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Energy Monitoring of Ontario Association of Architects Headquarters Building

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Report No.: A1-020998.1
Report Date: 2023-03-28
Contract No: A1-020998
Agreement date: August 22, 2016

National Research Council Canada
Conseil national de recherches Canada

Canada

Energy Monitoring of Ontario Association of Architects Headquarters Building

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Executive Summary

This report presents the analysis of the sub-metering electricity use data collected from the Ontario Association of Architects (OAA) Headquarters building from October 1, 2016 to December 31, 2022. The first section provides a detailed assessment of pre- and post-renovation electricity use in the building. Sub-metering data was explored to provide a better understanding of the building's energy performance. The breakdown of electricity use is presented to illustrate the proportion of loads that are sub-metered individually. By analyzing the monthly trends of each sub-meter reading, it was found that loads that are typically not weather-dependent were, indeed, generally stable between seasons, while the weather-dependent loads exhibited expected trends. A non-linear regression model was developed to estimate the post-renovation avoided electricity use. The results showed a 650-times reduction in net electricity use. The associated savings in cost and CO_2 are approximately $200,000 and 120 tonnes per year, respectively. The pre- and post-renovation energy performance of the OAA HQ building were compared with the Energy Star benchmark energy use intensity. The results showed poor pre-renovation energy performance. However, the post-renovation energy use intensity was significantly lower than the benchmark value, indicating the superior performance of the OAA building relative to the national benchmark indicator.

Potential electricity saving opportunities were identified (for example, lowering plug loads during weekends and holidays). However, over 70% of the total electrical load was used for heating and cooling systems. The results suggest that electricity use is mainly driven by the heating load and efforts to lower energy use should be focused on improving heating system energy performance. The findings suggest that building operations are in close proximity to achieving net-zero operation, and with minor adjustments, net-zero operation can be attained.

1. Introduction

In 2009, the Ontario Association of Architects (OAA) committed to the 2030 Challenge. The 2030 Challenge aims to take the building sector to carbon-neutral operation by reducing greenhouse gas emissions for all new buildings and major renovations by 90% in 2025, and becoming carbon-neutral by 2030.

A net-zero carbon building can be achieved by eliminating the use of fossil fuels, installing on-site low-carbon energy generation, energy efficiency, and securing certified carbon offsets for the remaining electricity consumption. The OAA aimed to achieve this by installing a ground source heat pump system and two types of solar panels - a photovoltaic and a thermal system - as well as reducing energy consumption through a deep energy retrofit (including an air leakage retrofit).

The solar thermal panels are connected to a closed-loop geothermal exchange system which consists of 15 wells that are more than 180 metres deep. In addition to the solar thermal panels, two types of photovoltaic (PV) solar panels were installed on the existing steel roof canopy. This includes more than 400 square metres of Heliene PV panels to generate 60,000 kWh annually, along with 200 square metres of customized Solar Pergola designed by Morgan Solar to generate 40,000 kWh annually. This innovative system combines translucent and opaque PV panels to form a semi-transparent canopy over the outdoor terrace which blocks about 75% of heat and glare while maintaining a view of the sky. The 15 strings of Heliene PV modules are connected in parallel to 3 Fronius inverters. Table 1 summarizes the Heliene PV system.

Table 1: Heliene PV system specifications

Parameter	**Value**
Manufacturer	Heliene
Module Model	72M-370W
Total module count	208
Maximum power	370 W
Voltage	40.153 V
Current	9.28A

Open circuit voltage	48.81V

To enable detailed energy monitoring, 14 sub-meters and a remote data collection system from Z3 Controls were deployed at the OAA building. The technical specifications of the sub-meters can be found on the manufacturer's website [1].

The preliminary data analysis, performed in 2017, showed that sub-meters were able to capture 89% of the total load. Therefore, four extra sub-meters were installed during the renovation process. The new meters measure electricity use from the kitchen, house services, and fire panels. What each sub-meter has been metering during the pre- and post-renovation periods of time are provided in Table 2. Note that the electrical panels went through changes as part of the renovation process. The pre- and post-renovation electrical layout schematics are presented in Appendix A.

Table 2: Sub-meters and main meter

Meter/Sub-meter	**Pre- load**	**Post- load**
HP Electric	Electric Baseboards (secondary heating source)	Merged - Mechanical equipment (e.g. pumps, AHUs and VAV boxes)
Mechanical RM	Chiller, Fans & Pumps	
2nd RP2C Plugs	Plug Load on 2nd Floor	Plug Load on 2nd Floor
3rd RP Plugs	Plug Load on 3rd Floor	Plug Load on 3rd Floor
2nd West Lighting	Internal Lighting on 2nd Floor West Section	Internal Lighting on 2nd Floor West Section
2nd East Lighting	Internal Lighting on 2nd Floor East Section	Internal Lighting on 2nd Floor East Section
3rd Lighting	Internal Lighting on 3rd Floor	Internal Lighting on 3rd Floor
External Lighting	External Lighting	External Lighting
Elevator	Elevator	Elevator
Not Sub-metered	kitchen, house services and fire panel	N/A
RP	N/A	kitchen, house services and fire panel
PV-SYSTEM	N/A	Photovoltaic panel generation
Main	Main Power	Main Power

To deliver a better understanding of the pre- and post-renovation building energy performance the electricity sub-metering analysis section is presented in the following sections:

- Breakdown of Electricity Consumption
- Daily Trend of Sub-metered Loads
- Weekly Profiles of Sub-metered Loads
- On-site photovoltaic generation

2. Electricity Sub-metering Analysis

2.1. Breakdown of Electricity Consumption

To understand the OAA HQ building's energy performance, a starting point is to investigate the electricity use of the different sub-meters. The breakdown shown in Figure 1a is performed for the 12-month data collecting period from December 2016 to December 2017. Loads on chillers, fans, and pumps metered by Mechanical RM use the largest portion (31%) of the building's total electricity, followed by 25% used for baseboard heating metered by HP Electric (or 56% of total electricity usage for heating and cooling systems). Grouped lighting and plug load take up 21% and 11% of the total, respectively. Only 1% of electricity goes to elevators and 3% to external lighting. The 9 sub-meters are able to capture 89% of the total load, leaving 11% not sub-metered.

Figure 1b shows the post-renovation (December 2021 to December 2022) electricity use. Similar to the pre-renovation breakdown, the load on mechanical equipment used for heating and cooling consumes the largest portion of the building's total electricity. Grouped lighting and plug load take up 7% and 11% of the total, respectively. Only 1% percent of electricity goes to elevators and 9% to the kitchen and house services. Figure 1b shows that the distribution of post-renovation electricity use is generally similar to the pre-renovation breakdown. The main differences are the higher portion of mechanical equipment load (72% post- vs 56% pre-renovation) and the smaller load of the lighting system (7% post vs 21% pre-renovation). The next sections provide more details on electricity use in the building.

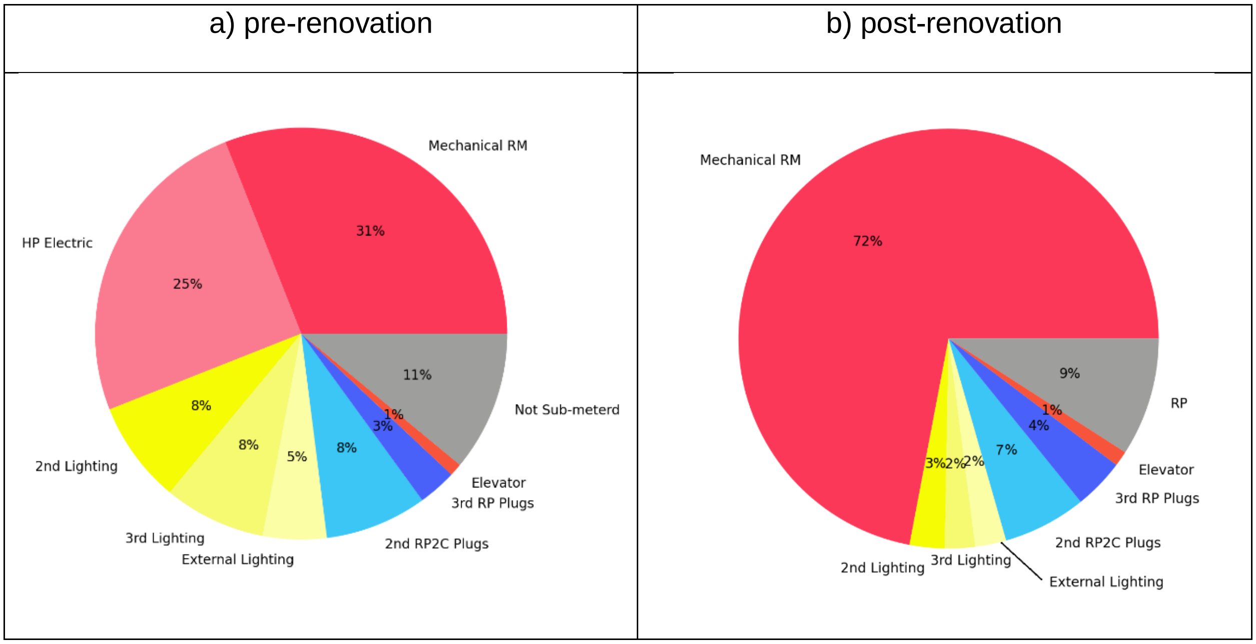

Figure 1: Electricity load breakdown by sub-meters

2.2. Daily Trend of Sub-metered Loads

The breakdown of electricity consumption varies over time, especially when there are weather-dependent load components. The daily aggregation of each sub-meter is therefore compiled to give a better idea of how the building's electricity needs change over time during both pre- and post-renovation analysis periods. As mentioned in the previous section, only 89% of the total electricity use was sub-metered before the renovation. Therefore, in this section, three groups of loads, namely: mechanical equipment, lighting, and plug loads, are compared.

