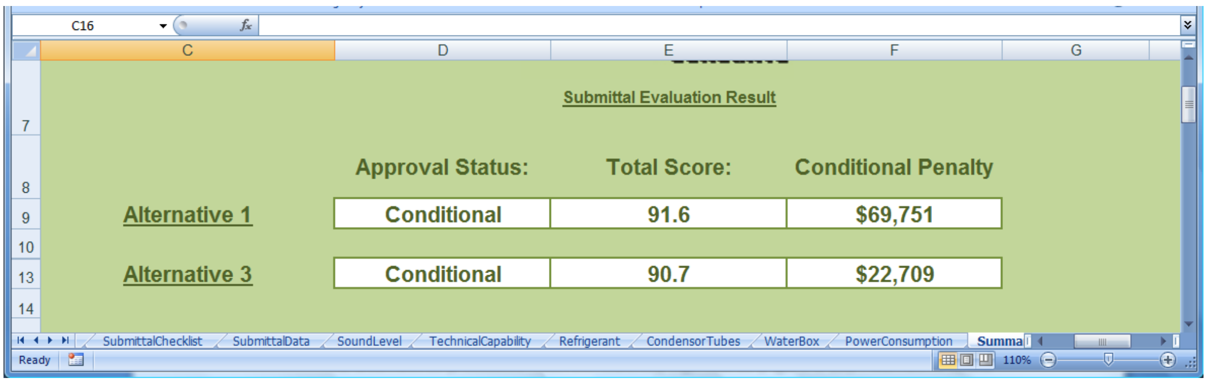


Figure 6-14: Results for Case 2 as Presented in the EXCEL Spreadsheet

The results were presented to the organization. Eng. Y confirmed that the resulting score matched their actual decision, which took them about 8 hours for the technical review alone. They also advised that they never consider cost compensation in the submittal approach because they do not consider the impact on the operational stage. The developed system, for him, is useful especially for filtering out non-compliant submittals, thus making the process much faster. The system's feature of reporting the reasons for rejection also interested Eng. Y, and he suggests providing even more details to highlight the variations required for a resubmittal. He made the additional suggestion that the concept of compensation should be discussed with the contractor during the bidding stage.

Table 6-4: Summary Results for Case 2

		Alternative 1	Alternative 2	Alternative 3
System Suggestion	**Score**	**91.6** > 80	Denied in the checklist stage.	**90.7** > 80
	Approval Status	Approved with Condition	Denied	Approved with Condition
	Compensation	**$69,751**	N/A	**$22,709**
	Reasons for decision:	**Power input and cooling capacity are higher than required. Service support for supplier is rated 90 %**	**Starter type is not as required - Rejected during pre-screening stage**	**Power input is higher than the required and Service support for supplier is rated as 80 %**

6.4 Case Study 3: (Multiple alternatives against no-LEED default requirements)

This case presents a scenario to examine the value of the submitted item against the organizational requirements/preferences. It is evaluating the three alternatives submitted in the previous real-life case against new requirements that is the no-LEED system default, as shown in Table 6-5, in which the range for the power input is set at 1.0 – 0.55 KW/ton.

Table 6-5: Submittal Alternatives and Required Parameter Values for Case 3

	← Changed →	←	Same as Case 1	→
Parameters	Requirements	Alternative 1	Alternative 2	Alternative 3
Chiller Capacity (tons)	600	678	630	600
Motor Type	Water-cooled	Water-cooled	Water-cooled	Water-cooled
Motor Cooling Mean	Hermetic	Hermetic	Hermetic	Hermetic
Starter Type	VFD	VFD	Y-Delta	VFD
Water Supply Temperature	6	6	6	6
Water Return Temperature	12	12	12	12
Water Flow Rate	114	114	114	114
Condenser Tube, inches	Titanium	0.035" Copper	0.035" Copper	0.035" Copper
Condenser Water Box	Marine	Marine	Marine	Marine
Power Consumption	0.7	0.751	0.716	0.748
After Sale Services	Excellent	Excellent	Good	Good
Sound Level	Min. per ARI 575	Min. per ARI 575	Min. per ARI 575	Min. per ARI 575
Refrigerant Type	R-134a	R-134a	R-134a	R-134a

The results presented in Table 6-6 show that alternative 1 received a score of 82.1, as opposed to 91.6 in the previous scenario. Alternative 2 was still denied in this case because it does not fulfill the checklist requirements. The score for alternative 3 also dropped from 90.7 to 81.5 in the present case. Both alternatives 1 and 3 were approved with condition, but their score were just above the minimum acceptable (80) with high compensation cost in compare to the previous case results. Such dramatic change in score and compensation cost demonstrates the role of organizational requirements in such an evaluation where submittal value has been changed due to the organizational preferences.

Table 6-6: Results for Case 3

		Alternative 1	Alternative 2	Alternative 3
System Suggestion	Score	83.4 > 80	Denied in the checklist stage	81.5 > 80
	Approval Status	Approved with condition	Denied	Approved with condition
	Compensation	$154,690	N/A	$105,676
	Reasons for decision:	Variations in power input, cooling capacity, condenser tube characteristics cause a low score and a high compensation cost	Starter type is not as required. It is rejected during pre-screening (checklist) stage.	Variations in power input, refrigerant type, supplier rate, and condenser tube characteristics cause a low score and a compensation cost

Alternative that is received a high score for an organization may be denied by another organization based on their specific preferences. Since the current submittal evaluation process is much dependant on the personal experiences, the developed system has the advantage of representing the organizational preferences, with less dependence on personal experience.

6.5 Case Study 4: (Single alternative against LEED default requirements)

This case was received from KFUPM (Appendix D-5 & D-6) as part of an approved submittal. The power input for the case was not identified but was obtained from the Carrier Company website: 0.35 KW/ton (Carrier 2010). The case was used to examine the impact of variations in the LEED requirements for a single alternative; it was processed against the system default LEED requirement. The first scenario for this case was based on the assumption that the organization must obtain two points from power. Two points means that the savings should be 36 % above the baseline, which make the required power input 0.352 KW/ton. The results of the case with the first scenario are presented in Table 6-7. The case is approved conditionally with a score of about 87, and it achieved the required LEED points.

Table 6-7: Results for Case 4, Scenario 1

System Suggestion	Score	**86.8** > 80
	Approval Status	Approved with condition
	Compensation	**$33,228**
	Reasons for decision:	**Variations in supplier rate, condenser tubes, and sound level caused a lower score and compensation cost**
LEED Points Earned		**2**

In the second scenario, the organization changed the required number of LEED points to three, which are obtained by achieving 0.319 KW/ton. Running the case against the system requirements after changing the power required produced conditional approval, as shown in Table 6-8. The score for this scenario was lower than for the first scenario, and the compensation was higher, while the required LEED points were not achieved. In such a case, the system should refer to the consultant to decide whether to accept the loss of the required LEED point. This case study shows the effect on the submittal value of changing the LEED requirements with respect to power points.

Table 6-8: Results for Case 4, Scenario 2

System Suggestion	Score	**81.1** > 80
	Approval Status	Approved with condition
	Compensation	**$46,228**
	Reasons for decision:	**Variations in power input, supplier rate, condenser tubes, and sound level caused a lower score and compensation cost**
LEED Points Earned		**2**

6.6 Hypothetical Case Study 5: (Multiple alternatives against LEED default requirements)

In this hypothetical case study, the organization sought three LEED points from two parameters: energy efficiency (power input) and refrigerant type. An energy efficient unit with savings of 30 % above the power baseline provides one point for power while two points can be obtained by using an R-134a refrigerant. The corresponding requirements are shown in Table 6-9. The submittal includes three alternatives, as shown in the table, which include values different from the developed requirements.

Table 6-9: Submittal Alternatives and Required Parameter Values for Case 5

Parameters	Requirements	Alternative 1	Alternative 2	Alternative 3
Chiller Capacity (tons)	600	600	630	620
Motor Type	Water-cooled	Water-cooled	Water-cooled	Water-cooled
Motor Cooling Mean	Hermetic	Hermetic	Hermetic	Hermetic
Starter Type	VFD	VFD	VFD	VFD
Water Supply Temp.	6	6	6	6
Water Return Temp.	12	12	12	12
Chilled Water Flow Rate	114	114	114	114
Condenser Tube (inches)	Titanium	Titanium	0.035" Copper	0.028" Copper/Nickel
Condenser Water Box	Marine	Marine	Marine	Marine
Power Consumption	0.385 (1 LEED point)	0.4	0.421	0.395
After Sales Services	Excellent	V. Good	Good	Excellent
Sound Level	Min. as ARI 575	Table 6-10 (R-1)	Table 6-10 (R-2)	Table 6-10 (R-3)
Refrigerant Type	R-134a (2 LEED points)	R-123	R-134a	R-134a

With regard to the sound level, the R-1 value shown in Table 6-10 are taken from a real-life set of chiller data dB values that were used in case study 4 (Appendix D-6). The sound level data for the other two alternatives, R-2 and R-3, were assumed to have minor random differences from the sound data for R-1.

Table 6-10: Chiller Sound Level (dB) for Case 5

	Frequency, Hz							
Alternative	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
R-1	67	74	86	77	76	78	82	75
R-2	70	75	76	80	78	75	82	70
R-3	70	76	76	82	84	72	76	74

The setup module was processed in order to update the specification parameters to reflect the new requirements. The results of evaluating the alternatives are presented in Table 6-11. Although alternative 1 passed the checklist evaluation, it was nonetheless denied because its total score is less than the acceptable threshold value. Although alternatives 2 and 3 were both approved with a condition, the score for alternative 2 is close to the minimum acceptable score and thus has a higher compensation cost value than does alternative 3, a result that reflects the high risk of accepting alternative 2.

Table 6-11: Results for Case 5, Original Submitted

		Alternative 1	Alternative 2	Alternative 3
System Suggestion	Score	78.9 < 80	81.0 > 80	87.1 > 80
	Approval Status	Denied	Approved with condition	Approved with condition
	Compensation	NA	$33,488	$28,850
	Reasons for decision:	Total score is less than the minimum acceptable score, which is 80.	Variations in power input, cooling capacity, supplier rate, condenser tubes, and sound level caused a lower score and compensation cost	Variations in power input, cooling capacity, supplier rate, condenser tubes, and sound level caused a lower score and compensation cost
LEED Points Earned		NA	3	3

Whenever an alternative is approved, even with a condition, it provides good value for the project. The contractor, therefore, may select any of the approved choices, even if it has the lowest score or requires higher compensation. Such a decision depends on the values the contractor associates with procuring the item (e.g., speedy delivery, initial cost, or other criteria).

