M&V of Heavily Insulated Yukon Housing Construction | Project 10747.000

CMHC Northern Housing M and V Study, Vancouver, BC

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Contents

1 Executive Summary

The Yukon Housing Corporation has supported the design and construction of a number of residential buildings in the territory that exceed the energy performance of typical construction. The intent of these buildings is to reduce the energy consumption and demand required to operate the buildings through use of high efficiency enclosures and other improved design elements. A number of these buildings have been equipment with sensors to monitor performance including electricity use and enclosure performance. The Canada Mortgage and Housing Corporation (CMHC) supports the performance assessment of energy efficient housing designs including analysis of high efficiency buildings in the North.

This study consisted of the analysis of two buildings in Whitehorse, Yukon to determine the impact of energy efficient design on building performance. The analysis included comparison of energy consumption between different suites within the buildings as well as energy modeling to determine the energy savings due to constructing the buildings with high efficiency design.

The energy efficiency features in the study buildings compared to typical construction included greater levels of enclosure insulation, higher performance windows (triple or quad pane), and increased heat recovery efficiency in the ventilation system. Heating was also provided by electric baseboards instead of fossil fuel furnaces. This design allows for a reduction in heating demand while simultaneously moving away from fossil fuel use eliminating the need for fuel oil delivery to the building. Both Building 1 (18.4 MWh/yr/unit) and Building 2 (15.6 MWh/yr/unit) were found to use less energy than the typical Whitehorse dwelling (26.6 MWh/yr/unit), this is likely due in part to small floor areas from rowhouses and apartment buildings compared to the standard.

Occupant behaviour was found to have a significant impact on the energy use of units within both buildings. Comparison between units in Building 1 showed that the highest energy consuming unit used 63% more energy per dwelling unit (34% when normalized by floor area) than the lowest energy consuming unit. Occupants can affect energy use through operation choices such as thermostat temperature settings, behaviour patterns such as window opening or lighting use, and hot water consumption practices.

Energy modeling was used to compare the energy use from the actual buildings to a theoretical baseline with the same operating characteristics but with construction characteristics of typical new buildings in Whitehorse. The energy efficiency improvements included in Building 1 resulted in 46.1 kWh/m^2/yr (27.8%) of energy savings and 19.6 kg/m^2/yr (76.6%) of GHG savings per year compared to the baseline model. The energy efficiency improvements included in Building 2 resulted in 48.3 kWh/m^2/yr (25.6%) of energy savings and 24.6 kg/m^2/yr (77.8%) of GHG savings per year compared to the baseline model. These savings are predominantly a result of the reduction in space heating energy use and a switch from fossil fuel burning in an oil-fired furnace for the baseline to the use of electric baseboard heating in the actual building.

The analysis in this work shows that buildings being constructed by the Yukon Housing Corporation with better than code energy performance can save energy while providing a comfortable environment and durable enclosure.

2 Introduction

2.1 Background

Buildings located in northern regions of Canada are exposed to unique climate conditions that can often result in increased energy consumption compared to those located in other regions though the specific characteristics of their energy use are not well understood. Understanding energy consumption by buildings in Northern climates and determining potential methods to improve efficiency of the existing and new building stock is the focus of increasing research efforts. New technologies and construction practices aimed at energy reduction are most often piloted in less remote locations and therefore their efficacy in remote Northern regions is uncertain.

Yukon Territory has adopted Section 9.36 of the National Building Code of Canada (with amendments) to set energy efficiency standards for buildings. The City of Whitehorse has a more stringent energy efficiency requirement for buildings set out in the Green Building Standard[1]. The Yukon Housing Corporation has supported the design and construction of a number of energy efficient residential buildings in northern Canada with the aim of identifying technologies and design practices that lead to reduced energy consumption. These buildings often incorporate novel designs features and high performance building enclosures. As part of the construction process Yukon Housing Corporation has had several buildings equipped with sensors to monitor building operation and energy consumption. The Canada Mortgage and Housing Corporation (CMHC) supports performance assessment of energy efficient housing designs including those in Northern locations to identify the benefits of energy efficiency on the building stock.

Analysis of the building designs, energy consumption and monitoring data will provide an improved understanding of the typical energy use and identify any potential efficiency gains from the construction of these high performance buildings. The sub-metered data available from these buildings provides a unique opportunity to compare the differences in operating performance of residential units within the same building to identify the impact of occupant behaviour on energy use in high performance buildings in Northern Climates.

2.2 Purpose

The purpose of this study is to:

- → Characterize energy use patterns and end-use breakdown for buildings in Yukon Territory
- → Quantify energy use and greenhouse gas (GHG) reductions from high performance buildings in Yukon
- → Determine the impact of energy efficient designs on performance of buildings in cold climates
- → Identify the impact of occupant behaviour on the energy use within residential buildings

[1] Whitehorse Green Building Standard: http://whitehorse.ca/departments/planning-building-services/building-inspections/new-green-building-standards

→ Provide recommendations for potential changes to building operation to improve performance

2.3 Methodology

The performance of two buildings constructed in Whitehorse, Yukon by the Yukon Housing Corporation was analyzed using a combination of construction documents, utility billing data, sub-metered electrical data, environmental monitoring equipment, and energy modeling.

The energy data provided from utility meters and sub-metered data was processed and analyzed to provide a comparison of annual energy use, energy use breakdown (where possible), and the differences in energy consumption between different units within the building. Data frequency varied between sources and was aggregated as required for analysis. Indoor environmental conditions and temperature through the building enclosure was also analyzed for Building 2.

Energy models of each of the buildings were created using the construction documents and calibrated to the energy consumption using utility and sub-metering data. Although HOT2000 is typically used for modeling townhouse buildings eQuest was chosen as the energy modeling software for this project to provide consistency between the two buildings as one is a townhouse and one an apartment building. The actual building models were then modified to match the construction characteristics of typical new buildings in Whitehorse. These models with typical construction were used as a baseline to compare the energy use of the high performance buildings. The energy savings from constructing to the actual, higher performance buildings versus similar buildings with the typical construction practices was then estimated using the difference in the model results.

3 Building 1

Figure 3.1 Photo of Building 1, a 10,490ft^2 6-plex of rowhouses in Whitehorse, YT

3.1 Building Description

3.1.1 General Description

Building 1 is a two storey, 10,490 ft^2 (975m^2) row house 6-plex constructed in 2010 in Whitehorse, YT. The floor plans for the building are shown in Figure 3.2. The two end units have 1,975ft^2 (184m^2) of floor area and include 4 bedrooms. The four interior units have 1,635 ft^2 (152m^2) of floor area and include 3 bedrooms. The general unit design consists of three bedrooms on the upper floor and living space on the bottom floor. The larger four bedroom units have an additional bedroom on the main floor. There is a heated crawlspace below the building allowing for mechanical services.

The building was designed with the intent of reducing the heating energy consumption through increased building enclosure performance relative to the Yukon Housing Green Building Standard[2] (EnerGuide 80). The heating demand was to be met with all electric equipment to prevent the need for on site fuel oil use. The trend of fuel switching from fossil fuel heating to electric heating has become common in the Yukon recently[3]. The reason for this switch to electricity is to increase the ease of maintenance and prevent the risk of spills from the storage of fuel oil on site. Switching to electricity without improving the building performance can result in increased utility bills and local electrical grid demand increases. Additional insulation in the building design can be used to mitigate these impacts through load reduction.

[2] Requirements for the Whitehorse Green Building Standard can be found at http://whitehorse.ca/departments/planning-building-services/building-inspections/new-green-building-standards
[3] Shifting Demands: Yukon Home Heating Trends 2015. Yukon Government. http://www.energy.gov.yk.ca/pdf/Shifting-Demand-in-Yukon-Heating.pdf

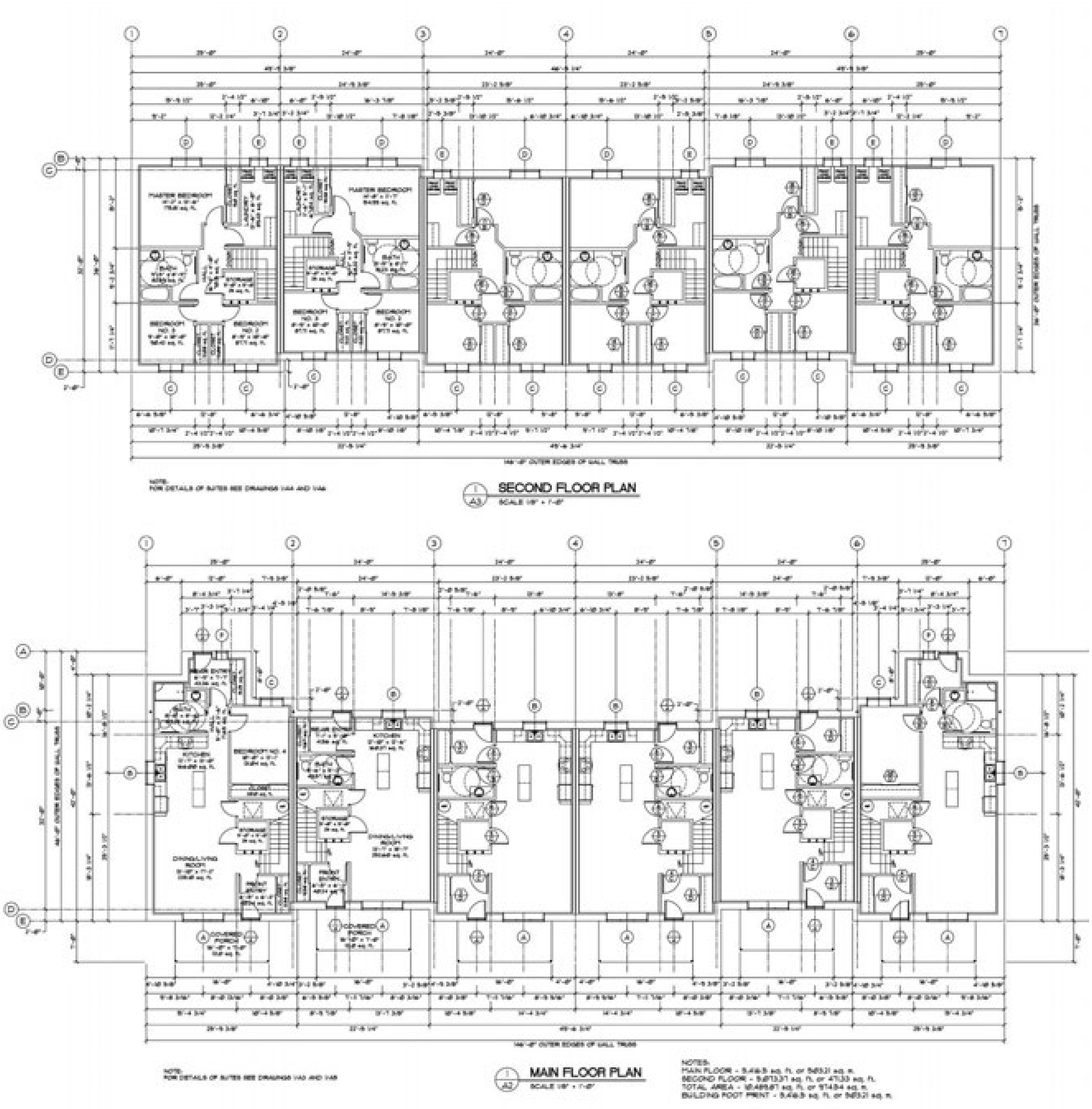


Figure 3.2 Building 1 floor plans

3.1.2 Building Enclosure

The building enclosure was designed to provide increased thermal insulation compared to code minimum or standard practice. This increased enclosure performance allows for smaller heating equipment sizing and reduced heating costs. Notable aspects of the enclosure assembly are provided below.

The roof construction consists of asphalt shingles over an attic with 24” high heeled engineered trusses at 24” o.c. The insulation layer consists of 22” of loose filled cellulose between the trusses. This assembly provides an effective thermal resistance of R-75. Details of the roof construction are shown in Figure 3.3,

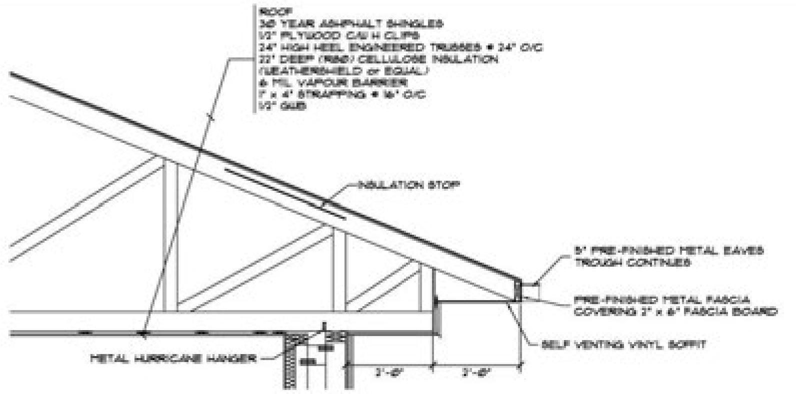


Figure 3.3 Building 1 roof details (N.T.S.)

The wall assembly is shown in Figure 3.4 for both the above grade wall (left) and below grade wall (right) of the heated crawlspace. The above grade wall construction includes a 14” thick wall truss at 16” o.c. filled with loose fill cellulose and 2x3 strapping over R8 batt insulation for an overall effective R-value of approximately R-50. The below grade wall has a similar construction but consists of a 16” truss with loose fill cellulose and no batt insulation.

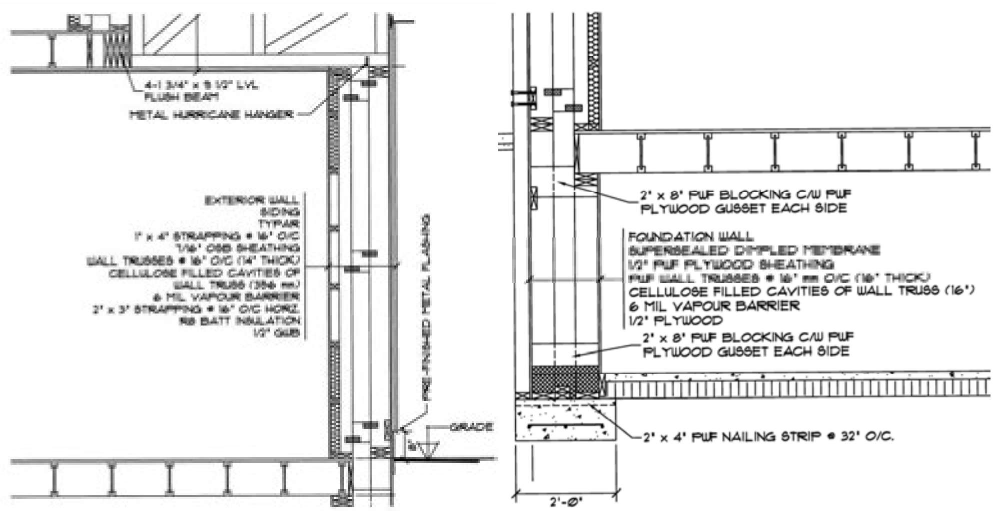


Figure 3.4 Building 1 above grade wall (left) and below grade wall (right) details (N.T.S.)

The windows installed throughout the building are quadruple pane vinyl windows, argon-filled with insulating spacers and two layers of soft coat low-e coatings. The window performance is approximately USI-1.1 (U-0.2) for fixed windows.

3.1.3 Mechanical

The building mechanical system consists of all-electric equipment. Each unit in the building has a dedicated HRV providing the required ventilation with >70% sensible heat recovery effectiveness. The HRV is located within the mechanical closet in each unit with ductwork distributed through the heated crawlspace and in the joist space of the first floor. Ventilation air is supplied to each of the rooms in the building to provide adequate distribution and is exhausted from the washrooms, the kitchen, and the mechanical closet.

The space heating is provided by electric baseboards throughout the units with individual unit temperature control by wall thermostats. Domestic hot water is provided to each unit individually by a Rheem Marathon 40-gal tank-type electric water heater with 0.93 to 0.95 EF.

