Passive House 6-Plex Energy & IAQ Monitoring Study | Project 11102.002

Final Report

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1 Introduction

Passive house is a voluntary, low-energy performance standard for buildings. The fundamental objective of Passive House design is to reduce building space conditioning loads through an efficient enclosure to such a point that the remaining loads can be met with a smaller, more efficient mechanical system. The key certification criteria include a space heating and cooling demand of less than 15 kWh/m²/yr each, a total primary energy demand of less than 120 kWh/m²/yr, and a building enclosure airtightness of 0.6 ACH@50Pa or less. In addition to these requirements, there are also other requirements relating to occupant comfort and building durability that must be met. For example, the modelled interior temperature within a certified Passive House may rise above 25˚C no more than 10% of the hours in a given year. These performance-based targets result in buildings that are significantly more energy efficient and thermally comfortable than conventional or code-minimum building designs. Compliance with the energy performance targets is determined through modeling of the building using the Passive House Planning Package (PHPP).

Whole building energy modelling methodologies, including PHPP, require that several assumptions relating to equipment installation, occupant behaviour, and other factors be made, and these assumptions often lead to variation between the modelled and actual building energy use. Site monitoring provides an opportunity to measure in-service building performance to assess the modelling methodology and any associated assumptions, as well as to compare the overall energy performance against the Passive House targets.

This project conducted monitoring at a 6-unit Passive House townhome complex in British Columbia in order to assess actual building performance. Energy consumption, indoor air quality, surface temperatures, and heat recovery ventilator (HRV) efficiency indicators were monitored to allow for comparison against various performance metrics required by the Passive House Institute (PHI) standard. As all six townhome suites were constructed to be nearly identical, this project also provides a unique opportunity to examine occupant behavior and its effect on energy consumption in a Passive House context.

This final report summarizes an analysis of the collected data between March 2018 and end of February 2020. This study was originally intended to be for one year; however, due to monitoring equipment complications, the monitoring period was extended for an additional year. In all, the energy monitoring portion of this study is specifically between March 1st, 2019 and February 26th, 2020, whereas the indoor environmental quality results are derived from monitored data and analysis throughout the two-year period.

Figure 1: 6-plex Passive House building that was the subject of this monitoring study.

1.1 Objectives

The objectives for this monitoring study are divided into three main categories: energy, indoor environmental quality (IEQ), and Passive House Institute (PHI) certified components.

Energy

- → Measure whole building energy consumption to allow for comparison of measured energy use with that indicated by the PHPP model.
- → Measure energy consumption associated with various end uses to allow for comparison and evaluation against inputs assumed for the PHPP energy modelling, as well as against the results of the modelling.
- → Measure whole building and individual end use energy consumption for multiple similar suites in the building to allow for evaluation of the impact of occupant behaviour in similarly outfitted suites.

Indoor Environmental Quality

- → Measure indicators of IEQ to allow for evaluation against industry guidelines and benchmarks.
- → Measure indicators of thermal comfort of the interior environment to allow for evaluation against industry guidelines and benchmarks as well as the Passive House certification requirements.

PHI Certified Components

- → Measure and evaluate the in-situ performance of Passive House Institute (PHI) certified heat recovery ventilators (HRVs).
- → Measure window interior surface temperatures to allow for assessment of the condensation risk of the PHI certified window system and comparison against PHI required performance.

1.2 Methodology

1.2.1 Energy Monitoring

The total energy use of the six townhouse units was measured on a suite-by-suite basis with the energy consumption of each unit further sub-metered by end use, including for lighting and appliances. The space conditioning and domestic hot water (DHW) systems distribute space heating/cooling and DHW to the six building units from a central location (mechanical shed). As such, monitoring equipment was also installed in the mechanical shed in order to measure these energy loads on a whole building basis. It was assumed that the space conditioning and DHW energy loads were evenly distributed between the six suites as the monitoring program did not provide measurement at a suite-by-suite level. The baseboard electric resistance heaters are the only space conditioning loads measured on a per-suite basis.

In order to ensure a just comparison, the measured energy consumption of the building was adjusted to reflect the weather-related assumptions in the PHPP model. Climate files for energy modelling, typically based on years of historical averages are used to approximate average heating and cooling loads in buildings. Since weather conditions during the monitoring period may differ from the assumed weather in PHPP, this can affect the amount of energy consumed throughout the year; incoming service water temperature varies throughout the year. For example, a colder than average winter may result in a higher heating load. Therefore, the measured electricity associated with both space conditioning and domestic hot water was weather normalized by establishing a quantifiable trend between measured electricity and heating degree day values (HDD). The resulting polynomial fit of the curve can then be used to predict energy consumption at any HDD with regression, such as the HDD values assumed in the PHPP model. Note that all measured and utility data in this report has been weather normalized to reflect the PHPP assumed HDD values.

The equipment used for this monitoring study was The Energy Detective (TED) by Energy Inc. which uses Measuring Transmitting Units (MTU) along with split-core current transformers (CTs) to measure total electricity consumption in each suite as well as the mechanical room. Sub-loads measured in the mechanical room include an air source heat pump, a heat pump hot water heater, and a backup resistance hot water heater. Measured sub-loads in each suite include the baseboard electric resistance heaters, kitchen range, refrigerator, base building lighting, clothes washer, dryer and HRV. By subtracting all of the measured suite sub-loads from that suite's total MTU reading, the plug loads were determined. All measured energy data was stored on an Energy Control Center (ECC) and can be accessed via an internet cloud service. A description of the energy monitoring equipment is included in Table 1.1 below. For more details on sensor installation, refer to Appendix E.

TABLE 1.1 ELECTRICITY MEASUREMENT LIST AND CORRESPONDING EQUIPMENT		
MEASUREMENTS	**MONITORING EQUIPMENT**	**ACCURACY***
Total suite electricity	Measuring Transmitting Unit (MTU)	+/- 1%
Sub-loads	Current Transformers (Pro Spyder)	+/- 7%
Data storage	Energy Control Center (ECC)	N/A

*Values from TED specification sheets (http://www.theenergydetective.com/prodocs)

When measuring total electricity consumption, the MTUs continuously adjust the power factor to distinguish between true and apparent power. The result of a continuously adjusting power factor ensures that the reactive power (i.e., the difference between apparent and true power) is not included in the resulting data that represents true or useful power. The reactive power (KiloVolt-ampere reactive, or kVAR) is needed to create and maintain the magnetic field which, for example, rotates a motor, but does not provide useful power (kiloWatts). In order to confirm the measurements of the MTU, a resident of the 6-plex volunteered to provide two full months of utility data within the monitoring period. The total electricity measured for the same period was compared against the utility data and it was found that results had a less than 1% difference.

The TED Pro Spyders monitoring equipment does not have the capacity to continuously adjust the power factor of each sub-metered load. Instead, each Spyder CT is assigned a factory default power factor setting of 92%. The default power factor can be adjusted to a static value at the installation stage or after a monitoring period.[1] During installation, the MTU can be used to read the power factor of the equipment at the time of install and adjusted in the Spyder CT settings. Note that this pre-installation method of adjusting the power factor was not performed for this study.

Rather, a post-monitoring approach to adjusting power factor was intended. By finding periods in the data where a single sub-metered load was drawing energy and comparing the Spyder CT reading against the MTU reading, it is possible to estimate the power factor of each sub-load. In other words, while the MTU measures total energy, when a single sub-load is isolated, the MTU can measure the real or true power of the same load that the Spyder CT is measuring. Because the MTU power factor is dynamic, the resulting true power measurement should read slightly higher or lower than the Spyder CT depending on its relation to the Spyder's default power factor of 92%. This exercise was initially completed for all measured sub-loads and the raw data from the Spyder CTs was then manipulated using a multiplier that accounted for the discrepancy between the MTU and Spyder readings.

This approach to adjusting the power factor of the Spyder CTs post installation presented some challenges. Many sub-metered loads rarely operate when no other loads are present. While a refrigerator will operate periodically throughout the night and therefore is relatively easy to isolate, appliances such as kitchen ranges are often operated while other loads are active in the home, which adds uncertainty to this approach. In addition, the plug loads were not directly sub-metered for this project and therefore were often assumed, based on significantly higher MTU readings, to be present at times even when

[1] TED Pro User Manual V3.9. Accessed March 23, 2020. Available at https://www.theenergydetective.com/prodocs

only a single Spyder CT was active. Issues such as these resulted in inaccuracies within the adjusted data.

As a result, the default power factor of 92% was used for all sub-metered loads. Based on the equipment literature and confirmation from the supplier, utilizing the default power factor was considered a reasonable approach. For a typical residential application using the Spyder system, a power factor of 92% results in sub-metered measurements within +/- 7%.[2]

1.2.2 IEQ Analysis and PHI Certified Components

Onset HOBO monitoring equipment was installed within two suites (Suite 3 and 5). This monitoring equipment was installed to measure air and surface temperatures, relative humidity, and carbon dioxide concentrations at various locations within the suites. *Table 1.2* describes the HOBO equipment that was used for the monitoring study. A schematic indicating the location of these sensors is provided in *Appendix A*. Note that the exterior ambient temperature data was sourced from Hope Airport in British Columbia via the Government of Canada's historical weather database.[3]

TABLE 1.2 IEQ/PHI COMPONENT MEASUREMENT AND CORRESPONDING EQUIPMENT

MEASUREMENTS	MONITORING EQUIPMENT	ACCURACY
CO_2, Air Temperature and Relative Humidity	HOBO MX1101 HOBO MX1102	+/- 50ppm +/- 5% of reading at 25°C +/- 0.21°C from 0° to 50°C +/- 2% from 20% to 80%
Window Surface Temperature	HOBO UX100-014M + Thermocouple	+/- 0.6°C (J-Type)
HRV Air Temperature (outdoor, exhaust, supply, extract)	HOBO UX120-014M + Thermocouple	+/- 0.6°C (J-Type)

Note that due to the extended monitoring period (from 12 to 24 months of IAQ data), the CO_2 monitoring equipment experienced what is referred to as sensor drift, which is a common issue with CO_2 sensors. Because the measurements relative to their minimum reading are still correct, this drift in the measurements was adjusted by shifting all of the data so the minimums are realigned at 400ppm. This is also a common strategy for auto-calibrating CO_2 sensors.

Data collected from these sensors provides an indication of IEQ within the suites and can also be utilized to verify the performance of the windows and HRV system as compared to Passive House assumptions. As well as general analysis and comparison against industry

[2] MTU vs. Spyder. The Energy Detective (TED) - Documents & Downloads. Accessed March 23, 2020. Available at https://www.theenergydetective.com/downloads/spydercompare.pdf
[3] https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

benchmarks, data collected from these monitoring sensors was also specifically compared against the following design criteria as defined by the Passive House standard.

Overheating

A key component of the Passive House standard is to limit overheating events within the building, in a given year, to no more than 10% of hours. Less frequent overheating is recommended – typically no more than 1-2%. Passive House considers interior ambient air temperatures greater than 25˚C to constitute overheating. The human comfort range for relative humidity strongly depends on the individual and the surroundings but is generally within the range of 25-60%[4,5]. Relative humidity levels below or above this range may cause occupant irritation or discomfort. Note that the PHPP model for this building included 1% overheating and assumed that no mechanical cooling should be required to maintain thermal comfort. Therefore, one would not expect these suites to overheat given that each is equipped with mechanical cooling in the main floor living rooms.

Surface Temperatures

Reduced interior surface temperatures relative to the ambient air temperature will typically lower occupant thermal comfort, through both the sensation of being cold and the asymmetry in temperature associated with some surfaces being cold while others are warm. To ensure occupant thermal satisfaction is maintained, the Passive House standard includes comfort criteria for limiting this temperature differential:

$$\left|\theta_{si} - \theta_{op}\right| \leq 4.2K$$

Where θ_{si} is the minimum interior surface temperature (typically located on a window/door) and θ_{op} is the operative temperature or perceived occupant temperature (average of air and surface temperatures), which is assumed to be 22ºC for calculation purposes.[6] Therefore, an interior surface temperature of 17.8ºC or above would be considered Passive House compliant. For windows where this is most frequently calculated, this temperature is typically applied to the average temperature of the window, rather than any individual point on the surface of the window. However, point measurements on window frame and edge of glass were taken for this evaluation.

Hygiene Criteria

Low interior surface temperatures also negatively affect building durability. Cold interior surfaces are at a higher risk of condensation formation and consequently damage to adjacent moisture sensitive materials. Thermal bridge related 'cold-spots' on interior wall/floor/ceiling surfaces may fall below the dew point of humid interior air causing a portion of the airborne water vapour to condense. In order to manage this risk, Passive House applies a metric called the temperature factor or hygiene criteria (f_{Rsi}) that is a measure of the condensation and mould risk:

$$f_{Rsi} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e} \geq 0.7$$

[4]ASHRAE, 2013. 2013 ASHRAE Handbook: Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 2013.

[5]Lstiburek, J. 2002. "Research Report – 0203 – Relative Humidity". Building Science Corporation.

[6]Criteria and Algorithms for Certified Passive House Components. V5.2. Accessed March 23, 2020. Available at: https://passiv.de/downloads/03_certification_criteria_transparent_components_en.pdf

Where θ_{si} is the minimum interior surface temperature (typically located at a window/door), θ_e is the exterior ambient temperature, and θ_i is the interior ambient temperature. To certify a Passive House building in British Columbia, the hygiene criteria must be equal to or greater than 0.7 at all interior surfaces such that the condensation/mould risk is adequately mitigated[7].

HRV Efficiency

HRVs are installed in each unit to minimize ventilation associated energy losses. The high efficiency HRVs extract heat from stale conditioned interior air and transfer this energy to incoming fresh outdoor air prior to being exhausted. This process greatly reduces the space conditioning energy demand of the building. The efficiency at which heat from the outgoing interior air is transferred to the incoming outdoor air before it is exhausted is known as the heat recovery rate. To determine the in-service heat recovery rate (also known as heat recovery efficiency) of the HRV units, the extract, exhaust, outdoor air intake, and supply air temperatures were measured. The Passive House standard calculates this efficiency using the following equation:

$$Heat\ recovery\ efficiency\ rate\ [\%] = \frac{(\theta_{ETA} - \theta_{EHA}) + \frac{P_{el}}{\dot{m} \cdot C_p}}{(\theta_{ETA} - \theta_{ODA})}$$

where θ_{ETA} is the extract air temperature in ˚C, θ_{EHA} is the exhaust air temperature in ˚C, θ_{ODA} is the outdoor air temperature in ˚C, P_{el} is the electric power in Watts, $\dot{m}$ is the mass flow rate in kg/h, and C_p is the specific heat capacity in Wh/(kg K).

This analysis assumes that HRV electrical power demand, air mass flow rate, and specific heat capacity of air remain constant. The standard flow rate assumed in PHPP is 77m³/h per suite, which when multiplied by the volumetric heat capacity of air (0.33 Wh/m³K) is the amount of energy in the air per degree Kelvin (25.4 W/K). The specific electric power of the Comfoair 200 HRV, tested at external pressure of 100 Pa is 0.42 Wh/m³, which when multiplied by the volumetric heat capacity of air, is 32.3 W of electrical demand. Therefore, $P_{el}/(\dot{m} \cdot C_p)$ is assumed to be a constant of 1.3˚K. Note that the mass flow rate is fixed, therefore assumes it is not operating in boost mode, which periodically may not be the case. Using this equation allows for a comparison of the measured heat recovery efficiency of the HRV with the equipment's rated efficiency. *Figure 2* is a diagram of an HRV system to provide a clearer understanding of the parameters measured and how it is intended to operate.

[7]The Passive House Institute (PHI) allows for some deviation from this requirement; however, only in specific cases at the discretion of the Passive House certifier (heating system adjacent detail/component, etc.)

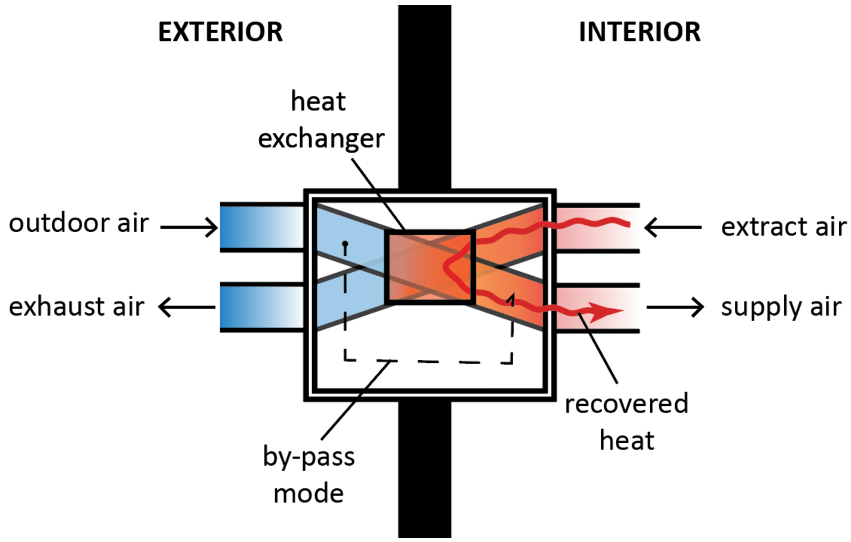

Figure 2: Diagram of HRV demonstrating how some heat is recovered from extract air before it is exhausted. Before outdoor air is supplied to interior, heat is absorbed at the heat exchanger which pre-heats the supply air. By-pass mode is when outdoor air travels directly to supply airstream without absorbing heat from heat exchanger.

1.3 Building Description

The monitored Passive House building is a six-suite multi-unit residential building with a total floor area of 401m² (66.8m² per suite). Designed with R-87 effective roof, R-64 effective floor and R-44 effective walls, the building has a highly-insulated enclosure with minimal thermal bridging. High performance PHI certified Euroline 4700 ThermoPlus series windows with a glazing and frame U-value of 0.62 W/m²·K and 0.92 W/m²·K, respectively, were used to optimize the thermal performance of transparent enclosure areas. It was constructed and airtightness testing resulted in an air leakage rate of 0.44 ACH at 50Pa.

The DHW is provided by a Sanden SanCO_2 Heat Pump with a rated COP of 4.5 and a backup Bradford White ElectriFLEX MD electric water heater with a 98% rated efficiency. The primary space heating and cooling system is an LG Multi F MAX multi head ductless heat pump with, based on the manufacturer's literature, a rated COP of 3.7 at 8.8˚C. Additional heating is supplied by Ouellet OFM standard electric baseboard heaters. Space heating and DHW are distributed centrally from a mechanical room, with the exception of the baseboard heaters. The space conditioning mode of the heat pump system is controlled centrally, so tenants cannot switch from heating to cooling mode from their individual suites. A PHI certified Zehnder ComfoAir 200 in-suite heat recovery ventilator with a 92% rated efficiency (PHI rating) is installed in each unit to provide fresh air. *Table 1.3* provides a summary of the mechanical equipment installed within the building.

TABLE 1.3 MECHANICAL EQUIPMENT LIST	
SYSTEM	**EQUIPMENT**
Primary Heating & Cooling	LG Multi F Max Heat Pump
Secondary Heating	Standard baseboards
Primary DHW	Sanden SanCO_2 Heat Pump
Secondary DHW	Bradford White ElectriFlex MD electric water heater
HRV	Zehnder ComfoAir 200

The building was constructed as a social housing complex for a First Nations community located in ASHRAE Climate Zone 5. It is assumed in PHPP that the whole building is occupied by 12 residents (two people per suite). Assuming an interior temperature of 20˚C, the modelled building annual heating demand is 11.2 kWh/m²/yr and the cooling demand for the building is 0.9 kWh/m²/yr; however, the PHPP model assumes that all cooling demand is met with passive measures such as natural ventilation (opening windows). The modelled building Primary Energy demand is 100.2 kWh/m²/yr, which is equivalent to an annual site energy consumption of 38.6 kWh/m²/yr.

Note that RDH Building Science Inc. was not the modeller for this project and that the PHPP provided was not certified; therefore, some revisions and modifications during the certification process would be expected and may affect the overall results of the model.

The modelled COP of the heat pumps was based on the manufacturer's heating seasonal performance factor (HSPF) of 11. As heat pump performance will vary across different climates and locations, regression equations were used to adjust the manufacturer provided efficiency rating such that it better approximated the actual HSPF that the heat pump will experience in Hope, BC.[8] As a result, the HSPF of 11 was reduced to 8.5, which equates to a COP of 2.5. *Table 1.4* provides a list of the modelled annual energy use of various loads as determined by the PHPP model.

TABLE 1.4 PHPP WHOLE BUILDING ENERGY MODEL RESULTS

END USE	CONSUMPTION [KWH/YEAR]	CONSUMPTION [KWH/M²/YEAR]
Heat Pump	1,795*	4.5
DHW	5,413	13.5
Dryer	1,796	4.5
Washer	414	1.0
HRV	1,517	3.8
Range	1,500	3.7
Baseboard	0	0
Fridge	1,577	3.9
Base Lighting	334	0.8
Plugs	1,128	2.8
Total	**15,473**	**38.6**

*Based on a Coefficient of Performance (COP) of 2.5 calculated from manufacturers HSPF of 11 (per ANSI/AHRI Standard 210-240) and normalized to local BC climate.

[8]Fairey, P., D.S. Parker, B. Wilcox and M. Lombardi. Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps. *ASHRAE Transactions,* American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, June 2004.

2 Results and Discussion

2.1 Energy Analysis

The energy analysis is separated in to three sections: comparison with utility data, total energy consumption, and energy consumption by end use.

2.1.1 Comparison with Utility Data

To validate the results of this study, the measured data of the mechanical room was compared with the utility data for the same period. Though suite utility data is typically preferred, tenants pay their own utilities and therefore it was not possible to attain the data for an entire year (with the exception of one resident who volunteered a sample of their utility bills – see methodology section above). The utility bills for the mechanical room, however, were provided by the property management and the results of the comparison are presented in *Figure 3*. The mechanical room meter includes items such as the heat pump for heating, cooling, and domestic hot water, receptacles in soffits and for heat trace, and a baseboard to heat the mechanical room. The graph shows that the measured consumption of the mechanical room is very similar to the utility data, often less than or equal to 1%, with the exception of a 2.2% difference in November 2019. The total annual energy consumption based on the utility data was 22,755kWh and 22,718kWh based on the monitoring equipment, a difference of 0.2%.

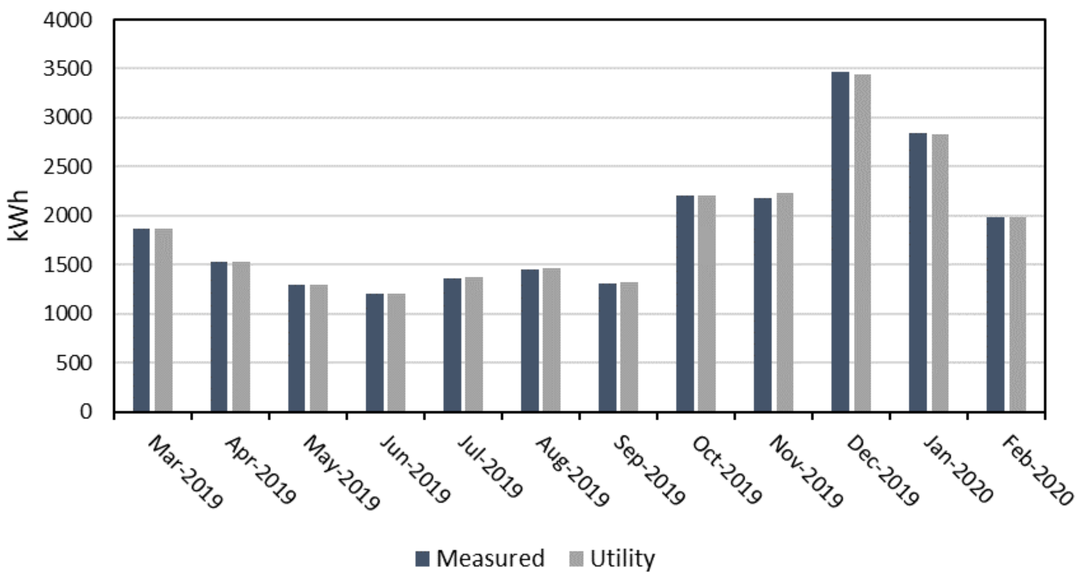

Figure 3: Monthly mechanical room consumption (measured vs. utility data).

2.1.2 Total Energy Consumption

The energy use intensity (EUI), or total energy divided by Treated Floor Area (TFA) per year, is an important metric used to normalize the energy use for a building or suite in order to understand, for example, how it compares with other similar buildings. Note that, compared to the Gross Floor Area (GFA), the TFA used for Passive House typically underestimates the total floor area (e.g. does not account of stairs, only 60% of storage areas or closets are accounted for, etc.), and therefore can result in relatively higher EUI results. Nonetheless, the measured EUI per suite was also derived using TFA and is presented in *Figure 4*.

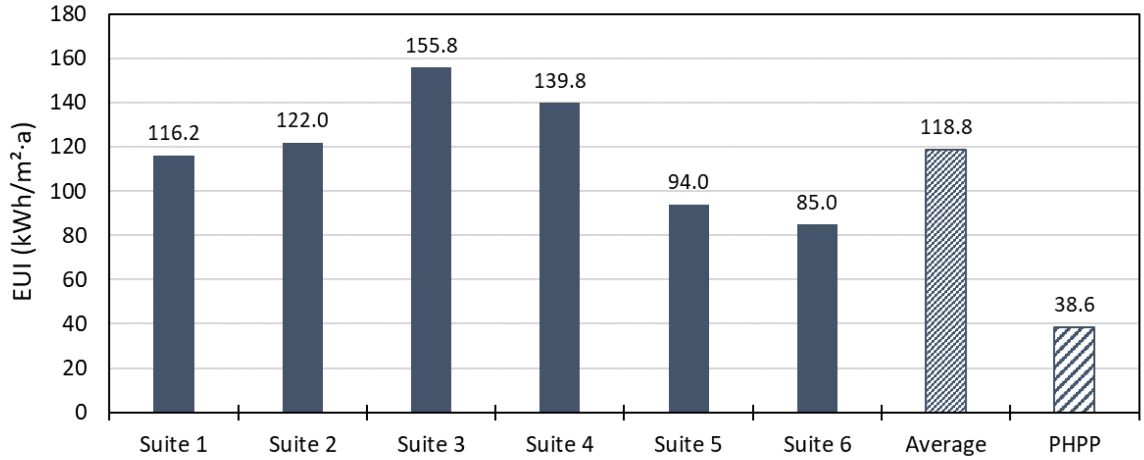

Figure 4: Total energy use intensity from March 1, 2019 to February 26, 2020.

The graph above shows that the EUI of each suite differs, which is typically driven by occupant behaviour. For the monitoring period, the average EUI for the building is approximately 120 kWh/m² per year. Although the average measured EUI of the building is higher than PHPP (38.6kWh/m² per year), it is important to note that the EUI of the building as a whole is significantly lower than the average low-rise multi-unit residential building at roughly 170 kWh/m² per year.[9]

In addition, a comparison of energy use between the Passive House 6-plex and another conventionally built housing complex in the same area as the 6-plex area was performed and results are shown in *Figure 5*. For context, the 150 m², two-storey duplex was originally occupied as a single-family home but was renovated in 2016 and is now occupied by as many as 8 to 10 people at a given time. Like the 6-plex, the duplex uses electricity to provide space conditioning and domestic hot water. Unfortunately, further information regarding the construction of this building is not available. Results show that the EUI of the duplex exceeds the 6-plex in all months of the year, particularly during the heating season. In all, the total EUI for the duplex was found to be 206 kWh/m² per year.