Sensitivity analysis of the rejected alternative (alternative 1) was processed in the system in order to evaluate the effect of each parameter. In four different scenarios in case 5 (Table 6-12), parameters 1, 2, 3 and, 5 were modified to meet the requirements one by one while all other parameter values were kept as submitted. The four scenarios produce different values for the submittal and transform the rejected submittal into an approved one, as shown in scenarios 1, 2, and 4 in Table 6-12.

Table 6-12: Results for Case 5, Four Different Scenarios

	Criteria Number						Evaluation	
	*1	*2	*3	*4	*5	*6	Score	Compensation
Specification	**0.385**	**R-134a**	**1**	**Titanium**	**Min.**	**Marine**	**100**	**0**
Original Submitted	0.4	R-123	2	Titanium	R1	Marine	**78.9**	**NA** (Denied)
Scenario 1: power Input Changed	**0.385**	R-123	2	Titanium	R1	Marine	**82.7**	**$ 58,633.00**
Scenario 2: Refrigerant Changed	0.4	**R-134a**	2	Titanium	R1	Marine	**88.4**	**$ 7,243.00**
Scenario 3: After-Sale Capabilities Changed	0.4	R-123	**1**	Titanium	R1	Marine	**78.9**	**NA** (Denied)
Scenario 4: Sound Level Changed	0.4	R-123	2	Titanium	**Min**	Marine	**85.4**	**$ 64,750.00**

*1 = Power Input *2 = Refrigerant Type *3 = After-Sale Capabilities *4 = Condenser Tube *5 = Sound Level *6 = Water-Box

Presenting the results shown in Table 6-12 as part of the final evaluation enables the contractor to determine immediately that changing only the refrigerant type (scenario 2) would result in the submittal becoming acceptable with a low compensation cost. The system therefore provides guidance, not just with respect to the original rejection decision and not only to help the contractor, but also to benefit the whole project. Such guidance cannot be provided without the analysis because each parameter can introduce different values. Scenario 3 is a clear example of an instance in which modifying the third parameter does not produce an improvement in the rejected submittal. Thus, system automation and the ability to conduct this kind of sensitivity analysis helps provide the best possible value for the project.

6.7 Conclusion

The chapter has presented five cases that were tested using the new system. The first case examined the model when the parameters were varied using one alternative from a real-life submittal. The second case, also a real-life submittal, was used to process a multiple-alternative submittal relative to organizational requirements. One of the alternatives was filtered out during the first stage of the evaluation: the checklist. The other two alternatives were both approved conditionally but with different scores and compensation cost values due to their deviations from the specifications. The higher-score alternative matched the selection of the consultant from the organization, which had already been determined as a result of manual evaluation by the organization. A discussion with the organization's engineer revealed that a compensation cost was never considered for submittal and should be discussed during the bidding period.

In the third case evaluation, the three alternatives produced in the previous case were examined using the default system requirements as different organizational specifications. The scores for the two previously approved alternatives were much lower than the ones obtained for the second case. The drop in the score values reflected the role of organizational preferences in determining the submittal value and the evaluation decision.

LEED requirements were examined in two scenarios within the fourth case, in which the submittal included only one alternative. The LEED points requirement was changed for each scenario and the submittal was processed. The results showed changes in the value of the submittal that corresponded to the LEED points. The alternative did not provide the three points required for power in the second scenario within this case. The case results revealed the important role of the consultant in confirming the decision.

The fifth case examined LEED requirements against a multiple-alternative submittal. When the alternatives were processed, all passed the checklist stage. However, two were conditionally approved with differing compensation cost values and scores, whereas the third (first alternative) was denied because it received a score lower than the minimum acceptable. One of the conditionally approved alternatives was identified as involving greater risk because its score was close to the defined threshold with a relatively high compensation cost. From an organizational perspective, all of the conditionally approved alternatives provide an acceptable value for the project as long as the contractor agrees to the compensation determined. By indicating the effect of the parameters on the final decision, sensitivity analysis provided an option that would make the rejected submittal acceptable.

When the results and the system were shared with the experts, they confirmed usefulness of the developed system in filtering out non-compliant submittals and making the initial process faster. The determination of a monetary compensation value as a condition for accepting a submittal, whereby the client is offered money that can be used for contingencies during the project, was a feature that greatly interested.

Chapter 7
Conclusion

7.1 Summary and Conclusion

During construction, engineers can be overwhelmed by the submittal review process. They are always under pressure to provide speedy processing and approval of these submittals in order to avoid blame for project delays. The submittal evaluation process, however, is not simple, particularly when the submittal introduces minor differences from the specification requirements that may result in a major negative impact on the operation of the project.

Submittal evaluation has traditionally been a time-consuming, manual process that is subject to numerous interpretations, despite the availability of many electronic systems to manage the flow of documents and submittals. Materials and equipment typically involve many options that must be included in submittal, and selecting the best alternative remains subjective since the decision making often lacks defined evaluation criteria.

The objective of this research was therefore to develop an automated, dynamic, and practical decision support system for submittal evaluation. Utilization of the multi-attribute utility theory (MAUT) suits the nature of this decision problem and provides a dynamic environment for value-based evaluation. For any key submittal, defining a generic set of criteria is difficult since each organization has its own preferences that must be incorporated into the decision process.

Before the decision support system was developed, data were collected from three organizations in order to determine the key building submittals. The top 10 building submittals were then listed, and were found to relate mainly to mechanical and electrical items. The centrifugal chiller, as the top-ranked key submittal, was selected for further investigation in order to develop the proposed framework for submittal evaluation.

The process of setting up the system was based on organizational requirements, including acceptance checklists, criteria, weights, and utility functions. Throughout the development process, feedback from engineers at a variety of organizations was obtained through interviews, and their input was used to define the criteria and the checklist parameters. Several rounds of discussion were required in order to formulate the parameters and evaluation criteria. The framework consists of two main stages for the submittal evaluation process: pre-screening based on a checklist and value-based evaluation using defined criteria.

Utility functions and cost calculations were developed for each of the evaluation criteria. Using the VBA programming language, a prototype of the framework was then coded in an Excel spreadsheet in order to automate the submittal evaluation process. The prototype was then tested using a real-life case study. The framework is dynamic so that organizations can modify the requirements according to their needs.

Discussing the system results with the experts proved its usefulness. The automatic results of the system for the case study matched the manual decision that consumed around 8 hours for the reviewer to check the technical requirements without any condition calculation for acceptance. This long review time in for single submittal in addition to the time needed for circulation, delivery, and administrative processing time. The framework's unique feature of determining a monetary compensation value as a condition for accepting a submittal was particularly interesting to the experts. In this value-base evaluation, some experts welcomed the ability to save money on that item and use it as contingency in the project.

In summary, it has been demonstrated that a decision support system for the evaluation of construction submittals can be constructed and that it will provide numerous benefits: an expedited decision process, an audit trail for decisions, more consistent and objective decisions, risk identification, internal alignment of organizational values, information for negotiations, and improved lifecycle asset performance. The benefits were validated by demonstration, and by experts' evaluations.

7.2 Research Contributions

Based on the current development, the research offers many contributions:

- **Understanding and identifying the key submittals that affect building performance:** This study has developed and identified key submittals based on data collected from a variety of sources and through a series of interviews with experts from a number of organizations.

- **Categorizing submittal evaluation parameters:** Based on an investigation of the current submittal evaluation process, the study has developed an evaluation mechanism that can consider both flexible and non-flexible parameters. The mechanism introduces a prescreening level for the submittal that saves reviewer time and reduces the number of evaluation loops.

- **Reducing subjectivity in the decision process:** The proposed evaluation mechanism reduces the subjectivity inherent in traditional submittal evaluation by pre-modeling the decision makers' preferences using MAUT. MAUT provides more precise values for the evaluation and bring into consideration any implications for the short term (construction) and the long term (operation) as well as loss of satisfaction.

- **Considering LEED requirements:** By means of the criteria developed, the new evaluation process is able to take LEED requirements into consideration and can evaluate the contribution of each submittal toward LEED certification. This research suggests that key items in the building should earn points according to their contribution in LEED categories. The major energy consumers, for example, should earn points based on their contribution in the performance of the whole building.

- **Considering organization-dependent requirements:** Because a setup level was developed in the process in general and in the system in particular, any uniqueness in the requirements of the organization can be taken into consideration. Although the setup is customizable by organization, the evaluation process is independent of the personal preferences of the evaluator.

- **Developing a prototype decision support system for value-based evaluation and approval of submittals:** The research has developed an automated decision support system that is based on utility values for predefined criteria. The system offers an on-the-spot decision mechanism for reviewers and contractors. The framework contributes to the elimination of a number of problems that previously arose in the submittal process. Table 7-1 presents a list of problems that can be eliminated by the introduction of the developed system.

Table 7-1: Submittal Problems Addressed by the Study

No.	Resolved Submittal Problem
1	Forced substitutions in submittals because of limited time
2	Lengthy process
3	Quality of the process not maintained
4	Inefficient decisions
5	Undefined process
6	Inadequate information/incomplete or lack of preparation
7	Lack of clarity about the meaning of "Approved"
8	Trivial submittals
9	Over-delegation
10	Lack of support from owners
11	Lack of compliance with documents
12	Improper record of submittals
13	Submittal not reviewed by the contractor

7.3 Future Research

Potential improvements to the present study can be summarized as follows:

- Integrate the DSS with existing building information modeling (BIM) tools and standards to facilitate the storing and retrieval of project data, including specifications from BIM files. Since BIM tools model a building using 3-D objects linked to an extensive database of the specifications for all objects, using the proposed system in conjunction with BIM will ensure the automatic transfer of the most updated information, including organizational and lifespan data, directly into the submittal evaluation system.
- Once the system is linked to BIM, consider adding an extension to include a mechanism for the verification of shop-drawings.

- Consider a testing and commissioning stage, and then transfer updated system performance data to the operating stage in order to facilitate effective operating and maintenance.
- Analyze the requirements for other key building submittal items.
- Link the system to manufacturers' databases in order to automatically retrieve updated specifications and parameters for the items under evaluation and to save evaluation time.
- Consider propagating the changes for any item to other related items via the BIM and artificial intelligent techniques. Changes in the HVAC system, for example, may mandate the selection of a different class of windows in order to capture more sunlight.