3.2 Data Analysis

3.2.1 Data Provided

Electricity consumption was monitored in each unit using pulse counters (Itron Canada). Sub-metering was performed to provide separate readings of energy use for unit total consumption, unit heating energy, and unit hot water energy for each of the six units. The energy consumption (Wh) was recorded at 1 minute intervals between December 1st, 2011 through September 30th, 2016. The data was aggregated to provide daily, monthly or annual consumption as required for analysis in this work. An example of the total monthly data for the whole building is shown in Figure 3.5.

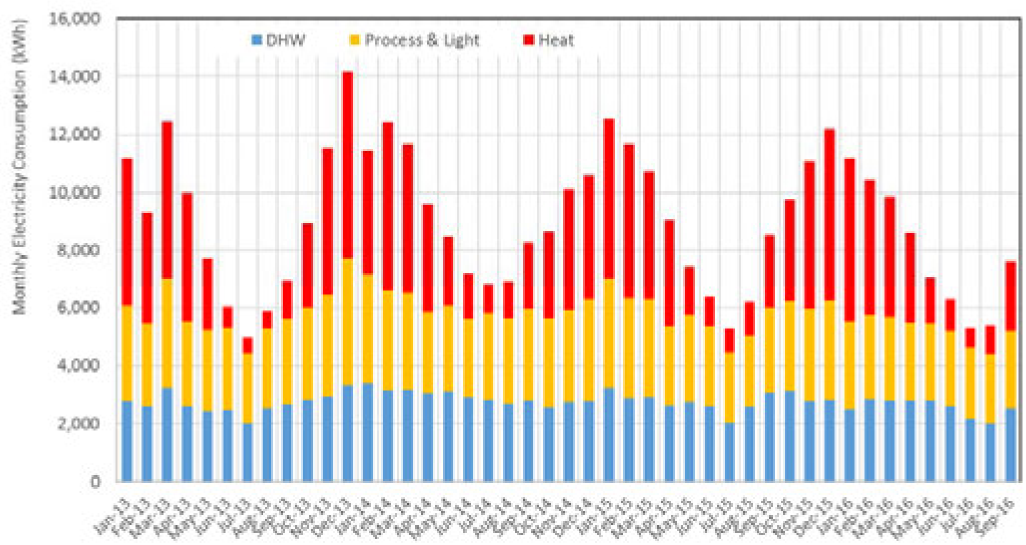


Figure 3.5 Monthly energy consumption breakdown for all units

3.2.2 Results

Total Building Consumption

The average annual energy consumption of new homes built in Whitehorse from 2010 to 2016 was 26.6 MWh of which 11.3 MWh was used for heating[4]. This figure includes both single family and multi-family dwellings in approximately equal proportions. The trend in

[4] Shifting Demands: Yukon Home Heating Trends 2015. Yukon Government. http://www.energy.gov.yk.ca/pdf/Shifting-Demand-in-Yukon-Heating.pdf

Whitehorse is to construct homes to higher than code requirements and this data represents homes that have higher than normal values of insulation. For comparison, the average energy use of existing double/row houses in Alberta is approximately 30.4 MWh/unit/yr[5]. The average annual total energy consumption of the 6-plex between 2012 and 2015 was 110.3 MWh, 113 kWh/m^2, or 18.4 MWh per unit (a 39% reduction per dwelling unit compared to the typical Alberta rowhouse). This is in close alignment with the values predicted from the EnerGuide Energy Efficiency Evaluation Reports for the units which indicated a range of annual energy use from 16.9 MWh/yr to 18.7 MWh/yr with an average of 17.5 MWh/yr.

The energy end use breakdown for the 6-plex is shown in Figure 3.6 for the years 2012 to 2015. There is a slight variation in energy end use between years but the typical breakdown is 30% for hot water heating, 36% for space heating, and 34% for lights and other process loads. The average end use breakdown of each suite in the building is shown in Figure 3.7. There is significant variability in the end use profiles between suites which can be attributed to construction (end units versus middle units) and occupant preferences (temperature setpoints, water use, schedules, etc.).

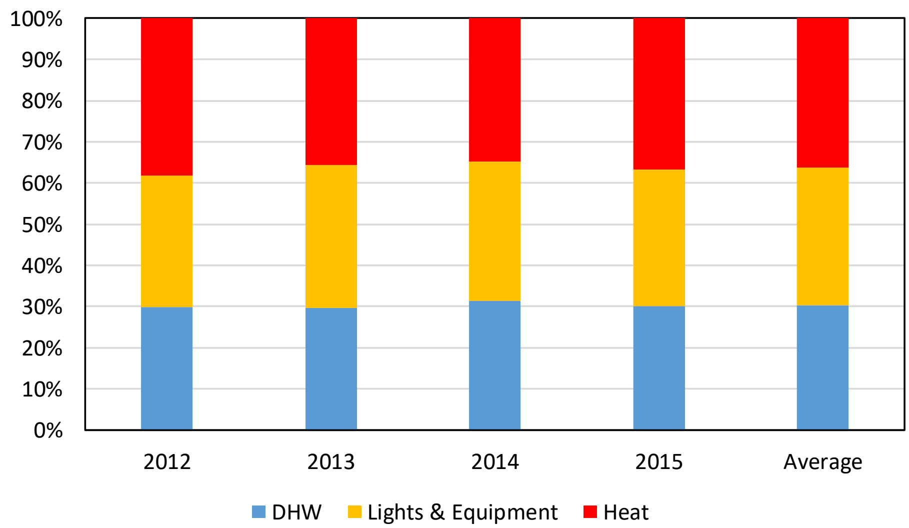


Figure 3.6 Building 1 - Whole Building End Use Breakdown

[5] NRCan. Survey of Household Energy Use (SHEU) 2011 Table 3.2. https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/sheu/2011/tables.cfm

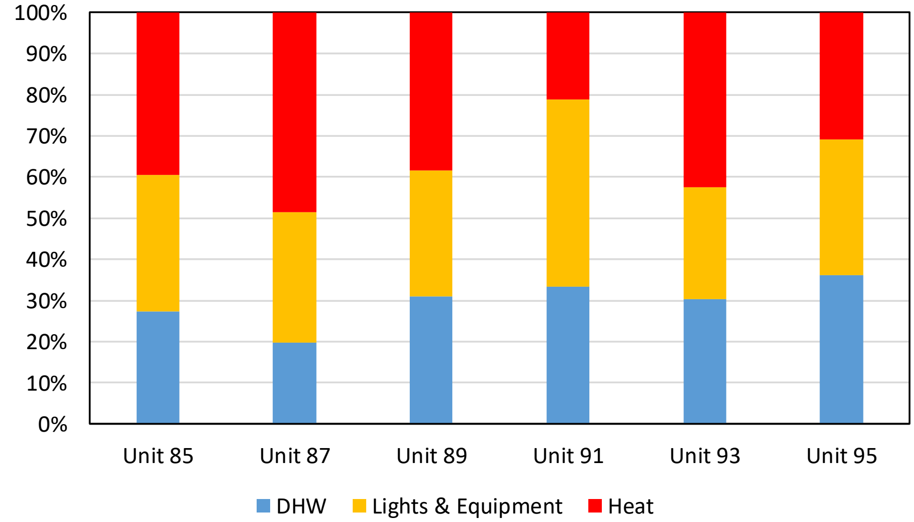
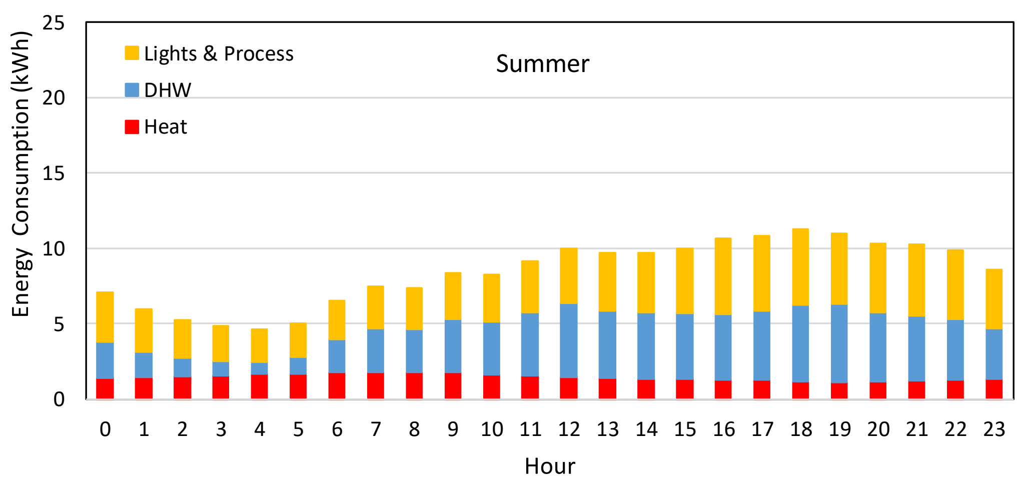


Figure 3.7 Average End Use Breakdown for Units in Building 1

The hourly average energy consumption for the building is shown in Figure 3.8 for summer months (top) and winter months (bottom). The building peak energy use occurs at approximately 6:00pm in the summer and 5:00pm in the winter. The different energy end uses show a significant variation throughout the typical day. The heating energy demand is highest during the early morning and reduces during the day. The space heating use is significantly higher during the summer. The domestic water heating consumption is lowest overnight and has three peaks throughout the day at 7:00am, 12:00pm, and 5:00pm to 7:00pm. Energy consumption from Lights & Process loads also shows a peak at 7:00am and increases throughout the day until a peak use at 6:00pm.



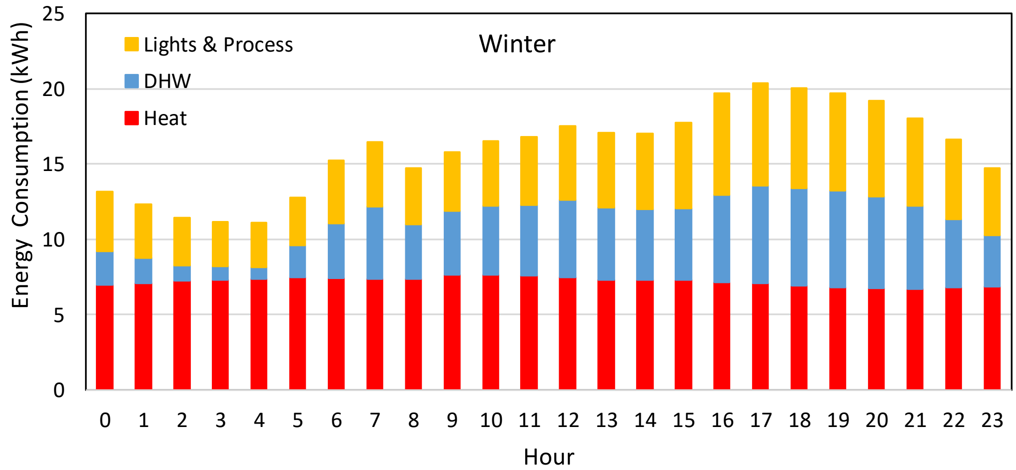


Figure 3.8 Average hourly consumption by end use for summer (top) and winter (bottom)

Inter-unit Comparison

Occupant behaviour can be a significant driver of building energy use and can impact the potential benefits of high performance buildings. Occupants can affect energy use through operation choices such as thermostat temperature settings and behaviour patterns such as window opening or lighting use. Other differences between units can also affect the energy use such as floor area, enclosure area, and location in the building. The sub-metering on each unit of the 6-plex allows for comparison of the energy use of different units in buildings with similar design.

Figure 3.9 compares the energy use of each of the 6 units between 2012 and 2015 (the years with complete datasets). Figure 3.10 provides a similar comparison but with the consumption normalized by unit floor area. The comparison shows a significant variation in energy use between units and a moderate variation between years. The end units (85 and 95) have the highest annual energy use in the building and use approximately 23.5 MWh/unit or 127 kWh/m^2 annually. The average use for the highest energy consuming unit (Unit 85) is 63% greater per dwelling unit, and 34% greater when normalized by floor area, than the lowest energy consuming unit (Unit 87). A portion of this variation would be attributed to the additional enclosure area of the end units compared to the middle units of the rowhouses. In addition, units 85 and 95 have an additional bedroom compared to the other units, and typically have higher occupancy than the other units. This will be explored further with respect to domestic water energy consumption. The energy use of the middle units in the building also varies substantially between 14.3 and 18.1 MWh/unit (94 to 119 kWh/m^2).

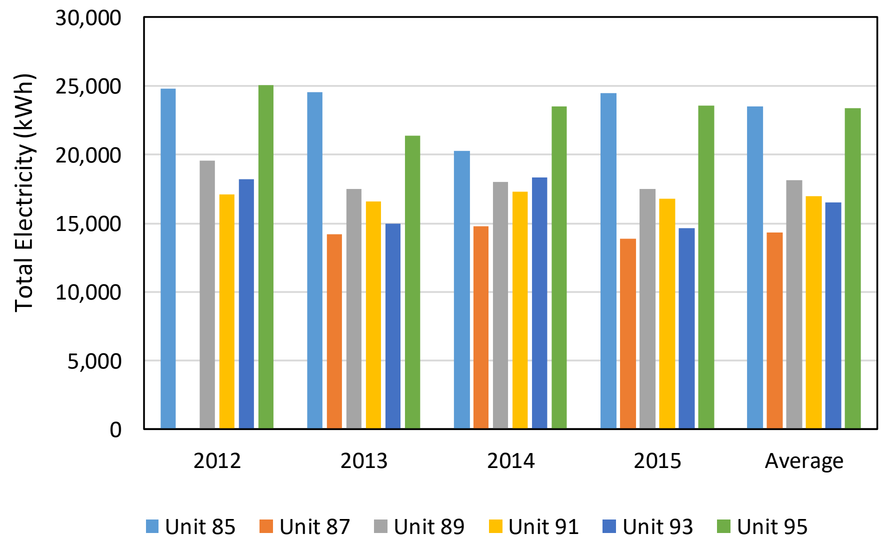


Figure 3.9 Comparison of total energy use per dwelling unit between units. Note that Units 85 and 95 are end units in the rowhouse complex and have both more floor area and more enclosure area.

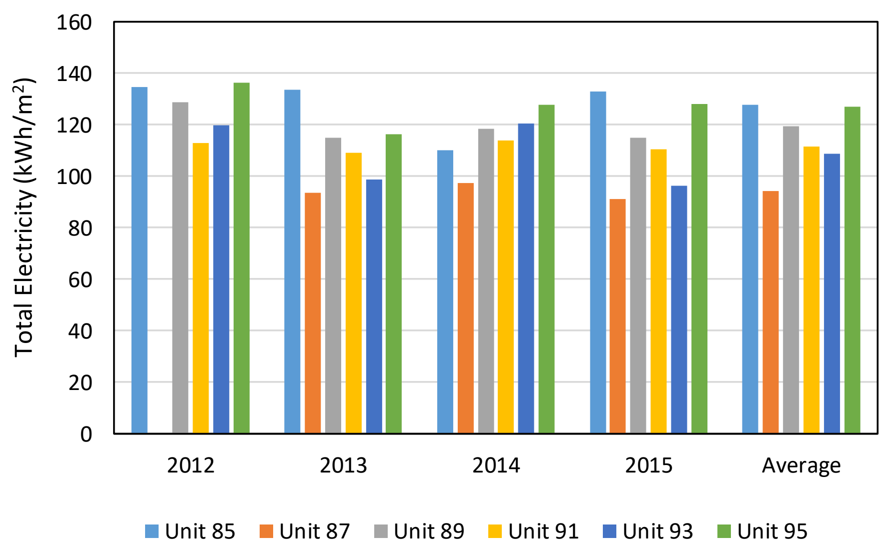


Figure 3.10 Comparison of area normalized total energy use between units. Note that Units 85 and 95 are end units in the rowhouse complex and have both more floor area and more enclosure area.

Figure 3.11 shows the annual energy use for hot water heating in each of the units between 2012 and 2015. Hot water energy use is expected to be impacted by the number of occupants in the space. Figure 3.12 and Figure 3.13 show the same data normalized by unit area and number of occupants, respectively. he energy used for hot water heating shows significant variability between each of the units. The highest energy consuming unit (Unit 95) uses 162% more energy than the lowest energy consuming unit (Unit 87). The end units (85 and 95) use more energy overall for domestic water heating than the middle units of the building due in part to higher occupancy. Hot water energy consumption for row homes has been estimated to be 2.3 to 5.0 MWh per year in B.C.

depending on fuel source[6]. The hot water use in Building 1 is higher than these values but may be a result of higher occupant density within the building.

