Comparing Simulated and Actual Energy Performance of a High Performance Canadian Office Building

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Abstract

A Grander View, the new headquarters for Enermodal Engineering Ltd., is a 2,015 m^2, three storey office building located in Kitchener, Ontario, Canada. By implementing many energy efficiency measures into the building design including a highly insulated envelope, efficient lighting design and a simple and highly efficient mechanical system, the building achieved an annual energy intensity of 76 kWh/m^2 (all utilities as measured by the building meter) for 2010, 81% lower than the Canadian national average of 400 $ekWh/m^2$ for office buildings (NRCan, 2007) making it Canada's most efficient office building, achieving a triple platinum LEED rating (New Construction, Commercial Interiors and Existing Building: Operations and Maintenance). This paper describes the work undertaken of utilizing the design energy model to verify and improve the operating of the building post construction.

1 Introduction

Energy efficiency in buildings became a topic of great interest in North America during the first energy crisis in the 1970s. In response to the crisis in August, 1975 the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) published what has been called, "the first document that restricted HVAC, lighting, and building envelope designs in the interest of energy conservation", Standard 90-75, *Energy Conservation in New Building Design* (Hunn 2010). In 1992, the U.S. Energy Policy Act was passed requiring that all states adopt energy codes for commercial and high-rise multi-family residential buildings at least as stringent as Standard 90.1. (Jarnagin 2010). Since then several updates to the document have been made, Figure 1 below illustrates the impact that Standard 90.1 has had on commercial building energy use from 1975 to 2010 (Hunn 2010).

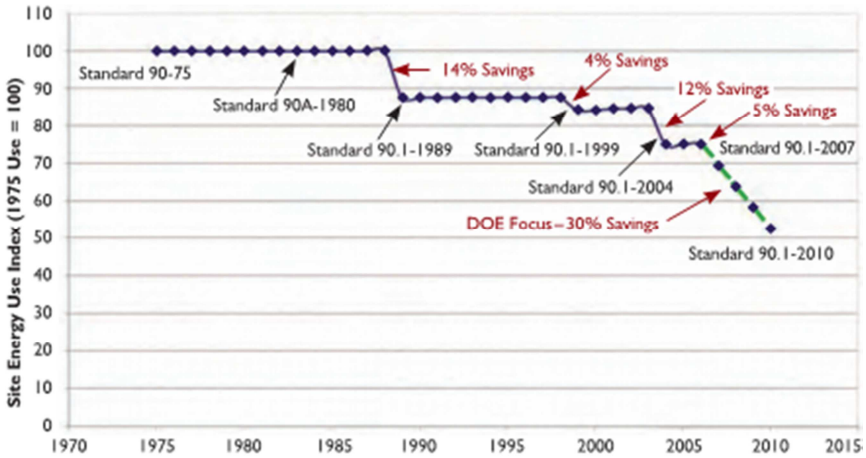

Figure 1: Improvements in Stringency from Standard 90-75 to 90.1-2010

The push for energy efficient buildings in Canada followed a similar trajectory and in 1992, the *Energy Efficiency Act* passed in Canada which provided for the making and enforcement of regulations related to minimum energy performance levels for energy-using products (OEE 2009). The *Energy Efficiency Act* marked the beginning of the government's involvement in energy efficiency in commercial buildings and in September, 1997, the National Research Council published the *Model National Energy Code for Buildings 1997* (MNECB) and in April of 1998 began offering an incentive program called the *Commercial Building Incentive Program* (CBIP). The intent of the CBIP program was to encourage energy-efficient design practices in commercial and institutional buildings and to bring about lasting change in the Canadian construction industry (NRC 2010). The program offered a financial incentive of up to $60,000 to building owners whose designs met the CBIP requirements, including reducing energy use by at least 25% when compared to the MNECB 1997 (CaGBC 2004) and ran until March 2007.

The push towards energy efficiency in buildings continued and in March 2000, the U.S. Green Building Council (USGBC) developed a third party certification program called LEED® which stands for Leadership in Energy and Environmental Design. In December 2004, the Canadian Green Building Council began implementing the LEED® Green Building Rating System in Canada. The work presented in this paper details how building energy simulation is a powerful tool that can aid in efficient building operation using *A Grander View*, Canada's most energy efficient office building as a case study. Using the building energy model created for LEED® compliance, calibrating the model to as-built and as-operated conditions, the building energy simulation is used to set realistic, achievable performance targets allowing building owners and operators to ensure their building is operating efficiently and if not, use the results of building energy modeling along with measured data to diagnose and fix operational problems.

2 The Building

In order to achieve a building energy intensity of 76 kWh/m^2 and create Canada's most energy efficient office building a two pronged approach was utilized. Many measures were implemented in order to first reduce the energy demand of the building and second, increase the efficiency of the energy systems within the building. Note that all energy used in the building is electricity.

Envelope

Energy demand reductions were achieved through the use of a narrow building footprint with the long axis oriented east-west and the implementation of a high performance building envelope. See Figure 2 below.

Figure 2: Building Footprint

The orientation and narrow footprint minimized the problematic east/west exposures as well as maximized the daylight penetration into the building through the long north and south exposures. Insulated concrete form (ICF) structural walls provide high insulation values of an average effective RSI-4.3 (R-24) including the effects of thermal bridging. ICFs also provide a reliable air barrier and construction site inspection of transition details (e.g. windows) further improved air tightness. A building blower door pressurization test resulted in an air-tightness value of 1.0 air change per hour (ACH) @ 50 Pascals. The windows are fibreglass framed and triple glazed with two low-e coatings and argon filled cavities achieving a rated CSA U-value of approximately 0.85 W/m²-C°. The overall glazing to wall ratio is approximately 35%, thus the window and wall combination results in a weighted average RSI of 2.2 (R-12.5). The exposed membrane roof uses poly-isocyanurate rigid insulation and achieves an average RSI-4.8 (R-27). Finally the east, south and west facades utilize external active solar shades to limit solar gains during periods of direct sunlight.

