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A Case Study in Actual Building Performance and Energy Modeling with Real Weather Data

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A CASE STUDY IN ACTUAL BUILDING PERFORMANCE AND ENERGY MODELING
WITH REAL WEATHER DATA

by

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Abstract

As part of this study, an issue has been identified with regards to there being a performance gap with energy efficient buildings. This has been validated through literature review in the areas of occupancy behavior, modeling accuracy and reviewing energy consumption of energy efficient buildings. In order to analyze the error generated between predicted and actual energy performance, a case study approach has been adopted. The Ron Joyce Centre is a LEED Gold Certified building that is part of the McMaster University campus in Burlington. Actual energy performance data has been collected along with detailed drawings to analyze its predicted energy performance using real weather data over a two-year period in eQUEST. The results indicate that eQuest is able to predict electrical consumption within 0.72% of actual on an annual basis. However, natural gas consumption is more erratic and inconsistent based on heating degree days and has fluctuating values with differences ranging between 21% to 4.5% on monthly basis. The overall predicted energy consumption for 2012 is 1096133 kWh and 33227 m^3. It is not possible to root the cause for this discrepancy with limited data, except to utilize two weather files in generating energy models. The default 30 year average from CTMY for Toronto and another to account for the maximum number of HDD, offering owners a range of natural gas consumption.

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Nomenclature

RJC: Ron Joyce Centre

HDD: Heating degree Celsius day

CDD: Cooling degree Celsius day

OAMU: (Turner, 2006) (Oates & Sullivan, 2012) outdoor air makeup unit

1 Introduction

It is a general knowledge that the current building population consumes a larger portion of the energy produced. In 2010 the commercial building sector consumed about 30% of the total electrical and about 21% of the natural gas produced in Canada (Natural Resoure Canada, 2011). This has been attributed to low efficiencies, poor thermal performance and improper design practices. The introduction of energy efficient buildings is having a steady growth in the Canadian market and aims to make new and renovated buildings more sustainable and efficient. The benefits of green building design help to reduced water consumption; improve indoor air and environment quality due to material selections and low VOC's; and address occupant comfort. Leadership in Energy and Environmental Design (LEED) is one of the most popular optional rating systems that address these issues in seven different areas. One of these is Energy and Atmosphere, which constitutes a big portion of improving a building's energy consumption. However, through literature review including research, reports and studies, evidence shows that these buildings are not performing as predicted through energy modeling simulation.

In order for a building to be certified under LEED, the design team has to generate a base line model in accordance with ASHRAE standard 90.1 or Model National Energy Code for Buildings (MNECB). In doing so, the projected savings for the proposed design may be established (U.S. Green Building Council, 2010). Despite efforts to accurately predict energy consumption pre-construction, there is a significant gap between predicted and actual energy consumption. This has brought about the

term known as performance gap with efforts being made to reduce this discrepancy (Carbon Trust, 2011). To give a perspective on the LEED market in Canada, there are over 4000 certified buildings and more still awaiting approval. This has amounted into a steady growth since 2001 of about 50% each year (Canada Green Building Council, 2013). Refer to Appendix A Figure A-1 for further information. The performance gap is not an issue present in all buildings but is an area of concern. As part of this report, the actual versus predicted energy consumption of the Ron Joyce Centre (RJC) will be evaluated. In order to accurately represent the building, eQUEST modeling tool will be utilized in conjunction with actual weather data collected from weather station Hamilton A between January 2011 and April 2013.

2 Literature Review

2.1 Energy Audits

In performing the literature review a number of research articles, reports and studies were studied to understand why buildings are not performing as intended and what steps can be taken to create a more robust energy model. The selection of articles specifically focus on commercial buildings pertaining to their performance, factors of influence over energy consumption and ability to simulate their daily operations. An initial review consists of studies pertaining to building energy audits and a review of their performance; this included the PROBE (Post-occupancy Review of Buildings and their Engineering) study, LEED buildings and energy efficient buildings.

The PROBE study was conducted between 1995 and 2002 involving the evaluation of 23 energy efficient buildings. The results of this study demonstrated that, of the 23 buildings studied; energy use was generally higher than anticipated due to sources such as, computer labs and office equipment adding 25% to 80% to the total building energy consumption (Bordass, Cohen, Standeven, & Leaman, 2001). Many of the inaccuracies stemmed during the modeling phase due to unrealistic assumptions (Bordass, Cohen, Standeven, & Leaman, 2001). Carbon Trust has further emphasized this in a recent study *Closing the Gap*, in which they outline key inaccuracies that occur during the modeling phase. As shown in Figure 1, the design prediction comprising of regulated energy use, does not take into account additional variations and inefficiencies that occur within commercial buildings. This invariably adds to the energy consumption, hence generating the performance gap (Carbon Trust, 2011).

Regulated energy use

Actual total energy use

Regulated energy use | Unregulated energy use | Extra occupancy and working hours | Inefficiencies | Special rooms

■ Regulated energy use includes heating, hot water, cooling, ventilation and lighting

■ Unregulated energy use includes plug loads, security, external lighting, and elevators

■ Extra occupancy, equipment and additional operating hours (i.e. evenings and weekends)

■ Inefficiencies from poor controls, improper commissioning and lack of maintenance

■ Special function (separate energy uses) including server rooms, cafeteria and emergency energy

Figure 1 Predicted energy vs. actual total energy use (Carbon Trust, 2011)

An earlier study on a low-energy building constructed in the early 1980's also suffered from unrealistic assumptions and occupant behavior. The simulation and calibration of a DOE-2.1 C model was required to understand the sources of the discrepancy that caused more than twice the predicted energy consumption within a building (Norford, Socolow, Hsieh, & Spadaro, 1994). It was evident through the

calibration process the energy consumption was heavily dependent with the way the building was used rather than its construction. The cause of the increased over the baseline energy consumption was attributed to tenant power requirements contributing to a 64% increase; HVAC systems were in operation for a longer time contributing to a 24% increase; reduced equipment performance and greater envelope heat transfer contributing to the final 12% increase. The performance gap in all three studies noted above stem from energy modeling inputs based on the very best energy behavior and rule out tenant lifestyle and operational inefficiencies (Norford, Socolow, Hsieh, & Spadaro, 1994). Despite the industry having an early understanding of the shortfalls of energy prediction and sources of inaccuracies, today's energy efficient buildings are still challenged by this.

Two similar studies conducted evaluated the post-occupancy energy performance of LEED buildings within the United States (Oates & Sullivan, 2012; Turner, 2006). LEED buildings are set out to be sustainable and energy efficient, with a large portion of the points allocated toward energy savings. The results of both papers arrived at a similar conclusion, with majority of the LEED buildings surveyed not performing as originally predicted and the energy savings not being realized (Oates & Sullivan, 2012; Turner, 2006). This could be attributed to the performance gap and inaccuracies mentioned in the section above. In Turner's results, she mentioned that the buildings were performing below baseline standards and no single building's actual energy use intensity was within 20% of the projected savings demonstrated from the proposed design model (Turner, 2006). In reviewing Oates and Sullivan's paper on medium and high-energy intensity buildings, consistent results to that of Turner and

Carbon Trust study were produced. Final results demonstrated that of the 19 buildings sampled, "four of the high energy intensity buildings performed 48% worse than the design case and 24% worse than the baseline model". "The 15 buildings of medium energy intensity underperformed the design model by 74% and the baseline model by 14%" (Oates & Sullivan, 2012). It must be noted that as many of the commercial buildings get bigger heat loss/ gain for heating and cooling will become smaller in comparison to other end uses like plug loads, lighting and ventilation.

Amongst the study conducted by Turner and Oates the concerns about energy savings not being achieved is evident; however, certain areas of concern must be drawn to the two studies. The first being, not all of the sampling for the LEED buildings were randomized and some were dependent on voluntary information prepared by the owner. This brings about a possible bias because the owners could have only provided the information under the pretext that they assumed their building was performing as expected, which through the studies suggest otherwise (Oates & Sullivan, 2012). The studies are limited because they examine a very small population of the total energy efficient buildings currently on the market; and only Oates and Sullivan study noted the possibility of reduced energy consumption past the first year of operations. This is critical because it takes about a year for the building maintenance and operations managers to optimize the performance of the building based on the loads due to occupancy, scheduling and equipment familiarity (Oates & Sullivan, 2012).

The Carbon Trust study and Oates and Sullivan research, address key reasons for the performance gap. This is significant because as presented in Figure 1 and as Oates and Sullivan mention, energy simulation relies on accurate assumptions such as,

operational hours, temperature set points, plug loads and number of occupants. These variables if changed have varying effects on the actual energy performance of the building, some more than others (Oates & Sullivan, 2012).

2.2 Accuracy of simulation tools

It is still unclear whether modeling tools can accurately predict total energy consumption of a building within an acceptable error margin. Menezes, Cripps and Buswell seek to understand this question by utilizing post occupancy evaulation as a tool to accurately predict lighting, plug loads (office equipment) and catering loads. In the study, detailed sub-metering monitored occupant behavior every half-hour for each of the four tenants in the seven-story building. The overall accuracy of the predicted model was within 3% of the actual energy consumption (Menezes, Cripps, & Buswell, 2011). The paper is limited since it does not take into account the interdependencies between the HVAC system, heating and cooling loads and energy losses through the envelope. All these variables increase the level of complexity when predicting energy consumption monthly and annually.

In a similar study real-time simulation was performed to analyze whole building performance. In their research Pang, Wetter, Bhattacharya, and Haves monitored a commerical buliding in real time to compare simulated energy consumption using EnergyPlus to that of actual data. Despite real-time inputs discrepencies were observed pertianing to chiller operation strategies (Pang, Wetter, Bhattacharya, & Haves, 2012). This can be attributed to the source code and equations used within the program (Zhu, Hong, Yan, & Chuang, 2013).

2.3 Sensitivity Analysis

Understanding relationships that exist within a building and factors that have a significant impact on energy consumption can help during the modeling process. Relationships such as a direct correlation between occupancy and energy consumption will entail time should be spent detailing schedules accurately. Elie Azar and Carol Menassa address the impact of occupant behavior on energy performance in a typical office building using nine different occupant behavior parameters (Azar & Menassa, 2012). These nine parameters will be of key focus when undertaking a site walkthrough and modeling of the RJC. Sensitivity analysis results for climate zone 1 with greater than 7000 HDD (^{o}F-day) will be reviewed, since this best represents Toronto's climate with 4066 HDD (^{o}C-day) (Natural Resource Canada, 2012) (Azar & Menassa, 2012).

Taking this into consideration is critical because it helps to understand which parameters within the building for Toronto weather have the greatest effect on energy consumption. As mentioned within the study, errors generated within predicted models are due to, "simplistic and idealistic data that does not represent actual building systems and occupancy" (Azar & Menassa, 2012). This is very closely related to the conclusions also drawn in the PROBE study. Combining this with the analysis of nine different occupancy behavior parameters will help reduce errors. A list of the nine parameters is shown in Table 1 below (Azar & Menassa, 2012).

1. After hours equipment use (AE)

2. After hours lighting use (AL)

3. Occupied hours temperature set points- cooling (OC)

4. Occupied hours temperature set points- heating (OH)

5. Unoccupied hours temperature set points- cooling (UC)

6. Unoccupied hours temperature set points- heating (UH)

7. After hours active HVAC system (AH)

8. Hot water consumption (WC)

9. Building schedule (BS)

Table 1 Influence coefficient values and ranking for occupancy parameters (Azar & Menassa, 2012)

Influence coefficient values and ranking (1= highest impact 9= lowest impact)									
Building description	1	2	3	4	5	6	7	8	9
Zone 1 moist	0.8052 (BS)	0.4529 (OH)	0.4168 (AE)	0.3243 (AL)	0.2519 (AH)	0.1155 (OC)	0.0668 (WC)	0.0317 (UH)	0.0001 (UC)

* Coefficients can only be applied to temperatures in degrees Celsius.

