UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program
Student Report

Heating Energy Sub-metering

[Measuring building energy savings from metering heating energy]

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APPP 506C: Capstone Project

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Measuring building energy savings from metering heating energy

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Executive Summary

UBC Properties Trust (UBCPT) is the office at UBC that is responsible for the development and operation of institutional, office, and residential buildings in UBC. With a focus on sustainability and how to develop a sustainable community, UBCPT is looking to study the effect of energy sub-metering in promoting a sustainable resident behavior. UBCPT is currently developing the first mixed use building (Site-D) at UBC that would apply energy sub-metering. Since electricity is already sub-metered, this project focuses on heat energy sub-metering in residential buildings.

Site-D is a mixed-use building designed aiming for REAP certification. It consists of a commercial area located at the ground level, and five levels of residential units. To conduct the study monthly heating energy data for Site-B, a recently constructed REAP certified mixed-use building at UBC, was supplied. Site-B has been in operation since July 2017. Unlike Site-D, Site-B had no heating energy sub-metering applied, the provided data was an aggregate of the heat energy consumed in the building for both space heating and Domestic hot water (DHW), there was no data for DHW consumptions at Site-B.

Energy data (Space heating, DHW) for four residential buildings located at Main land Vancouver, with similar build characteristics, was collected over the course of two years starting from December 2015 to December 2017. The data was then analysed and processed to establish a benchmark model for space heating energy usage in sub-metered buildings. The benchmark model was then used to benchmark the residential part of Site-B.

Analysis of the collected data revealed that DHW consumption is consistent throughout the year, which facilitated the estimation of the DHW heating load for Site-B. A baseline model for Site-B space heating was then established and measured to the benchmark model. Space heating energy savings of about 25% was calculated from applying the benchmark model for the same period of operation of Site-B, from October 2017 to September 2018. Similar reductions in GHG emissions and operational cost savings could be recognised. Yielding a payback period of eight years when sub-metering is applied.

A baseline model for Site-D Space heating energy consumption was established by readjusting the benchmark model to the total space area for Site-D. This base line model could be used to predict the energy consumption throughout the year. However, a better baseline model would be established after Site-D becomes operational, where actual consumptions data would be collected and analysed.

To follow on this study, it is recommended to apply partial sub-metering for Site-B Units, where selected units with different surface areas would be sub-metered and compared to other units that are not sub-metered. This would help fine tune the benchmark model to represent the sub-metered buildings with the same build characteristics.

Moving forward to realise the change in residents' behaviour when sub-metering is applied, it is recommended to operate Site-D similar to Site-B's billing operation for one year, then switch to submetering for another year. As suggested by literature, providing residents with a means to know about their energy consumption, would create awareness of energy use, and promote energy conservation.

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Introduction

Energy demand in the residential sector in Canada has seen an increase by 6.5% through the period between 1990 to 2013. Such demand is mainly dominated by space heating and hot water, accounting for 62% and 19% of energy end use, respectively (1). The increase in energy use is accompanied by an increase in GHG emissions. With raising concerns for increased emissions and its drastic effects on the climate and environment, in addition to global commitment to reduce energy consumption and GHG emissions. Energy efficiency and conservation measures need to be applied to obtain optimal energy use.

The rising costs of energy and requirements for energy consumption reduction, highlights the need for energy conservation techniques that would reduce household spending on energy. One of the techniques that would promote energy conservation among residents, is energy sub-metering.

Purpose:

With rising energy costs and the availability of metering technologies, UBC Properties Trust (UBCPT) is interested in better understanding the impact that energy submetering has on promoting sustainable resident behavior. While submetering allows Properties to pass utility costs on to users, leading to direct economic incentives to conserve energy, UBCPT would like to go further and understand the indirect impacts of submetering, such as the changes to residents' behaviors which would result in energy conservation, and in turn GHG emissions reduction. Furthermore, UBCPT can use the data as a business case for applying submetering to various projects at UBC.

The project comprises of two phases, Phase I of the project is to establish a benchmark for sub-metered buildings in UBC and measure the expected amount of energy savings expected for currently under construction market rental building with energy submetering (FOCAL/Site D). By comparing energy data for the recently constructed market rental building without energy sub-metering (CENTRAL/Site B) that is similar to Site D, along with a benchmark developed from energy data of other similar buildings in main land Vancouver that have sub-metering applied.(Appendix A: Site Overview)

Phase II of the project is planned to take place after delivery and operation of Site D where the impact of energy sub-metering will be measured on residents' behavior.

Objectives:

- Find the energy, space heating / cooling, water heating, hot / cold water consumptions for Site B by collecting the data for the previous year depending on data availability
- Establish baseline for Site B to be used for Site D (Similar occupancy and usage)
- Collect energy, Space heating / cooling, water heating, hot / cold water data for other sub-metered buildings, within the Lower Mainland Vancouver.
- Establish a benchmark for sub-metered buildings
- Develop an Energy model for Site D based on the collected data from Site B. and the studied buildings
- Determine expected energy savings from applying energy sub-metering.

Background:

UBC Properties Trust (UBCPT)

UBCPT is an office at UBC that leads the creation of on-campus market and faculty/staff rental housing. Established in 1984, under the approval of the UBC Board of Governors, to establish the designated area known now as Hampton Place as the first residential neighborhood in UBC. Following Hampton Place, UBCPT followed with the development of Hawthorn Place, Chancellor Place, East Campus and now Wesbrook Place. It is responsible for developing, leasing, and property management of residential, office, and retail portfolios. They also analyze projects requested by UBC and manage the construction of institutional projects. (3)

Site-B (Central)

University Boulevard Site-B (Central) is a newly constructed REAP certified building, located on University Boulevard just west of Wesbrook Mall immediately south of War Memorial Gym with a gross area of 75,499 sq.ft. Site-B is a 6-storey mixed-use building with retail/commercial uses on the ground floor and 5 stories of residential rental accommodation for students, faculty, and employees at UBC. It contains 98 residential units with areas ranging from 350 sq. ft to 1180 sq.ft (Appendix B: Site-B Units Breakdown). (4)

Site-D (Focal)

University Boulevard Site-D (Focal) is a new mixed-use building that is currently under construction, designed aiming for REAP certification. It is located on University Boulevard between the Student Union Building (The NEST) and the War Memorial Gym with gross area of 73,177 sq.ft. Site-D is a 6-storey mixed-use building with retail/commercial uses on the ground floor and 5 stories of residential rental accommodation. It is to contains 90 residential units with areas ranging from 355 sq. ft to 1384 sq.ft. (Appendix C: Site-D Units Breakdown) (4)

Energy savings estimation

To realize the energy savings from energy sub-metering, monthly energy consumption data for sub-metered buildings, with similar build standards to that of Site-B and Site-D, was collected and analyzed. Following data analysis, a benchmark baseline model for sub-metered buildings was obtained. On the other hand, monthly energy consumption data for the whole Site-B building was used to obtain a baseline model. Later the benchmark baseline was compared with Site-B baseline to quantify expected energy savings obtained by applying submetering.

Literature review:

The literature review presented below was conducted to cover the concepts of energy benchmarking, and energy metering. In addition to the review of similar studies conducted in Spain and Toronto, Canada to realize the effects of energy sub-metering on energy conservation as well as resident's behavior. The review helped establishing the concepts on which the study is to continue as well as develop an understanding of the expected results.

Building Energy Benchmarking

Building Energy Benchmarking is the process of comparing the Energy Performance Indicator (EPI) or Energy Use Intensity (EUI) in buildings of similar characteristics. EPI or EUI are ratios of energy use input to energy service output (e.g. Site energy per square meter, CO_2 emissions per home, etc.). A common EPI used for many building types is annual energy use per unit area. EPI is used as a starting point in energy audits and assesses saving opportunities by comparing with existing references (benchmarks) of average (typical), above average(good) and excellent (best) practice.

The benchmarking process consists of 4 stages. First, is the development of a database with information on the energy performance of a significant number of buildings, categorized by building type and size. Second is gathering the relevant information for the evaluation of the EPI for the Actual building. Third, a comparative analysis of the building performance against the samples held in the database gives a quantification of the quality of the building in terms of energy use. Finally, recommendations of energy efficiency measures that are feasible from both technical and economic perspectives.

Energy consumption can be obtained from energy bills, though it is difficult to get a split by the end uses. Another method is to monitor, or measurement based on sub-metering, which can be expensive, but offers detailed information that can be useful for energy auditing, or maintenance. However, Energy consumption is influenced by the occupant behavior, equipment usage, natural ventilation, hot water demand, etc. (5)

Energy metering

Heating in building accounts for 40% of the total energy used and contributes towards 30% of the total CO_2 emissions. Building Energy metering and environmental monitoring can help in identifying cost-saving opportunities, detecting inefficiencies, improve load planning and energy usage.