[9]RDH Building Science, 2017. "Energy Consumption in Low-Rise Multi-Family Residential Buildings in British Columbia". https://www.hscorp.ca/wp-content/uploads/2017/09/BC-Report-energy-low-rise.pdf

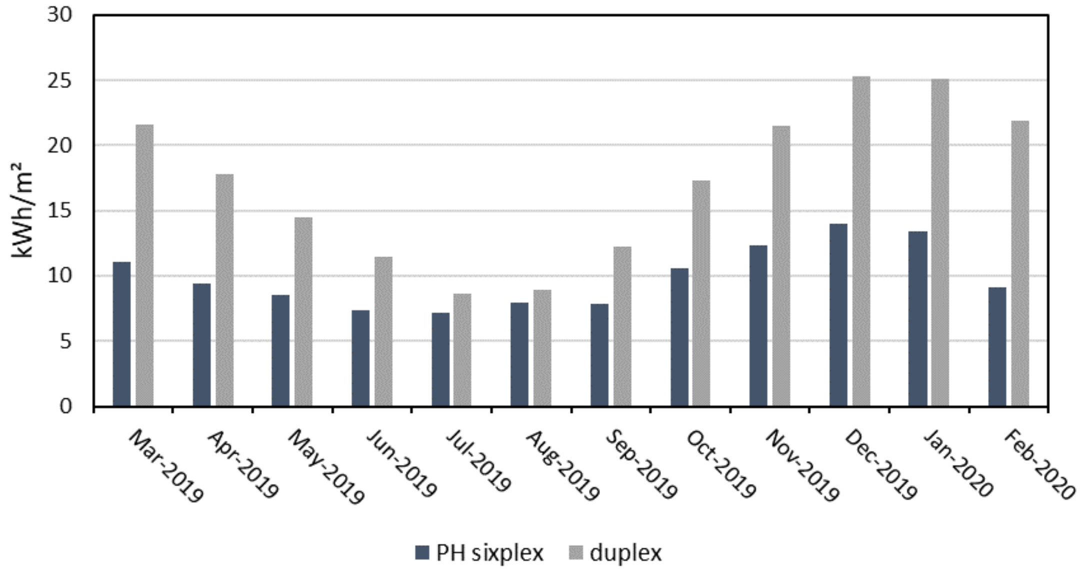

Figure 5: Monthly EUI comparison between the Passive House 6-plex and a conventionally built duplex in the same area.

To develop a clearer understanding of how the building is operating throughout the year, the total building energy use for each month was plotted and compared against the PHPP monthly total and average energy consumption (*Figure 6*). Actual values are presented in Table 2.1, and total EUI breakdown for space conditioning, DHW and other loads is provided in Table 2.2. Overall, the measured monthly energy consumption is significantly higher than the PHPP model.

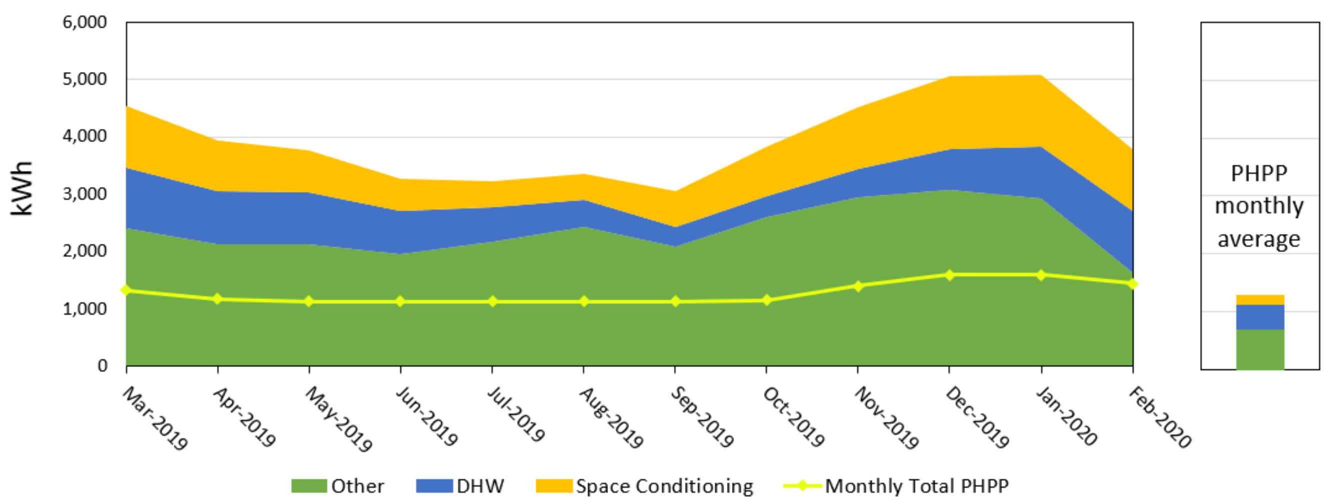

Figure 6: Monthly total building energy consumption from March 1, 2019 to February 26, 2020 compared to PHPP average monthly demand.

TABLE 2.1 MONTHLY TOTAL BUILDING ENERGY USE FROM MARCH 1, 2019 TO FEBRUARY 26, 2020 [kWh]				
DATE	**TOTAL**	**SPACE CONDITIONING**	**DHW**	**OTHER**
Mar 2019	4,453	1,070	907	2,399
Apr 2019	3,778	869	732	2,125
May 2019	3,429	698	582	2,127
Jun 2019	2,949	542	446	1,956
Jul 2019	2,886	391	315	2,180
Aug 2019	3,169	410	331	2,428
Sep 2019	3,152	579	478	2,091
Oct 2019	4,254	843	709	2,607
Nov 2019	4,964	1,061	899	2,944
Dec 2019	5,603	1,264	1,076	3,071
Jan 2020	5,383	1,253	1,066	2,933
Feb 2020	3,656	1,084	919	1,638
SUBTOTAL	**47,677**	**10,064**	**8,461**	**29,152**

TABLE 2.2 ANNUAL EUI FOR DIFFERENT END USES (MODELLED VS. MEASURED)		
ENERGY USE	**PHPP MODEL (kWh/m^2)**	**MEASURED (kWh/m^2)**
Space Conditioning	4.5	25.1
DHW	13.5	21.1
Other	20.6	72.7

A main reason why the monthly space conditioning in PHPP model is lower than measured is likely due to the model calculation that space conditioning is only required during the heating season. The PHPP model for this project calculates that all space conditioning needs in the summer and shoulder seasons can be met with passive strategies (i.e., natural ventilation) and therefore does not rely on any mechanical cooling. However, it is evident based on measurements that mechanical cooling is being used. DHW data from *Figure 6* above also suggest that there is a slight seasonal variability.

2.1.3 Energy Consumption by End Use

The measured and PHPP modelled average daily electricity consumption separated by end use from March 2019 to end of February 2020 is presented in *Figure 7*. Sub-metered loads for each suite include baseboards, range, fridge, washer, dryer, lights, and plug loads; however, as described in Section 1.3, the heat pump and DHW systems are measured from the mechanical room for the whole building. Therefore, the heat pump and DHW electricity consumption are simply distributed evenly between all six suites for this individual load analysis. Note that sub-metered energy consumption from the HRV was unfortunately not captured because the electrical current drawn from the HRV systems was too low for the installed current transmitters to measure their demand. While

HRVs sub-metering may not have been registered with the Spyder CTs, it could still add up to a significant amount of electricity usage over time if operated continuously.

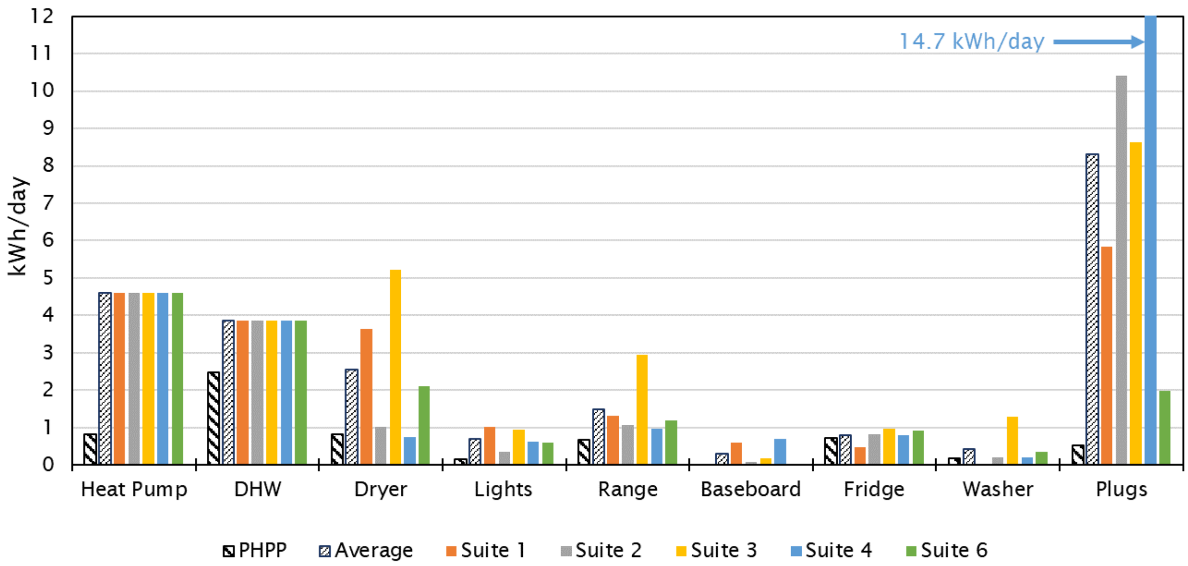

Figure 7: Measured vs. PHPP average daily energy by end use for each suite. Note: Suite 5 not included as submetering data was unavailable.

The results above show that plug loads make up the largest source of daily electricity consumption for most units. In fact, the average plug load use is shown to be greater than both space conditioning and DHW combined. This result is striking though somewhat understandable given the amount of auxiliary electrical equipment within several suites. Large televisions, home stereo systems, computers, additional kitchen appliances and lighting added by occupants, and even heavy-duty power tools for woodworking (in one instance) were noted during periodic site visits. In addition, most occupants were home during site visits and it was often noted how occupancy in general appeared to be more intensive than what would be generally considered typical.

It is also important to note that household equipment brands and models are identical in each of the six suites (e.g., ranges, fridges, washers, dryers, HRVs and built-in suite lighting). Therefore, differences shown in the energy consumption associated with these end uses between suites can largely be attributed to differences in number of occupants and occupant behaviour. For example, PHPP assumes two occupants per suite, whereas periodic site visits suggest that some units may have three to four occupants per suite, including children. This difference in occupancy likely impacts a variety of factors including internal heat gains, carbon dioxide production, amount of laundry washing, and more. Or in the case of space conditioning, if windows are open while the heat pump is operational, higher heating demands on the spacing heating equipment would be required than for suites where the windows are closed (see *Figure 8*). In addition, the measured heat recovery rate of the HRV (covered in Section 2.2.3) appears to be, on average, lower than the rated efficiency. This can result in higher than anticipated energy consumption and is discussed further in subsequent analysis sections.

Figure 8: Operable windows open in multiple suites on November 1st with outdoor ambient temperature roughly 13°C and rain.

2.2 Indoor Environmental Quality

2.2.1 Thermal Comfort

Air Temperature & Relative Humidity

For the 24-month monitoring period, the ambient air temperature, relative humidity, and dew point temperature were measured in the living room and bedrooms of two suites. *Figure 9* though *Figure 12* are 12-month sample plots of ambient conditions for both suites in the living room and bedroom, respectively. Based on the annual plots, it appears that the living room and bedroom experience some slight seasonal variability (i.e., slightly warmer in summer and colder in winter). In general, the interior air temperature in the bedrooms seems to fluctuate more and experiences higher temperatures overall.

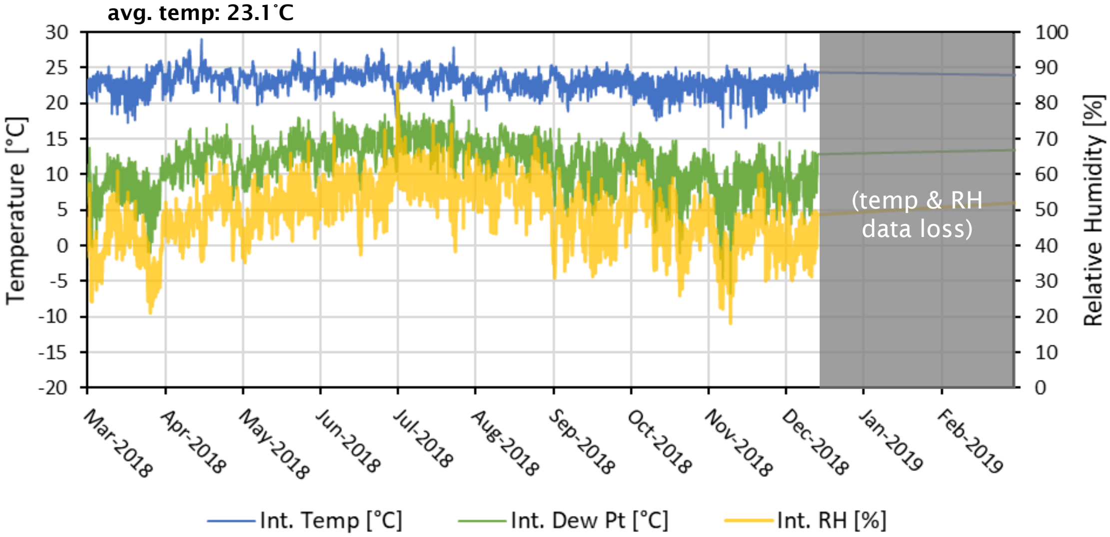

Figure 9: Interior air temperature, relative humidity and dew point temperature for one year in living room (Suite 3). Note that some data was lost throughout winter 2018/19.

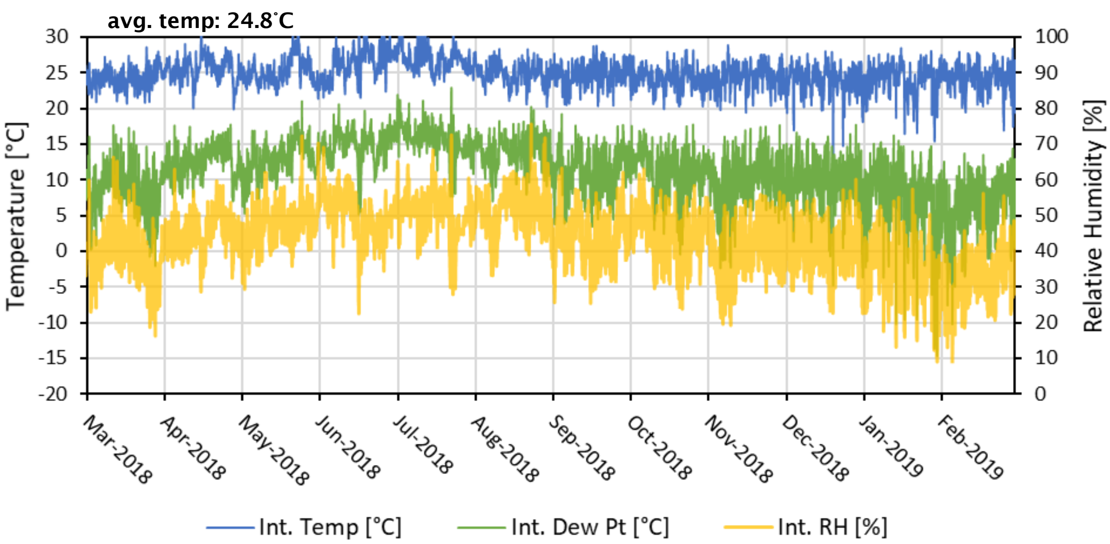

Figure 10: *Interior air temperature, relative humidity and dew point temperature for one year in bedroom (Suite 3).*

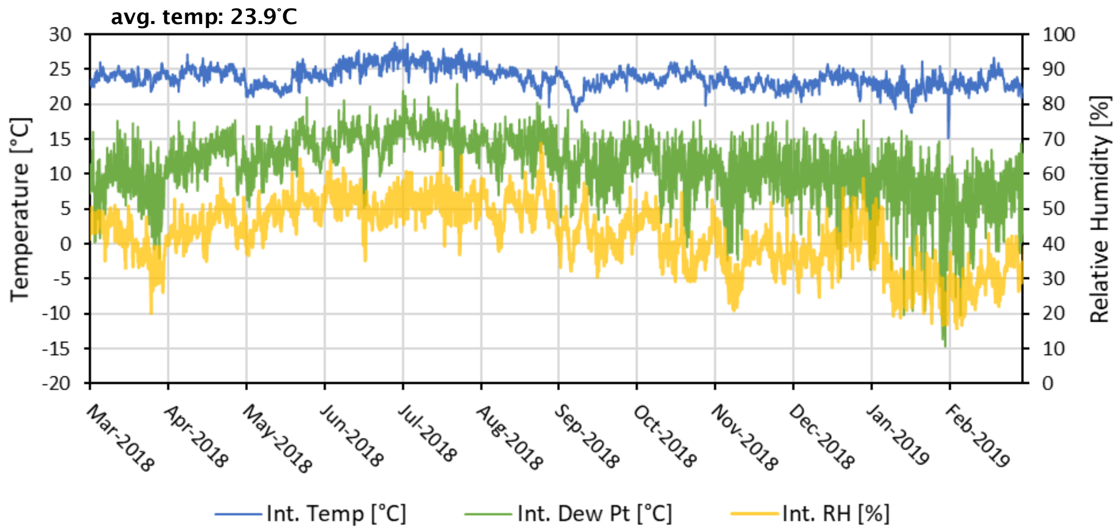

Figure 11: Interior air temperature, relative humidity and dew point temperature for one year in living room (Suite 5).

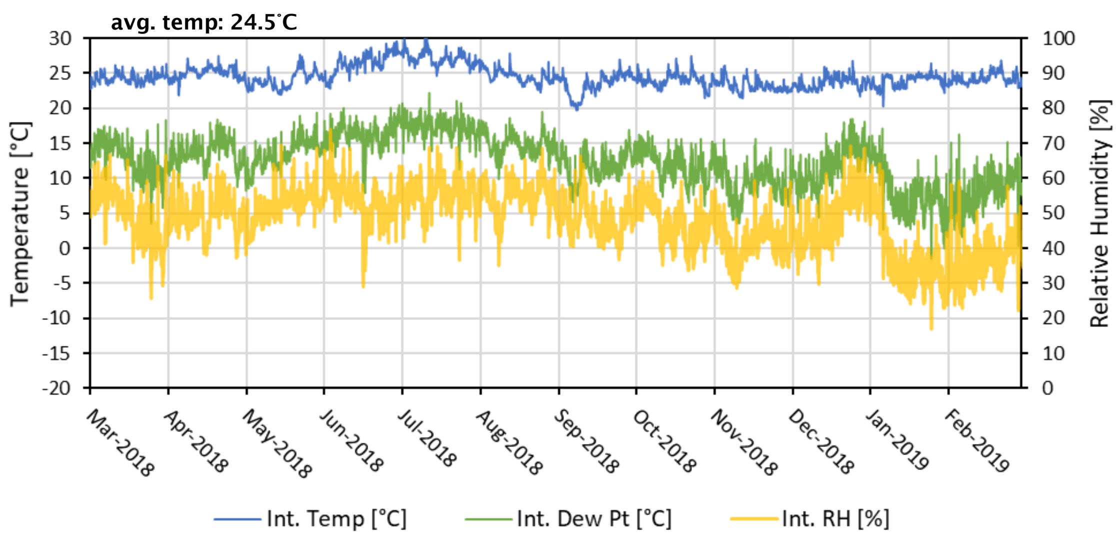

Figure 12: Interior air temperature, relative humidity and dew point temperature for one year in bedroom (Suite 5).

As mentioned in Section 1.2, a key component of the Passive House standard is to limit overheating events within the building, in a given year, to no more than 10% of hours, though 1-2% is recommended for certification. Also, note that the PHPP model for this building simulated overheating for 1% of hours without active cooling required. Passive House considers interior ambient air temperatures greater than 25˚C to constitute overheating. The human comfort range for relative humidity, however, strongly depends on the individual and the surroundings but is generally within the range of 25-60%.[10,11] Relative humidity levels below this range can cause irritation and levels above this range may cause feelings of discomfort. The ambient air temperature and relative humidity were therefore measured in the living room and bedroom of two suites. Table 2.3 lists the measured frequencies beyond the temperature and relative humidity limits listed above.

[10] ASHRAE, 2013. 2013 ASHRAE Handbook: Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 2013.
[11] Lstiburek, J. 2002. "Research Report – 0203 – Relative Humidity". Building Science Corporation.

TABLE 2.3 FREQUENCY OF HOURS ABOVE OR BELOW TEMPERATURE AND RELATIVE HUMIDITY LIMITS BY LOCATION				
PERIOD	**LOCATION**	**TEMP >25˚C**	**RH <25%**	**RH >60%**
2018/19	Suite 3 – living room	7%	0%	9%
	Suite 3 – bedroom	45%	2%	1%
	Suite 5 – living room	21%	2%	0%
	Suite 5 - bedroom	31%	0%	4%
2019/20	Suite 3 – living room	11%	0%	12%
	Suite 3 – bedroom	44%	2%	1%
	Suite 5 – living room	21%	2%	0%
	Suite 5 - bedroom	30%	0%	3%

The table above shows that the temperature of all locations in the measured suites, except for the living room in Suite 3, are above the 10% threshold determined by the Passive House Standard. Bedrooms also appear to exhibit higher temperatures for longer periods of time compared to the living rooms (see *Figure 13* and *Figure 14* below). Note that the living rooms are located on the main floor and bedrooms on the upper floor, and that the heat pumps providing mechanical heating and cooling are located in the living rooms only. These reasons likely explain the relatively warmer bedrooms. It is also worth noting that temperature in particular is highly dependent on set-points determined by the occupants since suites are equipped with both heating and cooling capability. For example, some occupants prefer to sleep in conditions that are either warmer or cooler than communal areas of a home.

Generally, the interior conditions were warmer than the 20˚C interior set-point temperature assumed for PHPP. The relative humidity levels in the measured areas are generally within the limits, having not exceeded 60% relative humidity for more than 10% of the monitoring period in all cases aside from the Suite 3 living room. The relative humidity levels were found to be below 25% less than 2% of the time, which tends to occur during the winter months.

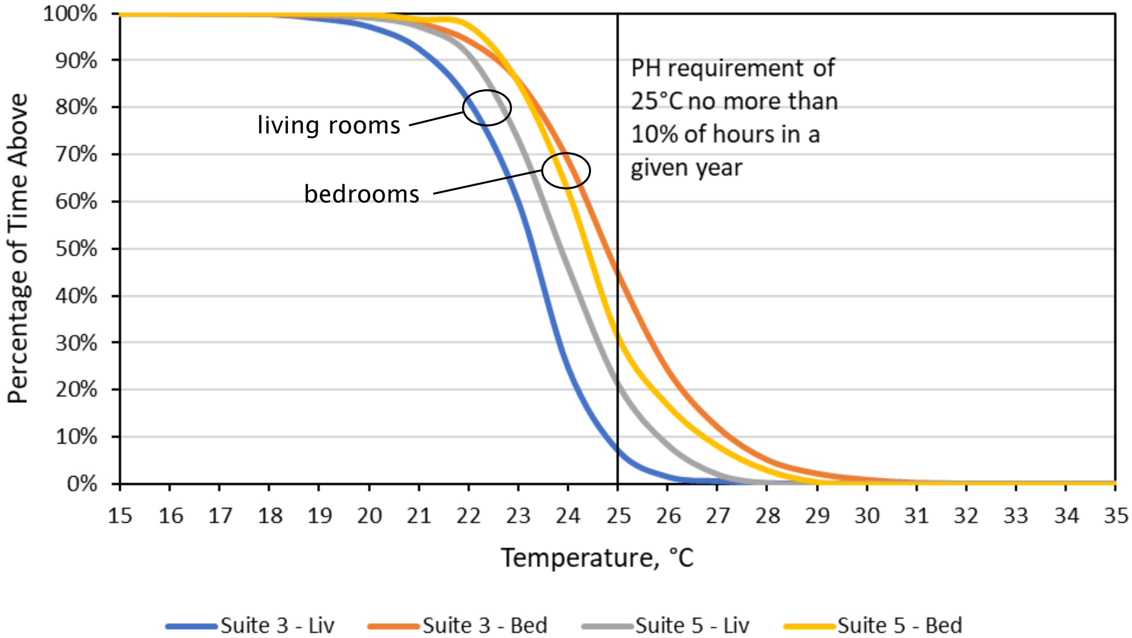

Figure 13: Fraction of time the indoor environment is above a given temperature (2018/19)

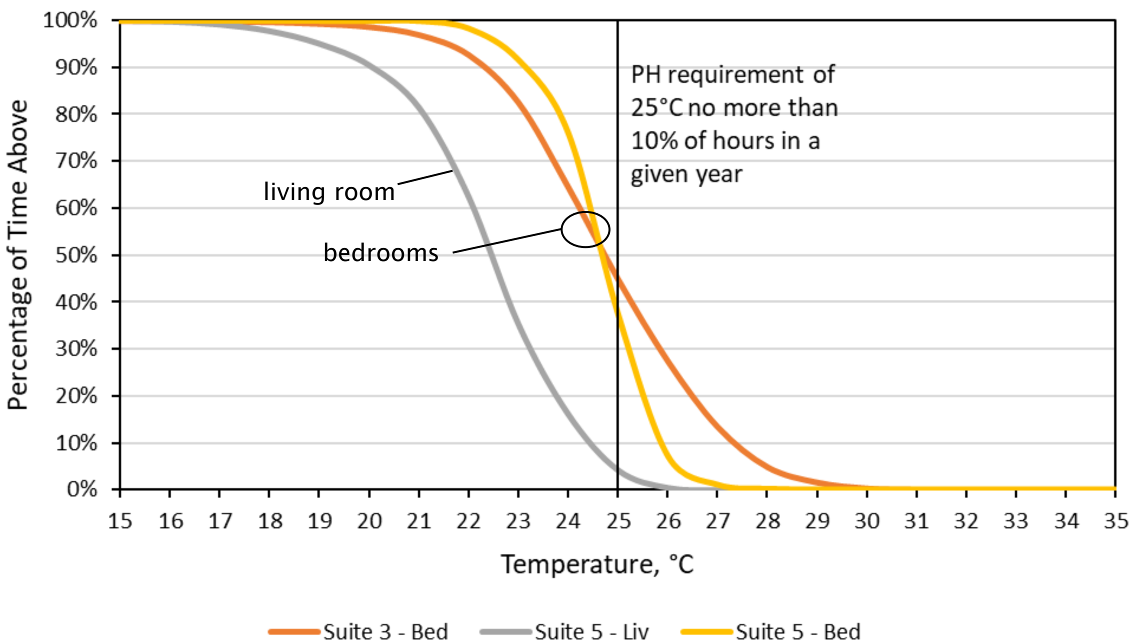

Figure 14: Fraction of time the indoor environment is above a given temperature (2019/20). Note that Suite 3 living room was omitted due to significant data was lost during summer.

It is important to note that personal factors including a person's metabolic rate and the type of clothing they are wearing also influence thermal comfort. To expand the thermal comfort analysis, measured data was plotted on a psychrometric chart which includes the ASHRAE thermal comfort range. This range assumes a typical occupant seated and relaxed (metabolic rate of 1 MET), wearing pants and a short-sleeve shirt as outerwear (clothing insulation level of 0.6 clo). *Figure 15* through *Figure 18* plot the air temperature and humidity for Suite 3 and Suite 5 living room and bedroom, respectively, plotted in relation to the comfort ranges for the 24-month monitoring period. Results show that a significant portion of the data points lie outside of the ASHRAE 55 comfort zone in both suite living rooms and bedrooms. Note that the typical comfort range (blue shaded area) can vary in either direction depending on metabolic rate and clothing insulation. For example, wearing more clothing (1 clo) would shift the comfort range lower to increase the frequency of comfortable points. Based on the ASHRAE comfort ranges, it appears that Suite 5 living room and bedroom may be relatively more comfortable, though overheating in the bedroom is still noted. However, as stated previously, preferred thermal comfort conditions may lie beyond these ranges, particularly in bedrooms as the data from this study suggests.