When normalized by the average number of occupants in the units (Figure 3.13) the ranking of energy use changes but still shows significant variation. The unit that consumes the most energy per person for hot water heating (Unit 91) consumes 1,883 kWh/yr/person. This is 129% more energy than the lowest energy consuming unit (Unit 87) at 790 kWh/yr/person. This indicates that both the number of occupants and their individual preferences can have a large impact on hot water use.

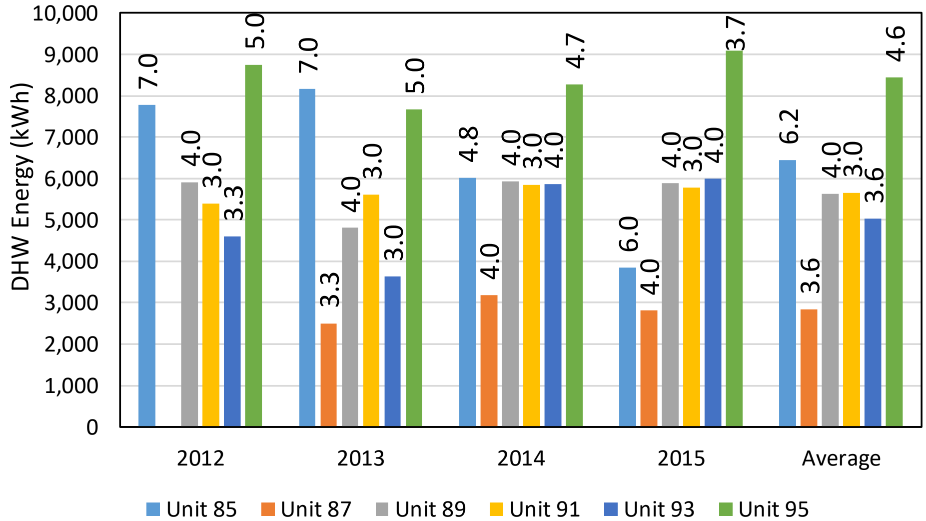


Figure 3.11 Comparison of DHW energy use per dwelling unit between units. Note that Units 85 and 95 are end units in the rowhouse complex and have both more floor area and more enclosure area. The numbers above each bar indicates the average number of occupants in the unit through the year. Fractional numbers result from monthly fluctuations in occupancy.

[6] Review of Standard Operating Conditions for HOT2000. Innes Hood Consulting. The standard operating conditions are for buildings in British Columbia.

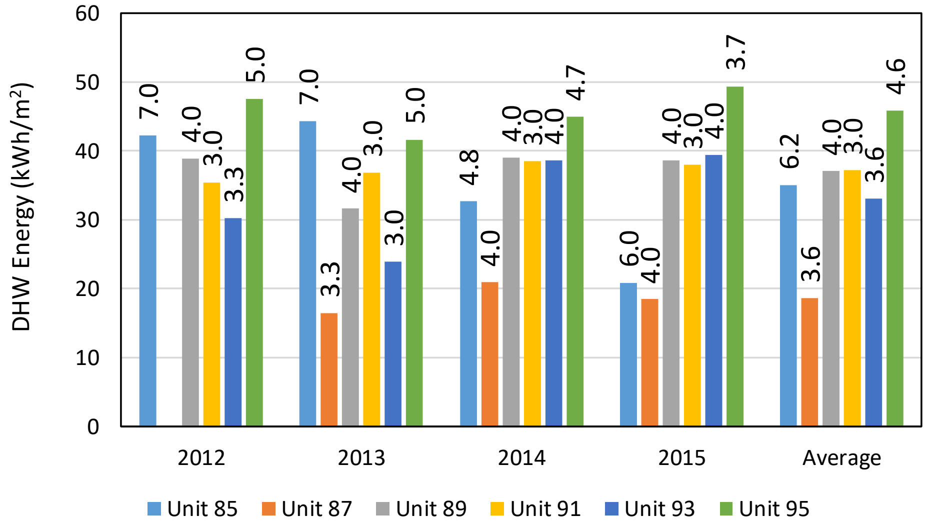


Figure 3.12 Comparison of area normalized DHW energy use between units. The numbers above each bar indicates the average number of occupants in the unit through the year. Fractional numbers result from monthly fluctuations in occupancy.

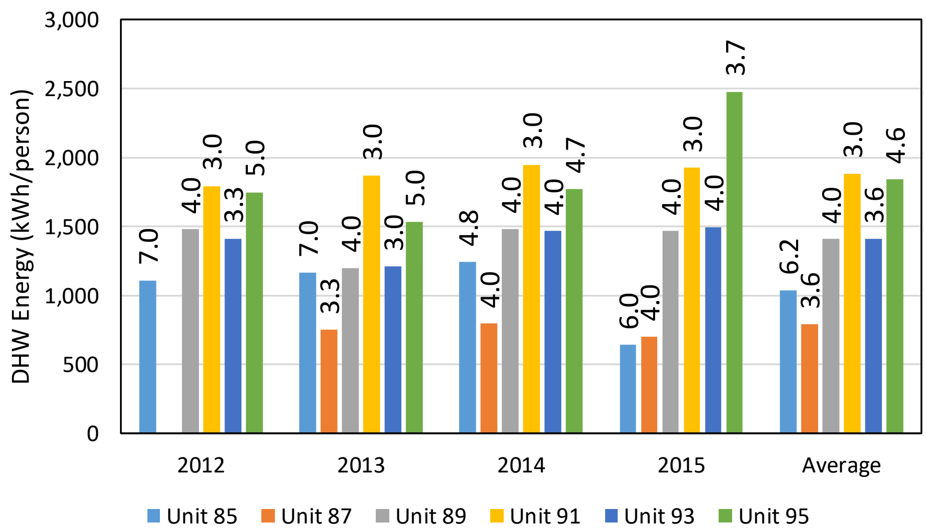


Figure 3.13 Comparison of DHW energy use per person between units. The numbers above each bar indicates the average number of occupants in the unit through the year. Fractional numbers result from monthly fluctuations in occupancy.

The annual energy consumption for space heating in each unit is shown in Figure 3.14 for 2012 through 2015. The highest heating energy consuming unit (Unit 85) uses 165% more energy than the lowest consuming unit (Unit 91). When normalized by building area (Figure 3.15) the consumption of Unit 85 is less of an outlier but still 139% higher than unit 91. A potential cause for the lower heating energy consumption in Unit 91 could be a lower temperature setpoint within the space or a temporary absence of the occupants at some time during the year.

The heating energy demand in Unit 85 shows a significant variation between different years. The heating energy consumption almost doubled between 2014 and 2015. A similar, though less pronounced increase is seen in the total unit energy consumption in

Figure 3.9. This may be a result of a change in occupants that occurred at the end of 2014 as determined from Yukon Housing Corporation monthly occupancy estimates. The metered data indicates that the new occupants use more heating energy which may be a result of differences in preference for space temperature setpoint. The trend of higher space heating load continues into the winter months of 2016 (data not shown due to missing data points) indicating that it is a long-term change in the space use.

The daily heating energy consumption is plotted against average outdoor air temperature in Figure 3.16. The outdoor air temperature used was taken from an outdoor air temperature sensor mounted on Building 2. The daily energy consumption is highest for Unit 85 as would be expected from the annual heating energy consumption figures. Little heating is used when average outdoor temperatures are above 25˚C.

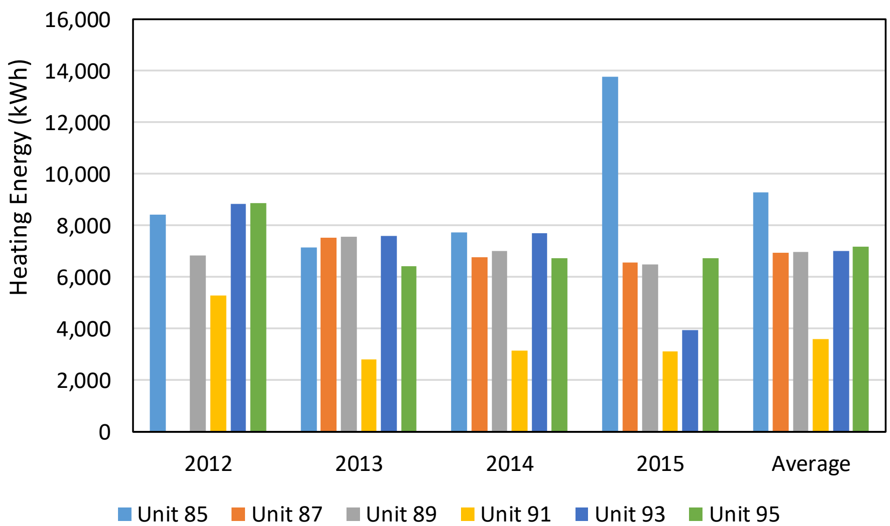


Figure 3.14 Comparison of heating energy use per dwelling unit between units. Note that Units 85 and 95 are end units in the rowhouse complex and have both more floor area and more enclosure area.

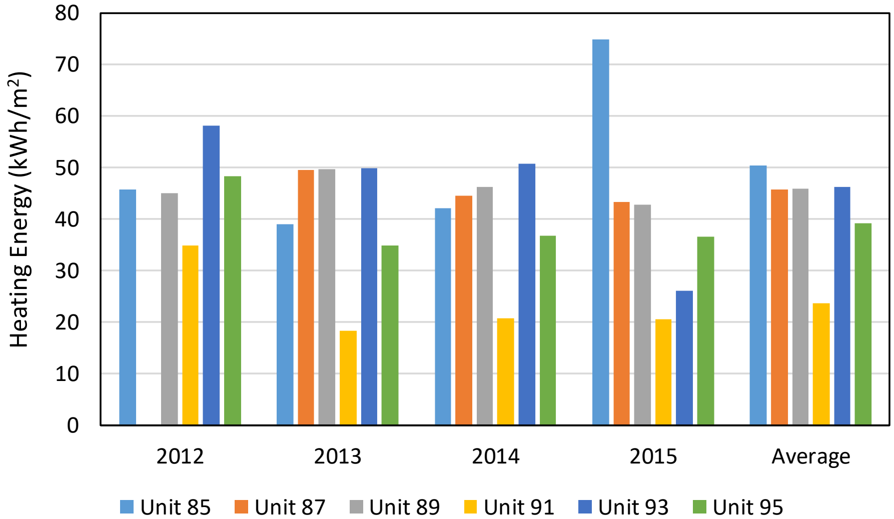


Figure 3.15 Comparison of area normalized heating energy use between units. Note that Units 85 and 95 are end units in the rowhouse complex and have both more floor area and more enclosure area.

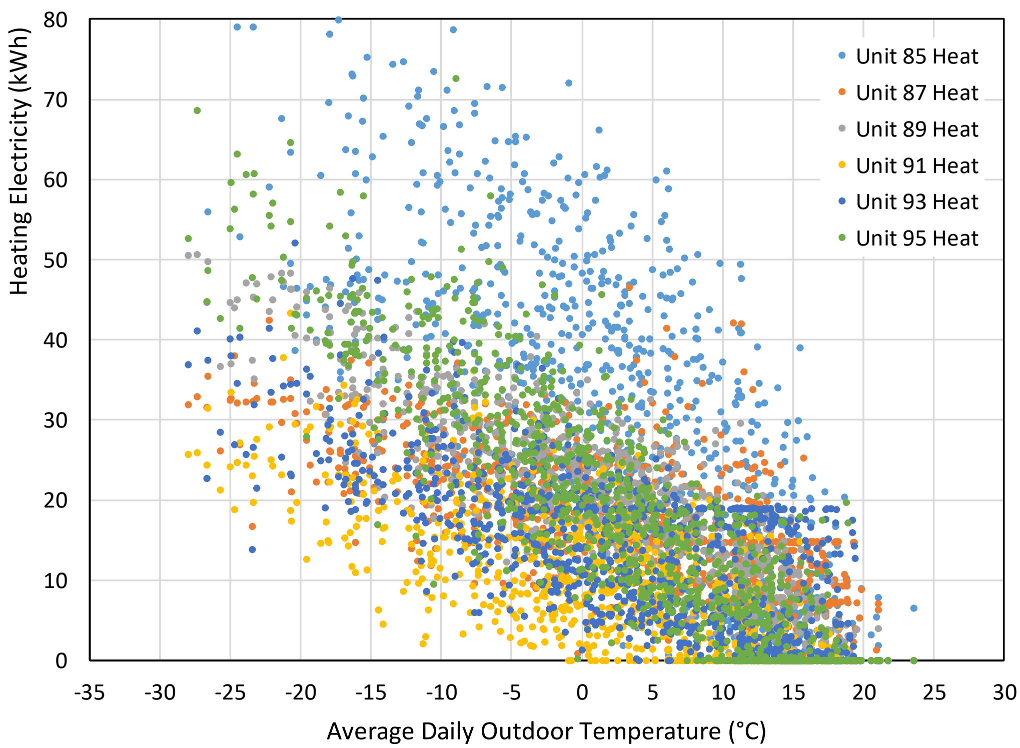


Figure 3.16 Unit daily heating energy consumption versus outdoor air temperature

Figure 3.17 compares the energy use from equipment and lighting loads in each unit between 2012 and 2015. This data is not measured directly but is determined by subtracting the Heating and DHW meter data from the total unit meter. These loads show a significant variability between the different units though there appears to be two groupings of units using similar amounts of energy on the low and high end of the distribution. The highest energy consumer per dwelling unit (Unit 85) 92% higher than the lowest energy consumer (Unit 93). The lighting and process loads can be impacted significantly by occupant behaviour and preference. This can include lighting use behaviour, cooking, as well as the intensity of electronics in the home. It should be noted that Unit 91, which had low heating consumption has a high energy use for lights and process loads which could be offsetting some of the heat requirements through high internal heat gains. Normalizing by unit floor area (Figure 3.18) impacts the relative ranking of energy consumption but does not significantly change the underlying variability in the equipment and lighting energy use results.

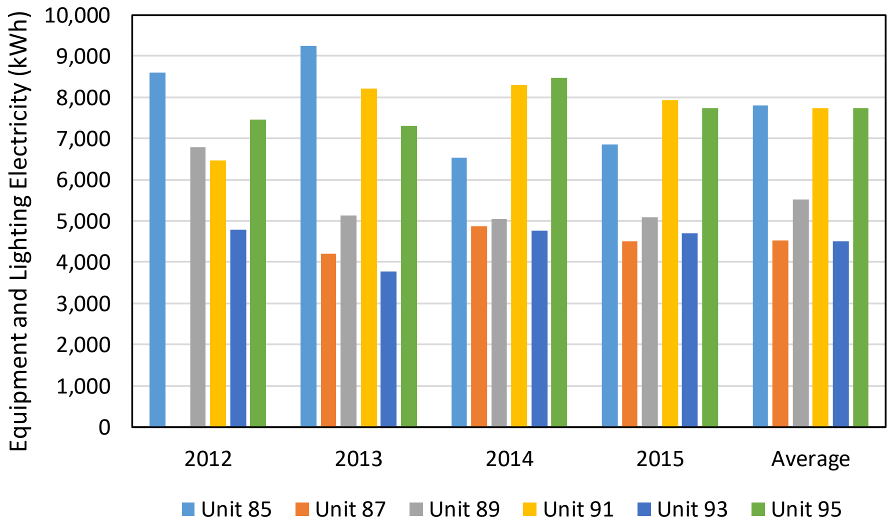


Figure 3.17 Comparison of equipment and lighting energy use per dwelling unit between units. Note that Units 85 and 95 are end units in the rowhouse complex and have both more floor area and more enclosure area.