Figure 2 shows the daily plug loads. The significant drop in pre-renovation load after September 2019 is possibly caused by lower occupancy due to the renovation process. However, the weekly variation of plug loads is obvious in both cases which is common for office buildings with lower occupancy during the weekends. On average, the post-renovation plug loads are 65% lower than the pre-renovation values. It is noteworthy that during the post-renovation period, there is a constant plug load of about 35 kWh/day even during weekends. Although this value is relatively small compared to the total building load, it could be further investigated to better understand plug loads during low and no occupancy hours to potentially reduce unnecessary loads (e.g. large screens left on).

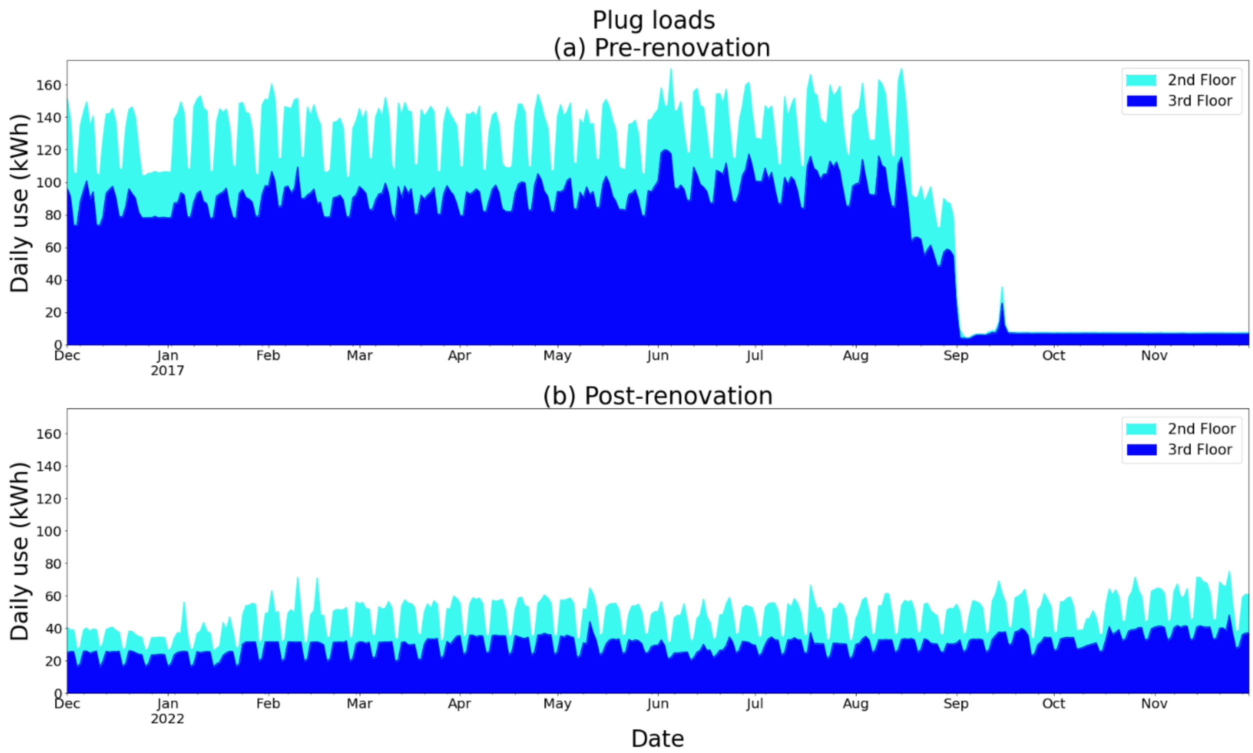

Figure 2: Comparison of pre- and post-renovation daily plug loads

Figure 3 shows the pre- and post-renovation daily lighting electricity loads. Similar to Figure 2a we see a change in pre-renovation electricity use trends after September 2017. The external lighting remains fairly consistent throughout the year; whereas internal lighting loads follow a weekly profile. Regardless of these variations, the post-renovation values are significantly lower due to the highly efficient lighting and glazing systems used in the building. On average, the post-renovation electricity use is 85% lower than pre-renovation values.

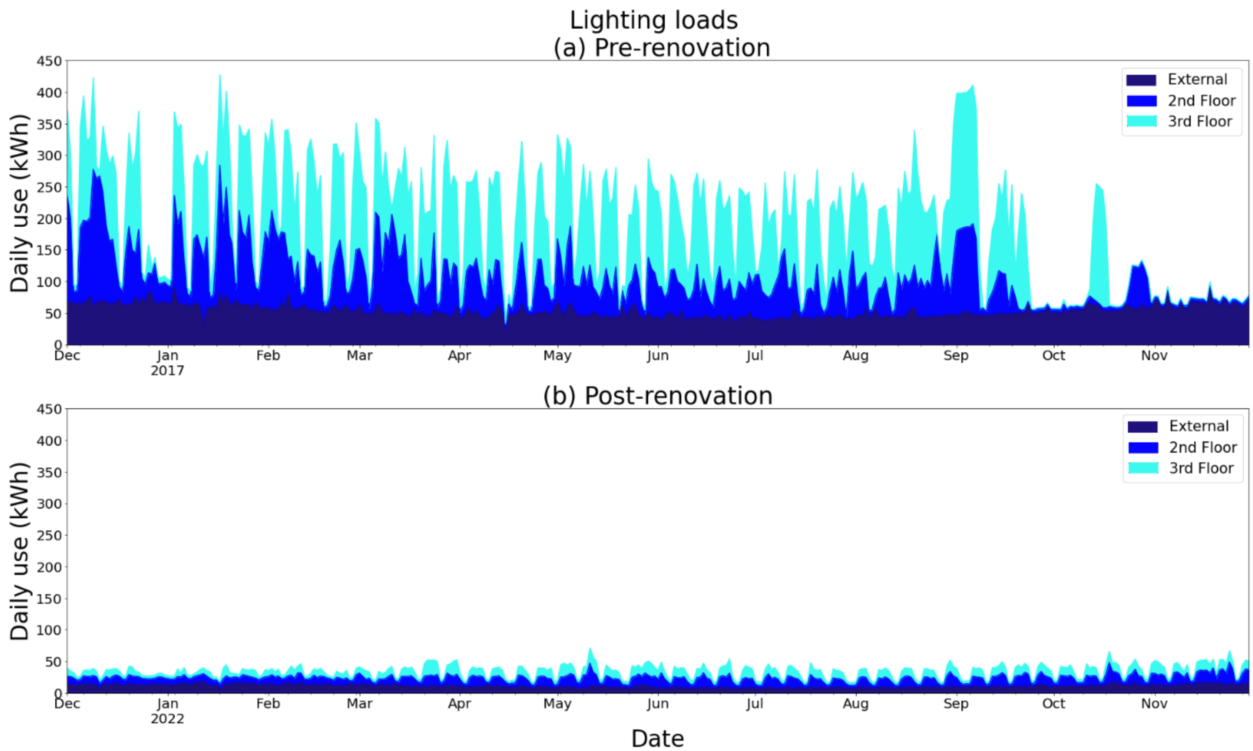

Figure 3: Comparison of pre- and post-renovation daily lighting loads

Figure 4 shows the variation of both pre- and post-renovation mechanical equipment loads. As presented in Table 2, the pre-renovation values for total mechanical equipment load were measured by two meters (HP for electric baseboard heaters and Mechanical RM for chillers, pumps, etc). After the renovation, only one meter was used to measure the total mechanical equipment load. Figure 4 compares the total mechanical load during pre- and post-renovation periods for easier visual comparison. Post-renovation values are significantly lower than pre-renovation values. The post-renovation load profile is on average 26%, 64%, and 62% lower than the pre-renovation values during winter, summer and shoulder seasons, respectively. The smallest reduction is observed during the winter season. It is however important to note that natural gas use for heating has been totally eliminated as a result of the renovations, so the actual energy and associated CO_2 savings are higher than the electrical only values reflected in this section. Further, the current section is focuses only on electricity use in the building and does not consider on-site renewable generation. These will be discussed in more detail in the next sections.

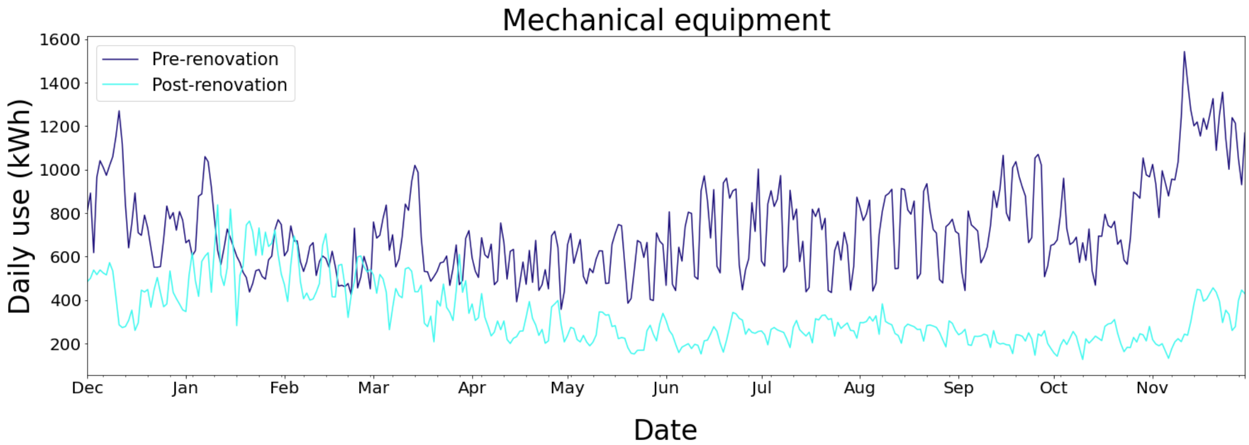

Figure 4: Comparison of pre- and post-renovation daily mechanical equipment loads

In order to provide more insights into the mechanical load changes, Figure 5 shows variation in the pre-renovation load profile against average daily temperature. The daily electricity loads on mechanical equipment are sensitive to weather changes. A rapid reduction in the outdoor temperature in November, December, and January is commonly associated with a peak in electricity use. This is mainly due to the use of electric baseboard heaters during the pre-renovation period. The cooling load begins to climb in May and the weekly patterns remain relatively steady during summer.

