Evaluation of Energy Performance of LEED Building (Friedman) at UBC

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---Technical Report---

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--June 2nd 2013---

Abstract

Recent studies conducted by New Buildings Institute have shown that there were gaps between modeled and actual performance of numerous LEED Buildings. This study was conducted to investigate this phenomenon in one of LEED Buildings in University of British Columbia, try to identify possible sources of discrepancies, and establish guidelines to repeat similar investigations on other buildings.

Based on the recommendations of the project client, Friedman Building was chosen in the study. To achieve the project objectives, several efforts were made such as analyzing annual and monthly energy consumption data, comparing LEED drawings and as-built drawings, comparing the occupancy pattern in the building, and conducting interviews with the program administrators.

There were several sources of discrepancies identified in the study: changes in energy demand throughout the year, changes in design before and after submission of LEED Application, inaccurate plug load assumptions, and building envelope degradation.

Acknowledgement

We would like to express our gratitude to our project supervisor, Dr. Murray Hodgson, and our teaching assistant, Nima Khalkali, for providing us valuable feedbacks throughout the term. We also want to thank our project clients from UBC Campus + Community Planning for their support during the project: Lilian Zaremba, Bud Fraser, and Penny Martyn.

In addition, it wouldn't be possible to successfully complete this project without the supports of Deb Capps, Green Zone Facility Manager; Larry Smithe and Liam Mulrooney from Division of Physical Therapy of the School of Rehabilitation Sciences; and Clint Meyers from School of Audiology and Speech Sciences. We want to thank them for giving us numerous helps during our audit process in Friedman Building.

Lastly, we would also like to thank fellow SBSP members, Mahdi Salehi, Belgin Terim Cavka, and Stefan Storey for sharing their resources with us and their involvement during numerous discussions on the project.

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1. Introduction

While LEED accreditation is often used to evaluate the performance of green buildings, there are some evidences which show performance gap between modelled expectations and actual performances of many LEED Buildings.

In 2008, New Buildings Institute studied 121 different LEED buildings and summarized their findings in a report written for US Green Building Council. Across the buildings studied by NBI, there was a wide scattering of data observed. While some buildings did much better than anticipated, almost the same number of buildings performed worse or even much worse [1].

This study was conducted to follow up NBI's study and investigated sources of discrepancies which might result in the performance gap between the modelled and actual building performance. Due to the time limitation, this study only focused on one LEED building in UBC, Friedman Building. The results from Friedman building would then be used as a foundation for future studies on other UBC buildings.

To accomplish this research objective several efforts have been made by the authors such as evaluating mechanical, electrical, and architectural drawings of the building, conducting site visit to check the consistency between the design and actual implementation, conducting interviews with the program administrators, and analyzing electrical and steam consumption of the building.

2. Research Methodologies

This study was mainly conducted to provide insights to the performance gap issues which were often encountered in LEED buildings. Furthermore, it would also use the results from Friedman building to develop guidelines for future investigation on other LEED buildings in UBC. To achieve these objectives, the following methods were pursued in the study:

1. Reviewed background information on the renovation project of Friedman building
2. Analyzed annual and monthly energy consumption data
3. Reviewed weather normalization technique
4. Reviewed any changes in drawings since LEED application has been submitted
5. Conducted site visit to compare the actual equipment used in the building with the drawings
6. Conducted interview with program administrators of both Department of Physical Therapy and School of Audiology and Speech Sciences
7. Analyzed the occupancy pattern for classrooms in the building
8. Provided recommendations for future studies on other UBC buildings

3. Background Information

a. Previous Study

Numerous certified LEED NC buildings (121 buildings) in 2008 were studied by New Buildings Institute (NBI) to provide information with regards to the link between design intention and outcome for LEED projects. In a report prepared for US Green Building Council (USGBC), NBI showed that there were large variations in performances between these buildings. While some buildings performed better than intended, similar number of buildings performed worse or even much worse [1].

To provide meaningful data, NBI has included buildings with all type of LEED certifications in the study. Distributions of the buildings based on the certification types and year of certification can be seen in the figures below.

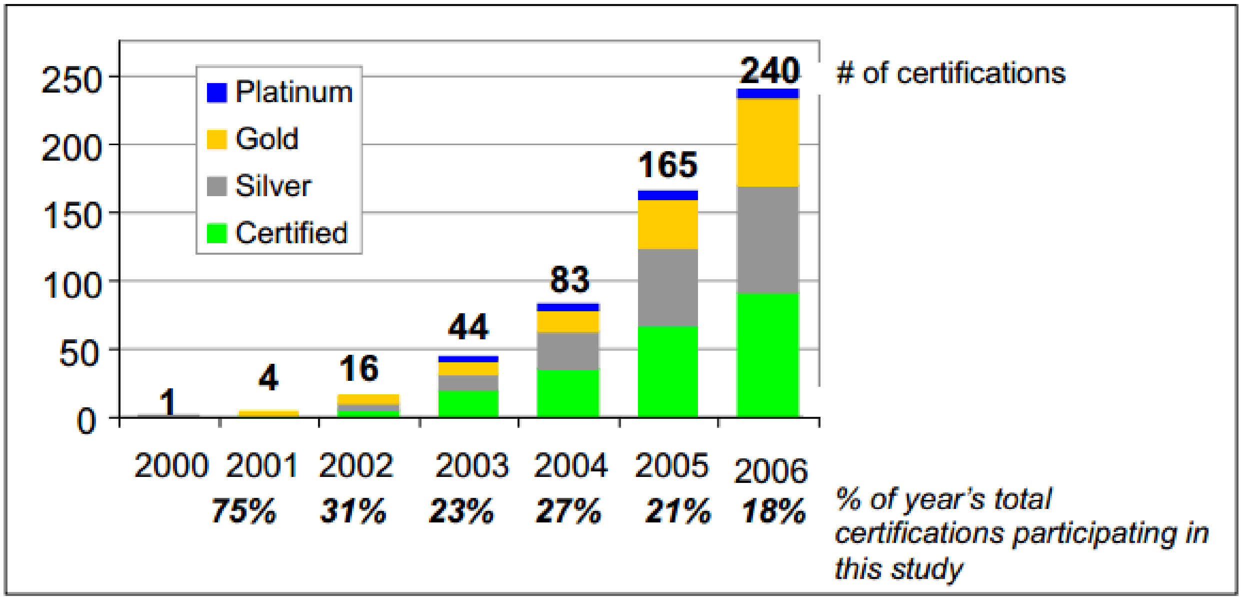


Figure 1. LEED-NC Certifications by Year [1]

In the study, three different metrics were utilized to analyze the energy performance of the building: Energy Use Intensity (EUI) comparison between LEED and national building stock, Energy Star Rating of the LEED buildings, and the measured performance results compared to initial design and baseline modelling.

As seen in the figure below, EUI of the buildings were compared to the data from Commercial Building Energy Consumption Survey (CBECS). For all LEED building analyzed in the study excluding 21 high energy type buildings, the median measured EUI was approximately 69 kBtu/sf or 24% better than the CBECS national average. Furthermore, LEED EUIs average for offices, the most common building type, was 33% better than CBECS.

As mentioned previously, 21 high energy buildings were considered separately in the study. The EUI of these buildings reached up to nearly 700 kBtu/sf with the median of 238 kBtu/sf.

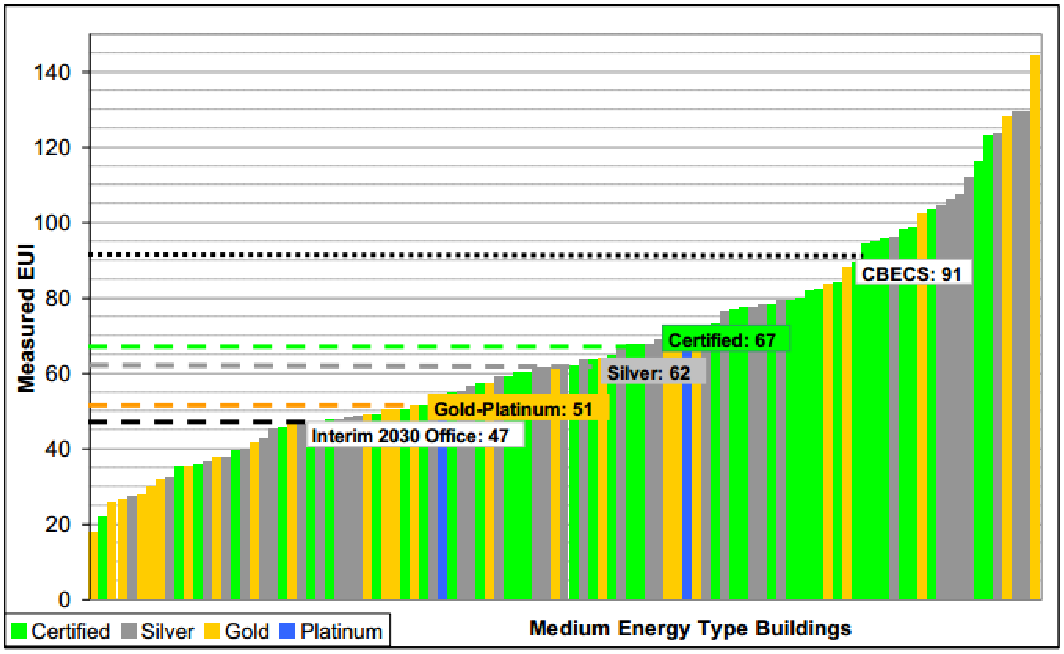


Figure 2. EUI Distributions across buildings [1]

Unlike the first metric, Energy Star program which was proposed by U.S. Environmental Protection Agency (EPA) rated a building's energy use in relation to existing building stock for the same activity category. Based on the study, average Energy Star rating of LEED buildings was 68 which indicated that it was better than 68% of similar buildings. Even though this result showed favourable results, there were approximately one quarter of the buildings with rating below 50, "meaning they used more energy than average comparable existing building stock [1]." The distribution of Energy Star Rating could be seen below.

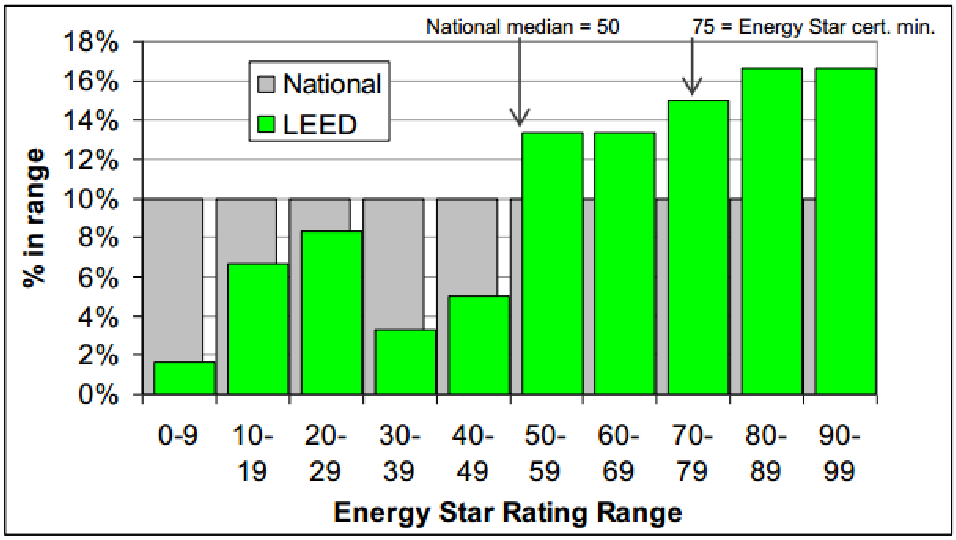


Figure 2. Distribution of Energy Star Rating [1]

In addition to the two metrics above, the third metric that was used in the study compared the measured energy performances to the modelled code baseline building which was determined using the Energy Cost Budget (ECB) and performance requirements in ASHRAE 90.1.

In comparing the measured and design EUIs of the buildings, NBI has found significant amount of variations between individual building results. As seen in the figure below, numbers of building which were doing worse than predicted were approximately similar to the ones which were doing better.

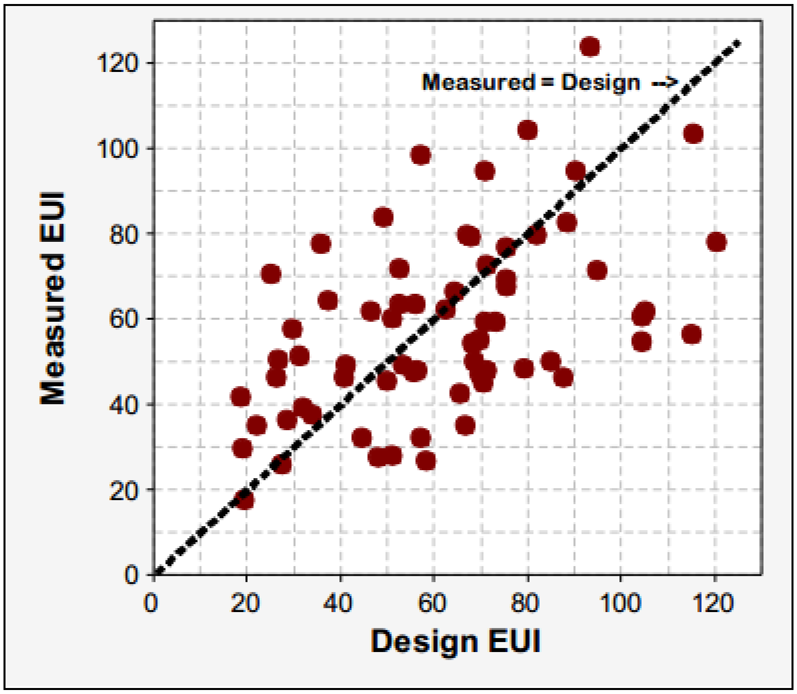


Figure 3. Measured versus Design EUIs [1]

The measured and proposed savings of the buildings also showed significant amount of variation with several buildings utilized more energy than the code baseline. This comparison could be seen in the figure below.

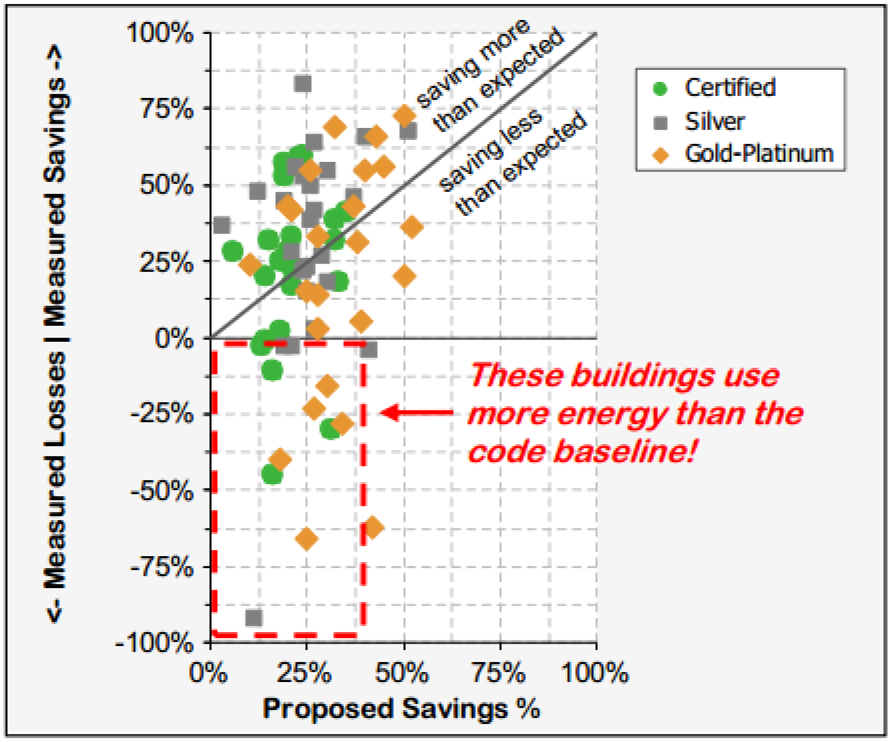


Figure 4. Measured vs Proposed Savings Percentage [1]

There were several sources of variations mentioned in the study such as differences in operational practices and schedules, equipment, construction changes, and others issues not anticipated in energy modelling process.

b. Renovation of Friedman Building

Originally built in 1959, Friedman building was the place for the Department of Anatomy which had multiple energy- intensive laboratories. As part of the UBC Renew program, Friedman building were renovated in 2008 to “improve life safety, accessibility, energy efficiency, and opportunities for student/ faculty interaction [2].” Furthermore, it would instead house the School of Audiology and Speech Sciences and Physical Therapy Division of the School of Rehabilitation Sciences. Because of the change in occupants and their energy demand, this renovation was sufficient to upgrade the LEED certification of the building from Silver to Gold.

The renovation of Friedman building was considered as a major renovation. Because of this, it was categorized under LEED New Construction (NC) certification. To understand the scale of the renovation, the authors have studied previous report written by MCW Consultants Ltd. who was responsible for analyzing the performance of the building before and after the renovation.

Due to the lack of measurement system before the renovation, building energy performance were simulated by MCW using eQuest software. The simulated performance of the building before renovations was as followed.

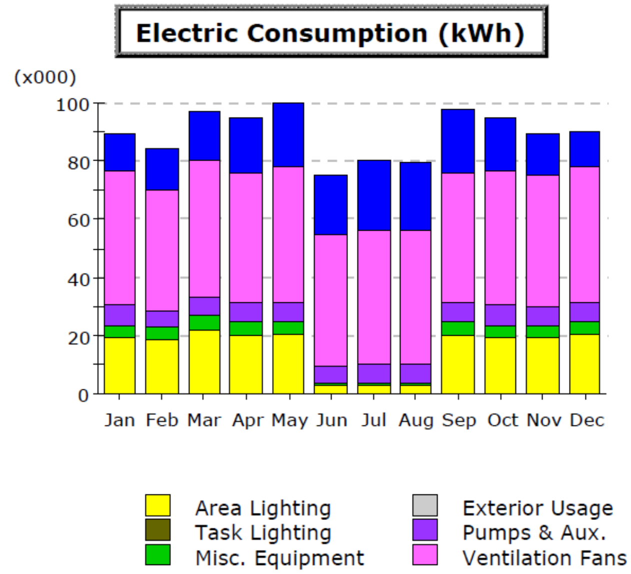


Figure 5. Simulated Electrical Consumption before Simulation [2]

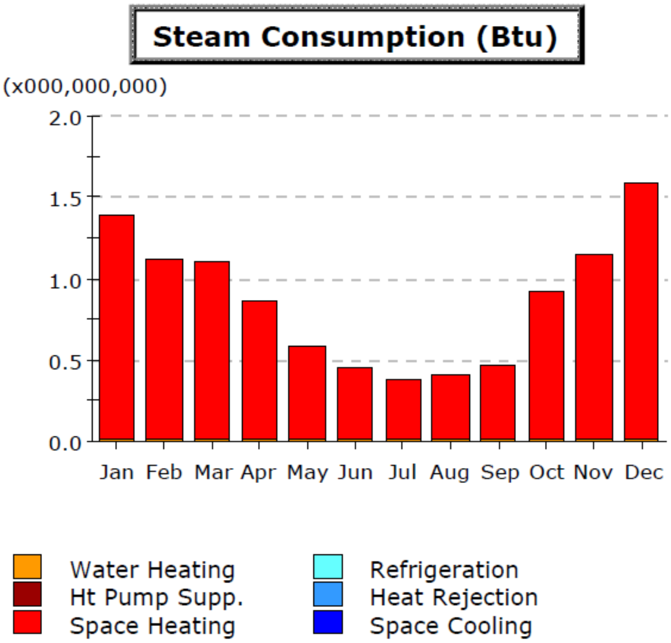
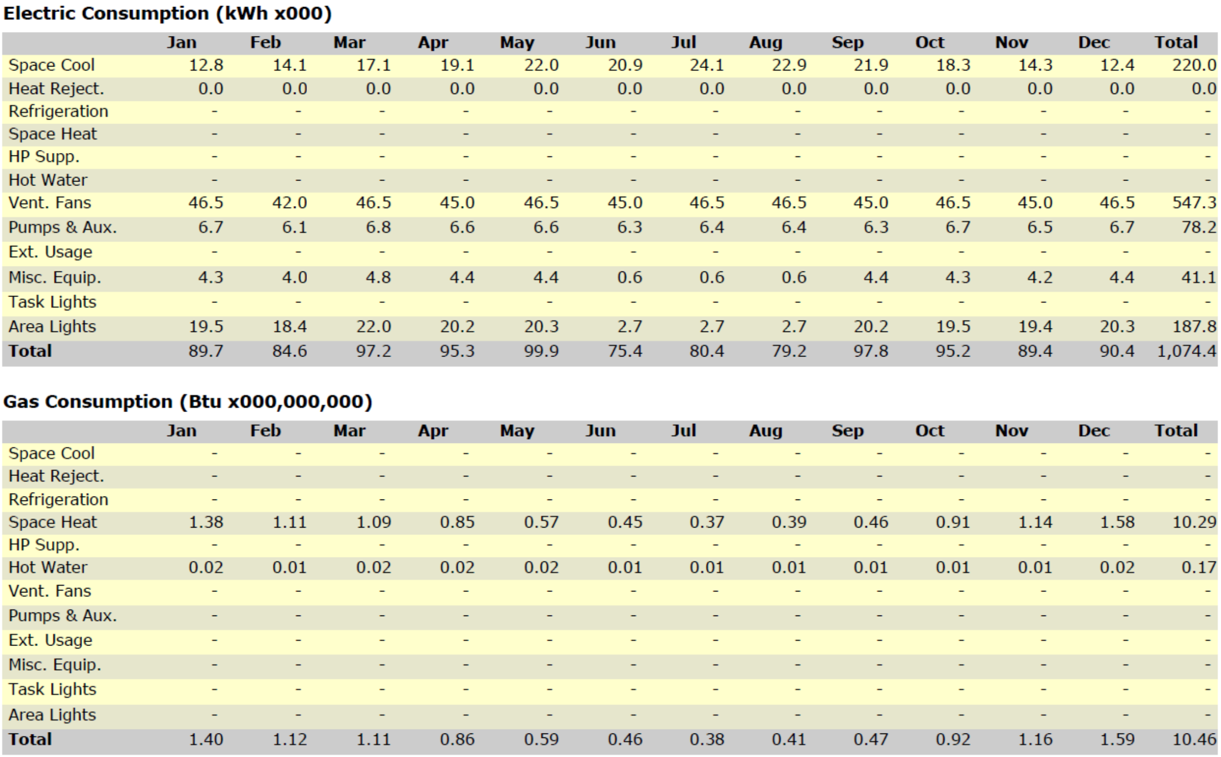