It was also observed that there is a direct relationship noted to the research conducted by *Menezes et. al* where they noted the effects of leaving the computers on after hours increased energy consumption from 90 kWh/m^2 to 155 kWh/m^2 (Menezes, Cripps, & Buswell, 2011). In a similar sensitivity analysis study, the top three factors having the greatest influence on an office building were mechanical ventilation rate during daytime winter, lighting control and infiltration rate during nighttime winter (Heiselberg, Brohus, Hesselholt, Rasmussen, Seinre, & Thomas, 2009). Furthermore, as noted from Figure 1, the Carbon Trust study also noted that lighting, scheduling effects were generally excluded which have a significant impact on energy consumption (Carbon Trust, 2011). With synergy being drawn to a number of studies it is evident that the nine parameters do play a critical role in energy consumption and adds relevance

and validity to this study performed.

Thus, based on the literature review it is conclusive that the performance gap is an issue in today's LEED energy efficient buildings. The studies have demonstrated that taking into consideration occupant behavior, scheduling, set points and after hour activities can help develop strong design predictions. Implementing the suggestions and practices mentioned will require a detailed site and systems analysis of the RJC.

By adding a full building analysis as compared to the study performed by *Menezes et. al* this paper will help fill the gap of modeling accuracy using the most recent building data and specification (Menezes, Cripps, & Buswell, 2011). It will also add to the analysis of occupancy behavior where all the nine occupancy behavior parameters are taken into consideration and not analyzed in isolation. By taking actual data this report will analyze the error difference between actual performance and predicted using real weather data, current scheduling patterns, occupancy loads, lighting systems used and equipment; an effort not represented by current research reviewed.

2.4 Review of simulation tools

There are currently well over 200 building energy simulation tools on the market for engineers, architects and owners to utilize to evaluate their design. Each program has its own capabilities and limitations for different climate zones. For the purpose of this paper eQuest has been selected. The reason for this is because RJC is a LEED Gold certified building and eQuest is one of the eight approved modeling programs set out by Canada Green Building Council (CaGBC). During the LEED certification process Enermodal Engineering utilized this program for their proposed savings the building

would achieve. However, despite this it is important to understand the limitation of this program to help access any discrepancy between actual and predicted energy performance. To understand the limitations of eQuest, comparison will be made to EE4, DOE-2, EnergyPlus, IES Virtual Environment, Hourly Analysis Program (HAP), TRACE 700 and EnergyPro v5.1, approved energy simulation programs by CaGBC.

DOE-2 is a simulation engine with a number of various graphical interfaces including eQuest, EnergPro and EE4 (Zhu, Hong, Yan, & Chuang, 2013). DOE-2 has been used within the industry for more than 25 years and is a "developing and test building energy standard in the U.S and around the world" (Crawley, Hand, Kummert, & Griffith, 2008). Reviewing the paper further, Crawley et al. (2008) set out to compare a number of different programs with regards to their features and functions. eQuest does lack features and options in the areas such as zone loads, interior surface convection, and solar/day lighting analysis. These limitations are not present in programs such as EnergyPlus and IES-VE (Crawley, Hand, Kummert, & Griffith, 2008). Furthermore, analysis outlined in "Comparison of Building Energy Modeling Programs: Building Loads" seeks to "analyze algorithms, modeling assumptions and simplifications that lead to large discrepancies" in the modeling softwares (Zhu, Hong, Yan, & Chuang, 2013). Therefore, it is not only important to understand the features that are lacking within each program as outline by Crawley et al. (2008) but also how each program inputs "default values, or algorithms for load simulations" (Zhu, Hong, Yan, & Chuang, 2013). Through simple testing and verification such as ASHRAE Standard 140-2007, DOE-2.1E and EnergyPlus "had the fundamental capabilities and appropriate modeling assumptions for load simulation" (Zhu, Hong, Yan, & Chuang, 2013). In further testing,

DOE-2.1E was found to be limited in accurately calculating the heat balance between multiple zones because of its simplification for long-wave radiation exchange and multiple zone solutions. Thus, caution should be given when modeling radiant cooling or heating applications and different operating conditions in adjacent spaces. The effect of this can be observed in higher cooling loads and lower heating loads over an annual basis (Zhu, Hong, Yan, & Chuang, 2013). Awareness of these limitations within the source code of the program will help analyze the output data with better understanding and any discrepancies.

eQuest is a great program for the novice user but with its detailed mode option it allows for in-depth adjustments to default values. It is for the user to understand how the values should be adjusted based on the interpretation of the program. Taking all this into consideration, the RJC building does have radiant infloor heating but it is limited to the main floor perimeter. There are limited adjacent spaces within the building that have varying operating conditions that could cause any large inaccuracies for space heating and cooling. Some of the areas might include mechanical, electrical rooms, elevator shaft and stairwells. Overall, eQuest is the appropriate simulation program of choice because CaGBC accredits it and was the program of choice by Enermodal Engineering for the LEED energy consumption and saving simulation.

3 Background

3.1 Post-Occupancy evaluation

A number of the papers reviewed attribute the evaluation of energy consumption within the building as post-occupancy evaluation (POE). As described by *Preiser,* post occupancy evaluation seeks to satisfy the needs of the occupants within the building (Preiser, 2013). It evaluates to see if the facilities within the space support the people's needs. This is significantly different from what is described as a technical test such as, energy audits in which the tests are done regardless of its occupants (Preiser, 2013). This does become confusing because examining the energy performance (energy audit) of a building is dependent on the occupancy load, schedule and the building systems to meet the required set points. Thus, it can be said that an energy audit may be one component of POE because an energy audit may "draw on available knowledge through data collection and instruments in order to predict a building's likely performance over a period of time" (Preiser, 2013).

Therefore, in order to perform an accurate energy audit of the RJC a site assessment will have to take place. This walk through of the site will take note of occupancy load, scheduling, instruments installed within spaces to reduce energy consumption, equipment installed and HVAC system. A more detailed outline will be provided in the methodology.

3.2 Limitation in current case study and sources of discrepancy

In comparing the actual energy performance versus modeled energy performance it is critical not to repeat mistakes that cause the performance gap in the

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first place. Based on the PROBE study and Carbon Trust the major source of discrepancy was a combination of poor assumptions primarily in the area of occupancy behavior due to the increased level of controllability within the space; operational hours; lack of allocating power consumed by small plug loads; and external lighting (CIBSE Energy Performance Group, 2012). All these small differences can amount to 30% of energy consumed in office buildings; followed by lack of monitoring post-occupancy the industry is not able to correct itself to better improve their modeling assumptions and methods (CIBSE Energy Performance Group, 2012). These issues could prevail in this research however; steps will be taken to help reduce such errors, which will be outlined in detail through the methodology.

4 Methodology

In order to analyze and compare the actual versus predicted energy consumption a case study approach is being adopted. A similar process adopted by the PROBE study with few modifications will guide the process of analyzing the energy consumption of the Ron Joyce Centre.

4.1 Actual Data

To create an accurate energy model using eQUEST a complete issue for construction (IFC) package will be obtained from Enermodal Engineering and Sodexo. The IFC package includes as built AutoCAD drawings outlining architectural plans, lighting schedules and mechanical systems. This information is critical to designing the shell of the building with proper zoning allocations and envelope design. Data pertaining to commissioning and onsite testing will help determine the equipment efficiency and heating and cooling capacity for mechanical systems installed. This is in relation to heat pump CFM, fan coil heaters, exhaust fans and the air-handling unit (AHU). In addition, monthly utility bills and sub-metered data will aid in the calibration and validation process. Regular site visits will be conducted to gather information related to number of computers in use, window blinds closure, café operation hours and class schedules.

4.2 Simulation

Gathering all the information from site visits, IFC packages and commissioning reports will be utilized to create an eQUEST model of the building. The initial construction of the building will be created using the Design Development Wizard to input initial zoning allocation, window placement, scheduling and HVAC design. A few

deviations in the shell design will be encountered due to simplification (grouping) of the interior spaces. This process will lead to a takeoff and calculations for the building to input lighting density, equipment load and general scheduling depending on zone characteristics. This process will help reduce any assumption entered into the program and reduce calibration and validation time in detailed design mode. There will be a total of four simulation runs being performed including 2011, 2012, 2013 January to April and CTMY- 30 year Toronto average.

4.3 Weather file

To accurately simulate the energy consumption of the building for the time period of January 2011 to April 2013 real weather data will be retrieved from Environment Canada weather station. Figure 2 below displays the six possible weather stations in proximity to the RJC. Onsite weather data will be collected from the building automation system (BAS) for 3-4 days to help determine the local weather station that best correlates with respect to temperatures and relative humidity the building experienced over the years. Through this process an ".epw" weather file will be created and converted into a ".bin" using eQuest weather conversion software.

Figure 2 Environment Canada weather stations near RJC

4.4 Validation and calibration

After creating the eQUEST model using the wizard mode and performing an initial simulation, reference will be made to the actual utility bills for validation and calibration purposes. This process is necessary to make any adjustments to equipment loads, café operations, occupancy loads and scheduling. In order to make the necessary changes adjustments will be made using eQUEST detailed mode where specific input parameters may be adjusted to individual zones and equipment.

The validation technique most likely to take place is empirical test in which calculated results from eQuest will be compared to monitored data from the RJC building (Neymark et al., 2002). This technique offers an approximate truth within experimental accuracy and at any complexity (Neymark et al., 2002). The main disadvantage is the

uncertainties, which stem from two main groups, which include external errors and internal errors (Neymark et al., 2002).

External error types
- *Differences between the actual microclimate that affects the building versus the weather input used by the program.*
- *Differences between the actual schedules, control strategies, effects of occupant behavior and effects from the building existing in the "real world", versus those assumed by the program user.*
- *User error in deriving building input files.*
- *Differences between the actual thermal, optical and other physical properties of the building including its HVAC systems versus those input by the user.*

Internal error types
- *Differences between the actual thermal transfer mechanisms taking place in the real building and its HVAC systems versus the simplified model of those physical processes in the simulation (all models are by definition simplifications of reality).*
- *Errors or inaccuracies in the mathematical solution of the models.*
- *Coding errors.*

The biggest challenge is interpreting the results because "all possible error sources are simultaneously operative" (Neymark et al., 2002). Thus, reviewing and analyzing the output data from eQuest can make adjustments to lighting, café and occupancy schedules, and HVAC system for natural gas consumption. Though this process helps to refine the input parameters into the program it does not eliminate the errors completely.

5 Description of Case study

5.1 General

The Ron Joyce Centre located in Burlington, Ontario, is a five story, 9,624 square-meter university building, part of McMaster University's Burlington campus. The facility includes a teaching auditorium, classrooms, offices, amenity spaces and a café on the main floor of the building. Currently only three floors of the building are occupied with the fourth floor remaining incomplete and used as a storage space. The fifth floor contains the mechanical room and other miscellaneous equipment needed to operate the building.

5.2 Shell and HVAC

The basic design of the building shell comprises of a curtain wall system for maximum daylight penetration. The interior of the building has a central atrium space that allows daylight to enter deep into the core of the structure. The mechanical system is a hybrid system comprised of a water loop heat pump system in conjunction with an outdoor air makeup unit for fresh air ventilation. The system contains an economizer and energy recovery wheel to help save energy. Smaller systems are also incorporated including radiant floor heating on the first floor along the perimeter and fan coil heaters in designated zones.