There are three categories for building sensors and meters for measuring different building performance parameters. Temperature, occupancy, humidity, CO_2, and air quality sensors are used to sense occupant comfort and activity. Building energy meter, sub-metering, plug load measurement, natural gas meters, and other sources of energy meters are used to measure energy consumption. Measurement of machinery characteristics can be done by using refrigerant temperature, machinery electrical current, machinery vibration, and return and supply air flows.

The selection of sensors and meters is influenced by different factors. Accuracy is the main influence, as it represents to what extent the measured usage matches the real usage. Ease of deployment, as the deployment of meters and sensors, can offer different installation and networking challenges. there is a wide range of communication protocols and networking technologies that transfer the sensor and metering data. Resolution of the measurement determines the possible level of analysis that can be performed on the metered data. The cost might be perceived as a financial risk factor for building owners. Availability of a particular technology or manufacturer varies geographically which might limit the selection process in lead time, availability of technical support and spare parts. (6)

Conservation Effects of Energy Sub-metering

A recent study conducted in Spain aiming to evaluate and quantify the potential of individual metering and charging of heat and hot water for saving energy in residential buildings in temperate climates, where the energy consumption of a residential was monitored for four complete heating seasons. Individual metering (sub-metering) was implemented halfway through the period of the study. The results showed that sub-metering has brought a reduction of normalized energy consumption of 15 – 20% during the first

2 years after implementation, and a simple payback period of 10 years. The study confirmed that sub-metering affects directly on user behavior encouraging inhabitants to change their habits to reduce their energy consumption. (Appendix D: Energy Conservation by sub-metering) (2)

The building under study had a centralized heating system supplying both heating and DHW to all apartments of the building. Heat is supplied to DHW and Heating circuits via three consecutive diesel boilers (2×700 kW+350 kW) connected in cascade, with a total heating capacity of 1750 kW. The heating system operates based on a temperature sensor (thermostat) reading the outside air temperature. During the heating season, if the outdoor temperature was below 11 °C at 13.30 h, the heating system was activated and kept on working until 22.00 h; otherwise, (i.e. if the outdoor temperature was higher than 11 °C at 13.30 h), the system started running at 16.30 h until 22.00 h. Meanwhile, the DHW system was on from 4.00 h to 23.59 h. (2)

During the study the team was challenged with allocating the share of heat energy that is used by DHW, which was solved by analyzing DHW consumption throughout the period and found a relation between DHW consumption and Heating Degree Days (HDD). The amount of energy consumed in DHW was calculated based on the consumption of energy in times where space heating was not required. A model was developed for DHW energy consumption and was tested with the actual consumptions values obtained after applying sub-metering. (Appendix E: Energy share of DHW Calculated Vs. Actual)

In their conclusion the authors expect higher energy savings in terms of absolute values, and lower payback periods (assuming that initial investment will be similar) in locations of higher winter severity, than the location of the study where winter severity was classified with letter C (2).

Behavioral Effects of Energy Sub-Metering.

A major Challenge in promoting energy conservation is to increase the visibility of energy consumption in homes and occupant's awareness of the connection between their behavior and financial/ environmental consequences. The only connection between occupants and their energy consumption is their monthly bill that summarizes the cost of their energy consumption.

It was reported that rents in bulk-metered apartments are significantly higher than sub-metered apartments, however, the premiums that bulk-metered apartments tenants pay exceeds the cost of their energy consumption. Anecdotal evidence suggests that sub-metering of household utilities can result in 30% energy savings, as opposed to including energy costs with rent. (7)

Based on case study for energy metering conducted on a residential building in Toronto, Ontario, that uses electric heaters for space heating. Where the building was bulk-metered until June 2011, and then it was retrofitted with sub-meters in each unit. No modification conducted to the building envelop or HVAC system or change in the occupancy were reported for the building. It was noticed that the electricity uses during the shoulder seasons and the electricity use during the heating season decreased notably after submetering. It was noted that bulk-metered household consumed higher energy, maintaining their units at a higher temperature during the heating season, and were less likely to take adaptive measures like clothing level adjustment, and nighttime thermostat adjustment(Appendix F: Effect of Sub-metering on energy use). (8)

Another observational investigation of 40 occupants living in sub-metered and bulk-metered buildings in Ottawa, Ontario to reveal the behavioral, attitudinal, habitual, and perceptional differences about heating energy use. Furthermore, the indoor air temperature was measured during the heating season in the living rooms and the bedrooms of participants. The results suggest that on average participants living in the bulk-metered apartments keep their units 2℃ warmer than participants living in sub-metered apartments. Participants living in sub-metered apartments reported being more sensitive to engaging in personal adaptive behaviors and were more sensitive about their thermal comfort. They were also found to be more influenced by health concerns related to indoor temperature compared to participants living in bulk-metered apartments. Participants living in sub-metered apartments frequently adjusted their thermostats in a periodic manner, whereas participants living in bulk-metered apartments had little interaction with their thermostats. These frequent and periodic interactions with the thermostat settings were most likely undertaken consciously and responsibly to save energy and therefor cost. (Appendix G: Indoor temperatures setting). (8)

Data and Methodology

Methodology

The methodology depicted in this study was based on the concepts learned from the literature review of energy benchmarking process, which involved establishing a database of building energy data, then analyzing the data to establish a benchmark model, to which the performance of the bulk metered building Site-B was assessed.

In the process of establishing a benchmark for sub-metered buildings, monthly energy data (Heating, DHW) for buildings located in main land Vancouver with similar build characteristics to Site-B was obtained for a period of two years (2016 – 2017). The selected buildings had hydronic space heating, and sub-metering applied to space heating, and DHW. The data was then analyzed by calculating EUI values and comparing them together to rule out buildings that show to be over or under performing.

A weather normalized baseline model was then established for each of the benchmark candidate buildings. Historical weather data for main land Vancouver was obtained, based on data form Vancouver International airport weather station. HDD days were calculated for the period of the available data. Regression analysis was conducted, using Microsoft Excel regression tool, to establish a weather normalized baseline relation for energy consumption in each of the candidate buildings. Similarly, a baseline model for Site-B was established.

A baseline benchmark was then obtained by averaging the baselines of the candidate buildings. Further tuning of the baseline was conducted to account for space area and utilization differences between Site-B and the benchmark model buildings. Another adjustment was also conducted to account for Site-D space area and develop a baseline model for the expected performance of the currently under construction Site-D building.

The actual energy consumption of Site-B was compared with benchmark model by applying the HDD values for the period of operation of Site-B (from Oct-2017 to Sept 2018). A cumulative sum of the expected energy saving was aggregated over the same period, to quantify the expected energy savings from applying sub-metering in Site-B.

Data

Monthly energy consumption data for a period of two years (2016 – 2017) was collected for the individual units of four different buildings, located at main land Vancouver. The buildings were chosen based on the below criteria:

- Built to the same or similar standards as Site-B. (LEED or REAP).
- Hydronic space heating system used for space heating.
- Sub-metering for space heating energy consumption, and DHW applied.

(Building names were kept undisclosed for proprietary reasons)

Monthly bulk metered energy data for Site-B was obtained for the period from July 2017 to October 2018. Data for DHW consumption was not provided due to lack of metering equipment installed on DHW lines. A detailed description of the buildings used in this study supplied below.

Building 1:

A REAP certified low rise residential building located at UBC area, comprised of 2 wood frame buildings, hereafter named at Building 1_1 and Building 1_2, with total space area of 13,760 squared meters. UBC district heating system supplies both buildings with the heat energy required for space heating and DHW.

Building 1_1 has space area of 7,495 squared meters, consisting of 99 units ranging from 1-bedroom to 3-bedroom apartments. Building 1_2 has a space area of 6,075 squared meters, consisting of 77 units ranging from 1-bedroom to 3-bedroom apartments.

Each unit is billed on Space heating, DHW, and cold-water consumptions on a bi-monthly basis. Analysis of the data showed consistent hot water consumption throughout the year. Energy baseline models for space heating energy consumption were established (Building 1_1 Data,Building 1_2 Data)

Building 1_1: $E = 150\ HDD - 12996$

Building 1_2: $E = 121\ HDD - 12285$

The energy use intensity for both buildings was calculated for the year 2017 to be 49 kWh/m^2

Building 2:

A LEED Gold certified wood frame low rise mixed use building located at Kitslano area. Containing 70 units ranging from 1-bedroom to 3-bedroom apartments, with a total space area of 5,880 squared meter. A Natural Gas (NG) boiler supplies both the hydronic space heating and DHW system with the heat needed. Monthly Energy and DHW data was collected and analysed showing consistent consumption of DHW throughout the year. The EUI for the building was calculated to be around 15 kWh/m^2, such value shows to be a very competitive value revealing the very high performance of the building. However, no further analysis of the building data was conducted as it would result in a misleading benchmark.