Figure 6. Simulated Steam Consumption before Renovation [2]

Table 1. Electrical and Gas Consumption Distribution before Renovation [2]



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	12.8	14.1	17.1	19.1	22.0	20.9	24.1	22.9	21.9	18.3	14.3	12.4	220.0
Heat Reject.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	46.5	42.0	46.5	45.0	46.5	45.0	46.5	46.5	45.0	46.5	45.0	46.5	547.3
Pumps & Aux.	6.7	6.1	6.8	6.6	6.6	6.3	6.4	6.4	6.3	6.7	6.5	6.7	78.2
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	4.3	4.0	4.8	4.4	4.4	0.6	0.6	0.6	4.4	4.3	4.2	4.4	41.1
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	19.5	18.4	22.0	20.2	20.3	2.7	2.7	2.7	20.2	19.5	19.4	20.3	187.8
Total	89.7	84.6	97.2	95.3	99.9	75.4	80.4	79.2	97.8	95.2	89.4	90.4	1,074.4

Gas Consumption (Btu x000,000,000)

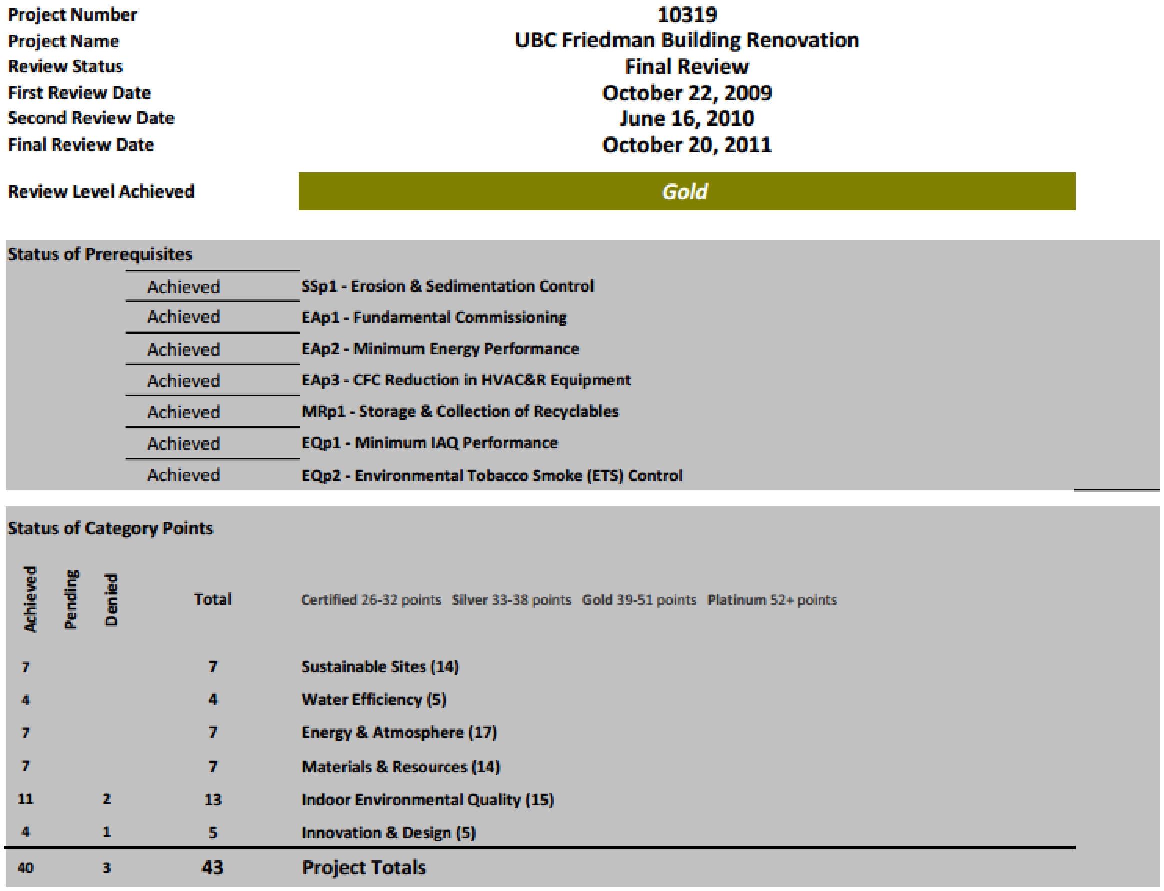
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.38	1.11	1.09	0.85	0.57	0.45	0.37	0.39	0.46	0.91	1.14	1.58	10.29
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.17
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1.40	1.12	1.11	0.86	0.59	0.46	0.38	0.41	0.47	0.92	1.16	1.59	10.46

As seen in the table above, total electrical consumption of the building before renovation was approximately 1,074,400 kWh or 3,867,840 MJ. The total natural gas consumption was approximately 10,460,000,000 Btu or 11,035,890 MJ, while miscellaneous excluded equipment accounted for 41,100 kWh or 147,960 MJ (not shown in the table). Under the assumption that the conditioned floor area was approximately 5,235 m^2 [2], energy unit intensity (EUI) of the building was about 2,810 MJ/m^2 or 247.48 kBtu/sf. Comparing this value to the buildings studied by NBI, the original Friedman building would be comparable to the excluded high energy type building which has the median EUI value of 238 kBtu/sf.

On the other hand, the modelled energy performance of the renovated building was significantly less. It was estimated to be 1,118,044 MJ for electricity and 2,958,529 MJ for natural gas. Therefore, total EUI of the renovated building was approximately 181.8 kWh/m^2 or 57.59 kBtu/sf. This value was less than 25% of the original consumption value. The detail of this prediction model would be discussed further in Appendix A.

c. LEED Accreditation

As mentioned in the previous section, the renovation was intended to upgrade the LEED certification of Friedman Building from Silver to Gold. There were total of 7 credits awarded in the Energy & Atmosphere category (5 credits for optimized energy performance, 1 point for ozone protection, and 1 point for green power). The breakdown of the LEED credits for the renovated Friedman building could be seen in the figure below.



Project Number	**10319**
Project Name	**UBC Friedman Building Renovation**
Review Status	**Final Review**
First Review Date	**October 22, 2009**
Second Review Date	**June 16, 2010**
Final Review Date	**October 20, 2011**
Review Level Achieved	***Gold***

Status of Prerequisites

Achieved	**SSp1 - Erosion & Sedimentation Control**
Achieved	**EAp1 - Fundamental Commissioning**
Achieved	**EAp2 - Minimum Energy Performance**
Achieved	**EAp3 - CFC Reduction in HVAC&R Equipment**
Achieved	**MRp1 - Storage & Collection of Recyclables**
Achieved	**EQp1 - Minimum IAQ Performance**
Achieved	**EQp2 - Environmental Tobacco Smoke (ETS) Control**

Status of Category Points

Achieved	Pending	Denied	Total	Certified 26-32 points Silver 33-38 points Gold 39-51 points Platinum 52+ points
7			7	Sustainable Sites (14)
4			4	Water Efficiency (5)
7			7	Energy & Atmosphere (17)
7			7	Materials & Resources (14)
11		2	13	Indoor Environmental Quality (15)
4		1	5	Innovation & Design (5)
40		3	43	Project Totals

Figure 7. LEED credit breakdown for Friedman Building [3]

Table 2. Energy & Atmosphere Points Breakdown

Categories	Description	Points
Optimize Energy Performance	34% energy reduction compared to MNECB	5
Ozone Protection	HVAC system free of HCFCs	1
Green Power	100% electricity from green power	1

As seen in the table above, most of the points in the Energy& Atmosphere category were achieved through optimizing the energy performance of the building. It should be noted that these points and LEED certification were awarded based on LEED NC 1.0 guideline. For buildings built after 2009, LEED NC 2009 should be followed instead.

There are some differences between the two versions of LEED NC. One of the most notable revisions in LEED NC 2009 is the overall increase of available points. Thus, increases the point requirements for each certification levels. Furthermore, in the Energy and Atmosphere category, more emphasis has been given to renewable energy as well as measurement and verification criteria. Differences in the two guidelines could be briefly summarized in the following tables.

Table 3. Points Requirements for LEED NC 1.0 and LEED NC 2009

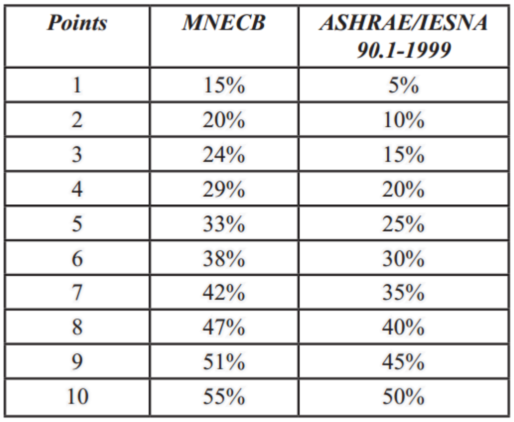
Certification	LEED NC 1.0	LEED NC 2009
Certified	26-32	40-49
Silver	33-38	50-59
Gold	39-51	60-79
Platinum	52-70	80

Table 4. Energy & Atmosphere Category in LEED NC 1.0 and LEED NC 2009

Criteria	LEED NC 1.0	LEED NC 2009
Fundamental Building Commission	Prerequisite 1	Prerequisite 1
Minimum Energy Performance	Prerequisite 2	Prerequisite 2
Fundamental Refrigerant Management	Prerequisite 3	Prerequisite 3
Optimize Energy Performance	Varies	Varies
On- Site Renewable Energy	1-3	1-7
Enhanced Commissioning	1	2
Enhanced Refrigerant Management	-	2
Measurement and Verification	1	3
Green Power	1	2

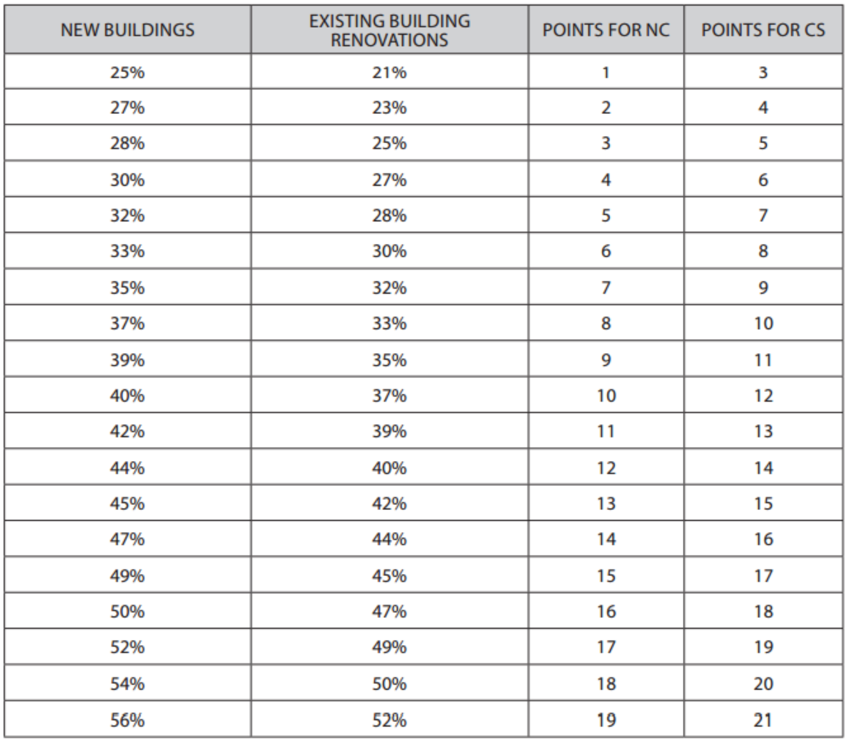
There is also a considerable difference in the optimized energy performance criteria. In LEED 2009, new buildings and existing building renovations are completely separated, leading to distinct performance requirements.

Table 5. Optimized Energy Performance Criterion for LEED NC 1.0 [4]



Points	*MNECB*	*ASHRAE/IESNA 90.1-1999*
1	15%	5%
2	20%	10%
3	24%	15%
4	29%	20%
5	33%	25%
6	38%	30%
7	42%	35%
8	47%	40%
9	51%	45%
10	55%	50%

Table 6. Optimized Energy Performance Criterion for LEED NC 2009 [5]



NEW BUILDINGS	EXISTING BUILDING RENOVATIONS	POINTS FOR NC	POINTS FOR CS
25%	21%	1	3
27%	23%	2	4
28%	25%	3	5
30%	27%	4	6
32%	28%	5	7
33%	30%	6	8
35%	32%	7	9
37%	33%	8	10
39%	35%	9	11
40%	37%	10	12
42%	39%	11	13
44%	40%	12	14
45%	42%	13	15
47%	44%	14	16
49%	45%	15	17
50%	47%	16	18
52%	49%	17	19
54%	50%	18	20
56%	52%	19	21

d. Weather Normalization Technique

In heated or cooled buildings like UBC Friedman Building, energy consumption tends to depend on the outside air temperature. If the outside air temperature is cold, then energy is needed for heating to provide thermal comfort to the building occupants. Apparently, the colder the outside air temperature is, the more energy is needed.

If the outside air temperature is warm, then energy is needed for cooling to provide thermal comfort to the building occupants. Apparently, the warmer the outside air temperature is, the more energy is needed.

"Weather normalization", or "weather correction" techniques are used very often for comparing fairly energy consumption figures. So, when this normalization is very useful, because it allows us to compare fairly the energy consumption per year and is used to identify any changes in a building's energy consumption.

Weather normalization of energy consumption uses degree days. Degree days is a simplified form of historical weather data. Degree days are used in analyzing the relationship between energy consumption and outside air temperature. This process is often used to identify excess consumption and to quantify the savings from improvements in energy efficiency.

There are two main types of degree days: Heating degree days (HDD) and Cooling degree days (CDD). Heating degree days (HDD) are used for calculations that relate to the heating of buildings and Cooling degree days (CDD) are used for calculations that relate to the cooling of buildings.

Heating degree days are defined relative to a base temperature—the outside temperature above which a building needs no heating. The base temperature varies from country to country. In Canada, heating degree-days for a given day are the number of degrees Celsius that the mean temperature is below 18°C. If the temperature is equal to or greater than 18°C, then the number will be zero.

e. Vancouver Climate Condition

As indicated in a previous study by Sina Radmard and Nima Khalkali Shijini, Vancouver is situated at latitude of 49.2505^0N and longitude of 123.1119^0W and has the following climatic specifications [6]:

- Average 2100 hours of sunshine per year
- Minimum average daily solar irradiation of 2.5kWh/m^2. This daily average depends on inclination angle, and for Vancouver has the boundary conditions of 3.2 kWh/m^2 for horizontal surface and 2.5 kWh/m^2 for vertical surface. Although Vancouver is well known for its cloudy weather condition, its average solar potential is slightly less than Miami as an example (only 8% less on annual basis as indicated in Figure 1)

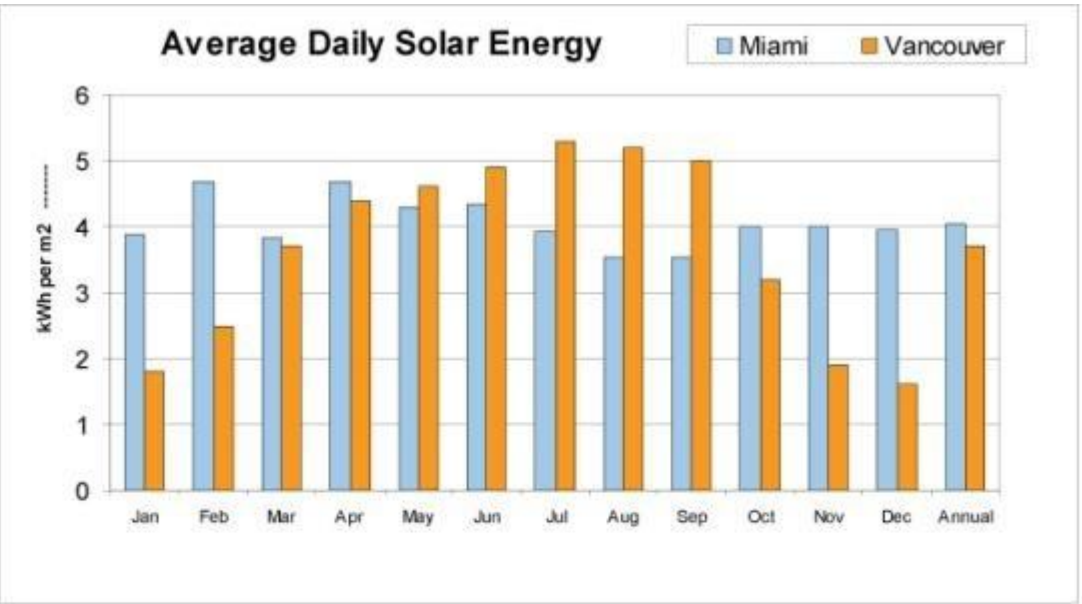


Figure 8. Averages solar irradiation of Vancouver compared to Miami [6]

i. Temperatures

The annual average temperature in Vancouver is 10.4 °C at the Airport and it is one of the warmest in Canada. Vancouver temperature ranges on average from 0.8^{0}C in December to 22.2^{0}C in August as indicated in figure 9 below.

Unusually for a Canadian city, Vancouver has relatively mild winters with little snow. The cold air from the Arctic that sweeps over the rest of Canada in winter is unable to reach Vancouver. The Rocky Mountains block it. Combine the lack of Arctic air with the mildness of Vancouver's location on the shores of the Pacific Ocean and it's not surprising that Vancouver is the warmest of Canada's major metropolitan cities in winter by far. Snow depths of greater than 1 cm are seen on about 10 days each year in Vancouver compared with about 65 days in Toronto. Vancouver has one of the wettest and foggiest climates of Canada's cities. At times, in winter, it can seem that the rain will never stop. Compensating for the wet winters, Vancouver usually enjoys excellent summer weather characterized by very pleasant, warm days with abundant sunshine. Vancouver also differs from most other Canadian cities in that it has a genuine spring and fall/autumn. In many Canadian cities it often seems that warm, summer weather replaces frigid, winter weather in a matter of a very few weeks or even days. Vancouver has a western maritime climate; hence its weather can be changeable throughout the year. Vancouver is less windy than most other Canadian cities [7].

Figure 9. Average temperature of Vancouver [6]

ii. Daylight

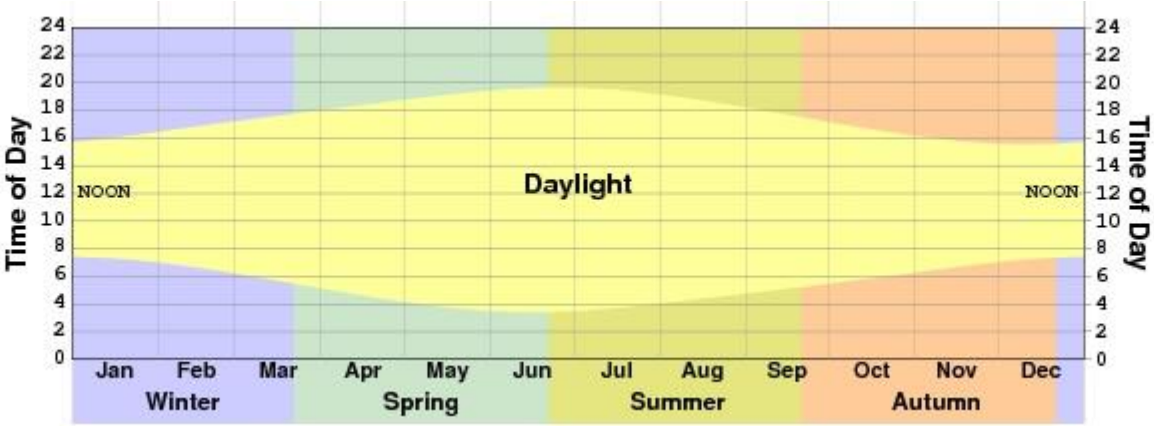


Figure 10. Daylight in Vancouver [8]

Winters in Vancouver can be quite dark. The relatively high latitude means early sunsets (as early as 4:15 pm) and late sunrises (as late as 8:10 am).