The big hall and auditorium on main floor have CO_2 sensors to help regulate ventilation within the space. For the purposes of this simulation, the demand ventilation control will not be installed rather operate of a fixed schedule, Monday to Sunday.

5.3 Utility Data

Utility bills for gas and hydro from January 2011 to April 2013 have been complied for comparison against simulated energy consumption. The electrical metering is done by Burlington Hydro Inc. In addition, McMaster has an independent sub metering system within the building to measure electrical consumption by end use. The end use categories are lighting, HVAC, elevators, emergency, power panels and café. However, it must be noted in pervious attempts to record this data, the sub metered readings did not correlate with the utility bills. The sum of sub metered electrical consumption was about up to twice the actual electrical consumption noted by Burlington Hydro Inc. Appendix B Table B-1 details data recordings of electrical consumption for 2011 and is compared to 2011 actual energy consumption. Thus, the sub-metered information may only be useful in comparing the relative energy consumption by end use. A detailed analysis of energy consumption within the building is noted in Appendix B Figure B-1 and Figure B-2.

In addition, it must be noted from August 2010 to November 2, 2011 the natural gas consumption was estimated by Union Gas. This resulted in no measured natural gas consumption per month, due to an initial and final reading spanning more than a year. This will render cross-referencing between predicted and actual consumption ineffective. By calculating the ratio of heating degree-day to natural gas consumption for 2012 a more accurate estimate may be generated for 2011.

6 Objective

As part of this case study two questions are going to be answered including:

1. Examine the variation between simulated and real data and be able to explain the cause for the differences. Focus will be on 2012 results, as this year has the most complete data.

2. Compare and analyze the difference between LEED proposed energy consumption and 2012 building energy consumption.

By answering these questions it would be valuable to both the McMaster University and the operation and management team ensuring the building is running efficiently. For future reference McMaster University can have a benchmark to follow in future constructions or in evaluating existing buildings on campus with similar functionality. Though the building is operated by a third party company this data will help improve the building on a yearly basis or just ensure that it's running optimally.

7 Modeling

Modeling of the RJC building was completed using eQuest v3.64 and the following sections summarizes modeling notes for the design of the building.

7.1 Zoning

Each floor of the building was modeled as a separate shell in eQuest to generate the four-story building. Areas of similar use, occupancy schedule and set point temperatures were grouped together to simplify the design of the building. A detailed zoning drawing for each floor is provided in "Appendix C" for review. In creating the zoning for the fifth floor, screened exterior spaces located in the north and south were discounted due to exposure to exterior environment.

7.2 Building Shell

The envelope construction of the building consists mainly of a curtain wall system and opaque sections between floors. A detailed material selection and thermal resistant values for different envelope sections are listed in Table 2.

Table 2 Building Envelope and material selection

Envelope section	Material selection	Thermal resistance m^2K/W (RSI)
Exterior wall types	w4 - insulated walls behind exterior curtain wall spandrel panel 92mm metal studs @ 400 o.c. max. with foam filled insulation (r-10) with 16mm gypsum board (tape, sand, prime, paint)	2.29
	w4a - insulated walls behind exterior curtain wall spandrel panel 92mm metal studs @ 400 o.c. max. with foam filled insulation (r-10) with sprayed thermal barrier	2.29

	w6 - exterior curtain wall exterior prefinished aluminum curtain wall system with vision glass, glass spandrel, metal spandrel in insulated sealed unit Note: provide 100mm semi-rigid insulation at spandrels (r17)	3
Roof	r1 - roof at penthouse level (1 hr) -ulc f906 coated modified bituminous roofing membranes on tapered insulation (min 25mm) on100mm polyisocyanurate insulation on vapour barrier on reinforced concrete slab on 76mm metal deck on steel structure	5.33
	r2 - penthouse roof coated modified bituminous roofing membranes on tapered insulation (min. 25mm) on100mm polyisocyanurate insulation on vapour barrier on 38mm metal deck on steel structure	5.33
Curtain wall	6mm Blue, Low-E/ 12mm Grey St/ St spacer c/w Argon/ 6mmm clear tempered	0.13

7.3 Scheduling

Accurately representing the schedule for the building is a challenge. Students are free to enter and leave during operating hours of the building. Given the class schedule and events that may take place during the weekend a detailed schedule was generated. Refer to Appendix D for a detailed outline of the schedule for occupancy, lighting, office, and miscellaneous equipment. The occupancy ratio for each month was generated based on maximum capacity for each floor. The capacity for each floor is as follows; first floor 600 persons; second and third 300 persons each; fourth is not applicable (incomplete); and fifth 11 persons. Related schedules such as lighting, HVAC, plug

loads, and miscellaneous loads were based on occupancy since there is a direct correlation.

7.4 Weather data

Site temperature reading for June 2, 3, 4, 6, 7, 18 and 19th 2013 were gathered from the BAS. Comparisons were made to local weather stations including Hamilton A, Burlington Piers (AUT), Oakville Town Ontario, Grimsby Mountain Ontario, Southern Ontario emergency and Hamilton RBG CS. Station Hamilton A correlated best with site temperatures recorded over the selected days with minor differences in temperature readings. Figure 3 shows the delta temperature between site and Hamilton A station readings. It must be noted the site temperature readings have a consistently high reading between the time of 5pm and 7pm each day. This would be attributed to direct solar radiation on the sensor, generating an inaccurate reading. The average temperature difference as displayed in Figure 3 is 0.32 degrees Celsius.

In generating the weather file for eQuest, station Hamilton A detailed all the required information except global horizontal and direct normal solar radiation. This data was retrieved from the Canadian Weather for Energy Calculations (CWEC) for Toronto weather. Cumulating this information together, weather files were generated for 2011, 2012 and 2013 January to April. Appendix E details the weather file information.

Figure 3 Temperature difference between site and Hamilton A station (^{o}C)

7.5 HVAC

The design of the HVAC system in eQuest was modeled based on IFC mechanical engineering drawings. Appendix F details the actual systems within the building including, air schematic and hydraulic schematic. Modeling this information into eQuest is divided into two sections, water-side HVAC and air-side HVAC design.

7.5.1 Water-side HVAC

Three boilers were modeled in total for the system. Boiler one provides hot water for baseboard heaters, unit heaters and fan coil heaters located on the first, fourth and fifth floor. Boiler two ties in with the water loop heat pump for the first, second and third floor. Boiler three supplies hot water to the outdoor air makeup unit (OAMU) to precondition the outdoor air for the whole building. The OAMU is assigned to a dummy

zone within the building. Section 7.5.2 will go into more detail with regards to this. It must be noted that the load from boiler three is taken into consideration for total electricity consumption in the building and does not have a value of zero. Four electric hot water tanks located throughout the building supply domestic hot water to washrooms, kitchens and showers.

7.5.2 Air-side HVAC

Heat pumps, unit ventilators, fan coil heaters and/or baseboard heaters supply each of the zones. Fresh air for the building is supplied by the OAMU, which has an actual output of 7931 L/s (16,805 CFM). The OAMU is assigned to a dummy zone within the building since eQuest cannot model multiple HVAC systems for a given zone. The dummy zone has no internal loads such as people, lighting, equipment, exterior surfaces and envelope. The energy consumed by the OAMU supplying the dummy zone will be included in the total electrical and natural gas consumption.

With a total area of 7024 m^2 (75,623 ft^2) covering the first to third floor, the average actual ventilation rate is 1.13 $L/s.m^2$ (0.22 CFM/ft^2). With a maximum of 1200 persons the average actual ventilation rate per person is 6.6 L/s.person (14 CFM/person). This compares to AHSHRAE 62.1 ventilation rates ranging from 0.6-0.9 $L/s.m^2$ (0.12- 0.18 CFM/ft^2) and 3.8-5 L/s.person (7.5-10 CFM/person). Thus, the building is well within the requirements of AHRAE 62.1. With the future competition of the fourth floor the total area will be an additional 2063m^2 and 300 persons, totaling 9087 m^2 with 1500 total person capacity. The ventilation rates will be 0.88 $L/s.m^2$ (0.17 CFM/ft^2) and 5.33 L/s.person (11.2 CFM/person), which is well within the requirements of ASHRAE 62.1.

For each zone the total heating and cooling capacity was calculated along with their respective coefficient of performance (COP). Table 3 & 4 provides detailed specifications for heat pumps and heating systems on each floor. Test results of actual air flow output for each heat pump was taken into consideration when assigning overall airflow into each zone. In addition, exhaust fans (EF) 1.1, 1.2, 2, 4, and 6 were modeled into the building; with an exclusion of EF 3, which is used under emergency situations only. Table 5 below details each EF and their corresponding airflow.

Table 3 Heat Pump's, Heating and Cool Capacity

Floor	HP type	Quantity	Model	Cooling		Heating	
				TC (kW)	EER	HC (kW)	COP
1	B	1	12	3.19	12.6	3.92	3.7
	C	3	18	5.33	14.4	6.97	4.9
	D	4	24	7.15	16.3	9.11	4.74
	F	12	36	9.46	16.5	12	5.09
	1	1	192	51.6	11.8	69.3	4.5
2	A	11	6	1.58	12.4	2.25	4.2
	B	3	12	3.19	12.6	3.92	3.7
	C	9	18	5.33	14.4	6.97	4.9
	D	3	24	7.15	16.3	9.11	4.74
	E	6	30	8.26	14.9	10.55	4.64
	F	4	36	9.46	16.5	3.51	5.09
	G	1	42	36.5	15.8	14.82	5.02
3	A	9	6	1.58	12.4	2.25	4.2
	B	2	12	3.19	12.6	3.92	3.7
	C	12	18	5.33	14.4	6.97	4.9
	D	3	24	7.15	16.3	9.11	4.74
	E	5	30	8.26	14.9	10.55	4.64
	F	2	36	9.46	16.5	3.51	5.09
	G	1	42	10.69	15.8	14.82	5.02
	H	1	48	13.65	14.8	18.25	4.53
4	B	1	12	3.19	12.6	3.92	3.7

Table 4 Unit heaters, force flow, in-floor heating and fan coil heater specifications

Tag No.	Location	Quantity	kW	L/s
UH 1.1	Level 1 Incoming services	1	2.63	198
UH 1.2	Level 1 Electrical Room	1	2.63	188
UH 1.3	Garbage & Recycling Room	1	2.63	188
UH 2	Level 4	6	3.95	391
UH 2.1	Mezzanine Floor	1	4.57	349
UH 2.2	Mezzanine Floor	1	4.57	349
FF 1.3	Level 1 Main Entry Doors	1	15.27	292
FF 1.4	Level 1 Main Entry Doors	1	15.27	316
FC 2.1	Level 2	1	8.67	276
FC 2.2	Level 2	1	8.67	302
FC 2.3	Level 2	1	5.97	181
FC 2.4	Level 2	1	5.97	198
FC 3.1	Level 3	1	8.67	297
FC 3.2	Level 3	1	8.67	292
FC 3.3	Level 3	1	5.97	188
FC 3.4	Level 3	1	5.97	188
In-floor heating	Level 1	1	41557	