Lighting System

Lighting systems are typically one of the largest energy uses in office buildings (USDOE 2008). While potentially not a major energy consumer in colder climates, lighting is one end-use that can be designed and closely controlled to ensure efficient operation. The main source of lighting at *A Grander View* is daylighting. Daylight levels throughout the building are exceptionally high due to the narrow building floorplate. Daylighting sensors are used to decrease the need for electric lighting when the daylight is sufficient and infra-red occupancy sensors are used to turn off lights when a space is unoccupied. However all lighting requires manual operation to turn them on. The lighting fixtures are indirect-direct type suspended from the ceiling and use either T8 lamps or compact fluorescents in narrower areas. Dimming electronic ballasts are used in all areas that receive daylight.

Mechanical System

In terms of mechanical systems, typical office buildings of this size in the local market are heated by boilers and cooled and ventilated by rooftop air conditioners – two systems that work independently of one another, often at the same time. The mechanical system at *A Grander View* utilizes a dedicated outdoor air system through six independent energy recovery ventilators (ERV). Each ERV serves half of a floor and are controlled by a combination of occupancy sensors and CO_2 sensors. If the occupancy sensors detect no one in the area served by the ERV then the unit turns off. If the return air CO_2 sensor detects high CO_2 levels, the ERV operates in high speed. Three additional ERVs serve the meeting rooms and are controlled in a similar manner. Additionally, before ventilation air enters the building, it passes through earth tubes – concrete tubes buried underground – that temper the air using the ambient temperature of the earth.

Heating and cooling of the building are accomplished through three variable speed air-source heat pumps. Three condenser units located on the roof provide heat exchange between the outdoor air and the indoor refrigerant system. The heat pumps are connected to 33 small direct expansion (DX) fan coil units located throughout the building that distribute heating or cooling from the heat pumps at the zone level. Heat transfer between the outdoor units and the fan coils is by refrigerant. There is no hydronic heating or cooling – all heat transfer is by the refrigerant system. The condenser units each contain a variable speed compressor that generates either heating or cooling for the building as needed. The pressure difference created by the compressor also provides the driving force to move the refrigerant between the condenser unit and the fan coils – there is no separate pumping system. Each fan coil is controlled by a programmable thermostat that sends a signal to the automation system integrated into the fan coils. In addition the infra-red occupancy sensors determine if the zone is occupied and in-

struct the thermostats to change the set point to reduce the call for heating or cooling when the space is unoccupied. Figure 3 shows a schematic representation of the ventilation system and the heating and cooling system.

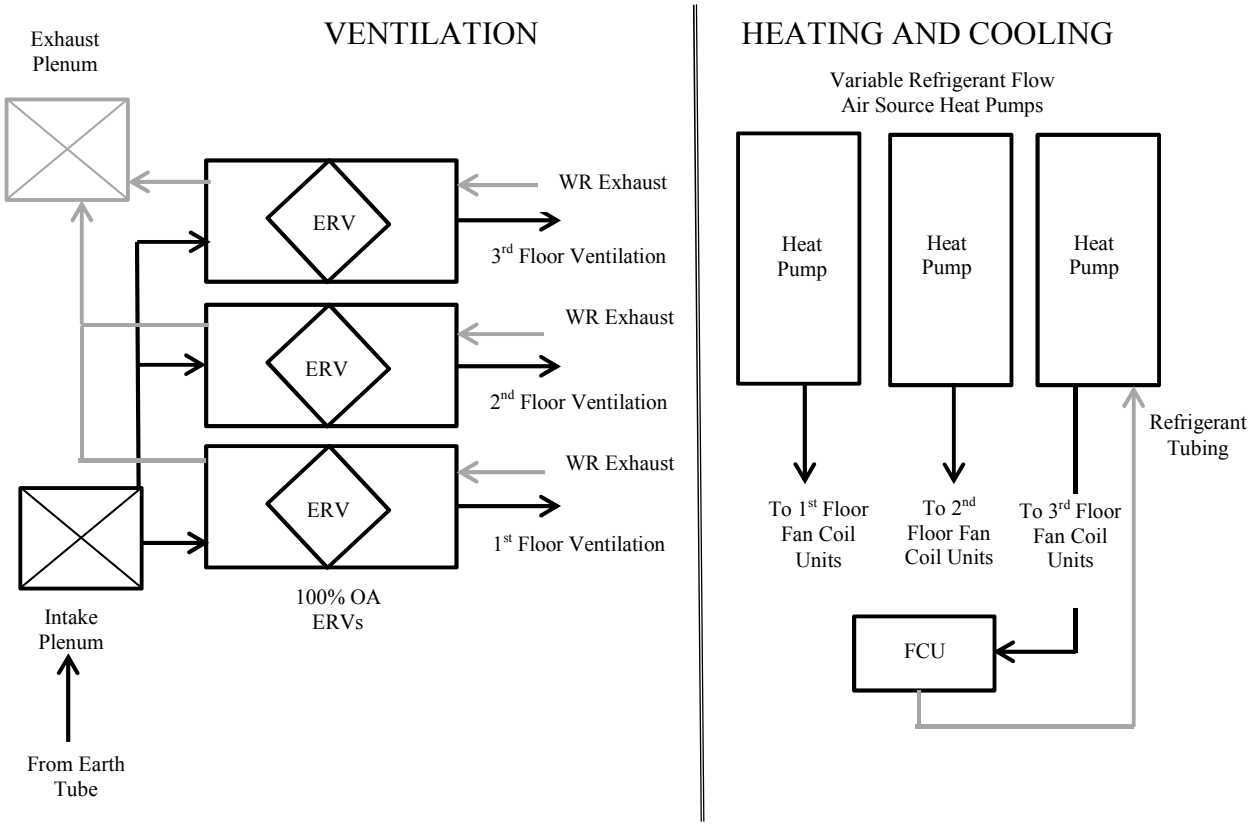

Figure 3: Schematic of Ventilation System and Heating and Cooling System

All windows include an operator to allow for user controlled access to outdoor air and potential free-cooling. The shallow floor plate allows for good cross flow ventilation when windows are opened. In addition the centre of the building houses an exhaust fan at the top of the atrium powered by a small 2 horse power motor, which can be manually turned on to provide free-cooling. When outdoor conditions fall within the appropriate temperature and humidity range to allow for free-cooling, the building operator sends an email to all building occupants informing them that conditions are right to allow for free cooling and to open their windows. When in this mode the heat-pump cooling ability is locked out. The occupants are instructed to close their windows when outdoor conditions are no longer within the free-cooling range.