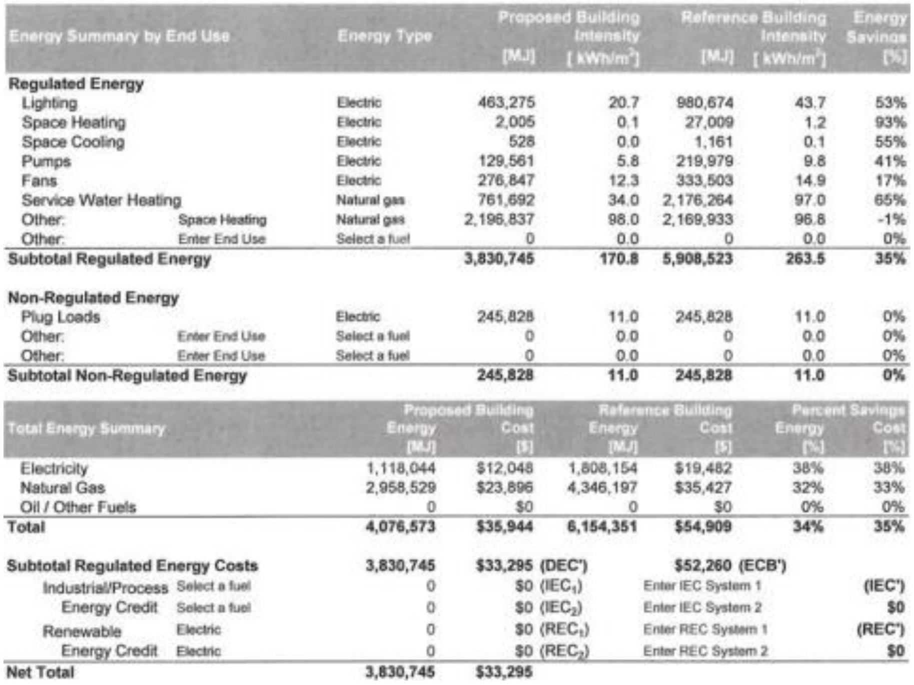
From November to February, on average more than 70% of the already short daytime is completely cloudy in Vancouver.

A different pattern can be seen on summers. July and August are the months with the higher percentage of daylight.

4. Energy Performance Analysis

a. Modelled and Measured Energy Performance

MCW Consultant's made several simulations to predict the energy performance of the renovated building using EE4 software. The most recent revision could be seen below.



Energy Summary by End Use		Energy Type	Proposed Building [MJ]	Proposed Building Intensity [kWh/m²]	Reference Building [MJ]	Reference Building Intensity [kWh/m²]	Energy Savings [%]
Regulated Energy							
Lighting		Electric	463,275	20.7	980,674	43.7	53%
Space Heating		Electric	2,005	0.1	27,009	1.2	93%
Space Cooling		Electric	528	0.0	1,161	0.1	55%
Pumps		Electric	129,561	5.8	219,979	9.8	41%
Fans		Electric	276,847	12.3	333,503	14.9	17%
Service Water Heating		Natural gas	761,692	34.0	2,176,264	97.0	65%
Other:	Space Heating	Natural gas	2,196,837	98.0	2,169,933	96.8	-1%
Other:	Enter End Use	Select a fuel	0	0.0	0	0.0	0%
Subtotal Regulated Energy			**3,830,745**	**170.8**	**5,908,523**	**263.5**	**35%**
Non-Regulated Energy							
Plug Loads		Electric	245,828	11.0	245,828	11.0	0%
Other:	Enter End Use	Select a fuel	0	0.0	0	0.0	0%
Other:	Enter End Use	Select a fuel	0	0.0	0	0.0	0%
Subtotal Non-Regulated Energy			**245,828**	**11.0**	**245,828**	**11.0**	**0%**

Total Energy Summary	Proposed Building Energy [MJ]	Proposed Building Cost [$]	Reference Building Energy [MJ]	Reference Building Cost [$]	Percent Savings Energy [%]	Percent Savings Cost [%]
Electricity	1,118,044	$12,048	1,808,154	$19,482	38%	38%
Natural Gas	2,958,529	$23,896	4,346,197	$35,427	32%	33%
Oil / Other Fuels	0	$0	0	$0	0%	0%
Total	**4,076,573**	**$35,944**	**6,154,351**	**$54,909**	**34%**	**35%**

Subtotal Regulated Energy Costs		**3,830,745**	**$33,295 (DEC')**	**$52,260 (ECB')**	
Industrial/Process	Select a fuel	0	$0 (IEC$_1$)	Enter IEC System 1	**(IEC')**
Energy Credit	Select a fuel	0	$0 (IEC$_2$)	Enter IEC System 2	**$0**
Renewable	Electric	0	$0 (REC$_1$)	Enter REC System 1	**(REC')**
Energy Credit	Electric	0	$0 (REC$_2$)	Enter REC System 2	**$0**
Net Total		**3,830,745**	**$33,295**		

Figure 11. Predicted Energy Performance [9]

As seen in the predicted energy performance above, renovation of Friedman building was aimed have 34% less energy consumption compared to reference building (MNECB). The EE4 model used the assumption which can be seen in Appendix A.

To verify the modelled energy performance, annual energy consumption of the building were then analyzed and compared as follows. Both electricity and steam consumption were taken directly from the meter data at the building. To properly convert the steam consumption to the actual natural gas consumption of the building, the efficiency of the steam distribution system in UBC was taken into account. According to Joshua Wauthy, Energy Conservation Engineer from UBC Building Operations, overall efficiency to convert natural gas to steam was approximately 60% (80% plant efficiency and 75% distribution system efficiency). Because of this, 1 lbs of steam (1.055 MJ of steam) delivered to Friedman building required approximately 1.76 MJ of natural gas. This was consistent with the value which was used by MCW Consultants Ltd. in their simulation.

It should be noted that UBC were planning to convert the steam system to hot water system during the time of this study. Changing the system would increase the overall efficiency of the system to about 84.5% (87% plant efficiency and 97% distribution system efficiency).

Table 7. Energy Consumption Comparison

Year	Predicted	2010	2011	2012	2013
Electricity (MJ)	1,118,044	2,027,828	2,003,282	2,057,401	2,198,320
Steam (MJ)		1,036,048	1,347,065	1,481,742	1,922,850
Natural Gas (MJ)	2,958,529	1,729,218	2,247,237	2,471,911	3,207,788
Total Energy (MJ)	4,076,573	3,757,046	4,250,518	4,529,312	5,406,109
% Difference		-7.84%	4.27%	11.11%	32%

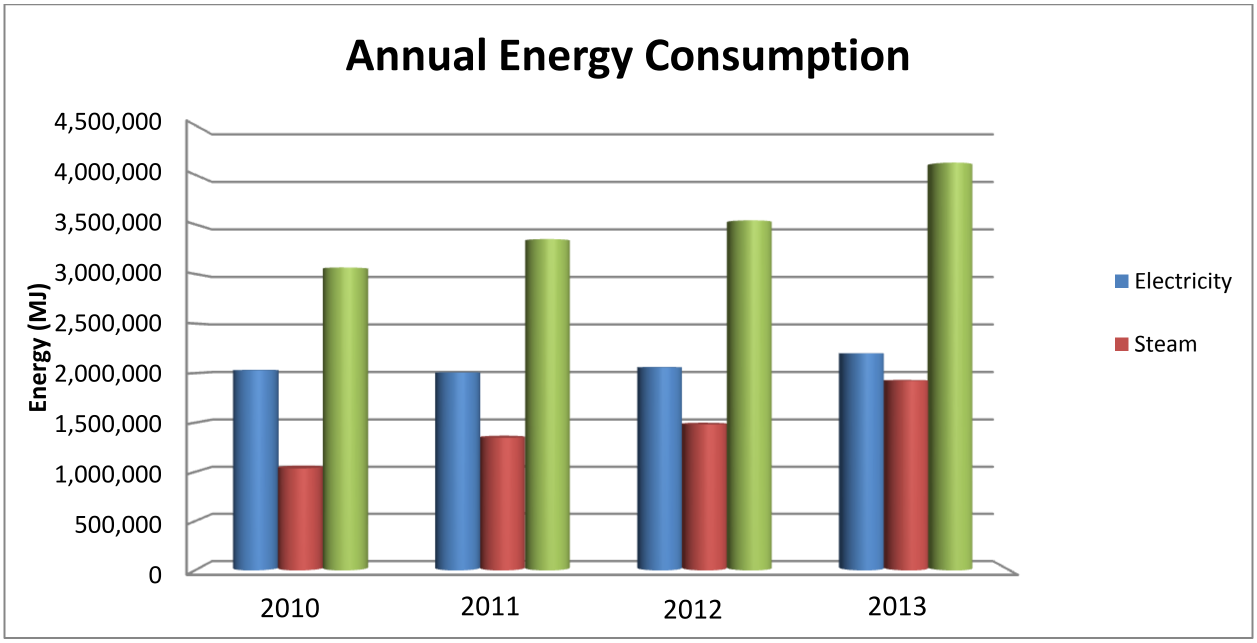


Figure 12. Annual Energy Consumption of Friedman Building based on the Meter Data

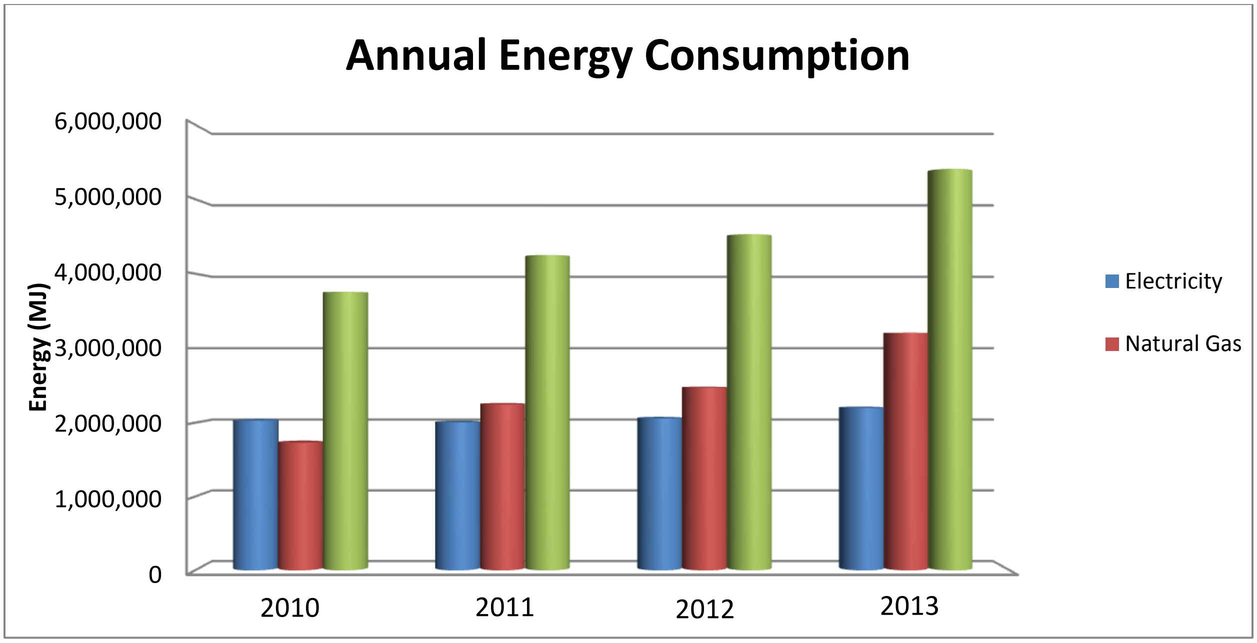


Figure 13. Annual Energy Consumption of Friedman Building, Taking Energy Conversion Ration from Natural Gas to Steam into Consideration

Based on the table and figures above, without considering the conversion ratio of natural gas to steam, the building annual energy consumption was actually better or comparable to the predicted value. However, once the energy distribution system was taken into account, the building performed much worse than expected, with only the performance in year 2010 was actually better than expected.

Electrical energy consumption of the building through year 2010-2013 was consistently off by up to almost 100% compared to the predicted value. Interestingly, there was also a noticeable increase in year 2013 which would be discussed further in the report.

On the other hand, natural gas consumption of the building increased steadily throughout the year. There were several factors which might cause this phenomenon: changes in climate and building thermal performance degradation over time. To investigate these effects, monthly and daily energy demand were investigated in the following section.

b. Monthly and Daily Energy Demand Trend

Using Pulse Energy Dashboard for UBC, the monthly electrical and steam demand could be analyzed. In figure 11-18, actual energy demand for year 2010-2013 were compared to the typical values predicted, “based on historical behaviour and correlates with weather conditions, time of the day, day of the week, month, season, and other available variables [10].”