Table 5 Exhaust fans

Exhaust Fan	Actual L/s
1.1	231

1.2	290
2	266
4	571
6	287
Sum	1647

8 Heating Degree-day

To get a better understanding of energy consumption for the RJC it is important to analyze natural gas consumption with respect to heating degree-days (HDD) for each month. Union Gas did not document the natural gas consumption for 2011 accurately thus separate calculations will be performed in this section to generate an estimated consumption. Figures 4 and 5 detail the 2012 and 2013 HDD to natural gas consumption.
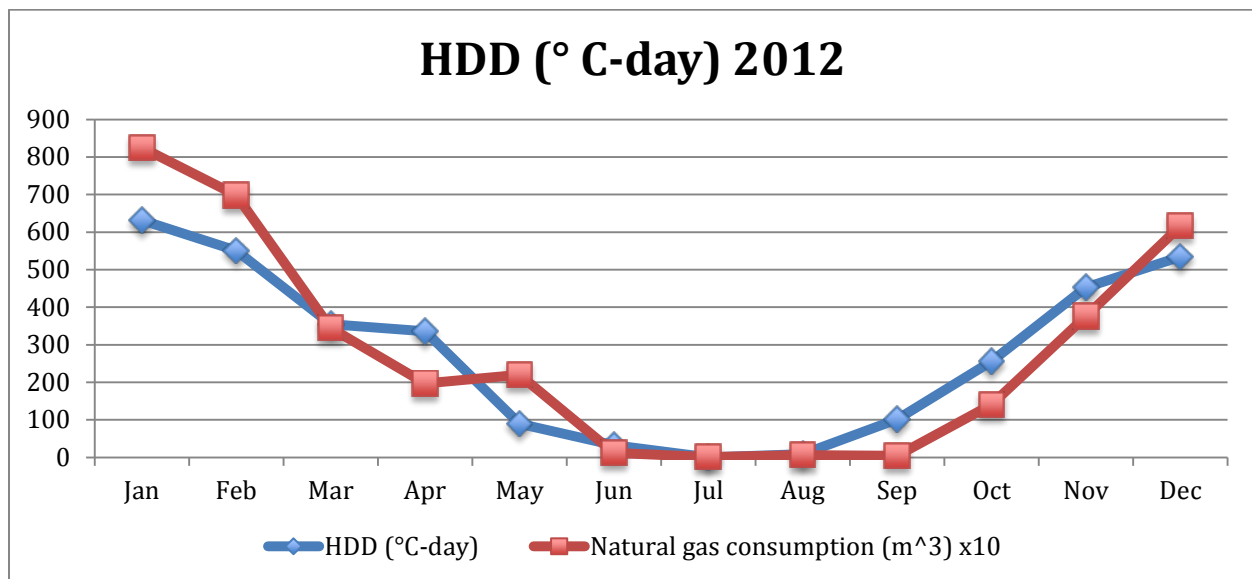

Figure 4 HDD 2012 and total natural gas consumption, 18°C reference temperature, Hamilton A station

HDD (° C-day) 2013

Legend: HDD (°C-day) · Natural gas consumption (m^3) x10

Figure 5 HDD 2013 and total natural gas consumption, 18°C reference temperature, Hamilton A station

Examining the graphs, it is evident that there is a direct correlation between natural gas consumption and HDD. For 2012 this relationship is presented over an annual cycle with the summer time sustaining the lowest natural gas consumption for heating.

Graphing the relationship between natural gas consumption and HDD will help determine R squared, coefficient of determination and the equation of the line. Utilizing the equation will help estimate the 2011 natural gas consumption based on the number of HDD per month. Figure 6 illustrates 2012 natural gas consumption to HDD relationship, with R^2 equaling 0.88082. This relationship is generated based on Environment Canada reference temperature of 18 °C for weather station Hamilton A. Altering this reference temperature to increase R squared required a number of iteration to arrive at a final T_{ref}= 13 °C and R^2= 0.92448. Figure 7 illustrates the relationship between HDD and natural gas consumption for a reference temperature of 13 °C.

Figure 6 HDD versus natural gas consumption for reference temperature of 18 °C

Figure 7 HDD versus natural gas consumption, reference temperature 13 °C

With the equation generated for reference temperature of 13 °C the 2011 estimated natural gas consumption is presented in Figure 8.

Examining the reallocation of natural gas consumption for space heating, 2011 consumed considerably more given the number of HDD. The annual consumption in 2011 is estimated at 55789 m^3 for 3817 HDD, compared to 2012's 34790 m^3 for 3347 HDD.

Figure 8 HDD 2011 and reallocated total natural gas consumption, 13°C reference temperature

9 Results and Analysis

Based on the modeled information, the output results from eQuest for 2011 to 2013 and CTMY Toronto weather average are presented in the following section. The generated output is divided into two energy consumption sources including electricity (kWh) and natural gas (m^3).

9.1 2011 Results

Figure 9 offers a break down of the electrical consumption predicted by eQuest and actual based on utility bills per month. The total electrical consumption for 2011 predicted by eQuest is 1097115 kWh with actual totaling 1031486 kWh, which is only a 6.38% difference. On a monthly basis, May experienced the largest difference between predicted and actual, 94938 kWh versus 62636 kWh respectively.

The monthly electrical consumption is subdivided by end use in Figure 10. Examining the electrical consumption by end use for space heating and cooling they fluctuate on an annual basis based on heating and cooling degree days. Majority of the lingering end uses remain fairly constant due to it being independent of outdoor environment and climate conditions. Lighting ideally would fluctuate seasonally; however, due to the core and closed spaces requiring constant ambient light this value remains relatively constant in all simulation runs.

2011 electricial consumption

Figure 9 2011 electrical consumption

2011 Electrical consumption by end use

Figure 10 2011 predicted electrical consumption by end use

As per calculations based on heating degree days the estimated natural gas consumption for 2011 is considerably different from predicted values, as illustrated in Figure 11. The average difference between January to April is 38%; in addition October and November being 42% and 51% respectively. On an annual basis the discrepancy

averages itself to 33% for natural gas consumption. Overall, with inaccurate estimation by Union Gas for 2011 a definite conclusion cannot be drawn.

2011 Natural gas consumption

Figure 11 2011 natural gas consumption

9.2 2012 Results

For 2012 the total predicted electrical consumption is 1096133 kWh compared to the actual 1088331 kWh, which is less than a 1% difference, as shown in Figure 12. The largest variation is in April with a 17.79% difference. The end use electrical consumption demonstrates a similar pattern to 2011 with no variations, as per Figure 13.

Figure 12 2012 electrical consumption

Figure 13 2012 predicted electrical consumption by end use

The predicted natural gas consumption for 2012 totaled 33227m^3 versus the actual of 34798m^3, as shown in Figure 14. Compared to 2011, 2012 is demonstrating greater accuracy on an annual basis for natural gas and electrical consumption. The largest discrepancy in natural gas consumption for 2012 occurred in May with a 75%

difference and in October with 64%. The transition months between space heating and cooling could be a key area to further examine within eQuest due to a large difference occurring during these time periods.

Figure 14 2012 natural gas consumption

9.3   2013 Results

For 2013 the data is very much incomplete because it only covers a quarter of the year, refer to Figure 15 and 16. Between January to March the average difference in electrical consumption is about 10%. From 2011 to 2013 actual electrical consumption has been fairly constant with minor difference, which can be attributed to changes in occupancy load and scheduling.

Figure 15 2013 electrical consumption

Figure 16 2013 predicted electrical consumption by end use

Natural gas consumption once again shows larger differences compared to electrical when using eQuest, as per Figure 17. With the average difference in 2013 being 32% between January to March. This difference, which is also present in 2011 analysis is establishing a possibility that eQuest has difficulty in accurately predicting

natural gas consumption. This cannot be conclusively demonstrated with such little data but is a potential area of further examination.

Figure 17 2013 natural gas consumption

9.4 CTMY Toronto

The CTMY Toronto weather file is a 30 year average and the most appropriate weather file for energy modelers to use for buildings in Southern and Central Ontario. The output of this weather file will be compared to 2012 actual energy consumption from the RJC.

In evaluating the electrical consumption there is no significant difference between actual (2012) versus predicted data. In Figure 18 the monthly results from eQuest is compared with 2012 actual utility data. On an annual basis the CTMY Toronto average has a discrepancy of only 0.32%, while the 2012 weather file has a discrepancy of 0.72%. Both weather files accurately predict electrical consumption for the building to within less than one percent; however, CTMY has a smaller error.

Figure 18 CTMY Toronto electrical consumption

Figure 19 CTMY Toronto predicted electrical consumption by end use

When examining natural gas consumption the overall annual error averaged to 15%, refer to Figure 20. The major sources of discrepancy occurred once again in April and October with an error of 84% and 86% respectively. This result is significantly higher compared to 2012 weather file output, which had an error of 4.5% averaged over an annual period. To further understand the reason for this difference it will require

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analyzing the CTMY weather file pertaining specifically to the number of HDD since this

has a direct effect on space heating.

CTMY Toronto natural gas consumption

Figure 20 CTMY Toronto natural gas consumption

9.5 Comparison to LEED submission

As illustrated through the literature review, many of the LEED certified buildings

are not meeting their expected energy consumption. The sources of generated error

have been documented and presented along with means of resolving the performance

gap. Since the RJC is a LEED Gold certified building, validating its current energy

consumption to the proposed design would serve as a relevant analysis.

Before analyzing and comparing the results between the LEED proposed, 2012

actual and CTMY a preliminary review of the inputs in the program was performed. Key

differences to take note of between the initial LEED simulation and current simulation

runs mainly include schedules and occupancy loads. In the LEED proposed design the

building has an occupancy load of 90%. In comparison, the current simulations have a

significantly lower occupancy load at around 50% of maximum capacity, as illustrated in

Appendix D, Table D-1. This combined with different scheduling patterns would invariably present a difference when making the evaluation. Secondary factors include small differences in lighting density, zoning patterns for spaces and total heating and cooling capacity for mechanical equipment. The fourth floor in the LEED proposed design has no occupants.

As shown in Figure 21, the LEED proposed electrical consumption is on average 30% higher than 2012 actual and CTMY predicted electricity consumption. The total annual electricity consumption predicted in the LEED proposed model is 1,421,247 kWh compared to 2012 actual of 1,088,331 kWh. To understand the source of this discrepancy further analysis into electrical consumption by end use will be required, refer to Figure 22.

Figure 23 and 24 display the annual electrical consumption by endues for LEED proposed design and CTMY respectively. Examining the electrical consumption by end use, the largest discrepancies are occurring in the areas of miscellaneous equipment and vent fans. The average electrical consumption for miscellaneous equipment for the LEED design is 31000 kWh compared to the current design of 10800 kWh. For vent fans the average electrical consumption is 28000 kWh for the LEED proposed designed compared to the current design, which is 14200 kWh. Electrical consumption for lighting, space heating, and domestic hot water use also exhibited higher energy consumption compared to current simulation runs.

Figure 21 LEED proposed electrical consumption

Figure 22 LEED proposed natural gas consumption

Figure 23 LEED proposed design, electrical consumption by end use

Figure 24 CTMY Toronto average, electrical consumption by end use

The LEED proposed natural gas consumption is lower than the CTMY simulation and 2012 actual, Figure 25. The difference between LEED proposed and 2012 actual

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natural gas consumption equates itself to a difference of 27% over an annual period. A possible source for such a discrepancy could be allocated towards the occupancy load within the building and also setpoint supply air temperatures. The outdoor air makeup unit (AHU-1) in the LEED proposed design has a supply air temperature for cooling and heating at 21°C and 17°C respectively. In the current design of the building and in reference to operation specifications the supply air temperature is designed to be 16°C for heating and 12.8°C for cooling. This difference in supply air temperature setpoint and occupancy load being higher would account for this discrepancy experienced in the LEED proposed design. Also the setpoint temperature for the heat pumps is at 22.7 °C for cooling and 21°C for heating.

Figure 25 LEED proposed electrical consumption by end use

9.6 Modifications

In current simulation runs the building is not operating at full capacity, with an average occupancy load of about 50%. This proved to be challenging when making a comparison with the LEED proposed design, which had an occupancy load of 90%.