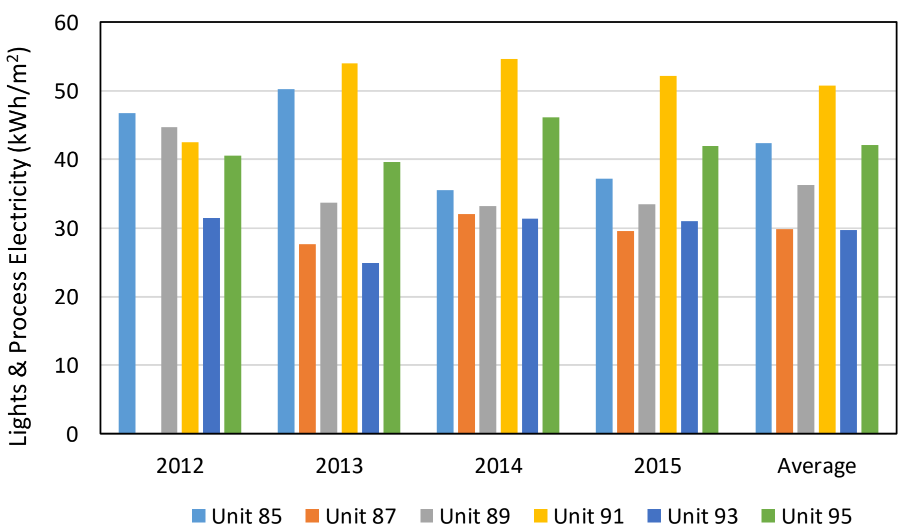


Figure 3.18 Comparison of area normalized equipment and lighting energy use between units. Note that Units 85 and 95 are end units in the rowhouse complex and have both more floor area and more enclosure area.

Summary

Analysis of the energy use of units in Building 1 shows that they use significantly less energy (~29%) compared to the energy use of current new construction with better than code insulation values, however, the end units were found to have a higher energy consumption than the average. On a per dwelling unit basis the highest energy consuming unit in the building was found to use 63% more electricity than the lowest energy consuming unit (using annual averages from 2012-2015). When normalized by floor area the highest energy consuming unit in the building was found to use 34% more electricity than the lowest energy consuming unit. The contrasts were more stark when comparing the differences in end use breakdown between units. The unit with the highest annual average DHW electricity consumption was 165% higher than that with the lowest consumption whereas the unit with the highest annual average heating consumption was more than 2.5x higher than that with the lowest heating consumption. When the floor area is accounted for the space heating in the most intensive unit is 2.4x higher than the least energy intensive unit. The differences in energy consumption between units in the building indicates that the occupant preferences can have an impact on energy use. Additional factors that also contribute to the differences in energy consumption between units likely includes differences in the number of occupants, equipment in the building, as well as larger enclosure area of the end units. The data from this building shows that constructing housing with improved building enclosure performance can result in lower energy consumption but the amount of energy use is heavily impacted by the building occupant.

3.3 Energy Modeling

Energy modeling was used to determine the impact of the energy efficient design choices on the building energy consumption. A model of the actual building was first created using the construction documents and calibrated to the metered energy use. The building design characteristics were then modified to match the Typical Construction of buildings in Whitehorse to use as a baseline. The energy savings of the actual building versus a similar building with typical construction was then determined by comparing the results of the two models.

3.3.1 Calibrated Model Inputs

The construction documents and sub-metered energy data were used to create a calibrated energy model for Building 1. Key model inputs are shown in Table 3.1.

TABLE 3.1 KEY MODEL INPUTS FOR BUILDING 1

	Units	**Value**	**Notes and References**
Building Geometry			
Storeys		2	
Total conditioned area	m^2	956	
Internal Loads and Schedules			
Occupant Density	pers/unit	4	Based on available bedrooms
Heating Set Point	°C	22	Calibrated modeling

TABLE 3.1 KEY MODEL INPUTS FOR BUILDING 1			
	Units	**Value**	**Notes and References**
Heating Set Back	°C	None	
Plug & Process Loads	W/m^2	5	Calibrated modeling
Lighting	W/m^2	6.45	Calibrated modeling
Average Daily DHW Consumption	Gal/unit/day	50	Calibrated modeling
Schedules	N/A		See Appendix
Building Enclosure			
Above Grade Wall R-Value	m^2-K/W (hr-ft^2-F/Btu)	8.5 (48)	14" cellulose between wall trusses 14" O/C and 2x3 strapping with R8 batt insulation
Below Grade Wall R-Value	m^2-K/W (hr-ft^2-F/Btu)	7.9 (45)	16" cellulose between wall trusses 16" O/C
Roof R-value	m^2-K/W (hr-ft^2-F/Btu)	13.5 (77)	24" wood trusses 24" O/C 22" Cellulose insulation (R80)
Slab on Grade R-value	m^2-K/W (hr-ft^2-F/Btu)	3.6 (20)	4" rigid XPS insulation 2" concrete slab
Window U-Value (Fixed)	W/m^2-K (Btu/hr-ft^2-F)	1.1 (0.20)	Quad glazed, 2 layers of soft coat low-e, 2 x 1/2" insulating spacers, argon fill and vinyl frames.
Window U-Value (Operable)		1.4 (0.24)	
Window SHGC (Fixed)		0.25	
Window SHGC (Operable)		0.22	
Window to Wall Ratio		12%	Building drawing
Infiltration rate	ACH@50Pa	1.24	Air tightness testing results. Increased in summer to represent operable windows.
Mechanical Systems			
Heating	Electric baseboards		
Cooling	None		
Ventilation	73% sensible effectiveness heat recovery ventilator		
Domestic Hot Water	Electric tank-type, 4500 watts/unit		

3.3.2 Calibrated Model Results

Figure 3.19 shows the distribution of energy consumption by end-use for the Building 1 model. The total energy use intensity is 119.5 kWh/m^2 (19 MWh per unit). The end use breakdown shows similar trends to the metered data and allows for further breakdown of the Equipment and Lighting loads to show that of the modeled 33%, the Lighting accounts for 14%, Misc. Equipment 16%, and Fans 2%.

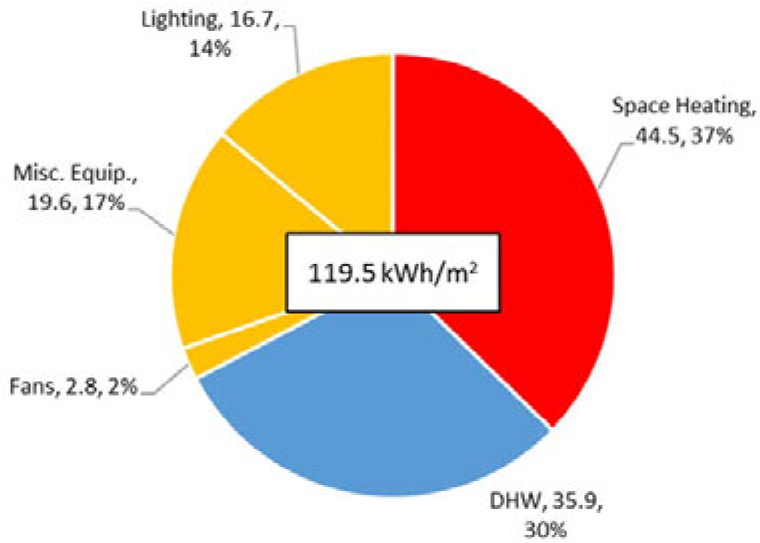


Figure 3.19 Energy consumption by end-use for modeled Building 1

The average metered energy data was used in calibrating the Building 1 model to ensure good agreement with the actual energy use profile. A comparison of the total monthly electricity use, monthly space heating use, and domestic water heating energy use are shown in Figure 3.20 through Figure 3.22, respectively. The percentages indicated represent the deviation of the monthly modeled energy use from the monthly metered energy use. The model shows good agreement with both total energy use and space heating throughout the year and follows seasonal variations in heating demands and space use. The modeled total electricity use is within ±10% of the metered data for every month of the year. The modeled space heating use is within ±10% of the metered data for all months except January which is an outlier.

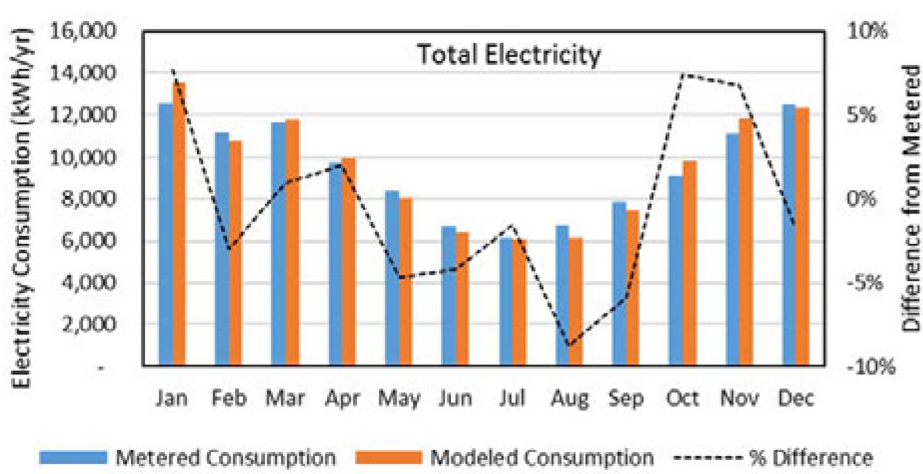


Figure 3.20 Comparison of Building 1 monthly metered and modeled whole building total electricity use

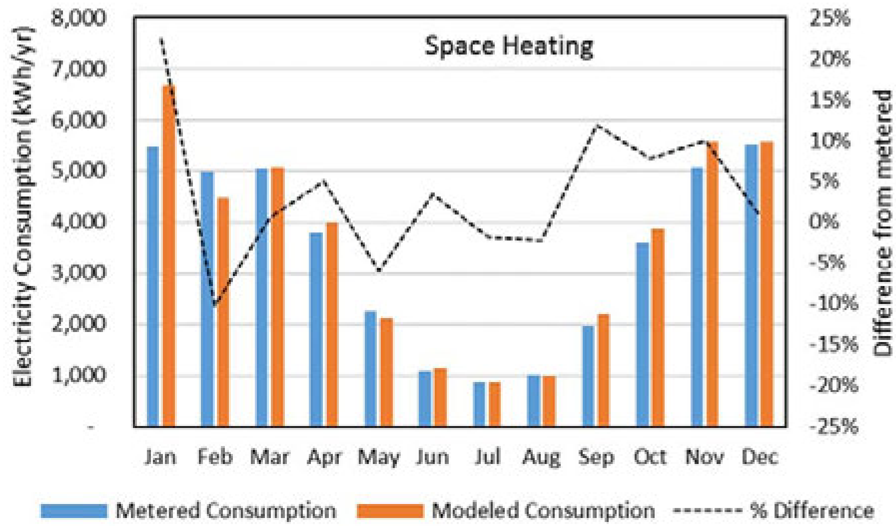


Figure 3.21 Comparison of Building 1 monthly metered and modeled whole building space heating electricity use

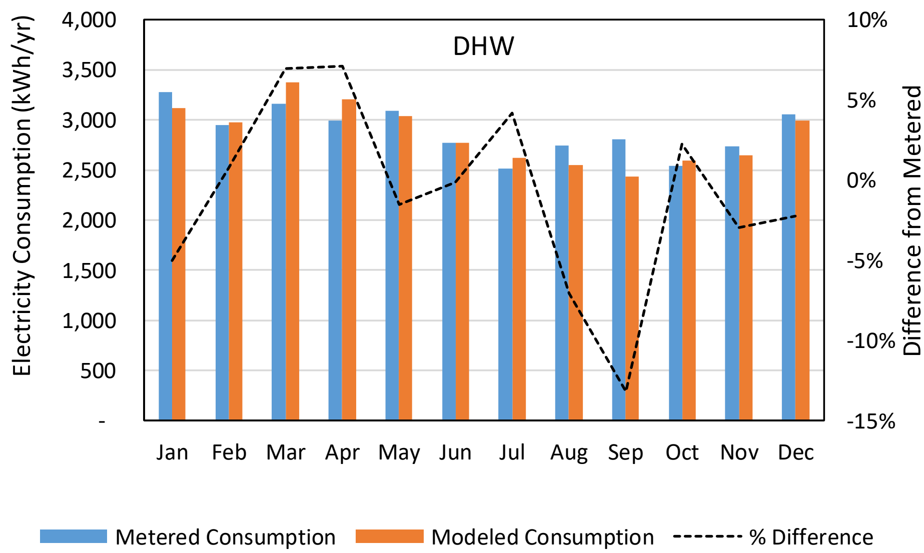


Figure 3.22 Comparison of Building 1 monthly metered and modeled whole building domestic water heating electricity use

3.3.3 Baseline Model (Typical Construction) Inputs

The calibrated model of Building 1 was modified to include characteristics of typical construction to be used as a baseline for comparison to the higher performance design of the actual building. The baseline building was assumed to be constructed to slightly higher than Whitehorse Green Building Standard minimum standards based on typical construction in Whitehorse. The characteristics of the baseline building used in the energy model are provided in Table 3.2. Changes from the actual building model are shown in bold.

TABLE 3.2 BASELINE MODEL INPUTS FOR BUILDING 1			
	Units	**Value**	**Notes and References**
Building Geometry			
Storeys		2	
Total conditioned area	m^2	965	
Internal Loads and Schedules			
Occupant Density	pers/unit	4	Based on available bedrooms
Heating Set Point	˚C	22	Calibrated modeling
Heating Set Back	˚C	None	
Plug & Process Loads	W/m^2	5	Calibrated modeling
Lighting	W/m^2	6.45	Calibrated modeling
Average Daily DHW Consumption	Gal/unit/day	50	Calibrated modeling
Schedules	N/A		See Appendix
Building Enclosure			
Above Grade Wall R-Value	m^2-K/W (hr-ft^2-F/Btu)	**4.9 (25)**	2x6 wood stud @ 16" o.c. with fiberglass batt and 2.5" fiberglass batt interior insulation
Below Grade Wall R-Value	m^2-K/W (hr-ft^2-F/Btu)	**4.9 (25)**	2x6 wood stud @ 16" o.c. with fiberglass batt and 2.5" fiberglass batt interior insulation
Roof R-value	m^2-K/W (hr-ft^2-F/Btu)	**10.6 (60)**	24" wood trusses 24" O/C 18" Cellulose insulation (R63)
Slab on Grade R-value	m^2-K/W (hr-ft^2-F/Btu)	**1.8 (10)**	2" XPS insulation 2" concrete slab
Window U-Value	W/m^2-K (Btu/hr-ft^2-F)	**1.4 (0.25)**	Vinyl, triple pane, argon fill, 2 low-e coatings
Window SHGC		**0.25**	
Window to Wall Ratio		12%	Building drawing
Infiltration rate	ACH@50Pa	**1.5**	Whitehorse Green Building req.
Mechanical Systems			
Heating	**Oil 85% AFUE (ducted forced air)**		
Cooling	None		
Ventilation	**63%** sensible effectiveness heat recovery ventilator		
Domestic Hot Water	Electric tank-type, 4500 watts/unit		

3.3.4 Comparison to Baseline

Figure 3.23 shows the distribution of energy consumption by end-use for the Building 1 baseline model. The total energy use intensity is 166 kWh/m^2 (26.4 MWh per unit). The energy end-use breakdown shows that space heating accounts for 51% of the energy use in the Building 1 baseline model while DHW and Equipment & Lighting loads account for 22% and 27%, respectively.

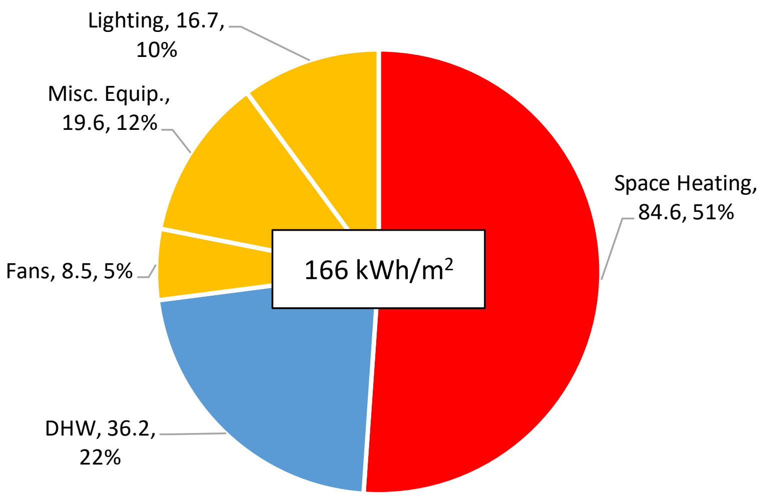


Figure 3.23 Energy consumption by end-use for modeled Building 1 baseline with typical construction characteristics

The monthly total energy use, space heating, DHW, and equipment & lighting energy consumption for the modeled Building 1 as constructed versus the building model with typical construction characteristics (baseline) is shown in Figure 3.24 through Figure 3.27. The calibrated Building 1 model uses less energy than the baseline in all months except July with the greatest savings occurring throughout the winter. This is a result of the substantial savings in space heating energy during the winter months. Fan energy savings also occur throughout the year due to the use of an HRV with electric baseboards in the actual building compared to the an HRV and oil fired furnace in the baseline.