The domestic hot water (DHW) system is made up of small local distributed electric resistance DHW tanks. The domestic hot water load is off-set by recovering heat from the server room using an air-to-water heat pump system. Not only does this heat recovery process reduce the energy requirement for domestic hot water, it also reduces the demand for mechanical cooling in the server room. The heat pump maintains a pre-heat domestic hot water tank at 55°C and the local DHW tanks increase the delivered temperature to 65°C.

A 5.5 kW photovoltaic array is installed on the rooftop, however as of this writing the PV array is not operating due to a delay in the local utility inspection required for this grid connected system.

3 The Measurement and Verification System

An important part of an energy efficient building is performance monitoring. It is imperative that building owners and operators understand how a building is operating in order to ensure that it operates efficiently. *A Grander View* installed a complete performance monitoring system to ensure that all aspects of the building operation are measured and logged for analysis. The performance monitoring system is comprised of Carlo Gavazzi CPT DIN transducer type electrical meters. The electrical single line diagram illustrated in Figure 4 shows the electrical metering points throughout the building. As seen in Figure 4, the main switchboard, lighting, receptacle and mechanical loads on each of the three floors are separately metered.

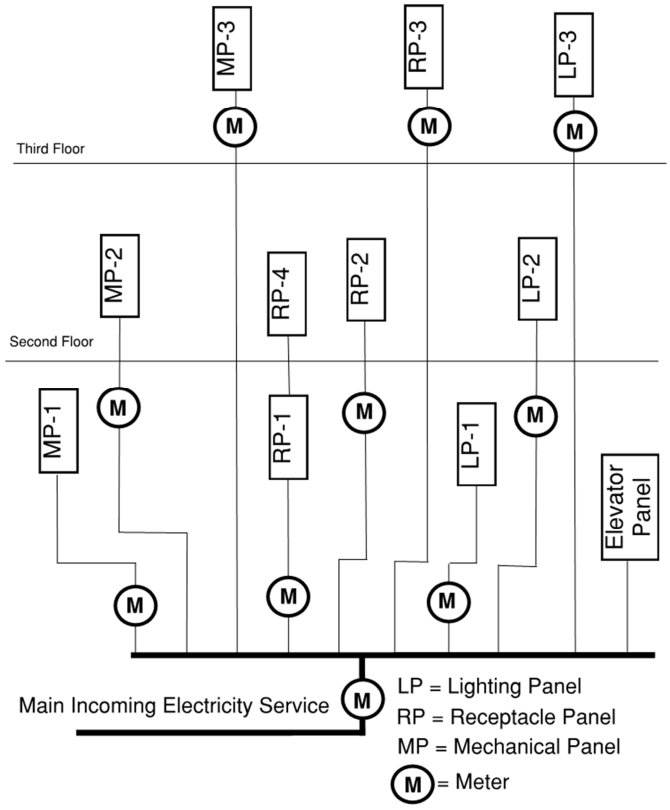

Figure 4: Electrical Metering Schematic

All of the electrical meters are connected to a central data logging server where the data is stored. The data from each of the meters is read at fifteen minute intervals and stored in a file on the data logging server. In addition, all of the heat pumps, ERVs, fan coils and local thermostats are tied to a central monitoring system. Trend logs and data archives are set up for the different operational parameters so that the operational data is archived and available for analysis. Lastly, Neptune T10 water meters are installed to measure the potable and non-potable water consumption of the building.

The performance monitoring system installed at *A Grander View* is a robust system that allows for the logging of energy demand and consumption data. While the system installed was not a pre-packaged system, there are many packaged systems available for building performance monitoring. One of the difficulties encountered during the system set-up was ensuring the correct installation of the hardware components and ensuring the correct set-up of the software systems – with special attention paid to the meter multipliers implemented.

4 The Model

The LEED® Compliance Model

An energy model for *A Grander View* was developed as part of the LEED® certification package. This model was developed using the space type method in EE4. There were several work-arounds that were implemented as many of the energy efficiency measures could not be directly modeled in the software and the intent of the model was not only to meet the LEED® modeling requirements, but also to predict the annual energy use of the building by modeling all of the features of the building as accurately as possible.

Modeling the Mechanical System

EE4 does not have an integral model that is directly suitable for simulating the variable flow refrigerant system therefore an EE4 simulation combined with an external spreadsheet analysis was used to estimate the performance of the mechanical system at *A Grander View*. Using EE4, the system was defined as a four-pipe fan coil model with an electric boiler as the heat source and an electric reciprocating chiller as the cooling source. The COP of the modeled chiller was set to the estimated seasonal cooling COP. In cooling mode, the system is very similar to an air-cooled chiller system, except that the fan coils are DX (i.e. cooling energy is moved out to the zones by the action of the compressor rather than a pump/hydronic system).

The EE4 simulation was used to determine the monthly building heating and cooling loads and an external spreadsheet was used to estimate the monthly electrical energy input into the heat pump/fan coil system that would be required to meet the loads. Based on power and capacity adjustment curves provided by the manufacturer, the heating and cooling COPs for the heat pumps were estimated based on the average monthly outdoor air temperature. The COPs also account for the fan power consumption of the fan coils which occurs only when heating or cooling is being provided. The fan coil fan power is not entered in the zone level in EE4 because the software would overestimate this fan power (as it assumes that these fans would run at the same schedule as the ventilation fans, rather than cycle with the heating/cooling loads). Thus the estimated monthly COPs account for all electricity (compressors and fan coil fans) used to move heat between the outdoors and the indoor spaces. Figure 5 shows the estimated heating and cooling COPs as they vary with outdoor air temperature.