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Appendix A: Submittal Forms Samples

Figure B. A product submittal cover sheet

PRODUCT SUBMITTAL

Project ______________________ Date of Submittal ____________

General Contractor ______________________

Subcontractor/Supplier ______________________

Specification Section ______________________ Paragraph Reference ____________

Manufacturer ______________________ Model No. ____________

Dimensions ______________________ Color/Texture ____________

THIS SUBMITTAL CONSISTS OF (SELECT):

- ❑ Product Data
- ❑ Installation Instructions
- ❑ Material Schedule
- ❑ Maintenance Instructions
- ❑ Manufacturer's Test Report
- ❑ Manufacturer's Approval of Applicator/Installer
- ❑ Material Sample (describe) ______________________
- ❑ Other (describe) ______________________

This submittal is in conformance with the Contract Documents for the Project. Select one of the following:

This is not a substitution. X______________________
(Contractor's Signature)

This is a preapproved substitution X______________________
(Contractor's Signature)

This substitution is offered with supporting documentation in accordance with the Contract Documents. X______________________
(Contractor's Signature)

Architect/Engineer Comments ______________________

____

Engineer's Shop Drawing Review Stamp	Architect's Shop Drawing Review Stamp

Appendix A - 1: Submittal Form (Wyatt, 1997)

Attachment A

SAMPLE SUBMITTAL TRANSMITTAL FORM

PROJECT: ______________________________

CONTRACT NUMBER: ______________________________

SUBMITTAL NUMBER: ______________________ RESUBMITTAL: YES NO

DATE: __________________ NUMBER OF COPIES SUBMITTED: ________

SUBMITTAL DESCRIPTION: ______________________________

____

____

RELATED DESIGN DISCIPLINE (circle):

Civil Landscape Architectural Structural Mechanical Electrical

Telecommunications Security Fire Protection Controls

Other: ______________________________

ASSOCIATED SPECIFICATION SECTION NO: ______________________

REFERENCED DRAWING SHEET NO: ______________________

SUBCONTRACTOR/SUPPLIER/MANUFACTURER PROVIDING SUBMITTAL DATA:

Name: ______________________________

Address: ______________________________

Telephone Number: ______________________________

CONTRACTOR:

Name: ______________________________

Address: ______________________________

Telephone Number: ______________________________

Appendix A - 2: Submittal Form

ZUHAIR FAYEZ PARTNERSHIP	PROJECT	CONTRACTOR

SUBMITTAL FORM

SUBJECT: ____________________

Specs. Code & Ref.	B.O.Q. Code Ref.	Drawing Nb.	Submittal No. ______ Date Received: ______ Date Returned: ______

Sub-contractor
Name: ____________________ Address: ____________________
Address: ____________________ Phone: __________ Telex: __________

Manufacturer	Supplier/Agent
Name: ______	Name: ______
Address: ______	Address ______
Phone: ______	Phone: ______
Fax: ______ Telex: ______	Fax: ______ Telex: ______

Information submitted and attached:

Certificates	☐	Operation & Maintenance Manual	☐
Technical Brochure	☐	Spare Parts List	☐
Manufacturer's Data & Specs.	☐	As Built Drawings	☐
Shop Drawings	☐	Warranty	☐
Samples	☐	Others (specify)	☐

Contractor's Comments:

See Attachment ☐

Note: This review does not relieve the contractor of his responsibilities under the terms of the contract nor authorize additional compensation.

(Contractor)
Signature: ____________________
Date: ____________________

Consultant's Comments:

See Attachment ☐

Status:			Discipline		Sign & Date	Resident Engineer
Approved	1	☐	☐	Arch		
Approved as noted	2	☐	☐	Civil		Sign: ______
Revise and submit	3	☐	☐	Mech		Date: ______
Rejected	4	☐	☐	Elect		
			☐	HVAC		
			☐	LS		

Doc. Ref: CSF08a/4
Issue Date: 27-Jul-99

Appendix A - 3: Submittal Form Sample (ZFP)

SUBMITTAL/SHOP DRAWING REVIEW FORM

PROJECT NAME: University of Waterloo Engineering V Building

ARCHITECT: ATTENTION:

CONTRACTOR / SUPPLIER:: Trane

ITEM / SERVICE: Centrifugal Chiller

PROJECT NO.: 07067.000.m.001 DATE: January 14th, 2009

SHOP DRAWING NO. 15674 NO. OF PAGES: 34

REVIEWED BY:

FOR: ☐ REVIEWED ☒ REVIEWED WITH COMMENTS ☐ RESUBMIT

Comment #	Reference	Comment
1	15674-2.1.7	Ensure evaporator and condenser heads and shall be provided with sacrificial anodes for cathodic protection of the tubes.
2		Co-ordinate Electrical Requirements with Division 16.

:

This review is for the sole purpose of ascertaining conformance with the general design concept and for general arrangement. This shall no mean approval of the detail design inherent in the shop drawings, responsibility for which shall remain with the Contractor and such review shall no relieve the Contractor of his responsibility for errors or omissions in the shop drawings or of his responsibility for meeting all requirements of the Contract Documents. The Contractor is responsible for dimension to be confirmed and correlated at the job site for information that pertains solely to fabrication processes, quantities or the techniques of construction and installation and for co-ordination with related work. This form is a record of transmittal to return the documents to the individual noted above.

Appendix A - 4: Submittal Form Sample (University of Waterloo)

ABACORP ABDULAZIZ ALI ALTURKI & PARTNERS (Subsidiary of Rawabi Holding Co)	**Quality Management System** **ISO 9001:2000**	Issue date 01/01/2007	Issue No. 01	Form No. SR:FM:01
TITLE	**SUBMITTAL REVIEW**			

Project Title: **Refurbishment of Berth and Construction of 20 Villas** Submittal No: **065**
Project #: **272** B.I. #: J.O. #

To: Client's / Consultant's Name: **Sir Bruce White , Wolf Barry & Partners Consulting Engineers**

Submittal for: ☐ Drawing. ☐ Material. ☐ Procedure. ☐ Equipment. ☐ Other (Specify)---------------

Description **: 1" PVC PIPE HEAT INSULATION**
Referrence Specification **: SAMPLE**
Manufacturer / Supplier: **FAWAS REGRIGERATION AND AIRCONDITIONING GROUP**
Vendor Address**: ABACORP . PO BOX # 30445, AL-KHOBAR 31952**
Expected Delivery Time:

<u> When it is not complying with specifications, Provide justification & attach support documents.</u>*

Submitted By **(ABACORP)**	Received by: Client's Representative
Name: **Samir Rizk Ayoub**	Name: **Joseph Lazaro**
Designation: **Project Manager**	Designation: **Secretary**
Signature:	Signature:
Date: **November 22,2008**	Date: 22/11/08

(For Client's / Consultant's Use)

The Submittal is:	REMARKS:--
☐ Accepted ☐ Accepted, as noted ☐ Rejected (Re-submit) ☐ Provide Additional Information ☐ Correct & Re-submit	--
Name: Signature: Date:	**Received by**: Name: **ABACORP** Signature: Date:

Cc: Project Manager, QA/QC Manager, QC In-charge, Project's file.

Appendix A - 5: Submittal Form Sample (Contractor)

OWNER
King Fahd University of Petroleum & Minerals
PROJECTS DEPARTMENT
P.O.BOX: 5019 DHAHRAN - 31261
TEL : 860 4500 FAX 860 3788

CONTRACTOR
ABDULHAMID A. AL-MUTAWA & PARTNERS CO.
P. O. Box #9278, Dammam 31413
Tel. No.: (03) 8561169 Ext. 300
Fax No.: (03) 856-6311

PROJECT No. 1561 LOCATION:DHAHRAN

PROJECT NAME: BUILDING NO. 63 - COMPUTER SCIENCE BUILDING

MATERIAL SUBMITTAL

[ ] New Submittal — Submittal No. KFUPM-EE-003 REV. 1 — Previous Submittal No. KFUPM-EE-003

[X] Resubmittal — Submittal Date 14 FEBRUARY 2007 — Previous Submittal Date 16 SEPTEMBER 2006

PURPOSE OF SUBMITTAL: [ ] For information [ ] For Comments [X] For Approval

DISCIPLINE: [ ] CIVIL [ ] ARCHITECTURAL [ ] HVAC [ ] PLUMBING [X] ELECTRICAL

TYPE OF DRAWING: [ ] SHOP DRAWING [ ] AS BUILT DRAWING [ ] VENDOR DRAWING [X] Document Submittal

MATERIAL/EQUIPMENT Note: Please use the attachment in case items are more than the provided space

Sr.No.	Name, No. and Description	Origin	Manufacturer/Supplier	Specification Reference	Standard	Approval Status
01	FIRE ALARM SYSTEM (REV.)	USA	1. SIMPLEX / EL-AJOU	(As per end-		
	- Control panel		(a.k.a. ESE)	users speci-		C
	- Dot matrix printer			fications)		
	- LCD anunciator					
	- Call point break blass & pull					
	- Ionization smoke sensor					
	- True alarm smoke sensor					
	- Duct sensor					
	- True alarm heat detector					
	- True alert horn/flasher					

Contractor's Remarks: We clarify that above submittal is strictly adhered with contract specifications except otherwise as stated below

Exceptions:

MAHMOUD ABU JOBARA
Project Manager
Date 14-02-07 Signature:

Projects Department Comments: Approval of the above materials does not relieve the contractor from his contractual obligations.