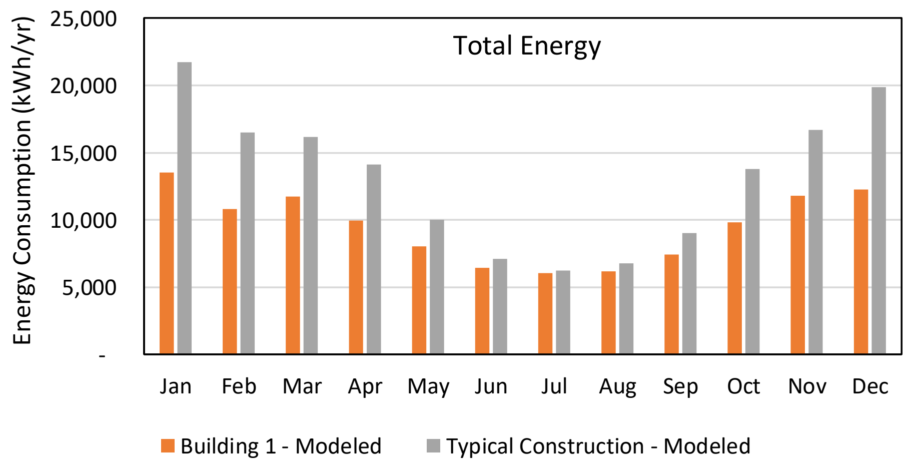


Figure 3.24 Comparison of Building 1 monthly modeled and baseline (Typical Construction) whole building total energy use

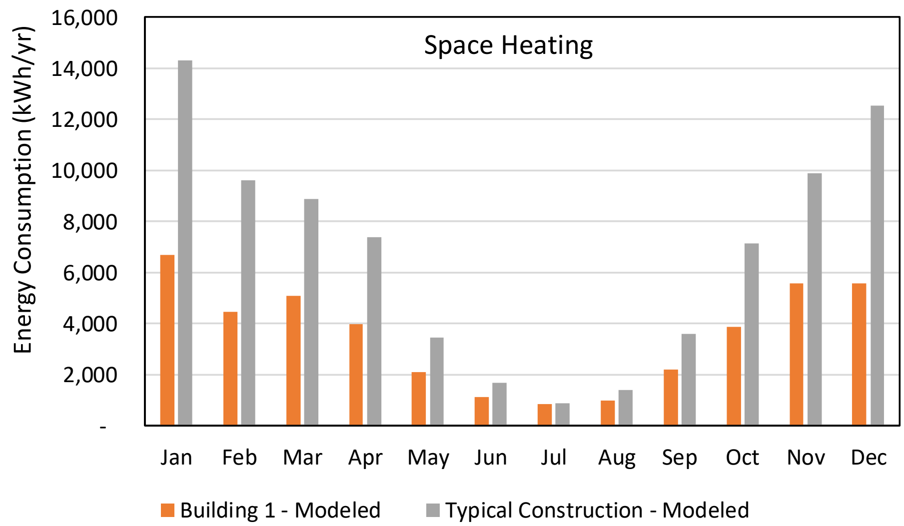


Figure 3.25 Comparison of Building 1 monthly modeled and baseline (Typical Construction) whole building space heating energy use

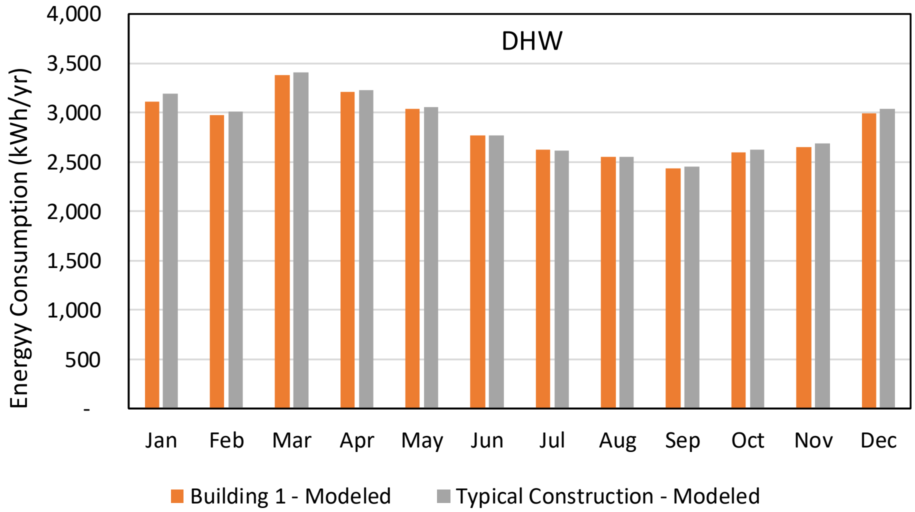


Figure 3.26 Comparison of Building 1 monthly modeled and baseline (Typical Construction) whole building DHW energy use

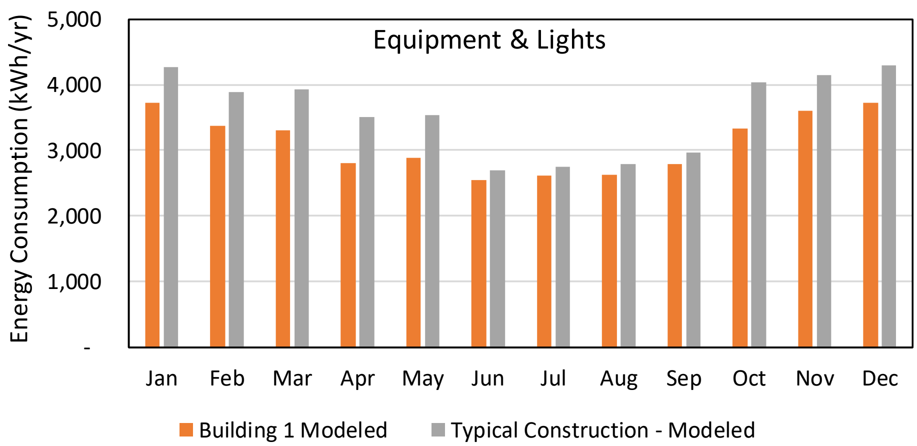


Figure 3.27 Comparison of Building 1 monthly modeled and baseline (Typical Construction) whole building Equipment & Lighting energy use

The annual operational energy and GHG savings from the design of Building 1 with improved energy efficiency features (Table 3.1) compared to the baseline with typical construction in Whitehorse (Table 3.2) are shown in Table 3.3. The emissions factor used for Whitehorse were 2.74 kg/L (0.254 kg CO_2e/kWh) for Fuel Oil and 0.05 kg CO_2e/kWh electricity[7].The energy efficiency improvements included in the building construction result in 25.2 kWh/m^2/yr (17.4%) of energy savings and 14.3 kg/m^2/yr (70.5%) of GHG savings per year. This is predominantly a result of the reduction in space heating energy use and a switch from fossil fuel burning in an oil-fired furnace for the baseline to the use of electric baseboard heating in the actual building. Building 1 as constructed uses approximately 30% less energy for space heating than a comparable building of typical

[7] Emission factors obtained from City of Whitehorse Corporate Milestone 5 Report (https://www.fcm.ca/Documents/reports/PCP/Whitehorse_Corporate_Milestone5_Report.pdf) Table 1. Note, the emissions factors indicted in the table should be in units kg/L or kg/kWh to align with actual energy densities.

construction in Whitehorse. The modest GHG savings resulting from Equipment & Lights are a result of not having a furnace fan in the actual building.

TABLE 3.3 COMPARISON OF ANNUAL ENERGY AND GHG SAVINGS FROM BUILDING 1 VERSUS THE BASELINE TYPICAL WHITEHORSE BUILDING CONSTRUCTION						
	Baseline (Typical Construction)		**Building 1 (Actual Construction)**		**Savings**	
End Use	**Energy (kWh/m^2)**	**GHG (kg/m^2)**	**Energy (kWh/m^2)**	**GHG (kg/m^2)**	**Energy (kWh/m^2)**	**GHG (kg/m^2)**
Space Heating	84.6	21.5	44.5	2.2	40.0 (47.4%)	19.3 (89.6%)
DHW	36.2	1.8	35.9	1.8	0.3 (0.7%)	0.0 (0.7%)
Equip. & Lights	44.8	2.2	39.0	2.0	5.7 (12.7%)	0.3 (12.7%)
Total	165.5	25.5	119.5	6.0	46.1 (27.8%)	19.6 (76.6%)

Note: The space heating in the baseline model uses fuel oil whereas the space heating in the Building 1 model uses electricity.

4 Building 2

Figure 4.1 Photo of Building 2, a 10,120ft² 8-plex in Whitehorse, YT

4.1 Building Description

4.1.1 General Description

Building 2 is a two storey, 10,120 ft² (940m²) 8-plex apartment building constructed in 2010 in Whitehorse, YK. The building layout includes a common ground floor entry area leading to four single level units on each floor. The ground floor plans are shown in Figure 4.2. The four ground floor units have 1,018ft² (95m²) of floor area and include 2 bedrooms. Two of the units on the top floor have a similar floor plan while the remaining two top floor units have 3 bedrooms and are 1,250 ft² (116m²) and 1,310 ft² (122m²), respectively.

Similar to Building 1, the building was designed with the intent of reducing the heating energy consumption through increased building enclosure performance relative to standard construction in Whitehorse. The heating demand was to be met with all electric equipment to prevent the need for on site fuel oil use.

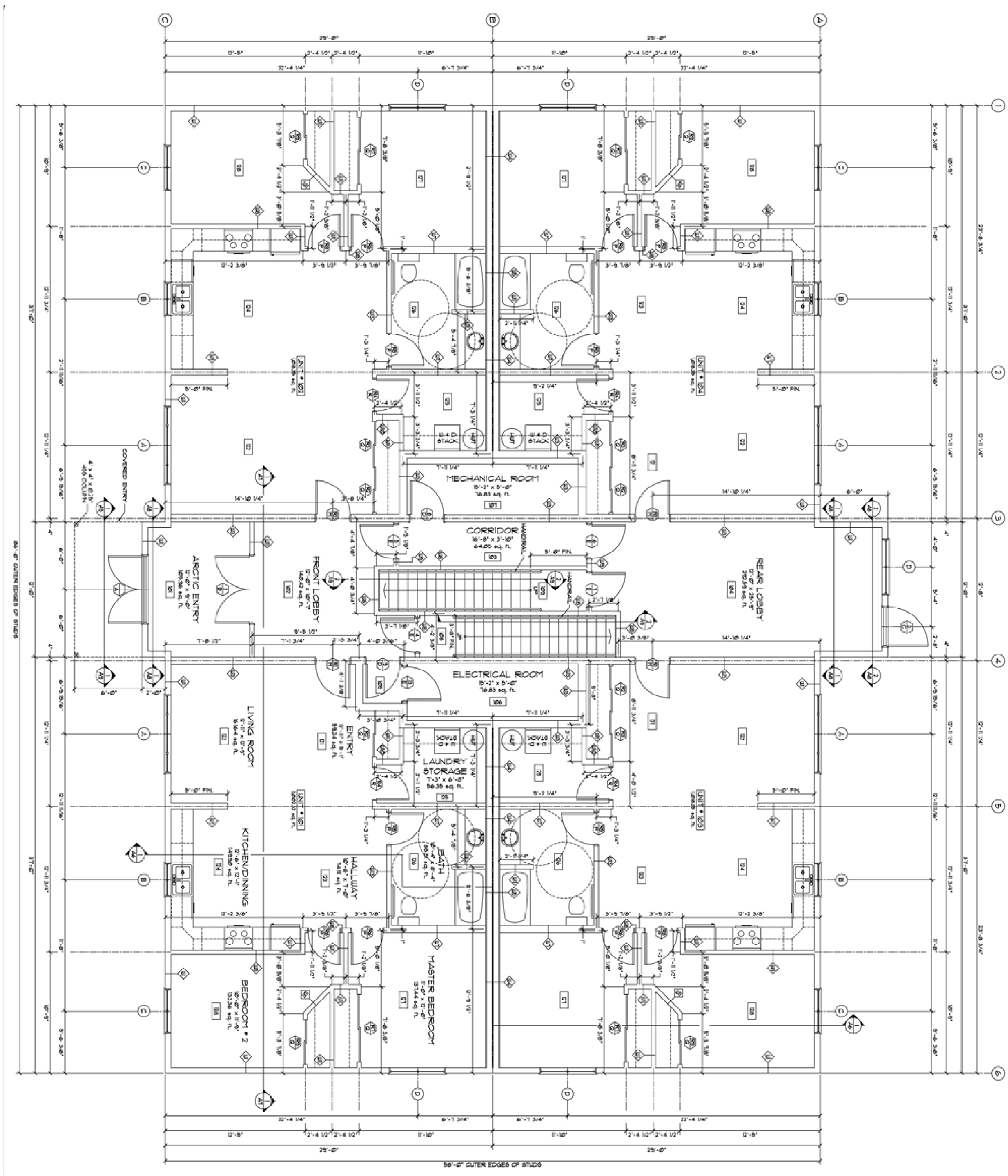


Figure 4.2 Building 2 ground floor plan

4.1.2 Building Enclosure

The building enclosure was designed to provide increased thermal insulation compared to code minimum or standard practice. This increased enclosure performance allows for smaller heating equipment sizing and reduced heating costs.

The roof construction consists of asphalt shingles over an attic with 24" high heeled engineered trusses at 24" o.c. The insulation layer consists of R-80 batt insulation between the trusses. This assembly provides an effective thermal resistance of R-75. Details of the roof construction are shown in Figure 4.3.

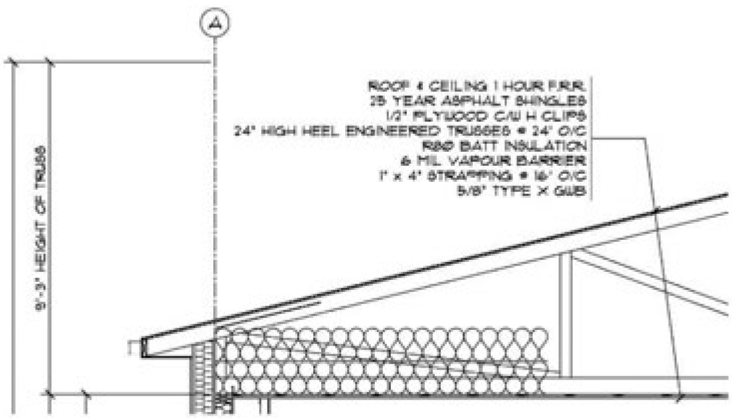


Figure 4.3 Building 2 roof details (N.T.S.)

The wall assembly is shown in Figure 4.4. The construction includes 6" of mechanically fastened XPS insulation connected to 5/8" plywood sheathing on 2x6 framing at 16" o.c. with R-20 batt insulation. The overall effective R-value of the assembly is R-46. The floor assembly (also Figure 4.4) consists of a 4" concrete slab above 4" of XPS insulation (R-20).

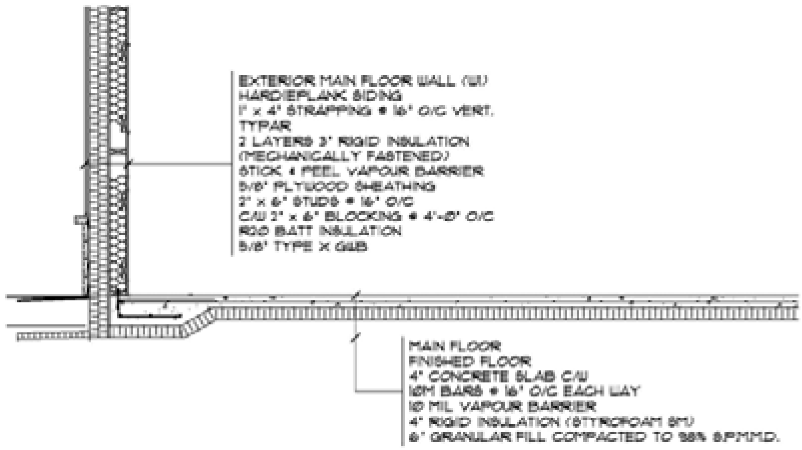


Figure 4.4 Building 2 above grade wall and slab on grade floor assembly details (N.T.S.)