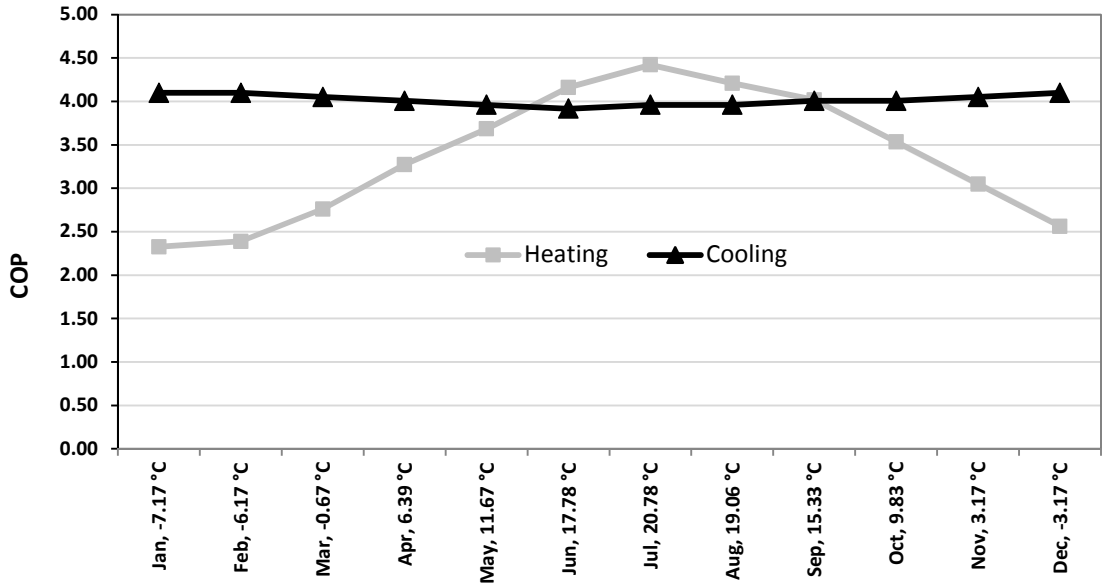

Figure 5: Heating and Cooling COP Annual Variation

Modeling Waste Heat Recovery from Server Room

Water heating at *A Grander View* is provided by a combination of electric resistance heaters plus an air source heat pump that uses waste heat in the server room as its heat source. The air source heat pump provides for cooling for the server room, and the recovered waste heat us used to preheat the supply water to the electric resistance heaters. In order to estimate the amount of energy saved due to the waste heat recovery heat pump, it was assumed that there is a server load of 2.5 kW and that the heating COP of the heat pump is 3.4. Therefore the amount of work the compressor will be doing to remove the 2.5 kW of heat from the server room is:

$$\dot{W} = \frac{\dot{Q}_R}{COP_H - 1}$$

Where:

$\dot{W}$ = work of the compressor

$\dot{Q}_R$ = heat removal rate (2.5 kW)

COP_H = heating coefficient of performance (3.4)

$$\dot{W} = 1.04\ kW$$

And the recoverable heat will be:

Where:

$\dot{Q}_H$ = recoverable heat

$$\dot{Q}_H = \dot{Q}_R + \dot{W}$$

$$\dot{Q}_H = 3.54\ kW$$

This is the maximum rate at which the heat pump water heater can provide heat. Any load above this would be met by the electric resistance heaters. The hourly domestic hot water demand was extracted from the output file and a spreadsheet analysis was performed to determine the energy savings of the server room waste heat recovery. The domestic hot water heating energy savings due to the server room heat recovery was calculated to be 7,548 kWh/year. Note that the server process load is included in the model and therefore the cooling requirement is also modeled. It is assumed that the waste heat and the envelope insulation are enough to meet any heating requirements and therefore no significant annual heating requirement is modeled for the server room.

Modeling Earth Tubes

The effects of the earth tubes had to be estimated outside of EE4 and the EE4 inputs modified to account for their effects. In order to account for the effect of the earth tubes the following calculation procedure was followed. Two calculations were performed, one to estimate the impact of pre-heating and one to estimate the impact of pre-cooling the incoming ventilation air using winter time conditions and summer time conditions.. Figure 6 illustrates the calculation procedure.