As per document submitted, it complies KFUPM requirements, but furthermore it should satisfy project requirement for Bldg. 63
Submit sample board for accessories.
PROVIDE LIST OF [illegible] PROJECTS DONE BY THE CONTRACTOR 02/17/2007

Project Supervisor:

Concerned Dept Comments: Telecom
Date Out: 18-02-07 Date In:

1) OK
2) We would emphasize that the local FACP must be connected with central Fire Alarm panel in Bldg 55 (Telephone operators room) 21/2/2007

DIRECTOR SUPERVISION
Signature: Date:

DIRECTOR GENERAL, PROJECTS
Signature: Date:

APPROVAL STATUS: [A] Approved [B] Approved as noted Resubmittal is not required [C] Approved as noted, Resubmittal is required [D] Disapproved [E] No Action

REF. IN Signature Date

REF. OUT Signature Date

Appendix A - 6: Submittal Form Sample (KFUPM)

Appendix B: Logs/Registers Samples

Project: KFUPM - CONSTRUCTION OF BUILDING #63
Location: DHAHRAN, KSA
Contractor: [redacted]

Data Date: As of 01 May 2007

Prepared by: [redacted]

SUBMITTAL LOG

ITEM NO.	DESCRIPTION	SUPPLIER/ MANUFACTURER	SUBMITTAL NUMBER	DATE SUBMITED/ RESUBMITTED	DATE RETURNED	APPROVAL STATUS (A/B/C/D/E)	REMARKS	ACTION BY
I	GENERAL							
a	CONSTRUCTION SCHEDULE	-	GEN-KFUPM-001 / REV. 3	26 July 2006	04 August 2006	A	Approved	-
b	QUALITY CONTROL MANUAL	-	GEN-KFUPM-002 / REV. 1	10 July 2006	23 July 2006	B	Approved	-
c	SAFETY PROGRAM MANUAL	-	GEN-KFUPM-003 / REV. 1	10 July 2006	23 July 2006	B	Approved	-
d	TECH'L SUBMITTALS & SHOP DWG. SCHED.	-	GEN-KFUPM-004 / REV. 2	10 July 2006	15 July 2006	A	Approved	-
e	PROPOSED ORGANIZATIONAL CHART	-	GEN-KFUPM-005 / REV. 1	10 July 2006	11 July 2006	B	Approved	-
f	INDEPENDENT TESTING LABORATORY	[redacted]	GEN-KFUPM-006 / REV. 1	16 July 2006	19 July 2006	B	Approved	-
g	RESUME OF PROPOSED PM	-	GEN-KFUPM-007/ REV. 1	10 July 2006	17 July 2006	B	Approved	-
h	RESUME OF DISCIPLINE ENGINEERS	-	GEN-KFUPM-008	10 December 2006	17 December 2006	B	Approved	-
i	RESUME OF PROPOSED SAFETY ENGINEER	-	GEN-KFUPM-009	19 December 2006			Under Review	KFUPM
j	RESUME OF PROJECT MANAGER (ALT.)	-	GEN-KFUPM-010	22 January 2007	31 January 2007	B	(Probationary)	-
k	ORGANIZATIONAL CHART (ACTUAL)	-	GEN-KFUPM-05A	31 January 2007	20 February 2007	C	With Comment	Al-Mutawa
l	REVISED CONSTRUCTION SCHEDULE	-	GEN-KFUPM-011	01 March 2007	05 March 2007	E	No Comment	Al-Mutawa
m	TOWER CRANE LOCATION		KFUPM-GEN-012	05 APRIL 2007	-	E		
n	TOWER CRANE LOCATION WITH RELATING CONSTRUCTION JOINT		KFUPM-GEN-012	09 APRIL 2007	-	-		
	-							
II	SHOP DRAWINGS							
a	PROFILE OF NATURAL GROUND LEVELS	-	SD-KFUPM-001	15 June 2006	20 June 2006	B	Approved	-
b	PROPOSED EXCAVATION PROFILE REV. 1	-	SD-KFUPM-002 / REV. 1	04 July 2006	14 August 2006	B	Approved	-
c	CONTROL POINTS FOR CONTRACT	-	SD-KFUPM-003 / REV. 1	02 August 2006	06 August 2006	B	Approved	-
d	PROFILE OF NGL - PARKING	-	SD-KFUPM-004 / REV. 1	07 August 2006	14 August 2006	B	Approved	-
e	PROPOSED EXCAVATION PROFILE REV.3 FOR PARKING BUILDING	-	SD-KFUPM-005 REV. 3	26 February 2007	-	-	Under Review	KFUPM
f	PROPOSED DESIGNED ELEVATIONS	-	SD-KFUPM-006	03 September 2006	(Lost IN KFUPM)	(Lost in KFUPM)	(To be revised)	Al-Mutawa
g	PROPOSED LOCATION OF BORE HOLES	-	SD-KFUPM-007	13 September 2006	25 September 2006	C	With Comment	-
i	PROPOSED LIMIT OIF EPOXY COATED REBARS	-	SD-KFUPM-009	03 October 2006	30 October 2006	B	Approved	-
j	COORDINATES OR CORNER POINTS (P/B)	-	SD-KFUPM-010	28 October 2006	06 November 2006	A	Approved	-
k	PROPOSED CONSTRUCTION JOINT DETAIL	-	SD-KFUPM-011	05 November 2006	14 November 2006	B	Approved	-
l	PARKING BUILDING (ARCHITECTURAL)	-	SD-KFUPM-012 REV. 1	09 January 2007	26 February 2007	B/C	With Comment	Al-Mutawa
m	PARKING BLDG. (SECTIONAL DETAILS)	-	SD-KFUPM-013	27 January 2007	26 February 2007	B/C	With Comment	Al-Mutawa
n	PROPOSED CONST. JOINT AT FOUNDATION	-	SD-KFUPM-014	28 January 2007	03 February 2007	C	With Comment	Al-Mutawa
o	PROPOSED LOCATION OF CHILLER ROOM AND ELECTRICAL ROOM	-	SD-KFUPM-015	06 February 2007	14 March 2007	D	-	Al-Mutawa
p	PROPOSED PROCEDURE AND LOCATION OF PROBE HOLES FOR CAVITY PROBING	-	SD-KFUPM-016	24 February 2007	-	(Cancelled)	(Not Required)	-
q	EXISTING GRADE ELEVATION AT THE LOCATION OF CHILLER & ELECTRICAL ROOMS	-	SD-KFUPM-017	25 February 2007	10 March 2007	B	Approved	-
r	REVISED STRUCTURAL DRAWINGS FOR P/B	-	SD-KFUPM-018	05 March 2007	10 March 2007	E	(No Action)	Al-Mutawa
s	EXISTING GRADE OUTSIDE THE BUILDINGS	-	SD-KFUPM-019	05 March 2007	14 March 2007	B	Approved	-
t	BAR BENDING SCHEDULE FOR FOOTINGS OF MAIN BUILDING	-	SD-KFUPM-020	18 March 2007				
u	LOWER BASEMENT SLAB AND ITS DETAILS LOWER BASEMENT RAFT FOUNDATION AND ITS DETAILS TYPICAL SECTION OF FOOTINGS LOWER BASEMENT CALCULATION SHEET FOR LOAD DESIGN	-	SD-KFUPM-021	9 April 2007				
v	ELEVATOR SHAFT (1350 Kg) FOR MAIN BUILDING ELEVATOR SHAFT (1350 Kg) FOR PARKING BUILDING	-	SD-KFUPM-022	9 April 2007				

Appendix B - 1: Submittal Log (KFUPM)

[redacted]

SUBMITTAL STATUS LOG

PROJECT: [redacted]
REF #
UPDATE: 19-Feb-09

Status Legend
R - Reviewed
NR - Not Reviewed
R+R - Revise & Resubmit
RAM - Reviewed As Modified

SECTION	ITEM	SUBMITTALS	CONTRACTOR	DATE SUBMITTED	DATE RETURNED	STATUS	SHOP DRAWING #
02150		SHORING					
		SHORING SHOPDRAWING	[redacted]				
02200		EXCAVATION - SITE SERVICES	[redacted]				
		SITE SERVICE SHOPDRAWING					
02488		PLANTING	[redacted]				
		ONE YEAR GUARANTEE					
02513		ASPHALT PAVING	[redacted]				
		TWO YEAR WARRANTY					
		Verify compaction of granular base courses prior to paving.					
02600		SITE PIPING					
		SITE PIPING -SHOPDRAWING					
02613		UNIT PAVING	[redacted]				
		ONE YEAR WARRANTY					
02820		SITE FURNITURE	[redacted]				
		ONE YEAR WARRANTY					
03100		CONCRETE FORMWORK					
	01	ARCHITECTURAL CONCRETE FORMWORK - SHOPDRAWING	[redacted]	27-Nov-08	13-Jan-09	RAM	03100-01-00
	02	ARCHITECTURAL CONCRETE FORMWORK - SHOPDRAWING (2)		14-Jan-09	19-Jan-09	R+R	03100-02-00
	02R	ARCHITECTURAL CONCRETE FORMWORK SHOPDRAWING (2)		5-Feb-09			03100-02-01
03300		CAST-IN-PLACE CONCRETE					
	01	CONCRETE MIX DESIGN	[redacted]	8-Apr-08	14-May-08		03300-01-00
03315		CORROSION-INHIBITING CONCRETE ADMIXTURE					
	01	PRODUCT DATA	[redacted]	8-Apr-08	14-May-08		03300-01-00

Appendix B - 2: Submittal Log (TDSB)

DELTERA

SUBMITTAL STATUS LOG

PROJECT: NORTH TORONTO COLLEGIATE INSTITUTE
REF #
UPDATE: 19-Feb-09

Status Legend
R - Reviewed
NR - Not Reviewed
R+R - Revise & Resubmit
RAM - Reviewed As Modified