The windows installed throughout the building are triple pane vinyl windows, argon-filled with insulating spacers and two layers of soft coat low-e coatings. The window performance is approximately USI-1.2.

4.1.3 Mechanical

The building mechanical system consists of all-electric products. Each unit in the building has a dedicated Greentek PH10.22 HRV providing the required ventilation with 82% adjusted sensible recovery efficiency. The airflow measurement from the balancing report indicates the HRV provides between 60-75 CFM of ventilation air to each unit.

The space heating is provided by electric baseboards throughout the units with individual unit temperature control by wall thermostats. Domestic hot water is provided by a 189.3L (50 GAL) tank-type electric water heater with two 1500 watt (upper and lower) elements for each of the units individually.

4.2 Data Analysis

4.2.1 Data Provided

Monthly electric utility billing data was provided for both unit/tenant meters as well as the “House” meter paid for by the Yukon Housing Corporation. The tenant meters include consumption from lighting and equipment loads within the units including the HRVs. The “House” meter captures the loads for all of the domestic water heating in the building, all building heating (unit and common areas), as well as common area lighting and receptacles. Heating electricity consumption was sub metered in each unit using current transducers within the electrical panel. Sub-metering data was recorded at 1 minute intervals between February 2012 and December 2016 though has periods of missing data. Utility billing data was provided between January 1st, 2011 through December 31st, 2016.

Temperature sensors were also installed within the building and wall assembly to measure performance throughout operation. Temperature data was recorded at 1 minute intervals between February 2012 and December 2016 though has periods of missing data. Further details on temperature sensor locations will be described below in the results section.

The data was aggregated and combined between sources as required for analysis in this work. An example of the total monthly data for all units is shown in Figure 4.5.

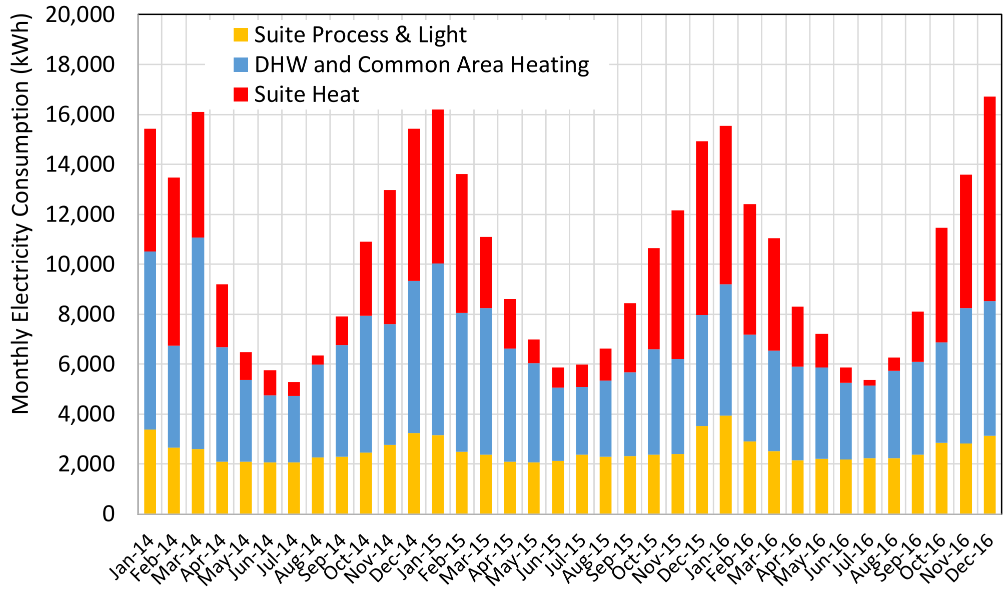


Figure 4.5 Monthly energy consumption breakdown for all units in Building 2

4.2.2 Results – Energy Data

Total Building Consumption

The average annual total energy consumption of Building 2 between 2011 and 2016 was 124.6 MWh, 132.5 kWh/m², or 15.6 MWh per unit. The energy end use breakdown for the 8-plex is shown in Figure 4.6 for the years 2014 to 2016 (those for which complete data was available). There is a slight variation in energy end use between years but the typical breakdown is 30% for hot water heating, 49% for space heating, and 21% for lights and other equipment. The domestic hot water consumption was estimated from available July "House" meter data and is approximate[8].

The hourly average energy consumption for Building 2 is only available for the unit space heating. This data shows little variation throughout the hours of the day (similar to Building 1) and is therefore not shown below.

[8] The domestic water load was estimated using the average July "House" meter consumption after subtracting the heating consumption. This monthly consumption was multiplied by 12 months and assumed equal for all years.

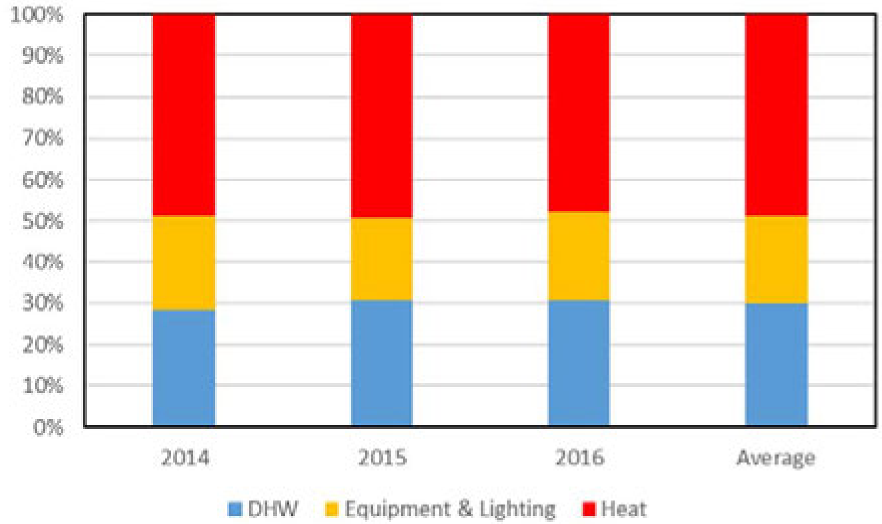


Figure 4.6 Building 2 - Whole Building End Use Breakdown

Inter-unit Comparison

Occupant behaviour can be a driver of building energy use and can impact the potential benefits of high performance buildings. Occupants can impact energy use through operation choices such as thermostat temperature settings and behaviour patterns such as window opening or lighting use. The sub-metering on each of the 8-plex units allows for comparison of the energy use of different occupants in buildings with similar design.

Total energy use for each unit and domestic hot water energy use were not sub-metered by unit in Building 2 and is therefore excluded from this portion of the analysis. The units are labelled ‘a’ through ‘h’ when discussing heating energy and ‘A’ through ‘H’ in the figures discussing Equipment and Lighting because identifying information on specific suites was not available with the utility billing. Data was provided for individual units but specific units could not be identified from the data and therefore unit ‘a’ does not correspond to unit ‘A’.

The annual energy consumption for space heating in each unit is shown in Figure 4.7 for 2013 through 2016. The data has been normalized by the area of each unit in Figure 4.8 to provide a heating energy use intensity. Note that the data in Figure 4.8 includes only the area associated with the dwelling units and excludes common space floor area. The number in parentheses indicates the floor on which the unit is located. The space heating is comparable for most units in the building with the exception of Unit h which has a significantly lower heating consumption. Note: Unit h data indicates no heating energy consumption between approximately May and September of each year. Occupancy data provided by the Yukon Housing Corporation indicated that none of the units were habitually unoccupied during that timeframe. The low energy use could be a result of the occupant being temporarily absent or the unit being adequately heated by adjacent spaces. Data from unit-level Equipment & Lighting energy consumption (below) supports the theory that the occupant of Unit h is not absent during this time and therefore other explanations for the differences are likely.

The average annual heating energy consumption per dwelling unit (Figure 4.7) of the unit using the most heating energy (Unit a) was 390% more energy than the unit using the least heating energy (Unit h). If unit h is excluded as an outlier the difference between the unit with the highest annual heating energy consumption and the lowest annual heating energy consumption is 62%. When normalized by floor area the percentage differences are the same as the highest consuming and lowest consuming units have the same floor area. There is no clear differentiation of heating energy consumption between units on the lower floor and those on the upper floor despite the top floor having the added thermal load resulting from exposure to the roof of the building and more floor area. A potential cause for the lower heating energy consumption in Unit h could be a lower temperature setpoint within the space or differences in window operation or ventilation control.

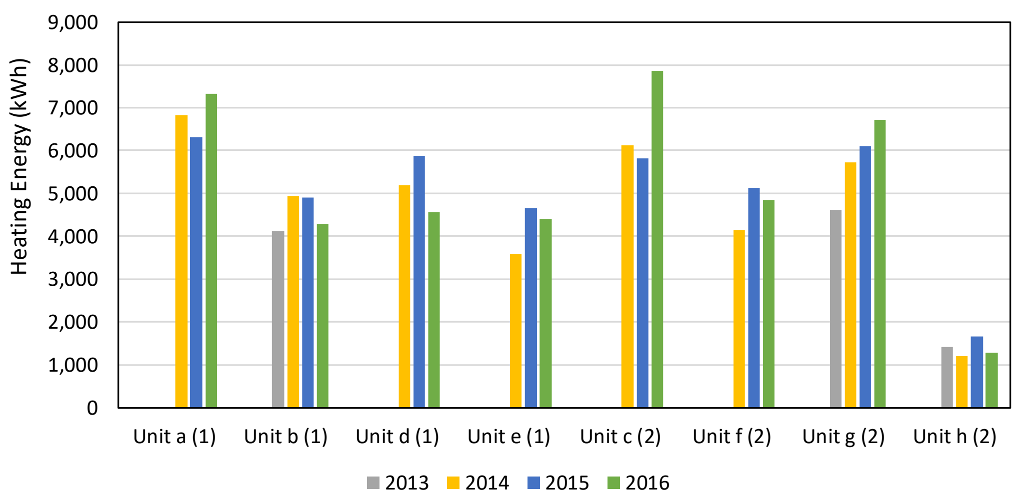


Figure 4.7 Comparison of heating energy use per dwelling unit in Building 2. Numbers in parentheses indicate floor of building.

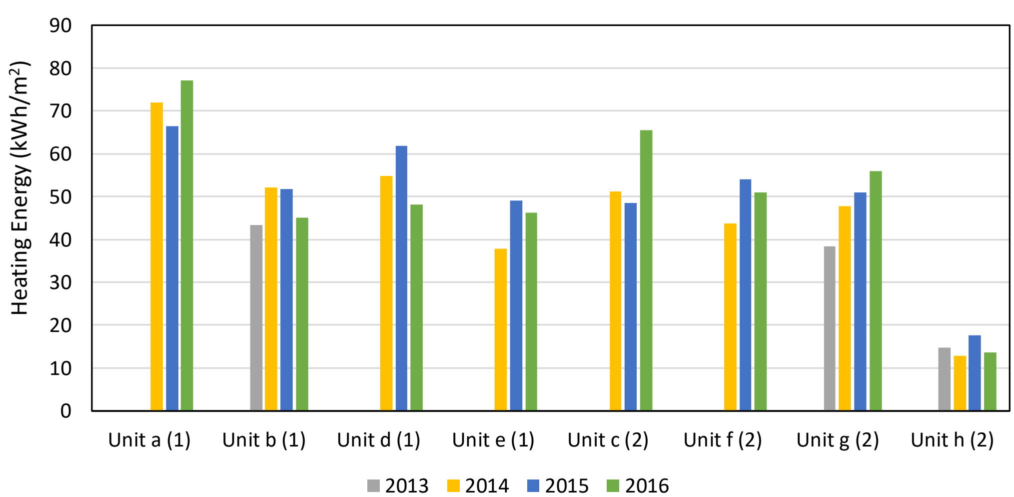


Figure 4.8 Comparison of area normalized heating energy use between units in Building 2. Numbers in parentheses indicate floor of building.

The daily heating energy consumption versus average outdoor air temperature is plotted in Figure 4.9 and Figure 4.10 for the four units on the lower and upper floor, respectively.

There is little heating in units when the average outdoor temperature exceeds 20˚C. Units on the upper and lower floors follow similar trends of heating consumption versus outdoor temperature irrespective of floor in the building. One unit (Figure 4.10) deviates from the typical trend and reports using less energy at all temperatures and little heating above 10°C.

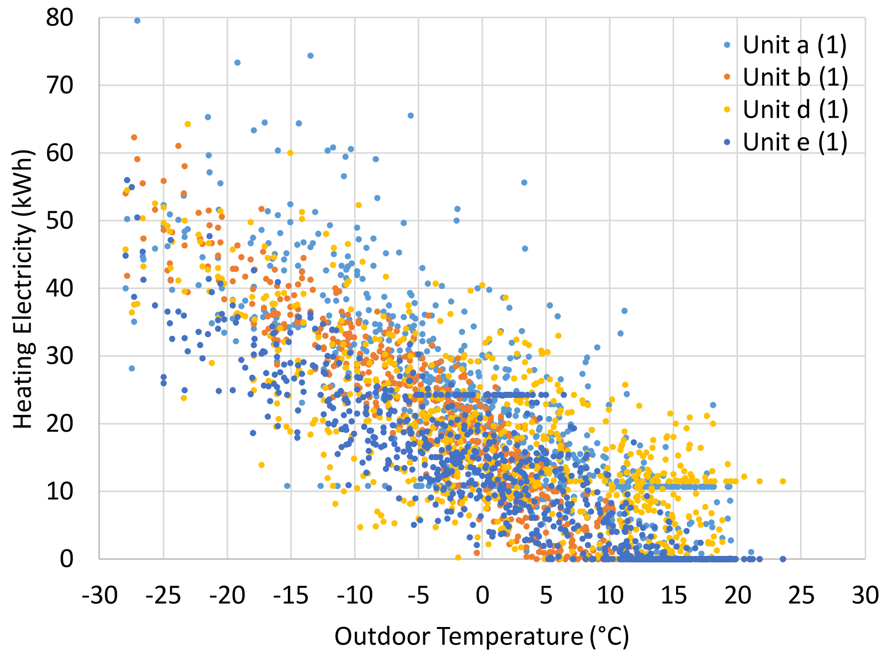


Figure 4.9 Unit daily heating energy versus average outdoor air temperature for lower floor units

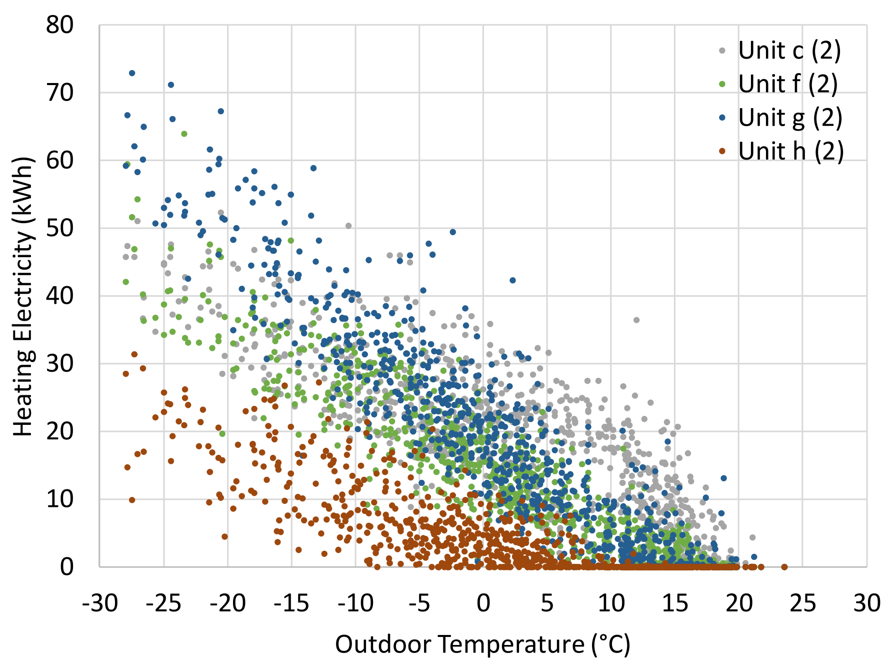


Figure 4.10 Unit daily heating energy versus average outdoor air temperature for upper floor units

Figure 4.11 compares the energy use from equipment and lighting in each unit between 2011 and 2016. The units are labelled with the same letters as in the data presenting heating loads but it should be noted that 'Unit A' is not the same unit as 'Unit a' because the utility data provided was anonymized. There is no way to link unit specific end-use consumption between Figure 4.7 and Figure 4.11. There is also no way of area normalizing this data.