Building 3

A LEED certified wood frame low rise building located at False Creek area. Containing 67 units, with total space area of 4,084 squared meters. False Creek district heating system supplies the building with the required heat energy. Monthly energy and DHW data was analysed to show a consistent consumption of DHW throughout the year.

The EUI of the building for the year of 2017 was calculated to be 47 kWh/m^2. An energy bas line model was established for the building to be (Building 3 Data)

$$E = 79\ HDD - 3551$$

Building 4

A LEED GOLD certified wood frame low rise building located at False Creek area. Containing 84 units, ranging from 1-bedroom to 3-bedroom apartments, with total space area of 7,433 squared meters. False Creek district heating system supplies the building with the required heat energy. Monthly energy and DHW data was analysed to show a consistent consumption of DHW throughout the year.

The EUI of the building for the year of 2017 was calculated to be 36 kWh/m^2. An energy baseline model was established for the building to be (Building 4 Data)

$$E = 107\ HDD - 10344$$

Site-B

Due to the lack of sub-metering in Site-B Building, monthly energy consumption data was an aggregate of both space heating and DHW. By analyzing the DHW consumption of the candidate buildings, it was deduced that in this study DHW consumption showed to be consistent throughout the year. There were no major variations between the heating season or the rest of the year. Hence, it was assumed that energy consumed during the summer month of August 2017 would be a good representative for the DHW base load. Accordingly, a value equal to the energy consumption of the month of August 2017 (7000 kWh) was deducted from the monthly energy data to account for monthly space heating. The EUI for Site-B was calculated to be 62 kWh/m^2, a baseline model was then established. (Site-B Data)

$$E = 127\ HDD + 3125$$

Results and Discussion

Benchmarking

Following the establishment of Energy baselines for the selected buildings, a benchmark baseline was established by averaging the baselines of the selected buildings. The established benchmark baseline is represented by the below equation, and a benchmark EUI of 45 kWh/m^2.

$$E = 114\,HDD - 9794$$

However, the benchmark had to be readjusted to account for difference in space area and utilisation of Site-B. Hence the new benchmark baseline model to be compared with Site-B baseline is represented by the below equation, and modified benchmark EUI of 46 kWh/m^2 (Benchmarking and Modeling Results)

$$E = 118\,HDD - 10055$$

It worth mentioning that the developed Bench mark does not account for electricity or DHW usages, mainly because Site-B lacked DHW consumption metering, as well as the lengthy process to obtain electricity consumptions data from the utility provider.

Energy Savings from applying sub-metering

Following the establishment of a benchmark that represents a sub-metered building with similar characteristics to Site-B, the benchmark was then used to calculate the predicted monthly energy consumption for the period of operation of Site-B (October 2017 - Sept 2018). Using the cumulative sum approach, a value for the expected energy savings resulting from applying energy sub-metering was found to be around 166 MWh.

The analysis showed that energy savings of about 25% can be obtained by applying heat energy sub-metering in buildings. Such savings would also mean reduction in GHG emissions, which was calculated based on the GHG intensity of UBC district heating (169 kg CO_2e/MWh) to be around 28 tonnes of CO_2. (Estimated Energy Savings Results)

In addition to Energy and GHG emissions savings, operational cost savings of $13,753 of saved energy costs based on UBC District heating system charges of $83/MWh, and an additional $980 savings in carbon taxes resulting form GHG emissions reductions. Based on the rough estimations of a $108,000 cost of applying submetering to Site-B, a payback period of eight years was calculated from energy savings. (Estimated Payback period)

Although there may be other attributes leading to energy savings we can reasonably assume that energy savings recognized in the results are mostly due to sub-metering, as the studied buildings have similar build characteristics as Site-B, being either REAP or LEED certified buildings.

Site -D Energy Baseline Model.

A baseline model for expected space heating energy consumption in Site-D was established after modifications for the benchmark baseline model to account for space difference. The developed base line model is represented by the below equation. And expected EUI of 34 kWh/m^2. (Benchmarking and Modeling Results)

$$E = 85\,HDD - 7313$$

The developed base line model could be considered to estimate the expected energy consumptions for Site-D, however the actual performance may vary due to construction and behavioral aspects. Hence a better baseline model would be obtained after processing actual consumption data.

Conclusion

During the course of the study energy consumption data was collected, analysed, and processed to establish a benchmark for sub-metered residential buildings for future developments in UBC. The collected data comprised of space heating energy consumption, Domestic Hot Water (DHW) consumptions for a set of sub-metered buildings located around mainland Vancouver area for years 2016 and 2017.

Analysing DHW data showed consistent consumption throughout the year with no major changes happening due to changes in weather seasons. Consistency in DHW consumption lead to conclude that the energy used for heating DHW would also be consistent through out the year, hence it could be considered heating baseload in the buildings.

As for the buildings heating energy consumed in buildings, data showed that energy consumed in space heating would reach its maximum values in the winter months of December and January of each year, while its minimum values were in the summer months of July and August of each year, with August showing the least consumption if not zero. This consumption pattern was noticed in all the buildings involved in the study.

Reaching the above conclusions led to the assumption that for Site-B, where the heating energy data was an aggregate of both space heating and DHW, the energy used in the month of August 2017 could be considered as mainly the basic heating load of heating DHW. Accordingly, the energy consumption for space heating was then calculated for the period of building operation.

Processing the collected data led the establishment of a benchmark for sub-metered residential buildings. Site-B energy consumptions were compared to the developed benchmark to quantify the energy savings that could be recognised from applying sub-metering. A reduction in EUI of 25% was notice, accordingly similar reduction in GHG emissions resulting from energy generation would be expected.

Recommendations

Proceeding forward from the conducted study, and to complete the main goals of the project, this section offers some recommendations for future work that would help the development of better refined models

The study was only able to recognise savings in energy used for space heating, while it failed to recognise the savings in DHW consumption, this was mainly due to lack of DHW data for Site-B. Hence it is recommended to install a DHW meter to measure the over all DHW consumption for Site-B, such data could then help establish a refined baseline model for Site-B that would account for DHW. Furthermore, partial sub-metering for Site-B units could be utilised to establish an estimated performance with sub-metering applied in the same building or benchmarking on the unit level instead of the building level.

Since the study is aiming to measure the change in residents' behaviours by applying submetering, it would be recommended to conduct a similar study on Site-D after delivery. Where Site-D is operated similar to Site-B's billing operation for a period of a year, then applying sub-metering for the following year. And as the literature recommends, facilitating the access of residents to their energy consumption, would help them make decisions that promote energy conservation. This could be achieved through the application of web-based interface that would inform residents of their consumptions.

Acknowledgements

The results of the study heavily relied on the data collected from buildings, which could have not been possible without the help from Brendan Mongeon of Enerpro, who has helped providing the required data. I would like also to express my appreciation to my mentors Jacquelyne Fitchell, E3 Eco Project manager representing UBC Properties Trust, and Ralph Wells, Community energy manager at UBC, for their continuous support, insights and guidance throughout the project. Last but not least, I would like to thank Surabhi. Shakkarwar, UBC SEEDS project coordinator, and David Gill, UBC SEEDS Program and Policy Planner, for helping keep the project on track.