SECTION	ITEM	SUBMITTALS	CONTRACTOR	DATE SUBMITTED	DATE RETURNED	STATUS	SHOP DRAWING #
	01	SHOPDRAWING	THYSSENKRUPP	2-Jun-08	17-Jul-08	Reviewed as Modified	14210-01-00
	02	ELEVATOR SHOPDRAWING		8-Aug-08	2-Sep-08	Reviewed as Modified	14210-02-00
	03	ELEVATOR FINISH SELECTION		19-Sep-08	29-Oct-088	Reviewed as Modified	14210-03-00
15000		MECHANICAL					
	01	Booster Pump, Cooling Tower Make-up Pump & Fire pump Shopdrawing	SANET MECHANICAL	4-Jun-08	14-Jul-08	R+R / RAM	15000-01-00
	02	Pumps, Flo-Trex Valves & Suction Guides Shopdrawings		4-Jun-08			15000-02-00
	03	Boiler Shopdrawing		4-Jun-08	14-Jul-08	RAM	15000-03-00
	04	Drains & Accessories Shopdrawings		4-Jun-08	14-Jul-08	R+R / RAM	15000-04-00
	05	Heat Exchangers		10-Jun-08	14-Jul-08	R+R	15000-05-00
	05R	Heat Exchangers (Revised)		19-Aug-08	6-Oct-08	RAM	15000-05-01
	06	Expansion Tanks		10-Jun-08	14-Jul-08	R+R	15000-06-00
	06R	Expansion Tanks (Revised)		8-Aug-08	22-Aug-08	R	15000-06-01
	07	Fan Coil Unit		16-Jun-08	17-Jul-08	RAM	15000-07-00
	08	Water Treatment		16-Jun-08	14-Jul-08	R+R / RAM	15000-08-00
	08R	Water Treatment Revised		19-Aug-08	26-Sep-08	R	15000-08-01
	09	Domestic Water Heater		16-Jun-08	14-Jul-08	RAM	15000-09-00
	10	Fire Extinguishers, Cabinets & Fire Blankets Shopdrawing		20-Jun-08	14-Jul-08	RAM / R+R	15000-10-00
	10R	Fire Extinguishers, Cabinets & Fire Blankets Shopdrawing(Revised)		8-Aug-08	9-Oct-08	RAM	15000-10-01
	11	Refrigerant Monitor & SCBA Shopdrawings		20-Jun-08	14-Jul-08	R	15000-11-00
	12	Centrifugal Chiller CH-1 Shop Drawings		20-Jun-08	14-Jul-08	RAM / R+R	15000-12-00
	12R	Centrifugal Chiller CH-1 Shop Drawings		18-Jul-08	31-Jul-08	RAM	15000-12-01
	13	Heat Recovery Units S1, S2, S3, & S4		3-Jul-08	17-Jul-08	RAM	15000-13-00
	14	Plumbing Fixture Shopdrawing		14-Jul-08	26-Sep-08	RAM	15000-14-00
	15	Fire Stopping Product Data		14-Jul-08	22-Aug-08	R	15000-15-00
	16	Insulation Product Data		14-Jul-08	22-Aug-08	R	15000-16-00
	17	Insulation Samples		14-Jul-08			15000-17-00
	18	Runtal Radiator		8-Aug-08	23-Sep-08	RAM	15000-18-00
	19	Humidifiers		8-Aug-08	23-Sep-08	R+R	15000-19-00
	20	Runtal Radiator Colour Chart		8-Aug-08			15000-20-00
	21	Variable Speed Drives		19-Aug-08	26-Sep-08	R	15000-21-00
	22	Wallfins, Cabinet Unit Heaters and Reheat Coils Shopdrawing		19-Aug-08	20-Oct-08	R	15000-22-00
	23	Radiant Floor heating & Cooling Accessories Shopdrawings		2-Sep-08	23-Sep-08	R+R	15000-23-00
	23R	Radiant Floor Heating & Cooling Accessories Shopdrawings (Revised)		9-Oct-08	17-Dec-08	R+R	15000-23-01
	24	Radiant Floor heating & Cooling Layout Shopdrawing		2-Sep-08	23-Sep-08	R+R	15000-24-00
	24R	Radiant Floor heating & Cooling Layout Shopdrawing (Revised)		9-Oct-08	13-Jan-09	RAM	15000-24-01
	25	Check Valves, Ball Valves and Butterfly Valves Shop Drawings		2-Sep-08	26-Sep-08	R	15000-25-00
	26	Boilers Breeching & Stacks		26-Sep-08	7-Jan-09	Reviewed	15000-26-00
	27	Water Heaters Breeching & Stacks		26-Sep-08	7-Jan-09	Reviewed	15000-27-00
	28	Humifier Breaching and Stack		26-Sep-08	7-Jan-09	Reviewed	15000-28-00
	29	HRU / AHU (S1 to S8) Shopdrawing		26-Sep-08	11-Nov-08		15000-29-00
	30	Pumps		3-Oct-08	11-Nov-08	Reviewed	15000-30-00
	31	Fire Pump		3-Oct-08	10-Feb-09	R+R	15000-31-00

Appendix B - 3: Submittal Log (TDSB)

SUBMITTAL REGISTER
(ER 415 1-10)

TITLE AND LOCATION	CONTRACTOR	ONTRACT NO.
		PECIFICATION SECTION

ACTIVITY NO	TRANS-MITTAL NO.	ITEM NO	SPECIFICATION PARAGRAPH NUMBER	DESCRIPTION OF ITEM SUBMITTED	TYPE OF SUBMITTAL: DATA	DRAWINGS	INSTRUCTIONS	SCHEDULES	STATEMENTS	REPORTS	CERTIFICATES	SAMPLES	RECORDS	O & M MANUALS	CLASSIFICATION: INFORMATION ONLY	GOVERNMENT APPROVED	REVIEWER	CONTRACTOR EDULE DATES: SUBMIT	APPROVAL NEEDED BY	MATERIAL NEEDED BY	CONTRACTOR ACTION: CODE	DATE	SUBMIT TO GOVERNMENT	ERN ACTION: CODE	DATE	REMARKS
a.	b.	c.	d.	e.	f.	g.	h.	i.	j.	k.	l.	m.	n.	o.	p.	q.	r.	s.	t.	u.	v.	w.	x.	y.	z.	aa.

ENG FORM 4288-R, JAN 97 EDITION OF MAR 95 IS OBSOLETE. PAGE 1 OF ____ PAGES (Proponent: CEMP-CE)

Appendix B - 4: Submittal Log

01.10.95 [redacted] CN.# 7.100

CONTRACT NO. 7.100

HVAC SHOP DRAWINGS LIST.

S. NO	TRANSMITTAL NO	SUBMITTAL NO	DRAWING NO.	DRAWING TITLE	SUBMITTAL PLAN DATE	SUBMITTAL ACT DATE	RETURN DATE	CODE	RE-SUB DATE	RETURN DATE	CODE	REMARK
1	ME-56	7.100-15801-15	AC-35	HVAC 1ST FLOOR PLAN ZONE B1,B2,B3,B4	10.08.95	21.06.95	19.07.95	C				
2	ME-56	7.100-15801-15	AC-36	HVAC 1ST FLOOR SECTION DETAIL B1,B2,B3,B4,B5	10.08.95	21.06.95	19.07.95	C				
3	ME-57	7.100-15801-16	AC-40	HVAC 1ST FLOOR PLAN ZONE C1,C2,C3,C4	10.08.95	21.06.95	19.07.95	C				
4	ME-60	7.100-15801-19	AC-56	PLANT ROOM CHILED WATER PIPING LAYOUT	10.08.95	31.05.95	06.07.95	C				
5	ME-61	7.100-15801-20	AC-60	HVAC 2ND FLOOR PLAN ZONE C1,C2,C3,C4,C5	10.08.95							
6	ME-62	7.100-15801-21	AC-65	HVAC ROOF PLAN ZONE A1,A2,A3,A4	10.08.95							
7	ME-63	7.100-15801-22	AC-67	HVAC ROOF PLAN ZONE D1,D2,D3,D4	10.08.95							
8	ME-64	7.100-15801-23	AC-69	HVAC ROOF PLAN ZONE B1,B2,B3,B4,B5	10.08.95							
9	ME-64	7.100-15801-23	AC-70	HVAC ROOF SECTION DETAILS B1,B2,B3,B4,B5	10.08.95							
10	ME-65	7.100-15801-24	AC-71	HVAC ROOF PLAN ZONE C1,C2,C3,C4,C5	10.08.95							
11	ME-65	7.100-15801-24	AC-72	HVAC ROOF SECTION DETAILS C1,C2,C3,C4,C5	10.08.95							
12	ME-56	7.100-15801-15		HVAC 1ST FLOOR PLAN & SECTION ZONE B1,B2,B3,B4	10.08.95							
13	ME-57	7.100-15801-16		HVAC 1ST FLOOR PLAN ZONE C1,C2,C3,C4	10.08.95							

Appendix B - 5: HVAC Submittal Log (Contractor)