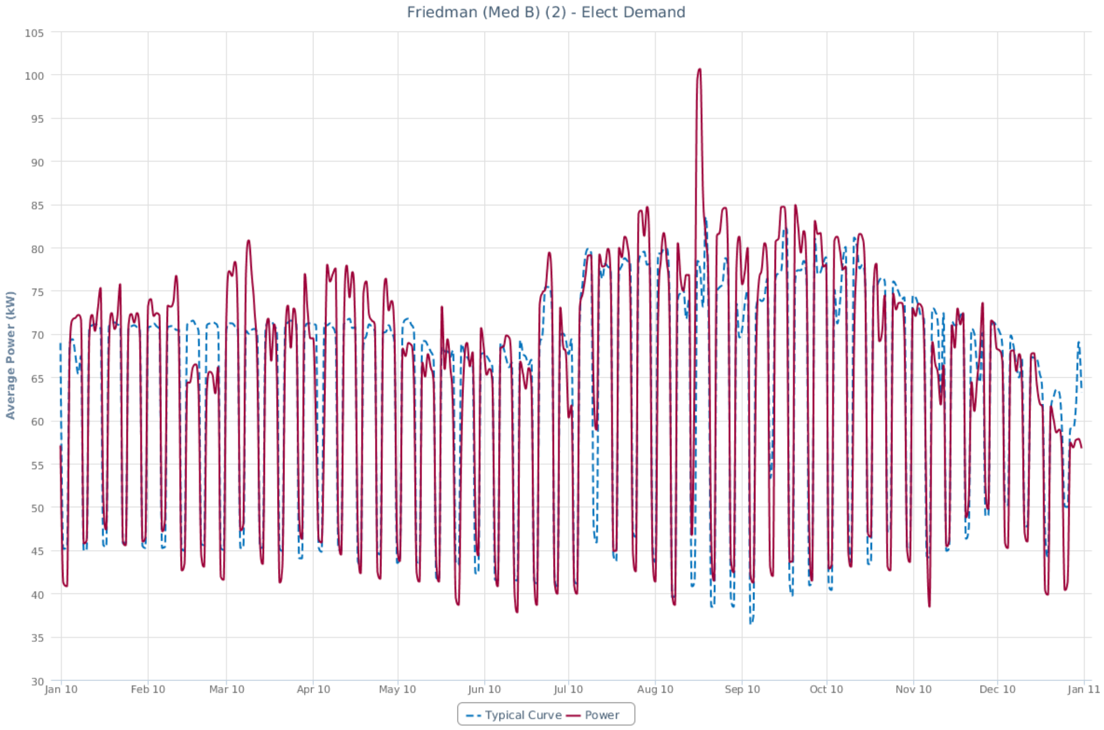


Figure 14. Electrical Demand in Year 2010

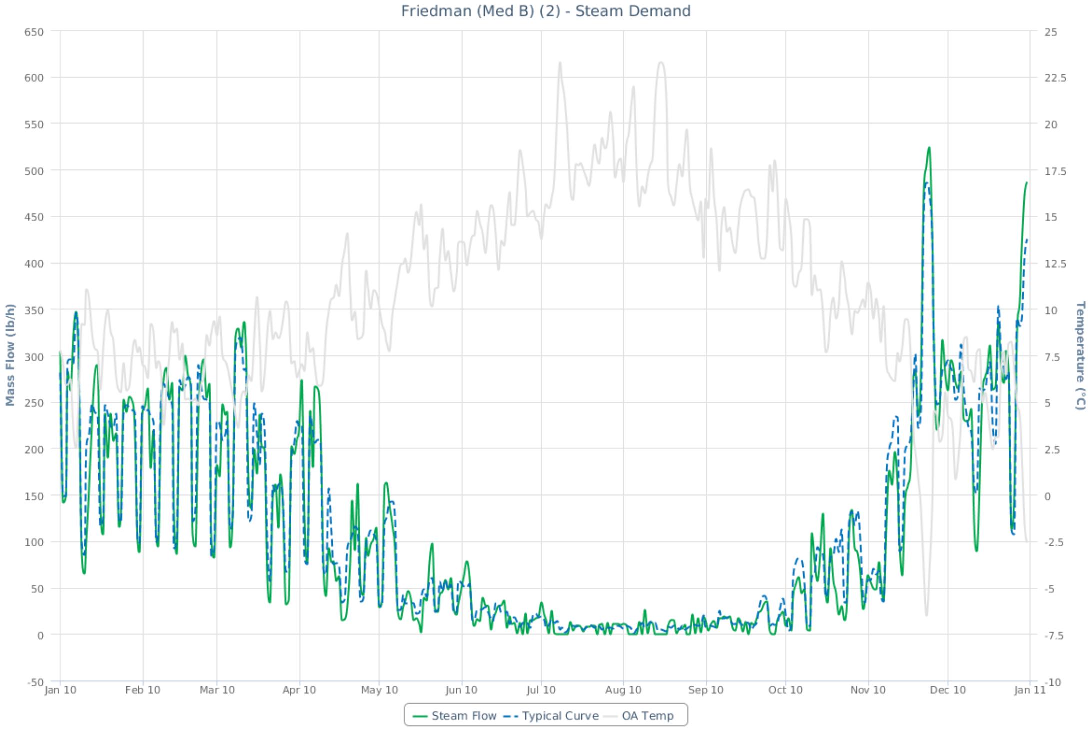


Figure 15. Steam Demand in Year 2010

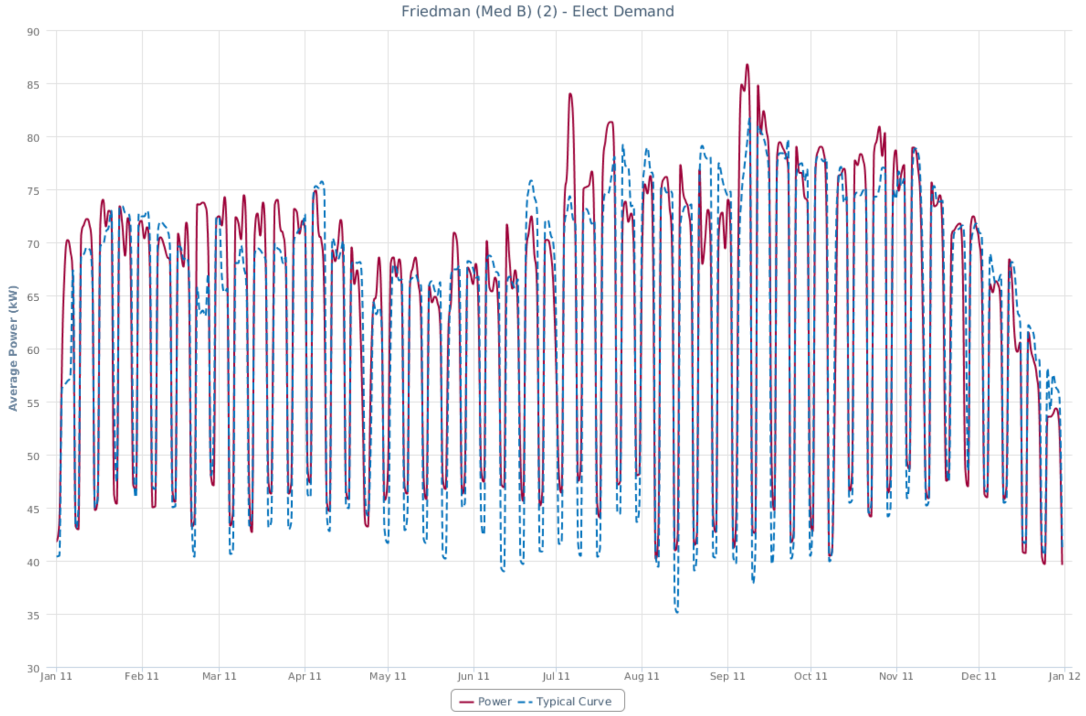


Figure 16. Electrical Demand in Year 2011

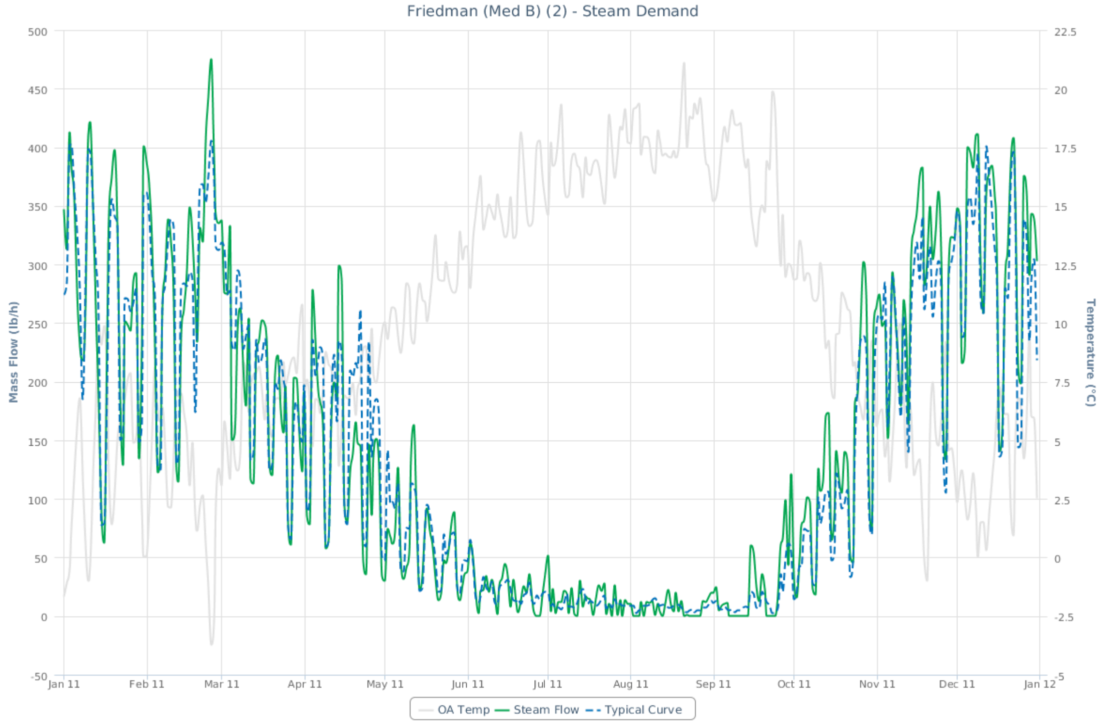


Figure 17. Steam Demand in Year 2011

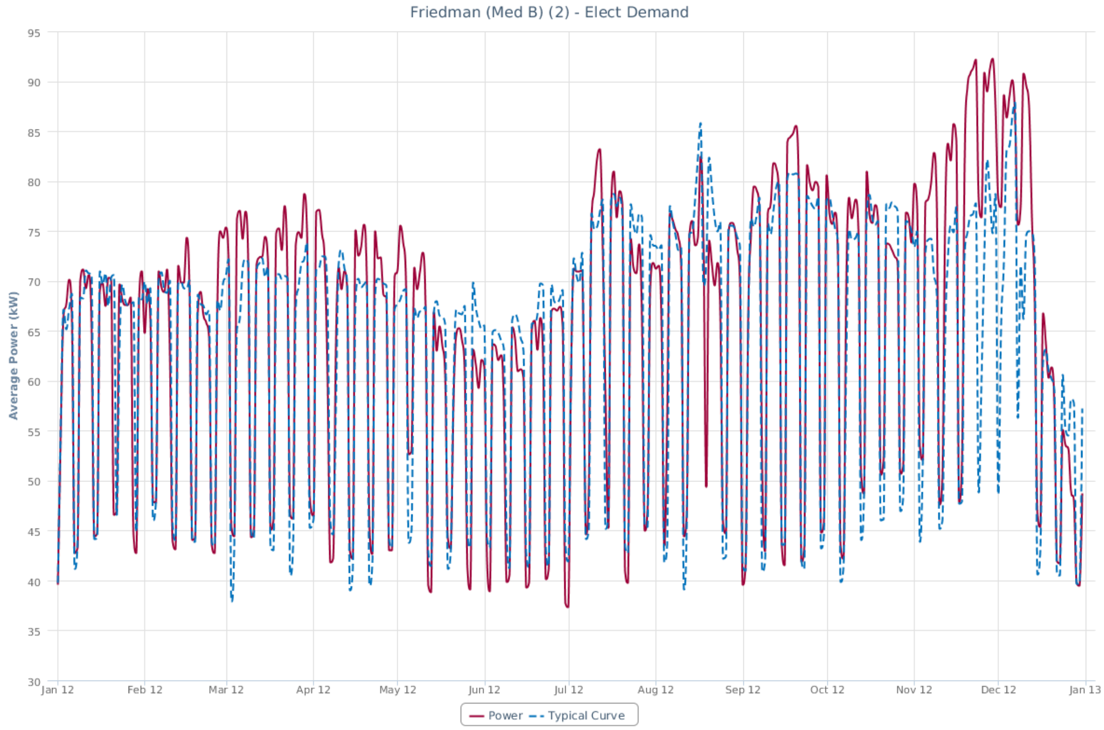


Figure 18. Electrical Demand in Year 2012

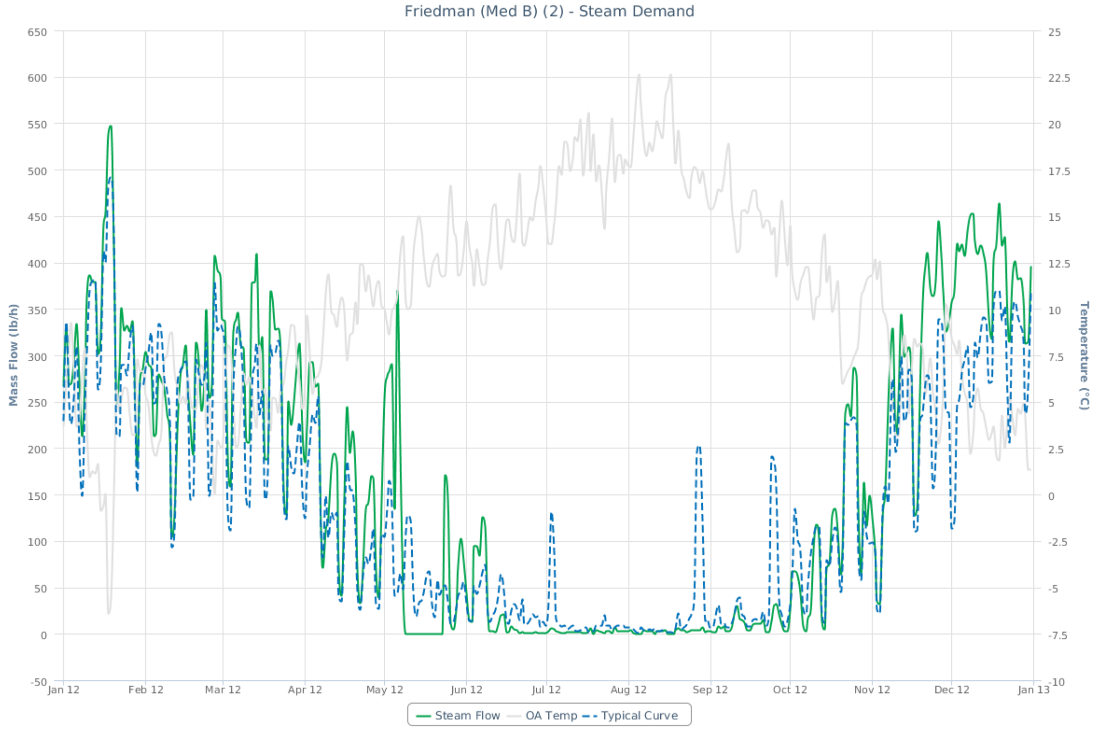


Figure 19. Steam Demand in Year 2012

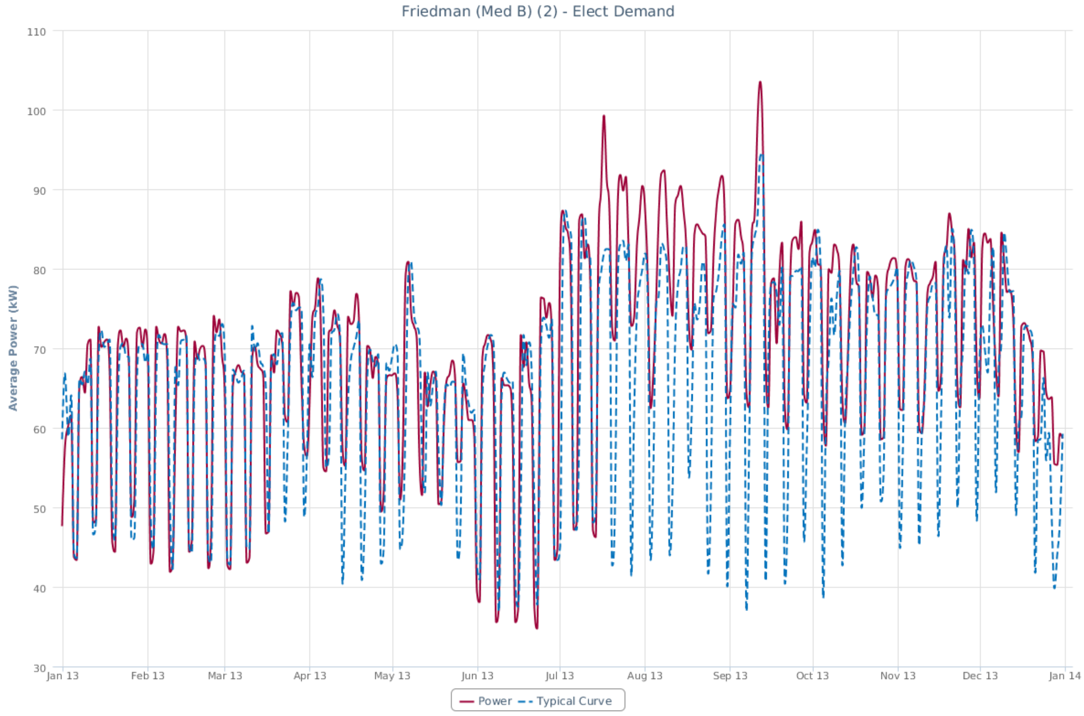


Figure 20. Electrical Demand in Year 2013

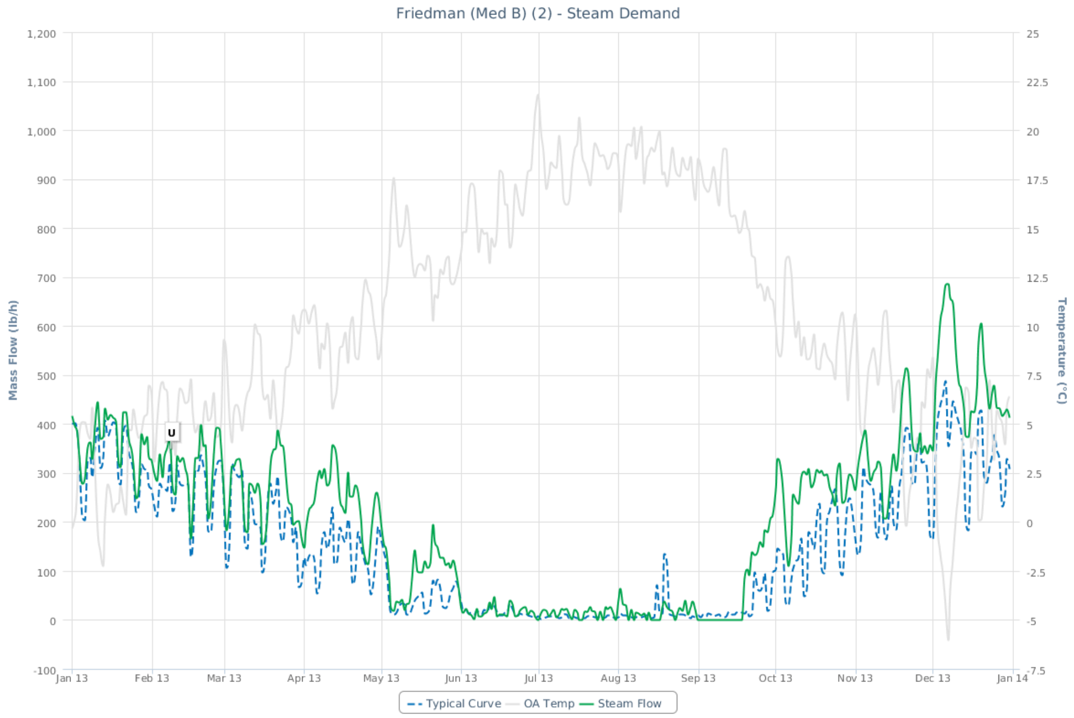


Figure 21. Steam Demand in Year 2013

As seen in figure 14-21 above, most data points were higher than the typical values, most notably in the steam consumption data. This strongly suggest that the thermal performance of the building degraded over time.

Furthermore, there was also a notable increase in electrical energy demand after July 2013. The baseline electrical values were considerably higher compared to the typical/predicted values. This was most likely caused by the additional equipment installed in the building which will be discussed in section 5.

To further clarify the contributions of these factors, daily energy demand of the building were also analyzed. Since it was not feasible to analyze all 365 days in a year, representative time of the year was chosen based on the energy demand distribution which can be seen in the figures below.