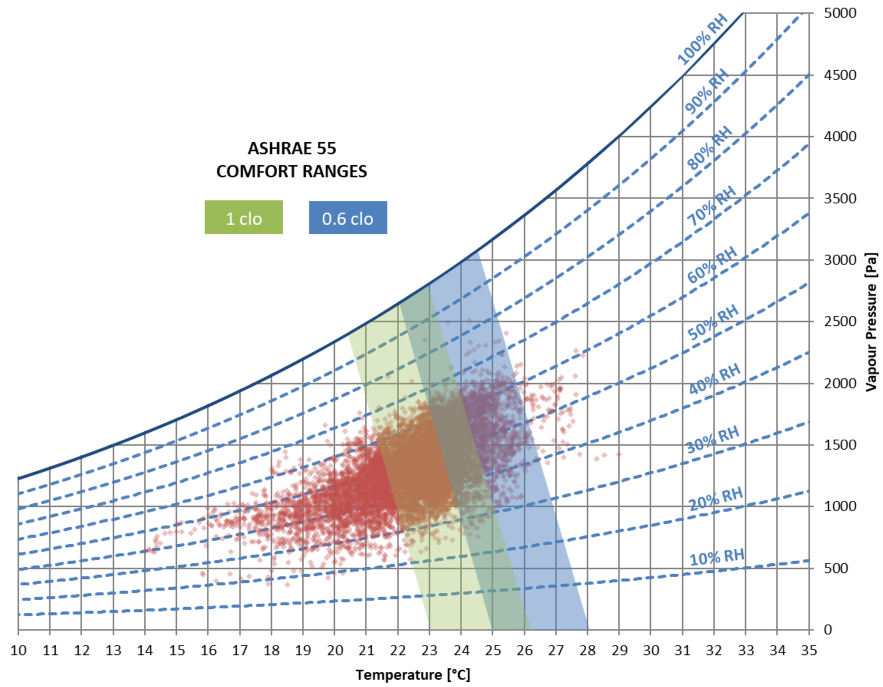

Figure 15: Temperature & relative humidity on psychrometric chart (Suite 3 – living room) during 24-month monitoring period

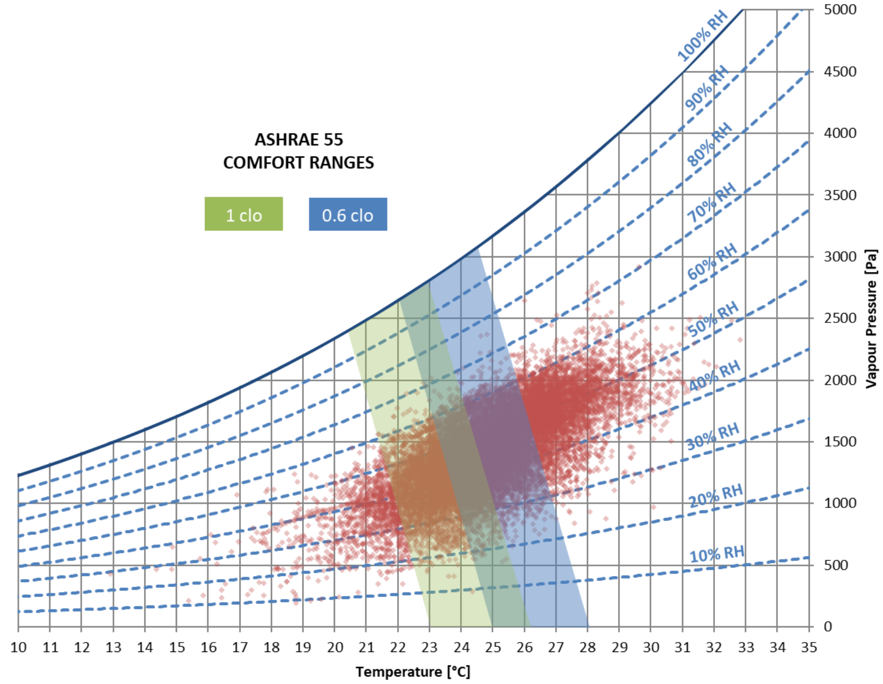

Figure 16: Temperature & relative humidity on psychrometric chart (Suite 3 – bedroom) during 24-month monitoring period

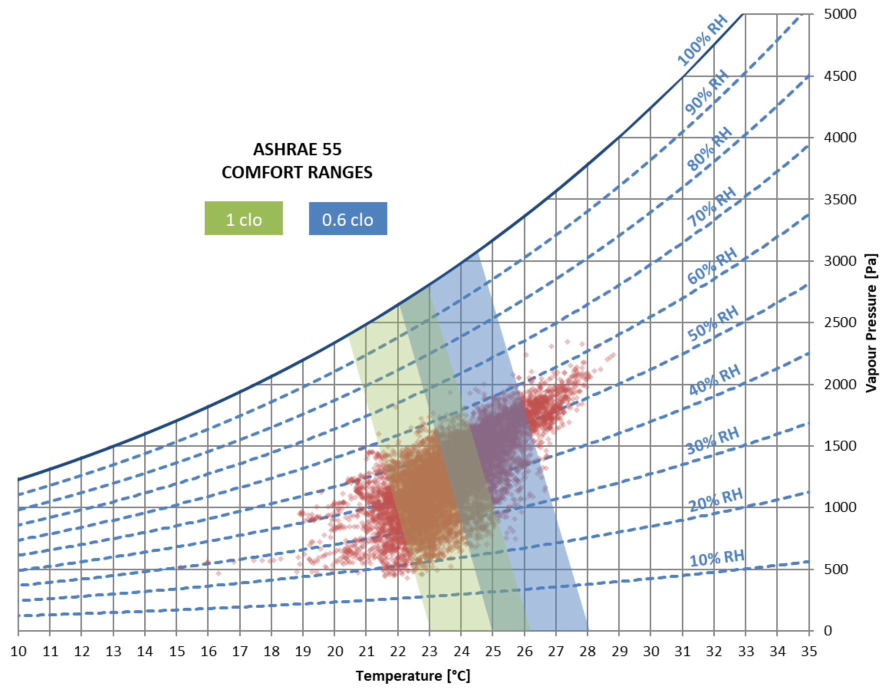

Figure 17: Temperature & relative humidity on psychrometric chart (Suite 5 – living room) during 24-month monitoring period

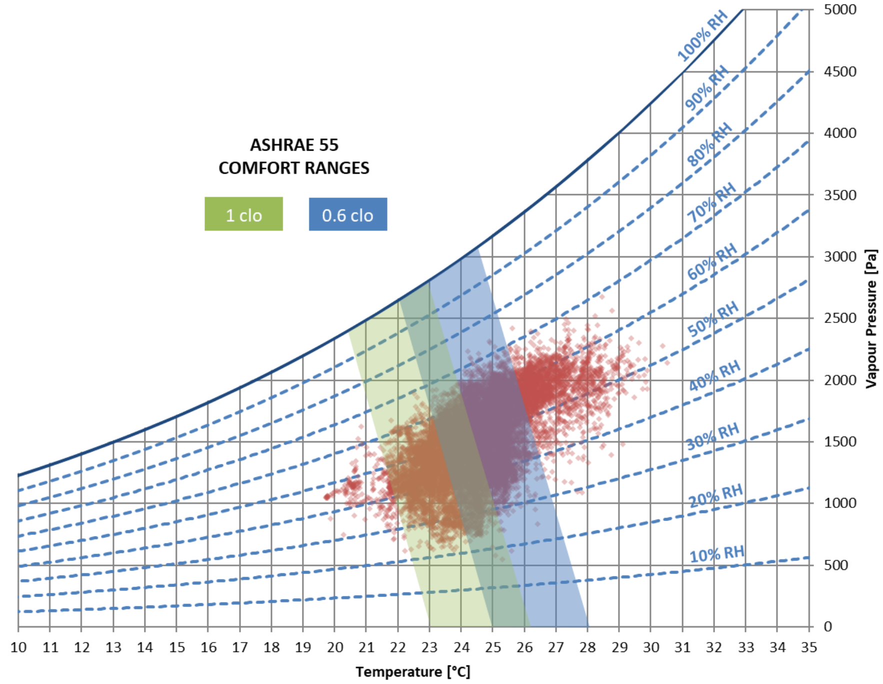

Figure 18: Temperature & relative humidity on psychrometric chart (Suite 5 – bedroom) during 24-month monitoring period

Surface Temperatures & Condensation Risk

Window frame and glass surface temperatures are typically the coolest interior surface temperatures in a building and were therefore measured in the kitchen and living room of two units. *Figure 19* through *Figure 22* show window surface temperatures in Suites 3 and 5 combined with other measured criteria for two typical weeks in the winter and spring. Generally, these plots show that where window surface temperatures drop below the Passive House minimum surface temperature, the interior temperatures are significantly below 17.8°C. This is particularly evident in *Figure 19*. This is likely due to either an open window or a period of unoccupancy within the suite. Note that the PHI minimum surface temperature criteria shown refers to the 17.8˚C which is an average for the surface of the window including both the glass and the frame. The frame is typically colder than the glass, so if only the frame is below the threshold temperature, it is likely that the window product is still meeting this threshold on average.

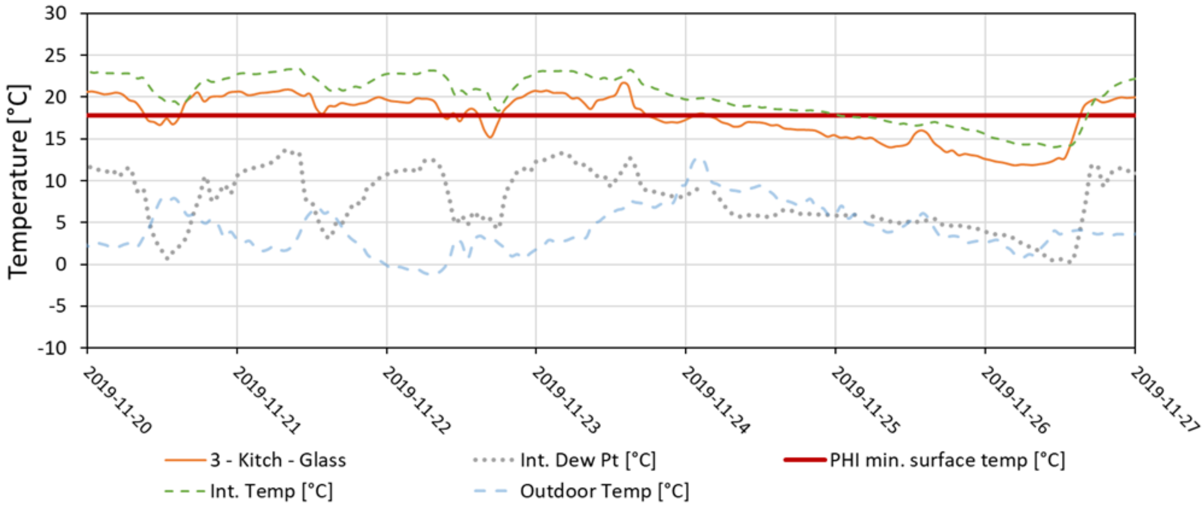

Figure 19: Frame surface temperatures in kitchen during a sample week in winter season (Suite 3). Note that only window glass surface temperature was measured in this location.

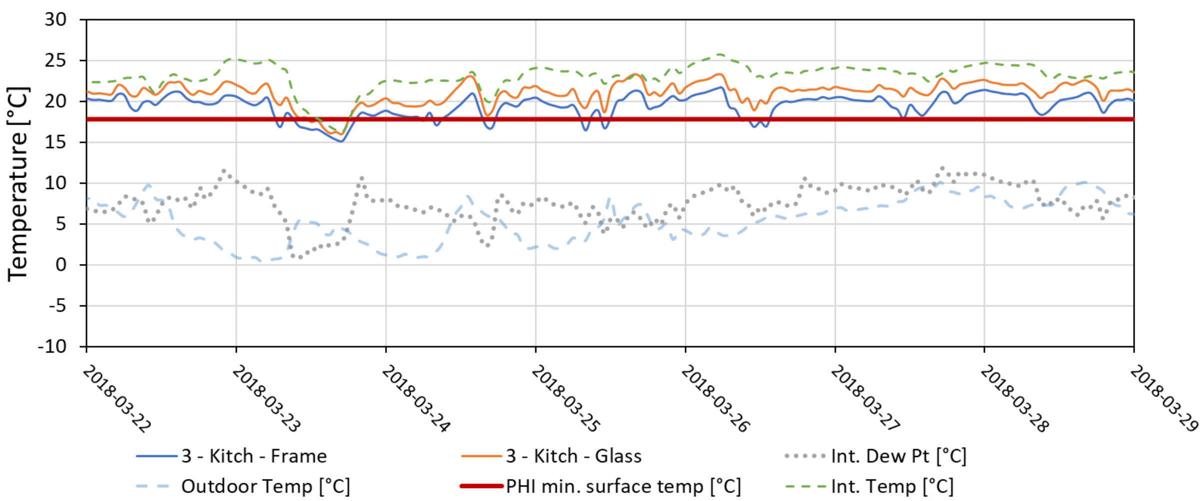

Figure 20: Frame and glass surface temperatures in living room during a sample week in spring season (Suite 3).

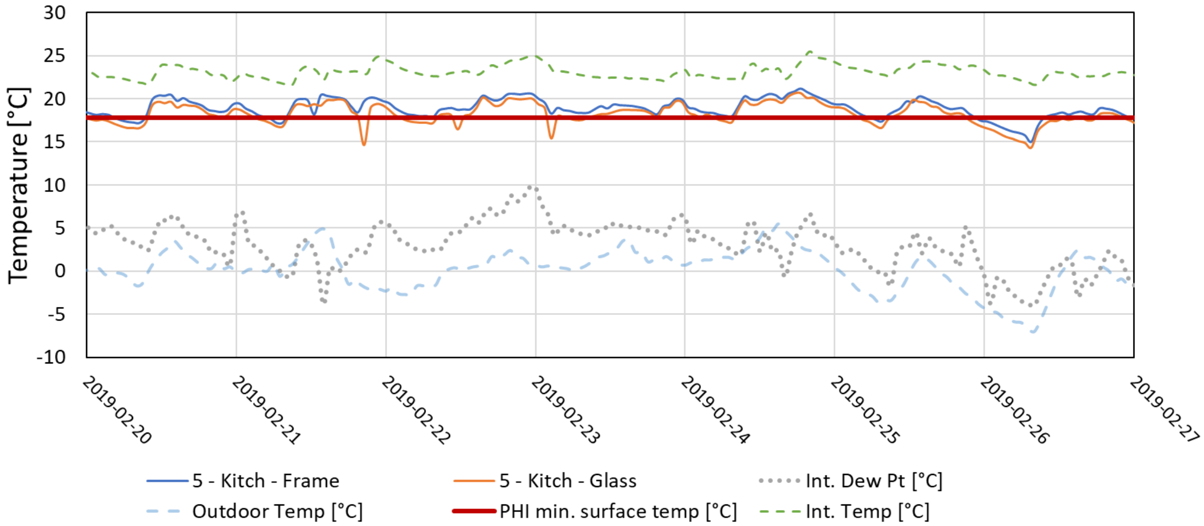

Figure 21: Frame and glass surface temperatures in kitchen during a sample week in winter season (Suite 5).

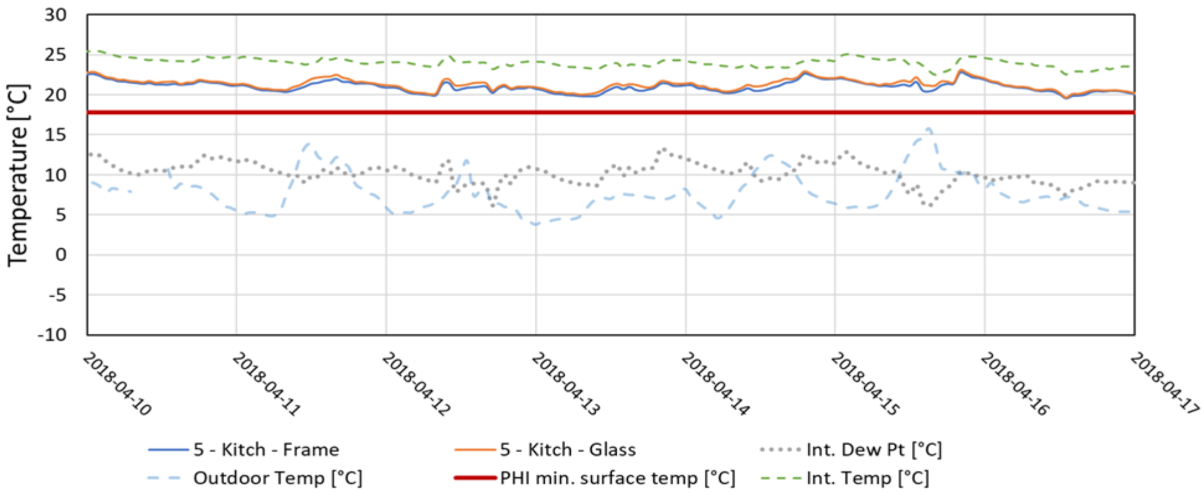

Figure 22: Frame and glass surface temperatures in living room during a sample week in spring season (Suite 5).

Table 2.4 lists the percentage of time that the window glass or frame surface temperatures went below the Passive House comfort criteria of 17.8˚C during the monitoring period. Results show that the window surface temperatures generally dropped below the comfort criteria for less than 10% of the monitoring period, with the exception of Suite 5 kitchen window glass. As stated above, many instances where window glass and/or frame surface temperatures dropped below 17.8˚C are likely the result of windows being opened during the colder months of the year as interior air temperatures typically fell in concert with window surface temperatures.

In addition, the surface temperature measurements throughout the monitoring period were compared against the interior dew point temperatures. The analysis indicated that all window surface temperatures were above the interior dew point temperature throughout the monitoring period and hence at a relatively low risk of condensation formation.

TABLE 2.4 WINDOW SURFACE TEMPERATURE FREQUENCY BELOW PASSIVE HOUSE COMFORT CRITERIA OF 17.8˚C	
LOCATION	**PERCENT OF TIME**
Suite 3 – Kitchen – Frame	8%
Suite 3 – Kitchen – Glass	4%
Suite 3 – Living Room – Frame	2%
Suite 5 – Kitchen – Frame	2%
Suite 5 – Kitchen – Glass	14%
Suite 5 – Living Room – Frame	5%
Suite 5 – Living Room – Glass	3%

The Passive House hygiene criteria for determining the condensation resistance of the installed Passive House windows was also calculated for the coldest hour of the monitoring period (1:00am on February 4th, 2019). All measured window frame temperatures achieved a hygiene criteria value (f_{Rsi}) of 0.8 or greater (Table 2.5). Note that an f_{Rsi} value greater than or equal to 0.7 is considered acceptable for British Columbia climactic conditions based on Passive House guidance. As such, the installed Euroline 4700-series ThermoPlus Passive House windows appear to be performing in general conformance with the Passive House standards.

TABLE 2.5 PASSIVE HOUSE HYGIENE CRITERIA TARGET OF ≥0.7				
LOCATION	SUITE 3 KITCHEN	SUITE 3 LIVING ROOM	SUITE 5 KITCHEN	SUITE 5 LIVING ROOM
Surface Temperature	15.4	17	21	16
Exterior ambient air	-11.7	-11.7	-11.7	-11.7
Interior ambient air	24.4	24.4	22.7	23.8
f_{Rsi}	**0.8**	**0.8**	**1.0**	**0.8**

2.2.2 Indoor Air Quality

Carbon Dioxide Concentrations

To ensure a healthy indoor environment within an airtight building enclosure, stale air must be exhausted from the building to avoid high concentrations of pollutants. Replacing stale air with fresh outdoor air can be achieved mechanically, such as by an HRV installed within each unit, or passively by opening windows. Carbon Dioxide (CO_2) is produced generally by people when they exhale and is an easily measurable pollutant that is often used as an indicator of occupancy and indoor air quality. Low CO_2 concentrations typically indicate that fresh air is being provided to the space in sufficient quantities to remove the build-up of many common pollutants, and particularly bioeffluents. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) provides guidance for the design of clean indoor environments in ASHRAE Standard 62.1 -

Ventilation for Acceptable Indoor Air Quality[12] and the Indoor Air Quality Guide[13]. The recommended design airflow rates of the prescriptive design procedure in ASHRAE 62.1 are provided to control CO_2 concentrations to 700 parts per million (ppm) above outdoor conditions, which provides indoor concentrations of roughly 1100ppm. Recent research indicates that CO_2 itself may be considered an indoor pollutant that impairs a person's decision-making abilities at levels previously considered to be below safe limits[14]. The control of CO_2 and other indoor pollutants is an important aspect of a healthy building.

Figure 23 through *Figure 25* are 24-months plot the CO_2 levels of the Suite 3 bedroom and Suite 5 living room and bedroom throughout the monitoring period. Note that significant CO_2 concentrations data loss was experienced in Suite 3 living and is therefore not shown.

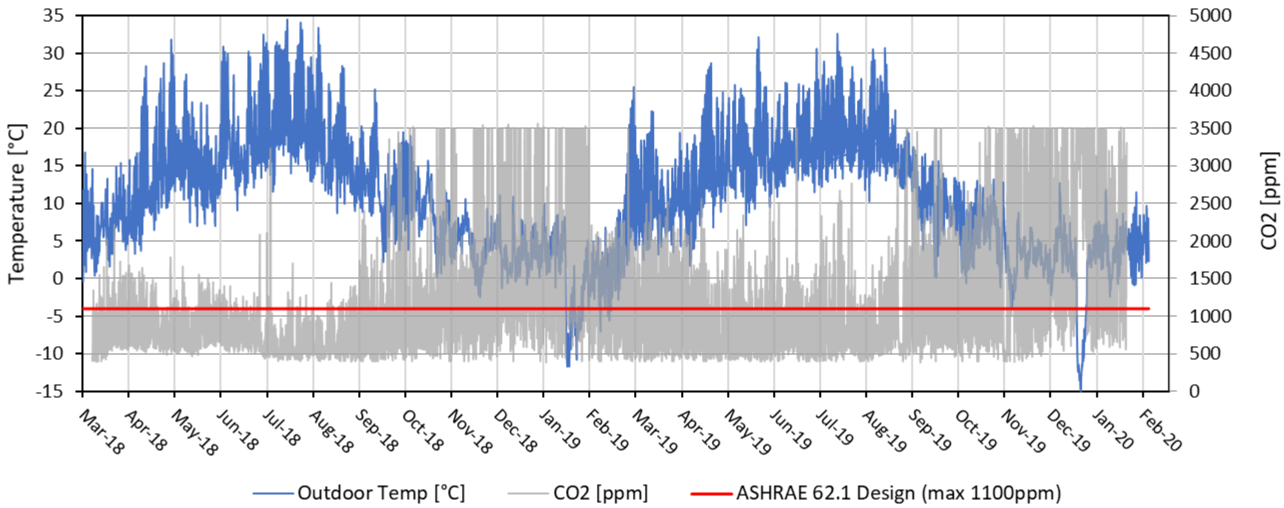

Figure 23: CO_2 levels in bedroom during two years of monitoring (Suite 3).

[12]ASHRAE, 2013. "ANSI/ASHRAE Standard 62.1-2013 Ventilation for Acceptable Indoor Air Quality". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

[13]ASHRAE, 2009. "Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

[14]LBNL, 2013. "Is CO2 an Indoor Pollutant? Higher Levels of CO2 May Diminish Decision Making Performance". Lawrence Berkeley National Laboratory. Available at: http://eetd.lbl.gov/sites/all/files/lbnl-6148e-is_co2_an_indoor_pollutant_v3.pdf

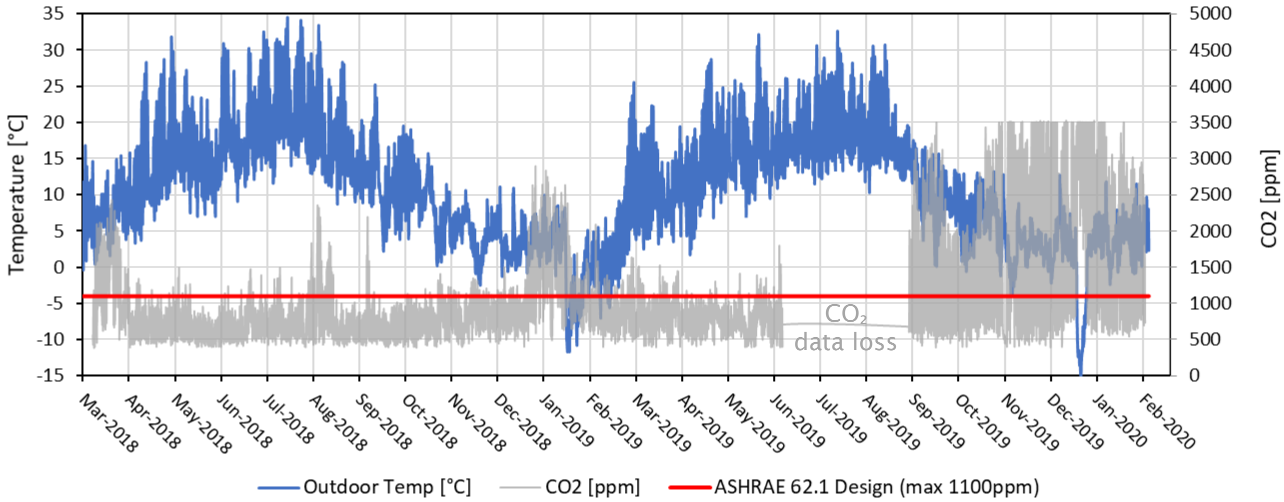

Figure 24: CO_2 levels in living room during two years of monitoring (Suite 5).

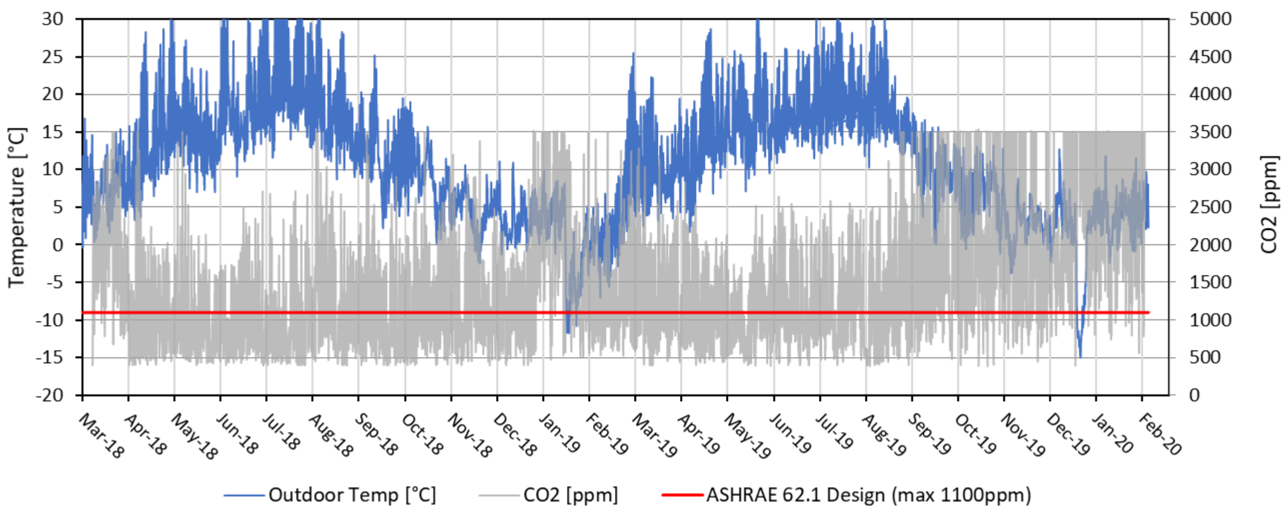

Figure 25: CO_2 levels in bedroom during two years of monitoring (Suite 5).