KING ABDUL AZIZ UNIVERSITY

WOMEN'S FACULTY OF SCIENCE

[redacted] CN NO. 7.100

Printed Date : 23-Jan -95

LONG LEAD MATERIAL SUBMITTAL SCHEDULE

ACT ID	DESCRIPTION	Transmittal No	SUBMITTAL DATES				APPROVAL		ISSUE PURCHASE		DELIVERY			CONST. SCHEDULE	
			EARLY START	EARLY FINISH	PLAN TO SUBMIT	ACTUAL	DATE	CODE	DATE	ORDER NO.	EARLY START	EARLY FINISH	REQD AT SITE	EARLY START	LATE START
04102103	Specialty Stone Supplier	CA-22	18-Jan-95	14-Feb-95	07-Feb-95						07-Mar-95	07-Apr-95	14-Apr-95	14-May-95	15-Jul-95
05101103	Mild Steel Balustrade & Turnstiles	CA-23	25-Jan-95	23-Mar-95	14-Mar-95						01-Feb-95	01-Mar-95	01-Mar-95	16-Mar-95	12-Apr-95
05201410	Gratings	CA-24	18-Jan-95	01-Feb-95	01-Feb-95						01-Mar-95	01-May-95	14-May-95	28-May-95	15-Aug-95
06101103	Lab. Casework	CA-31	24-Aug-94	24-Sep-94	24-Sep-94				19-Nov-94	OA/94/RFI/WFS/PO/534	24-Sep-94	13-Jun-95	01-Apr-95	22-Apr-95	05-Jun-95
06102110	General Fitments - Pegboards	CA-32	06-Sep-94	06-Oct-94	06-Sep-94	22-Nov-94	28-Dec-94	B			01-Feb-95	14-Mar-95	22-Mar-95	22-Apr-95	11-Jun-95
07100110	Water Proofing	CA-52-B	08-Aug-94	08-Aug-94	06-Jul-94	26-Dec-94	18-Jan-95	B			14-Jan-95	29-Mar-95	16-Feb-95	16-Feb-95	17-Apr-95
08100103	Wood Doors	CA-64-1	16-Apr-94	27-Sep-94	27-Aug-94	25-Aug-94	07-Sep-94	B			09-Feb-95	21-Mar-95	22-Mar-95	22-Mar-95	26-Apr-95
08100410	Store Fronts (Glazed)	CA-63-2	16-Apr-94	15-Sep-94	25-Apr-94	03-Jan-95	(Resubmit)				26-Jan-95	08-Mar-95	14-Apr-95	23-Apr-95	03-Jun-95
08100610	Door (Metal Frames)	CA-62-1	16-Apr-94	15-Sep-94	27-Apr-94	17-Dec-94	20-Dec-94	B			26-Jan-95	08-Mar-95	14-Apr-95	23-Apr-95	03-Jun-95
08110103	Doors Hardware	CA-61-1	16-Apr-94	02-Jun-94	28-Aug-94	13-Dec-94	15-Jan-95	B			26-Jan-95	13-Apr-95	14-Apr-95	23-Apr-95	03-Jun-95
09106155	Louver Ceiling	CA-93-1	23-Jul-94	06-Dec-94	28-Sep-94	07-Dec-94	09-Jan-95	B			14-Feb-95	24-Apr-95	05-May-95	05-Jun-95	01-Aug-95
09106155	Metal Faceted Ceiling	CA-88-1	23-Jul-94	06-Dec-94	08-Aug-94	14-Sep-94	18-Sep-94	A			05-Feb-95	23-May-95	24-Jun-95	24-Jun-95	25-Jun-95
10101103	Tackboard	CA-51	25-Jan-95	04-Feb-95	04-Feb-95						13-Feb-95	13-Apr-95	03-Jul-95	03-Aug-95	23-Aug-95
10102103	Louver (Sand Trap)	CA-70	05-Feb-95	21-Feb-95	06-Sep-95						14-Feb-95	24-Apr-95	05-May-95	05-Jun-95	01-Aug-95
10104105	Lockers	CA-54	05-Feb-95	21-Feb-95	21-Feb-95						08-Mar-95	04-Jun-95	03-Jul-95	03-Aug-95	19-Aug-95
10105105	Toilet & Bath Accesories	CA-103	03-Jul-94	08-Nov-94	08-Sep-94	31-Jul-94	14-Aug-94	B			14-Feb-95	30-Apr-95	23-Jul-95	23-Jul-95	17-Aug-95
11100105	Projection Screen	CA-74	05-Feb-95	20-Feb-95	20-Feb-95						08-Mar-95	03-Jun-95	03-Jul-95	23-Jul-95	17-Aug-95
11100125	Unit Kitchen	CA-75	14-Jan-95	23-Jan-95	23-Jan-95						08-Mar-95	03-Jun-95	03-Jun-95	02-Jul-95	05-Aug-95
11100133	Laboratory Hoods	CA-107-	16-Apr-94	20-Jun-94	20-Jun-94	02-Jan-95	(Resubmit)				24-Jan-95	01-Apr-95	12-May-95	12-Jun-95	15-Jun-95
12102105	Auditorium Seating	CA-80	14-Jan-95	28-Jan-95	28-Jan-95						08-Feb-95	07-Jun-95	02-Jul-95	02-Aug-95	17-Aug-95
13100110	Walk In Cold Room	CR-01	16-Apr-94	08-Jun-94	08-Jun-94	08-Sep-94					14-Jan-95	16-Feb-95	03-Apr-95	03-May-95	27-Jun-95
14100110	Hydraulic Elevator	M-32-1	16-Apr-94	28-May-94	28-May-94	02-Apr-94	02-Jun-94	B	13-Apr-94	OA/94/SETA/WO/WFS/368	28-Sep-94	25-Apr-95	02-Jun-95	02-Jul-95	12-Jul-95
15104110	Acid Waste Pipes	AW-02	16-Apr-94	08-Jan-95	30-Apr-94	27-Apr-94	02-May-94	B	22-Jun-94	OA/94/PONT/PO/WFS/403	07-Jun-94	15-Aug-94	17-Aug-94	14-Jun-94	06-Mar-95
15201610	Chillers	ME-01	27-Jul-94	31-Jul-94	30-Sep-94	10-Aug-94	13-Aug-94	B	18-Oct-94	441/5194	15-Jan-95	15-Apr-95	05-May-95	06-Jun-95	20-Jun-95
15202810	Air Handling Units	ME-03	27-Jul-94	16-Oct-94	27-Aug-94	28-Aug-94	18-Sep-94	B	18-Oct-94	551/J/94	16-Nov-94	24-May-95	31-May-95	05-Jun-95	26-Jun-95
15202810	Fan Coil Units	ME-02	27-Jul-94	16-Oct-94	16-Sep-94	04-Sep-94	01-Oct-94	B	18-Oct-94	431/J/94	16-Nov-94	24-May-95	31-May-95	05-Jun-95	26-Jun-95
15202810	Package Units	ME-04	27-Jul-94	16-Oct-94	16-Sep-94	04-Sep-94	01-Oct-94	B	18-Oct-94	431/J/94	16-Nov-94	24-May-95	31-May-95	05-Jun-95	26-Jun-95
15202810	Roof Exhaust Fans	ME-05	27-Jul-94	16-Oct-94	16-Sep-94	13-Dec-94	(Resubmit)				14-Jan-95	12-Feb-95	29-Mar-95	29-Apr-95	29-May-95
15203110	Fume Extract System	ME-18	24-Apr-94	28-Aug-94	28-Aug-94	17-Jul-94	27-Jul-94	B			14-Jan-95	10-Feb-95	10-Feb-95	12-Feb-95	15-Feb-95
15204210	Building Automation System	E-17	19-Sep-94	25-Sep-94	15-Sep-94	14-Jul-94	18-Jul-94	B	29-Aug-94	AFS/464	15-Jan-95	06-Jul-95	06-Jul-95	08-Jul-95	19-Jul-95
16208210	Fire Alarm & Detection System	E-01A	14-Jun-94	03-Aug-94	03-Aug-94	13-Dec-94	19-Dec-94	A			04-Mar-95	10-Jun-95	10-Jun-95	11-Jun-95	12-Jul-95
16300110	LV Dist. Switch Gear	E-24	07-Jul-94	08-Nov-94	21-Oct-94	14-Jul-94	23-Nov-94	B			12-Mar-95	20-Apr-95	20-Apr-95	27-Apr-95	07-Jun-95
16300110	Motor Control Center	E-19	07-Jul-94	08-Nov-94	21-Oct-94	21-Dec-94	02-Jan-95	D			12-Mar-95	20-Apr-95	20-Apr-95	27-Apr-95	07-Jun-95

Appendix B - 6: Long Lead Material Schedule (ZFP)

Appendix C: Specification Samples

DIVISION 15 - MECHANICAL
SECTION 15674 - CONDENSERLESS CHILLER **Page 15674-3**

relief devices, discharge and liquid line shutoff valves, filter drier, moisture indicating sight glass, expansion valve, refrigerant economizer (unit sizes 161-271), and complete charge of compressor oil. The unit shall have a complete operating charge of refrigerant HFC-134a

2.6 CONTROLS, SAFETIES, AND DIAGNOSTICS:

.1 Unit controls shall include the following minimum components:

.1 Microprocessor with non-volatile memory. Battery backup system shall not be accepted.
.2 Power and control circuit terminal blocks.
.3 ON/OFF control switch.
.4 Replaceable solid-state relay panels.
.5 Thermistor installed to measure saturated condensing temperature, cooler saturation temperature, compressor return gas temperature, and cooler entering and leaving fluid temperatures.
.6 Chilled fluid flow switch.

.2 Unit controls shall include the following functions as standard:

.1 Automatic circuit lead/lag.
.2 Capacity control based on leaving chilled fluid temperature and compensated by rate of change of return-fluid temperature with temperature setpoint accuracy to 0.1 ° F (0.06° C).
.3 Limiting the chilled fluid temperature pull-down rate at start-up to an adjustable range of 0.2° F to 2° F (0.11° C to 1.1° C) per minute to prevent excessive demand spikes at start-up.
.4 Seven-day time schedule.
.5 Leaving chilled fluid temperature reset from return fluid, outdoor-air temperature, space temperature, or 4 to 20 mA input.
.6 Demand limit control with 2-stage control (0 to 100% each) or through 4 to 20 mA input (0 to 100%).
.7 Chilled and condenser water pump start/stop control.
.8 Dual chiller control for series chiller applications without addition of hardware modules or additional thermistors.
.9 Dual chiller control for parallel flow applications use one additional sensor.
.10 Amperage readout per compressor with %MTA per compressor.

.3 The control panel shall include, as standard, a portable hand held display module with a minimum of 4 lines and 20 characters per line, of clear English, Spanish, Portuguese or French language. Display menus shall provide clear language descriptions of all menu items, operating modes, configuration points and alarm diagnostics. Reference to factory codes shall not be accepted. An industrial grade coiled extension cord shall allow the display module to be moved around the chiller. Magnets shall hold the display module to any sheet metal panel to allow hands-free operation. Display module shall have NEMA 4x housing suitable for use in outdoor environments. Display shall have back light and contrast adjustment for easy viewing in bright sunlight or night conditions. The display module shall have raised surface buttons with positive tactile response.

Braeburn PS - Chiller Replacement Dec. 2005

Appendix C - 1: Chiller Specification Sample p1 (TDSB)

expansion tank fittings and all other associated piping accessories connected to chilled water circulating cooling system.

.2 Material:

.1 CGSB 51-GP-9M, rigid mineral fibre sleeving for piping and CGSB 51-GP-52M, vapour barrier jacket.
.2 Standard of Acceptance: Fiberglas 850, Manson, Knauf.

.3 Thickness: 1½"

2.3 P-3 FLEXIBLE ELASTOMERIC -40 TO 95 DEG. C.

.1 Application: insulation system P-3 for valves and fittings temperature range -40 to 95 degrees celsius on:

.1 Refrigeration suction and hot gas lines (where applicable).
.2 Chilled water strainers
.3 Chilled water valves
.4 Chilled water pumps
.5 Chilled water connections to chiller

.2 Material:

.1 CAN2-51.40-M80+Amdt-Aug-83, flexible elastomeric unicellular sheet and pipe covering.
.2 Standard of Acceptance: Armstrong Armaflex.

.3 Thickness: ½"

2.4 FASTENINGS

.1 For insulation systems P-1, P-2

.1 Tape: self adhesive tape rated under 25 for flame spread and under 50 for smoke development.

.2 Lap Seal Adhesive: quick-setting adhesive for joints and lap sealing of vapour barriers. Flame spread 10 smoke development 0. Standard of Acceptance: Foster 85-75 Drion.

.3 Self adhesive tape rated under 25 for flame spread and under 50 for smoke development plus aluminum straps 12 x 0.05 mm with locking clips.

.4 Lagging Adhesive: fire retardant coating approved by CFFM and authorities having jurisdiction prior to application.