The energy consumption data in Figure 4.11 shows a significant variability between the different units. The highest energy consuming unit (Unit E, 4.7MWh/yr) uses 75% more energy than the lowest energy consuming unit (Unit B, 2.6MWh/yr). The equipment and lighting loads can be impacted significantly by occupant behaviour and preference. This can include lighting use behaviour, cooking, as well as the intensity of electronics in the home. It is interesting to note that the least energy consuming unit here is not a far outlier as in the heating data provided in Figure 4.7. This may provide evidence that the Unit h in the heating data figure is lower not because of a lack of occupant but rather differences in heat requirement.

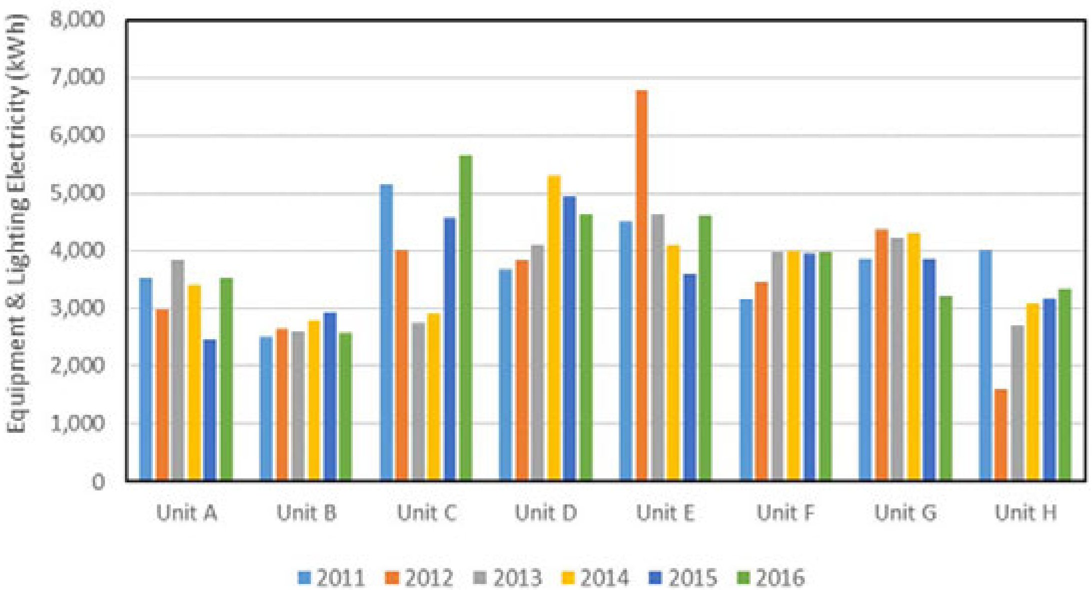


Figure 4.11 Comparison of lighting and process load energy use between units in Building 2

Summary

Analysis of the energy use of units in Building 2 shows that there is a significant energy reduction (~41.5%) compared to the energy use of typical homes constructed to better than code performance in Whitehorse though this number is likely caused in part by the building containing small units with large areas of shared enclosure. The average annual heating energy consumption is comparable for most units in the building but one outlier uses significantly less energy than the others. Energy consumption for equipment and lighting loads in the units also shows significant variability both between units and for the same unit from year to year. The highest energy consuming unit uses 75% more energy than the lowest energy consuming unit. The data from this building further supports the notion that constructing housing with improved building enclosure performance can result in lower energy consumption but the amount of energy use is heavily impacted by the building occupant.

4.2.3 Results – Environmental Data

Temperature sensors were installed in the building enclosure to determine temperature distribution through different locations. A schematic of the sensor locations is shown in Figure 4.12. Sensors were installed through the depth of the wall at the Exterior of the Insulation, in the Middle of the Insulation, at the Sheathing, and at the Drywall. The sensors were installed through the depth of the assembly at locations where the insulation is continuous ("Wall"), where the exterior insulation is fastened to the sheathing ("Screw"), and where the wood framing interrupts the batt insulation ("Stud").

Sensors were also installed to measure the outdoor temperature as well as the indoor temperature and relative humidity. The temperature and relative humidity can be used to calculate the dewpoint temperature which is compared to the temperature distribution through the enclosure. If the indoor dewpoint temperature is found to be above the drywall or sheathing temperature there is a potential risk of condensation and moisture concern.

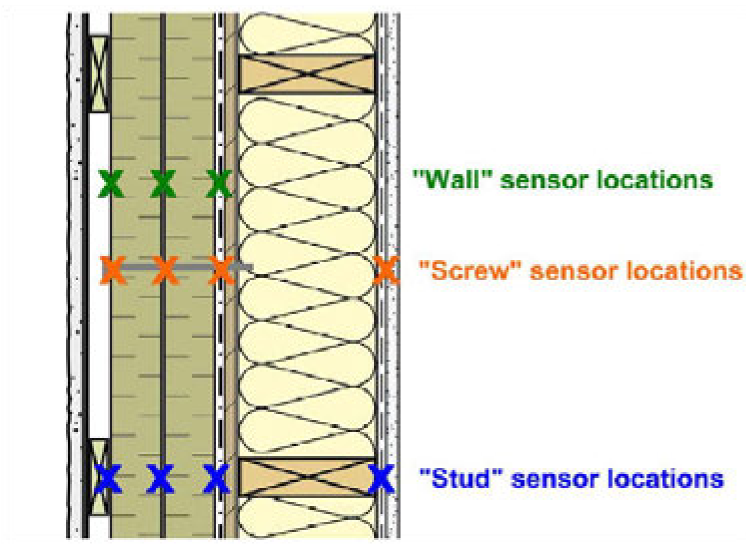


Figure 4.12 Wall assembly sensor location

Indoor Environmental Conditions

The average hourly indoor environmental conditions are plotted along with the outdoor temperature between October 8, 2014 and December 12, 2016 for one of the units in Building 2. The outdoor temperature reaches highs of 30°C during the summer months and lows of -30°C during winter months which represents a significant variation in conditions for maintaining control of the indoor environment. Throughout this range of outdoor conditions, the indoor environment is maintained between 16°C and 25°C at all times. The periods of high indoor temperature do not appear to be isolated to periods of high outdoor temperature but rather correspond to low outdoor temperatures indicating that they may be a result of thermostat setpoint changes to account for thermal comfort issues.

The relative humidity measurements taken during the winter season are typically between 10% and 30%. The dewpoint temperature within the space is also low during the winter with readings often below 0°C. These measurements indicate that the indoor environment is dry during the winter[9] and is therefore unlikely to pose potential condensation or moisture problem which are often found in Northern housing.

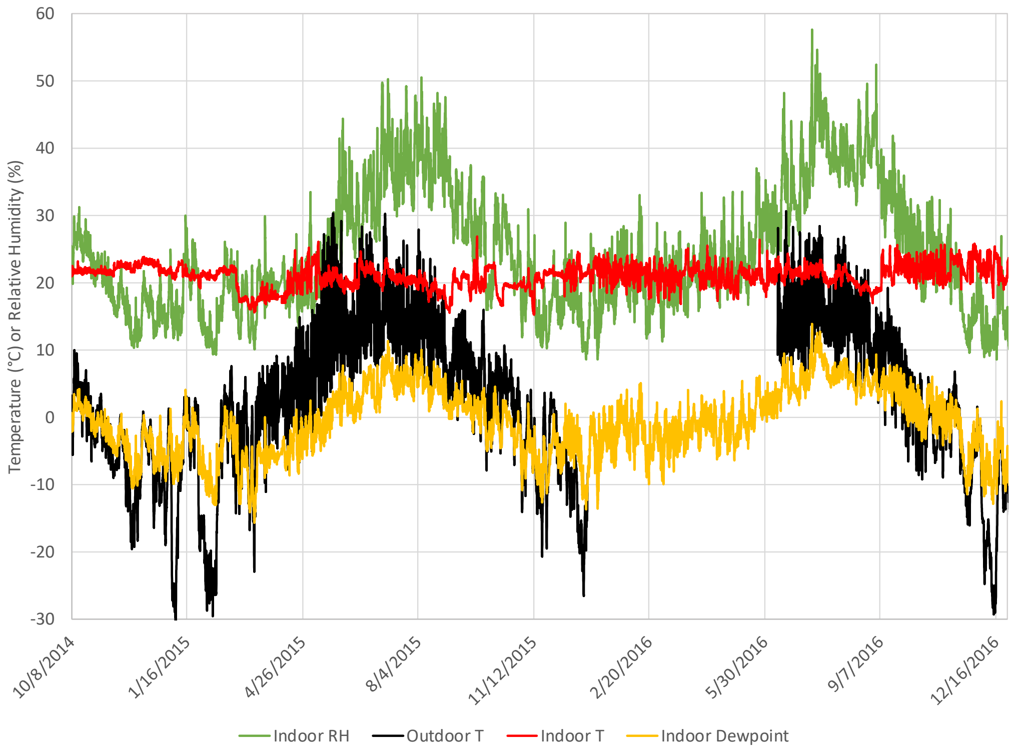


Figure 4.13 Indoor temperature and relative humidity, and outdoor temperature measurements in Building 2

Enclosure Temperature Monitoring

The temperature measurements taken within the enclosure assembly are shown for sample weeks in the Summer (Figure 4.14) and the Winter (Figure 4.15).

The summer data shows significant temperature swings of the exterior insulation surfaces from as low as 10°C through the night to as high as 45°C during the day. The high temperatures on the exterior insulation are higher than the outdoor temperature indicating significant solar heating. The enclosure temperature profiles show cyclic heating and cooling throughout the day with a lag in the assembly due to the thermal mass of the materials. During this period of significant temperature cycles of the outdoor temperature and exterior assembly temperatures, the indoor space temperature and

[9] Building Science Corporation 2002. RR-0203: Relative Humidity. https://buildingscience.com/documents/reports/rr-0203-relative-humidity/view

drywall temperatures remains relatively constant indicating good thermal comfort for the occupants.

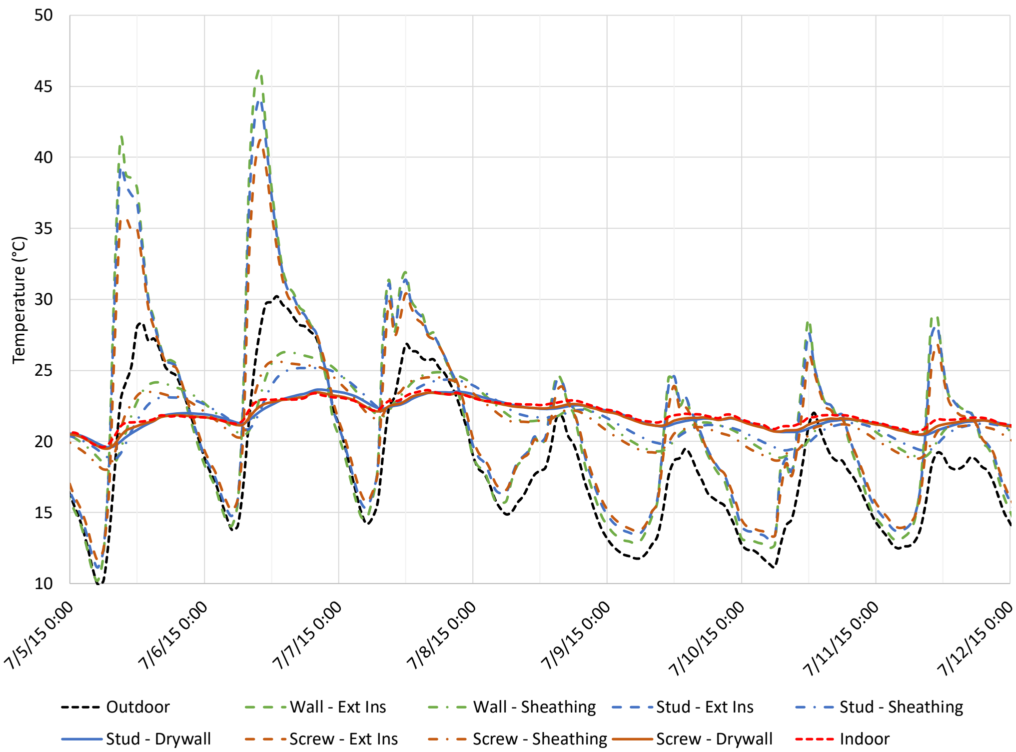


Figure 4.14 Example of one week of envelope temperature data during summer

The sample of measurements throughout a winter at the sheathing and drywall is shown in Figure 4.15. The temperature sensors placed at different locations along the same layer of the assembly (ie the screw, stud, or wall sensors at the mid insulation level) are all typically within a 3°C range indicating the impact of thermal bridging in the assembly.

The indoor dewpoint temperature is plotted with the assembly temperatures to explore the potential for condensation both on indoor surfaces and within the assembly (due to air exfiltration). The winter indoor dewpoint temperature is typically low. The maximum dewpoint temperature during a winter month (Jan-Mar, Oct-Dec) for the entire duration of monitoring was 6°C which is representative of a dry environment. The indoor dewpoint temperature is never above the drywall temperature or the sheathing temperature and only exceeds the temperature in the middle insulation layers on rare occasions. Surfaces temperatures above indoor dewpoint temperatures outboard of the sheathing present little risk to the enclosure. These measurements indicate that condensation is unlikely to be a concern on the indoor surfaces or within the enclosure assembly.

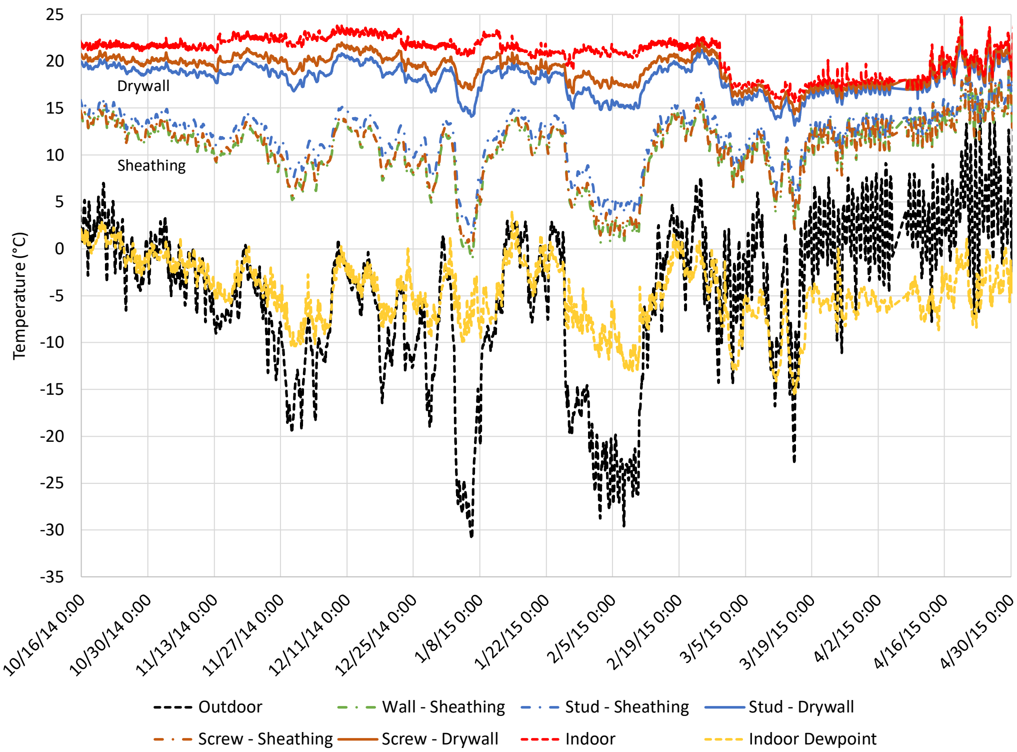


Figure 4.15 Example of one week of envelope temperature data during winter

4.3 Energy Modeling

Energy modeling was used to determine the impact of the energy efficient design choices on the building energy consumption. A model of the actual building was first created using the construction documents and calibrated to the metered energy use. The building design characteristics were then modified to match the Typical Construction of buildings in Whitehorse to use as a baseline. The energy savings of the actual building versus a similar building with typical construction was then determined by comparing the results of the two models.