Therefore, to evaluate the potential of the building under current conditions only the occupancy load of the building was increased to 90% year round and on Saturday 30%. All other schedules remained the same. The CTMY Toronto 30 year average weather file is used.

Through this modification the annual electrical consumption differs by 9.7% in comparison to the initial LEED design. The largest difference occurs in June at 18%. Figure 26, details the electrical consumption by month between the modified simulation and the original LEED proposed design.

Figure 26 Modified simulation, electrical consumption

Reviewing the energy consumption by end use, miscellaneous equipment and space cooling has increased energy consumption compared to previous 2012 and CTMY results, Figure 27. However, space heating and natural gas consumption in Figure 28 has a reduction in consumption most likely due to the increased internal heat

gains due to the increased occupancy load. The overall annual difference for natural gas due to the changes amounts to 13% annually.

Through the process of increasing the occupancy load to 90% of 1200 persons, the output values correlate very closely with the initial LEED proposed energy consumption. This process makes for a more valid comparison and demonstrates initial estimates hold validity.

Figure 27 Modified simulation, electrical consumption by end use

Figure 28 Modified simulation, natural gas consumption

10 Conclusion

In all four-simulation runs the electrical consumption for each year is very closely matched with actual electrical consumption. The largest difference between actual versus predicted occurred in May of 2011 with a difference of 51.57%. With the CTMY Toronto temperature file results being the most accurate over an annual basis at 0.32% of 2012 actual electrical consumption.

The predicted natural gas consumption is harder to analyze with certainty due to the lack of accurate data. There are high levels of fluctuation in the results given each year has a varying number of HDD. This has resulted in differences ranging from 33% for 2011 annually to a best result of 4.51% annually in 2012. This inconsistency makes it hard to validate actual building energy consumption to LEED proposed energy consumption and expected savings. As noted by the study conducted by Zhu et al. eQuest's results for natural gas consumption where not lower than actual. The results fluctuated between simulation runs as noted in Table 6, 2012 predicted value was lower than actual while CTMY Toronto average was higher than actual. No conclusive result can be drawn with limited data in reference to research performed by Zhu et al.

On a monthly basis, the natural gas consumption differences are larger, with 2012 having differences of 75.15% in May and 41% for February in 2013. CTMY Toronto weather file presented a similar difference in April and October with 84.14% and 86% difference respectively. It is in the transition months specifically May/April and October where the largest differences occur most likely due changing weather conditions.

In comparison to the LEED proposed design overall the building performing 23% better for electrical consumption but has a 37% increase in natural gas consumption at current occupancy loads. However, by increasing the occupancy load within the building the LEED proposed design holds more validity with electrical consumption increasing and natural gas consumption decreasing.

10.1 Recommendations

When evaluating a building's actual energy consumption versus predicted it is hard to find the root cause of the difference because all possible errors within the program are occurring simultaneously. This includes occupancy load, scheduling, lighting schedule, temperature set points and HVAC design.

For the study involving the RJC building the overall electrical consumption was highly accurate based on inputs into the program. However, natural gas consumption is highly erratic and consistency has not been demonstrated with the output data. This once again could be attributed to errors generated with inputs and settings placed by the modeler or an inherent discrepancy within the program.

In future studies involving the RJC it would be of primary importance to recalibrate the sub-metering system. In the process accurate end use electrical consumption within the building can be properly verified and cross-referenced with simulation runs and utility bills. This will help to accurately input values for plug loads, office equipment and miscellaneous equipment, which have a direct effect on internal heat gains. It must be noted that there will be an increase in electrical consumption as the occupancy load increases.

As the modified simulation proposes, with the increased occupancy load the natural gas consumption could reduce. This is due to increased internal heat gains; however, with the fluctuations in natural gas consumption this is not certain. Alternately, by installing a weather station at the building, daily weather data can be collected to create a customized weather file. This will be the most accurate way of simulating the environment and element the RJC is exposed to.

Table 6 Summary of results

Electricity kWh	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2011 predicted	88792	80035	88196	88839	94938	94423	107970	105076	95175	90237	79638	83798	1097115
Actual 2011	96973	78202	85329	71455	62636	96909	105621	96216	86743	83164	81257	86982	1031486
2012 predicted	87069	78436	89364	88564	97842	96079	107156	104727	93601	89672	79965	83656	1096133
Actual 2012	91818	81000	84247	75187	89791	97875	108460	99313	92399	92549	88009	87686	1088332
CTMY predicted	89520	80555	88440	89003	92941	92579	104410	104444	93367	90463	80698	85438	1091858
2013 predicted	87541	79211	87399	5890	0	0	0	0	0	0	0	0	346392
Actual 2013	99686	86100	97769	6331	0	0	0	0	0	0	0	0	289886
Natural gas m^3													
2011 Perdicted	8017	6464	5572	3495	1121	71	6	37	300	2349	3840	6101	37370
2011 Actual	12685	10422	9427	5619	2553	456	64	101	1142	4081	2531	6709	55789(est)
2012 Predicted	6880	5442	3280	3048	546	144	11	59	481	2312	5057	5963	33227
2012 Actual	8247	6984	3443	1967	2198	121	11	61	431	1407	3761	6166	34798
CTMY Predicted	8066	6684	5615	3628	1115	241	28	54	461	2626	4958	6849	40325
2013 Predicted	7324	6534	6065	0	0	0	0	0	0	0	0	0	23311
2013 Actual	10750	11142	7870	0	0	0	0	0	0	0	0	0	29761

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Appendix A: LEED Projects

Figure 29 Number of LEED buildings in Canada (Canada Green Building Council, 2013)

Appendix B: Sub-metered loads

Table 30 Sub-metered electrical consumption

Meter	Description	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
ATS-6XP	Emergency power	9,132	7,906	8,786	5,248	10,922	3,479	10,982	6,609	4,016
ATS-6EM	Feeds DP-6XP	20,880	19,980	22,411	14,703	27,728	7,452	26,962	19,310	10,108
DP-6AP	Mechanical	27,972	21,038	23,967	21,211	61,664	15,561	44,898	20,688	10,945
DP-6A3	3rd floor Lighting	12,385	11,514	13,377	11,114	23,706	5,818	19,918	13,157	6,149
LP-6A2	2nd floor Lighting	5,698	4,906	5,423	3,624	6,712	1,553	6,779	6,600	3,539
LP-6A1	1st floor Lighting	10,401	9,889	10,260	6,511	12,666	3,643	13,639	10,139	5,345
DP-6B1	Normal power	28,847	24,096	25,924	18,807	40,682	11,157	37,236	21,814	12,239
CAFÉ	Café	5,068	4,914	5,378	3,949	7,411	1,857	7,077	5,495	2,699
SP-6EE	Elevators	1,256	1,257	1,400	911	1,779	496	1,452	1,183	605
LP-6A3	3rd floor Lighting	5,614	5,081	5,594	3,948	7,278	1,872	6,961	5,660	3,108
LP-6A4	IT Lighting	1,453	1,290	1,493	1,052	1,889	403	1,726	1,472	779
	Total	128,706	111,871	124,013	91,078	202,437	53,291	177,630	112,127	59,532
	Actual	96972	78202	85328	71454	62636	96909	105620	96215	86742

The 11 sub metered loads is the total electrical consumption for the building and is compared to the actual utility bill by Burlington Hydro Inc.

Taking the sub metered loads from Table B-1 a pie chart is constructed outlining the percent energy consumption by end use. Comparing this to the simulated results in Figure B-2 a direct comparison can be made.

Lighting is consumption is very similar with metered at 29% and simulated at 25%. The total consumption for HVAC is considerably more in the simulated results totaling around 45% compared to 23% from building sub-metered loads. Further comparison is limited because specific meters will need to be allocated within eQuest for elevators and café; and within the building it would help if a meter were allocated to domestic hot water consumption, equipment and exterior lighting.

Figure 31 Sub-metered loads within RJC

Figure 32 Electrical endues simulated results from 2012 weather file

Appendix C: Zoning allocation

Aduitorium

Big Hall

Norht Service area

Washroom

Elevator

Atrium

Stairs

SouthService area

Computer lab

Cafe

Lobby

Vestabule

Classroom

Meeting and study rooms

Classroom

Common lounge

Quite study

I.T

Stairs

Washroom

Elevator

Atrium

Stairs

Washroom

Electrical room

Quite study

Office

Corrido

Office

Classroom

Meeting and study rooms

Classroom

MBA lounge

Classroom

Meeting and
study rooms

Classroom

Executive
lounge

Quite
study

I.T

Stairs

Washroom

Elevator

Atrium

Stairs

Washroom

Kitchen

Electrical
room

Quite
study

Meeting
room

Corrido

Offices

Classroom

Meeting and
study rooms

Classroom

Common
lounge

Storage

Stairs

Elevator

Atrium

Stairs

Storage

Stairs

Mechanical room

Elevator

Atrium

Stairs

Storage

Corrido

Appendix D: Occupancy schedule

Table 33 Annual schedule for RJC floors 1 to 3

Schedule	January			February			March			April	
	Weekday	Weekend		Weekday	Weekend		Weekday	Weekend		Weekday	Weekend
8:30am to 11:30am	0.0837	0.0125		0.0759	0.0363		0.0825	0.0727		0.0942	0.0646
11:30am to 2:30pm	0.1978	0.0125		0.1712	0.0000		0.1839	0.0000		0.1865	0.0238
2:30pm to 5:30pm	0.2992	0.0125		0.2428	0.0000		0.2581	0.0000		0.2563	0.0000
5:30pm to 7:00pm	0.3473	0.0000		0.2806	0.0000		0.2998	0.0000		0.2977	0.0000
7:00pm to 10:00pm	0.4746	0.0000		0.3942	0.0000		0.4083	0.0000		0.4046	0.0000

Schedule	May			June			July			August	
	Weekday	Weekend		Weekday	Weekend		Weekday	Weekend		Weekday	Weekend
8:30am to 11:30am	0.1039	0.1792		0.0858	0.0127		0.0527	0.0127		0.0721	0.0038
11:30am to 2:30pm	0.1928	0.0654		0.1493	0.0000		0.1152	0.0000		0.1355	0.0000
2:30pm to 5:30pm	0.2690	0.0333		0.2248	0.0000		0.1849	0.0000		0.1865	0.0000
5:30pm to 7:00pm	0.3074	0.0333		0.2743	0.0000		0.2235	0.0000		0.2240	0.0000
7:00pm to 10:00pm	0.4221	0.0848		0.3615	0.0000		0.2952	0.0000		0.2723	0.0000

Schedule	September			October			November			December	
	Weekday	Weekend		Weekday	Weekend		Weekday	Weekend		Weekday	Weekend
8:30am to 11:30am	0.1350	0.0965		0.0823	0.0873		0.0677	0.0675		0.0888	0.0714
11:30am to 2:30pm	0.3048	0.0333		0.2313	0.0198		0.1964	0.0000		0.1993	0.0000
2:30pm to 5:30pm	0.4693	0.0333		0.3704	0.0198		0.2928	0.0000		0.2917	0.0239
5:30pm to 7:00pm	0.5606	0.0000		0.4180	0.0000		0.3261	0.0000		0.3589	0.0000
7:00pm to 10:00pm	0.6803	0.0000		0.5528	0.0000		0.4522	0.0000		0.4698	0.0000