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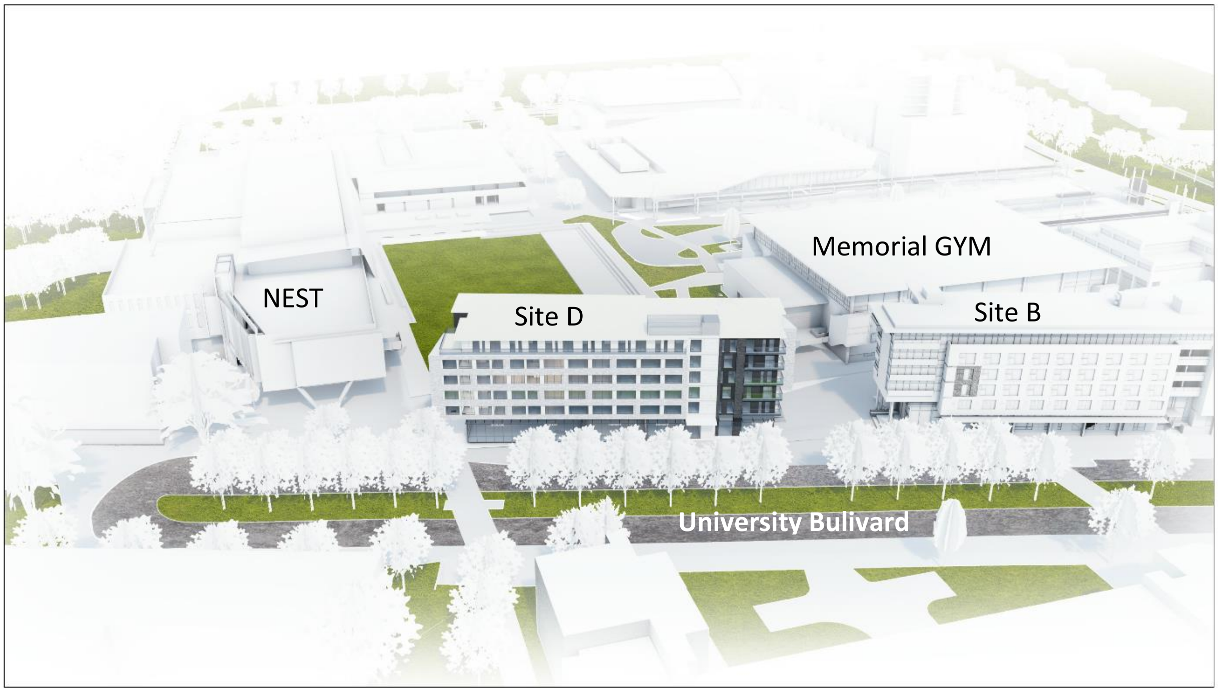
Appendices

Appendix A: Site Overview



Appendix B: Site-B Units Breakdown

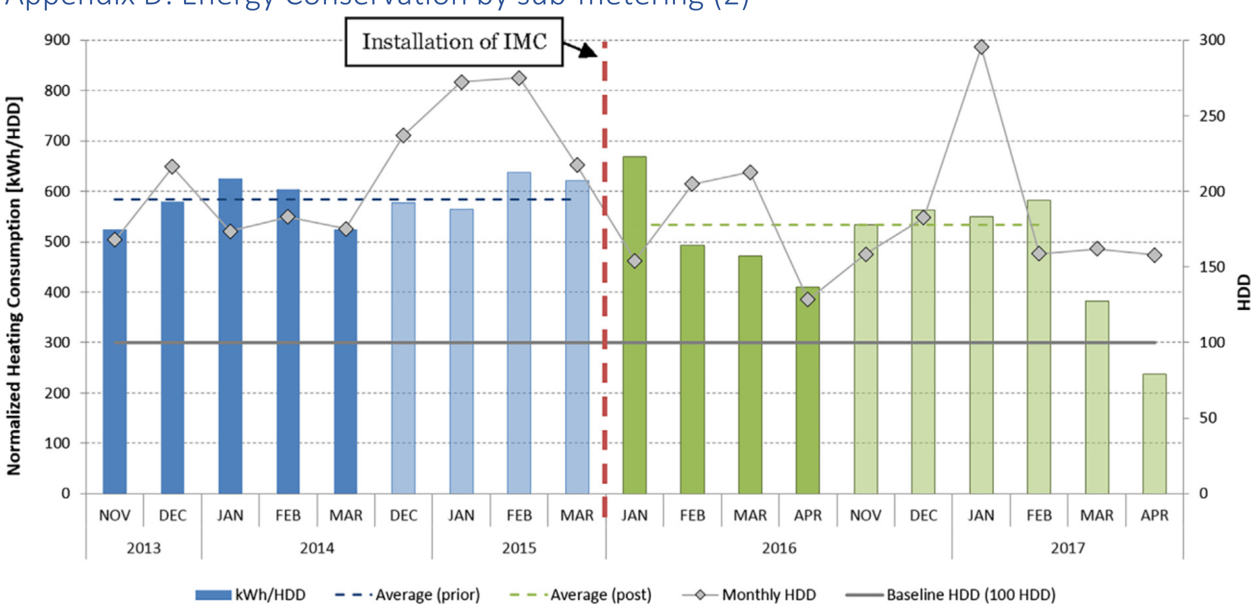
Site-B Apartment Building (Rental) - Unit Breakdown

Unit Type	# of Bedrooms	sf/Unit	# of units					Total # of Units
			L2	L3	L4	L5	L6	
A	Studio	350-495	15	15	15	15	-	60
B	1 Bedroom	525-677	2	2	2	2	1	9
C	2 Bedrooms	739-798	1	2	2	2	10	17
D	3 Bedrooms	961-1180	1	3	3	3	2	12
Sub total			19	22	22	22	13	98

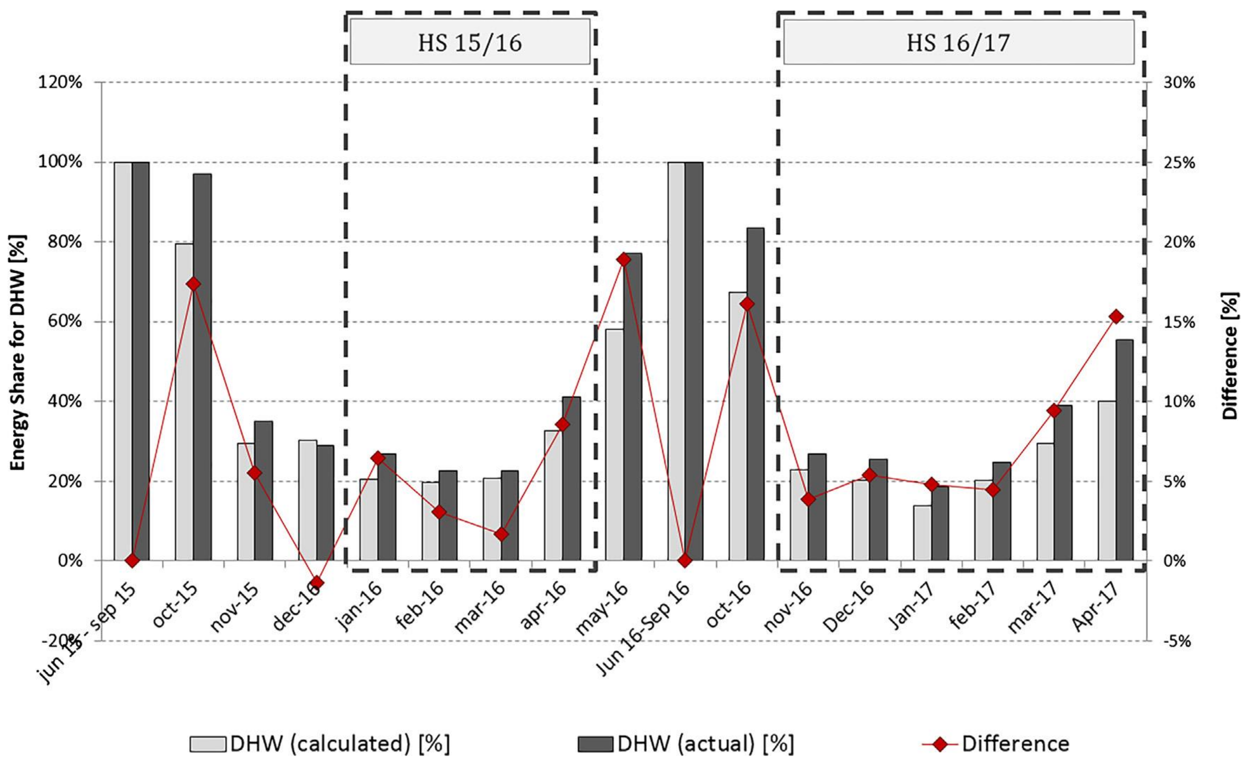
Appendix C: Site-D Units Breakdown

Site-D Apartment Building (Rental) - Unit Breakdown				
Unit Type	**Unit Type**	**Unit Area**	**# of Units**	**Total Unit Area**
A	Studio	450	25	11,250
B	Micro	355	22	7,810
C	Jr 2 Bedrooms	625	8	4,680
C1	Jr 2 Bedrooms	625	4	2,340
D	2 Bedrooms	842	15	12,030
E	1 Bedroom	602	3	1,686
F	3 Bedrooms	1,175	2	2,270
G	3 Bedrooms	1,384	1	1,344
H	2 Bedrooms	794	5	3,970
K	1 Bedroom	470	5	2,350
Sub total			90	49,730

Appendix D: Energy Conservation by sub-metering (2)



Appendix E: Energy share of DHW Calculated Vs. Actual (2)



Appendix F: Effect of Sub-metering on energy use (8)