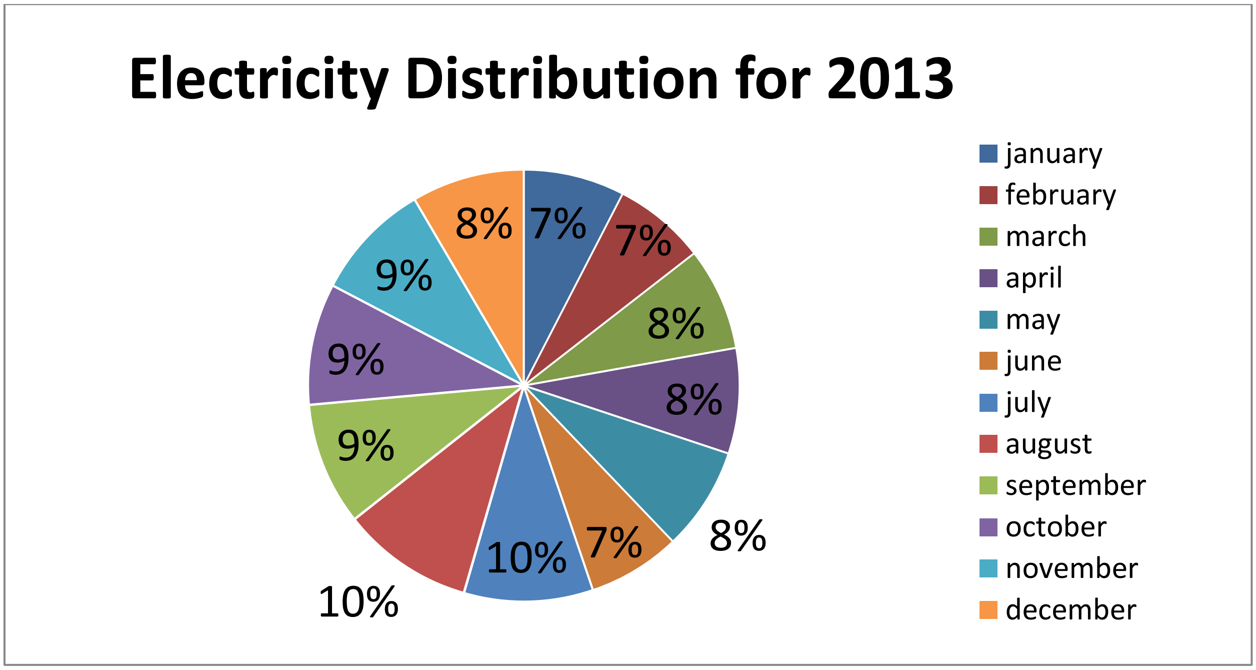


Figure 22. Electricity Demand Distribution for Year 2013

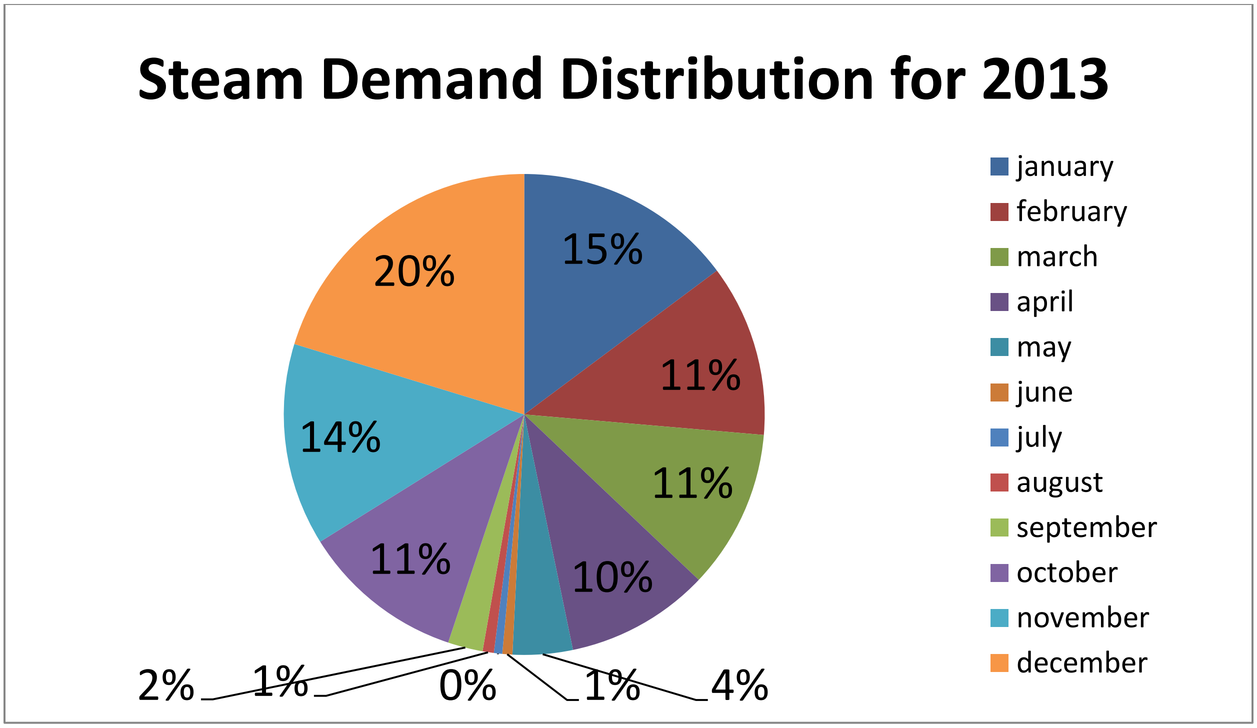


Figure 23. Steam Demand Distribution for Year 2013

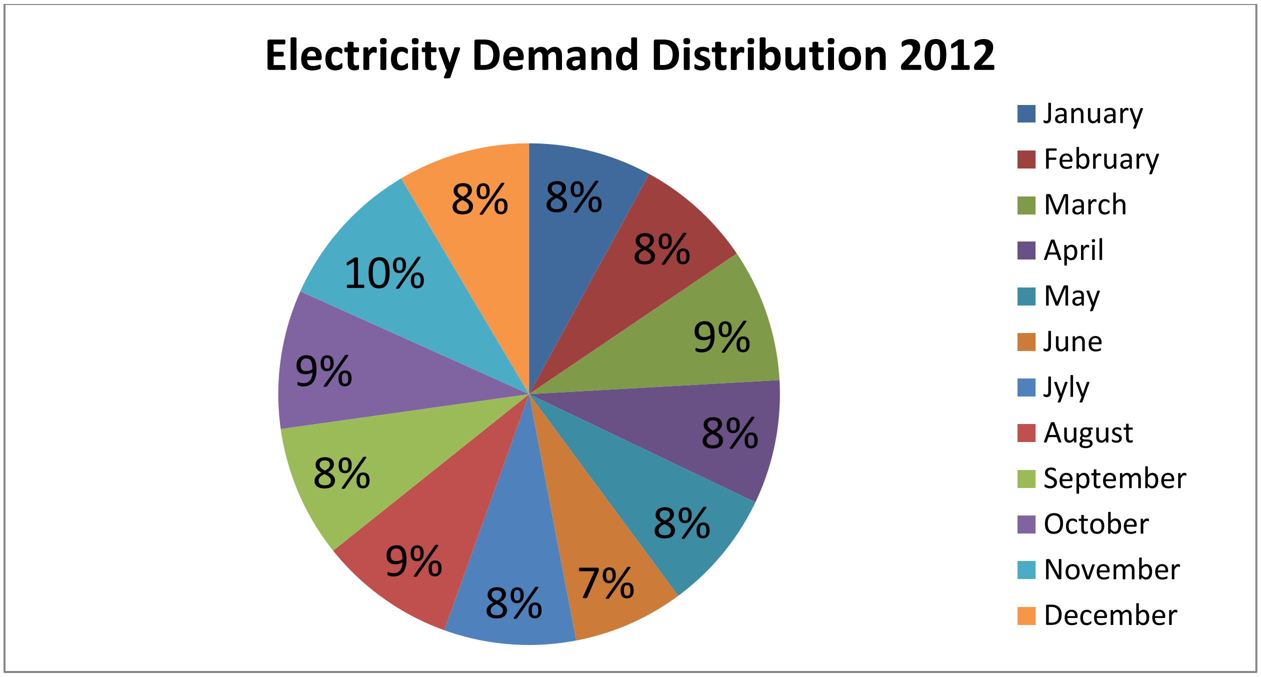


Figure 24. Electricity Demand Distribution 2012

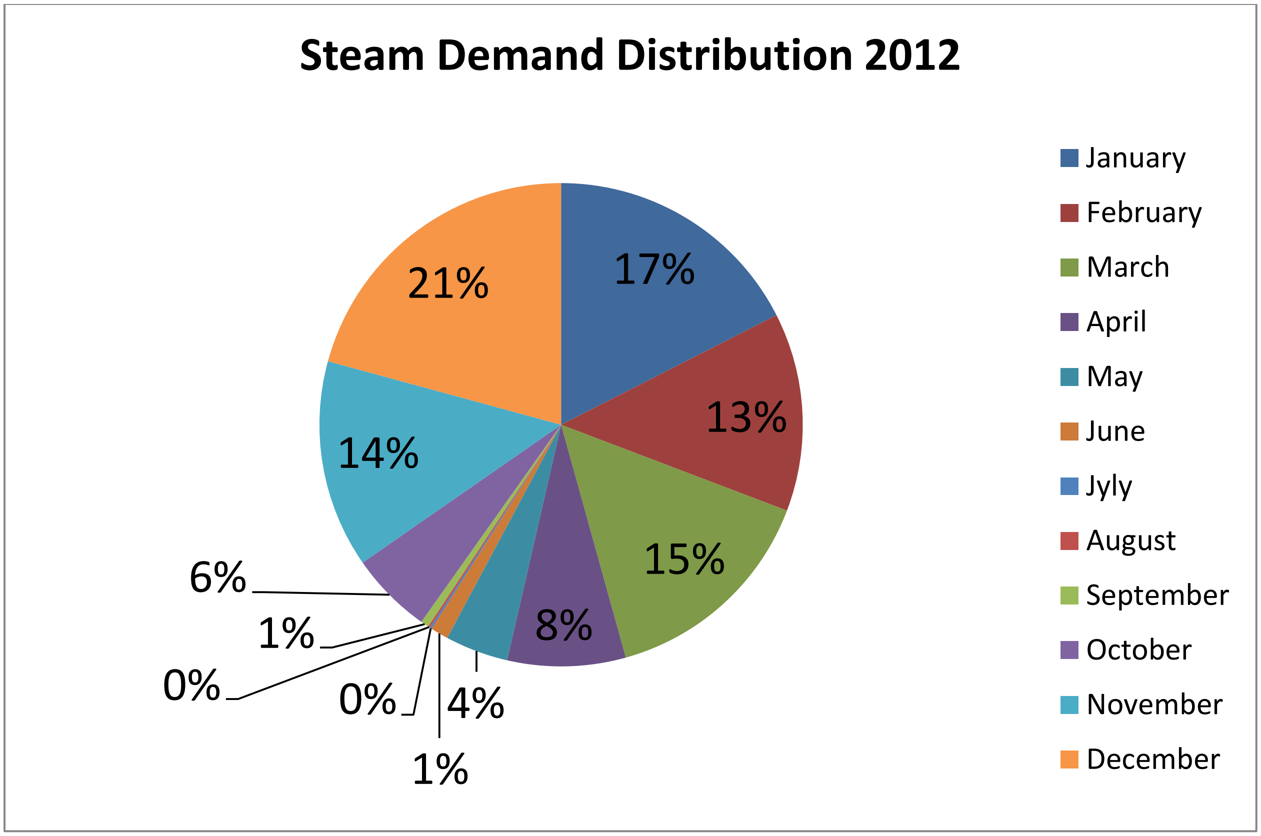


Figure 25. Steam Demand Distribution 2012

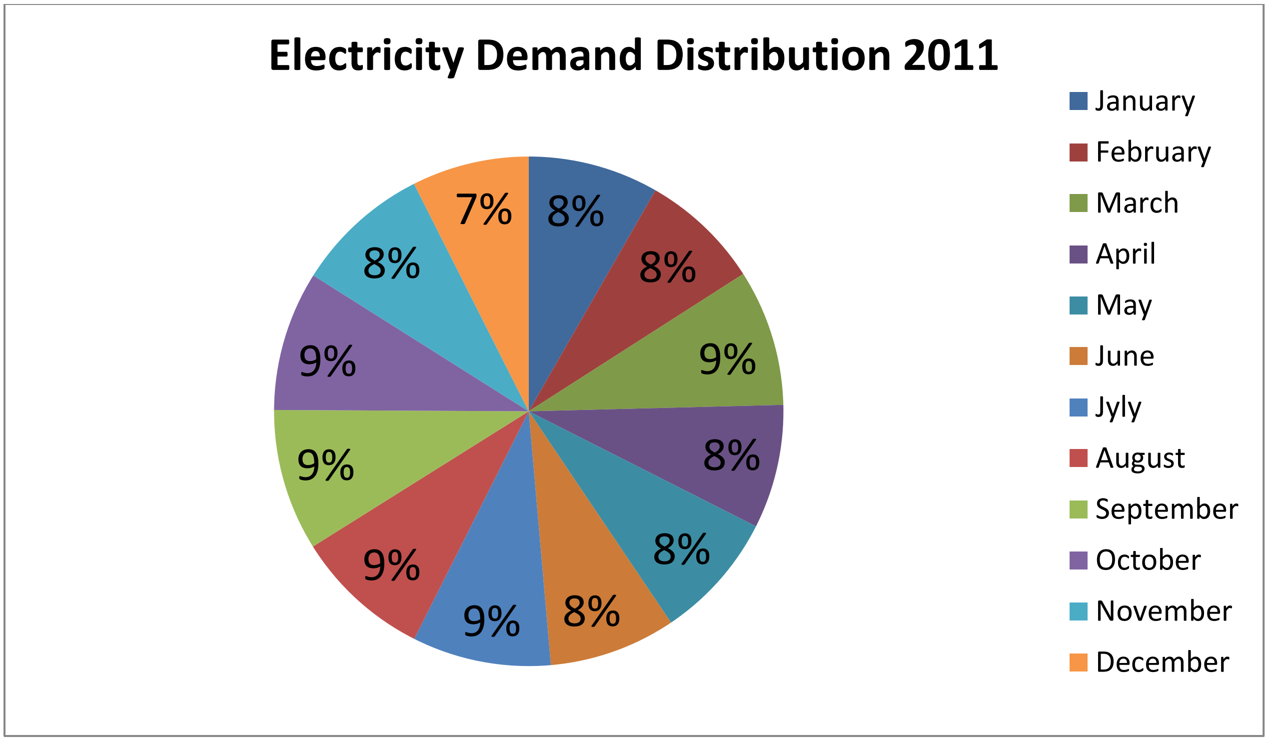


Figure 26. Electricity Demand Distribution 2011

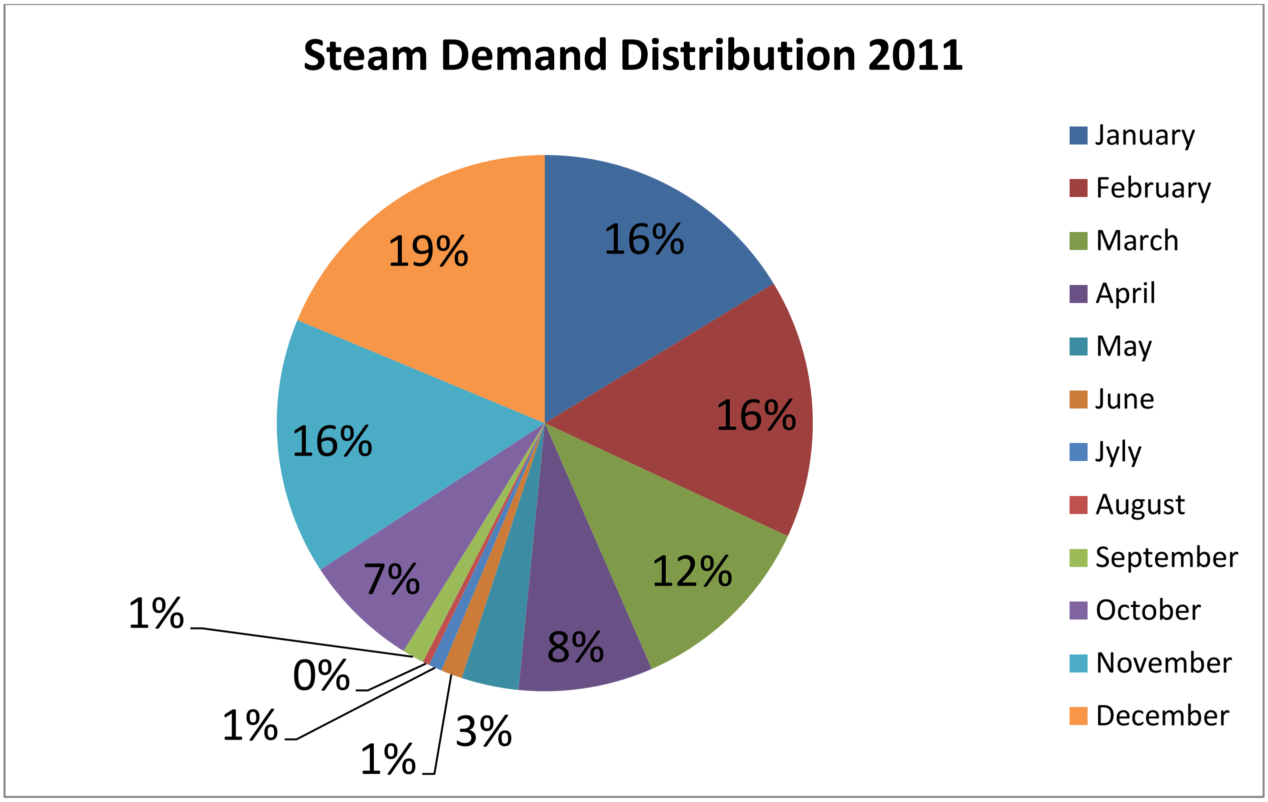


Figure 27. Steam Demand Distribution 2011

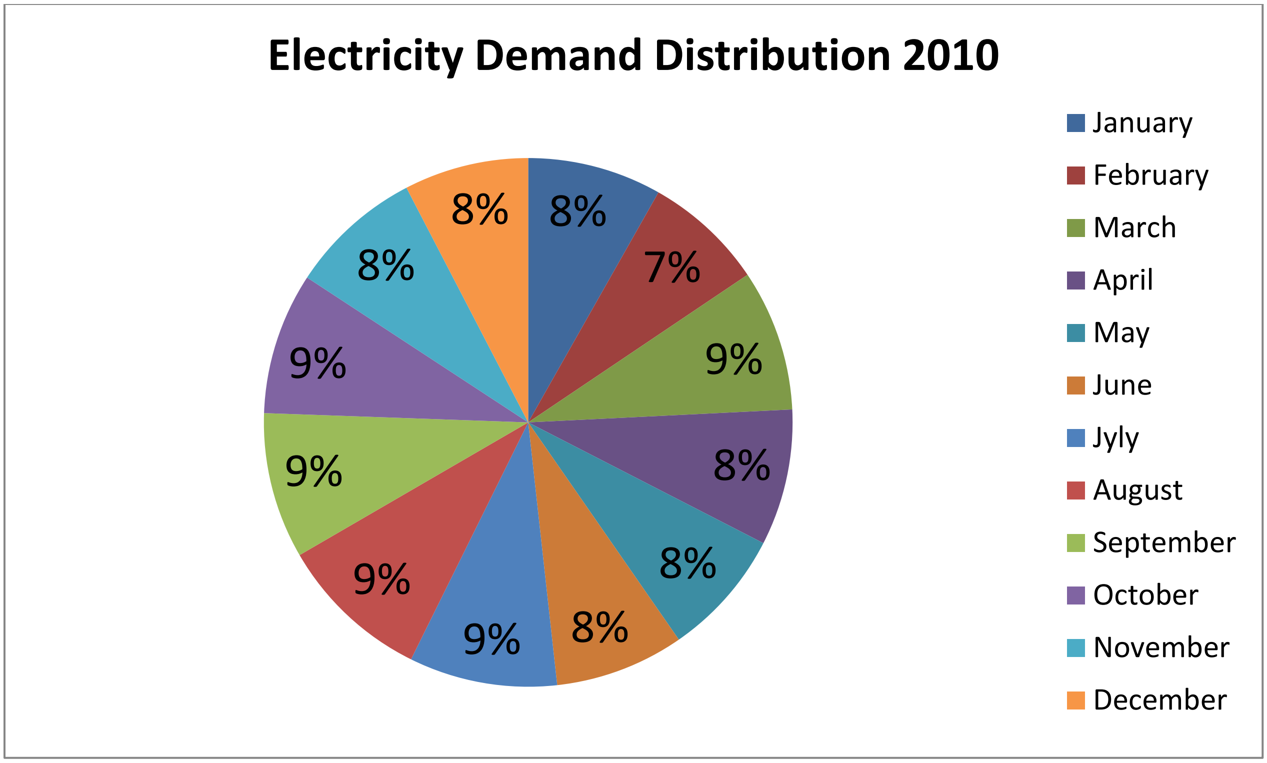


Figure 28. Electricity Demand Distribution 2010

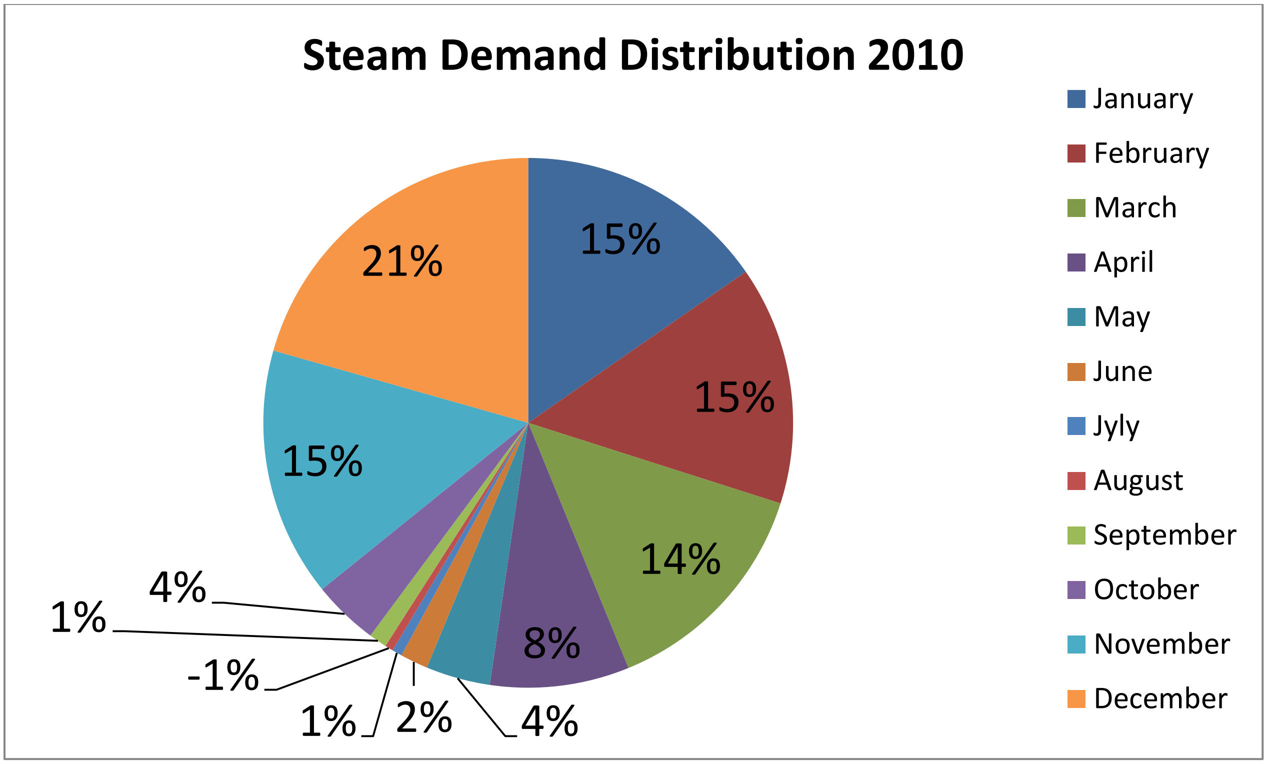


Figure 29. Steam Demand Distribution 2010

Based on figure 22- 29, one day in August and December were chosen as the representative time where electricity and steam energy demand were almost the highest respectively.

In figure 30 and 31 below, daily electricity demand and outdoor air temperature for the first Wednesday in August were plotted and compared.

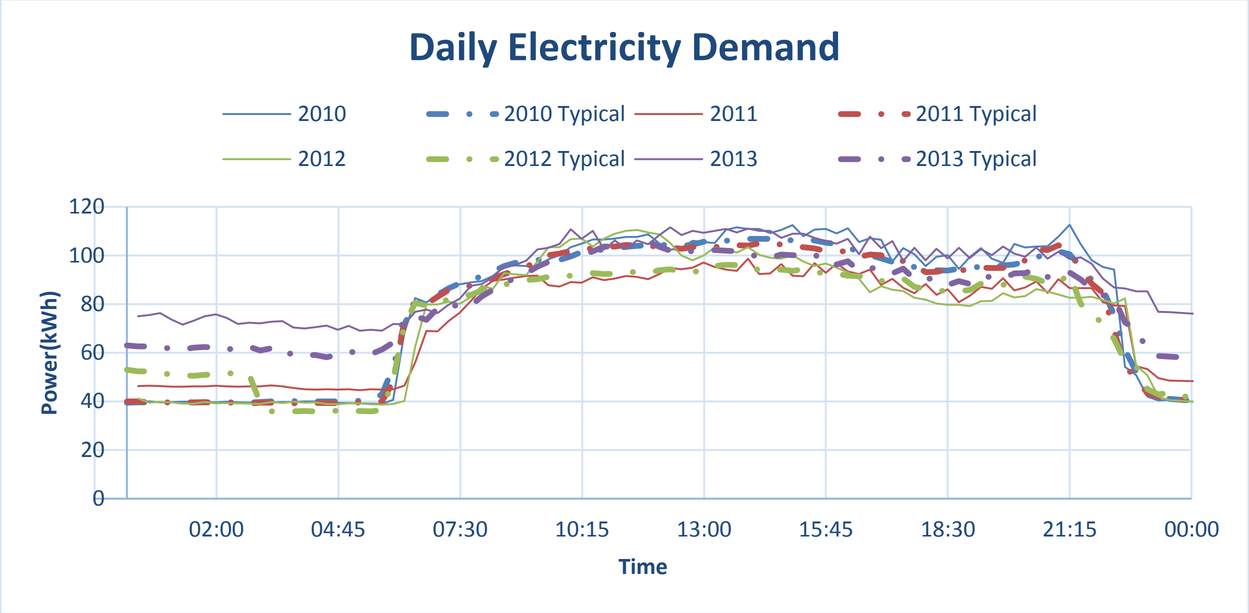


Figure 30. Daily Electricity Consumption on the First Wednesday in August

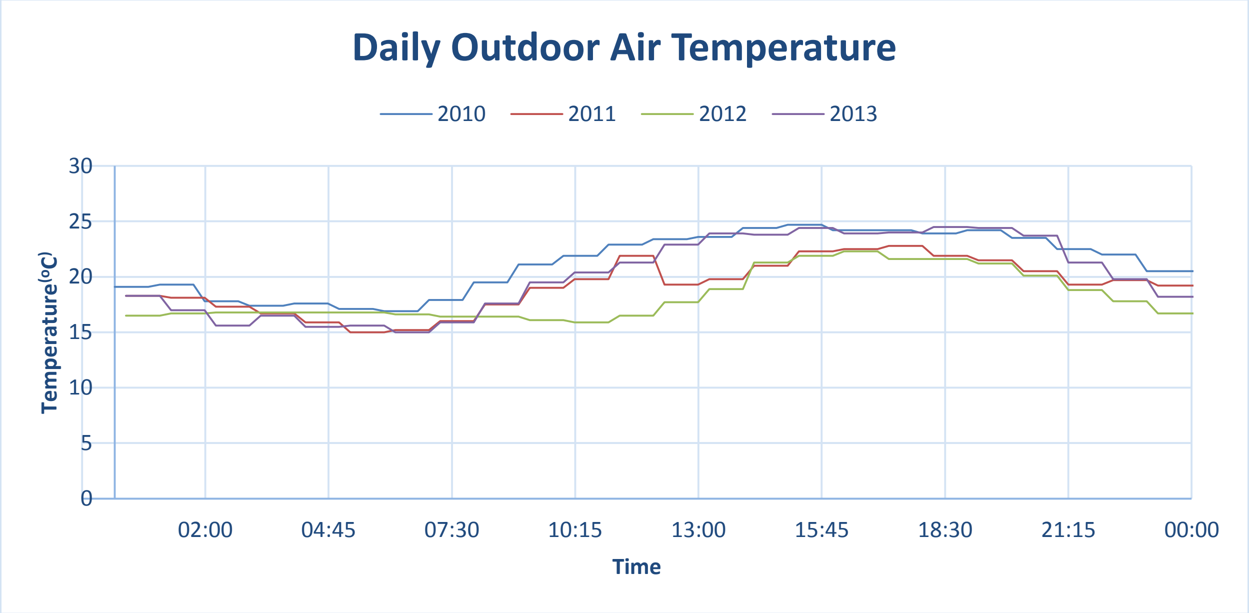


Figure 31. Outdoor Air Temperature on the First Wednesday in August

As seen in figure 30 and 31, electricity demand after considering the outdoor air temperature variation were relatively similar for year 2010-2012. However, there was a notable jump in electricity consumption during off-hour for year 2013. This finding was consistent with other days in the same month.