Table 34 Lighting schedule

Lighting Schedule	Weekday	Sat	Sunday/holiday	FL 4/5
midnight-1 am	0.05	0.05	0.05	0.9
1-2 am	0.05	0.05	0.05	0.9
2-3 am	0.05	0.05	0.05	0.9
3-4 am	0.05	0.05	0.05	0.9
4-5 am	0.05	0.05	0.05	0.9
5-6 am	0.05	0.05	0.05	0.9
6-7 am	0.0658	0.2385	0.05	0.9
7-8 am	0.4	0.622	0.05	0.9
8-9 am	0.7	0.7	0.05	0.9
9-10 am	0.85	0.7	0.05	0.9
10-11 am	0.9	0.7	0.05	0.9
11-noon	0.9	0.7	0.05	0.9
noon-1 pm	0.9	0.7	0.05	0.9
1-2 pm	0.9	0.7	0.05	0.9
2-3 pm	0.9	0.7	0.05	0.9
3-4 pm	0.9	0.7	0.05	0.9
4-5 pm	0.9	0.622	0.05	0.9
5-6 pm	0.9	0.3945	0.05	0.9
6-7 pm	0.9	0.2385	0.05	0.9
7-8 pm	0.9	0.2385	0.05	0.9
8-9 pm	0.9	0.089	0.05	0.9
9-10 pm	0.9	0.089	0.05	0.9
10-11 pm	0.9	0.05	0.05	0.9
11 midnight	0.05	0.05	0.05	0.9

Table 35 Lighting density for each floor by zoning area

FL 1	W/m^2	FL2	W/m^2	FL2	W/m^2
Auditorium	0.84	Office	1.04	I.T	0.69
North service area	0.6	Classroom NE	0.9	Stairs N	0.69
Computer lab	0.51	Meeting and study rooms E	0.8	Washroom N	0.48
Lobby	0.62	Classroom SE	0.68	Elevator	N/A
Vestibule	0.78	MBA lounge	0.83	Corridor	0.86
Café	1.7	Office	0.6	Atrium	N/S
South service area	0.86	Quite study S	0.57	Stairs S	N/A
Big hall	1.74	Common Lounge	0.81	Washroom S	0.48
Washroom	0.8	Classroom SW	0.68	Electric room	0.78
Elevator	N/A	Meeting and study rooms W	0.8	FL3	W/m^2
Atrium	N/A	Classroom NW	0.9	Office	0.98
Stairs	0.97	Quite study N	0.6	Classroom NE	1

FL3	W/m^2	FL3	W/m^2	FL4	W/m^2
Meeting and study rooms E	0.8	Stairs N	N/A	Elevator	N/A
Classroom SE	0.89	Washroom N	0.48	Atrium	N/A
Common Lounge	0.78	Elevator	N/A	Stairs S	N/A
Meeting room	0.76	Corridor	0.86	**FL5**	**W/m^2**
Quite study S	0.6	Atrium	N/A	Stairs N	0.18
Kitchen	0.6	Stairs S	N/A	Mechanical room	0.75
Executive lounge	0.78	Washroom S	0.48	Elevator	0.26
Classroom SW	0.71	Electric room	0.78	Corridor	0.72
Meeting and study rooms W	0.8	**FL4**	**W/m^2**	Atrium	N/A
Classroom NW	1	Storage W	0.1	Stairs S	0.23
Quite study N	0.6	Storage E	0.1	Storage	0.4
I.T	0.69	Stairs N	N/A		

Table 36 Miscellaneous equipment schedule

Misc Equip	Weekday	Sat	Sunday/holiday
midnight-1 am	0.1	0.051	0
1-2 am	0.1	0.051	0
2-3 am	0.1	0.051	0
3-4 am	0.1	0.051	0
4-5 am	0.1	0.051	0
5-6 am	0.1	0.051	0
6-7 am	0.1	0.0514	0
7-8 am	0.5	0.0536	0
8-9 am	0.7	0.054	0
9-10 am	0.9	0.054	0
10-11 am	0.9	0.054	0
11-noon	0.9	0.054	0
noon-1 pm	0.9	0.054	0
1-2 pm	0.9	0.054	0
2-3 pm	0.9	0.054	0
3-4 pm	0.9	0.054	0
4-5 pm	0.9	0.054	0
5-6 pm	0.9	0.0523	0
6-7 pm	0.9	0.0514	0
7-8 pm	0.9	0.0514	0
8-9 pm	0.9	0.051	0
9-10 pm	0.7	0.054	0
10-11 pm	0.5	0.054	0
11 midnight	0.3	0.054	0

Table 7 Office schedule

Office	Weekday	Sat	Sunday/holiday
midnight-1 am	0.1	0.1	0
1-2 am	0.1	0.1	0
2-3 am	0.1	0.1	0
3-4 am	0.1	0.1	0
4-5 am	0.1	0.1	0
5-6 am	0.1	0.1	0
6-7 am	0.1	0.1	0
7-8 am	0.7	0.5	0
8-9 am	0.7	0.5	0
9-10 am	0.9	0.5	0
10-11 am	0.9	0.5	0
11-noon	0.9	0.5	0
noon-1 pm	0.9	0.5	0
1-2 pm	0.7	0.5	0
2-3 pm	0.8	0.5	0
3-4 pm	0.9	0.5	0
4-5 pm	0.9	0	0
5-6 pm	0.5	0	0
6-7 pm	0.5	0	0
7-8 pm	0.5	0	0
8-9 pm	0.5	0	0
9-10 pm	0.5	0	0
10-11 pm	0.1	0	0
11 midnight	0.1	0	0

Table 8 Cafe and kitchen schedule

Cooking	Weekday	Sat	Sunday/holiday
midnight-1 am	0	0	0
1-2 am	0	0	0
2-3 am	0	0	0
3-4 am	0	0	0
4-5 am	0	0	0
5-6 am	0	0	0
6-7 am	0	0	0
7-8 am	0.5	0	0
8-9 am	0.5	0.5	0
9-10 am	0.3	0.5	0
10-11 am	0.6	0.7	0

11-noon	0.8	0.7	0
noon-1 pm	0.8	0.7	0
1-2 pm	0.8	0.6	0
2-3 pm	0.5	0.5	0
3-4 pm	0.3	0.4	0
4-5 pm	0.5	0.4	0
5-6 pm	0.5	0	0
6-7 pm	0.3	0	0
7-8 pm	0.3	0	0
8-9 pm	0.2	0	0
9-10 pm	0	0	0
10-11 pm	0	0	0
11 midnight	0	0	0

Appendix E: Weather file

Figure 37 2011 Dry bulb temperatures from station Hamilton A

Figure 38 2011 Solar radiation from CTMY Toronto average

Figure 39 2011 Wind speed and cloud cover from station Hamilton A

2012 Weather

Figure 40 2012 Dry-bulb temperatures from station Hamilton A

Figure 41 2012 Solar radiation form CTMY Toronto average

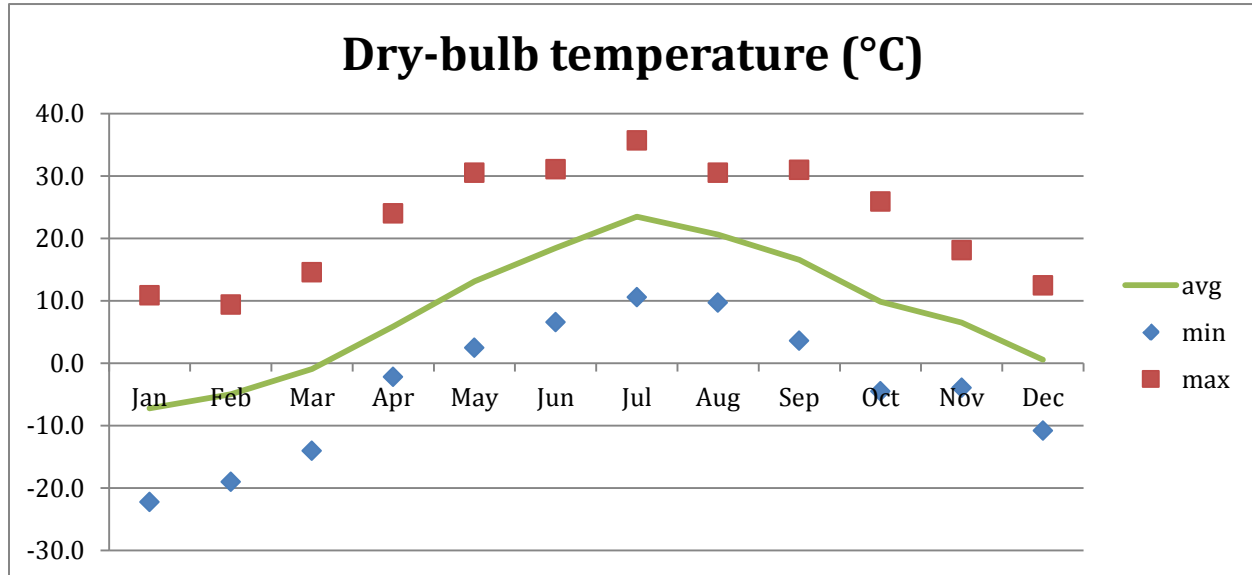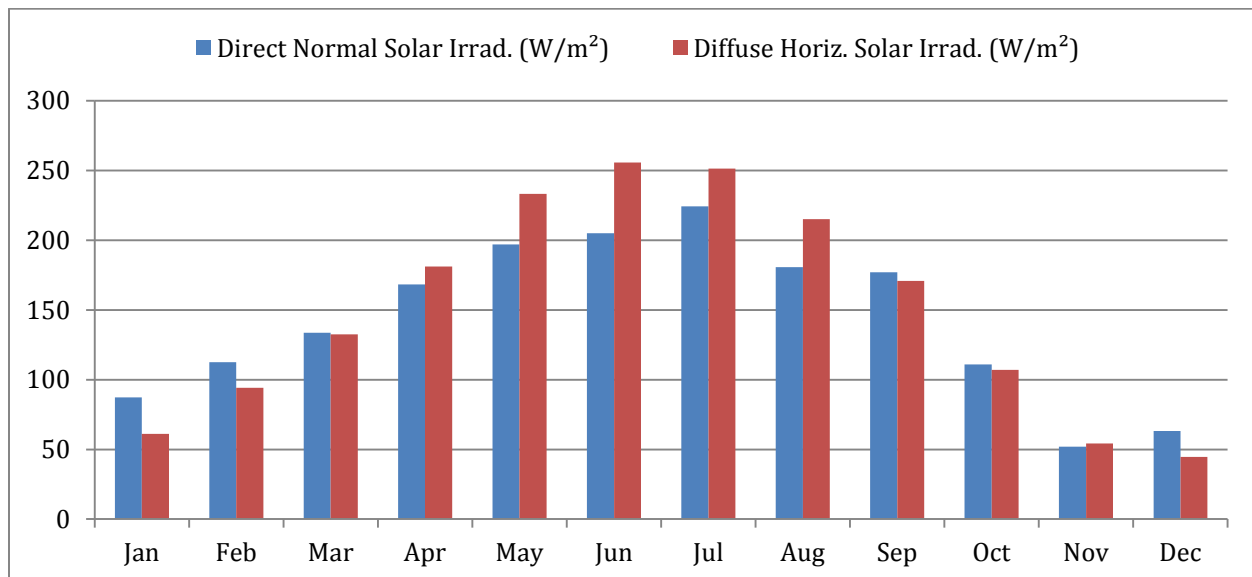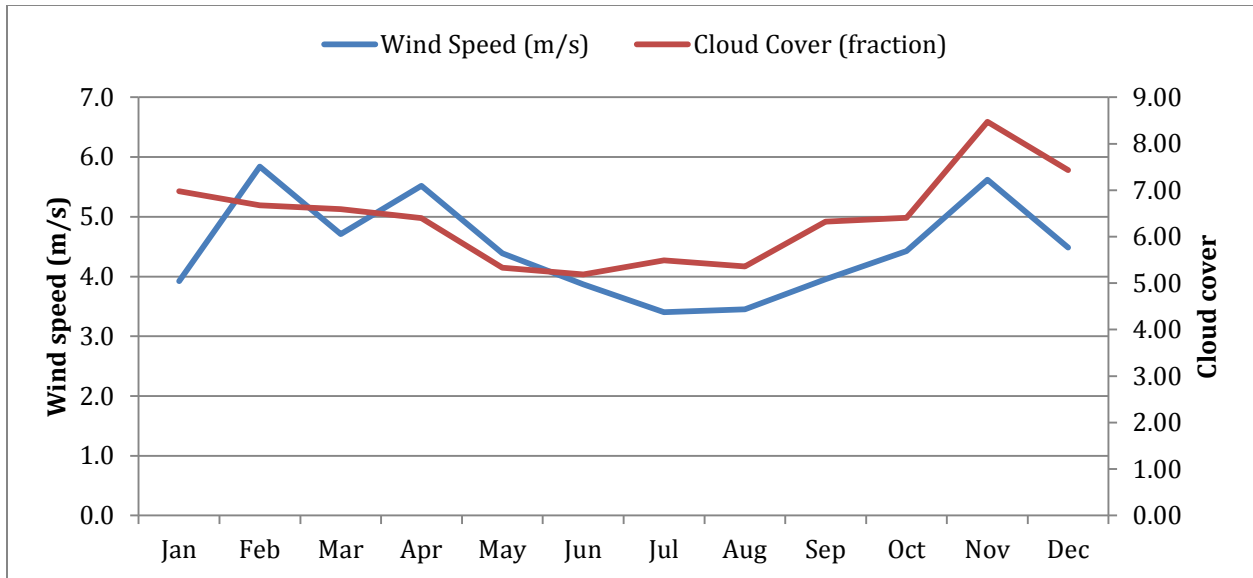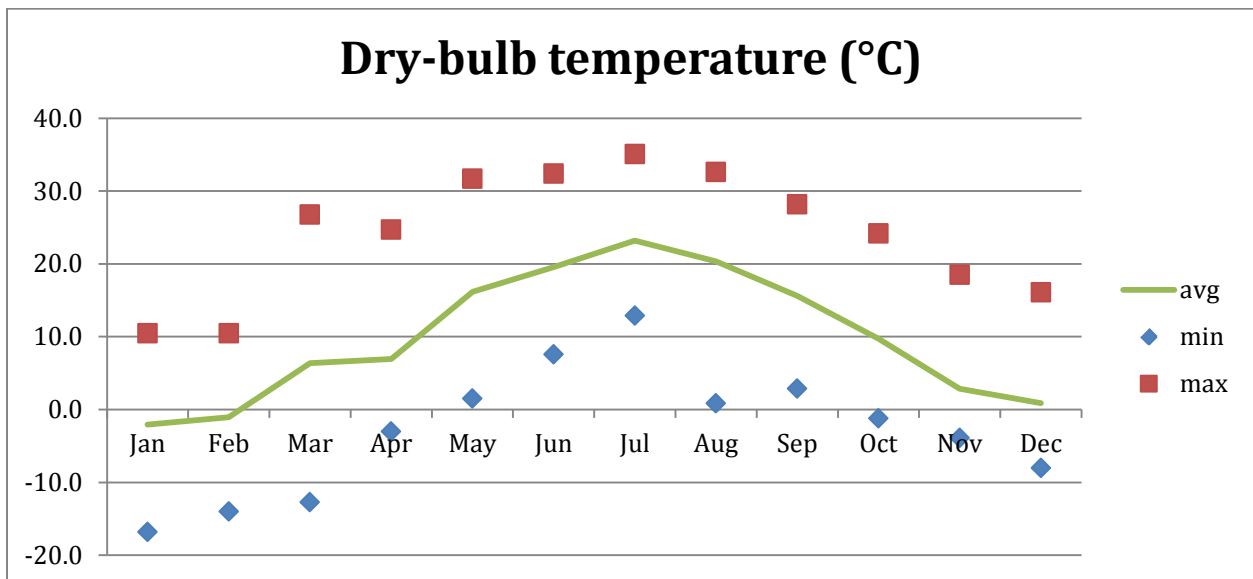Figure 42 2012 Wind speed and cloud cover from station Hamilton A