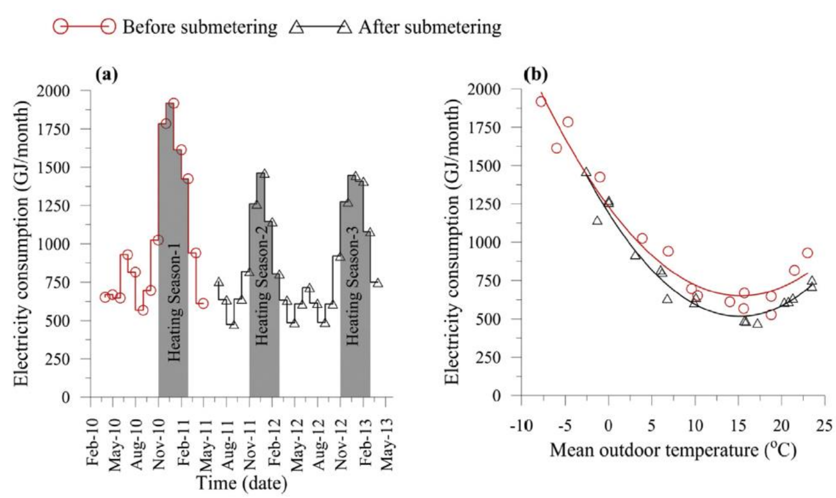


Fig. 1. Electricity use of a large electricity heated building in Toronto, Ontario before and after submetering with respect to (a) date and (b) mean outdoor temperature (outdoor temperature data was taken from Environment Canada [13]).

Appendix G: Indoor temperatures setting (8)

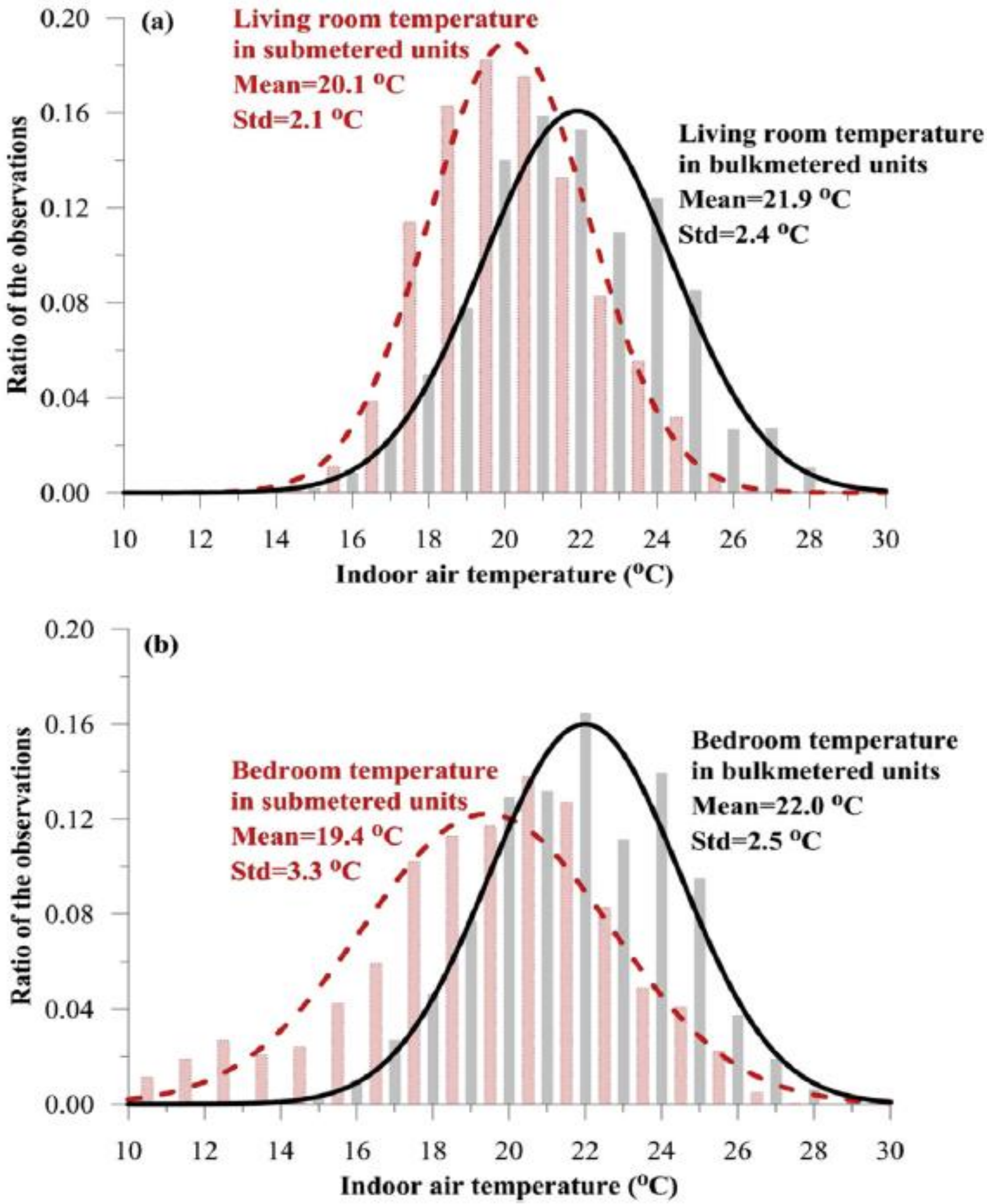
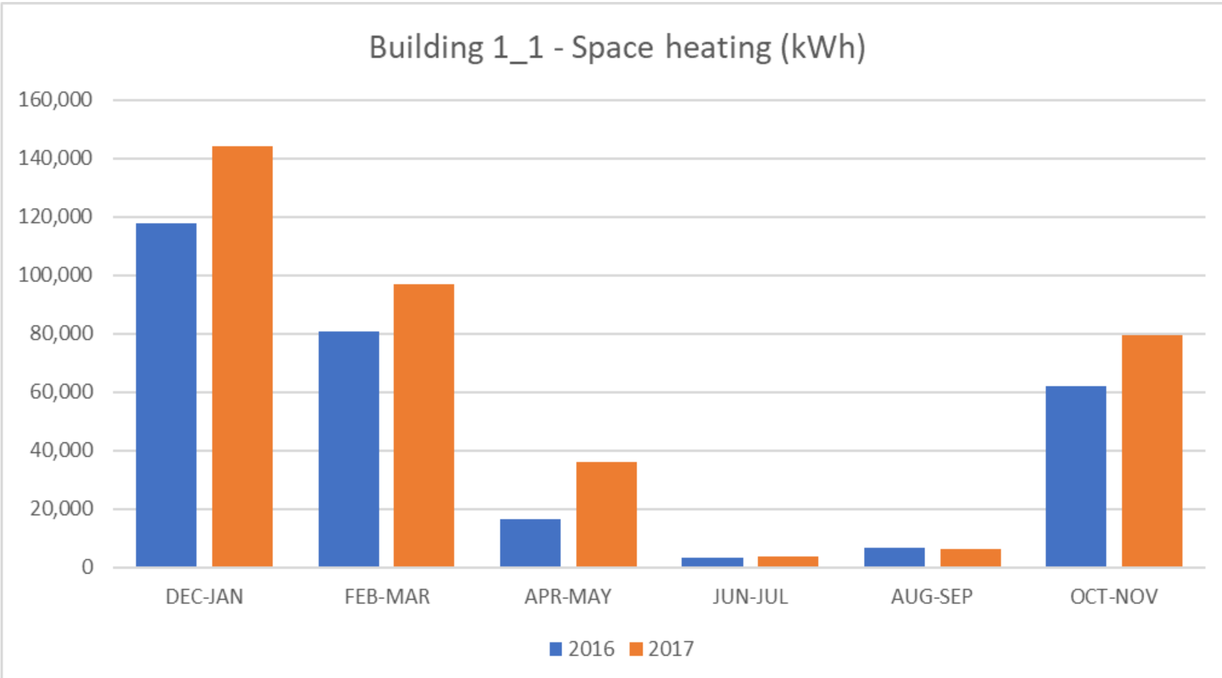
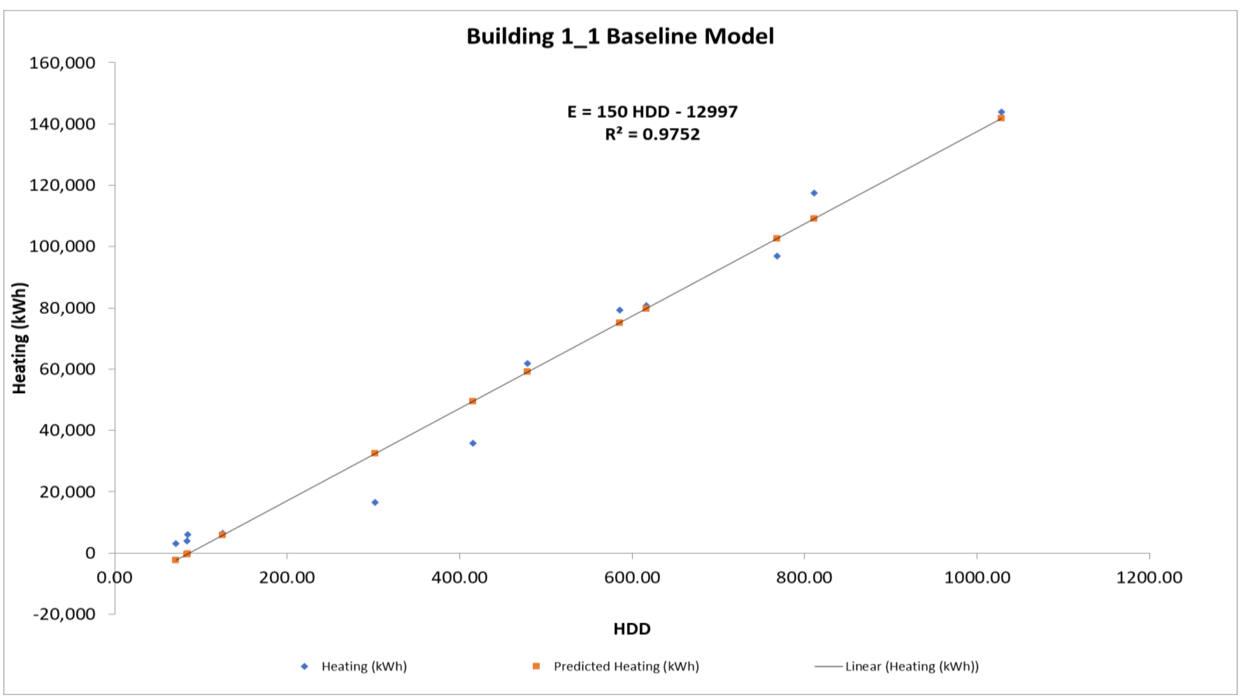