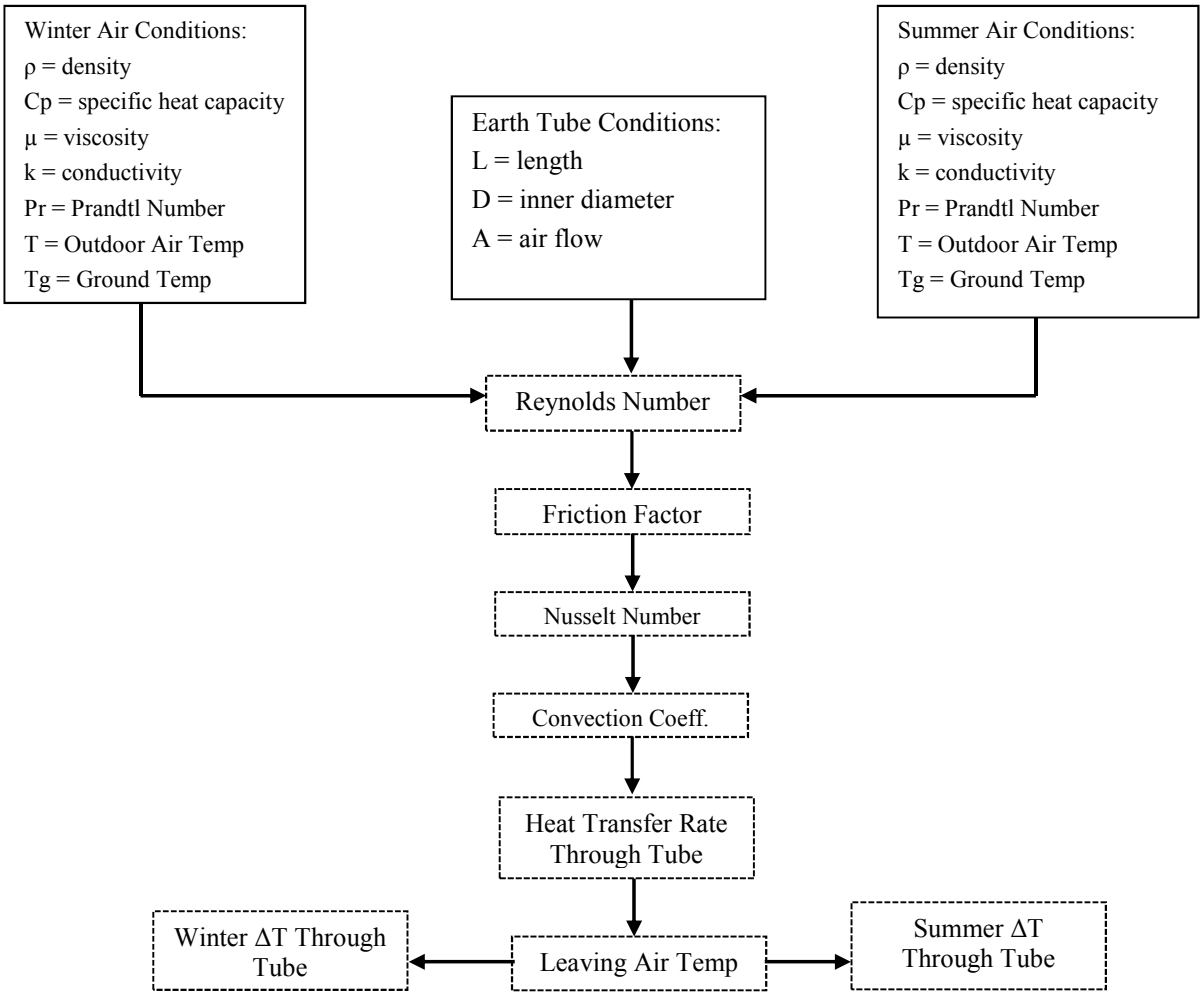

Figure 6: Earth Tube Modeling Procedure

Using the average outdoor air temperature and air speed and the heat transfer characteristics of the earth tube and assuming a constant wall temperature along the length of the earth tube, the calculations estimated a typical winter temperature rise across the earth tube of 0.6 ºC and a typical summer temperature drop of 1.1 ºC across the earth tube. The tempering effect of the earth tubes was included in the EE4 model by slightly increasing the modeled heat recovery effectiveness for those HVAC systems that utilize the earth tube system.

The Calibrated Model

The LEED® compliance model was calibrated to account for the actual weather experience at the site using hourly data from Environment Canada (Environment Canada 2011) and run time schedules were adjusted to more closely approximate the actual usage in the building.

5 Measured Building Performance

Figure 7 illustrates the measured building performance versus the performance predicted by the calibrated model.

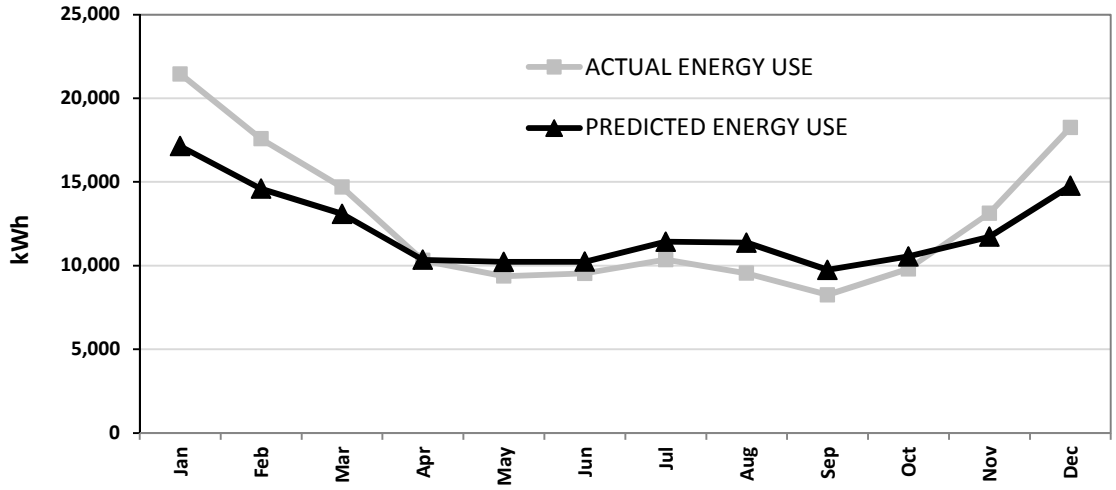

Figure 7: Actual and Predicted Annual Energy Consumption for 2010 (kWh)

As illustrated in Figure 7, the buildings energy performance improved as the year progressed. In the first quarter (January 2010 to March 2010), the difference between simulated and actual energy performance was 18%. As the year progressed and building commissioning was completed, the simulated and actual energy performance of the building were much closer – only a 11 % difference by the fourth quarter (October 2010 to December 2010) and a total of a 5% difference for the year. Figure 8 illustrates the difference between the actual building performance and the performance predicted by the calibrated model in terms of energy end-uses.