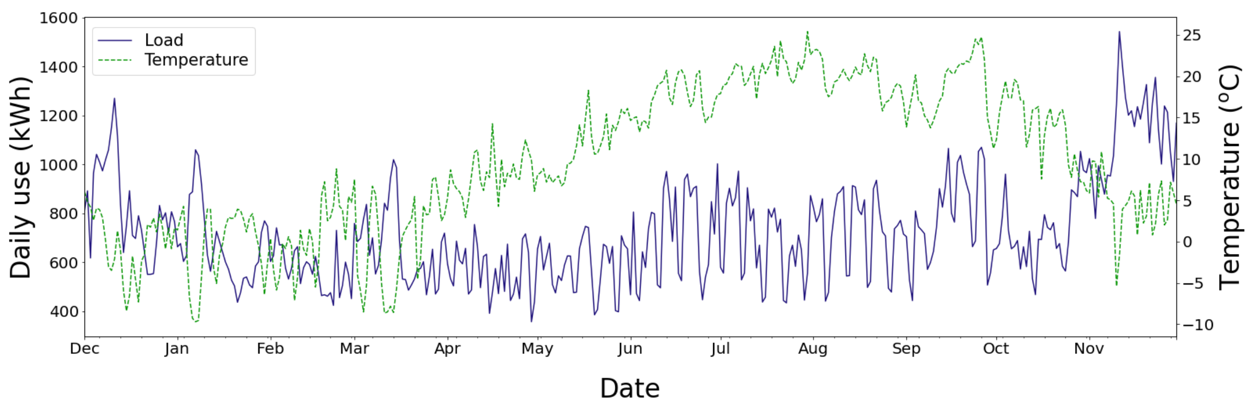

Figure 5: Pre-renovation Mechanical Daily Electricity Usage against Average Daily Outdoor Temperature (Dec. 2016 to Dec. 2017).

Similar to Figure 5, the variation of mechanical load against temperature during the post-renovation period is shown in Figure 6. In comparison with the previous figure, the mechanical equipment load is less sensitive to changes in outdoor temperature. This could be attributed to the more energy-efficient building envelope and HVAC equipment. However, the peaks of mechanical equipment load during the heating season are again associated with low daily temperatures. During the cooling season, the differences between weekdays and weekends (as can be seen in the weekly profile) are considerably smaller compared to pre-renovation values. This could be a result of more efficient cooling schedules as well as lower occupancy during this period of time.

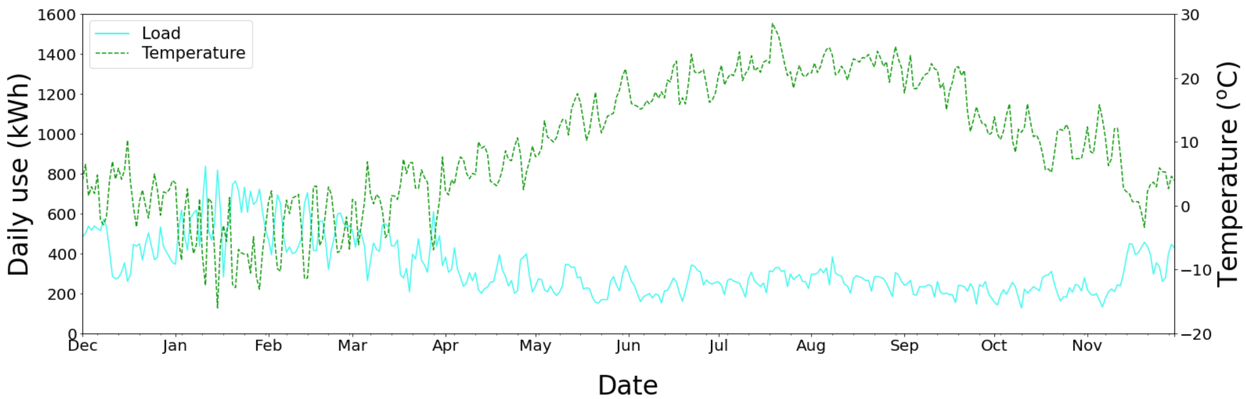

Figure 6: Post-renovation Mechanical Daily Electricity Usage against Average Daily Outdoor Temperature (Dec. 2021 to Dec. 2022).

2.3. Weekly Profiles of Sub-metered Loads

As shown in Figure 1, mechanical equipment loads make up more than half of the total consumption, therefore it is important to explore their variations in more detail. To move the analysis beyond the daily performance using aggregated data, hourly data collected by sub-meters is considered, offering a greater opportunity for exploration. To take advantage of this high-resolution data, it is visualized by plotting weekly profiles so that the hourly, daily, and weekly patterns of the building's energy use can be assessed.

In Figure 7, Figure 8, and Figure 9, four weekly profiles (a winter and a summer week for both pre- and post-renovation periods) are presented for lighting load, mechanical equipment load and plug & elevator load. Table 3 presents the selected weeks used in the weekly profile graphs.

Table 3: Selected periods of time for weekly profiles

Pre-renovation		**Post-renovation**	
Winter	Summer	Winter	Summer
2017-01-23 to 2017-01-30	2017-06-19 to 2017-06-26	2023-01-23 to 2023-01-30	2022-06-20 to 2022-06-27

A weekly pattern can be observed for the pre-renovation lighting load during the winter week (Figure 7a). The external lighting load remains consistent throughout the week; however, the internal load is substantially less during the weekend (the last two days in the graph) which is an indicator of lower occupancy during the weekend. The post-renovation winter week (Figure 7b) also shows a weekly pattern, however, the electricity usage is significantly less compared to pre-renovation values (note that the scale of the vertical axis is not the same, to better show the details of each load profile). The maximum hourly lighting load during the winter week has decreased from 14 kWh to only 1.7 kWh (~8 times smaller).

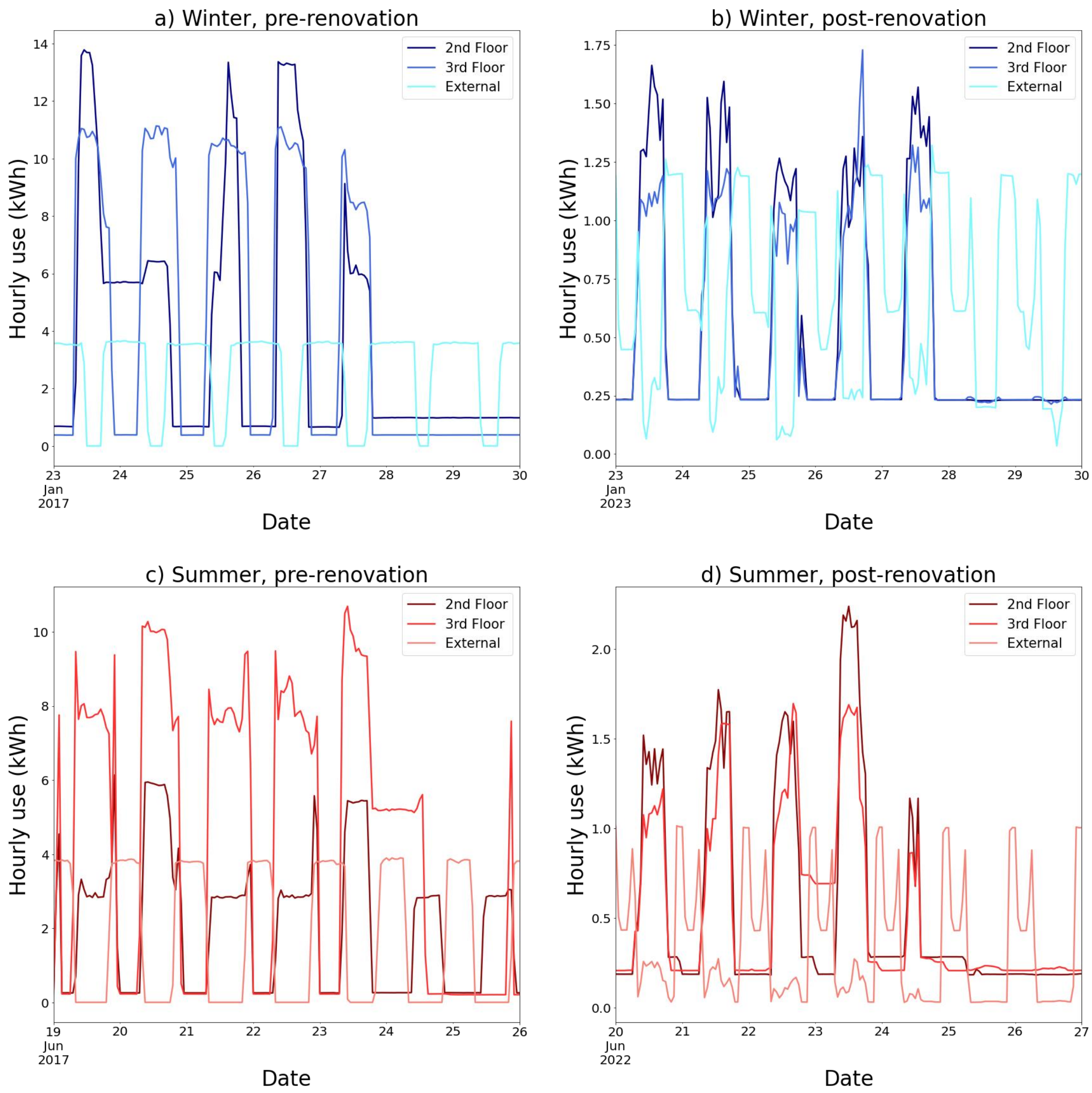

Figure 7: Weekly profile of the lighting load

The summer profiles (Figure 7c and d) show the same behaviour during weekdays and weekends. The pre-renovation summer loads are lower than winter loads (Figure 7a and c) which is expected due to longer daylight hours in June. However, in the post-renovation graphs (Figure 7b and d) the summer average load is slightly higher than winter values. This could be a result of variations in occupancy during the studied weeks as well as the glazing system which may limit direct natural sunlight. In general, the significant reduction in magnitude of the lighting load shows the superior performance of the post-renovation lighting system (both internal and external).