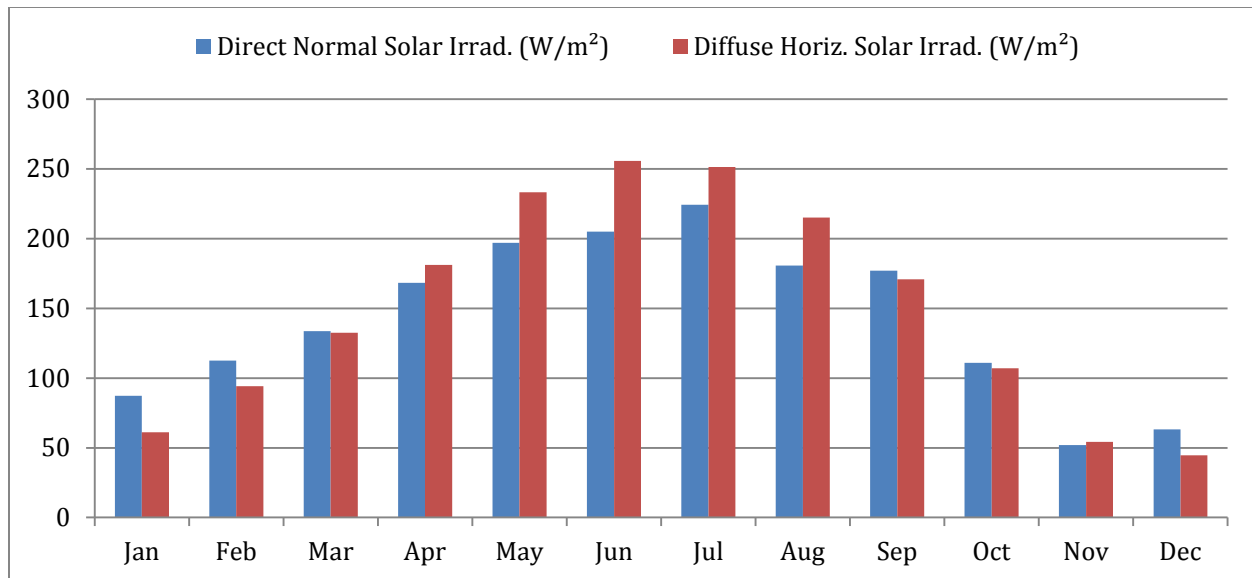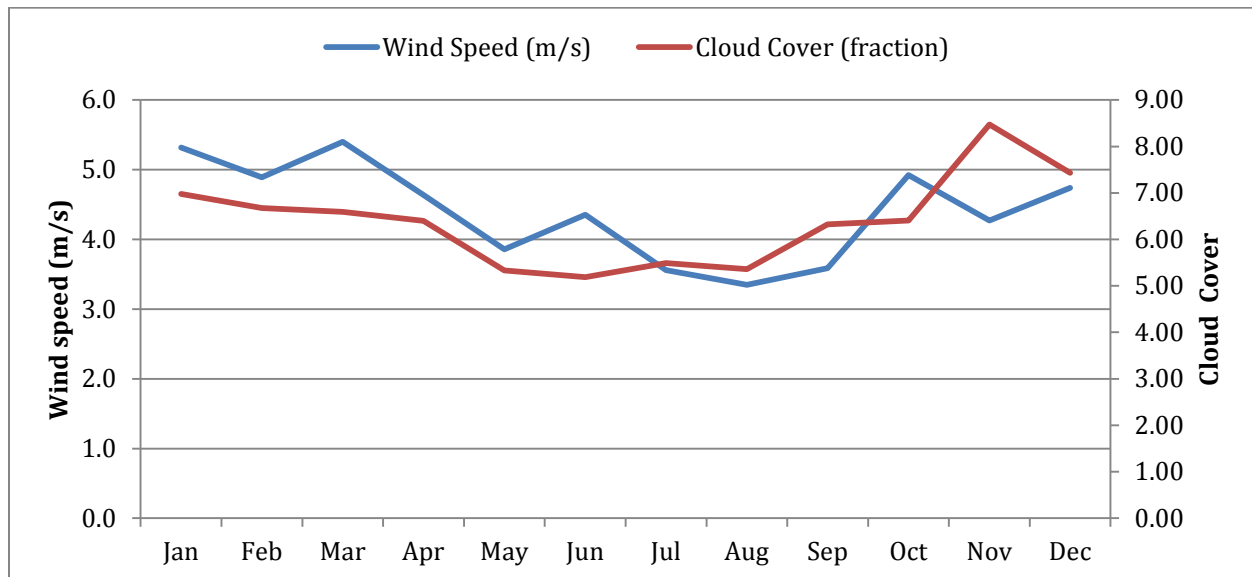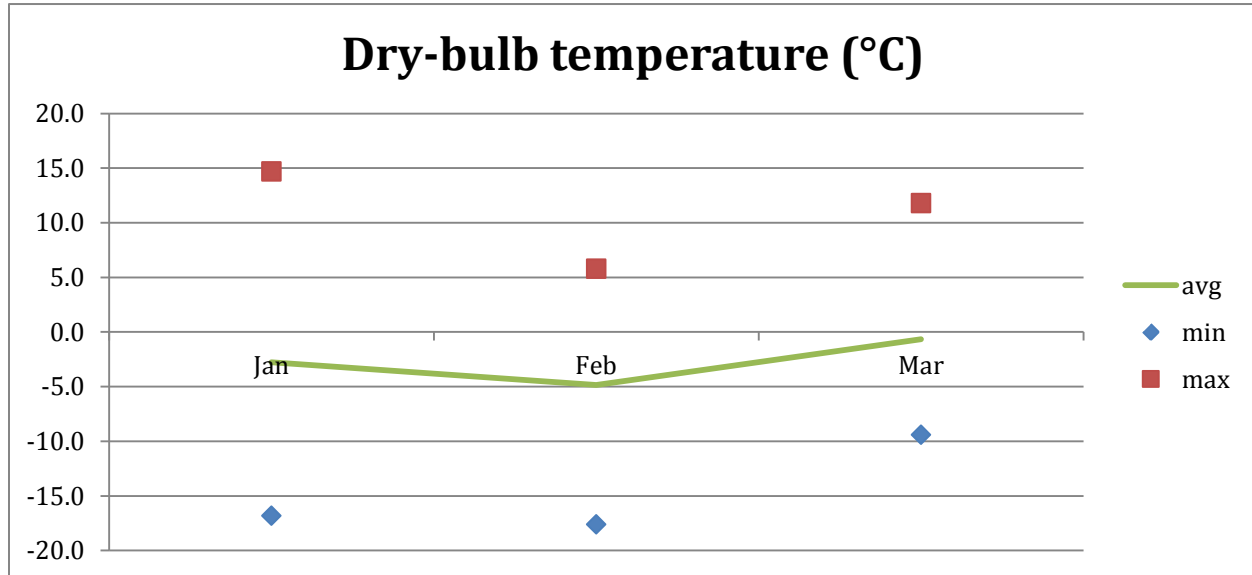Figure 43 2013 Dry bulb temperatures from station Hamilton A
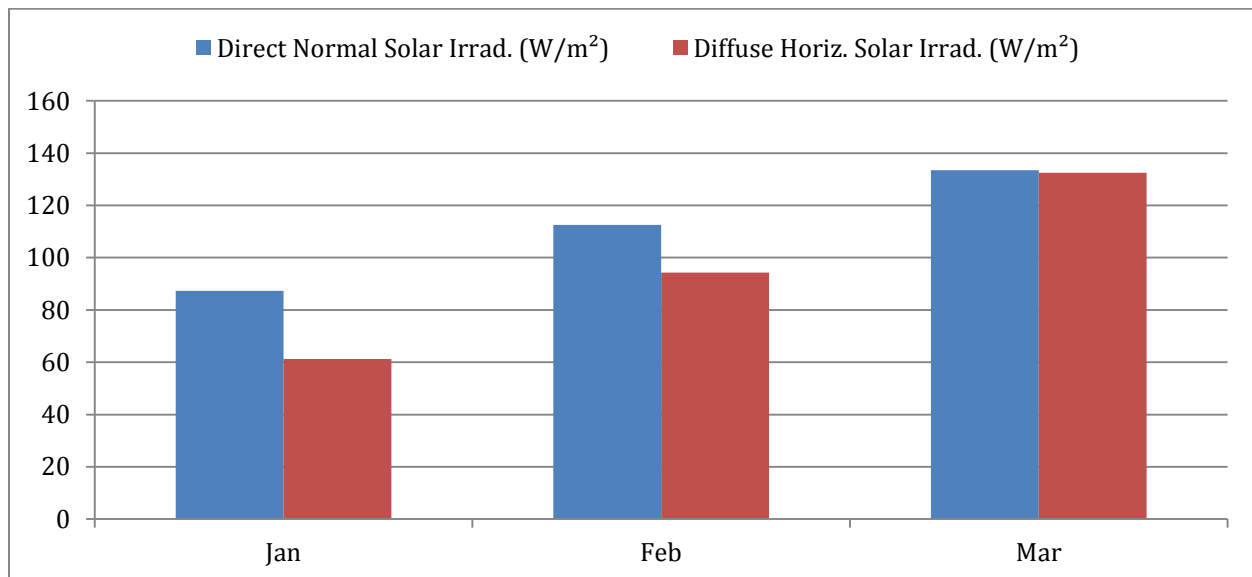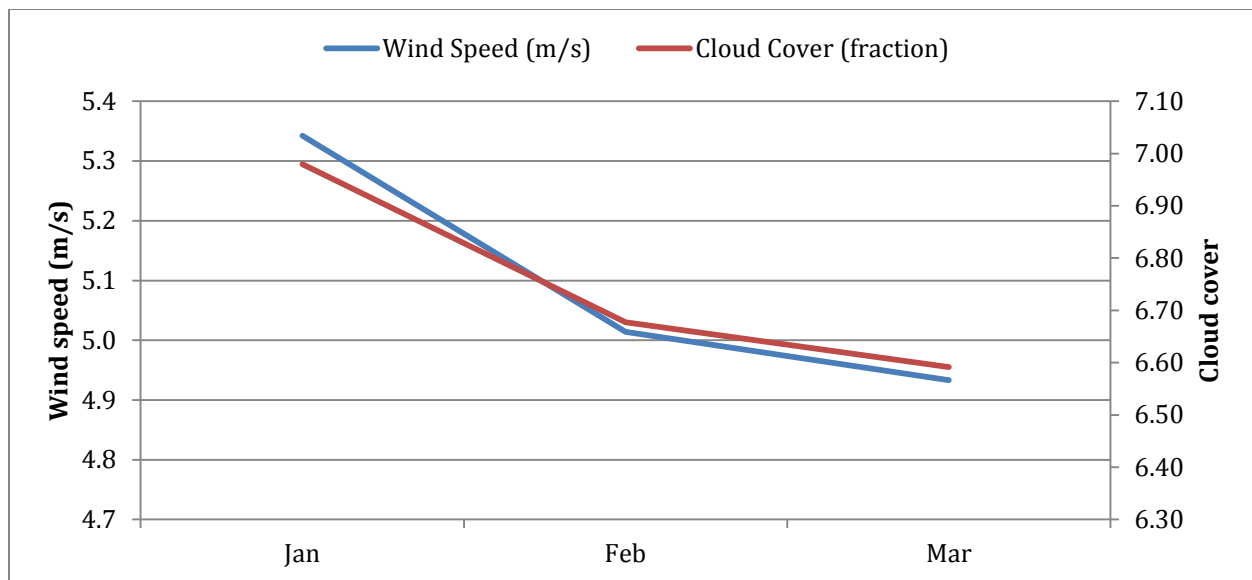