Appendix C - 2: Chiller Specification Sample p2 (TDSB)

Appendix D: Submittal Case-Studies Data

Technical Details

التقييم الأول

General	Company	PETRA	ZAMIL	YORK
	Model	APSa 500 (S)	ASY500B	YCIV0267SA40
	No. of pieces	1	1	2 (Parallel)
	Cooling Capacity (T.R.)	454.3	449.7	230.5
	Power Supply	380V / 3Ph / 60Hz	380V/3Ph/60Hz	380V/3Ph/60Hz
	Design Ambient (°F)	115 (46.1 °C)	115 (46.1 °C)	115 (46.1 °C)
Compressor Data	Type	Semi-Hermetic Screw	Semi-Hermetic Screw	Semi-Hermetic Screw
	No. of Compressors	3S	6	2x2
	Refrigerant	R 134a	R 134a	R 134a
	Power Input (kW)	649.6	764.9	(2x350)700
Cooler Data	Ent. / Lvg. Water Temp. (°F)	58.5 / 42.0	58/42.2	58/42
	Water Flow Rate (GPM)	658.5	684.2	[illegible]
	Circuiting	Independent	Independent	Independe[illegible]
	No. of Circuits	3		2x2
	Water Pressure Drop (Psi)	4.3	2.82	3x2
	Control	Electronic Expansion Valve	Electronic Expansion Valve	Electronic Expansion Valve
	No. of coolers	1	2	1x2
Condenser Coil Data	Condenser Type	Air Cooled	Air Cooled	Air Cooled
	Rows/Fins	4/12	4/14	3/17
	Face Velocity	598	547	443
	Total Face Area (Ft^2)	622.8	521.3	352x2
	Total Air Flow CFM	372615	285192	156000x2
	Material Coil / Fins	Copper Tube & Coated	Copper Tube & Aluminum Fins	Copper Tube & Aluminum Fins
	Test Pressure (Psi)	450		
Condenser Fan Data	Fan Type	Propeller Direct Drive	Propeller Direct Drive	Propeller Direct Drive
	No. of Fans	18/900mm	24/800 mm	12x2/900 mm
	FLA	6.8	3.5	3.5
	Power Input (kW)	54	45.6	20.2x2
	Motor Insulation	Class "F"		Class "F"
Electrical	Total Power Input (kW)	703.2	81[illegible]	370.1x2
	kW / T.R.	1.54	1.8	1.61
	EER (MBH/kW)	7.75	6.67	7.5
	IPLV	14.0		13.2
Casing	Material	Zinc Coated Galvanized Steel		
	Finish	Oven Baked Electrostatic Powder		
Sound	Sound Power Level (dBA)	103		102
	Sound Pressure Level @ 10ft	78	83.3	
Dimensions	LxWxH (m)	12.22x2.7x2.58	12x2.2x2.74	(8.07x2)X2.24X2.2.39
	ARI Certificate	Yes	No	Yes
	UL	Yes	No	Yes

Appendix D - 1: Submittal Case Form (ZFP)

Tag Data - Centrifugal Water Chillers (Qty: 2)

Item	Tag(s)	Qty	Description	Model Number
A1	CH-PH-01	1	Centrifugal Chiller (CTV) .571vfd	CVHE0450
A2	CH-PH-02	1	Centrifugal Chiller (CTV) .563	CVHF0485

Product Data - Centrifugal Water Chillers

All Units

Adaptiview controls
Compressor voltage: 575 volt 3 phase
Evaporator tubes: 0.75 inch (19.1 mm) dia. internally enhanced copper
Evaporator tube wall: .025 inch (0.6 mm) thick
Evaporator fluid type: Water
Evaporator waterbox type: Marine
Evaporator waterbox construction: Standard
Evaporator waterbox passes: Two pass
Evaporator waterbox pressure: 300 psig (2068 kPa)
Evaporator waterbox connection: Victaulic
Condenser shell size: 050 long
Condenser tube: 1.00 inch (25.4 mm) micro internally enhanced copper
Condenser tube wall: .028 inch (0.7 mm) thick
Condenser shell construction: Standard
Condenser fluid type: Water
Condenser waterbox type: 2 pass marine
Condenser waterbox construction: Standard
Condenser waterbox pressure: 150 psig (1034 kPa)
Condenser waterbox connection: Victaulic
Agency listing: U.L. listed unit includes energy efficiency verification
Factory performance test: Standard air run and vibration test
Factory tolerance test: Standard air run and vibration test
Complies with all versions of ASHRAE/IESNA 90.1
BACnet communication protocol on-board
With enhanced motor protection
Accessory: 2 Flow switches, 300 psi (2068 kPa) NEMA 1 (Fld)
Trane Supplied Refrigerant
Starter power connection: Circuit breaker
1st Year Parts and Labor Warranty Whole Unit with Trane Supplied Starter
2nd-5th Year Parts and Labor Warranty Motor/Compressor only
Davit Arms Both Ends Both Shells

Item: A1 Qty: 1 Tag(s): CH-PH-01

Remote mounted low voltage AFD
Remote mounted adaptive frequency drive
Left hand Piping connections

Item: A2 Qty: 1 Tag(s): CH-PH-02

Solid State Unit Mounted Starter with Circuit Breaker
Starter option: Lightning arrestor
Starter option: Ground fault protection
Right Hand piping connections

Appendix D - 2: Case-Study by University of Waterloo p1

Performance Data - Centrifugal Water Chillers

Tags	CH-PH-01	CH-PH-02
Primary tons of refrigeration (tons)	300.00	450.00
Primary kW/t (kW/ton)	0.571	0.563
Primary kW (kW)	171.30	253.50
NPLV (kW/ton)	0.384	0.487
Primary RLA (A)	193.50	276.5
Motor locked rotor amps (A)	1641.00	1641.00
Minimum circuit ampacity (A)	250.00	354.00
Maximum over current protection (A)	400.00	600.00
Evaporator entering fluid temp (F)	54.00	54.00
Evaporator leaving fluid temp (F)	42.00	42.00
Evaporator gallons per minute (gpm)	597.00	895.5
Evaporator pressure drop (ft H2O)	16.85	24.58
Evaporator fouling factor (hr-sq ft-deg F/Btu)	0.00010	0.00010
Condenser entering fluid temp (F)	85.00	85.00
Condenser leaving fluid temp (F)	94.33	94.35
Condenser gallons per minute (gpm)	900.00	1350.00
Condenser pressure drop (ft H2O)	18.13	26.33
Condenser fouling factor (hr-sq ft-deg F/Btu)	0.00025	0.00025
HCFC 123 refrigerant charge (lb)	550.0	750.0
Full load sound pressure (dBA)	84	84
Shipping weight (lb)	16696	17740
Operating weight (lb)	18730	20379
Heat rejected into equipment room (MBh)	2.92	4.33

Appendix D - 3: Case-Study by University of Waterloo p2

Mechanical Specifications - Centrifugal Water Chillers
Item: A1, A2 Qty: 2 Tag(s): CH-PH-01, CH-PH-02

Compressor-Motor
Direct drive multiple-stage compressor, multi-stage capacity control guide vanes. Shrouded aluminum alloy impellers dynamically balanced. Motor-compressor assembly balanced to .15 in./sec (.0038m/sec) maximum vibration measured on motor and bearing housings. Refrigerant cooled, hermetically sealed, two-pole, squirrel cage induction motor. Two pressure lubricated bearings support the rotating assembly. A direct drive submerged oil pump motor, 3/4 hp (.560 kW) 115V/50/60/1 provides filtered and temperature controlled oil to compressor bearings.

Evaporator-Condenser
Shells are carbon steel plate. Evaporator includes rupture disk per BSR/ASHRAE 15 Safety Code. Carbon steel tube sheets are drilled, reamed and grooved to accommodate tubes. Tubes are individually replaceable externally finned seamless copper. Tubes are mechanically expanded into tube sheets. Eliminators are installed over entire length of the evaporator tube bundle. A multiple orifice control system maintains proper refrigerant flow. Condenser baffle prevents direct impingement of compressor discharge gas upon the tubes. Refrigerant side of the assembled unit is tested at both pressure(30.00 psi leak test) and vacuum. Water side is hydrostatically tested at one and one-half times design working pressure, but not less than 225.00 psi.

Trane reserves the right to implement chiller technology enhancements that will reduce the chiller's refrigerant charge, with no impact on chiller performance. Changes may be reflected in the chiller's nameplate refrigerant charge and the quantity of refrigerant charge shipped to the jobsite, depending upon the final date of equipment manufacture.

Water Boxes
Drains and vents - All water boxes have 3/4-inch NPTI vents and drain connections provided. Evaporators have 2 vents and 2 drains, condensers have 1 vent and 1 drain.

Marine water boxes have removable end plates and water connections on the sides.

Economizer
A flash economizer with no moving parts provides power saving capability.

Purge System
The EarthWise(TM) purge includes a 1/4 hp 115V/60/1, 100V/50/1 air cooled condensing unit, purge tank, drier elements, a 1/20 hp (.037 kW) 115V/60/1, 110V/50/1 pump-out compressor, a carbon tank, and a heater. The purge is designed with an activated carbon filtration system that includes an autoregeneration feature which results in automatic high-efficiency removal of noncondensibles from the chiller without manual carbon maintenance. The purge is rated in accordance with ARI Standard 580.

Adaptiview Control Panel:

The Tracer(tm) Adaptiview is a microprocessor-based chiller control system that provides complete stand alone system control and monitoring for the water cooled CenTraVac (TM). It is a factory mounted package including a full complement of controls to safely and efficiently operate the CenTraVac chiller, including oil management, purge operation, interface to the starter, and comprehensive motor protection including three phase solid state motor overload. Inlet and outlet water (fluid) temperature sensors are located in the evaporator and condenser waterbox connections as standard.

The display is a touch sensitive 12 1/8" diagonal color liquid crystal display (LCD) that uses color graphics and animation to ensure ease of use. The touch sensitive interface allows the operator to view the chiller graphically and receive a status indication via subsystem animations. The operator can navigate easily between the primary chiller subsystems including: compressor, evaporator, condenser, and motor. For each subsystem, you can view status and detailed operating parameters. In addition, alarms, reports, trending, and settings can all be accessed quickly from the main screen. The display is mounted on a flexible "arm" that allows extensive height and viewing angle variations.

The panel supports an extensive list of Languages including the default English. The data can be set to be viewed in inch pounds IP or metric units SI. For remote starters - Class 1 control panel voltage (30-115 V) are clearly labeled in the control panel. Class 2 input voltage (30V max) is also labeled in the control panel.