The data shows that CO_2 concentrations fluctuate roughly below or slightly above the minimum criteria for most of the spring, summer, and fall seasons, with minor exceptions. During the winter, however, significant periods of elevated CO_2 concentrations are noted. Note that the concentrations reached the maximum 3500ppm reading of the sensor and therefore may actually be higher in some cases. These high concentration periods, as shown by the temperature plot, coincide with cold outdoor temperature periods and are likely times when occupants are choosing to keep their windows closed, as well as likely staying home more often. The second year of monitoring shows a similar but significantly more extreme response during cold periods of the year. The cause of this change is unknown, but potentially associated with change in occupancy (unconfirmed), and/or change in operation of the ventilation equipment. Note that CO_2 data was lost between July and October 2019 due to sensor battery issues. Nonetheless, significantly higher CO_2 concentrations were measured between October 2019 and February 2020.

For a better understanding of CO_2 concentrations at a diurnal scale, *Figure 26* and *Figure 27* focus on a typical week in December for Suite 5 during the first and second year of the study, respectively. Results show that CO_2 levels increase during the night, while occupants are likely home and sleeping, and decrease during the day when occupants may be away from the building. It is evident from these weekly plots that during the first year of monitoring, adequate ventilation is being provided in the living room such that CO_2 concentrations remain at or below ASHRAE's 1100ppm design limit.

The dew point temperature is also a useful metric for investigation of occupancy patterns as it is an absolute measurement of water vapour in the air regardless of air temperature and relative humidity. The weekly plots show that the spikes of interior dew point are largely independent of exterior dew point and this data tracks relatively with the CO_2 concentration (most notable in *Figure 27*).

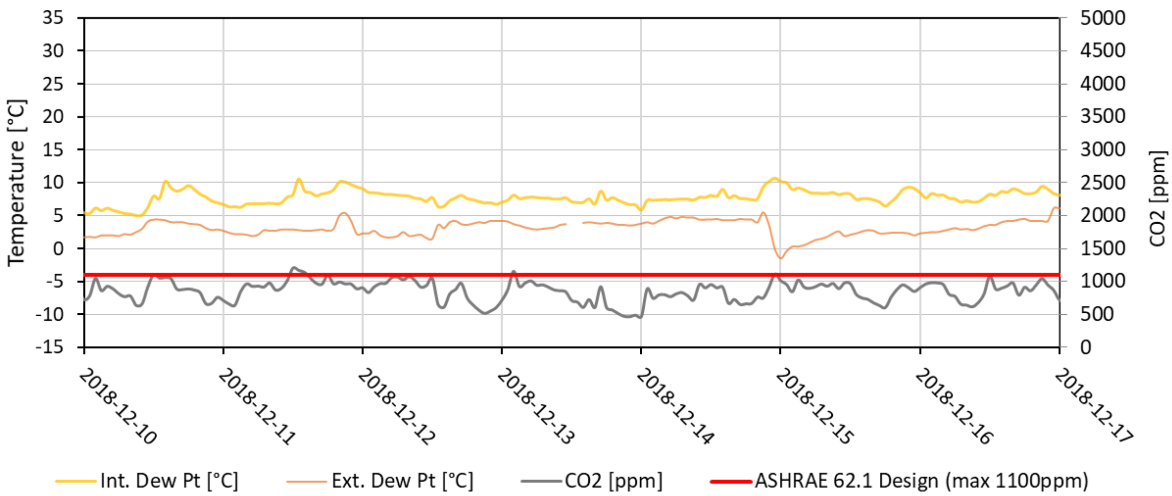

Figure 26: CO_2 levels in living room for a sample week in December during 1st year of monitoring (Suite 5).

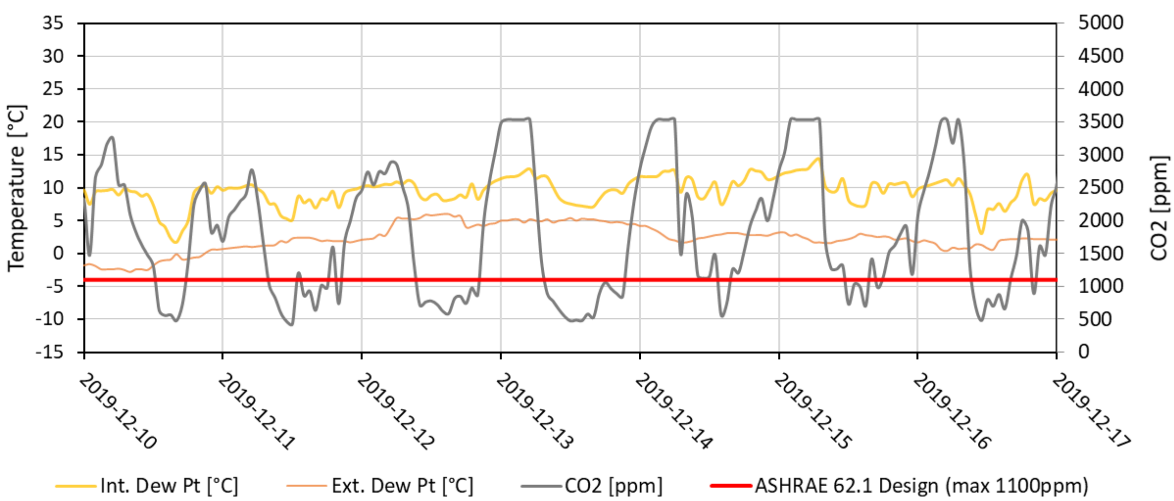

Figure 27: CO_2 levels in living room for a sample week in December during 2nd year of monitoring (Suite 5).

Table 2.6 lists the frequency that each measured location is above the ASHRAE minimum CO_2 concentration of 1100ppm for the 24-month monitoring period.

TABLE 2.6 FREQUENCY ABOVE ASHRAE MAXIMUM CARBON DIOXIDE CONCENTRATION OF 1100 PPM		
PERIOD	**LOCATION**	**CARBON DIOXIDE >1100 PPM**
2018/19	Suite 3 – Living Room	27%
	Suite 3 – Bedroom	27%
	Suite 5 – Living Room	11%
	Suite 5 - Bedroom	45%
2019/20	Suite 3 – Living Room	56%*
	Suite 3 – Bedroom	40%
	Suite 5 – Living Room	29%*
	Suite 5 - Bedroom	63%

**Periods with significant CO_2 concentration data loss during summer months when CO2 levels are relatively lower. Therefore, actual concentration frequency is likely lower.*

As noted previously in this report, the living room of Suite 3 is equipped with a full-size bed which suggests that it is also used as a bedroom during the nights. This is evident in the high frequency exhibited in Suite 3 living room which closely resembles values of for the Suite 3 bedroom. Although the frequencies shown in the table are significantly higher than the ASHRAE 62.1 limit, it is not clear from this information alone whether or not these concentrations are problematic from a health perspective; however, it is likely that adequate ventilation is not being supplied to these spaces.

Figure 28 and *Figure 29* provide a frequency distribution chart of CO_2 concentrations in the measured spaces during the first and second year of monitoring. This plot below is useful for providing a sense of how high the overall CO_2 concentrations are being experienced in each area. For example, it is evident that CO_2 concentrations above 2000ppm are occurring for a relatively significant fraction of time, particularly during 2019/20.

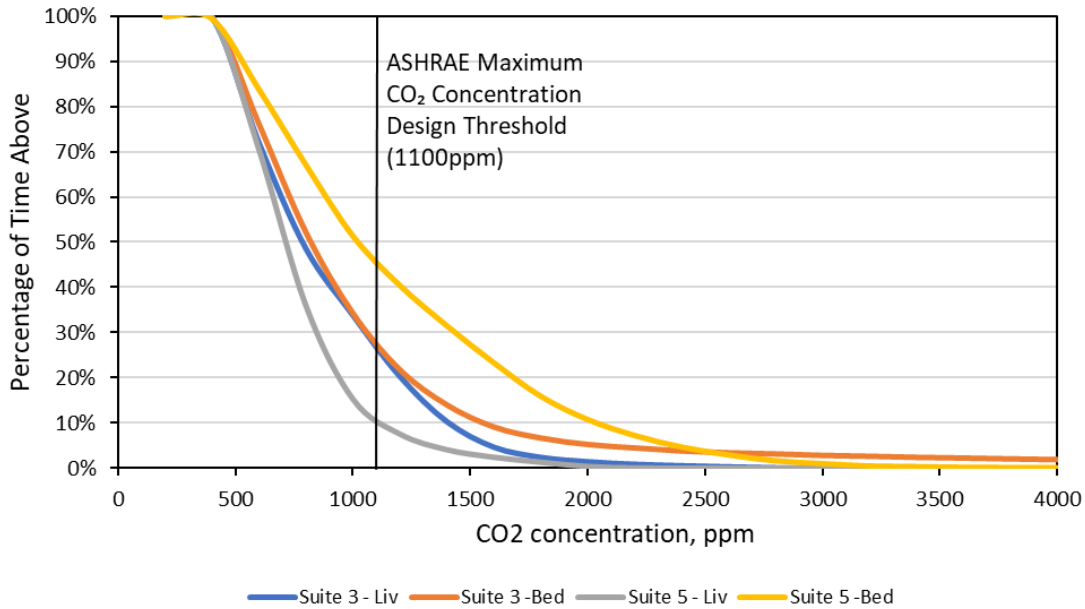

Figure 28: Fraction of time the indoor environment is above a given CO_2 concentration (2018/19).

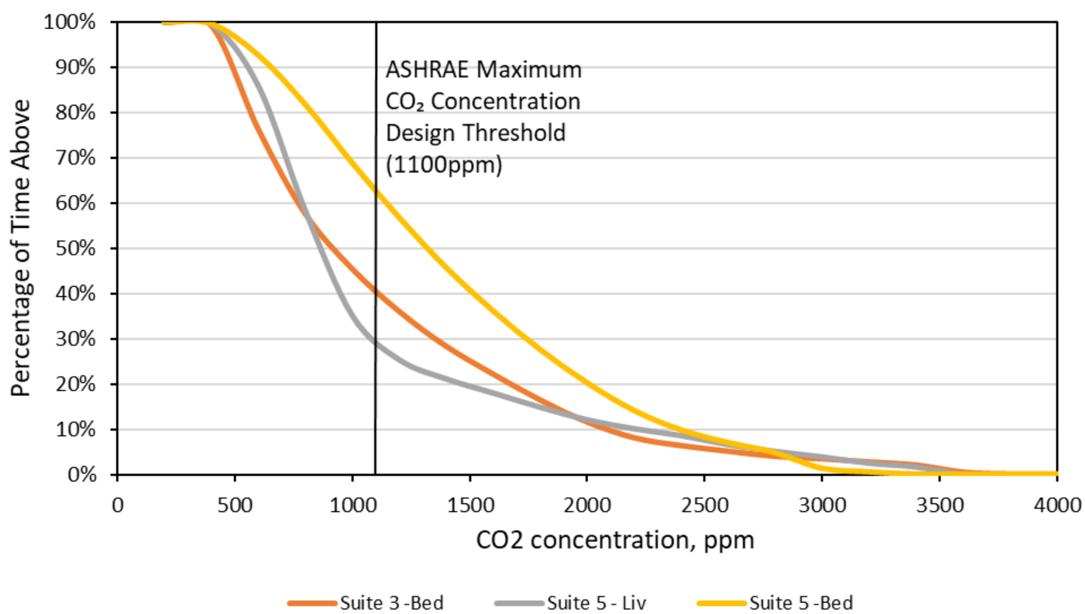

Figure 29: Fraction of time the indoor environment is above a given CO_2 concentration (2019/20). Note that Suite 3 living room was omitted due to significant data was lost during summer.

Overall, CO_2 concentrations fluctuate daily and seasonally, often above the ASHRAE 62.1 design limit of 1100ppm, particularly during periods of cold exterior conditions. These overall high concentrations may be due to the number of occupants in each suite. For example, the PHPP model assumes two people per suite for a total of 12 occupants; however, during multiple site visits, the total number of occupants for the whole building appeared to be higher. If the ventilation system is designed for fewer occupants, ventilation rates may not be high enough to adequately dilute pollutants based on actual use. It was also noted during many site visits that the HRVs were operated infrequently and may not have been in operation for prolonged periods of the winter whereas windows were likely open during the summer. If occupants turn off their mechanical ventilation and default to natural ventilation, overall ventilation can decrease during the colder months when opening windows is used less often, which the data strongly suggests. To further investigate operation of the HRVs and the potential impact on IEQ, the HRV controls and efficiency were examined in the following section.

Ventilation (HRV Efficiency & Controls)

Based on the method described in Section 1.2.2, air flow temperatures within the HRV system were monitored in Suite 3 and Suite 5 to determine the heat recovery rate, or efficiency of the units during the 24-month measurement period. *Figure 30* through *Figure 33* are plotted measurements and corresponding efficiencies for the two suites during the first and second year of monitoring, respectively.

Based on the significant spikes in theoretical efficiencies from up to approximately 100% or down to approximately 20%, the results suggest that the HRV systems are frequently being turned on and off or switched to bypass mode. In fact, during a site visit, a tenant mentioned that they had temporarily turned off their HRV in an effort to save on energy and utility costs.

As stated previously, Passive House design produces very airtight buildings and therefore it is typically recommended to provide continuous mechanical ventilation year-round. It is clear that occupants must be adequately educated as to the intended operation of the building systems. While the initial building occupants were educated on the use of the heat recovery ventilator, it’s possible that they have misunderstood the importance of the equipment or that subsequent tenants were not provided with the same information. Based on the 2019/20 plots, it is evident that the HRV in Suite 3 is continuing to be manually operated and Suite 5 appears to be running largely in bypass mode for the entire second year of monitoring (*Figure 33*).

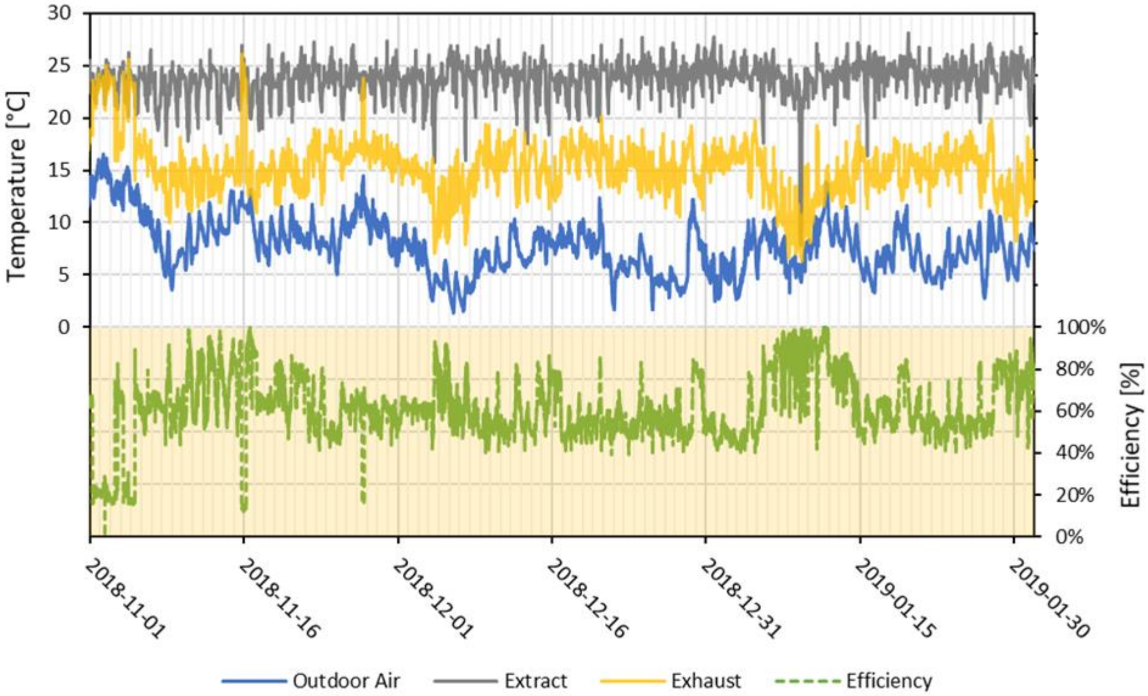

Figure 30: HRV heat recovery rate and corresponding air temperature measurements for Suite 3 during winter 2018/19

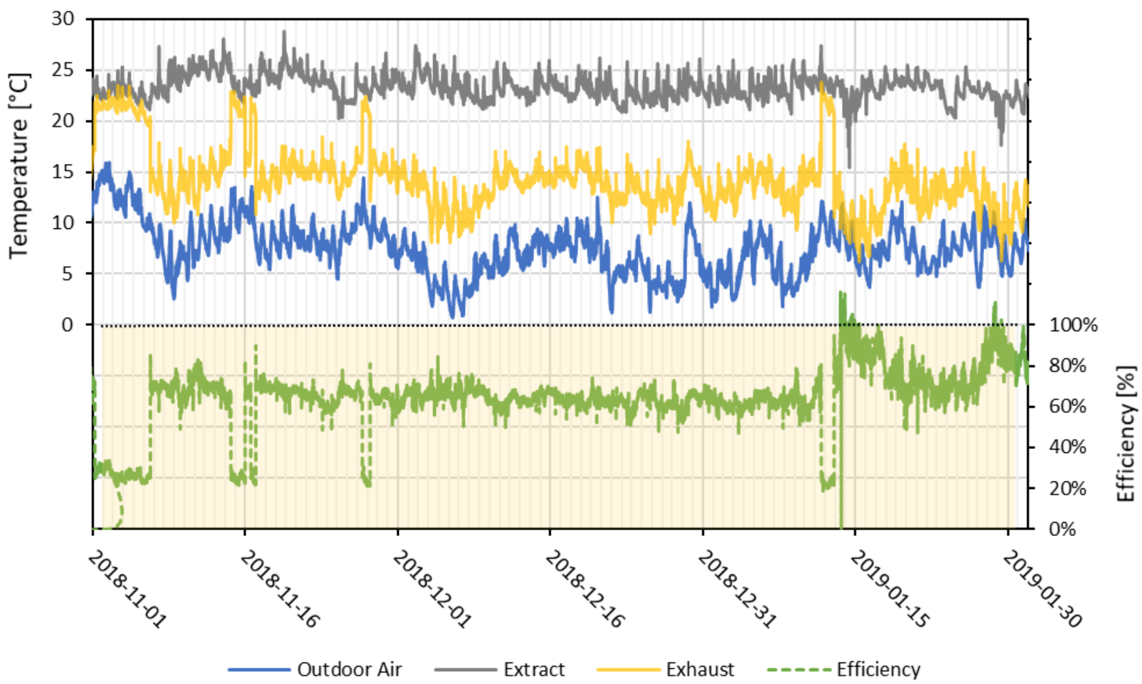

Figure 31: HRV heat recovery rate and corresponding air temperature measurements for Suite 5 during winter 2018/19

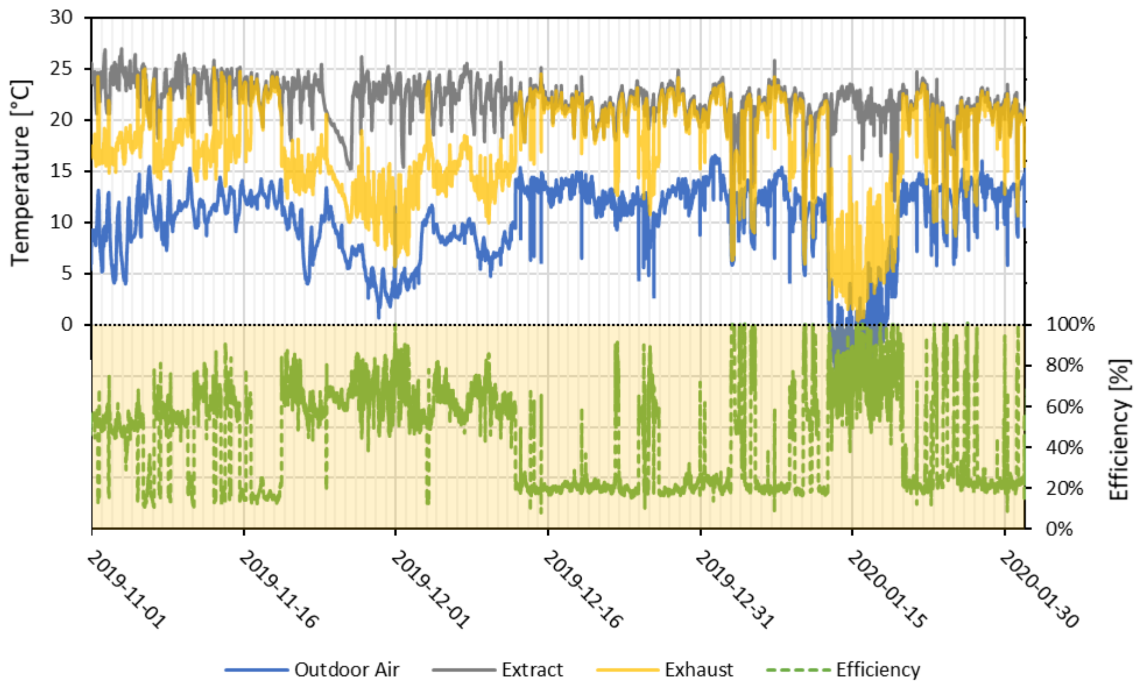

Figure 32: HRV heat recovery rate and corresponding air temperature measurements for Suite 3 during winter 2019/20

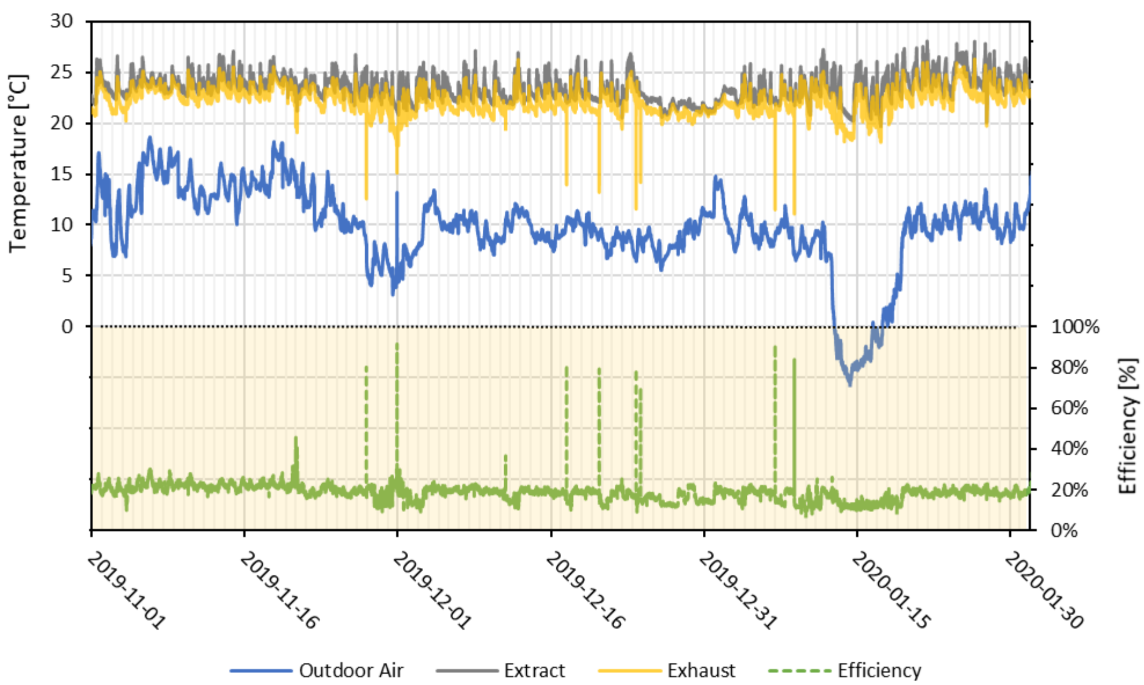

Figure 33: HRV heat recovery rate and corresponding measurements for Suite 5 during winter 2019/20. Measurements suggest HRV mainly operating in bypass mode.

In order to clarify the various manual HRV operations occurring in the monitored suites, *Figure 34* and *Figure 35: Sample week of HRV heat recovery rate and corresponding air temperature measurements for Suite 3 during winter 2019/20.* are sample weeks from Suite 3 and Suite 5, respectively. The results of the weekly plots seem to show three different scenarios. First, the heat recovery rate will occasionally rise to or above 100%

when the exhaust temperature drops towards outdoor temperature (see annotations in *Figure 35: Sample week of HRV heat recovery rate and corresponding air temperature measurements for Suite 3 during winter 2019/20.*). It is hypothesized that this condition indicates that the unit is not operating (i.e. it is off). Second, the heat recovery rate will occasionally drop to approximately 20% efficiency when the exhaust temperature rises to meet the extract temperature (see annotations in *Figure 35: Sample week of HRV heat recovery rate and corresponding air temperature measurements for Suite 3 during winter 2019/20.*). This is hypothesized to occur when the unit is operating in bypass mode with no heat recovery (i.e., fresh air is brought into the home without pre-heating). If the equipment is operating in this configuration, the exhaust is expected to be at approximately the same temperatures as the extract air since no heat has been redirected to the incoming air stream. A small amount of apparent heat recovery (i.e. approximately 20%) is likely the result of imperfect insulation between air streams even when in bypass, and heat generated by the fan motor being transferred to the incoming air stream. Lastly, if the unit is operating normally, the exhaust air stream should always be somewhat warmer than the outdoor air (during heating season), assuming that the building is being heated. The resulting measured efficiencies for the first two scenarios (i.e., when the HRV is not operating as a heat recovery ventilation system) should not be considered as part of the HRV efficiency evaluation. When the HRV systems are operating normally; however, the heat recovery rates appear to be operating between 50% and 70% efficiency.

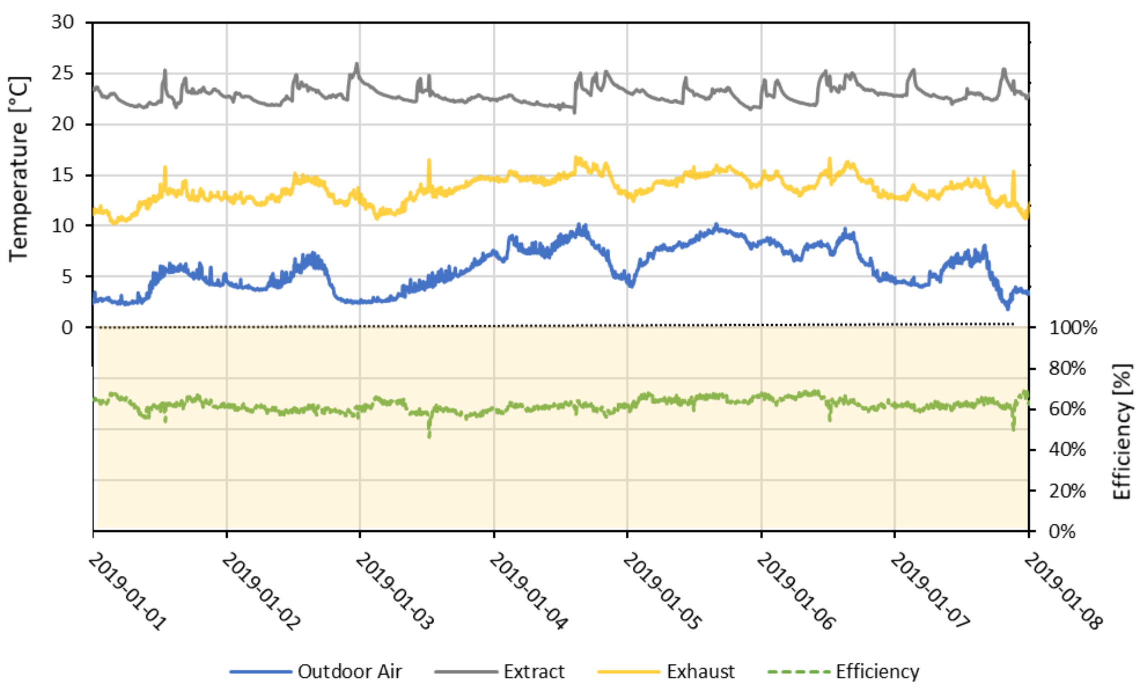

Figure 34: Sample week of HRV heat recovery rate and corresponding air temperature measurements for Suite 5 during winter 2018/19.