For the electrical HVAC load, a weekly pattern is less apparent – as this load is a function of outdoor temperature. For the winter week (Figure 8a and b), post-renovation electricity use is about 20% lower than pre-renovation values while, during the post-renovation period, outdoor temperatures are similar, there is no natural gas heating, and occupancy is lower (i.e. lower internal heat gain from occupants). During the summer week (Figure 8c and d), post-renovation cooling electricity use is about 27% higher than pre-renovation values. This higher post-renovation electricity use could be a result of higher outdoor temperatures during this period of time (average values of 20.4ºC vs 18.3ºC).

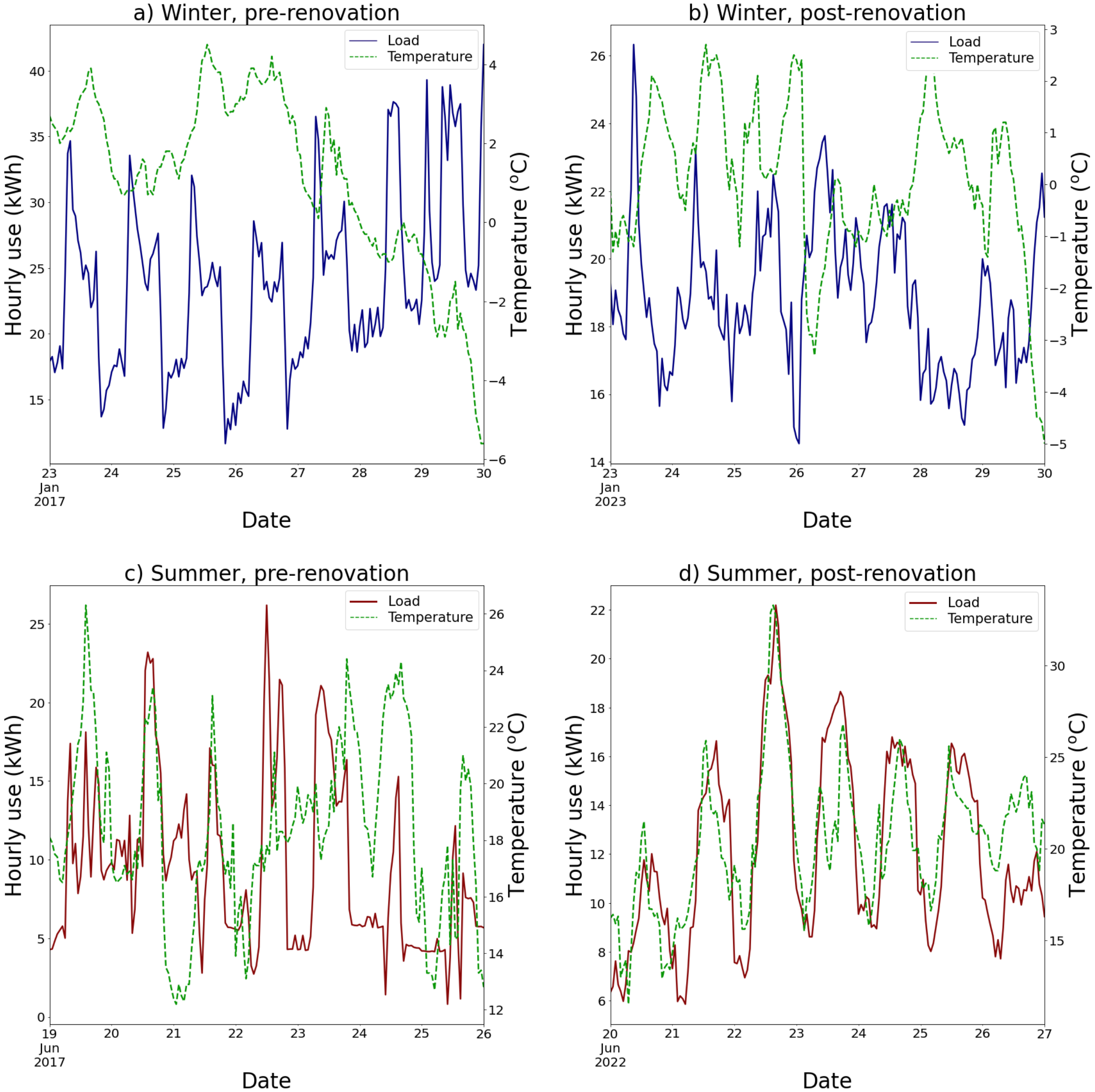

Figure 8: Weekly profile of mechanical equipment load

In post-renovation weeks, the load goes down during non-working hours and weekends, indicating proper HVAC schedules with setbacks. The building is also equipped with CO_2 sensors in the meeting areas for more efficient ventilation. However, there is a sharp increase in the post-renovation winter load (Figure 8d) with a peak value just before midnight. It may be beneficial to review nighttime temperature setpoints and revise pre-conditioning schedules.

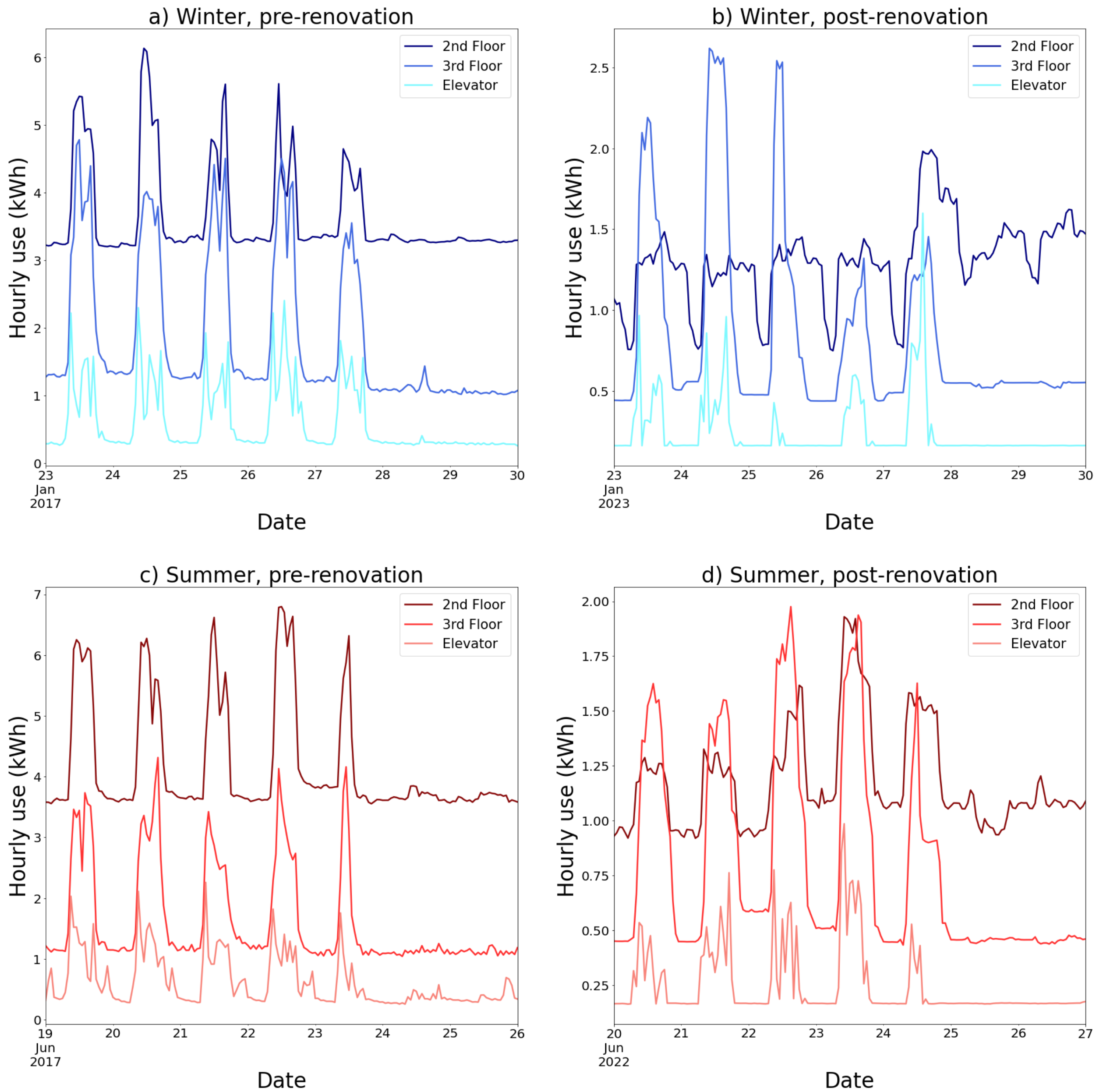

Figure 9: Weekly Profile of Plug and Elevator Loads

It can be seen from Figure 9 that there is a distinctive weekly pattern: both plug and elevator loads go up during working hours and go down at night and during weekends. Both plug load and elevator load are strong indicators of occupancy. The elevator load peaks every morning when employees arrive for work, immediately followed by a rapid rise of plug loads on both floors as people settle in for their day at work. During the pre-renovation weeks (Figure 9a and c) the same work hours are followed from Monday to Friday, though for the summer week Friday, the building is only occupied during the morning. For the two weeks shown here, little to no occupancy was indicated after working hours or during weekends. The post-renovation weekly profiles show the same pattern while the magnitude of loads is about half of the pre-renovation values. In the case of elevator loads, this suggests reduced occupancy during the studied weeks. The OAA staff follow a hybrid schedule so post-renovation occupancy is expected to be lower than pre-renovation values. The plug load during the winter weekend (the last two days in Figure 9b) is higher than the average nighttime value. It is possible that the building accommodates visitors on the weekend shown here. To further investigate this, four weeks of plug loads are shown in Figure 10. The weekends are highlighted in this figure. A similar pattern is observed during all weekends i.e. daytime plug load is on average 33% higher than nighttime values. This could be inspected by managers to see if the higher plug loads during weekends (e.g. from screens and/or workstations' lighting) can be avoided to improve energy efficiency.