Figure 44 2013 Solar radiation from CTMY Toronto average

Figure 45 2013 Wind speed and cloud cover from station Hamilton A

Appendix F: Mechanical drawings

ROOF

2150 CFM
TO B.A.S.
16,500 CFM
AH/1
VFD
HEAT RECOVERY WHEEL
19,050 CFM
E/A
SILENCER SL-2
E/A
600x800
500 CFM DMD
12000 CFM
VAV BOX
SILENCER SL-3
TO B.A.S.
S/A
CONSTANT VOLUME BOX
900x350 3,500 CFM
750x700 6400 CFM
O/A
VFD

FREE COOLING OUTSIDE AIR 6,400 CFM
E/A 6600 CFM
MD MD
TO MECHANICAL ROOM 600 CFM INTERLOCKED W/ EF-05
E/A
S/A
HP/1
R/A
RF/2
R/A
TO B.A.S.
TO B.A.S.

EF-2   EF-3   EF-4   EF-6
300x300 600 CFM
TO B.A.S. DMD
300x300   300x250

EF/5 DMD
600
MECHANICAL ROOM

PENTHOUSE

800x450 4,200 CFM
BLANK OFF FOR FUTURE CONNECTION
1050x1050 16,900 CFM
VFD
1050x850 12,700 CFM
450 CFM BLANK OFF FOR FUTURE CONNECTION
380 CFM BLANK OFF FOR FUTURE CONNECTION
850x300
750x400 3200 CFM
750x400

200x150 150 CFM
BLANK OFF FOR FUTURE CONNECTION
300x250 525 CFM

600x450 2,000 CFM

TF/4,2
ELECTRICAL ROOM 400 cfm
TF/4,1
ELECTRICAL ROOM 400 cfm

FOURTH FLOOR

800x450 4,200 CFM
S/A
850x750 8,500 CFM
450 CFM E/A
380 CFM E/A
750x400 2700 CFM E/A
E/A 500 CFM SERVERY

200x150 150 CFM
200x250 375 CFM

E/A 500 CFM
KITCHEN GENERAL EXHAUST

TF/4,2
ELECTRICAL ROOM 400 cfm
TF/3,1
ELECTRICAL ROOM 400 cfm

THIRD FLOOR

800x450 4,600 CFM
S/A
850x400 3,900 CFM
455 CFM E/A
380 CFM E/A
650x300
400x300
950x500
500x950 6,400 CFM
950x500 6,400 CFM

200x250 150 CFM E/A

TF/2,2
ELECTRICAL ROOM 400 cfm
TF/2,1
ELECTRICAL ROOM 400 cfm

SECOND FLOOR

800x450 4,600 CFM
S/A 1540 CFM
S/A 2360 CFM
850x300
S/A

E/A 1100 CFM
GARBAGE & RECYLING EXHAUST

FUEL PUMP RM. 200 cfm E/A
COFEE SHOP 500 cfm E/A
TF/M1 400 cfm
ELECTRICAL ROOM

EF/1,1

MEZZANINE FLOOR

450 CFM E/A
525 CFM E/A
AMPHITHEATER
200x200 225 CFM E/A
E/A

EF/1,2

TF/1,2
ELECTRICAL ROOM 400 cfm
TRANSFER FANS

GROUND FLOOR

SANITARY EXHAUST
SANITARY EXHAUST
KITCHEN GENERAL EXHAUST
TRANSFER FANS

1 AIR SCHEMATIC
M-700 1:100

SET PRESSURE
AT 12 PSI G

BY PASS FEEDER

FROM SYSTEM   BACKFLOW PREVENTER ASSEMBLY
25   25
20
TO GLYCOL MAKE-UP

20
FILTER
P.G.   FLO-TREX VALVE
P 4

65   HWS
40
BUILDING FORCE FLOW HEATERS & INFLOOR HEATING
PRESSURE BY-PASS ASSEMBLY SIZED AT 30% OF TOTAL FLOW

SUCTION GUIDE AND STRAINER
20
P.G.
P.G.   FLO-TREX VALVE
P 5

65
65   HWR   75
AIR SEPARATOR c/w AUTOMATIC AIR VENT
P.G.
300
THERMOWELL c/w TEMPERATURE SENSOR BY DIV. 15900
VARIABLE SPEED DRIVE

Penthouse

32

4TH FLOOR

65

3RD FLOOR

40

2ND FLOOR

50

FIRST/MEZZANINE FLOOR

EXPANSION TANK
ET 1

TO DRAIN

65ø
B 1
B 2
65
P 6   F.F.D
P 7   F.F.D

150
150
SOLENOID VALVE (INDOOR)
GLOBE VALVE TO CONTROL FLOW RATE
32ø DRAIN
F.F.D.

EC 1

65   65

INDOOR DRAIN VALVE c/w HOSE END CONNECTION (TYPICAL)
INDOOR FLUID COOLER ISOLATING VALVE

FROM MAIN BOILERS MAKE UP WATER SYSTEM

75

P.G.
150
P.G.
150

FLO-TREX VALVE
P 1
SUCTION GUIDE AND STRAINER
VARIABLE SPEED DRIVE
CAPPED FOR FUTURE STAND-BY PUMP P-11
BY PASS POT FEEDER
FILTER

AIR SEPARATOR
150

AIR SEPARATOR c/w AUTOMATIC AIR VENT
P 8
FLO-TREX VALVE
SUCTION GUIDE AND STRAINER
CAPPED FOR FUTURE STAND-BY PUMP P-9
BY PASS POT FEEDER
FILTER

REFRIGERANT PIPE (QTY. AS REQUIRED)
CD 1

NOTE:
CONTRACTOR SHALL ALLOW HOT GAS REFRIGERANT PIPING ACCORDING TO THE MANUFACTURER'S INSTRUCTIONS.

HE 1
HE 2
N.C.
150   150

PG
PG
PRV
ET 2
EXPANSION TANK
50
50
PG
PG
PRV
ET 3
EXPANSION TANK
50

65
65   65
B 3
65
AH 1

LOW LEVEL SWITCH
CONTROL PANEL
P 16
20 GLYCOL MAKE-UP
20 GLYCOL MAKE-UP
CONTROL PANEL
P 26
TEST VALVE
65
F.F.D.

N.C.   N.C.
P 2
150   150
150

HEAT PUMPS SYSTEM

SUCTION GUIDE AND STRAINER
FLO-TREX VALVE
P 3
FLO-TREX VALVE
SUCTION GUIDE AND STRAINER
VARIABLE SPEED DRIVE
BY PASS POT FEEDER
FILTER
150   150

GLYCOL TANK
CONTAINMENT BASIN
LOW LEVEL SWITCH

PG
PIPE WATER SYSTEM PRV TO NEAREST DRAIN (TYP.)
B.F.P.A.
20 COLD WATER FROM SYSTEM
EXPANSION TANK
ET 4
DRAIN

CAP FOR FUTURE CONNECTION
PENTHOUSE
100

4TH FLOOR
100

150
3RD FLOOR
100

2ND FLOOR
100
100

FIRST/MEZZANINE FLOOR

1   BUILDING HYDRAULIC SCHEMATIC WITH INDIVIDUAL INFLOOR PUMPS
M-720 NTS: 100