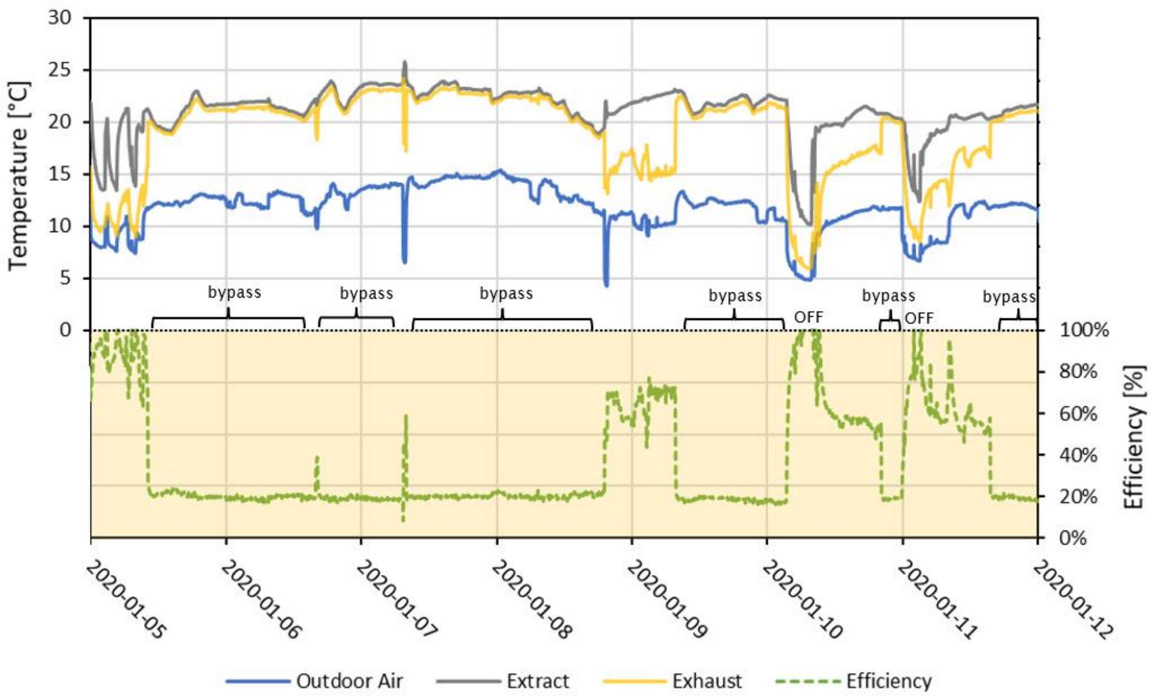

Figure 35: Sample week of HRV heat recovery rate and corresponding air temperature measurements for Suite 3 during winter 2019/20.

The relatively lower than anticipated efficiency (i.e., compared to manufacturer rated efficiency of 92%) may be caused by the HRV being manually operating in boost mode, leading to lower heat recovery rate in part due to the physical performance of the unit, and in part due to the assumed mass flow rate used for the purposes of the efficiency calculation used in this study. For example, the typical mass flow rate when the unit is operating in a normal state is assumed to be 77 m^3/h per unit but in boost mode is likely operating at its maximum design of around 100 m^3/h. Another possibility for lower than anticipated efficiencies is the limitations of the Passive House HRV efficiency equation in that it does not account for latent energy. In other words, when dewpoint of interior air is above exterior air temperature, water will condense out of the air stream and transfer some of its energy to the incoming air stream. This energy is significant and not included as the calculation only accounts for dry-bulb temperature, not moisture content of the air.

2.3 Cost Analysis

The manufacturer and installer of the monitored Passive House building, Metric Modular, provided costing data for the Passive House 6-plex as well as a typical modular building with conventional energy performance. The relative costs associated with designing, building, transporting, installing, and providing insurance for the two buildings are noted below in Table 2.7.

TABLE 2.7 PASSIVE HOUSE VS. CONVENTIONAL CONSTRUCTION – TOTAL COSTS

Description	Costs (Passive House)	Costs/ft²	Costs (Conventional)	Costs/ft²	% Difference
Construction	$ 892,108	$165.94	$ 709,514	$131.98	20%
Design and Engineering	$ 1,247,62	$ 23.21	$ 71,739	$ 13.34	42%
Transportation	$ 18,679	$ 3.47	$ 18,679	$ 3.47	0%
Installation and Sitework	$ 503,147	$ 93.59	$ 485,103	$ 90.23	4%
Home Warranty	$ 15,090	$ 2.81	$ 15,090	$ 2.81	0%
Project Total	**$1,553,786**	**$289.02**	**$1,300,125**	**$241.84**	**16%**

Based on the provided costing data, the Passive House 6-plex had an incremental construction cost of $253,661 ($508/m²) over a comparable conventional building built using the same modular method. The project engineering and design as well as Passive House materials/equipment and construction techniques represent the most significant increase in construction costs.

Note that the base building would be minimally compliant with base building code at the time the project was constructed. Furthermore, the differences in cost between the two buildings does not necessarily reflect Passive House requirements in isolation as building design may also differ based on owner preferences and other design objectives.

Table 2.8 provides a breakdown of the incremental material and equipment costs for the Passive House building as compared to a similar conventionally built Part 9 building. Note that this table includes only the portion of the construction cost impacted by the Passive House design.

TABLE 2.8 PASSIVE HOUSE VS. CONVENTIONAL HOUSE - CONSTRUCTION COSTS					
Building Element	**Description**	**Passive House Costs**	**Conventional Part 9 Costs**	**Cost Difference**	**% Difference**
Fasteners	Hecotopix" part threaded SS wood screws	$ 21,232	$ 8,086	$ 13,146	62%
Framing	16" deep TJI's for floors (in lieu of 2x10)	$ 32,890	$ 25,179	$ 7,711	23%
Sheathing	Huber ZIP panel, w/ ZIP tape (in lieu of OSB)	$ 39,423	$ 27,557	$ 11,866	30%
Air Barrier	Air/vapour barrier, "Soprema" Sopraseal Stick VP (in lieu of 6mil Polyethylene)	$ 57,854	$ 28,665	$ 29,189	50%
Insulation	Roof: R-80 batt insulation (in lieu of layer of R14 and R24 batt insulation)	$ 43,768	$ 19,002	$ 24,766	57%
	Walls: 2 layer 3" Rockwool ComfortBoard (in lieu of 1" Dow Styrofoam)				
	Floor: 1" Dow Styrofoam insulation and 2 layer R28 batt (in lieu of R31 batt)				
Windows	Triple-glazed vinyl (in lieu of double-glazed)	$ 28,647	$ 9,670	$ 18,977	66%
Doors	PHI door (in lieu of insulated metal door)	$ 30,261	$ 17,356	$ 12,905	43%
HVAC	Mini split system with Zender HRV (in lieu of baseboard heat c/w standard HRV)	$ 82,280	$ 47,079	$ 35,201	43%
Plumbing (HWT)	Sanden heat pump HWT with backup electric HWT (in lieu of electric HWT)	$ 25,052	$ 10,457	$ 14,595	58%
	TOTAL	**$361,407**	**$193,051**	**$ 168,356**	**47%**

High performance Passive House windows represent the largest material cost increase by percentage amongst the improved Passive House materials/equipment/components. However, on an absolute cost basis, the high-performance HVAC system, increased insulation levels, and self-adhered sheathing membrane (air barrier) are more impactful on the overall Passive House building construction budget.

The incremental construction costs provided by Metric Modular were combined with the annual electricity consumption of the Passive House building and a conventional building, respectively, in order to perform a cost analysis for the project. While not modular construction, a 150 m^2 duplex located on the same property as the Passive House building was selected to represent a conventional building for energy analysis purposes. Refer to the Energy Analysis section for further details on the duplex building.

Utility bills were used to determine the duplex monthly and annual electricity consumption for comparison with the monitored electricity consumption of the Passive House 6-plex. As the Passive House building floor area (499 m^2) was significantly higher than the duplex (150 m^2), the electricity consumption of the duplex was normalized to a comparable building with equivalent floor area to the Passive House 6-plex. Also note that both the monitored and utility electricity consumption data used for the financial analysis was weather normalized to the PHPP climate file. Table 2.9 shows the monthly and annual electricity consumption of the two buildings between March 2019 and February 2020.

TABLE 2.9 PASSIVE HOUSE 6-PLEX VS. DUPLEX MONTHLY ELECTRICITY CONSUMPTION [KWH]

DATE	PH 6-PLEX	DUPLEX	DUPLEX (NORMALIZED)
Mar 2019	4,453	3,214	10,692
Apr 2019	3,778	2,642	8,789
May 2019	3,429	2,153	7,162
Jun 2019	2,949	1,708	5,682
Jul 2019	2,886	1,280	4,258
Aug 2019	3,169	1,333	4,434
Sep 2019	3,152	1,814	6,035
Oct 2019	4,254	2,566	8,536
Nov 2019	4,964	3,189	10,609
Dec 2019	5,603	3,766	12,528
Jan 2020	5,383	3,735	12,425
Feb 2020	3,656	3,255	10,828
TOTAL	**47,677**	**30,655**	**101,979**

The annual energy cost savings associated with the Passive House building were then determined using standard electrical utility rates[15]. Additionally, the green house gas emission savings associated with the project were calculated using an emissions factor of 0.011 kg CO_2e/kWh. The financial metrics of the Passive House 6-plex including net present value (NPV), discounted payback period, and internal rate of return (IRR), are shown on an area-weighted basis in Table 2.10. Note that a discount rate of 5.0% and a building lifespan of 40 years was used for these calculations.

TABLE 2.10 FINANCIAL METRICS FOR PASSIVE HOUSE 6-PLEX

ANNUAL ENERGY SAVINGS (kWh/m^2/yr)	ANNUAL GHG SAVINGS (kg/m^2/yr)	NET PRESENT VALUE ($/m^2)	INTERNAL RATE OF RETURN (%)	DISCOUNTED PAYBACK PERIOD (Years)
109	1.20	-$246.36	1%	>40 yrs

The results of this cost analysis (and negative net present value) indicate that the Passive House 6-plex is not financially viable based on utility savings alone. Over the estimated 40-year lifespan of the building, utility savings ($7,619/year) will be insufficient to recoup the increased construction costs associated with Passive House construction.

It is not uncommon for Passive House and other high-performance buildings in North America to have negative financial metrics where utility rates are significantly lower than

[15] BC Hydro, 2020. "Residential Rates". BC Hydro. Available at: https://app.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/residential-rates.html

other global energy markets. As such, project objectives beyond cost including sustainability, interior environmental quality, and durability are often required in order to justify proceeding with a Passive House building; the financial performance of the Passive House 6-plex building monitored in this study is consistent with this trend.

3 Closure

The objective of this 6-plex Passive House monitoring study is to measure the in-service energy consumption and IEQ of a building constructed to the Passive House standard in order to assess the energy efficiency and secondary occupant benefits that are commonly associated with the standard. This final report summarizes an analysis of the collected data between March 2018 to the end of February 2020. The energy monitoring portion of this study is specifically between March 1st, 2019 and February 26th, 2020, whereas the IEQ findings are derived from monitored data and analysis throughout the two-year period.

The key findings are summarized below.

→ The results of the energy analysis indicate that the operational electricity consumption of the building is significantly higher (208%) than the energy consumption modelled in PHPP. While there are differences in various end uses, the biggest difference is due to space conditioning and plug loads. For example, on average the space conditioning and plug loads of the building are respectively 6 times and 17 times higher than modelled by PHPP. Site observations indicate that this divergence from the PHPP model may be driven by individual occupant behaviour and poor occupant understanding of building systems. Additionally, the heat pump system is currently delivering space cooling to the units whereas PHPP calculated that the cooling load would be met entirely by passive cooling strategies. Although the average measured EUI of the building is higher than PHPP, it is important to note that the energy use intensity of the building as a whole is significantly lower than a typical low-rise multi-unit residential building.

→ The IEQ indicators, particularly air temperature and carbon dioxide concentration, were found to be significantly higher than recommended, especially during summer and winter when outdoor temperatures are most extreme. For example, all measured areas exceeded Passive House's comfort criteria which limits air temperatures above 25˚C for no more than 10% of the year, with the exception of one living room. Bedrooms located upstairs were found to experience more overheating (45% of the year in once case) relative to living rooms on the main floor. It is worth noting, however, that some perceived overheating may be the result of occupant preference associated with set-points, as the monitored buildings are equipped with cooling. Measured CO_2 concentrations often exceeded the ASHRAE minimum of 1100ppm. As expected, areas where residents tend to sleep experience higher concentrations relative to common area. Site observations and discussions with building occupants indicate that the unit HRVs are operating sporadically whereas the design intends for these ventilation units to operate continuously. Higher unit occupancy may also be partially responsible for elevated cooling and ventilation requirements as compared to those calculated by the PHPP model.

→ As part of this energy and indoor air quality study, key Passive House components, windows and HRVs, were also monitored to verify their respective performance against the Passive House standard. Results suggest that both components are performing relatively as expected when operational (i.e. HRVs running and window operable vents in closed position). For example, during the coldest hours of the monitoring period, all measured window frame temperatures achieved a hygiene criteria value (f_{Rsi}) of 0.8 or greater. Results also show that the window surface temperatures generally dropped below the comfort criteria (17.8˚C) for less than 10% of the monitoring period, with the exception of Suite 5 kitchen window glass. Times where window glass and/or frame surface temperatures dropped below 17.8˚C may be the result of windows being opened or the building unoccupied during the colder months of the year as interior air temperatures typically fell in concert with window surface temperatures.

→ HRVs were found to be operating within a heat recovery rate between 50% and 70% efficiency. This is lower than anticipated and may be a result of occupants running their units in boost mode for extended periods, or lower in-service performance than rated. It was also found that the measured HRV units were not being operated continuously as recommended.

→ A cost analysis was performed on the Passive House 6-plex where the incremental construction costs and utility cost savings over a conventional building were evaluated. As expected, the Passive House building exhibited a negative net present value implying that the project was not viable based on utility cost savings alone. However, based on this study, the increase in construction costs can be justified due to other project objectives including sustainability, durability, resiliency, and improved IEQ for building occupants.

We trust that this report meets your needs at this time. Please contact the undersigned with any questions regarding this work.

Yours truly,

Christopher Marleau | MASc.
Building Scientist
cmarleau@rdh.com
604 873 1181
RDH Building Science Inc.

Michael Wilkinson | M.Eng., CPHD
Building Science Engineer (EIT)
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Reviewed by:

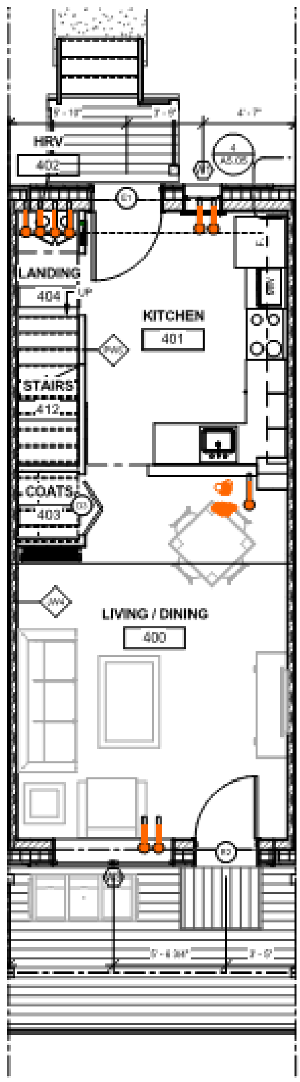
Lorne Ricketts | CPHD, MASc., P.Eng.
Principal, Building Science Specialist

Appendix A

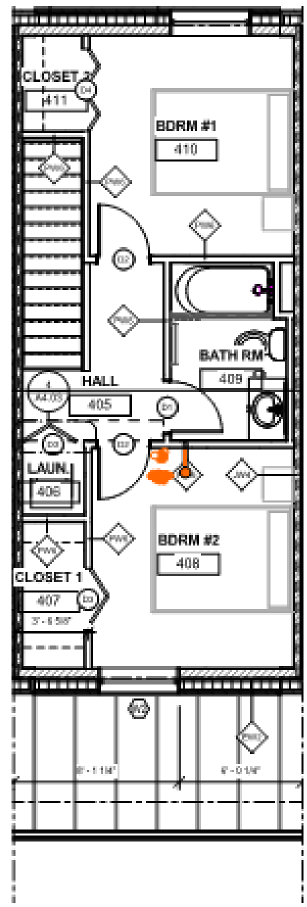
Schematic of Indoor Environmental Sensor Locations

Legend

- Temperature
- Relative humidity
- Carbon dioxide



Main Floor



Upper Floor

Appendix B

Passive House PHPP Comparison

Passive House Verification

Building:	7051		
Street:	Ruby Creek Rd		
Postcode/City:	V0M1G0	Agassiz	
Province/Country:	BC	CA-Canada	
Building type:	6 Unit Row House		
Climate data set:	ud---00-Muster		
Climate zone:	3: Cool-temperate	Altitude of location:	31.736 m
Home owner / Client:	Yale First Nation		
Street:	314 Hudson Bay St		
Postcode/City:	V0X1L0	Hope	
Province/Country:	BC	Canada	

Architecture:	Mobius Architecture			**Mechanical engineer:**	ITEC Systems Design	
Street:	Suite 3 4720 Sunshine Coast Highway			Street:	20092 93a Ave	
Postcode/City:	V0N3A2	Sechelt		Postcode/City:	V1M3Y4	Langely Township
Province/Country:	BC	CA-Canada		Province/Country:	BC	1-Residential building
Energy consultancy:	Britco LP			**Certification:**	Peel Passive House Consulting	
Street:	1825 Tower Rd			Street:	118 Craigleith Road	
Postcode/City:	V0M 1A2	Agassiz		Postcode/City:	L9Y 0S3	Blue Mountains
Province/Country:	BC	CA-Canada		Province/Country:	Ontario	CA-Canada

Year of construction:	2016	Interior temperature winter [°C]:	20.0	Interior temp. summer [°C]:	25.0
No. of dwelling units:	6	Internal heat gains (IHG) heating case [W/m²]:	2.8	IHG cooling case [W/m²]:	3.1
No. of occupants:	12.0	Specific capacity [Wh/K per m² TFA]:	60	Mechanical cooling:	

Specific building characteristics with reference to the treated floor area

				Criteria	Alternative criteria	Fullfilled?[2]
	Treated floor area m²	401.3				
Space heating	Heating demand kWh/(m²a)	13.98	≤	15	-	yes
	Heating load W/m²	9	≤	-	10	
Space cooling	Cooling & dehum. demand kWh/(m²a)	-	≤	-	-	-
	Cooling load W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C) %	0	≤	10		yes
	Frequency of excessively high humidity (> 12 g/kg) %	0	≤	20		yes
Airtightness	Pressurization test result n_{50} 1/h	0.6	≤	0.6		yes
Non-renewable Primary Energy (PE)	PE demand kWh/(m²a)	103	≤	-		-
Primary Energy Renewable (PER)	PER demand kWh/(m²a)	49	≤	60	60	yes
	Generation of renewable energy (in relation to projected building footprint area) kWh/(m²a)	0	≥	-	-	

[2] Empty field: Data missing; '-': No requirement

I confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The PHPP calculations are attached to this verification.

Passive House Classic? yes

Task:	First name:	Surname:	Signature:
1-Designer	Christie	Bokor	
Britco LP	Issued on:	City: Agassiz	

Appendix C

Costing Summary Documentation – Metric Modular (previously Britco)

Metric Modular
A Triple M Company

November 10, 2019 Sent to cmarleau@rdh.com

Christopher Marleau
Building Scientist
RDH Building Science Inc.

Dear Christopher

Re: Yale First Nation – Six Plex Passive House Modular Study (Project #1527400)

Further to our engagement on the modular passive house study with RDH comparing incremental costs between conventional modular systems and passive house modular systems, please find below the following information

Project Summary

- Yale First Nation - Ruby Creek Development
- Total of 13 modules constructed off-site in Agassiz, BC Metric Modular facility in 2016
- Transported by road and craned onto site installed concrete foundation system.
- Total sq.ft – 5,376
- Completed in 6 months from date of Contract

Itemized Summary as follows

Description	Modular Passive House Construction Costs	Sq.ft Costs	Modular Non Passive House Construction Costs	Sq.ft costs	% Difference
Building - Ex Works Agassiz Factory	892,108.00	165.94	709,513.75	131.98	20%
Design and Engineering	124,762.00	23.21	71,739.32	13.34	42%
Transportation of modules	18,679.00	3.47	18,679.00	3.47	0%
Installation of Modules plus Sitework	503,147.00	93.59	485,103.15	90.23	4%
Home Warranty	15,090.00	2.81	15,090.00	2.81	0%
Project Total	**1,553,786.00**	**289.02**	**1,300,125.21**	**241.84**	**16%**

Further details on the differences between scopes are as follows:

Factory Differences

Item no.	Building Element	Description	Passive Costs	Non-Passive Part 9 Costs
1	Fasteners	Hecotopix" Flange head, 8mm dia. Min. 220mm long part threaded SS wood screws	$21,231.86	$8,085.55
2	Wood Framing	First floor framing, 16" deep TJI's in lieu of 2 x 10.	$32,889.63	$25,179.20
3	Sheathing	7/16" (9.5 mm) "Huber" ZIP panel undersheathing, stapled, c/w ZIP system tape to all seams in lieu of std OSB.	$39,423.02	$27,557.15
4	Moisture Protection	Air/vapour barrier, "Soprema" Sopraseal Stick VP, self-adhesive in lieu of 6mil Polyurethane	$57,854.10	$28,665.26
5	Insulation	Roof: R80 Friction fit fiberglass batt insulation, installed in 2 layers R-40 in lieu of layer of R14 & R-24 batt insulation	$43,768.01	$19,002.37
		Walls: 2 layers 3" Roxul Comfort board CIS (R24) rigid insulation board to exterior with R-22 batt isulation in lieu of 1" Dow styrofoam clad mate with R22 batt insulation.		
		Floor: R5 1" Dow Styrofoam Roofmate rigid insulation between TJI top & bottom chords and 2 layers of R28 friction fit batt insulation in lieu of R31 batt insulation.		
6	Windows	Passive house certified triple glazed vinyl windows in lieu of double glazed vinyl windows.	$28,646.71	$9,669.52
7	Doors	Passive house certifed exterior doors in lieu of insulated residential metal skinned door with wood jamb.	$30,261.17	$17,356.10
8	HVAC	High efficency mini split system with Zender ERV in lieu of baseboard heat c/w stanadard HRV.	$82,280.41	$47,079.11
9	Plumbing (WWT)	Sanden heat pump HWT with backup electric HWT in lieu of electtric HWT in each suite.	$25,051.95	$10,456.87
	Totals		**$361,406.85**	**$182,594.25**

Design and Engineering Differences

Item no.	Design Element	Description	Passive Costs
1	Consultant	RDH Envelope and Blower Door Test	32,629.34
2	Consultant	Passive House Certifier	20,393.34
	Totals		**53,022.68**

Site Installation Element Differences

Item no.	Site Element	Description	Passive Costs
1	Envelope	Additional siding assembly installation labor – Incl 3" rigid, peel & stick, longer fasteners - 10 junctions	7,683.94
2	Labour	Additional aerial work platform time (one week) plus fuel	961.95
3	Envelope	Additional roof assembly installation labor – 5 junctions	1,515.80
4	Envelope	Sealing between bottom of mod, across sills, to foundation	1,818.96
5	Envelope	Sealing penetrations in crawl space	3,637.92
6	Labour	Time to test building and perform remedial work	2,425.28
	Totals		**18,043.85**

If you have any further questions or clarification on the information above, please don't hesitate to reach out.

Regards,

Craig Mitchell
Director, Innovative Solutions

Triple M Modular Ltd **Office:** 604.796.2257 **Fax:** 604.796.3755 **metricmodular.com**
1825 Tower Road Agassiz, BC V0M 1A2

Appendix D

Monthly Energy Consumption (Raw Measured vs. Weather Normalized)

TABLE D-1: RAW MEASURED - MONTHLY TOTAL BUILDING ENERGY USE FROM MARCH 1, 2019 TO FEBRUARY 26, 2020 [kWh]				
DATE	**TOTAL**	**SPACE CONDITIONING**	**DHW**	**OTHER**
Mar 2019	3,780	707	597	2,399
Apr 2019	3,124	470	477	2,125
May 2019	2,878	342	386	2,127
Jun 2019	2,723	383	379	1,956
Jul 2019	3,115	548	387	2,180
Aug 2019	3,434	594	412	2,428
Sep 2019	2,939	412	432	2,091
Oct 2019	4,428	1,143	583	2,607
Nov 2019	4,666	915	747	2,944
Dec 2019	5,978	1,248	1,466	3,071
Jan 2020	5,283	1,259	961	2,933
Feb 2020	3,013	806	554	1,638
SUBTOTAL	**45,362**	**8,828**	**7,381**	**29,152**

TABLE D-2: WEATHER NORMALIZED - MONTHLY TOTAL BUILDING ENERGY USE FROM MARCH 1, 2019 TO FEBRUARY 26, 2020 [kWh]				
DATE	**TOTAL**	**SPACE CONDITIONING**	**DHW**	**OTHER**
Mar 2019	4,453	1,070	907	2,399
Apr 2019	3,778	869	732	2,125
May 2019	3,429	698	582	2,127
Jun 2019	2,949	542	446	1,956
Jul 2019	2,886	391	315	2,180
Aug 2019	3,169	410	331	2,428
Sep 2019	3,152	579	478	2,091
Oct 2019	4,254	843	709	2,607
Nov 2019	4,964	1,061	899	2,944
Dec 2019	5,603	1,264	1,076	3,071
Jan 2020	5,383	1,253	1,066	2,933
Feb 2020	3,656	1,084	919	1,638
SUBTOTAL	**47,677**	**10,064**	**8,461**	**29,152**

Appendix E

Sensor Installation & Methodology Interim Report

RDH BUILDING SCIENCE

Sensor Installation & Methodology Interim Report | Project 11102.002

Yale First Nations Ruby Creek 6 Unit Passive House, 8339 Ruby Creek Rd., Agassiz, BC

To Mr. Raouf Chehaiber
Canada Mortgage and Housing Corporation
700 Montreal Road
Ottawa ON K1A 0P7

Submitted April 5, 2018 by
RDH Building Science Inc.
#400-4333 Still Creek Drive, Burnaby
Vancouver BC V5C 6S6

Contents

Appendices

1 Introduction

1.1 Background

Passive House is gaining popularity as a standard for low energy building design and construction. The standard utilizes performance targets for the building design including an annual heating demand of 15 kWh/m^2 or less, total primary energy of 120 kWh/m^2 or less, and an air tightness measurement of 0.6 ACH @ 50Pa. The aim of these performance targets is to achieve higher levels of energy efficiency and thermal comfort than typical or code minimum building designs. Compliance with these energy performance targets is determined through modeling of the building in Passive House Planning Package (PHPP) with operational airtightness being the only building enclosure metric that is physically tested. While operational performance data is easily obtainable for Passive House constructions in Europe, there is presently limited monitoring data available for Passive House designs in Canadian climate zones.