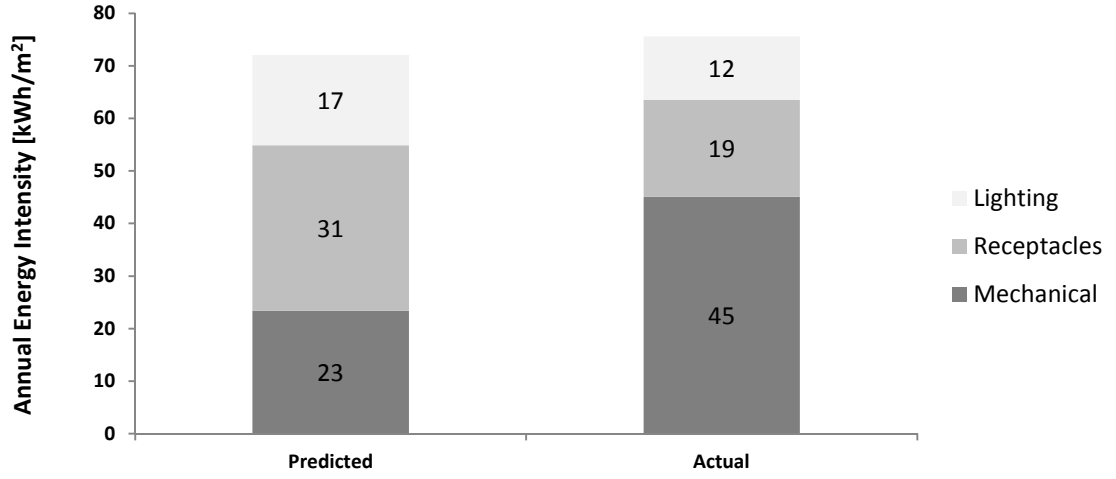

Figure 8: Predicted and Actual End-Uses (kWh/m^2)

As illustrated in Figure 8, there were differences in all of the reported end-uses. The lighting and receptacle end-uses are highly influenced by human behaviour. The occupants of the building are very conscious of energy consumption[1] and make great efforts to keep energy consumption low. Efforts such as turning lights completely off when daylighting is available, turning off monitors when leaving the workstation, and shutting down computers every night

1 Enermodal Engineering, the company occupying the building is a sustainable building consultant. Thus the employees are particularly energy conscious.

go a long way to reducing the energy consumption of the building. While the calibrated energy model does take into account the installed lighting controls and low receptacle power density, it does not account for the varied human behaviour – which likely lead to the discrepancies between the actual and predicted lighting and receptacle energy consumption. Note that determining human behaviour around lighting controls is an area of on-going research (Energy and Buildings 2006) and quantifying the impact of human behaviour on lighting and receptacle energy savings is outside of the scope of the current work.

While human behaviour is likely the main factor leading to the difference between the actual and predicted energy consumption for the lighting and receptacle end-uses, this is not the case for the mechanical energy consumption. The difference between the actual and predicted energy consumption for the mechanical systems is a result of on-going building commissioning during the first two quarters of operation. During the first six months of operation, the mechanical systems were not fully integrated with the building control system and were therefore running without a set schedule. In addition, the temperature set-back schedule and occupancy controls were not fully implemented. While the calibrated building energy model included full scheduling, temperature set-back and occupancy control, these features were not functional until the second half of the performance period leading to a considerable difference in the actual and predicted mechanical energy consumption. Besides the control and commissioning issues, work is on-going to ensure that the heat pump performance is modeled accurately. Utilizing one full year of performance data, further analysis and calibrations are detailed below.

Recalibration: Lighting and Receptacles

Based on the results of the 2010 year, specifically with respect to end-uses and seasonal variations, model recalibrations were required. The first recalibration was with respect to lighting and receptacle energy use. While great effort was made to accurately model the hardware, error is introduced since the lighting and receptacle energy predictions are based on the installed hardware, the occupancy schedule and lighting adjustment factors for lighting controls with no adjustments made for human behaviour. The building occupants in this case are acutely aware of building energy efficiency and are more apt to be very conscious to avoid using more lighting and receptacle energy than required. In addition, the very narrow floorplate of the building provides much of the required light levels need to work by on all but the most overcast of days, and of course at night—this combined with the predilection of the employees and the anecdotal observation of the authors has led to many lights simply not being turned on. Considering this and based on the predicted versus actual lighting and receptacle energy consumption numbers, the lighting and receptacle energy has been reduced in the model. The reduction of lighting and receptacle energy was based on the actual lighting energy consumption and actual receptacle energy consumption for 2010 as measured by the lighting sub-meters and receptacle sub-meters. The EE4 lighting inputs were adjusted such that the total lighting energy on a monthly basis was equal to the metered data for 2010 and the receptacle inputs were adjusted such that the total receptacle energy on a monthly basis was equal to the metered data for 2010. With the reduced lighting heat output to the building, it is expected that the calibrated model would increase its use of mechanical heating energy consumption.

Recalibration: External Active Solar Shades

The LEED® compliance model and calibrated model did not account for the effects of the external active solar shades installed on the building. The shades are controlled based on the amount of solar radiation hitting the building, lowering during periods of high solar radiation and retracting during periods of low solar radiation. During the 2010 year, the shading control

was not adjusted to account for seasonal effects meaning that the shades lowered during periods of high solar radiation, even in the winter when the passive solar gains are desirable. As such, the model has been calibrated to account for the shades by reducing the solar heat gain coefficient by 90%. Note that 90% was chosen based on discussions with the mechanical designer.

Recalibration: Mechanical System COPs

As illustrated in Figure 7, the difference between the actual and predicted energy consumption varies over the year with the largest difference between the two occurring during the heating season. As such, the COPs for the heat pumps were recalibrated using the monthly average temperatures based on actual temperature data (Environment Canada 2011). The COPs corresponding to these temperatures were determined using the manufacturer's temperature adjustment curves for input power and capacity. Note that the original simulation used the monthly average temperatures from the EE4 weather file to adjust the COPs of the heat pumps. Table 1 lists the COPs using the EE4 Typical Meteorological Year (TMY) weather data and the COPs using the actual weather data for the analysis year.