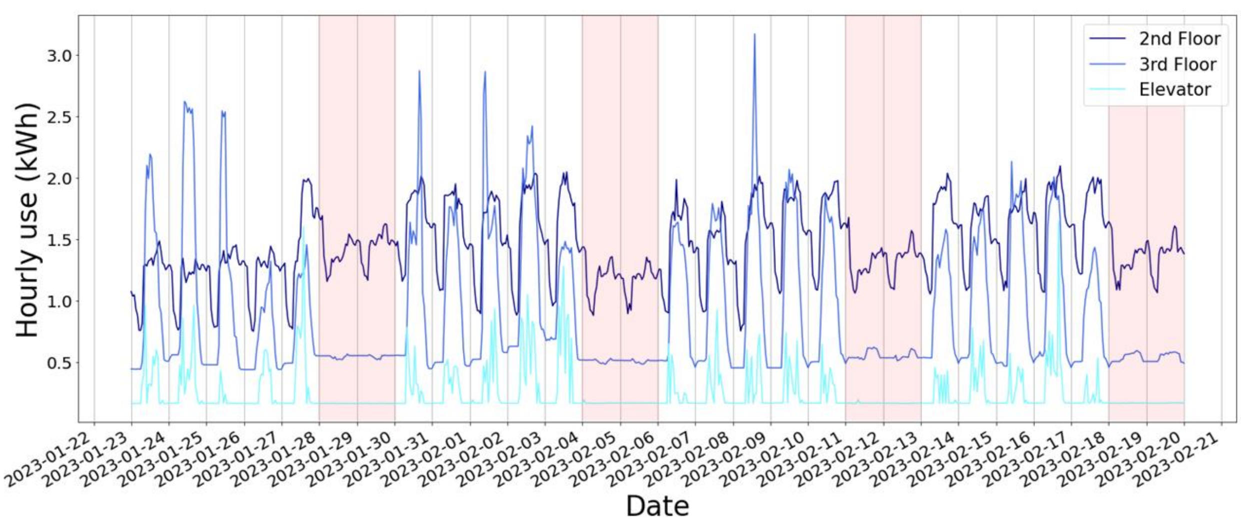

Figure 10: One Month of Plug and Elevator Loads Variation

2.4. On-site photovoltaic generation

As mentioned in section 1, the OAA HQ building is equipped with 600 square meters of photovoltaic (PV) panels with a nominal capacity of 100 MWh annually. Figure 11 shows two years of total electricity generation from the PV system. The 30-day moving average clearly shows the expected seasonal trend with maximum solar generation in July. Note that for the post-renovation analysis, only data from 2022 is used. During this period, the total generation varies from a minimum of only 0.3 kWh/day in January to a maximum value of 721.7 kWh/day in July 2022.

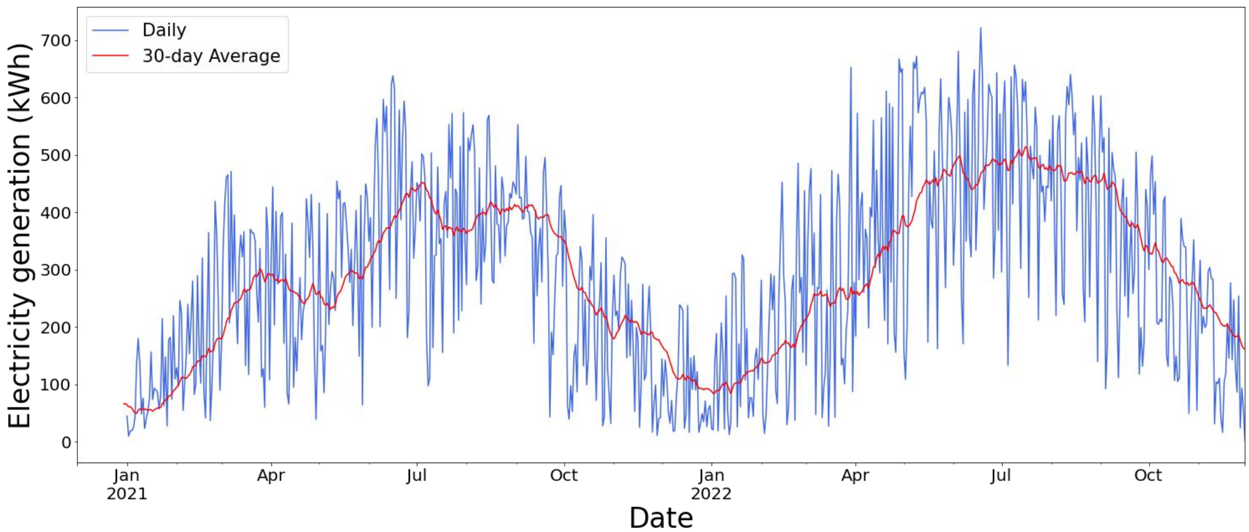

Figure 11: Daily and 30-day Moving Average Photovoltaic Generation

On-site PV generation is used to meet the building's electrical demand and surplus generation is returned to the grid. To better understand the concurrency between electricity use and generation in the building, Figure 12 compares the distribution of hourly total electricity use and PV generation during the post-renovation period. For the hourly PV generation plot, only daytime data is used. This figure shows that the magnitude of daily electric use is skewed to left with the most common values around 17 kWh while PV generation is more widely distributed with values as high as 95 kWh. PV generation values higher than 50 kWh provide the opportunity to return the excess generation to the grid and offset electricity use. The total electricity usage and return are discussed in the next section.

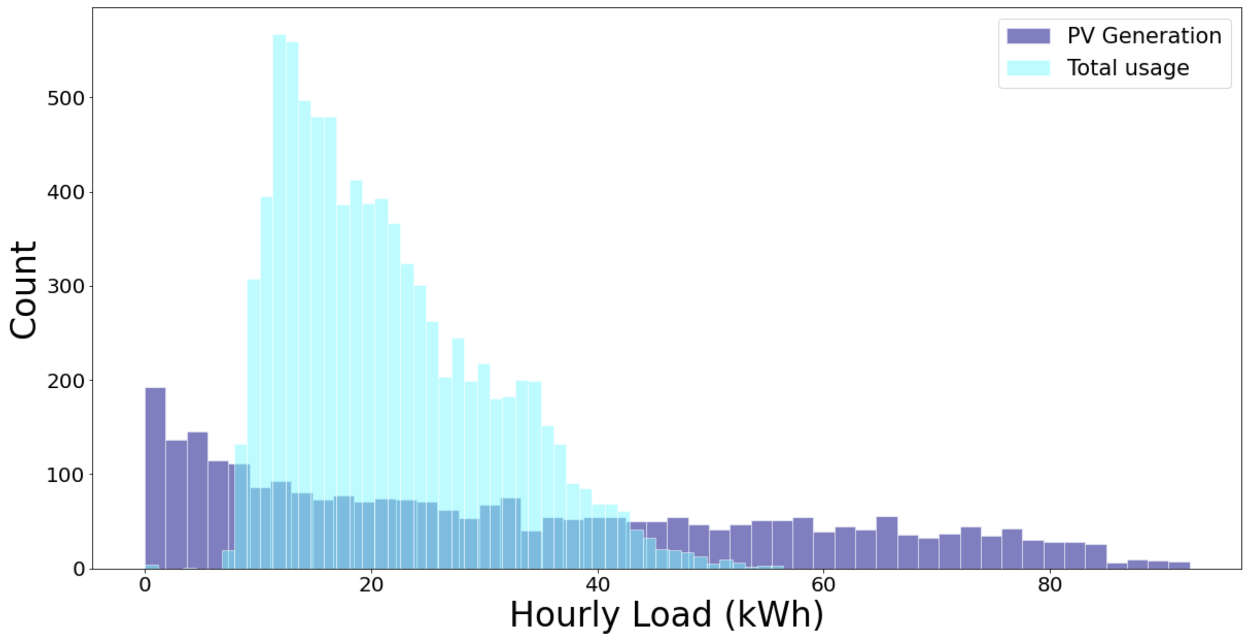

Figure 12: Comparison of Total PV generation and Electricity Usage

3. Pre- and post-renovation electricity use analysis

In this section, the building's energy performance during the pre- and post-renovation periods are compared. To this aim, first a model based on the pre-renovation values is developed. Then, the model is used to estimate the avoided electricity use during the post-renovation period. The calculated values are used to estimate the associated cost and carbon emission savings.