Construction of the Ruby Creek 6 Unit Passive House provides a unique opportunity to measure the operational performance of a townhouse complex constructed to meet the Passive House standard and, incidentally, verify the energy efficiency benefits of the construction standard. Furthermore, this monitoring project can be utilized to help quantify some of the secondary benefits associated with the Passive House standard including enhanced thermal comfort and improved indoor air quality (IAQ).

RDH has been retained to provide measurement and verification of the performance of the Ruby Creek 6-Plex. This process includes the installation of monitoring equipment, data collection, analysis, and reporting. This report presents the results of the initial monitoring equipment installation.

1.2 Objectives and Approach

By installing energy and indoor environment sensors, RDH is able to monitor and assess key performance metrics of the Ruby Creek 6-Unit Townhome over an 18-month period to achieve the following objectives:

→ Compare PHPP modelled energy consumption data against measured building performance and highlight any irregularities

→ Measure the energy use and electricity demand within the townhome complex. Isolate key mechanical equipment including the hot water tank in order to determine the relative impact of domestic hot water, ventilation, etc. on building energy use.

→ Ascertain the impact of occupant behavior on Passive House performance by measuring building parameters when units are occupied versus unoccupied

→ Quantify secondary Passive House benefits (thermal comfort, indoor air quality) by measuring the humidity, temperature, and carbon dioxide levels at several key locations, and compare this data with Passive House comfort criteria and/or best practices ventilation/thermal comfort design

→ Assess whether changes in design or operation of the building can improve performance metrics.

1.2.1 Energy Monitoring

The building electricity consumption and demand will be monitored for 18 months following occupancy and compared to PHPP modeling assumptions. The six townhouse units will be sub-metered in order to ascertain the impact of occupant behaviour on building energy use. Monitoring of critical components such as space heating, domestic water heating, heat recovery ventilators, lighting, and plug loads will be completed to determine the impact of different end uses on townhouse electricity consumption/demand. As all six townhouse units share the same hot water tank and heat pump equipment, these energy end uses will be measured on a whole building basis.

Energy monitoring data will be used to validate the modeling inputs assumed in Passive House certification and to determine how differences in townhouse design can impact system operations and end use energy breakdown.

Note that this report highlights only the sensor installation methodology whereas the second report will detail the preliminary monitoring results (first 9 months of accumulated data). The final nine months of monitoring data will be included in the final project report.

1.2.2 Indoor Environment Monitoring

A strong driver for Passive House design is the improved indoor environmental quality and thermal comfort. Sensors recording indoor environmental quality metrics will be installed in two of the units to monitor the interior environmental conditions to which occupants are exposed for 18 months following occupancy. A summary of the sensors includes:

→ Temperature, relative humidity, and carbon dioxide sensors will be installed in the main floor living area and in one bedroom

→ Temperature and relative humidity sensors will be installed within the washroom in the units to monitor for potential moisture generation concerns

→ Thermocouples will be mounted on key window surfaces to monitor the indoor surface temperatures for use in analyzing condensation risk and indoor thermal comfort metrics used in Passive House design.

→ Temperature measurements will be recorded within the airstreams of the heat recovery ventilators in two units to validate the performance of the mechanical ventilation system.

Later, the indoor environmental conditions will also be qualitatively gauged by distributing comfort surveys to building occupants completed in two different seasons. The perceived comfort feedback received in the occupant surveys will than be compared against measured data in order to determine whether a correlation exists.

2 Monitoring Equipment Installation

2.1 Equipment Description

The equipment used for energy monitoring is The Energy Detective (TED) from Energy Inc. which allows for up to 8 sub-circuits and recording intervals as frequent as 1 minute to distinguish load profiles of equipment with short cycle times. The equipment requires a wired connection to an internet router for cloud data storage. The energy monitoring equipment consists of current transducers and a data transmitter mounted within the electrical panels and concealed from view. The data is transmitted by power line communication (PLC) to a data logger which is connected to the internet. All six residential units and the mechanical room each have one set of the energy monitoring equipment.

Figure 2.1 The Energy Detective (TED) measurement equipment installed in the electrical panels

The indoor environmental monitoring equipment consists of a range of HOBO Series sensors from Onset Computer Corporation. These sensors have been programmed to record data at hourly intervals. The MX 1102 is used to measure temperature, relative humidity, and carbon dioxide within the same unit. The MX1101 is used to measure temperature and relative humidity (excluding carbon dioxide). Surface temperatures of the window frame and glass are monitored using HOBO UX100-014M with Type J Teflon insulated thermocouples.

The temperature of HRV airstreams is being monitored using a UX120-014M 4-channel thermocouple data logger with Type J Teflon insulated thermocouples. HRV temperatures are being recorded at 5-minute intervals.

Table 1 below is a list of the equipment installed to monitor the key performance metrics of the Ruby Creek 6 Unit Townhome over an 18-month period. For further information regarding the equipment, please refer to Appendix A.

TABLE 1 MEASUREMENT LIST AND CORRESPONDING EQUIPMENT	
MEASUREMENTS	**MONITORING EQUIPMENT**
Air Temperature and Relative Humidity	HOBO MX1101
CO_2, Air Temperature and Relative Humidity	HOBO MX1102
Window Surface Temperature	HOBO UX100-014M + Thermocouple
HRV Air Temperature	HOBO UX120-014M + Thermocouple
Electricity	The Energy Detective (TED) Pro Home

2.2 Monitoring Equipment Locations

2.2.1 Electricity Monitoring Equipment

The majority of the electricity monitoring equipment was installed within electrical panels and was concealed after the panel covers were remounted. Individual current transducers were mounted on the main feed to each panel and each circuit included in the sub-metering. Photographs of the installed equipment prior to remounting the covers is shown in Figure 2.2. This monitoring configuration was installed in each sub-panel within the 6-plex.

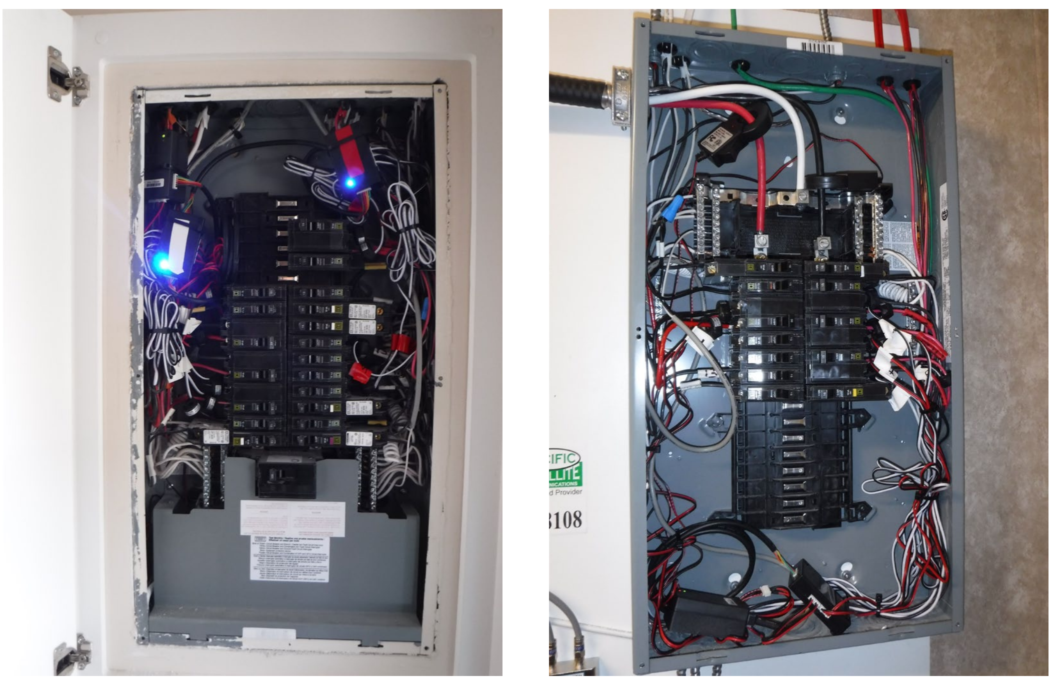


Figure 2.2 Photos of electricity monitoring equipment installed in suite electrical panel (left) and the mechanical room electrical panel (right)

A new internet router was installed within the mechanical room to transmit electricity monitoring data from site to a cloud server. Each data logging component from the electricity meter installed in each unit required a wired internet connection. Wireless relays with ethernet cables were installed in each unit and linked to the router within the mechanical room. The initial set-up with these relays was partially successful but the signals have since failed. Electricity data is currently being recorded on site but additional troubleshooting is required to determine an alternate solution to provide data connectivity to the cloud server.

2.2.2 Indoor Environmental Quality Monitoring Equipment

Indoor environmental quality sensors were installed in Units 3 and 5. A schematic of the installed sensor layout is shown in Figure 2.3.

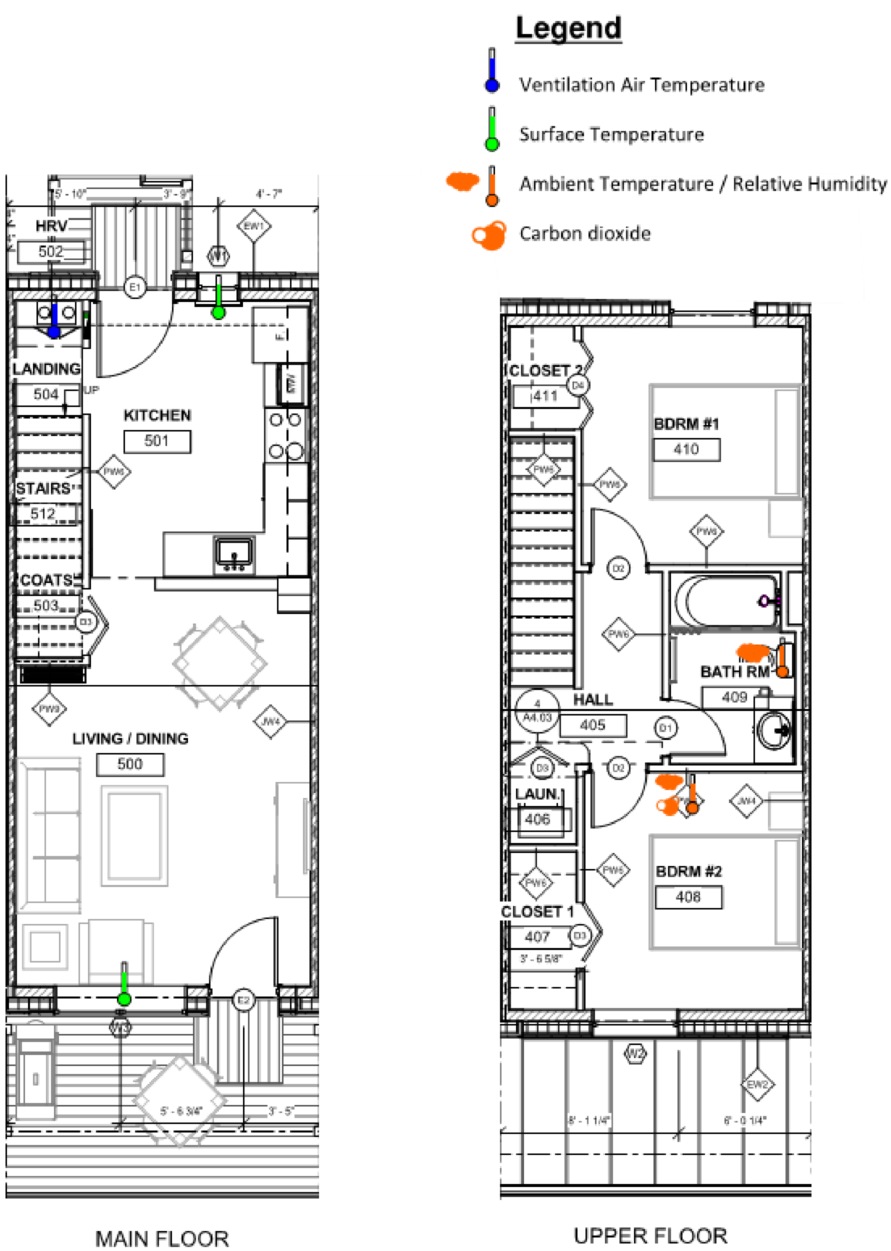


Figure 2.3 Schematic of indoor environmental sensor locations

Temperature, relative humidity, and carbon dioxide are monitored in the main living area and one bedroom. Examples of the sensors mounted in unit 5 are shown in Figure 2.4. Temperature and relative humidity are also being monitored in the washroom (not shown).

Figure 2.4 Temperature, relative humidity, and CO2 sensors installed in Unit 5

Window glazing and frame temperature are being monitored on the kitchen window and the living room window. An example of the window surface temperature sensor mounting is shown in Figure 2.5.

Figure 2.5 Window temperature sensors mounted to record frame and glass temperature on the fixed portion of the living room window

Thermocouples were also mounted within each of the Supply Air, Extract Air, Outdoor Air, and Exhaust airstreams within the body of the HRV. Photographs of the sensors installed within the casing and the data logger mounted on the HRV after the installation are shown in Figure 2.6.

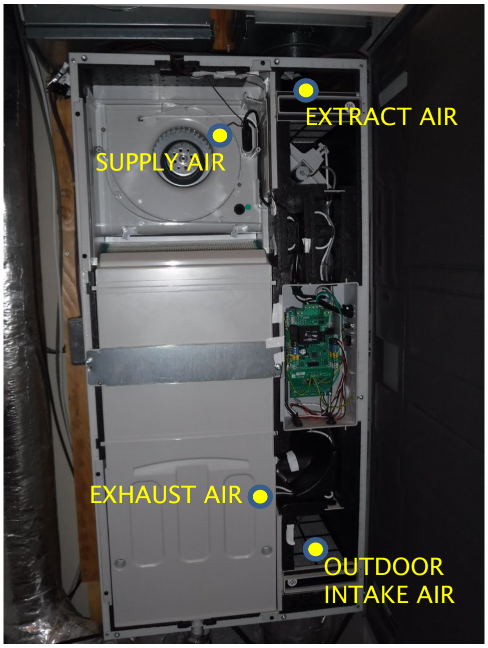


Figure 2.6 Thermocouples mounted within the HRV enclosure (left) and the datalogger mounted on the exterior of the HRV for data recording (right)

3 Closure

The sensors have all been physically installed at the Ruby Creek 6-plex. Additional troubleshooting is required to achieve data connection between the electricity monitoring equipment and the cloud server. This troubleshooting will be performed on the next site visit along with data download and confirmation of functionality of the remaining equipment.

We trust that this monitoring methodology and installation interim report meets your needs at this time. Please do not hesitate to contact the authors should you wish to discuss any aspect of this report.

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Appendix A

Monitoring Equipment Tech Sheets

HOBO® MX CO_2 Logger (MX1102) Manual

HOBO MX CO_2 Logger

MX1102

Included Items:

- Four AA 1.5 V alkaline batteries

Required Items:

- HOBOmobile app and device with iOS 8.3–9.0 or Android™ 4.4, 5.0, or 5.1 and Bluetooth 4.0

OR

- HOBOware 3.7.3 or later and USB cable

Accessories:

- Mounting kit with mounting brackets, screws, tie wraps, and Command™ strip

The HOBO MX CO_2 data logger records carbon dioxide, temperature, and relative humidity (RH) data in indoor environments using non-dispersive infrared (NDIR) self-calibrating CO_2 sensor technology and integrated temperature and RH sensors. This Bluetooth® Low Energy-enabled logger is designed for wireless communication with a mobile device and also supports a USB connection. Using the HOBOmobile® app on your phone or tablet or HOBOware software on your computer, you can easily configure the logger, read it out, and view plotted data. The logger can calculate minimum, maximum, average, and standard deviation statistics and can be configured to trip audible or visual alarms at thresholds you specify. In addition, it supports burst logging in which data is logged at a different interval when sensor readings are above or below certain limits. This logger also has a built-in LCD screen to display the current CO_2 level, temperature, RH, logging status, battery use, memory consumption, and more.

Specifications

Temperature Sensor	
Range	0° to 50°C (32° to 122°F)
Accuracy	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F), see Plot A
Resolution	0.024°C at 25°C (0.04°F at 77°F), see Plot A
Drift	<0.1°C (0.18°F) per year
RH Sensor*	
Range	1% to 70% RH when CO_2 sensor is enabled (non-condensing) 1% to 90% RH when CO_2 sensor is disabled (non-condensing)
Accuracy	±2% from 20% to 80% typical at 25°C (77°F), see Plot B
Hysteresis	±2% RH
Resolution	0.01% at 25°C (77°F)
Drift	<1% per year typical
CO_2 Sensor	
Range	0 to 5,000 ppm
Accuracy	±50 ppm ±5% of reading at 25°C (77°F), less than 70% RH and 1,013 mbar
Warm-up Time	15 seconds
Calibration	Auto or manual to 400 ppm
Non-linearity	<1% of FS
Pressure Dependence	0.13% of reading per mm Hg (corrected via user input for elevation/altitude)
Operating Pressure Range	950 to 1,050 mbar (use Altitude Compensation for outside of this range)
Compensated Pressure Range	-305 to 5,486 m (-1,000 to 18,000 ft)
Sensing Method	Non-dispersive infrared (NDIR) absorption
Response Time	
Temperature	12 minutes to 90% in airflow of 1 m/s (2.2 mph)
RH	1 minute to 90% in airflow of 1 m/s (2.2 mph)
CO_2	1 minute to 90% in airflow of 1 m/s (2.2 mph)
Logger	
Radio Power	1 mW (0 dBm)
Transmission Range	Approximately 30.5 m (100 ft) line-of-sight
Wireless Data Standard	Bluetooth Low Energy (Bluetooth Smart)
Logger Operating Range	0° to 50°C (32° to 122°F); 0 to 95% RH (non-condensing)

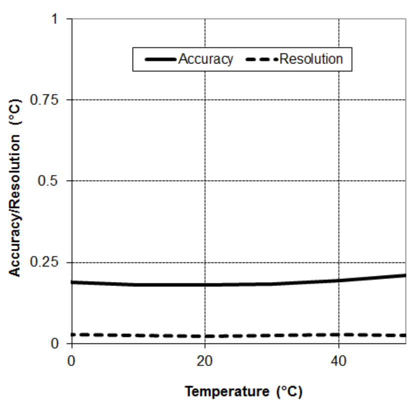
*Per RH sensor manufacturer data sheet
Note: The HOBO U-Shuttle (U-DT-1) is not compatible with this logger.

Specifications (continued)

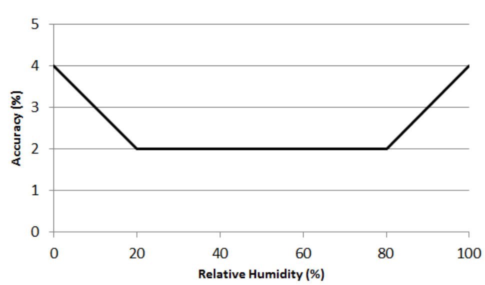
Logging Rate	1 second to 18 hours
Logging Modes	Fixed interval (normal, statistics) or burst
Memory Modes	Wrap when full or stop when full
Start Modes	Immediate, push button, date & time, or next interval
Stop Modes	When memory full, push button, date & time, or after a set logging period
Time Accuracy	±1 minute per month at 25°C (77°F), see Plot C
Power Source	4 AA 1.5 Volt batteries (user replaceable) or USB power source (5 V DC, 2 Watts)
Battery Life	6 months, typical with logging and sampling intervals of 5 minutes or slower; 6 months or less with logging and sampling intervals faster than 5 minutes while logging CO_2. Entering burst logging mode will impact battery life. With HOBOmobile use, battery life can be reduced by remaining connected, excessive readouts, checking of Full Status Details, audible alarms, and paging. Visual/audible alarms and other events can have a marginal impact on battery life.
Memory	128 KB (84,650 measurements, maximum)
Download Type	USB 2.0 interface or via Bluetooth Smart
Full Memory Download Time	20 seconds via USB; approximately 60 seconds via Bluetooth Smart, may take longer the further the device is from the logger
LCD	LCD is visible from 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range
Size	7.62 x 12.95 x 4.78 cm (3.0 x 5.1 x 1.88 inches
Weight	267.4 g (9.43 oz)
Environmental Rating	IP50
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).
FC	See last page

*Per RH sensor manufacturer data sheet

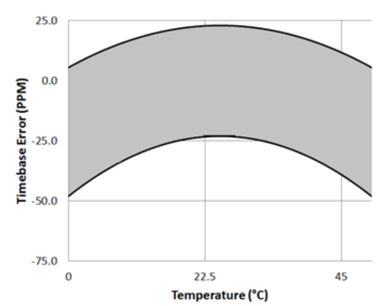
Note: The HOBO U-Shuttle (U-DT-1) is not compatible with this logger.



Plot A: Temperature Accuracy and Resolution

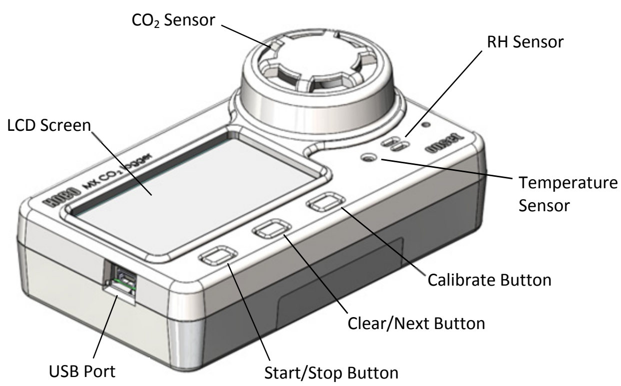


Plot B: Typical RH Accuracy*



Plot C: Time Accuracy

Logger Components and Operation



USB Port: Use this port to connect the logger to a computer for use with HOBOware or to power the logger for longer deployments or if faster logging intervals are required.

Start/Stop Button: Press this button for 3 seconds to start or stop logging data, or to resume logging on the next even logging interval. This requires configuring the logger with a push button start or stop (see *Choosing Logger Settings*). You can also press this button for 1 second to record an internal event (see *Recording Internal Logger Events*), to silence a beeping alarm (see *Setting up Alarms*), or to turn the LCD screen on if the option to turn off the LCD has been enabled (see *Choosing Logger Settings*).

Press both the Start/Stop button and the Clear/Next button simultaneously for 3 seconds to reset a logger password.

Clear/Next Button: Press this button for 1 second to switch between statistics, alarm readings, and the current sensor readings as applicable or to silence a beeping alarm. Press this button for 3 seconds to clear a visual alarm if the logger was configured to maintain the alarm until the button is pressed (see *Setting up Alarms*).

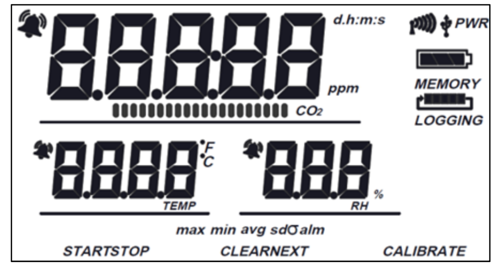
Calibrate Button: Press this button to start a five-minute manual calibration process of the CO_2 sensor. This requires configuring the logger with the manual calibration CO_2 sensor setting enabled in HOBOmobile or HOBOware and bringing the logger into a fresh air environment (see *Calibrating the Logger*).

Temperature Sensor: This sensor is located to the right of the LCD screen below the large CO_2 sensor.

RH Sensor: This sensor is located behind the vented panel in the logger case to the right of the temperature sensor.

CO_2 Sensor: This sensor is located below the large vented circular panel to the right of the LCD screen.

LCD Screen: This logger is equipped with an LCD screen that displays details about the current status. The example shows all symbols illuminated on the LCD screen followed by definitions of each symbol in the table.



LCD Symbol	Description
	The logger Is currently communicating with HOBOmobile via Bluetooth. The more bars there are, the stronger the Bluetooth signal.
	The logger is currently communicating with HOBOware via USB cable.
PWR	The logger is currently being powered by USB cable.
	The battery indicator shows the approximate battery power remaining.
	The logger has been configured to stop logging when memory fills. The memory bar indicates the approximate space remaining in the logger to record data. When first started, all five segments in the bar will be empty. In this example, the logger memory is almost full (only one segment in the memory bar is empty).
	The logger has been configured to never stop logging (wrapping). The logger will continue recording data indefinitely, with newest data overwriting the oldest data until the batteries die or the logger is reconfigured. When first launched, all five segments in the memory bar will be empty. In this example, the memory is full (all five segments are filled in) and new data is now overwriting the oldest data.
LOGGING	The logger is currently logging.
	A sensor reading is above or below the high or low alarm limit that you configured. Press and release the Clear/Next button until the "alm" symbol (described later in this table) is displayed on the screen. This symbol at left will clear depending on how alarms were configured to be cleared in the software. If the alarm was set to clear when the logger is reconfigured or relaunched, this symbol will remain on the LCD until the next time the logger is configured (see *Setting up Alarms*). Otherwise, it will clear when the sensor reading is back within the alarm limits or by pressing the Clear/Next button for 3 seconds.
START	The logger is waiting to be started. Press and hold the Start/Stop button for 3 seconds to start the logger.
STOP	The logger has been started with push button stop enabled; press and hold the Start/Stop button for 3 seconds to stop the logger.
CLEAR	An alarm displayed on the LCD is ready to be cleared. This will only appear if the logger was configured to maintain the alarm until the Clear/Next button is pressed (for 3 seconds). Note that an audible alarm can be silenced by pressing the Start/Stop button or Clear/Next button for 1 second.
NEXT	Press this button to view the latest statistics (if enabled) or the sensor reading associated with a tripped alarm.

LCD Symbol	Description
CALIBRATE	Press this button for 5 seconds to manually calibrate the CO_2 sensor (if enabled). "Calibrate" and "CO_2" will blink on the LCD during the 5-minute manual calibration process.
max min avg sdσ	These symbols show the maximum, minimum, average, and standard deviation values most recently calculated by the logger (if enabled). Press the Next/Clear button for 1 second to cycle through the available statistics and then back to the current sensor reading (or to the alarm value if applicable).
alm	This is the farthest out-of-range sample displayed during the logger deployment. Press the Clear/Next button to view this reading. Press the Clear/Next button again to cycle through any statistics (defined above) and ultimately back to the current sensor reading.
637 ppm CO_2	This is an example of a CO_2 reading in parts per million. **If the logger is powered by battery:** A new segment appears in the status bar every 15 seconds to indicate how long until the display will be updated. In this example, there are 18 segments. This means it has been 4 minutes and 30 seconds since the CO_2 reading was updated on the LCD. There are 30 seconds left (two segments) before the reading will be updated on the LCD. **If the logger is powered by USB cable:** The segmented status bar is not displayed and the current reading is updated every second.
80.82 °F TEMP	This is an example of a temperature reading. Temperature units are determined by the settings in the software. To switch between Celsius and Fahrenheit, change the units in the software and then reconfigure the logger. Temperature readings are updated on the LCD every 15 seconds if the logger is battery-powered or every second if it is USB-powered regardless of logging interval.
38.0 % RH	This is an example of an RH reading. RH readings are updated on the LCD every 15 seconds if the logger is battery-powered or every second if it is USB-powered regardless of logging interval.
05:38 d:h:m:s	The logger has been configured to start logging on a particular date/time. The display will count down in days, hours, minutes, and seconds until logging begins. In this example, 5 minutes and 38 seconds remain until logging will begin.
LoAd	The configure settings are being loaded onto the logger from the software.
Err	An error occurred while loading the configure settings onto the logger from the software. Try reconfiguring the logger.
StoP	The logger has been stopped with the software or because the memory is full.