Fig. 7. Histogram plots comparing the distribution of the indoor air temperature measurements (a) in the living rooms and (b) in the bedrooms of the bulkmetered and submetered units.

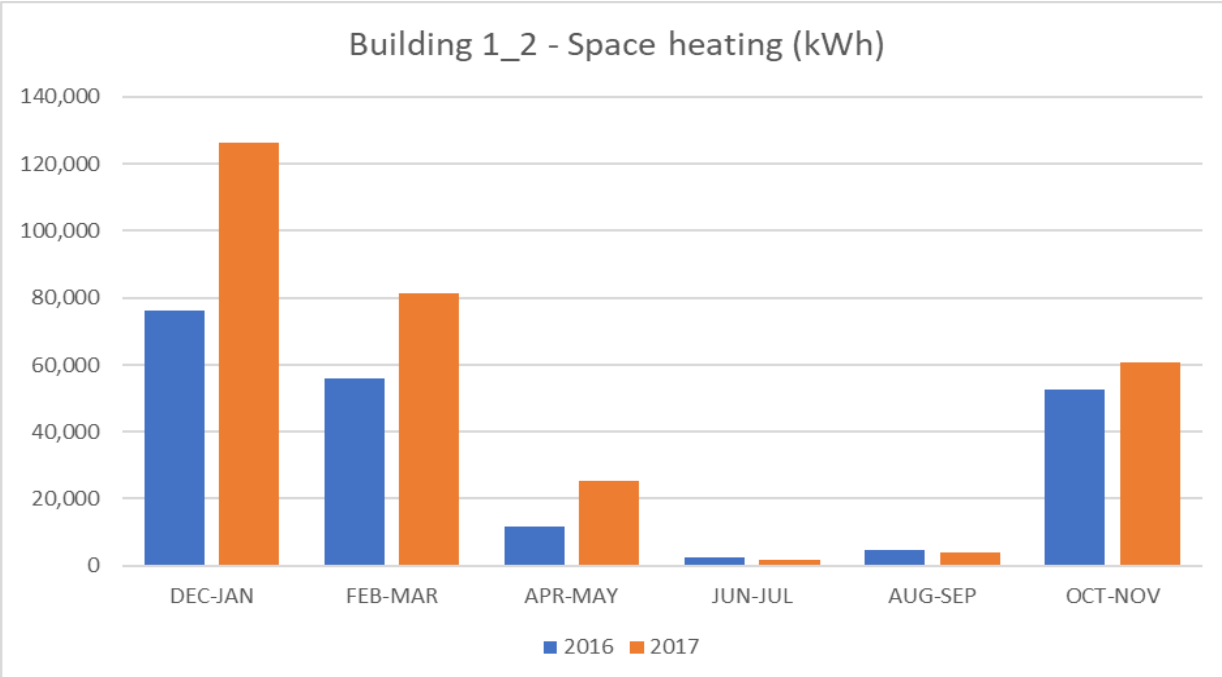
Appendix H: Data

a. Building 1_1 Data

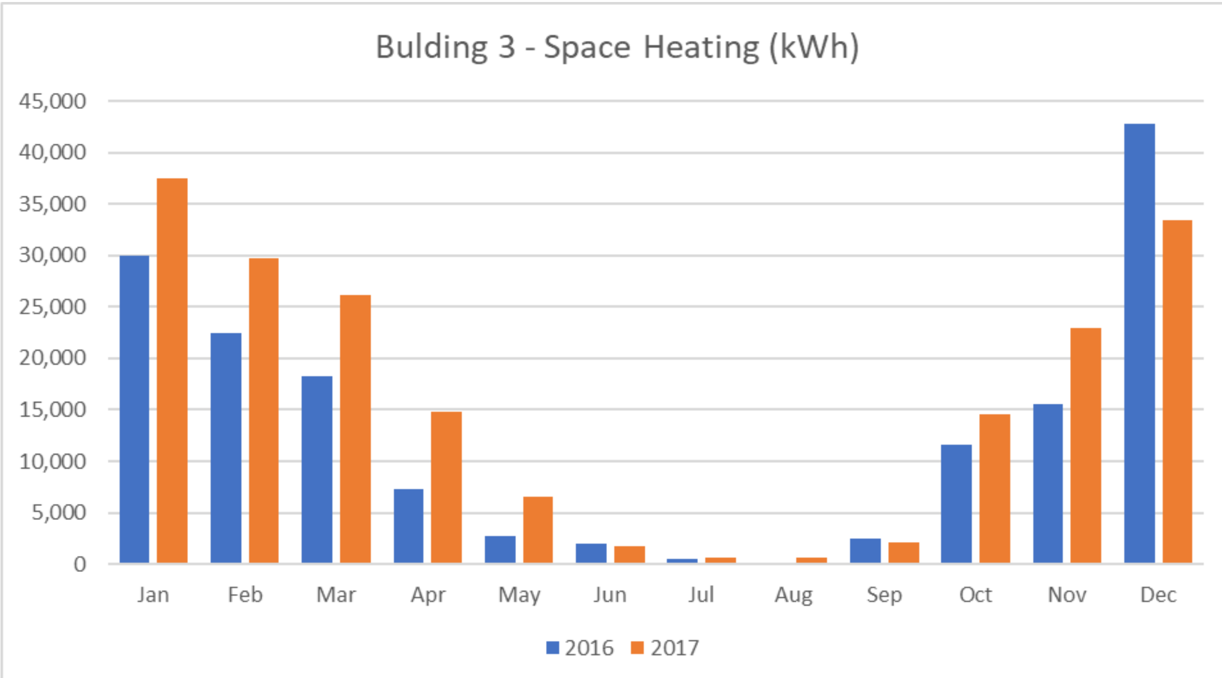


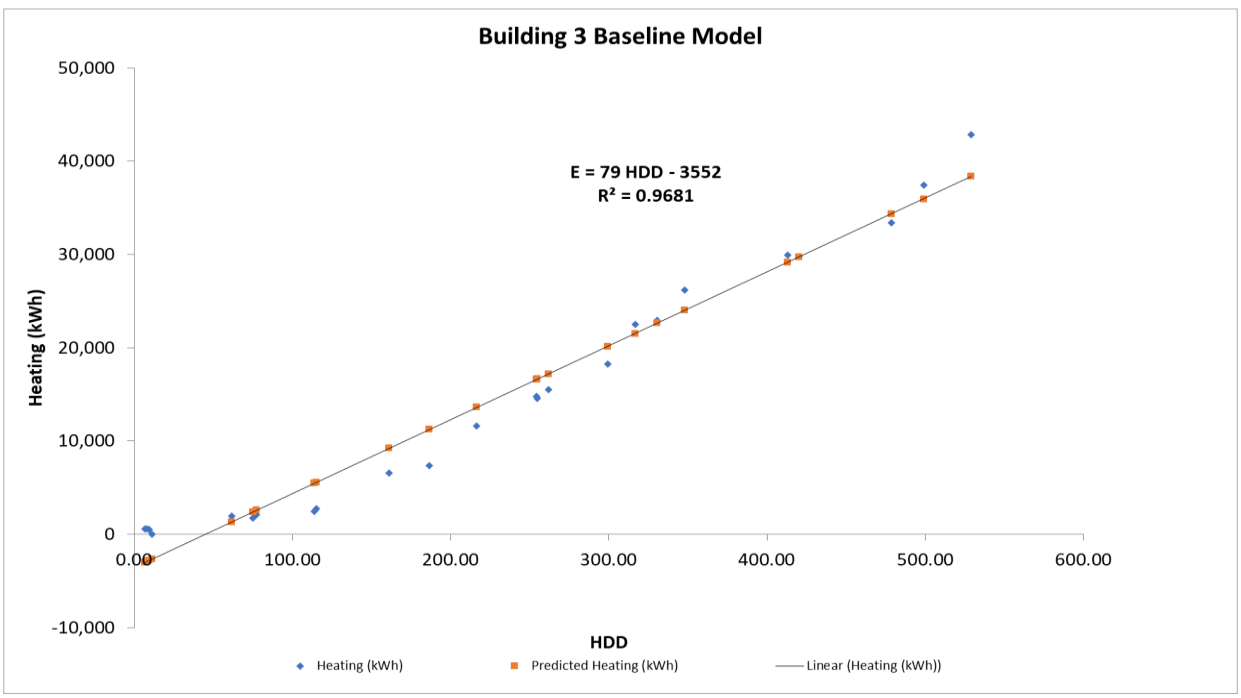


b. Building 1_2 Data

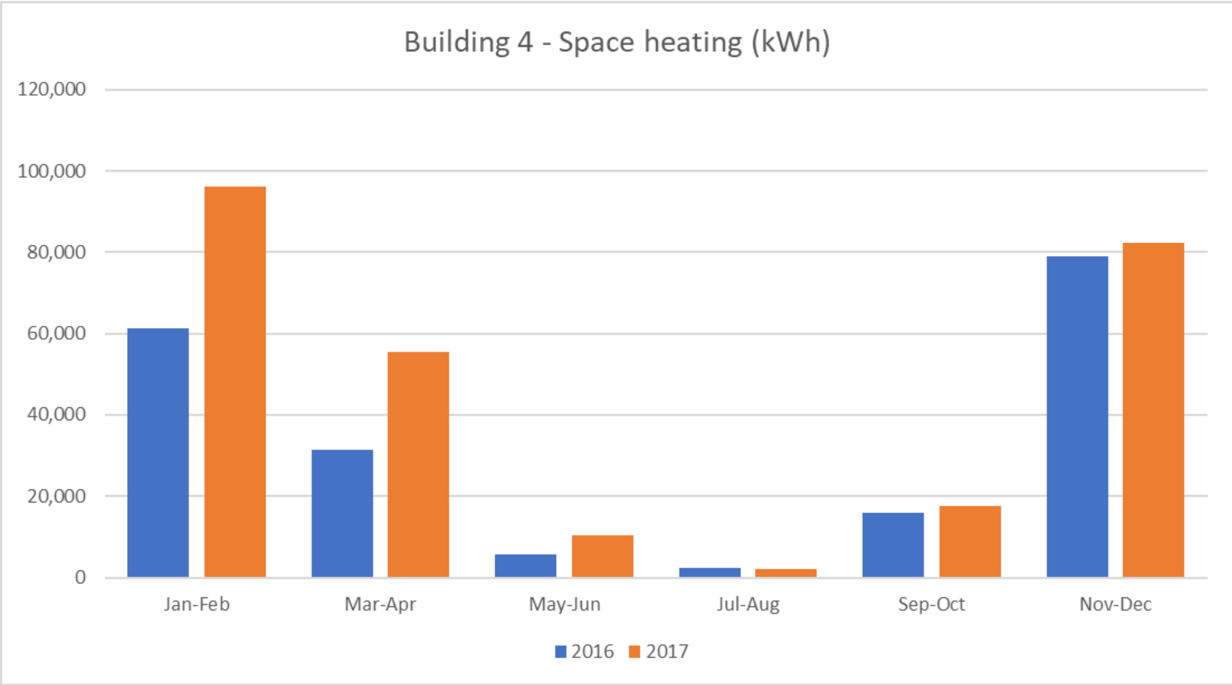


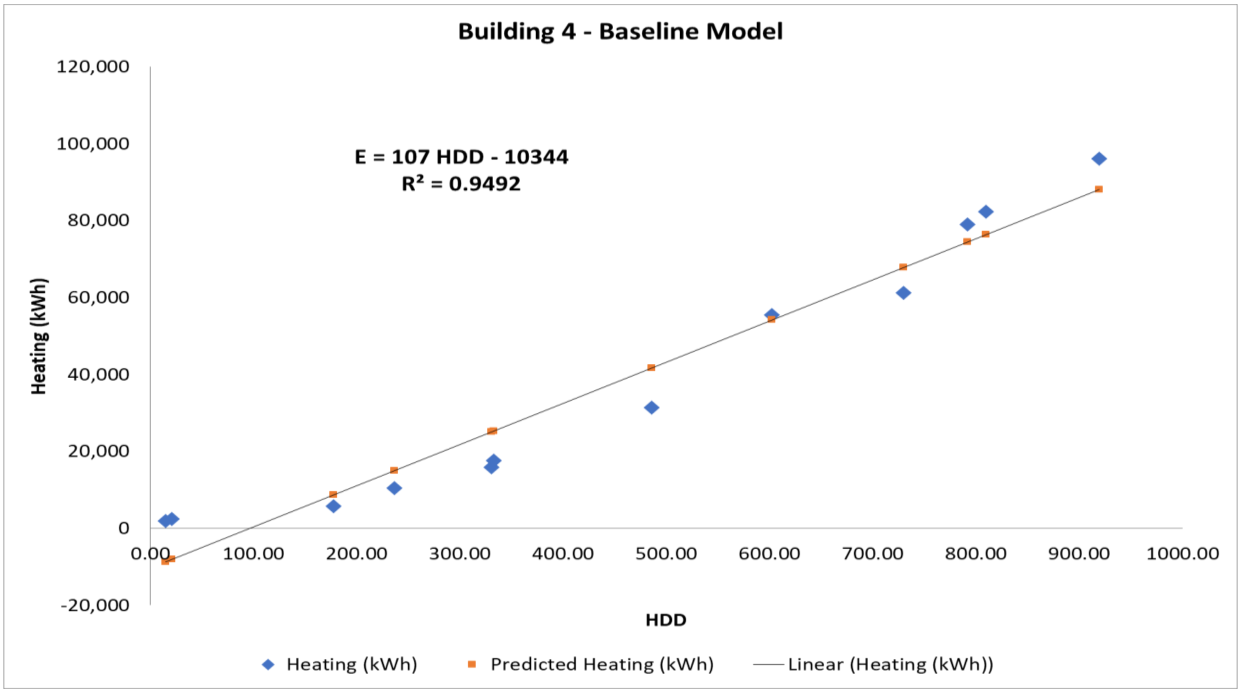
c. Building 3 Data



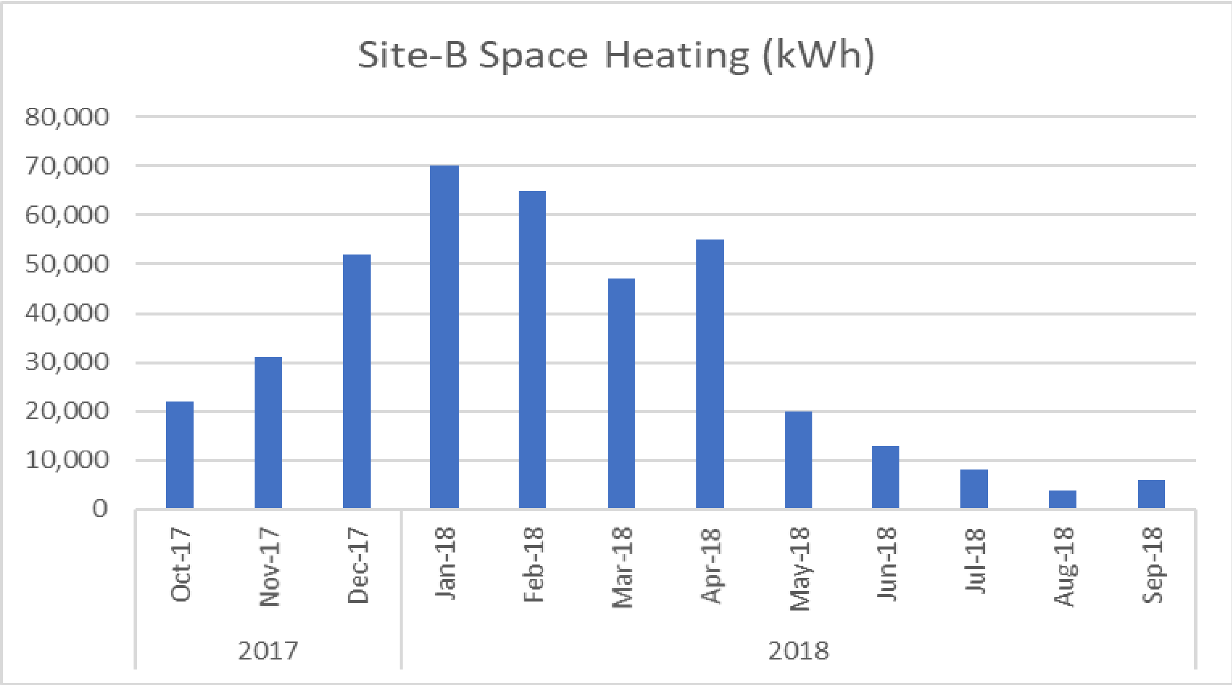


d. Building 4 Data