Table 1: Heat Pump COPs based on TMY and Actual Weather

Month	TMY Weather Data, Monthly Average		Actual Weather Data, Monthly Average	
	Heating COP	Cooling COP	Heating COP	Cooling COP
Jan	2.33	4.10	2.31	4.10
Feb	2.39	4.10	2.36	4.10
Mar	2.76	4.05	2.72	4.10
Apr	3.27	4.01	3.21	4.01
May	3.68	3.96	3.72	3.96
Jun	4.16	3.92	4.16	3.92
Jul	4.42	3.96	4.42	3.92
Aug	4.21	3.96	4.21	3.96
Sep	4.02	4.01	3.80	3.96
Oct	3.54	4.01	3.40	4.01
Nov	3.05	4.05	2.95	4.05
Dec	2.56	4.10	2.52	4.10

Figure 9 illustrates the energy performance of the actual building versus the potential performance as predicted by the recalibrated models.

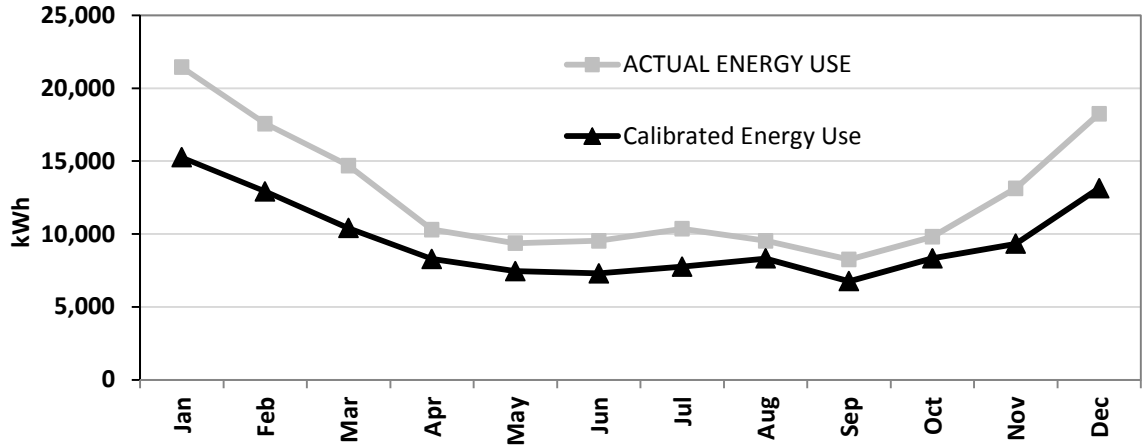

Figure 9: Actual Energy Use vs. Calibrated Energy Use

As can be seen in Figure 9, the discrepancy between the calibrated and actual energy use increased compared to the performance before the recalibrations (Figure 7). Figure 10 illustrates the differences in terms of energy end-uses.

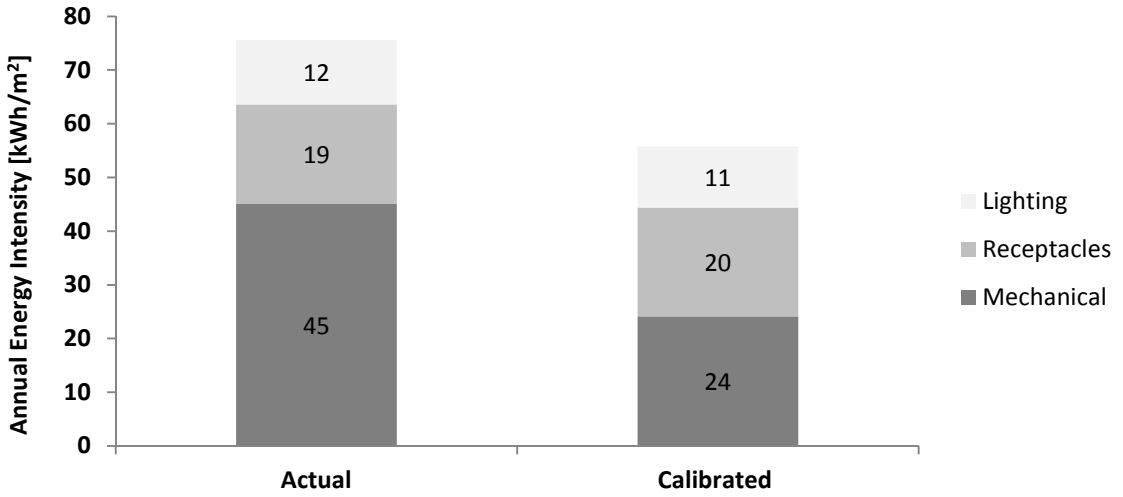

Figure 10: Actual and Predicted End-Use Intensities (kWh/m^2)

The results of the recalibrations indicate that the mechanical system is consuming more energy than the recalibrated model predicts. Assuming the underlying modeling engine, DOE, is accurate (Berkley Labs 2011), there are likely 4 possible causes for this discrepancy:

- the building envelope (windows and walls) has a higher conductivity than was assumed in the model
- the building has a higher infiltration rate than was assumed in the model
- the ventilation amounts are higher than was assumed in the model
- the efficiency of the heat pump system in response to the building load is worse than assumed in the model

As previously described, the building envelope is constructed from ICFs which greatly minimizes thermal bridging. The thermal bridging effects of the spandrel sections have been accounted for in the model. It is unlikely that the building envelope modeling is contributing greatly to the discrepancy between modeled and actual energy consumption.

Infiltration can contribute to discrepancies between actual and modeled energy consumption since infiltration can be difficult to quantify and difficult to model accurately. While the air tightness of *A Grander View* was measured and this data used to model infiltration, deliberate infiltration through opening doors is not modeled but can potentially impact the energy use of the building, though the impact is likely negligible. However, since infiltration was measured and modeled, it is unlikely that infiltration modeling is contributing greatly to the discrepancy between modeled and actual energy consumption.