3.1. Pre-renovation electricity use verification

As mentioned in the previous sections, around 11% of pre-renovation electricity use was not sub-metered. Therefore, in this section, main meter readings are used to develop the building electricity usage model. In order to verify the accuracy of this meter, the sum of hourly measured values is compared with data from utility bills as shown in Figure 13. Note that utility-meter data is considered 100% accurate for determining savings as it defines the payment for energy [2]. The main meter readings (i.e. the sum of hourly readings) consistently measure lower than the values from the utility bills. However, the mean absolute percentage error is 4.6% which suggests that the main meter readings are reasonably accurate.

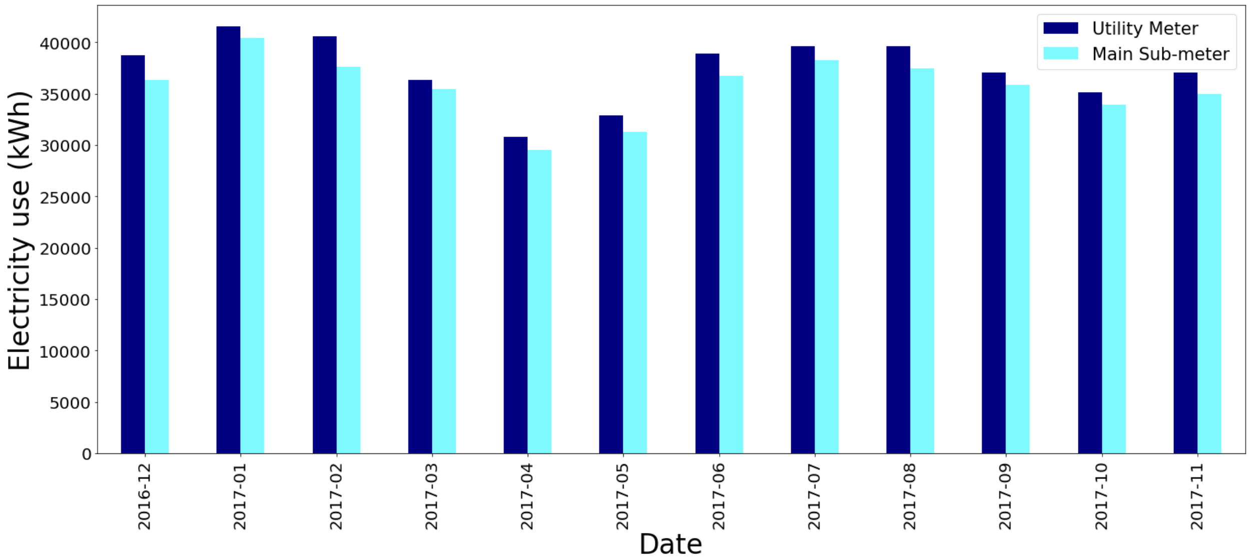

Figure 13: Comparison of pre-renovation utility and main meter readings

3.2. Pre-renovation electricity use model development

The following equation is used to assess the avoided electricity use [2]:

Savings (avoided electricity use) = Adjusted pre-renovation (baseline) electricity use – Post-renovation (reporting period) electricity use (1)

where adjusted pre-renovation electricity use is the baseline value plus any adjustments required to calibrate it for the conditions of the reporting period. Adjusted pre-renovation electricity use is found by developing a mathematical model which correlates actual baseline (pre-renovation) electricity use data with appropriate independent variables such as outdoor air temperature, relative humidity, and building operating schedule. Once the model is developed, each post-renovation independent variable is inserted into the mathematical model to produce the adjusted pre-renovation electricity use.

Traditionally, monthly utility bills were used to build simple models such as linear change-point regression models. In this project, the availability of hourly meter data enables more advanced and non-linear models with the potential for more accurate electricity saving assessment. To this aim, a random forest model is developed [3]. Random forest is a powerful and versatile supervised machine learning algorithm that grows and combines multiple decision trees to create a “forest”. One of the most important features of random forest is that it reduces the multicollinearity problem by reducing the possibility of the highly correlated features being selected [4]. Although random forests cannot completely resolve the multicollinearity issue, the contributions of the highly correlated features are retained, and the rank of the most important features will not be much affected [5].

After testing various independent variables, day of week (DoW), month of year (MoY), and outdoor temperature are considered for model development. In order to capture the proximity and ordering among DoW and MoY, they are converted into cyclic variables using a linear combination of the two sinusoidal terms as follows:

$$DoW_{cycle} = f\left(\sin\left(2\pi\frac{DoW}{7}\right), \cos\left(2\pi\frac{DoW}{7}\right)\right) \quad (2)$$

$$MoY_{cycle} = f\left(\sin\left(2\pi\frac{MoY}{12}\right), \cos\left(2\pi\frac{MoY}{12}\right)\right) \quad (3)$$

It has been shown that using historical outdoor air temperature terms can improve the performance of electricity use models in buildings [6] as it helps to consider the effects of the building’s thermal mass on the electrical demand. Two parameters: namely average daily dry-bulb temperature from the same day and average daily dry-bulb temperature from the previous day were used to consider the effects of outdoor temperature on the building’s electricity use.

The hyperparameters of a random forest model need to be tuned to improve its overall performance. While model parameters such as the slope and intercept in linear regression are learned during training, hyperparameters must be set before the training. Table 4 lists the hyperparameters used in the model development.

Table 4: Hyperparameters of the random forest model

Hyper-parameter	**Range**
Maximum depth limit	[2, 5, 10, 15]

Minimum samples split	[2, 3, 4]
Minimum samples leaf	[2, 3, 4]
Number of estimators	300

A 3-fold cross-validation with 3 repetitions with grid-search was used to tune the hyperparameters of the random forest model. The mean square error was used to find the best-performing combination of hyperparameters for the model. The mean square error (MSE) of model predictions is calculated as follows:

$$MSE = \frac{\sum_{i=1}^{N}(L_i - \hat{L}_i)^2}{N} \qquad (4)$$

where L and $\hat{L}$ are the real and predicted electrical loads, respectively, and N is the number of data points.

The hourly metered data was used to find the pre-renovation total daily electricity use. The autoregressive features were extracted from the timestamps, and outdoor temperature values were obtained from the nearest weather station. The model was implemented in scikit-learn [7].

3.3. Model performance

The developed model was used to estimate the daily electricity consumption. This section presents the results of the random forest model performance evaluation. Two main metrics: mean absolute percentage error (MAPE), and coefficient of the variation of the root mean square error (CVRMSE), were used to assess the model:

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{L_i - \hat{L}_i}{L_i}\right| \qquad (5)$$

$$CVRMSE = \frac{RMSE}{L_{mean}} \qquad (6)$$

$$Accuracy = 1 - CVRMSE \qquad (7)$$

where RMSE is the root square of MSE defined in equation (4) and L_{mean} is the average of real electricity load.

The calculated error and accuracy of the model are shown in Table 5. These values are based on the results from the whole training dataset with a split ratio of 25%. Unbiased sampling variance values are reported in APPENDIX B.

Table 5: Model performance evaluation results

Metric	**Value**
Mean absolute percentage error (MAPE)	11.1%
Root mean square error (RMSE)	171.0 kWh
Accuracy	85.6%

The main drawback of the avoided electricity use analysis is that occupancy levels have not been considered in the random forest model. According to the OAA staff, the building was occupied full-time prior to the COVID-19 pandemic. However, a hybrid work model with no fixed schedule is followed after the pandemic, and occupancy levels may change from day to day. However, the indoor conditions are kept within normal conditions throughout the weekdays. Furthermore, when the annual energy use is concerned, the effects of internal heat gain from occupants during heating and cooling seasons tend to cancel each other out. Resources such as the IPMVP [2] and ASHRAE Guideline 14 [8], establish criteria for the goodness-of-fit of the regression model. ASHRAE Guideline 14 requires a minimum accuracy of 75% when at least 12 months of data are used to compute the savings. The accuracy of the developed model is 85.6% which exceeds this requirement. This high accuracy suggests that the developed model can provide reliable estimations of electricity use without using occupancy as an independent variable.

4. Avoided electricity use analysis

The random forest model was used to estimate the avoided electricity use using Equation (1). Note that the pre-renovation natural gas consumption was not metered and this section does not take natural gas savings into account. Therefore, the total avoided energy use (natural gas and electricity) during the heating season will be higher than the calculated values. Table 6 compares the daily values of real (sub-metered) and estimated (calculated with the developed model) electricity use. In both cases, the values are reported for the post-renovation period.

Table 6: Comparison of the daily post-renovation real and estimated electricity use

Parameter	**Real electricity use (kWh)**	**Estimated electricity use (kWh)**
Average	515	1205
Standard deviation	196	190
25% percentile	368	1074
50% percentile	435	1227
75% percentile	666	1367
Sum	187812	439784

Table 6 shows that on average 690 kWh of electricity use per day has been avoided after the renovation (57% reduction compared to pre-renovation values). This is equivalent to 251,972 kWh of avoided electricity use per year. Note that this is the *avoided* electricity use as a result of the building envelope and HVAC and lighting systems renovation and does not consider onsite solar generation. The effects of solar generation on the total energy use in the building are presented in the next section.

4.1. Post-renovation net electricity use

Previous sections provided a detailed analysis of total, daily and hourly electricity use in the building. This section describes the net interaction between the building and the electrical grid. As shown in Figure 12, the hourly solar generation could at times be considerably higher than the hourly total electricity use. In this situation, the excess generation is returned to the grid. The interactions between the building and the grid may happen on a sub-hourly scale and therefore, the hourly sub-metered values may not accurately represent the net electricity use. To have a better understanding of the building-grid interactions, the power draw (power consumption from the grid) and power return (PV-generated electricity injection to the grid) based on values obtained from the utility bills are used in this section. Figure 14 shows the variation in monthly power draw, power return, and average outdoor temperature. Monthly power draw values are significantly lower than pre-renovation values (shown in Figure 13). The power draw is on average 393 times less that the total electricity use during the pre-renovation period. As shown in this figure, the power draw strongly depends on the outdoor temperature and is higher during the heating season. This trend is expected as there is no natural gas use for heating and solar generation (both thermal and PV) is lower during the winter. During the cooling season, the power return is greater than the power draw, which can be explained by higher PV generation during these months as previously shown in Figure 11.