Notes:

- You can disable the LCD screen in the software. When the LCD is turned off for logging, you can still temporarily view the LCD screen by pushing the Start/Stop or Clear/Next button. The LCD will then remain on for 10 minutes.
- When the logger is connected to the computer with the USB cable, the LCD screen refreshes every second regardless of logging interval.
- When the logger has stopped logging, the LCD screen will remain on with "STOP" displayed until the logger is offloaded (unless the LCD screen was turned off in the software). Once the logger has been offloaded, the LCD will turn off automatically after 2 hours.
- The LCD screen flashes "HELLO" when you page the logger from HOBOmobile (see *Getting Started with HOBOmobile*).
- The LCD screen flashes "CHIRP OFF" when an audible alarm is cleared.

Setting up the Logger

Important: The CO_2 sensor within this logger can experience measurement drift during storage and shipment. It is strongly recommended that a manual calibration be performed prior to deploying the logger. Start the logger as described in this section and perform a manual calibration. See *Calibrating the Logger* for more details; follow the manual calibration steps in that section. Improper manual calibration can cause incorrect sensor readings.

Install the batteries in the logger. Use a Phillips-head screwdriver to open the battery cover on the back of the logger and insert four AA batteries observing polarity (see *Battery Information*). Screw the cover back in place.

You can use both the HOBOmobile app and HOBOware software with this logger. The following sections provide an overview for using the logger with both programs. You can switch back and forth between the two programs (for example, configure the logger in HOBOware, and read it out in HOBOmobile). However, you can only connect to one program at a time. If you attempt to use HOBOmobile while the logger is connected to HOBOware, a message appears in HOBOmobile indicating a live USB session is underway. If you attempt to use the logger in HOBOware while it is connected to HOBOmobile, the device will not be found. If you want to connect to HOBOmobile after using the logger with HOBOware, you will need to disconnect the USB cable once you are done with HOBOware.

Getting Started with HOBOmobile

These steps provide an overview of setting up the logger with HOBOmobile. For complete details, see the *HOBOmobile User's Guide*.

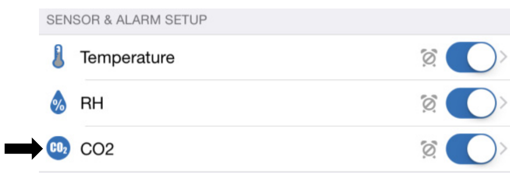
1. Go to the App Store[SM] or Google Play™ and download HOBOmobile to your phone or tablet.
2. Open HOBOmobile and enable Bluetooth in your device settings if prompted.
3. Tap HOBOs and then tap the logger in the Recently Seen/In Range list to connect to it. If the logger does not appear in the list, follow these tips for connecting:
   - Make sure the logger is within range of your mobile device. The range for successful wireless communication is approximately 30.5 m (100 ft) with full line-of-sight.
   - If your device can connect to the logger intermittently or loses its connection, move closer to the logger, within sight if possible.
   - If the logger appears in the Recently Seen/In Range list, but you cannot connect to it, close HOBOmobile and

power cycle the mobile device. This forces the previous Bluetooth connection to close.

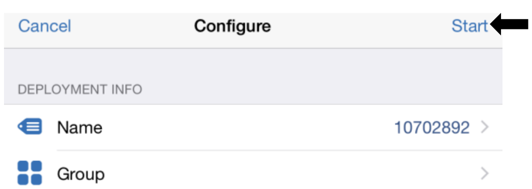
4. Once connected, tap Configure.

5. Choose your logger settings in the Configure screen. See *Choosing Logger Settings* for details on the available settings.

6. Tap the CO_2 sensor and select manual and/or auto calibration (both are selected by default). Select Altitute Compensation and enter the altitude above or below sea level. Tap Done. See *Calibrating the Logger* for more details on calibration settings.



7. Tap Start in the upper right corner of the Configure screen.



Logging will begin based on the settings you selected. Deploy the logger using the included mounting materials (see *Mounting the Logger*). After logging begins, you can read out the logger at any time (see *Reading Out the Logger* for details).

Note: The sensor readings displayed within HOBOmobile may not match what is displayed on the logger. The readings in the HOBOs screen are updated every minute and the readings in the Connected screen and Status Details screen are updated every 5 seconds.

When connected to the logger, the following actions are also available in addition to configure:

- **Readout.** Offload logger data. See *Reading Out the Logger*.
- **Full Status Details.** Check the battery level and view the configuration settings currently selected for the logger.
- **Start Logging.** This option appears if On Button Push is selected as a Start Logging setting as described in the *Choosing Logger Settings*.
- **Stop Logging.** Stop the logger from recording data (this overrides any Stop Logging settings described in *Choosing Logger Settings*).
- **Page.** Press and hold the Page icon and the logger will beep to help you locate a deployed logger (tap the Page icon if you only want the logger to beep once). "HELLO" also appears on the LCD when the logger is paged.
- **Clear Audible Alarm.** If audible alarms are enabled as described in *Setting up Alarms*, use this to clear a beeping alarm on the logger.
- **Logger Password.** Select this to create a password for the logger that will be required if another mobile device attempts to connect to it. To reset a password, simultaneously press both the Start/Stop button and the Clear/Next button for 3 seconds or tap Reset to Factory Default in the Set Logger Password screen.
- **Update Firmware.** When new logger firmware is available, this action appears in the list. Select it and follow the instructions on the screen. Note that if there is a communication failure during the firmware update process, the logger will revert to the previous firmware.

Important: Before updating the firmware on the logger, always read out the logger first. Check the remaining battery level by selecting Full Status Details and make sure it is no less than 30%. Make sure you have the time to complete the entire update process, which requires that the logger remains connected to the device during the upgrade.

- **Force Offload.** This may appear if an error was encountered when loading configure settings. Select this to offload all the data on the logger before reconfiguring the logger.

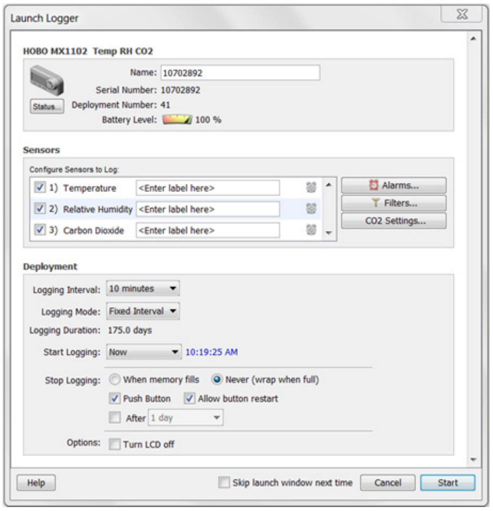
Getting Started with HOBOware

These steps provide an overview of setting up the logger with HOBOware. For complete details, see the HOBOware Help.

1. Install HOBOware on your computer.
2. Connect the logger to the computer with a USB cable.

Important: USB 2.0 specifications do not guarantee operation outside the range of 0°C (32°F) to 50°C (122°F).

3. From the device menu in HOBOware, select Launch.
4. Choose your logger settings. See *Choosing Logger Settings* for details on the available settings.
5. Click the CO_2 Settings button and select manual and/or auto calibration (both are selected by default). Select "Use Carbon Dioxide sensor altitude compensation" and enter the altitude above or below sea level. Click OK. See *Calibrating the Logger* for more details on calibration settings.



6. Click the Start button when finished. Note that the Start button text changes based on your Start Logging selection.

Logging will begin based on the settings you selected. Deploy the logger using the included mounting materials (see *Mounting the Logger*). After logging begins, you can read out the logger at any time (see *Reading Out the Logger* for details).

Choosing Logger Settings

The following table lists the available settings when configuring the logger with HOBOmobile or HOBOware.

Logger Setting	Action
Name	Enter a name for the logger up to 20 characters. This name will be used as the title on the graph and in the file name. A name also helps identify the logger in the HOBOs screen in HOBOmobile. If no name is entered, the logger serial number is used.
Group (HOBOmobile only)	Add the logger to the Favorites group or a custom group to help identify the logger and its resulting data files.
Logging Interval	Select how often the logger will record data when in normal mode.
Start Logging Options	Choose one of the following: • **Now.** Logging will begin 15 seconds after selecting Start. • **On Next Logging Interval.** Logging will begin at the next even interval as determined by the selected logging interval. • **On Button Push.** Logging will begin 15 seconds after you press the Start/Stop logging button on the logger for 3 seconds. • **On Date/Time.** Logging will begin at a date and time you specify.
Stop Logging Options	Choose a memory option: • **When Memory Fills.** The logger will continue recording data until the memory is full. • **Never (Wrap When Full).** The logger will continue recording data indefinitely, with newest data overwriting the oldest. This option is not available if the Logging Mode is set to Burst (see *Burst Logging*). Choose this stop logging option if desired: • **On Button Push.** Select this if you want to be able to stop logging by pushing the Start/Stop button on the logger. Note that if you also choose On Button Push for the Start Logging option, then you will not be able to stop logging until 30 seconds after logging begins. Choose a Stop Logging time-based option. • **Never.** Select this if you do not want the logger to stop at any predetermined time frame. • **On Date/Time.** Select this if you want the logger to stop logging on a specific date and time. Select the date and time and then tap Done. • **After.** Select this if you want to control how long the logger should continue logging once it starts. Choose the amount of time you want the logger to log data and then tap Done. For example, select 30 days if you want the logger to log data for 30 days after logging begins.
Sensors	Enable the sensor measurement types that will be logged: temperature, RH, and/or CO_2. Both temperature and RH are required to calculate dew point, which is an additional data series available for plotting after reading out the logger. You can configure alarms for sensors. See *Setting up Alarms*. If logging CO_2, you can select calibration settings. See *Calibrating the Logger*.
Alarms	Enable and configure sensor alarms. See *Setting up Alarms* for details.
Logging Mode and Statistics	Choose one of the following: • **Fixed Interval.** The logger records data for all enabled sensors and/or selected statistics. • **Burst Logging.** In burst mode, logging occurs at a different interval when a specified condition is met. See *Burst Logging* for more information. • **Statistics.** The logger records selected statistics (maximum, minimum, average, and standard deviation) for enabled sensors. See *Statistics Logging* for more information. In HOBOmobile, select Normal to log current readings and select the desired statistics. In HOBOware, select Fixed Interval if not logging statistics. Select Statistics if logging current readings and statistics or statistics only.
Show LCD	Enable or disable to control whether the LCD remains illuminated while the logger is logging. If you disable the LCD, the logger will not show the current reading, status, or other information while the logger is logging. You will, however, be able to temporarily turn the LCD screen on by pressing the Start/Stop button on the logger for 1 second.

Calibrating the Logger

The CO_2 sensor in the logger requires altitude compensation and regular calibration to ensure accurate readings are being taken in the location where it is deployed. Both auto and manual calibration are selected by default when first configuring the logger. Altitude compensation should be used if you are monitoring CO_2 at elevations above or below 305 meters (1,000 feet).

Some CO_2 measurement drift may occur during shipment and storage. A manual calibration immediately after logging begins is recommended for best accuracy.

Important: If performing a manual calibration, be sure to follow the instructions later in this section. Improper manual calibration can result in incorrect sensor readings.

The following CO_2 settings are available in both HOBOmobile and HOBOware:

- **Manual calibration.** Manual calibration is the best way to calibrate your logger. Use this option if you want to manually calibrate the logger to 400 ppm using the Calibrate button on the logger. This requires taking the logger outside in fresh air on a dry day or to an indoor location that is unoccupied and has no connection to a ventilation system for five minutes on a regular basis. Press the Calibrate button on the logger for 5 seconds to manually calibrate the CO_2 sensor. "Calibrate" and "CO_2" will blink on the LCD during the 5-minute manual calibration process in which 300 measurements are taken to get the average and create the offset from 400 ppm. (See the steps later in this section for more details on manual calibration.) This is recommended if the logger is deployed in a building that is always occupied, if you want the logger to be calibrated more frequently than every eight days (the normal auto calibration schedule), or if you want to calibrate the logger immediately after logging begins. **Note:** Once a manual calibration is performed, the 24-hour auto calibration is canceled and an auto calibration will be performed eight days from the time the manual calibration occurred.
- **Auto calibration.** Use this option if you want the logger to automatically calibrate within the first 24 hours after logging begins and then every eight days thereafter. The logger will be calibrated based on the average of the three CO_2 measurements that follow the lowest CO_2 value identified during the 24-hour or 8-day time period as applicable.

  Important: Accurate auto-calibration requires the building or location where the logger is deployed to be empty at least once during the eight-day period (for example, an empty office building during the weekend or overnight will typically have background CO_2 levels of 400 to 450 ppm).

  If the logger is deployed in an area where the CO_2 level does not go down to 400 ppm during the eight-day time period, then manual calibration should be performed regularly instead or inaccurate CO_2 readings will be reported. If you plan on using auto calibration but the A mabuilding will be occupied during the first day after logging begins, then you can use the manual calibration option as well. You can manually calibrate the logger immediately after logging begins and use auto calibration thereafter. **Note:** Every time the logger is started, auto calibration will occur after 24 hours and then again after eight days unless a manual calibration is performed first.
- **Altitude compensation.** The CO_2 sensor must compensate for locations above or below 305 meters (1,000 feet) to provide an accurate reading. You must enter the altitude above or below sea level in either meters or feet when configuring the logger if it will be deployed at a location above or below sea level. In normal use, the CO_2 measurement will vary by approximately 0.135% of the reading for each mbar change in barometric pressure (the sensor is calibrated at 1,013 mbar). Use altitude compensation when deploying the logger for the best CO_2 accuracy possible.

To access calibration and altitude compensation settings in HOBOmobile:

1. Connect to the logger.
2. Tap Configure.
3. Tap the CO_2 sensor.
4. Select auto calibration, manual calibration, or both.
5. Select "Altitude Compensation" and enter the altitude above or below sea level where the logger will be deployed in either meters or feet. You can also tap Use Location if you want the location services within the phone or tablet to calculate altitude.
6. Tap Done.
7. Tap Start to load settings to the logger.

To access calibration and altitude compensation settings in HOBOware:

1. Connect the logger to the computer with the USB cable.
2. From the Device menu in HOBOware, select Launch.
3. Click the CO_2 Settings button.
4. Select auto calibration, manual calibration, or both.
5. Select "Use Carbon Dioxide sensor altitude compensation" and enter the altitude above or below sea level where the logger will be deployed in either meters or feet.
6. Click OK.
7. Click Start in the Launch Logger window to load settings to the logger.

Note: If both auto calibration and manual calibration are selected, the logger will automatically calibrate within 24 hours after logging begins unless a manual calibration occurs during that time period. In addition, when both calibration settings are selected, the eight-day calibration cycle will be reset any time a manual calibration is performed.

To manually calibrate the CO_2 sensor:

Important: If you do not follow these manual calibration instructions as described, the sensor readings will be incorrect and you will need to manually calibrate the logger again.

1. Take the logger outside in fresh air on a dry day where the carbon dioxide level is 400 ppm. You can also use an indoor location for manual calibration if it is unoccupied and is not exposed to a ventilation system.
2. Press the Calibrate button on the logger for 5 seconds until it beeps. The logger will then calibrate for 5 minutes. The CO_2 and Calibrate symbols on the LCD will flash while the calibration is underway. A time- and date-stamped manual calibration event is logged in the data at the end of the 5-minute calibration sequence.
3. Once the Calibration process is complete, return the logger to its deployment location. Repeat this process at least once every eight days for best accuracy.

Setting up Alarms

You can set an alarm to trip on the logger when a sensor reading rises above or falls below a specified value. This can alert you to problems so you can take corrective action. To set up a sensor alarm:

1. In HOBOmobile: Connect to the logger and tap Configure.

   In HOBOware: From the device menu, select Launch. Click the Alarms button in the Launch Logger window.
2. Select the sensor that you want to set up with an alarm condition.
3. Enable the High Alarm if you want an alarm to trip when the sensor reading rises above the high alarm value. Drag the slider to the reading that will trip the alarm or type a specific reading.
4. Enable the Low Alarm if you want an alarm to trip when the sensor reading falls below the low alarm value. Drag the slider to the reading that will trip the alarm or type a specific reading.
5. Set the duration before an alarm is tripped.
6. Select either Cumulative Samples or Consecutive Samples. If you select Cumulative Samples, then the alarm will trip when the time the sensor is out of range over the course of the deployment is equal to the selected duration. If you select Consecutive Samples, then the alarm will trip when the time the sensor is continuously out of range is equal to the selected duration. For example, the high alarm for temperature is set to 85°F and the duration is set to 30 minutes. If Cumulative is selected, then an alarm will trip once a sensor reading has been at or above 85°F for a total of 30 minutes since the logger was configured; specifically, this could be 15 minutes above 85°F in the morning and then 15 minutes above 85°F again in the afternoon. If Consecutive is selected, then an alarm will trip only if all sensor readings are 85°F or above for a continuous 30-minute period.
7. Repeat steps 2–6 for any other sensors if desired (tap Done in HOBOmobile first).
8. Enable Audible Alarms if you want a beep to sound on the logger every 30 seconds when the sensor alarm trips (in HOBOmobile, enable this in the Configure screen; in HOBOware, select the Use Audible Alarm checkbox in the Configure Alarms window). The beeping will continue until the alarm is cleared from the software, a button on the logger is pressed, or 7 days have passed. Battery life will be slightly reduced when this setting is enabled. It is recommended that you only enable this feature if you have regular access to the logger so that you can easily turn off the beeping.
9. Select one of the following options for when to clear the alarm symbol that appears on the LCD (in HOBOmobile, enable this in the Configure screen; in HOBOware, select the checkbox in the Configure Alarms window).
   - **Logger reconfigured or relaunched.** The alarm icon will remain visible on the LCD until the next time the logger is reconfigured.
   - **Sensor is in limits.** The alarm icon will remain visible on the LCD until the sensor reading returns to the normal range between any configured high and low alarm limits.
   - **Alarm button is pressed.** The alarm icon will remain visible until you press the Clear/Next button on the logger.
10. In HOBOmobile: Tap Start in the Configure screen to load the alarm settings onto the logger when ready.

    In HOBOware: Click OK in the Configure Alarms window and then click Start in the Launch Logger window when ready.

Notes about alarms:

- The alarm icon will be illuminated on the logger LCD when the alarm trips. You can also press the Clear/Next button on the logger to view the farthest out-of-range value during the deployment.
- Alarm limits for temperature and RH sensors are checked every 15 seconds. The CO_2 alarm limits are checked every 15 seconds if the logger is powered by USB cable or every 5 minutes if it is powered by batteries. If you are configuring a CO_2 sensor alarm for a battery-powered logger, it is recommended that the duration you select is divisible by 5 and a minimum of 5 minutes.
- For USB-powered loggers, CO_2 alarms will not be tripped for the first 15 seconds after logging begins as the CO_2 sensor requires a 15-second warmup period.
- The actual values for the high and low alarm limits are set to the closest value supported by the logger. For example, the closest value to 85°F that the logger can record is 84.990°F and the closest value to 32°F is 32.043°F. In addition, alarms can trip or clear when the sensor reading is within the logger specifications of 0.02°C resolution. This means the value that triggers the alarm may differ slightly than the value entered. For example, if the High Alarm is set to 75.999°F, the alarm can trip when the sensor reading is 75.994°F (which is within the 0.02°C resolution).
- When you read out the logger, alarm events can be displayed on the plot or in the data file. See *Recording Internal Logger Events*.
- Once cleared, an audible alarm will start beeping again if the sensor values go out of the normal range. Even if an audible alarm is cleared, a visual alarm may remain on the logger LCD and in HOBOmobile (if applicable) depending on the settings selected for maintaining visual alarms or because the alarm condition may still be in effect. In addition, an audible alarm will continue beeping when the sensor values have returned to the normal range until it is cleared.
- Although an audible alarm and a visual alarm can occur at the same time when a sensor alarm is tripped, they are cleared in different ways. The audible alarm can be cleared from within the software, a button on the logger is pressed, or 7 days have passed. Meanwhile, a visual alarm is cleared as determined by the setting selected for maintaining an alarm in the software. This means you could clear a beeping audible alarm and the visual alarm will remain on the LCD and in HOBOmobile (if applicable) until the logger is reconfigured, the sensor is in limits, or the alarm button is pressed--whichever setting you selected.
- If the logger was configured to stop logging with a button push, any tripped alarms will be cleared automatically

when logging is stopped and no Alarm Cleared event will be logged in the data file.

Burst Logging

Burst logging is a logging mode that allows you to set up more frequent logging when a specified condition is met. For example, a logger is recording data at a 5-minute logging interval and burst logging is configured to log every 30 seconds when the temperature rises above 85°F (the high limit) or falls below 32°F (the low limit). This means the logger will record data every 5 minutes as long as the temperature remains between 85°F and 32°F. Once the temperature rises above 85°F, the logger will switch to the faster logging rate and record data every 30 seconds until the temperature falls back to 85°F. At that time, logging then resumes every 5 minutes at the normal logging interval. Similarly, if the temperature falls below 32°F, then the logger would switch to burst logging mode again and record data every 30 seconds. Once the temperature rises back to 32°F, the logger will then return to normal mode, logging every 5 minutes.

To set up burst logging:

1. In HOBOmobile: Connect to the logger and tap Configure.

   In HOBOware: From the Device menu, select Launch.
2. Set the Logging Mode to burst logging. (If already selected in HOBOware, click the Edit button.)
3. Select the sensor that will have burst limits.
4. Enable High Limit if you want burst logging to occur when the sensor reading rises above a specific reading. Drag the slider to the reading that will trigger burst logging or type a specific reading.
5. Enable Low Limit if you want burst logging to occur when the sensor reading falls below a specific reading. Drag the slider to the reading that will trigger burst logging or type a specific reading.
6. Repeat steps 3–5 for any other sensors if desired (tap Done in HOBOmobile first).
7. Set the burst logging interval. Select an interval faster than the logging interval. Keep in mind that the more frequent the burst logging rate, the greater the impact on battery life and the shorter the logging duration. In HOBOmobile, tap Done.
8. In HOBOmobile: Tap Done to return to the Configure screen. Tap Start to load the burst settings onto the logger when ready.

   In HOBOware: Click OK in the Burst Logging window and then click Start in the Launch Logger window when ready.

Notes about Burst Logging:

- Sensor alarms, statistics, and the Stop Logging option “Never (Wrapping)” are not available in burst logging mode.
- Once the logger is configured, the high and low burst limits are checked every 15 seconds. Therefore, if you set the logging interval to less than 15 seconds and the sensor reading falls outside the levels, the burst logging will not begin until the next 15-second cycle.
- If high and/or low limits have been configured for more than one sensor, then burst logging will begin when any high or low condition goes out of range. Burst logging will not end until all conditions on all sensors are back within normal range.
- The actual values for the burst logging limits are set to the closest value supported by the logger. For example, the closest value to 85°F that the logger can record is 84.990°F and the closest value to 32°F is 32.043°F.
- Burst logging mode can begin or end when the sensor reading is within the logger specifications of 0.02°C resolution. This means the value that triggers burst logging may differ slightly than the value entered. For example, if the high limit for a temperature alarm is set to 75.999°F, burst logging can start when the sensor reading is 75.994°F (which is within the 0.02°C resolution).
- Once the high or low condition clears, the logging interval time will be calculated using the last recorded data point in burst logging mode, not the last data point recorded in “normal mode.” For example, a logger has a 10-minute logging interval and logged a data point at 9:05. Then, the high limit was surpassed and burst logging began at 9:06. Burst logging then continued until 9:12 when the sensor reading fell back below the high limit. Now back in normal mode, the next logging interval will be 10 minutes from the last burst logging point, or 9:22 in this case. If burst logging had not occurred, the next data point would have been at 9:15.
- A New Interval event is created each time the logger enters or exits burst logging mode. See *Recording Internal Logger Events* for details on plotting and viewing the event. In addition, if the logger is stopped with a button push while in burst logging mode, then a New Interval event is automatically logged and the burst condition is cleared, even if the actual high or low condition has not cleared.

Statistics Logging

During fixed interval logging, the logger records data for enabled sensors and/or selected statistics at the logging interval selected. Statistics are calculated at a sampling rate you specify with the results for the sampling period recorded at each logging interval. The following statistics can be logged for each sensor:

- The maximum, or highest, sampled value,
- The minimum, or lowest, sampled value,
- An average of all sampled values, and
- The standard deviation from the average for all sampled values.

For example, a logger is configured with the temperature and CO_2 sensors enabled and the logging interval set to 5 minutes. The current reading and all four statistics are enabled. The statistics sampling interval is set to 30 seconds. Once logging begins, the logger will measure and record the actual temperature and CO_2 sensor values every 5 minutes. In addition, the logger will take a temperature and CO_2 sample every 30 seconds and temporarily store them in memory. The logger will then calculate the maximum, minimum, average, and standard deviation using the samples gathered over the previous 5-minute period and log the resulting values. When reading out the logger, this would result in the following 10 data series (not including any derived series): two sensor series (with temperature and CO_2 current readings logged every 5 minutes) plus eight maximum, minimum, average, and standard deviation series (four for temperature and four for CO_2 with values calculated and logged every 5 minutes based on the 30-second sampling rate).

To set up statistics:

1. In HOBOmobile: Connect to the logger and tap Configure.

   In HOBOware: From the Device menu, select Launch.
2. In HOBOmobile: Tap Logging Mode and then select Fixed Interval Logging.

   In HOBOware: Select Statistics for the logging mode.
3. Select Normal in HOBOmobile or Current Reading in HOBOware to record the current reading for each enabled sensor at the logging interval selected. Do not select this if you only want to log statistics.
4. Select the statistics you want the logger to record at each logging interval: Maximum, Minimum, Average, and Standard Deviation (average is automatically enabled when selecting Standard Deviation). Statistics will be logged for all enabled sensors. In addition, the more statistics you record, the shorter the logger duration and the more memory is required.
5. Set the statistics sampling interval. The rate selected must be less than, and a factor of, the logging interval. For example, if the logging interval is 1 minute and you select 5 seconds for the sampling rate, then the logger will take 12 sample readings between each logging interval (one sample every 5 seconds for a minute) and use the 12 samples to record the resulting statistics at each 1-minute logging interval. Note that the more frequent the sampling rate, the greater the impact on battery life. In HOBOmobile, tap Done.
6. In HOBOmobile: Tap Done to return to the Configure screen. Tap Start to load the burst settings onto the logger when ready.

   In HOBOware: Click OK in the Burst Logging window and then click Start in the Launch Logger window when ready.

Once logging begins, press the Clear/Next button on the logger to cycle through the current maximum, minimum, average, and standard deviation data on the LCD screen. Note that the logger will always display the current sensor readings in HOBOmobile (If applicable) even if they are not being logged. You can plot the statistics series once you read out the logger.

Reading Out the Logger

To offload data from the logger to HOBOmobile:

1. Connect to the logger and tap Readout.
2. Tap Data Files to view a mini-graph of the offloaded data.
3. Tap the mini-graph to view a larger version of the graph or to share the file. See the *HOBOmobile User's Guide* for details on viewing graphs and sharing data.

To offload date from the logger to HOBOware:

1. Connect the logger to the computer with the USB cable.
2. From the Device menu, select Readout.
3. Save the data file when prompted. See the HOBOware Help for details on plotting and exporting data in HOBOware.

Note: Data files read out from the logger in one program are not automatically available in the other. To open HOBOmobile files in HOBOware, share the file and select HOBO as the file type. Email the file and then open it in HOBOware. Files in HOBOware cannot be viewed in HOBOmobile. You can, however, export data in HOBOware to a text or Excel file that you can open on your mobile device. See the *HOBOmobile User's Guide* and HOBOware Help for details on sharing or exporting data.

Recording Internal Logger Events

The logger records the following internal events to track logger operation and status.

To plot events in HOBOmobile, tap a mini-graph and then tap ☰. Select the events you wish to plot and then tap ☰ again. You can also view events in shared or exported data files.