While ventilation air can be a large heating load on a building, the ventilation amounts, delivery schedules and associated controls have been modeled in detail. Furthermore, because occupancy is generally consistent, the ventilation amounts are also consistent, minimizing the variability of the ventilation air amounts delivered to the building. It is therefore unlikely that the modeled and actual ventilation air amounts are greatly different and therefore unlikely that ventilation air is contributing greatly to the discrepancy between the modeled and actual energy consumption.

The efficiency of mechanical system, specifically the difference between actual and modeled heat pump COPs is likely the main source of discrepancy between the actual and modeled energy consumption. The calibrated models assume heating and cooling COPs based on monthly average outdoor air temperatures, while in reality the actual heat pump performance constantly changes based on outdoor air temperature. Based on this analysis, it is likely that the majority of the discrepancy between the actual and modeled performance of the building is due to the heat pump performance, specifically in the winter. Further work is needed to investigate the cause of the discrepancy, specifically if it related to the model or to the actual performance of the heat pumps. Ideas for further work include:

- adjust COPs based on hourly temperature data and calculate energy consumption based on hourly loads and hourly adjusted COPs
- run simulations to quantify the impact of infiltration on the annual energy consumption (eg: sensitivity of annual energy consumption to infiltration)
- install monitoring equipment on the heat pumps to measure COPs

6 Comparison

Figure 11 illustrates the final energy intensity of the building based on the measured energy consumption for 2010.

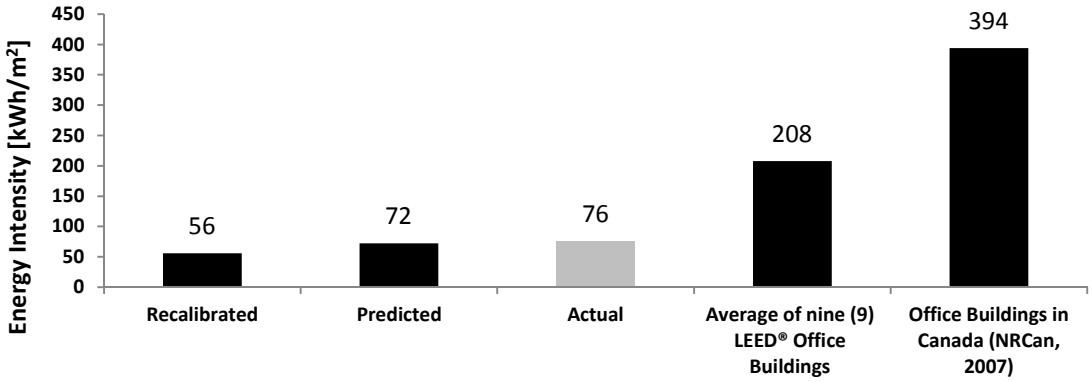

Figure 11: Comparison of Building Energy Intensity (ekWh/m^2)

As illustrated in Figure 11, the energy efficiency measures implemented in the building, the comprehensive building commissioning and the extensive performance monitoring have resulted in the most energy efficient office building in Canada – 81% more efficient that the average Canadian office building. While recalibration efforts highlighted that the mechanical system is not meeting the performance targets, it's difficult to say if this is due to mechanical system operation or modeling estimates.

7 Conclusions

As is illustrated through this work, simulation is a powerful tool that can set performance targets for real world buildings. Knowing the achievable performance level of a building will help commissioning agents, building operators, owners, and building occupants strive to meet the peak potential performance of the building. Furthermore, validating simulated performance with measured data can serve to verify the model and modeling process - specifically as it relates to modeling innovative and efficient buildings. Metered data can also be used to refine the building energy model allowing for in depth analysis isolating the building systems that are not meeting potential.

8 Acknowledgements

The authors would like to thank David Mather for his meticulous documentation of the modeling procedures used to generate the LEED® building energy model for *A Grander View*.

9 References

Canada Green Building Council 2004, *LEED Green Building Rating System For New Construction and Major Renovations LEED Canada-NC Version 1.0*

Canadian Climate Normals or Averages 1971-2000 2011, Environment Canada, viewed 21 November 2011 <http://www.climate.weatheroffice.gc.ca/climate_normals/results_e.html?stnID=4832&lang=e&dCode=1&province=ONT&provBut=&month1=0&month2=12>

DOE-2, Berkley Labs, viewed 7 December 2011 < http://gundog.lbl.gov/dirsoft/d2whatis.html#Validation of DOE-2>

Energy and Buildings 2006, 'Special Issue on Daylighting Buildings', vol 38, no. 7

Guide to Canada's Energy Efficiency Regulations 2009, Office of Energy Efficiency, Natural Resources Canada, viewed 15 November 2011, <http://oee.nrcan.gc.ca/regulations/html/EERGuide_foreward.cfm?attr=0>

Hunn, B 2010, '35 Years of Standard 90.1: Early and Mid 1970s', *ASHRAE Journa*l, March 2010, pp.36-38

Jarnagin, Ronald E, '35 Years of Standard 90.1: 1992 Energy Policy Act and 90.1-1999', ASHRAE Journal, March 201-, pp. 41-42

National Climate Data and Information Archive 2011, Environment Canada, viewed 15 March 2011 < http://www.climate.weatheroffice.gc.ca/climateData/canada_e.html>

Newsbrief – What is the Commercial Building Incentive Program? 2010, National Research Council Canada, viewed 15 November 2011, <http://www.nrc-cnrc.gc.ca/eng/ibp/irc/ci/volume-4-n2-5.html >

U.S. Department of Energy 2008, Energy Efficiency Trends in Residential and Commercial Buildings, U.S. Department of Energy, viewed 23 November 2011 <http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/bt_stateindustry.pdf>