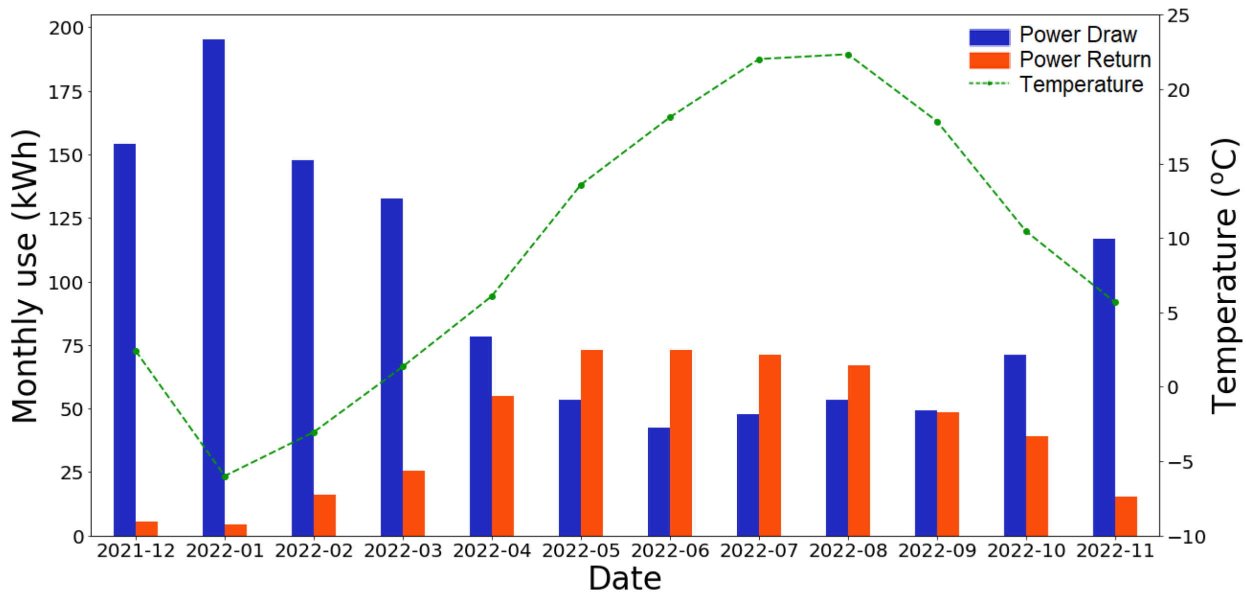

Figure 14: Post-renovation building-grid interaction and Outdoor Temperature

The net electricity use (or net-metering) can be defined as:

Net electricity use = Total power drawn from the grid – Total power returned to the grid (8)

The variation of post-renovation monthly net electricity use is shown in Figure 15. Negative monthly net electricity use indicates that the total PV return in that month is greater than the total power drawn from the grid. A negative net electricity use is observed during May, June, July and August of 2022 while in September, the net electricity use is very close to zero. The overall post-renovation net electricity use is 673 kWh with a maximum value of 191 kWh in January. As shown in Figure 14, January is the coldest month during the post-renovation period.

This suggests that the higher net electricity use is driven by the heating load and efforts to lower energy use should be focused on improving the heating system energy performance.

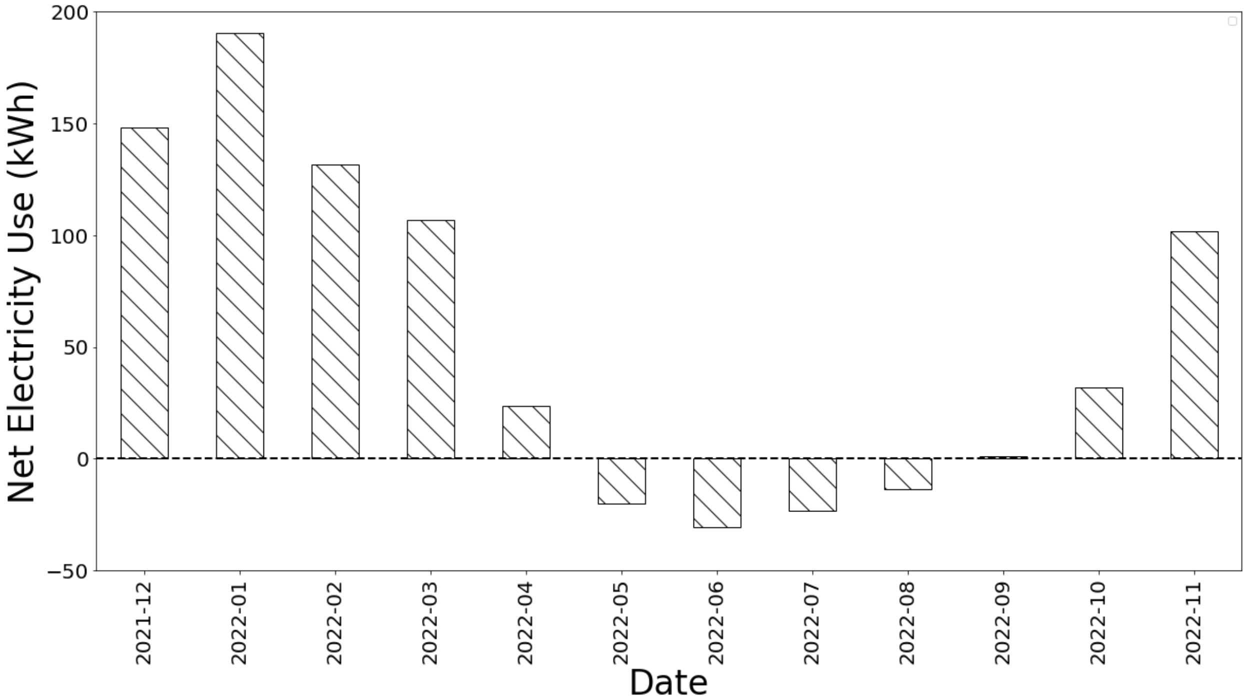

Figure 15: Post-Renovation Net Electricity Use

4.2. Avoided net electricity use analysis and associated savings

To estimate avoided net electricity use, first, adjusted electricity use values estimated by the random forest model are aggregated to monthly values. Then, the estimated monthly values are compared with net electricity use values obtained from the utility bills. The results show that 439,137 kWh of net electricity use is avoided during the post-renovation period. The details of the post-renovation net and estimated electricity use values are presented in Table 7.

Table 7: Comparison of the monthly estimated and net post-renovation electricity use

Parameter	Estimated electricity use (from random forest model) (kWh)	Net electricity use (from utility bills) (kWh)
Average	36,648	54
Standard deviation	2,865	78
25% percentile	34,513	-15
50% percentile	36,762	28
75% percentile	38,974	113
Sum	439,784	647

The results of the cost saving assessment are presented in Table 8. The real cost values were extracted from utility bills. The estimated electricity cost was calculated based on the total electricity use from the random forest model and the average electricity rate from Toronto Hydro. The pre-renovation natural gas use was not metered. Therefore, to estimate the natural gas savings, it was assumed that the natural gas consumption would remain the same during the reporting period [2]. The average natural gas rate was obtained from the Ontario Energy Board [9] for Enbridge consumers. The estimated cost saving is over $200,000 per year while 88% of savings are associated with the reduced electricity use.

Table 8: Pre- and post-renovation utility costs and estimated savings

Utility	**Real cost** ($)	**Estimated cost** ($)	**Estimated saving**($)
Electricity	551	183,650	183,099
Natural gas	0	24,250	24,250
Total	551	208,900	207,349

4.3. Energy use intensity

Energy use intensity (EUI) can be used as a reference value to compare the performance of a building to that of similar properties. Energy use values (both electricity and natural gas) from utility bills, along with historical natural gas rates [9], were used to estimate the pre- and post-renovation EUI values. Table 9 compares the calculated values with the Energy Star Portfolio Manager [10] benchmark metric (the median value of site EUI for office buildings based on the Survey of Commercial and Institutional Energy Use).

Table 9: Comparison of energy use intensities

Status	**Energy use intensity (kWh/m^2)**
Pre-renovation	513
Energy Star	275
Post-renovation	0.3

Note that the pre-renovation EUI value is about 86% higher than the national median value from the Energy Star Portfolio Manager. This indicates the relatively poor energy performance of the building prior to the renovation. However, the post-renovation EUI is significantly less than the benchmark value, which shows the near net-zero energy performance of the building.

Using the assumptions described in the previous section, and average emission factors from the Government of Canada [11], the estimated value of total CO_2 emission savings compared to the pre-renovation period is 121 tonnes/year.