In figure 32 and 33 below, daily steam demand and outdoor air temperature for the first Wednesday in December were plotted and compared.

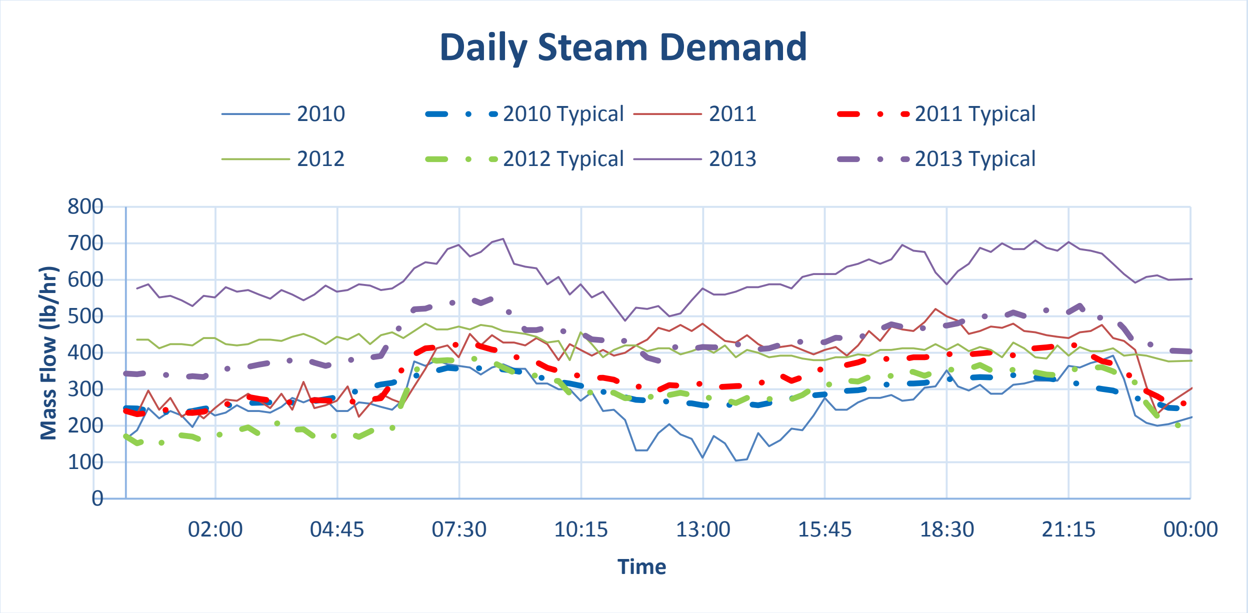


Figure 32. Daily Steam Demand on the First Wednesday in December

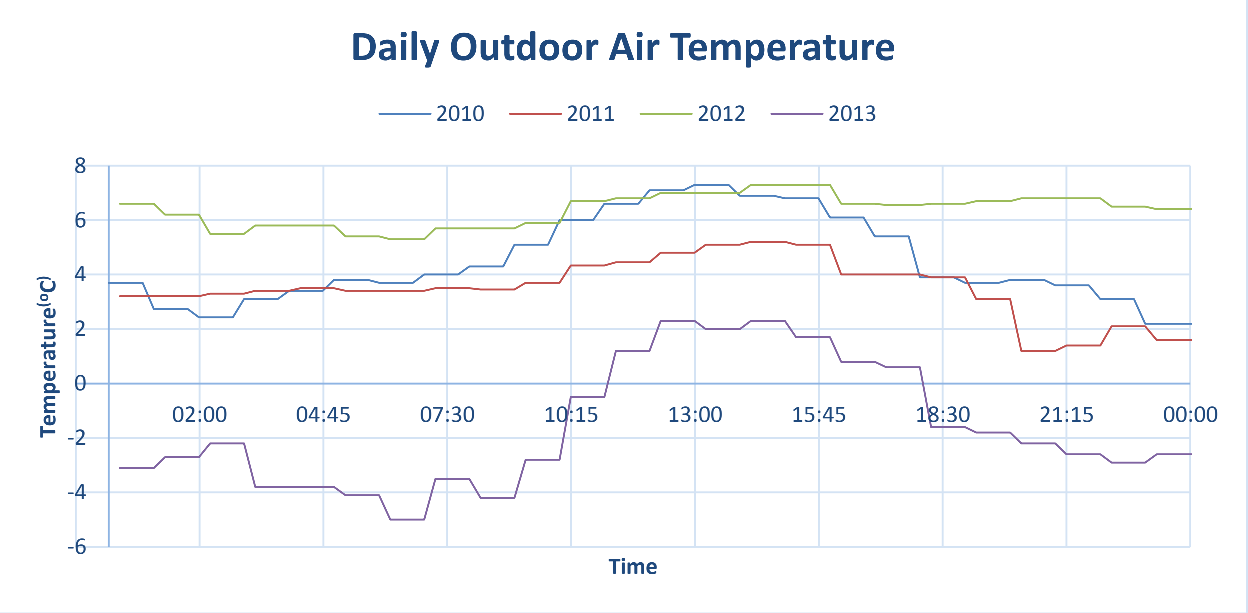


Figure 33. Outdoor Air Temperature on the First Wednesday in December

Unlike the similar values between the typical and actual daily electricity demand, there were increasing gaps found in the steam demand. Furthermore, the steam consumption throughout the day was relatively constant. There were no clear indications of typical work-hours in the figure. This was expected since there were relatively small numbers of students in the building in December. This variation in occupancy pattern will be further discussed in section 5a.

c. Weather Normalization of Energy Consumption for UBC Friedman Building

The procedure is described in Energy Lens website [11]. Before proceeding to the normalization procedure the weather-dependent and non-weather-dependent should be defined. It is very common for a single energy meter to measure both weather-dependent and non-weather-dependent energy consumption together. For example, a building with electric heating might have a single electricity meter measuring all its electricity consumption (heating, lighting, equipment etc).

In degree-day analysis, energy consumption that does not depend on the weather is often referred to as "baseload" energy consumption. It generally comes from energy uses that are not directly involved with heating or cooling the building; examples include electric lights, computer equipment, and industrial processes. For the purposes of the degree-day-based calculations, it is usually assumed that a building's baseload energy consumption is constant throughout the year. In UBC Friedman Building, natural gas is used for heating and the baseload kWh has not to be subtracted from the raw figures. This should have been done in case of the energy consumption (specifically, natural gas) was not 100% degree-day dependent and so, the raw energy consumption figures would contain baseload energy consumption as well as degree-day-dependent energy consumption.

Heating degree days are used to normalize the energy consumption of a heated building so that, the normalized figures can be compared on a like-for-like basis. So, for UBC Friedman Building, heating degree days enable us to calculate normalized energy consumption figures for 2010, 2011, 2012 and 2013. The procedure is described below and the results of these calculations can be seen on Table 9.

The <u>first step</u> is to find the total heating degree days for the years of our interest 2010, 2011, 2012 and 2013. Total heating degree days can be taken from Table 8 and can be seen on Figure 34, but they are presented in more detail on Figure 35 [12].

The <u>second step</u> for the normalization of the annual energy consumption figures of UBC Friedman Building was the calculation of the kWh per degree day for each kWh energy-consumption figure. By dividing by the degree factors out the effect of outside air temperature, and the resulting kWh per degree figures can be compared fairly.

The <u>third step</u> for the normalization of the annual energy consumption figures of UBC Friedman Building was to multiply the kWh per degree day figures by a single "average year" degree-day value. In this case, *2,785.664 degree days* were used as the *multiplier*-an average –year value calculated from the last 25 years' (1989-2013) worth of degree-day data from Vancouver, BC. T. The heating degree days over the last 25 years (1989-2013) are taken from Table 8 and they are presented schematically on Figure 34. This gives normalized equivalents of the original kWh figures that can be fairly compared.

The choice of the multiplier could also be a 10-or 20-year average degree days or "standard degree days" (to normalize figures in such a way that they can be compared between regions). It should be noted that, provided that just one multiplier is used (and not "rolling" averages), it is not matter much what multiplier is used, as our figures will at least be proportionally comparable.

Table 8. Heating degree days over the last 25 years (annual data) for Vancouver

Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Heating degree days	2869.2	2910.6	2893.6	2547.8	2778.8	2686	2544.4	3041.4	2685.5
Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Heating degree days	2538.5	2853.7	2908.1	2849.1	2841.2	2657.6	2526.9	2667.5	2724.7
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**		
Heating degree days	2879.5	3035.3	2924.9	2616.9	2981.8	2855.1	2823.5		

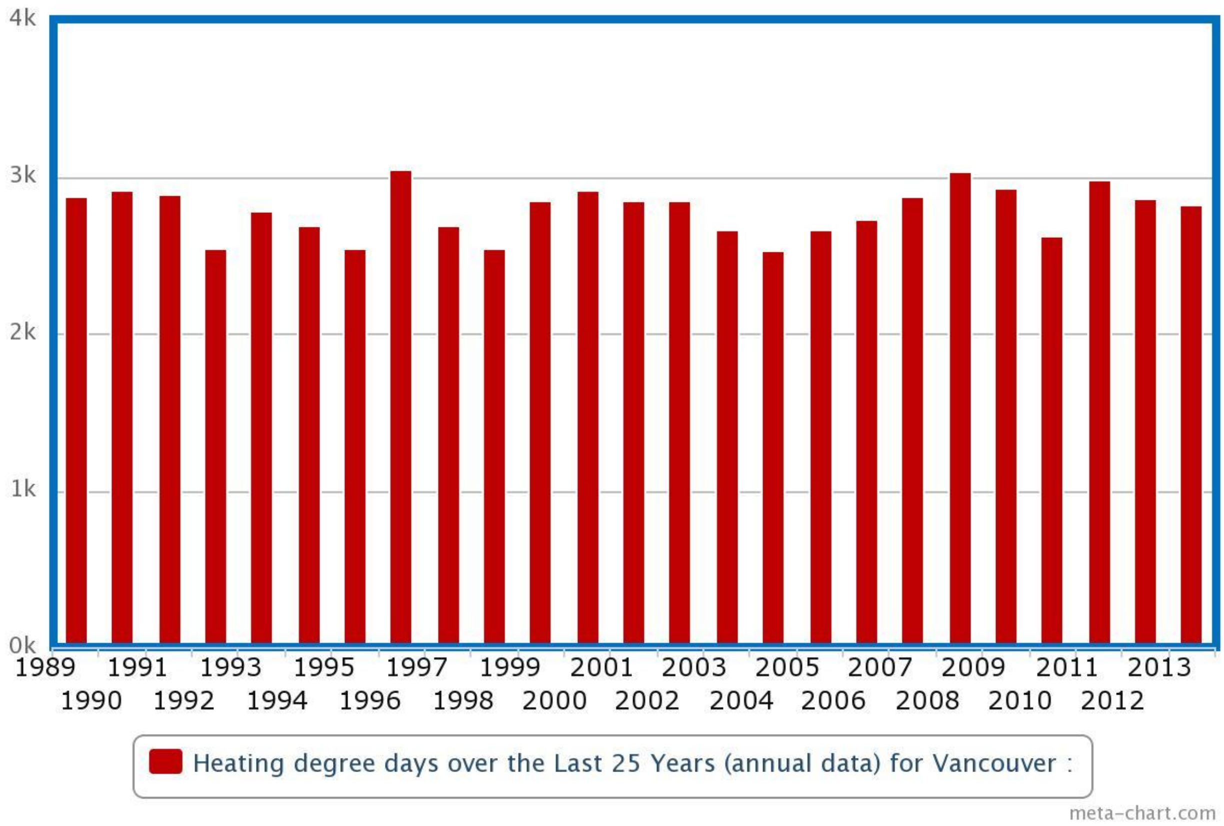


Figure 34. Heating degree days over the last 25 years (annual data) for Vancouver

Table 9. Weather normalization of energy consumption

Year	Total Energy Consumption (Steam)	Total heating degree days	kWh per degree days	Normalized kWh
2010	480338.33	2616.9	183.55	511308.627
2011	624232.50	2981.8	209.345	583164.830
2012	686641.94	2855.1	240.497	669943.835
2013	891052.22	2823.5	315.584	879110.988

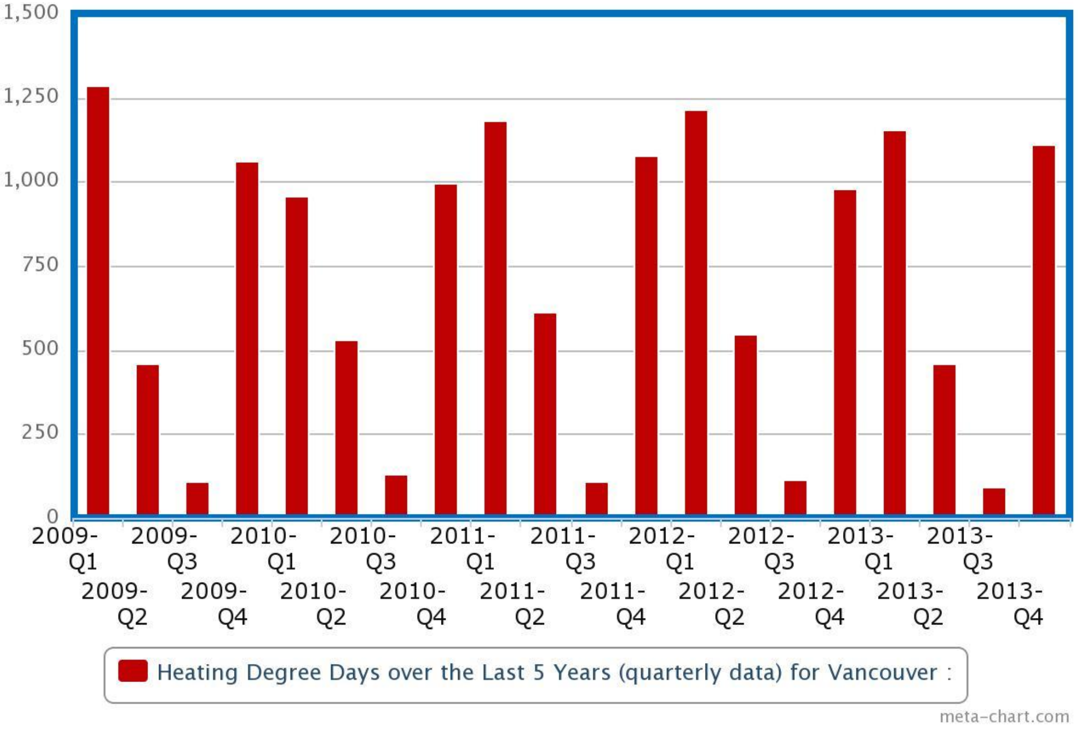


Figure 35. Heating degree days over the last 5 years (quarterly data) for Vancouver

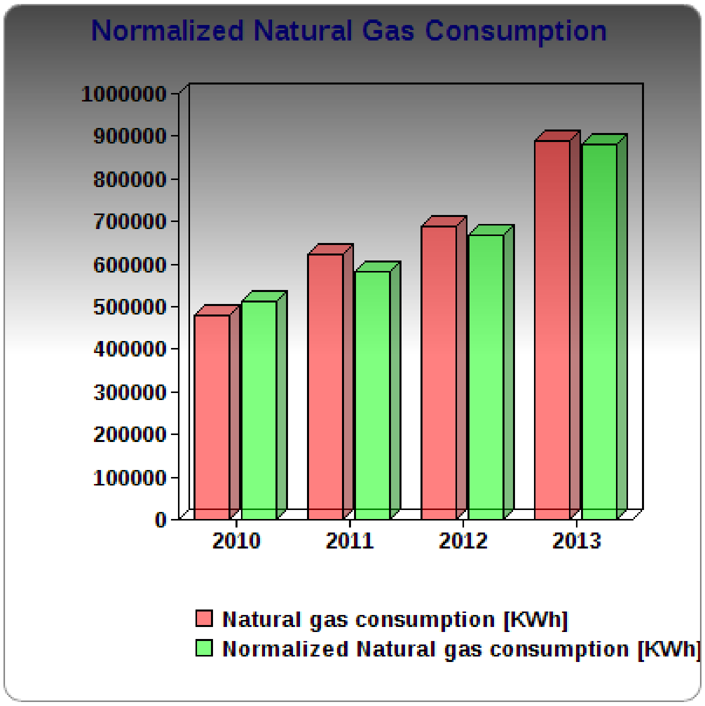


Figure 36. Normalized Natural gas consumption for years 2010, 2011, 2012 and 2013

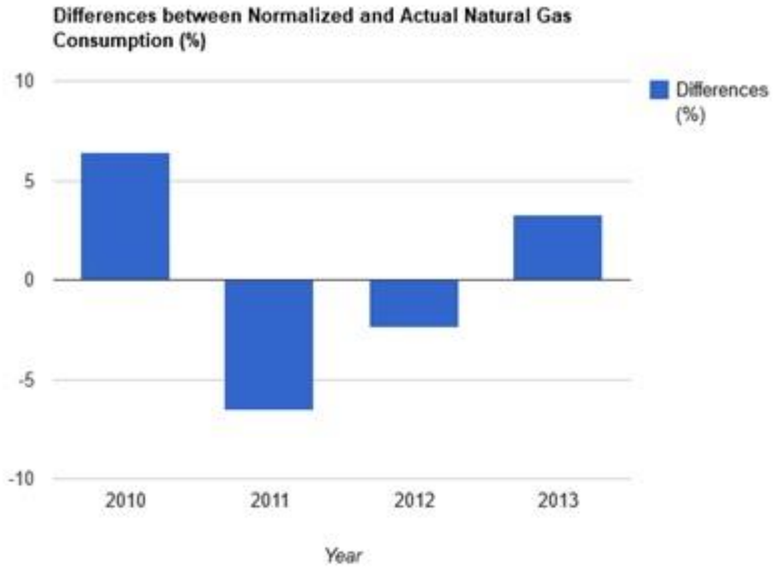


Figure 37. Differences between Normalized and Actual Natural Gas Consumption for Years 2010, 2011, 2012 and 2013

Figure 36 shows the comparison between the actual weather-dependent energy consumption (natural gas consumption) and the normalized values. The differences between normalized and actual natural gas consumption for years 2010, 2011 , 2012 and 2013 can be seen on Figure 37. There are not considerable differences between the raw figures and the normalized figures. Actual natural gas consumption is slightly higher than the normalized natural gas consumption in years 2011, 2012 and 2013. Respectively, normalized natural gas consumption is slightly higher than the actual natural gas consumption in 2010. And, the more important is that the raw figures show that the natural gas consumption of UBC Friedman Building increases steadily from 2010 to 2012 and there is a more rapid increase in 2013. Exactly the same pattern can be seen in normalized figures. Given these similar patterns, even though the normalization technique were relatively successful in taking into account the climate variation observed previously, the study wasn’t sufficient enough in explaining the steady increase in energy consumption demand.

5. Potential Sources of Discrepancies

Based on the findings above, there were several factors which might contribute to the performance gaps observed in LEED buildings such as: changes in energy demand, changes in design, inaccurate building plug load assumption, and building envelope degradation. This following section would explore each of these factors in detail and summarized the efforts which the authors have done to investigate them. Furthermore, effects of these factors observed in Friedman Building would also be discussed.

a. Changes in Energy Demand Throughout the year

One of the most prominent factors observed in the study is the change of energy demand throughout the year by weather condition, installation of new equipment, and changes in occupancy pattern.

i. Weather Contribution

As discussed in the previous section, weather condition, especially outdoor air temperature, contribute significantly to the changes in energy demand. As seen in figure 37, the normalization technique using heating degree days was able to remove the contribution from these factors and should be considered for energy consumption analysis.

ii. Installation of New Equipment

As observed in figure 20, there was a noticeable jump in electrical energy demand after July 2013, this was most likely caused by the installation of air conditioning unit for the teleconference devices in the Division of Physical Therapy of the School of Rehabilitation Science. This increase in energy demand was also observed in the building annual energy consumption.