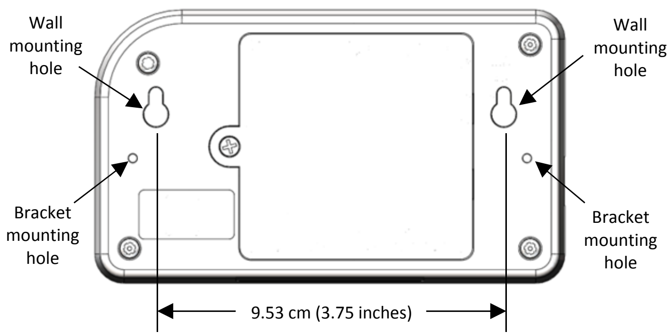
To plot events in HOBOware, select the events you wish to plot in the Plot Setup window when opening a data file. The following events may occur:

Internal Event Name	Definition
Host Connected	The logger was connected to the mobile device or computer as applicable.
Started	The Start/Stop button was pressed to begin or resume logging.
Stopped	The logger received a command to stop recording data (from the software or by pushing the Start/Stop button).
Button Up/Button Down	The Start/Stop button was pressed for 1 second.
Chan <#> Alarm Tripped	A sensor alarm has tripped; <#> is the sensor number, where 1 is CO_2, 2 is temperature, and 3 is RH.
Chan <#> Alarm Cleared	A sensor alarm has cleared; <#> is the sensor number, where 1 is CO_2, 2 is temperature, and 3 is RH. This event also contains the value that was furthest out of range for the sensor before the alarm cleared, which is only available in a shared or exported file.
New Interval	The logger has entered or exited burst logging mode.
Automatic Calibration	The CO_2 sensor has been calibrated automatically; the data file will show the offset calculated in PPM during the calibration.
Manual Calibration	The CO_2 sensor has been manually calibrated; the data file will show the offset calculated in PPM during the calibration.
Safe Shutdown	The battery level dropped below 2.5 V; the logger performs a safe shutdown.

Mounting the Logger

There are several ways to mount the logger using the materials included:

- Attach Command strips to the back of the logger to mount it to a wall or other flat surface.
- Screw in the brackets onto both sides of the logger using the two small holes labeled in the diagram below and then use tie wraps to mount it to a pole or pipe.
- Mount the logger to the wall or a flat surface using two screws and the included template. The dimensions are also shown in the following example.



Protecting the Logger

The logger is designed for indoor use and can be permanently damaged by corrosion if it gets wet. Protect it from condensation. If the message FAIL CLK appears on the LCD screen, there was a failure with the internal logger clock possibly due to condensation. Remove the battery immediately and dry the circuit board.

Note: Static electricity may cause the logger to stop logging. The logger has been tested to 8 KV, but avoid electrostatic discharge by grounding yourself to protect the logger. For more information, search for “static discharge” on onsetcomp.com.

Battery Information

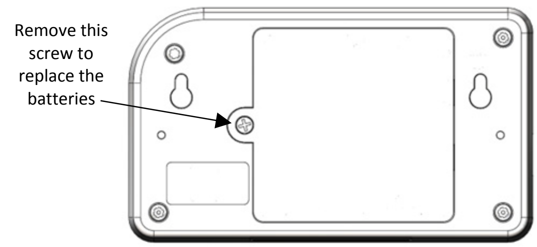
The logger requires four user-replaceable AA 1.5 V alkaline or optional lithium batteries for operation at the extreme ends of the logger operating range. Expected battery life varies based on the ambient temperature where the logger is deployed, the logging or sampling interval, frequency of offloading and connection to a mobile device, number of channels that are active, audible alarms duration, use of burst mode or statistics logging, and battery performance. New batteries typically last 6 months with logging and sampling intervals greater than 5 minutes.

Deployments in extremely cold or hot temperatures, or a logging or sampling interval faster than 5 minutes can impact battery life. Estimates are not guaranteed due to uncertainties in initial battery conditions and operating environment.

The logger can also be powered by the USB cable if faster logging intervals are desired or when the remaining battery voltage is too low for it to continue logging. Connect the logger to the computer, click the Readout button on the toolbar in HOBOware, and save the data as prompted. Replace the battery before launching the logger again.

To install or replace the batteries:

1. Use a Phillips-head screwdriver to unscrew the battery cover on the back of the logger.



2. Remove any old batteries.
3. Insert four new batteries observing polarity.
4. Screw the battery cover back in place.

⚠ **WARNING:** Do not cut open, incinerate, heat above 85°C (185°F), or recharge the lithium batteries. The batteries may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or batteries in fire. Do not expose the contents of the batteries to water. Dispose of the batteries according to local regulations for lithium batteries.

Note: CO_2 sensor readings may temporarily appear as 0 ppm in HOBOmobile when replacing the batteries until the logger begins logging again.

Federal Communication Commission Interference Statement

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one of the following measures:

- Reorient or relocate the receiving antenna
- Increase the separation between the equipment and receiver
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected
- Consult the dealer or an experienced radio/TV technician for help

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

FCC Caution: Any changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate this equipment.

Industry Canada Statements

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Avis de conformité pour l'Industrie Canada

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

To comply with FCC and Industry Canada RF radiation exposure limits for general population, the HOBO MX logger must be installed to provide a separation distance of at least 20 cm from all persons and must not be co-located or operating in conjunction with any other antenna or transmitter.

NCC Statement

經型式認證合格之低功率射頻電機，非經許可，公司、商號或使用者均不得擅自變更頻率、加大功率或變更原設計之特性及功能。

低功率射頻電機之使用不得影響飛航安全及干擾合法通信；經發現有干擾現象時，應立即停用，並改善至無干擾時方得繼續使用。前項合法通信，指依電信法規定作業之無線電通信。低功率射頻電機須忍受合法通信或工業、科學及醫療用電波輻射性電機設備之干擾。

Translation:

Article 12

Without permission granted by the NCC, any company, enterprise, or user is not allowed to change frequency, enhance transmitting power or alter original characteristic as well as performance to an approved low power radio-frequency device.

Article 14

The low power radio-frequency devices shall not influence aircraft security and interfere with legal communications. If found, the user shall cease operating immediately until no interference is achieved. The said legal communications means radio communications is operated in compliance with the Telecommunications Act. The low power radio-frequency devices must be susceptible with the interference from legal communications or ISM radio wave radiated devices.

Patent #: 8,860,569 19198-E

onset®
HOBO® Data Loggers

HOBO® Pro v2 Loggers

Weatherproof loggers for outdoor temperature and humidity measurements

HOBO Pro v2 data loggers are weatherproof loggers that provide high-accuracy temperature and relative humidity measurements in a wide range of outdoor environments.

Supported Measurements:
Temperature, Relative Humidity, Dew Point

Key Advantages:

- Weatherproof housing for use in outdoor or condensing environments
- High-accuracy measurements
- Replaceable RH sensor provides superior recovery from condensing conditions
- Small-diameter, external sensor versions for measurements in tight spaces
- Optic USB interface for fast and reliable download

Minimum System Requirements:

Software Base Station* Coupler[1]

*HOBO Base Station or HOBO Waterproof Shuttle required.
[1]Coupler included with HOBO Base Station or HOBO Waterproof Shuttle.

Part number	U23-001 (Internal Temp/RH)	U23-002 (External Temp/RH)	U23-003 (2x External Temp)	U23-004 (Temp/External Temp)
Memory	42,000 measurements			
Sampling rate	1 second to 18 hours, fixed rate or multiple logging intervals			
Battery life	3 years typical, user-replaceable,1/2 AA lithium			
	Internal Temperature			
Measurement range	-40° to 70°C (-40° to 158°F)			
Accuracy	± 0.21°C over 0° to 50°C (± 0.38°F over 32° to 122°F)			
Resolution (12-bit)	± 0.02°@ 25°C (± 0.04°@ 77°F)			
Stability (drift)	< 0.1°C (0.18°F) per year			
	Relative Humidity (U23-001 & U23-002 only)			
Measurement range	0 to 100% RH, -40° to 70°C (-40° to 158°F)			
Accuracy	± 2.5% from 10% to 90% RH (typical), to a maximum of ± 3.5% including hysteresis			
Resolution (12-bit)	0.03%			
	External Temperature			
Measurement Range	U23-002: -40° to 70°C (-40° to 158°F), U23-003 & U23-004: -40° to 100°C (-40° to 212°F) with sensor tip and cable immersion in fresh water up to 50°C (122°F) for one year			
Accuracy	± 0.21°C from 0° to 50°C (± 0.36°F from 32° to 122°F)			
Resolution	0.02°@ 25°C (0.04°@ 77°F)			
Dimensions	Housing measures 10.2 × 3.8 cm (4.0 × 1.5 in.)			
CE compliant	Yes			

HOBO® UX100 Loggers

Next-generation family of temperature and humidity data loggers

The HOBO UX100 Series is Onset's next-generation family of data loggers for tracking temperature and relative humidity in indoor environments.

HOBO UX100 Series offer a dramatic price/performance advantage over competitive products by delivering higher accuracy, larger measurement capacity, and more LCD display features to make environmental data collection faster and easier than ever. The loggers provide a variety of features to reduce deployment time, and offer new logging modes for recording and displaying more detailed data without extensive post-processing or memory use.

Supported Measurements:

Temperature, Relative Humidity, Dew Point

Key Advantages:

- Large memory capacity
- Flexible mounting options
- Visual high & low alarm thresholds
- New Burst and Statistics logging modes
- User-replaceable RH sensors
- Temp, humidity, and thermocouple models available

Minimum System Requirements:

Software

USB cable*

*USB cable included with software part # BHW-PRO-CD

For complete information and accessories, please visit: **www.onsetcomp.com**

Part number	**UX100-001** (Temp)	**UX100-003*** (Temp/RH)	**UX100-011*** (Temp/RH)	**UX100-023*** (Ext Temp/RH)
Memory	84,650 measurements			
Sampling Rate	1 second to 18 hours, user-selectable			
Battery Life	1 year typical with logging rate of 1 minute and sampling interval of 15 seconds or greater, user-replaceable, CR2032			
Dimensions	3.66 x 5.94 x 1.52 cm (1.44 x 2.34 x 0.6 in.)	3.66 x 8.48 x 1.52 cm (1.44 x 3.34 x 0.6 in.)		
Temperature				
Range	-20° to 70°C (-4° to 158°F)			
Accuracy	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F)			
Resolution	0.024°C at 25°C (0.04°F at 77°F)			
Response Time (airflow of 1 m/s (2.2mph))	8 minutes to 90%	4 minutes to 90%		6 minutes to 90%
Relative Humidity				
Range	n/a	15% to 95%	1% to 95%	
Accuracy	n/a	±3.5% from 25% to 85%	±2.5% from 10% to 90%	
Resolution	n/a	0.07% at 25°C (77°F)	0.05% at 25°C (77°F)	
Response Time (airflow of 1 m/s (2.2mph))	n/a	43 seconds to 90%	11 seconds to 90%	5 minutes to 90%
CE compliant	Yes			

Part number	**UX100-014M** (Thermocouple)		
Memory	208,076 measurements		
Sampling Rate	1 second to 18 hours, user-selectable		
Battery Life	1 year, typical with logging rate of 1 minute and sampling interval of 15 seconds or greater, user-replaceable, CR2032		
Dimensions	3.66 x 8.48 x 1.52 cm (1.44 x 3.34 x 0.6 in.)		
Operating Range	Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing)		
Thermocouple (probes sold separately)	**Range**	**Accuracy**	**Resolution**
Type J	-210° to 760°C (-346° to 1,400°F)	±0.6°C (±1.08°F) ± thermocouple probe accuracy	0.03°C (0.06°F)
Type K	-260° to 1,370°C (-436° to 2,498°F)	±0.7°C (±1.26°F) ± thermocouple probe accuracy	0.04°C (0.07°F)
Type T	-260° to 400°C (-436° to 752°F)	±0.6°C (±1.08°F) ± thermocouple probe accuracy	0.02°C (0.03°F)
Type E	-260° to 950°C (-436° to 1,742°F)	±0.6°C (±1.08°F) ± thermocouple probe accuracy	0.03°C at (0.05°F)
Type R	-50° to 1,550°C (-58° to 2,822°F)	±2.2°C (±3.96°F) ± thermocouple probe accuracy	0.08°C (0.15°F)
Type S	-50° to 1,720°C (-58° to 3,128°F)	±2.2°C (±3.96°F) ± thermocouple probe accuracy	0.08°C (0.15°F)
Type B	550° to 1,820°C (1,022° to 3,308°F)	±2.5°C (±4.5°F) ± thermocouple probe accuracy	0.1°C (0.18F)
Type N	-260° to 1,300°C (-436° to 2,372°F)	±1.0°C (±1.8°F) ± thermocouple probe accuracy	0.06°C (0.11°F)

*Note: Temp & RH NIST certification services available for this product. Please visit onsetcomp.com, or call us at 1-800-564-4377.

Contact Us

Sales (8am to 5pm ET, Monday through Friday)

- Email sales@onsetcomp.com
- Call 1-508-759-9500
- In U.S. toll free 1-800-564-4377
- Fax 1-508-759-9100

Technical Support (8am to 8pm ET, Monday through Friday)

- Contact Product Support onsetcomp.com/support/contact
- Call 1-508-759-9500
- In U.S. toll free 1-877-564-4377

Onset Computer Corporation
470 MacArthur Boulevard
Bourne, MA 02532

TED Pro Energy Monitoring and Control System

Single and Three-Phase Electrical Services Worldwide

OVERVIEW

The TED Pro Energy Monitoring and Control System is a state-of-the-art system for use in residential, commercial and government buildings and small industrial complexes. The system allows the user to monitor energy usage, thereby managing energy use through awareness of energy use and costs. Energy use and alerts can be presented on a custom display, computer, over the Internet, on mobile devices or by text or email messages. Colored LEDs alert the user to rate-tier changes, high demand, cost or other user-defined parameters.

The system is designed to work on any single or 3-phase electrical system anywhere in the world and is compatible with numerous energy or demand-rate billing systems, including fixed, time-of-use, step/tiered, seasonal, demand, or any combination of those mentioned. The system also accommodates taxes, fixed charges, and fuel surcharges to accurately reflect the monthly electric bill.

The basic system consists of an MTU and an ECC, descriptions of each follow below.

The Measuring Transmitting Unit (MTU) measures the energy consumption, demand, voltage, current, and power factor. We offer three types of MTU depending on the requirements of your electrical system:

- **MTU Pro** is designed for 3-phase systems in small-to-medium size commercial, institutional and industrial environments. It is suitable for any 3-phase system up to 5000A, 600V. It has two options for data-communication between MTU and ECC: PLC **or Ethernet**.
- **MTU Lite** is designed for 3-phase wye systems in small business applications where maximum amperage is 200A and maximum voltage is 277V. It is also ideally suited for residential occupancies with 3-phase services, common in some parts of Europe and South America. Data communication between MTU and ECC is via PLC.
- **MTU Home** is designed for single-phase residential and small commercial use with a maximum amperage of 400A and 240V. Data communication between MTU and ECC is via PLC.

The MTU is generally located at the main electrical panel and transmits the information collected over the building's existing electrical wiring, using a state-of-the-art Power Line Carrier communication (PLC) to an ECC which receives and interprets the data. Multiple MTUs can be used to give individual measurement of panels or loads. For systems with solar, wind or other alternative generation, TED will provide the user consumption, generation and net usage.

The Energy Control Center (ECC) is the communication hub for the system. It receives raw energy-use data from the MTU(s), interprets the data and calculates the current energy cost, cost today, month-to-date, etc. The ECC can be configured to communicate with mobile devices, computers, networks, thermostats, and load control devices via Ethernet, PLC, or WiFi. System can be configured to send text or e-mail alerts using the free TED Advisor feature.

Multiple ECCs in multiple locations can be monitored and compared via the Internet using TED's proprietary TED Commander software.

System and Utility Rate setup is quick, easy and intuitive using our setup wizards.

To this basic system can be added numerous options:

- Multiple MTUs can be added to separately measure various loads or generation.
- **TED Spyder** – The Spyder mounts in, or beside the electrical panel and is connected to the MTU. The Spyder records detailed usage of up to 8 single or multi-phase circuits. These individual readings are

stored in the ECC for display. Each TED system can support up to 4 MTUs and 4 Spyders, thus monitoring up to 36 separate, individual loads.

- Multiple systems can be used and the data aggregated at a central location.
- Communication Modules. ECC includes two USNAP ports, an Ethernet and USB port.
  - o WiFi modules – Allow wireless communication with a router or other WiFi-enabled device.
  - o ZigBee modules – Allows communication with Smart Meters, Smart Thermostats and other ZigBee-enabled devices.
- Smart Thermostats
  - o WiFi or ZigBee-based

MTU Pro

ECC (Energy Control Center)

MTU Lite / MTU Home

Spyder

How TED Works

TECHNICAL SPECIFICATIONS

Measuring Transmitting Units (MTUs)			
	Pro	**Pro Lite**	**Pro Home**
Types of Services			
Single-phase 2-Wire or 3-Wire	Yes	Yes	Yes
3-phase 4-Wire Wye	Yes	Yes	No
3-phase 3-Wire Delta	Yes	No	No
3-phase 4-Wire Hi-leg Delta	Yes	No	No
Frequency	50/60 Hz	50/60 Hz	50/60 Hz
Maximum Voltage - Phase/Phase	600 V	n/a	n/a
Maximum Voltage - Phase/Neutral	347 V	277 V	240 V
Minimum Voltage	180 V	95 V	95 V
Maximum Current - per phase	5000A *	200A	400A**
Maximum Wire Size	500 MCM (23mm OD)*	4/0 AWG (15mm OD)	4/0 AWG (15mm OD)
Voltage Measurement	Voltage Divider Circuit	Voltage Divider Circuit	Voltage Divider Circuit
Current Measurement	400A:3V Split-Core CTs	200A:1.5V Split-Core CTs	200A:1.5V Split-Core CTs
Operating Temperature	-40°C<T_A<+50°C	-40°C<T_A<+50°C	-40°C<T_A<+50°C
Energy Measurement and Calculations	ADE 7854ACPZ	Cirrus CS5461A	Cirrus CS5461A
Overall Accuracy	*** Better than ± 2%	*** Better than ± 2% 1-phase, ± 4% 3-phase	*** Better than ± 2%
Measure and Transmit Energy	± 1W	± 1W	± 1W
Measure and Transmit Demand	± 1VA	± 1VA	± 1VA
Measure and Transmit Voltage	± 0.1V	± 0.1V	± 0.1V
Measure and Transmit Phase Currents	± 0.01A	± 0.01A	± 0.01A
Measure and Transmit Power Factor	± 0.1%	± 0.1%	± 0.1%
Communication Interface	PLC / Ethernet	PLC	PLC
PLC System	Yitran IT700 System	Yitran IT700 System	Yitran IT700 System
Tested and Approved to:	FCC Part 15, UL916, CSA C22.2#205, IEC 61010-1		

* Will measure up to 5000A with three 400A parallel feeds using additional CT sets. For systems over 1200A please contact TED Customer Service.

** Will measure up to 400A with two parallel 200A using additional CT set or with optional 400A CT set.

*** From 1.5% to 100% of Full Scale

Data-Receiving Units	
	Energy Control Center (ECC)
Works w/ 3-phase & single phase MTU	Yes
Maximum Voltage Phase/Neutral	277 V
Minimum Voltage Phase/Neutral	95 V
Frequency	50/60 Hz
Cord Types Available	UL / EU / UK / AU
Operating Temperature	+5°C<T_A<+40°C
Communication Methods Available	PLC, Ethernet, Wifi, ZigBee
USB 2.0 Port	1

Data-Receiving Device	
	Energy Control Center (ECC)
USNAP 2.0 Port	2
Display Port	1
Compatible w/ ZigBee SE 2.0 smart meter	Yes
Accept Demand Reduction Request from Utility	Yes
Maximum number of MTUs on one system	4
Maximum number of Spyders on one system	4
Maximum number of Loads Measured	36
Power-on LED	Blue
Link Status LED	Green / Yellow
Transmit / Receive	Green / Red
Energy-Use Indicator Bar	Green / Yellow / Red

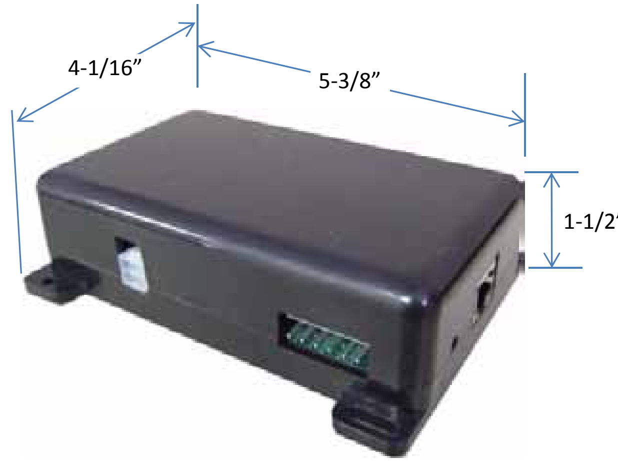
OPERATIONAL SPECIFICATIONS

	Energy Control Center (ECC)
Software	
TED Footprints™ - Historical, Graphical, Profiling, TED Advisor, TED Commander	Included*
System and Utility Rate Setup	Wizard Setup
Solar / Wind Generation	
Display System Load	Yes
Display System Generation	Yes
Display Net Usage	Yes
Data Display Options	
Computer - TED Footprints™ Software	Yes
Desktop LCD Display	Yes
Wireless LCD Display	Yes
Mobile Phones or Pads	Yes
TED Commander - Aggregates data from multiple systems	Yes
Third Party Applications	Yes
Data Storage / Display	
Second Data	Every second for 1 hour
Minute Data	Every minute for 48 hours
Hour Data	Every hour for 90 days
Day Data	Every day for 2 years
Month Data	Every month for 24 years

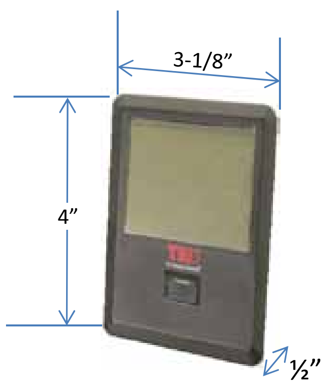
	Energy Control Center (ECC)
Rate Structures	
Rates downloadable from Internet	Yes
Rates can be pre-programmed	Yes
Number of TOU Rates	4
Number of Tier/Step Rates	4
Critical Peak Rates	Yes
Weekend Rates	Yes
Holiday Rates (US and Canada)	Yes
Seasonal Rates (4 seasons)	Yes
Tier/Step within Seasons	Yes
Tier/Step within TOU periods	Yes
TOU Rates within Seasons	Yes
Demand Charges or Demand Penalties	Yes
Update Time	1 Second
Optional Devices / Equipment	
Wireless Display with Backlight/Battery	Yes
Smart Thermostats	Wifi or ZigBee
USNAP Modules	Yes - 2 (Wifi or ZigBee)
USB Dongle	Wifi or ZigBee

TED Pro Series Dimensions

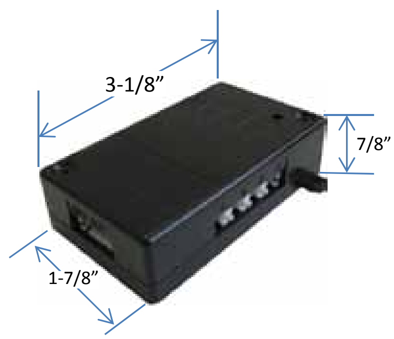
ECC – Energy Control Center



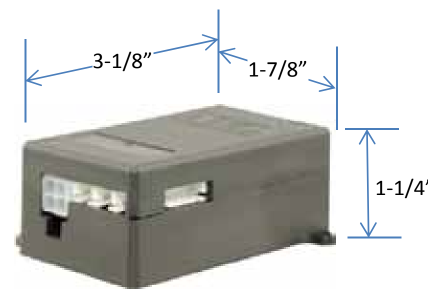
Pro MTU and MTU-RC



Wired and Wireless Display



Spyder

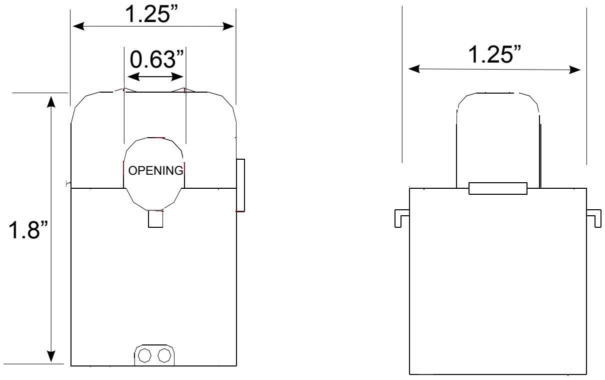


MTU Home and Lite

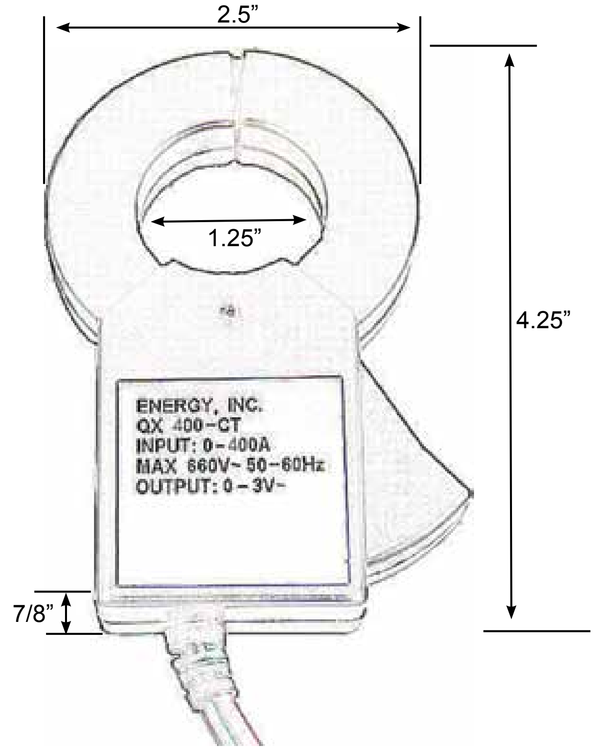
TED Pro Current Transformers

CT601B - 200A Split-core CT

Front View **Side View**

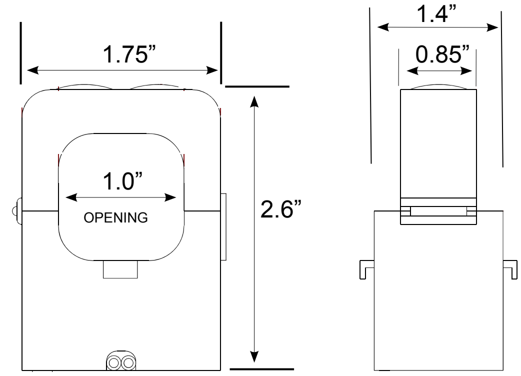


CT400XL - 400A Large Split-core CT



CT301 - 400A Standard Split-core CT

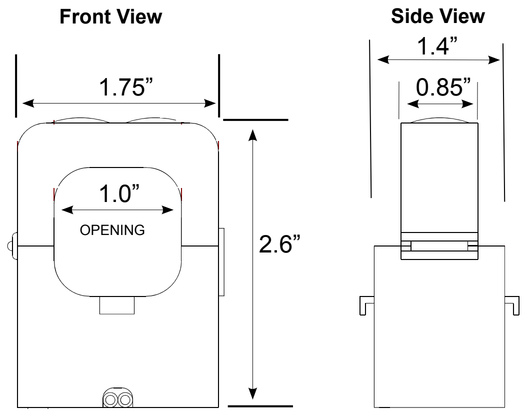
Front View **Side View**



All CT Wire: UL1015 22AWG PVC Wire (600V)

TED Pro 400A Current Transformers

CT301 - 400A Standard Split-core CT



CT Wire: UL1015 22AWG PVC Wire (600V)

CT400XL - 400A Large Split-core CT