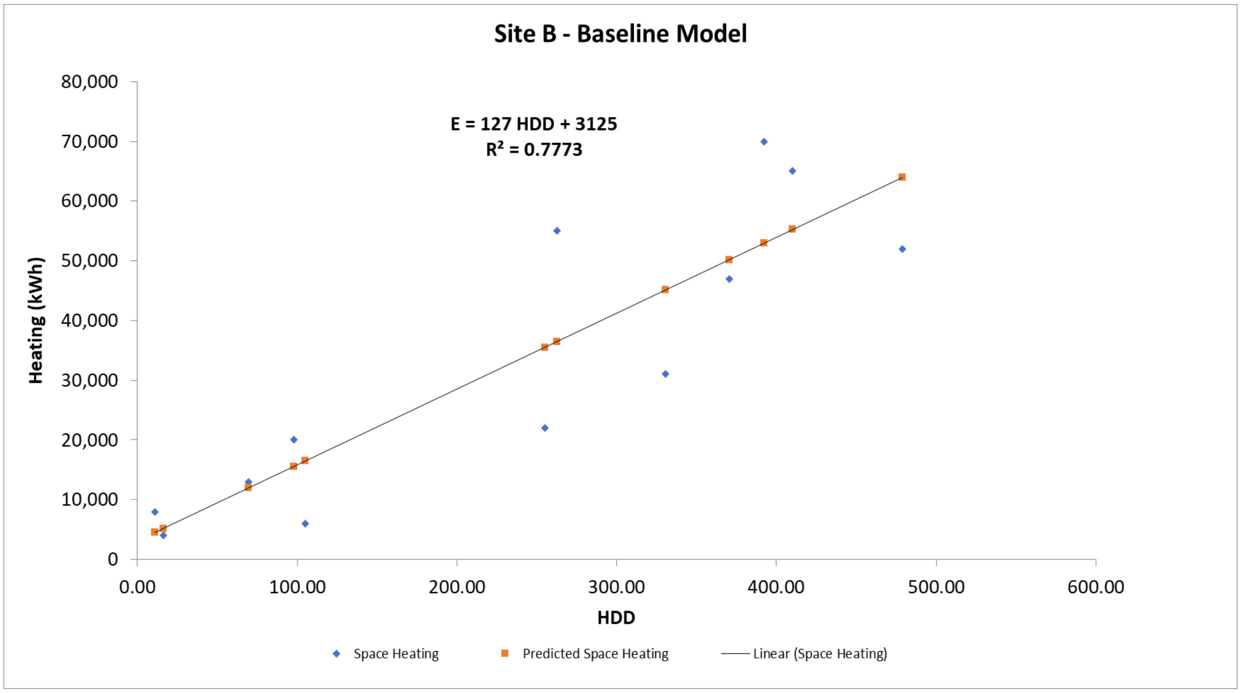




e. Site-B Data



Site-B Space Heating (kWh)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Oct-17
Nov-17
Dec-17
Jan-18
Feb-18
Mar-18
Apr-18
May-18
Jun-18
Jul-18
Aug-18
Sep-18
2017
2018



Site B - Baseline Model
E = 127 HDD + 3125
R² = 0.7773
Heating (kWh)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0.00
100.00
200.00
300.00
400.00
500.00
600.00
HDD
Space Heating
Predicted Space Heating
Linear (Space Heating)

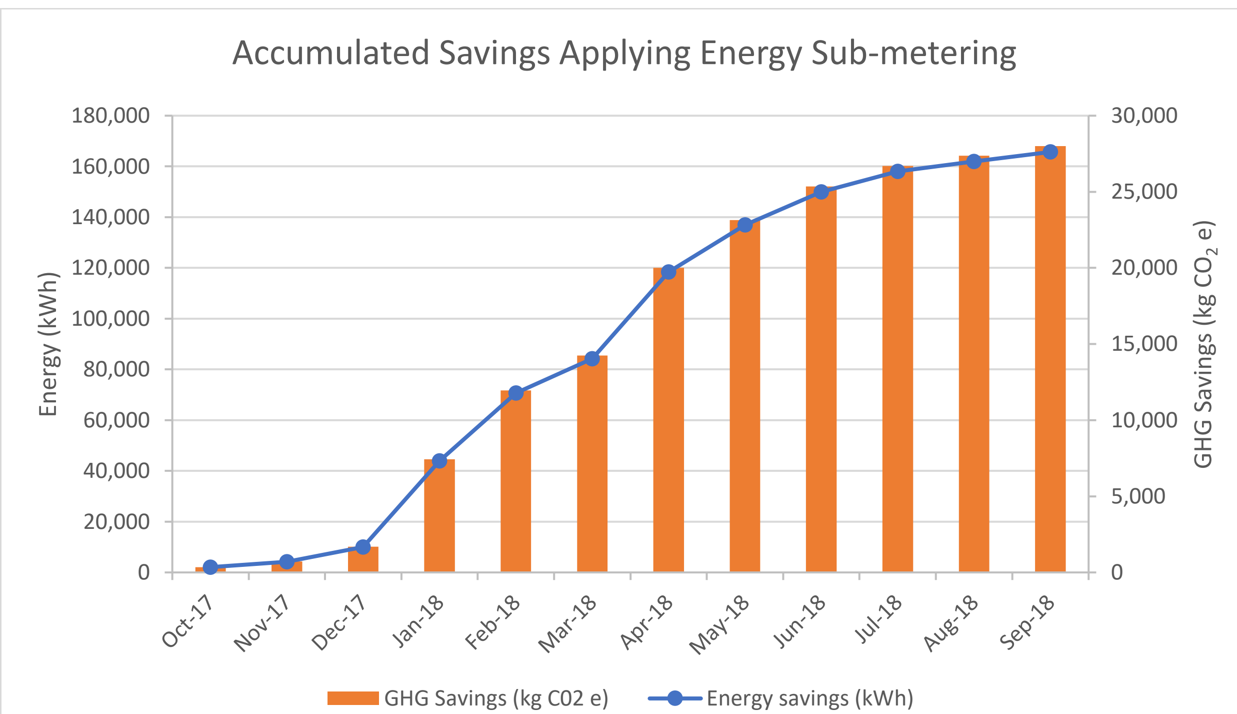
Appendix I: Results

a. Benchmarking and Modeling Results

Building	Area (m^2)	Overall Utilization	HDD Coefficient.	Intercept	SHEUI* (kWh/m^2)
Building 1_1	7,494	98%	151	-12997	50
Building 1_2	6,075	97%	121	-12285	51
Building 3	4,084	99%	79	-3551	47
Building 4	7,433	99%	107	-10344	36
Benchmark	6,271	98%	114	-9794	46
Site B	6,318	100%	127	3125	62
Adjusted Benchmark	**6,318**	**100%**	**118**	**-10055**	**47**
Site D Model	**4,595**	**100%**	**85**	**-7313**	**34**

* SHEUI : Space Heating Energy Use Intensity

b. Estimated Energy Savings Results



c. Estimated Payback period