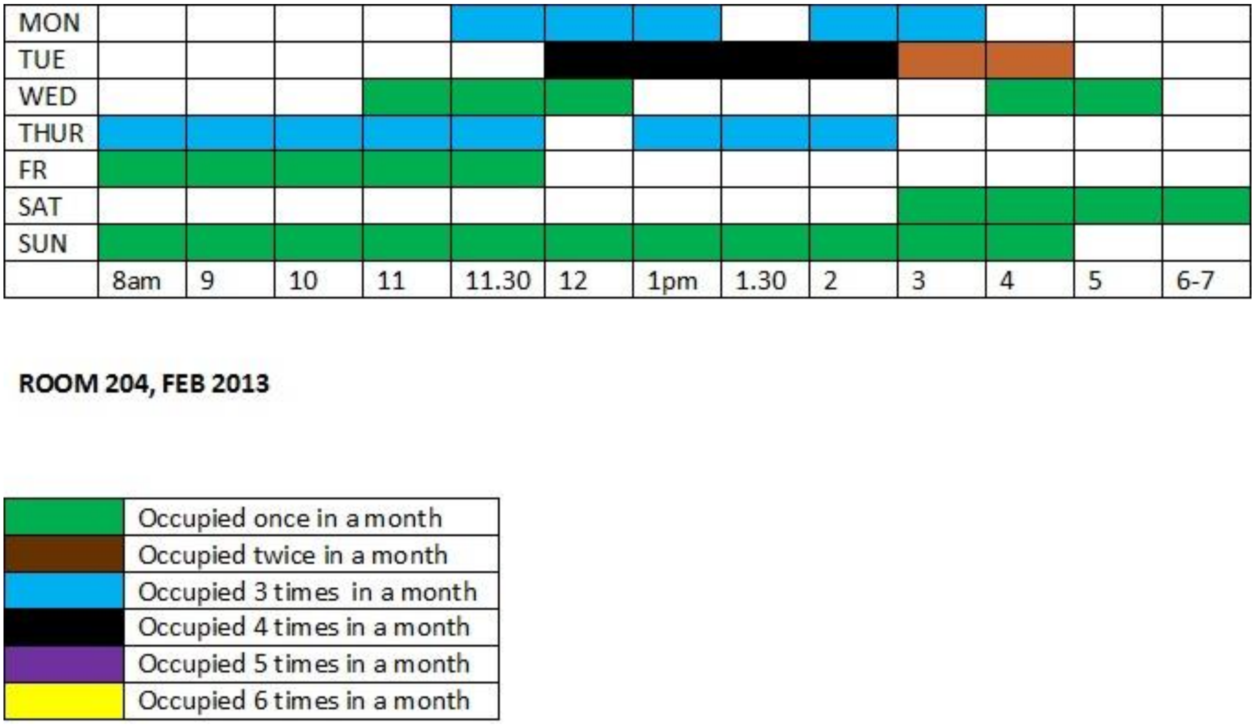
iii. Changes in Occupancy Pattern

Changes in occupancy pattern in the building might have also contributed to the performance gap between predicted and measured value. This was evident in the annual electrical energy demand graphs which can be seen in figure 14,16,18, and 20. In those figures, there were noticeable dips in electricity demand during the Summer term and holiday season in December. However, the contributions of changing occupancy pattern with the steam consumption weren't as obvious.

After the assessment of the annual energy usage data, there were actually three different months which were of particular interest: August (highest electrical consumption, almost the lowest steam consumption), December (highest steam consumption), and February (lowest electrical consumption).

To analyze the changes in occupancy pattern during these three months, calendar information of year 2013 were used for the study of the occupancy pattern in several rooms which were chosen based on the recommendations the program administrators of the buildings. These rooms were considered as rooms with relatively high occupancies. They were: rooms 204 and 304 from the Physical Therapy Division of School of Rehabilitation Sciences as well as Room 354 and 355 from School of Audiology and Speech Sciences.

The rooms' monthly room usage data (booked hours and approximate number of occupants were studied to determine the occupancy pattern in the months of interest and identify any possible sources of the existing discrepancies.

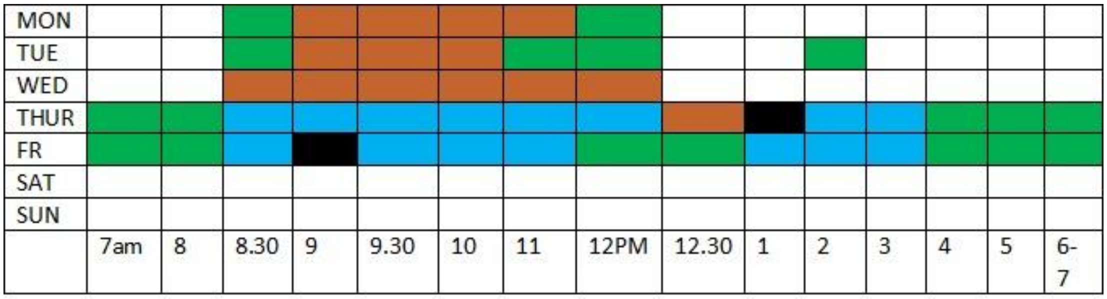


MON					🟦	🟦	🟦		🟦	🟦			
TUE						⬛	⬛	⬛	⬛	🟧	🟧		
WED				🟩	🟩	🟩					🟩	🟩	
THUR	🟦	🟦	🟦	🟦	🟦		🟦	🟦	🟦				
FR	🟩	🟩	🟩	🟩	🟩								
SAT										🟩	🟩	🟩	🟩
SUN	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
	8am	9	10	11	11.30	12	1pm	1.30	2	3	4	5	6-7

ROOM 204, FEB 2013

🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

Figure 38. Occupancy Pattern for Room 204-Feb 2013



MON			🟩	🟫	🟫	🟫	🟫	🟩							
TUE			🟩	🟫	🟫	🟫	🟩	🟩			🟩				
WED			🟫	🟫	🟫	🟫	🟫	🟫							
THUR	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟫	⬛	🟦	🟦	🟩	🟩	🟩
FR	🟩	🟩	🟦	⬛	🟦	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟩	🟩	🟩
SAT															
SUN															
	7am	8	8.30	9	9.30	10	11	12PM	12.30	1	2	3	4	5	6-7

ROOM 204, AUG 2013

🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

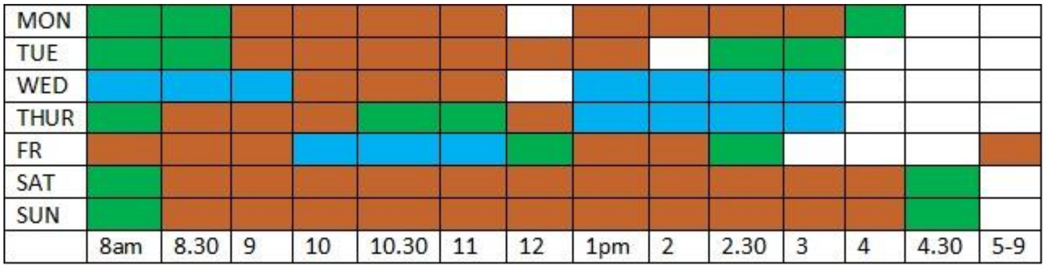
Figure 39. Occupancy Pattern for Room 204- Aug 2013

MON					
TUE		🟩	🟩	🟩	
WED					
THUR					
FR			🟩		
SAT	🟩	🟩	🟩	🟩	🟩
SUN	🟫	🟫	🟫	🟫	🟫
	7am	7.30am	8am	4pm	5-7

ROOM 204, DEC 2013

🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

Figure 40. Occupancy Pattern for Room 204- Dec 2013

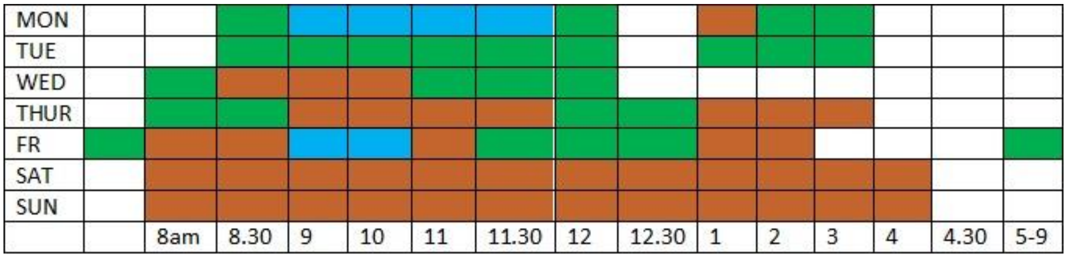


MON	🟩	🟩	🟫	🟫	🟫	🟫		🟫	🟫	🟫	🟫	🟩		
TUE	🟩	🟩	🟫	🟫	🟫	🟫	🟫	🟫		🟩	🟩			
WED	🟦	🟦	🟦	🟫	🟫	🟫		🟦	🟦	🟦	🟦			
THUR	🟩	🟫	🟫	🟫	🟩	🟩	🟫	🟦	🟦	🟦	🟦			
FR	🟫	🟫	🟫	🟦	🟦	🟦	🟩	🟫	🟫	🟩				🟫
SAT	🟩	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟩	
SUN	🟩	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟩	
	8am	8.30	9	10	10.30	11	12	1pm	2	2.30	3	4	4.30	5-9

ROOM 304, FEB 2013

🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

Figure 41. Occupancy Pattern for Room 304- Feb 2013



MON			🟩	🟦	🟦	🟦	🟦	🟩		🟫	🟩	🟩			
TUE			🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩			
WED		🟩	🟫	🟫	🟫	🟩	🟩	🟩							
THUR		🟩	🟩	🟫	🟫	🟫	🟫	🟩	🟩	🟫	🟫	🟫			
FR	🟩	🟫	🟫	🟦	🟦	🟫	🟩	🟩	🟩	🟫	🟫				🟩
SAT		🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫		
SUN		🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫		
		8am	8.30	9	10	11	11.30	12	12.30	1	2	3	4	4.30	5-9

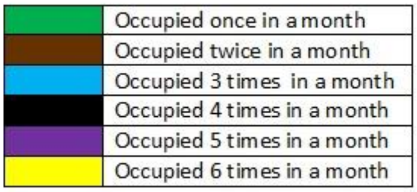
ROOM 304, AUG 2013

🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

Figure 42. Occupancy Pattern for Room 304- Aug 2013

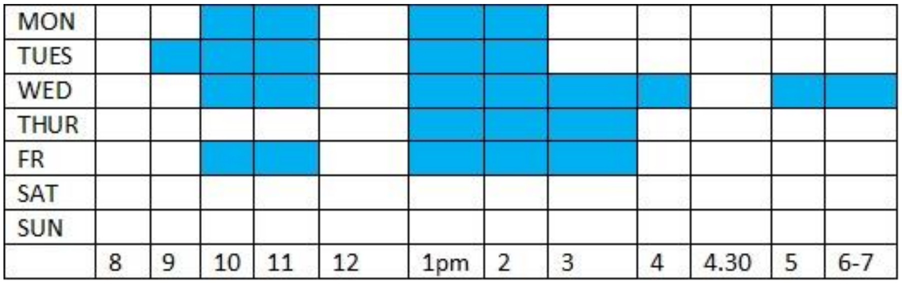
MON		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
TUE	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
WED											
THUR											
FR											
SAT											
SUN											
	7.30am	8	10	11	11.30	12	1pm	1.30	2	3	4-5

ROOM 304, DEC 2013



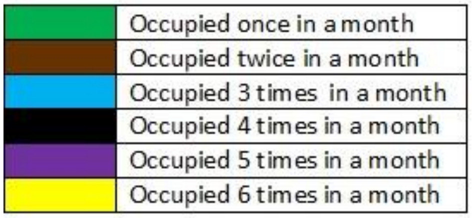
🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

Figure 43. Occupancy Pattern for Room 304- Dec 2013



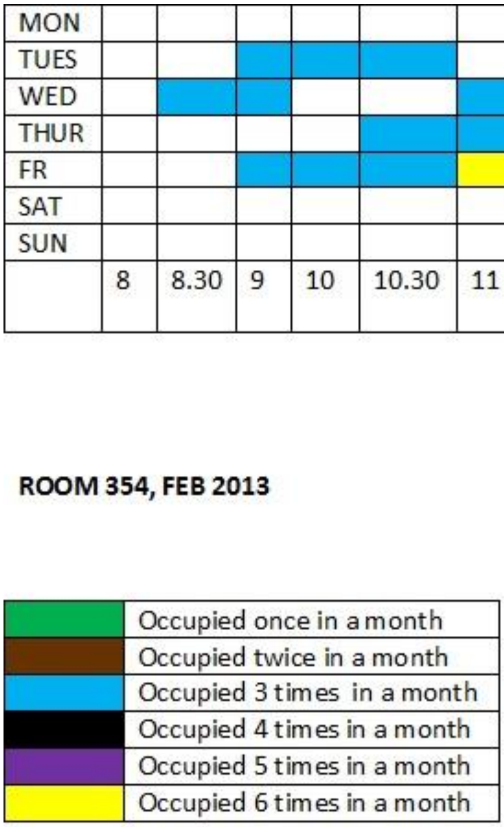
MON			🟦	🟦		🟦	🟦					
TUES		🟦	🟦	🟦		🟦	🟦					
WED			🟦	🟦		🟦	🟦	🟦	🟦		🟦	🟦
THUR						🟦	🟦	🟦				
FR			🟦	🟦		🟦	🟦	🟦				
SAT												
SUN												
	8	9	10	11	12	1pm	2	3	4	4.30	5	6-7

ROOM 355, FEBRUARY 2013



🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

Figure 44. Occupancy Pattern for Room 354- Feb 2013



MON																	
TUES			🟦	🟦	🟦												
WED		🟦	🟦			🟦	🟦			🟦	🟦	🟦				🟦	🟦
THUR					🟦	🟦	🟦			🟦	🟦	🟦	🟦			🟦	
FR			🟦	🟦	🟦	🟨	🟦	🟦	🟦	🟦	🟦						
SAT																	
SUN																	
	8	8.30	9	10	10.30	11	12	12.30	1	1.30	2	2.30	3	3.30	4	5	6-7

ROOM 354, FEB 2013

🟩	Occupied once in a month
🟫	Occupied twice in a month
🟦	Occupied 3 times in a month
⬛	Occupied 4 times in a month
🟪	Occupied 5 times in a month
🟨	Occupied 6 times in a month

Figure 45.Occupancy Pattern for Room 355

As seen in the figures above, the occupancy pattern of these rooms were different for each month and might contributed significantly to the peaks and dips observed in the annual energy demand trend of the building. Even though the buildings had no mechanical cooling system, changes in occupancy pattern would change the plug load in the building.

b. Changes in Design before and after LEED Application

The possibility of changes in Design before and after LEED Application was investigated. Comparing the Leed Drawings (2006) with the As-Built Drawings (2008), we can see that there are changes in Design before and after LEED Application. A new Air Handling Unit is indicated in As Built Drawings which cannot be seen in LEED Drawings. Also, there are five New Single-Duct VAV Terminal Units indicated in As Built Drawings which cannot be seen in LEED Drawings. The new components are presented in Table 10 and 11. It should be noticed that there is additional air handling unit which was added after the LEED application submission. This might have caused the significant difference in predicted and measured electrical energy consumption rate.

Table 10. New Single-Duct VAV Terminal Units indicated in As Built Drawings compared to LEED Drawings

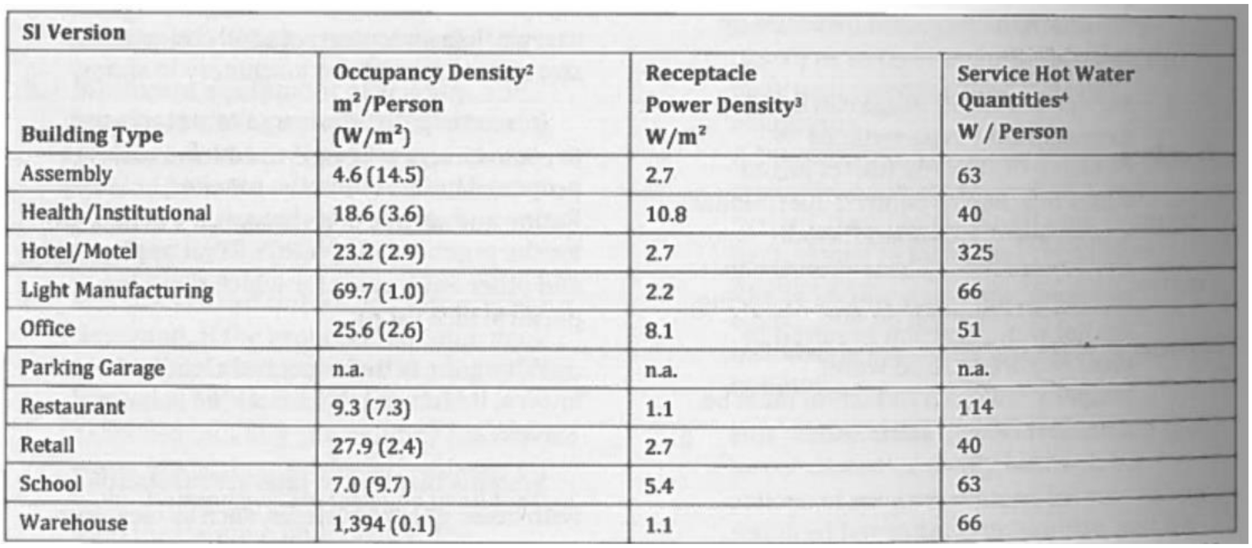
			PRIMARYAIR FLOW (L/s)		HYDRAULIC HEATING COIL		ATTENJATOR SIZE (MM)		
TAGS	MODEL	MIN	MAX	DESIGN	KW	L/s	DISCHARGE	INLET	MECHANICAL REMARKS
V3-2-05	SDV-04	20	40	40	-	-	305x203	102ø	SINGLE DUCT VAV BOX
V3-2-07	SDV-04	30	65	65	-	-	305x203	102ø	SINGLE DUCT VAV BOX
V3-2-08	SDV-04	30	50	50	-	-	305x203	102ø	SINGLE DUCT VAV BOX
V3-3-07	SDV-06	45	95	95	-	-	305x203	152ø	SINGLE DUCT VAV BOX
V3-3-08	SDV-06	45	95	95	-	-	305x203	152ø	SINGLE DUCT VAV BOX

Table 11. New Air Handling Unit indicated in As Built Drawings compared to LEED Drawings

REF	DESCRIPTION	WEIGHT LBS	LOCATION		HEATING CAPACITY	HYDRAULIC HEATING COIL	SUPPLY FAN		0/A Max/min L/S
AHU-4	AIR HANDLING UNIT FOR BASEMENT	154	ROOM B002	25.13(85.7) BY HOT WATER	0.53(8.24)	TYPE: 1 ROW	944	250	944/95

c. Inaccurate Building Plug Load Assumption

Most simulations used a certain plug load values based on the function of each space. For the renovation of Friedman building, average Energy Power Density was 4.30 W/m^2 or 0.40 W/ft^2. This value was comparable with the ASHRAE 90.1 guideline.



SI Version			
Building Type	Occupancy Density[2] m^2/Person (W/m^2)	Receptacle Power Density[3] W/m^2	Service Hot Water Quantities[4] W / Person
Assembly	4.6 (14.5)	2.7	63
Health/Institutional	18.6 (3.6)	10.8	40
Hotel/Motel	23.2 (2.9)	2.7	325
Light Manufacturing	69.7 (1.0)	2.2	66
Office	25.6 (2.6)	8.1	51
Parking Garage	n.a.	n.a.	n.a.
Restaurant	9.3 (7.3)	1.1	114
Retail	27.9 (2.4)	2.7	40
School	7.0 (9.7)	5.4	63
Warehouse	1,394 (0.1)	1.1	66

Figure 46. ASHRAE 90.1 Guideline for Occupancy Density, Receptacle Density, and Service Hot Water Quantities.

To qualitatively check the discrepancy in plug load estimation, a site visit was conducted by the authors to check if there were any energy intensive devices in the buildings which might have contributed to the performance gap between the predicted and measured energy. The photos of the typical rooms and devices in the building could be seen in Appendix C.

Based on the site visit results, there were no significant addition of plug loads except for the teleconference devices and lab equipment found in the building. However, the contributions of these devices to the overall electricity demand, which were off by a significant amount, were not clear. With the help of UBC electricians, the authors have explored the possibility of installing metering equipment in some of the energy intensive areas to investigate the contribution of plug loads to the overall energy consumption. Even though this plan was deemed feasible, it wasn't carried through because of time conflict. By the time the permission for this operation was granted, the spring term has come to an end.

d. Building Envelope Degradation

Due to the time constraint of the project, the authors weren't able to analyze the envelope degradation phenomenon. However, based on the increasing annual energy consumption rate, this factor might have a significant role in affecting the thermal performance of the building, thus creating the performance gaps found in many LEED buildings. To fully investigate this phenomenon, it's recommended to do a long term study to monitor the thermal resistance value of building facades and leakages in the building.