Operating Data including:
*operating hours
*number of starts

Appendix D - 4: Case-Study by University of Waterloo p3

Tag Name: Selection1_600 no option

Chiller
- Chiller Model **19XR-56554R6DFS64-**
- Starter / VFD .... **Starter - Unit Mounted, Wye-Delta**
- Refrigerant Type **R-134a**

Cooler
- Size **56**
- Waterbox Type .... **Nozzle-in-Head, 150 psi**
- Passes **2**
- Nozzle Arrangement .... **Will Advise**
- Tubing .... **Super E2 (SUPE2), .025 in, Copper**
- Fluid Type .... **Fresh Water**

Compressor
- Size **4R6**

Flow Controls
- Float Valve Size **8**
- Flasc Orifice **27**

Weights and Approximate Dimensions
- Total Rigging Weight .... **21802** lb
- Total Operating Weight .... **26374** lb
- Refrigerant Weight .... **1430** lb
- Length x Width x Height .... **N/A**

Condenser
- Size **55**
- Waterbox Type .... **Marine Waterbox, 150 psi**
- Passes **2**
- Nozzle Arrangement .... **Will Advise**
- Tubing .... **Spike Fin III (SPK3), .025 in, Copper**
- Fluid Type .... **Fresh Water**

Motor
- Size .... **DFS**
- Line Voltage/Hertz **480-3-60**
- Oil Pump Voltage/Hertz **460-3-60**

Specified Chiller Options:
- Isolation Valve Package
- Insulation Type: Factory Insulation (3/4 inch)
- Refrigerant Shipment: Shipped Separately

Unit Mounted Starter:
- Type: Wye-Delta
- Factory Mounting
- Standard Interrupt Main Circuit Breaker

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فرع الخبر س.ت ٢٠٥١٠٠٧٣٨٠
Carrier
ARABIAN AIR CONDITIONING CO. LTD.
AL-KHOBAR BRANCH - 2051007380

Note: This list of specified chiller options does not include any of the separate-ship accessories (gasket kits, refrigerant cylinders, standalone pumpout units, or storage tank / pumpout units), nor any items specified on a Quote Control. These items are specified as part of a bid, and not in the chiller tag. The Pricing Report includes all of these items as specified in a bid.

Evergreen Chiller Builder v4.36 Page 1 of 1

Appendix D - 5: Case-Study by KFUPM p1

Evergreen Chiller Estimated Acoustic Data

Project Name: KFUPM - PH 3
Sales Office: ARABIAN AIR CONDITIONING CO

01/16/2008
04:15 PM

Tag Name .... Selection1_600 no option
Chiller Model 19XR-56554R6DFS64
Sound Treatment .... No Treatment

Airborne Sound Pressure, dB

		Octave Band Center Frequency, Hz								
Percent Load	**DBA**	**31.5**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
100	86	64	67	74	76	77	76	78	82	75

Notes:

timated Sound Pressure Levels - dB re: 20 micropascal.

Sound pressure levels used to develop this program were measured per ARI Standard 575.

The sound pressure levels were measured in an acoustical free-field, i.e. a non-reflective environment. Field sound measurements can vary significantly as a function of the reflectivity and proximity of nearby surfaces and the presence of other sound sources.

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ARABIAN AIR CONDITIONING CO. LTD.
AL-KHOBAR BRANCH - 2051007380

Evergreen Chiller Builder v4.36

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Appendix D - 6: Case-Study by KFUPM p3

Appendix E: Miscellaneous

University of
Waterloo

Civil and Environmental Engineering Department

Survey # 1
In the process of completing a Ph. D. research
Mr. Khaled Sherbini

Dear Eng.

Thank you for your help in the process of data collection.

Based on the collected data, we developed a list of critical submittals. They are critical among the submitted items by contractor for consultant evaluation and approval during construction. The criticality is measured mainly by the impact on operation in term of resources consuming like power, water, and gas consumption that increases the operation cost. It is also measured by the impact on owner satisfaction level during operation. The objective is to have the top ten most critical items while the list provides thirteen items.

Water Conservation
– faucets
– flushing
– Showers

Table 1. List of critical submittal items

	Rank	***Critical item***
1	1	Chiller
1	2	Boiler / Electric heat / gas heating
	3	LV Dist. Switch Gear/Electrical Panel Board ✗
3	4	Fan Coil Unit
	5	Package Unit ✗
	6	Fume Extract System ✗
3	7	Air Handling Unit / FCU
6	8	Exhaust and Ventilation Fans
5	9	Motor control centre
7	10	Building Automation System / BMS
	11	Security/access system / application based
	12	Lighting ~~Fixture~~ types
	13	Sound/address system depend on application/function

energy Consumption { 1 [7, 2

2 – Cooling tower
4 – pumps
– BMS. (Building mgmt System)

Appendix E - 1: Sample of Filled Communication

Space Input Data

Project Name: KFUPM-3.A.FF 06/29/08
Prepared by: al jabr contracting co 12:43 PM

BLG4,14 B1-214-217 SF

1. General Details:

Floor Area 257.0 ft²
Avg. Ceiling Height 9.000 ft
Building Weight 70.000 lb/ft²

2. Internals:

2.1. Overhead Lighting:

Fixture Type Recessed (Unvented)
Wattage 3.00 W/ft²
Ballast Multiplier 1.25
Schedule LIGHTING

2.2. Task Lighting:

Wattage 0.00 W/ft²
Schedule None

2.3. Electrical Equipment:

Wattage 1000.0 Watts
Schedule COMPUTERS,PRINTERS ETC

2.4. People:

Occupancy 2 People
Activity Level Medium Work
Sensible 295.0 BTU/hr/person
Latent 455.0 BTU/hr/person
Schedule OCCUPANTS

2.5. Miscellaneous Loads:

Sensible 0 BTU/hr
Schedule None
Latent 0 BTU/hr
Schedule None

3. Walls, Windows, Doors:

Exp.	Wall Gross Area (ft²)	Window 1 Qty.	Window 2 Qty.	Door 1 Qty.
NW	145.0	1	0	0

3.1. Construction Types for Exposure NW

Wall Type Medium Weight Wall
1st Window Type W-01
2nd Window Type W-01

4. Roofs, Skylights:

Exp.	Roof Gross Area (ft²)	Roof Slope (deg.)	Skylight Qty.
H	257.0	0	0

4.1. Construction Types for Exposure H

Roof Type Medium Weight Roof-c.paver+2"ins+screed+mem+8"

5. Infiltration:

Design Cooling 20.0 CFM
Design Heating 0.0 CFM
Energy Analysis 0.0 CFM
Infiltration occurs only when the fan is off.

6. Floors:

Type Floor Above Conditioned Space
(No additional input required for this floor type)

7. Partitions:

7.1. 1st Partition Details:

Partition Type Wall Partition
Area 331.0 ft²
U-Value 0.310 BTU/hr/ft²/F
Uncondit. Space Max Temp 75.0 °F
Ambient at Space Max Temp 95.0 °F
Uncondit. Space Min Temp 75.0 °F
Ambient at Space Min Temp 55.0 °F

7.2. 2nd Partition Details:

Partition Type Wall Partition
Area 186.5 ft²
U-Value 0.310 BTU/hr/ft²/F
Uncondit. Space Max Temp 75.0 °F
Ambient at Space Max Temp 95.0 °F
Uncondit. Space Min Temp 75.0 °F
Ambient at Space Min Temp 55.0 °F

Carrier Hourly Analysis Program v4.04 Page 1

Appendix E - 2: Space Load Calculation Sheet by KFUPM

Contract. Communications by and with the Architect's consultants shall be through the Architect. Communications by and with Subcontractors and material suppliers shall be through the Contractor. Communications by and with separate contractors shall be through the Owner.

§ 4.2.5 Based on the Architect's evaluations of the Contractor's Applications for Payment, the Architect will review and certify the amounts due the Contractor and will issue Certificates for Payment in such amounts.

§ 4.2.6 The Architect will have authority to reject Work that does not conform to the Contract Documents. Whenever the Architect considers it necessary or advisable, the Architect will have authority to require inspection or testing of the Work in accordance with Sections 13.5.2 and 13.5.3, whether or not such Work is fabricated, installed or completed. However, neither this authority of the Architect nor a decision made in good faith either to exercise or not to exercise such authority shall give rise to a duty or responsibility of the Architect to the Contractor, Subcontractors, material and equipment suppliers, their agents or employees, or other persons or entities performing portions of the Work.

§ 4.2.7 The Architect will review and approve or take other appropriate action upon the Contractor's submittals such as Shop Drawings, Product Data and Samples, but only for the limited purpose of checking for conformance with information given and the design concept expressed in the Contract Documents. The Architect's action will be taken with such reasonable promptness as to cause no delay in the Work or in the activities of the Owner, Contractor or separate contractors, while allowing sufficient time in the Architect's professional judgment to permit adequate review. Review of such submittals is not conducted for the purpose of determining the accuracy and completeness of other details such as dimensions and quantities, or for substantiating instructions for installation or performance of equipment or systems, all of which remain the responsibility of the Contractor as required by the Contract Documents. The Architect's review of the Contractor's submittals shall not relieve the Contractor of the obligations under Sections 3.3, 3.5 and 3.12. The Architect's review shall not constitute approval of safety precautions or, unless otherwise specifically stated by the Architect, of any construction means, methods, techniques, sequences or procedures. The Architect's approval of a specific item shall not indicate approval of an assembly of which the item is a component.

§ 4.2.8 The Architect will prepare Change Orders and Construction Change Directives, and may authorize minor changes in the Work as provided in Section 7.4.

§ 4.2.9 The Architect will conduct inspections to determine the date or dates of Substantial Completion and the date of final completion, will receive and forward to the Owner, for the Owner's review and records, written warranties and related documents required by the Contract and assembled by the Contractor, and will issue a final Certificate for Payment upon compliance with the requirements of the Contract Documents.

§ 4.2.10 If the Owner and Architect agree, the Architect will provide one or more project representatives to assist in carrying out the Architect's responsibilities at the site. The duties, responsibilities and limitations of authority of such project representatives shall be as set forth in an exhibit to be incorporated in the Contract Documents.

§ 4.2.11 The Architect will interpret and decide matters concerning performance under and requirements of, the Contract Documents on written request of either the Owner or Contractor. The Architect's response to such requests will be made in writing within any time limits agreed upon or otherwise with reasonable promptness. If no agreement is made concerning the time within which interpretations required of the Architect shall be furnished in compliance with this Section 4.2, then delay shall not be recognized on account of failure by the Architect to furnish such interpretations until 15 days after written request is made for them.

§ 4.2.12 Interpretations and decisions of the Architect will be consistent with the intent of and reasonably inferable from the Contract Documents and will be in writing or in the form of drawings. When making such interpretations and initial decisions, the Architect will endeavor to secure faithful performance by both Owner and Contractor, will not show partiality to either and will not be liable for results of interpretations or decisions so rendered in good faith.

§ 4.2.13 The Architect's decisions on matters relating to aesthetic effect will be final if consistent with the intent expressed in the Contract Documents.

§ 4.3 CLAIMS AND DISPUTES

§ 4.3.1 Definition. A Claim is a demand or assertion by one of the parties seeking, as a matter of right, adjustment or interpretation of Contract terms, payment of money, extension of time or other relief with respect to the terms of

Appendix E - 3: Submittal within AIA Document A201 (1997)