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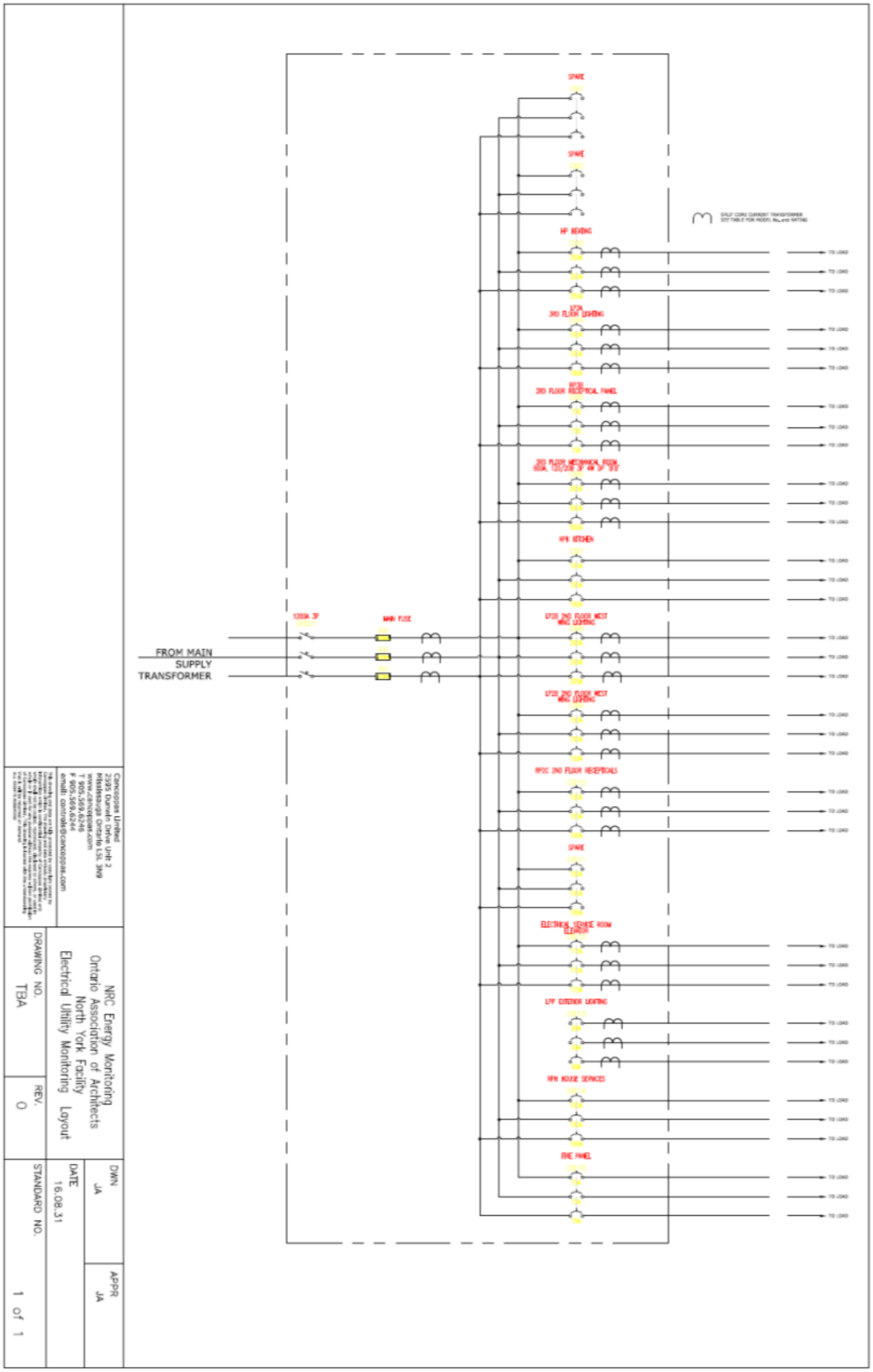
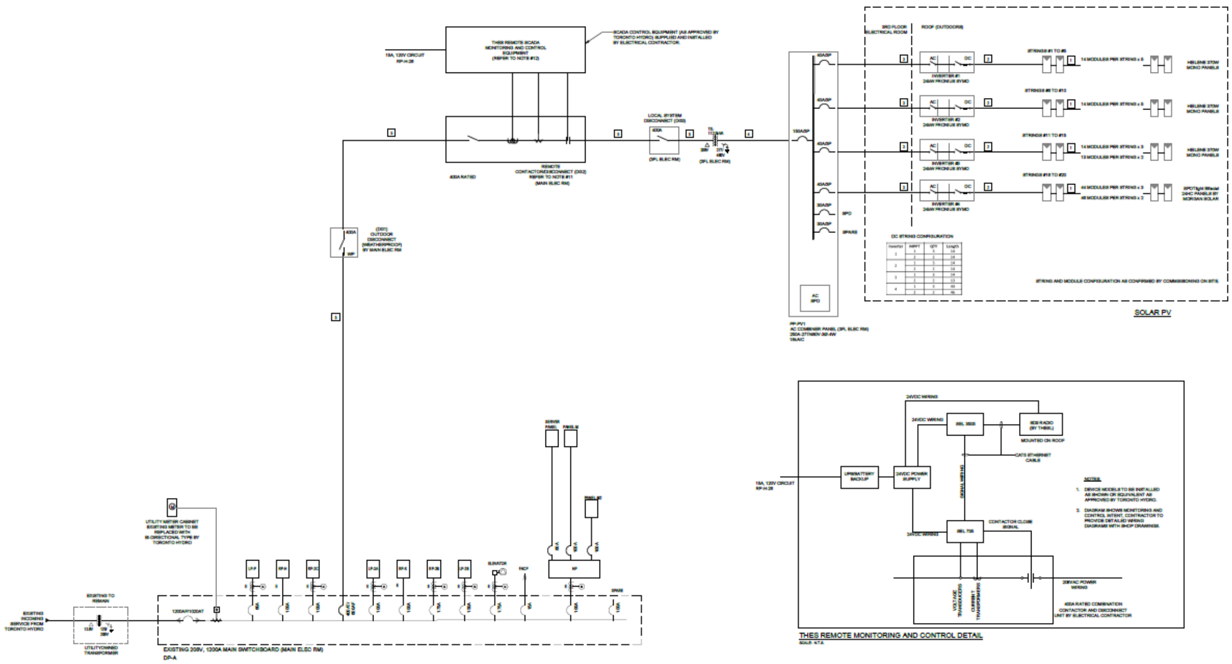
Appendix A - Electrical Utility Monitoring Layout




SOLAR PV
EXISTING 208V, 1200A MAIN SWITCHBOARD (MAIN ELEC RM)
DP-A
THES REMOTE MONITORING AND CONTROL DETAIL
CONTACTOR CLOSE SIGNAL
VOLTAGE TRANSDUCERS
400A RATED COMBINATION CONTACTOR AND DISCONNECT UNIT BY ELECTRICAL CONTRACTOR

NRC·CNRC

Appendix B - Unbiased sampling variance values of the random forest model

Unbiased sampling variance (kWh)	Real Load (kWh)	Estimated load (kWh)
44.5061859	1544.113	1469.573
38.60844561	1268.835	1198.168
44.68148045	1469.14	1447.936
44.25383538	922.539	951.8735
30.61555902	1113.491	1224.142
47.957645	1395.138	1253.413
32.60232016	1174.75	1234.159
29.90578669	1295.161	1204.041
38.04891179	1330.143	1201.49
29.03954915	1196.224	1205.262
41.75644113	1188.632	981.5127
41.02952398	1513.14	1440.916
78.2645236	915.991	1029.725
27.57528653	1137.309	1237.089
40.006702	910.793	1150.541
28.46513144	1341.108	1400.973
39.47321038	1418.13	1172.708
40.09211802	1023.332	951.4764
37.06454366	1187.567	1116.556
87.7143869	1297.894	1310.773
97.47073773	1641.275	1140.374
62.43437223	1270.769	1168.677
132.8896926	942.761	1233.164
55.87074665	1424.033	1448.831
37.75277347	842.975	865.4428
48.20871438	1412.157	1298.416
55.33852612	963.814	860.5521
30.64273446	1417.449	1418.998
32.19106202	1410.339	1266.907
66.60827044	1415.784	1446.582

74.50579271	1261.973	1450.289
98.10433053	863.333	965.9708
31.15036523	1143.451	1220.008
33.22101264	1429.2	979.6298
34.56968279	1276.115	1272.024
29.3324449	772.281	856.7441
61.18856075	1317.051	1304.908
97.62096738	1203.141	1338.359
44.98028197	1150.36	1308.162
47.30563788	1165.026	975.1658
29.34253332	1502.104	1389.446
104.5335819	1676.571	1312.106
94.25273616	1151.89	1052.124
69.6815223	968.754	1093.716
51.73347583	1114.63	1229.571
50.78403367	791.209	902.0334
36.99709069	1363.355	1209.271
32.54521482	1140.33	1204.381
55.61095667	1613.66	1349.871
105.3278295	1070.643	1303.637
47.75652275	831.693	896.8098
62.47056852	1586.455	1059.462
78.75028529	902.544	1015.094
56.81345028	995.177	923.0649
33.6440529	1151.71	1188.354
48.57247518	995.227	1156.4
96.18645436	1069.103	1304.767
87.86854694	1244.383	1033.633
42.61053989	1207.163	985.3684
52.56221367	1160.595	1326.629
39.70811707	1129.986	1384.611
37.18636913	1482.177	1401.52
69.58427467	1120.878	1319.462
43.33637081	1209.089	1337.893
37.91944979	1289.774	1311.099
85.64586455	1009.952	995.9398
31.8497017	1159.201	1271.201

37.19984384	1261.249	1187.647
31.48920683	1491.997	1278.057
54.293333	1130.622	1228.582
99.60532789	1168.461	1285.766
32.75592772	909.956	896.9362
72.28326568	935.914	1015.451
38.20442089	1496.474	1282.474
98.02571036	1087.917	1129.764
53.25788874	1413.434	1277.561
38.60999556	1236.034	1289.114
33.37331135	1399.859	1215.238
115.4843791	1446.035	1146.736
108.2388886	1090.725	1306.389
131.0678127	1105.635	1245.914
33.36094843	1237.735	1313.865
33.14443565	1601.347	1290.336
33.48508603	1277.283	1222.054
40.51235002	1245.302	1217.449
35.71934467	1019.01	933.9297
66.55427538	1140.715	1012.081
40.8171209	873.113	891.905
35.15143871	764.254	1202.548
34.15245157	1092.465	1226.762
35.64888122	1013.677	973.4108
44.80825918	1308.604	1386.988