6. Conclusions and Recommendations

Based on the study on Friedman building, similar performance gaps as shown in previous study by New Building Institute [1] were encountered. Annual electricity consumption of the building was consistently different by up to almost 100% compared to the modelled performance. Even though annual natural gas consumption was relatively better than predicted for the first year (2010), there was an almost linearly increasing trend found in year 2011-2013, causing wider performance gaps for each year.

There were several sources of discrepancies identified in the study: changes in energy demand due to weather contribution, installation of new equipment, and changes in occupancy pattern; changes in design before and after the LEED application; inaccurate building plug load assumption; and building envelope degradation. While the contributions of each factor has been identified and analyzed, it was unfeasible to conduct investigation on buildings envelope degradation and measurement of actual plug load of the building. Nevertheless, the analysis methods laid out in the report should be considered for conducting similar investigation on other UBC LEED Buildings.

7. References

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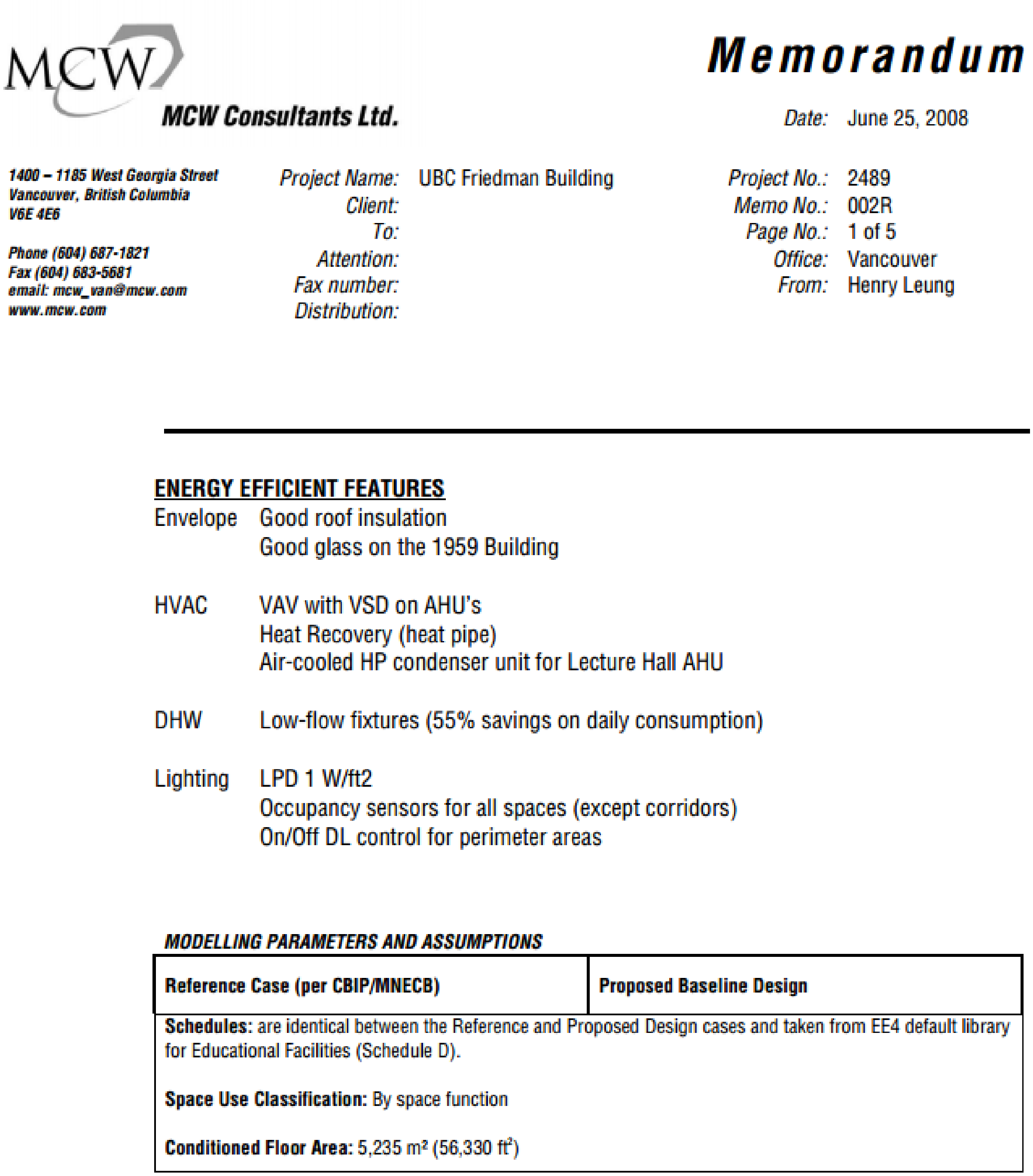
[11] BizEE Energy Lens. Degree Days - Handle with Care!. [Online]. http://www.energylens.com/articles/degree-days

[12] Vancouver Historical HEating Degree Days. [Online]. http://vancouver.weatherstats.ca/metrics/hdd.html

8. Appendix

a. Modelling Parameters [13]



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Memorandum

Date: June 25, 2008

Project Name: UBC Friedman Building
Client:
To:
Attention:
Fax number:
Distribution:

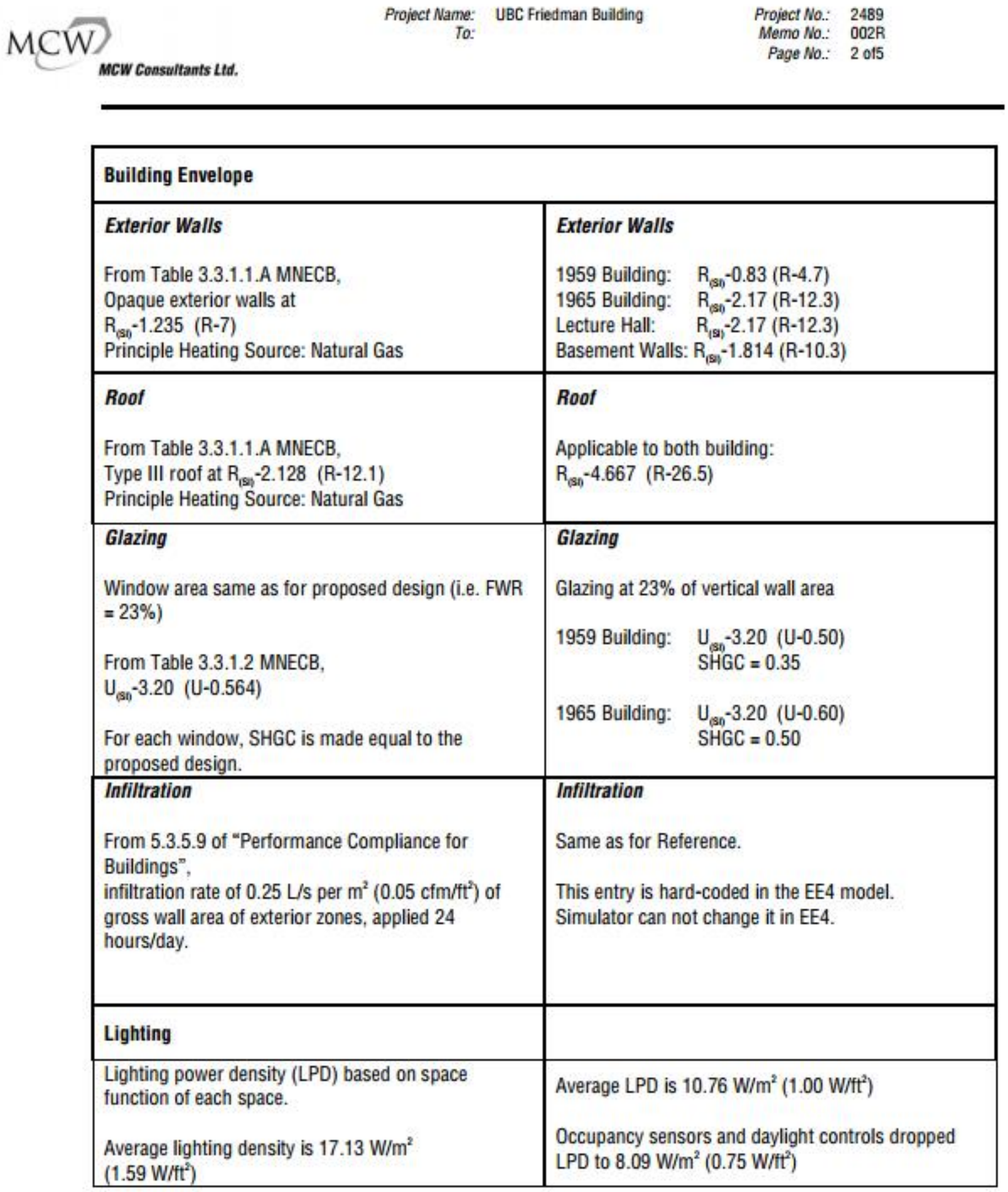
Project No.: 2489
Memo No.: 002R
Page No.: 1 of 5
Office: Vancouver
From: Henry Leung

ENERGY EFFICIENT FEATURES

Envelope	Good roof insulation Good glass on the 1959 Building
HVAC	VAV with VSD on AHU's Heat Recovery (heat pipe) Air-cooled HP condenser unit for Lecture Hall AHU
DHW	Low-flow fixtures (55% savings on daily consumption)
Lighting	LPD 1 W/ft2 Occupancy sensors for all spaces (except corridors) On/Off DL control for perimeter areas

MODELLING PARAMETERS AND ASSUMPTIONS

Reference Case (per CBIP/MNECB)	**Proposed Baseline Design**
Schedules: are identical between the Reference and Proposed Design cases and taken from EE4 default library for Educational Facilities (Schedule D). **Space Use Classification:** By space function **Conditioned Floor Area:** 5,235 m² (56,330 ft^2)	

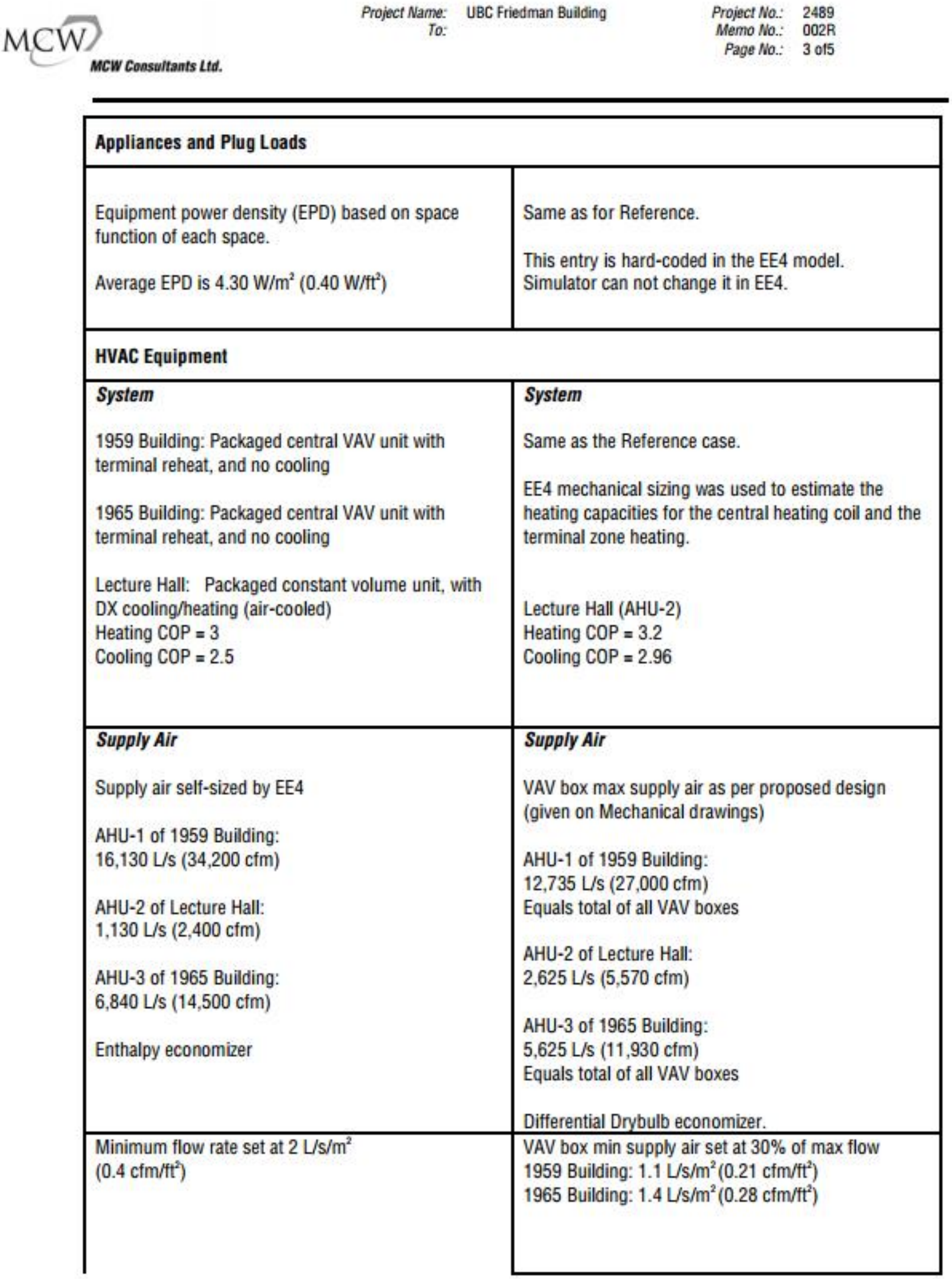


MCW Consultants Ltd.

Project Name: UBC Friedman Building
To:

Project No.: 2489
Memo No.: 002R
Page No.: 2 of5

Building Envelope	
Exterior Walls From Table 3.3.1.1.A MNECB, Opaque exterior walls at $R_{(SI)}$-1.235 (R-7) Principle Heating Source: Natural Gas	***Exterior Walls*** 1959 Building: $R_{(SI)}$-0.83 (R-4.7) 1965 Building: $R_{(SI)}$-2.17 (R-12.3) Lecture Hall: $R_{(SI)}$-2.17 (R-12.3) Basement Walls: $R_{(SI)}$-1.814 (R-10.3)
Roof From Table 3.3.1.1.A MNECB, Type III roof at $R_{(SI)}$-2.128 (R-12.1) Principle Heating Source: Natural Gas	***Roof*** Applicable to both building: $R_{(SI)}$-4.667 (R-26.5)
Glazing Window area same as for proposed design (i.e. FWR = 23%) From Table 3.3.1.2 MNECB, $U_{(SI)}$-3.20 (U-0.564) For each window, SHGC is made equal to the proposed design.	***Glazing*** Glazing at 23% of vertical wall area 1959 Building: $U_{(SI)}$-3.20 (U-0.50) SHGC = 0.35 1965 Building: $U_{(SI)}$-3.20 (U-0.60) SHGC = 0.50
Infiltration From 5.3.5.9 of "Performance Compliance for Buildings", infiltration rate of 0.25 L/s per m² (0.05 cfm/ft²) of gross wall area of exterior zones, applied 24 hours/day.	***Infiltration*** Same as for Reference. This entry is hard-coded in the EE4 model. Simulator can not change it in EE4.
Lighting	
Lighting power density (LPD) based on space function of each space. Average lighting density is 17.13 W/m² (1.59 W/ft²)	Average LPD is 10.76 W/m² (1.00 W/ft²) Occupancy sensors and daylight controls dropped LPD to 8.09 W/m² (0.75 W/ft²)



Appliances and Plug Loads	
Equipment power density (EPD) based on space function of each space. Average EPD is 4.30 W/m² (0.40 W/ft²)	Same as for Reference. This entry is hard-coded in the EE4 model. Simulator can not change it in EE4.
HVAC Equipment	
System 1959 Building: Packaged central VAV unit with terminal reheat, and no cooling 1965 Building: Packaged central VAV unit with terminal reheat, and no cooling Lecture Hall: Packaged constant volume unit, with DX cooling/heating (air-cooled) Heating COP = 3 Cooling COP = 2.5	***System*** Same as the Reference case. EE4 mechanical sizing was used to estimate the heating capacities for the central heating coil and the terminal zone heating. Lecture Hall (AHU-2) Heating COP = 3.2 Cooling COP = 2.96
Supply Air Supply air self-sized by EE4 AHU-1 of 1959 Building: 16,130 L/s (34,200 cfm) AHU-2 of Lecture Hall: 1,130 L/s (2,400 cfm) AHU-3 of 1965 Building: 6,840 L/s (14,500 cfm) Enthalpy economizer	***Supply Air*** VAV box max supply air as per proposed design (given on Mechanical drawings) AHU-1 of 1959 Building: 12,735 L/s (27,000 cfm) Equals total of all VAV boxes AHU-2 of Lecture Hall: 2,625 L/s (5,570 cfm) AHU-3 of 1965 Building: 5,625 L/s (11,930 cfm) Equals total of all VAV boxes Differential Drybulb economizer.
Minimum flow rate set at 2 L/s/m² (0.4 cfm/ft²)	VAV box min supply air set at 30% of max flow 1959 Building: 1.1 L/s/m² (0.21 cfm/ft²) 1965 Building: 1.4 L/s/m² (0.28 cfm/ft²)

same as for Proposed case.	Supply air at a constant 12.8°C (55°F) for cooling, reset based on warmest zone. 43.3°C (110°F) for heating.
Fan Total Static Pressure (in. wc): AHU-1: SA fan 3", RA fan 0.6" AHU-2: SA fan 1.3", no RA fan AHU-3: SA fan 3", RA fan 0.6"	Fan Total Static Pressure (in. wc): AHU-1: SA fan 5.5", RA fan 3.5" AHU-2: SA fan 5", RA fan 3" AHU-3: SA fan 3", RA fan 1.3"
Fan Efficiencies: AHU-1: SA fan 55%, RA fan 28% AHU-2: SA fan 55%, no RA fan AHU-3: SA fan 55%, RA fan 28%	Fan Efficiencies: Assumed at 60% for both SA and RA fans for all AHU's
Ventilation Air Same as for the Proposed case. Based on LEED-Ca Reference Guide, the Reference case must not exceed a certain % allowance above ASHRAE62 minimum requirements. The current model assumes that the Reference case matches the Proposed case in terms of outdoor air rates. Detailed calculations must be done by the design team to determine the exact amount of the minimum outdoor air rate, and then verify whether the proposed design falls within the allowable % mentioned above. This issue has significant impact on the results. Careful attention should be given. ***Number of People*** Same as for the Proposed case. **NO Exhaust Air Heat Recovery**	***Ventilation Air*** Equals VAV min flow rates for each zone (i.e. 30% of max flow) AHU-1: 8,400 cfm AHU-2: 900 cfm AHU-3: 4,200 cfm ***Number of People*** AHU-1: 264 occupants AHU-2: 57 occupants AHU-3: 189 occupants **Exhaust Air Heat Recovery:** 50% Effectiveness for AHU-1 and AHU-3.
Control Heating and cooling setpoints, setback temperatures, and schedules same as proposed design	***Control*** Heating setpoints at: 70°F. Cooling setpoints: 74°F

Heating Plant One gas-fired boiler at 80% combustion efficiency from table 5.2.13.1 MNECB. Self-sized to assure appropriate relative sizing with Proposed. HW loop circulation pump at 100 ft head and 65% efficiency.	***Heating Plant*** Steam from remote plant. This was modelled by one boiler (1000MBH) at 80% efficiency The capacity was determined based on the PS-H report from DOE output. HW loop circulation pump at 100 ft head and 65% efficiency.
Cooling Based on the CBIP modeling rules, if the proposed design does not have mechanical cooling, the Reference case will not have mechanical cooling.	***Cooling*** No chiller as no mechanical cooling is provided.
Domestic Hot Water (DHW) Fossil fired water heating at 80% efficiency. Load same as Proposed.	**Domestic Hot Water (DHW)** Fossil fired water heating at 80% efficiency. Heating capacity and storage volume was auto-sized by EE4. Based on LEED EA credit 3, Proposed water usage is 2041 L, Baseline water usage is 4513 L. Therefore total DHW saving estimated at 55%. That % saving was manually applied in the results spreadsheet, by deducting 55% of the Reference case DHW energy consumption.
Utility Rates	
Electricity rate same as Proposed. Fossil rates same as Proposed.	Electricity rates: Based on information from Ting Pan, Recollective: \$0.0388/kWh No Demand Charges Steam rates: Based on information from Ting Pan, Recollective: This was modeled as Natural Gas rate of \$0.31/m^3.

b. Drawings

i. LEED Package

ii. As- Built Drawings

c. Site Visit Results and Photos

i. Division of Physical Therapy, School of Rehabilitation Sciences

ii. School of Audiology and Speech Sciences