4.3.1 Calibrated Model Inputs

The construction documents and sub-metered energy data were used to create an energy model for Building 2. The model inputs are shown in Table 4.1.

TABLE 4.1 KEY MODEL INPUTS FOR BUILDING 2			
	Units	**Value**	**Notes and References**
Building Geometry			
Storeys		2	
Total conditioned area	m^2	901	
Internal Loads and Schedules			
Occupant Density	pers/unit	3.25	Based on available bedrooms
Heating Set Point	˚C	22	Calibrated modeling

TABLE 4.1 KEY MODEL INPUTS FOR BUILDING 2			
	Units	**Value**	**Notes and References**
Heating Set Back	˚C	None	
Plug & Process Loads	W/m^2	5	Calibrated modeling
Lighting	W/m^2	6.45	Calibrated modeling
Average Daily DHW Consumption	Gal/unit/day	50	Calibrated modeling
Schedules	N/A		See Appendix
Building Enclosure			
Above Grade Wall R-Value	m^2-K/W ($hr-ft^2$-F/Btu)	6.7 (46)	6" rigid exterior insulation on 2x6 framing @ 16" o.c. with R-20 batt insulation
Below Grade Wall R-Value	m^2-K/W ($hr-ft^2$-F/Btu)	N/A	N/A
Roof R-value	m^2-K/W ($hr-ft^2$-F/Btu)	13.2 (75)	24" wood trusses 24" O/C R80 fiberglass batt insulation
Slab on Grade R-value	m^2-K/W ($hr-ft^2$-F/Btu)	3.6 (20)	4" rigid XPS insulation 2" concrete slab
Window U-Value (Fixed)	W/m^2-K ($Btu/hr-ft^2$-F)	1.1 (0.20)	Triple glazed, 2 layers of soft coat low-e, insulating spacers, argon fill and vinyl frames.
Window U-Value (Operable)		1.6 (0.28)	
Window SHGC (Fixed)		0.27	
Window SHGC (Operable)		0.22	
Window to Wall Ratio		14%	Building drawing
Infiltration rate	ACH@50Pa	1.24	Matches air tightness testing of Building 1. Increased in summer to represent operable windows.
Mechanical Systems			
Heating	Electric baseboards		
Cooling	None		
Ventilation	82% apparent sensible effeciency heat recovery ventilator		
Domestic Hot Water	Electric tank-type, 3000 watts/unit		

4.3.2 Calibrated Model Results

Figure 4.16 shows the distribution of energy consumption by end-use for the Building 2 model. The total energy use intensity is 140.2 kWh/m^2 (15.8 MWh per unit). The end use breakdown shows similar trends to the metered data and allows for further breakdown of the components. The domestic hot water accounts for 27%, space heating (unit and common area) accounts for 49%, Lighting accounts for 9%, Misc. Equipment 14%, and Fans 1% of energy use.

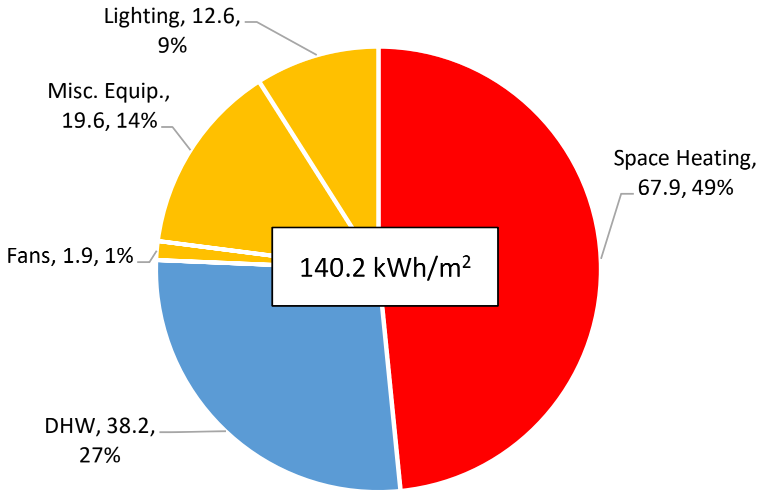


Figure 4.16 Energy consumption by end-use for modeled Building 2

The metered energy data was used in calibrating the Building 2 model to ensure good agreement with the actual energy use profile. The available groupings of metered data varies slightly from that of Building 1 but can still be used for calibration. A comparison of the total monthly electricity use and monthly space heating use are shown in Figure 4.17 and Figure 4.18, respectively. The percentages indicated represent deviation of the monthly modeled from metered energy use. The model shows good agreement with both total energy use and space heating throughout the year and follows seasonal variations in heating demands and space use. The annual modeled whole building energy use deviates from the metered value by 1%. The greatest monthly deviation of modeled from metered whole building energy use occurred in July (10%).

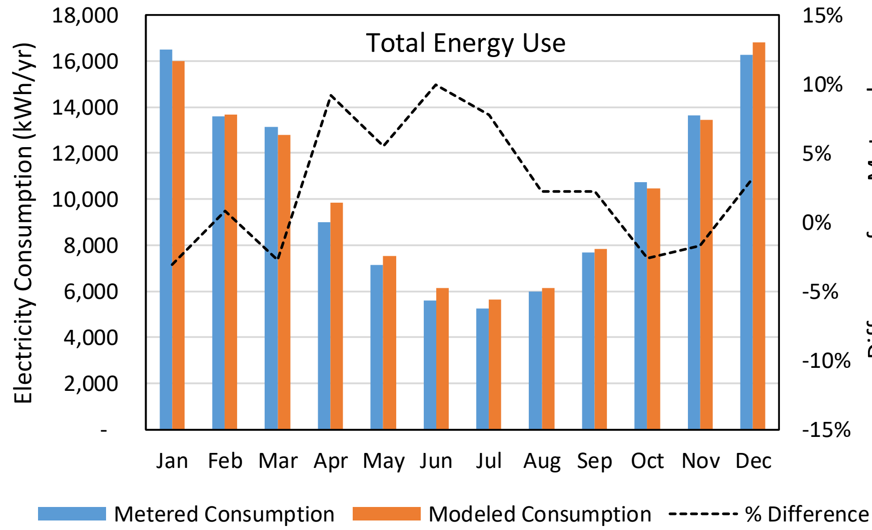


Figure 4.17 Comparison of Building 2 monthly metered and modeled whole building total electricity use

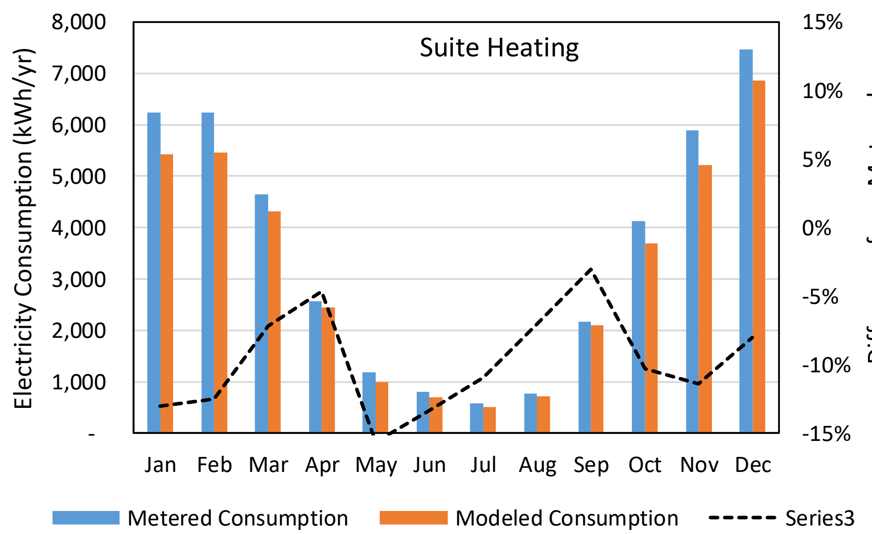


Figure 4.18 Comparison of Building 2 monthly metered and modeled unit space heating electricity use

4.3.3 Baseline Model (Typical Construction) Inputs

The calibrated model of Building 2 was modified to include characteristics of typical construction to be used as a baseline for comparison to the higher performance design of the actual building. The baseline building was assumed to be constructed to slightly higher than code minimum standards based on typical construction in Yukon. The characteristics of the baseline building used in the energy model are provided in Table 3.2. The changes from the actual Building 2 model are shown in bold.

TABLE 4.2 BASELINE MODEL INPUTS FOR BUILDING 2			
	Units	**Value**	**Notes and References**
Building Geometry			
Storeys		2	
Total conditioned area	m^2	901	
Internal Loads and Schedules			
Occupant Density	pers/unit	3.25	Based on available bedrooms
Heating Set Point	˚C	22	Calibrated modeling
Heating Set Back	˚C	None	
Plug & Process Loads	W/m^2	5	Calibrated modeling
Lighting	W/m^2	6.5	Calibrated modeling
Average Daily DHW Consumption	Gal/unit/day	55	Calibrated modeling
Schedules	N/A		See Appendix
Building Enclosure			
Above Grade Wall R-Value	m^2-K/W (hr-ft^2-F/Btu)	**4.9 (25)**	**2x6 wood stud @ 16" o.c. with fiberglass batt and 2.5" fiberglass batt interior insulation**
Below Grade Wall R-Value	m^2-K/W (hr-ft^2-F/Btu)	N/A	N/A
Roof R-value	m^2-K/W (hr-ft^2-F/Btu)	**10.6 (60)**	**24" wood trusses 24" O/C** **18" Cellulose insulation (R63)**
Slab on Grade R-value	m^2-K/W (hr-ft^2-F/Btu)	**1.8 (10)**	**2" XPS insulation** **2" concrete slab**
Window U-Value	W/m^2-K	**1.4 (0.25)**	**Vinyl, triple pane, argon fill, 2 low-e coatings**
Window SHGC		**0.25**	**Zone 4, ASHRAE 90.2010 Res**
Window to Wall Ratio		14%	Building drawing
Infiltration rate	ACH@50Pa	**1.5**	**Whitehorse Green Building req.**
Mechanical Systems			
Heating	**Oil 85% AFUE (ducted forced air)**		
Cooling	None		
Ventilation	**63% sensible effectiveness heat recovery ventilator**		
Domestic Hot Water	Electric tank-type, 3000 watts/unit		

4.3.4 Comparison to Baseline

Figure 4.19 shows the distribution of energy consumption by end-use for the Building 2 baseline model with typical construction. The total energy use intensity is 174.5 kWh/m^2 (22.2 MWh per unit). The energy end-use breakdown shows that space heating accounts for 55% of the energy use in the Building 2 baseline model while DHW and Equipment & Lighting loads account for 22% and 23%, respectively.

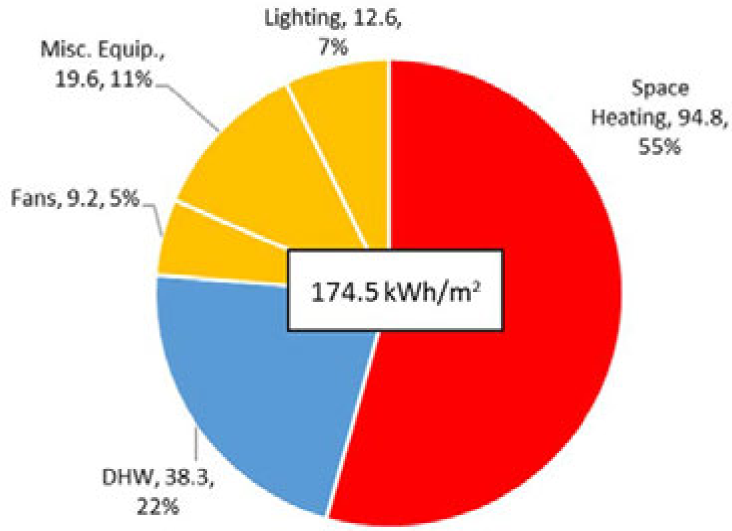


Figure 4.19 Energy consumption by end-use for modeled Building 2 baseline with typical construction characteristics

The monthly total energy use, space heating, DHW, and equipment & lighting energy consumption for the modeled Building 2 baseline is shown in Figure 4.20 through Figure 4.23. The Building 2 model uses less energy than the baseline in all months of the year with the greatest savings occurring throughout the winter. This is a result of the substantial savings in space heating energy during the winter months. Savings also occur throughout the year for Equipment & Lighting loads due to the use of an HRV with electric baseboards in the actual building compared to the an HRV and oil fired furnace in the baseline.

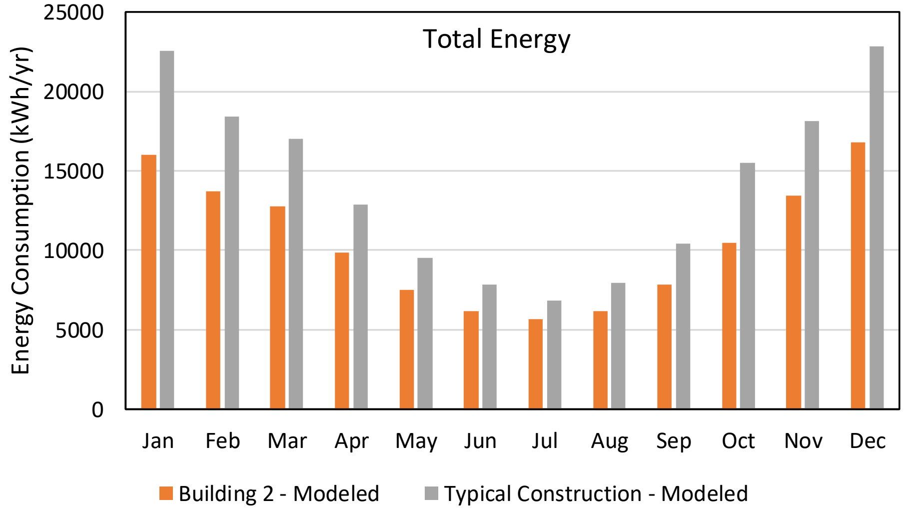


Figure 4.20 Comparison of Building 2 monthly modeled and baseline (Typical Construction) whole building total heating energy use

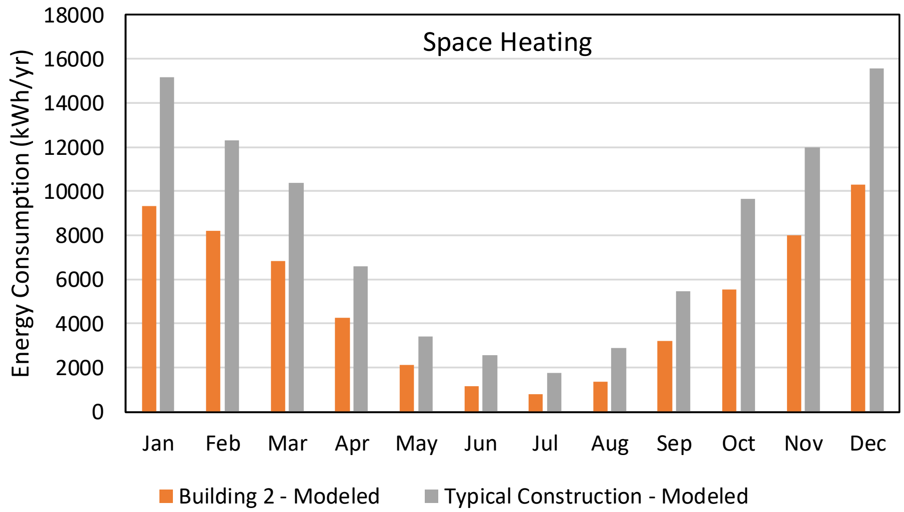


Figure 4.21 Comparison of Building 2 monthly modeled and baseline (Typical Construction) whole building space heating energy use

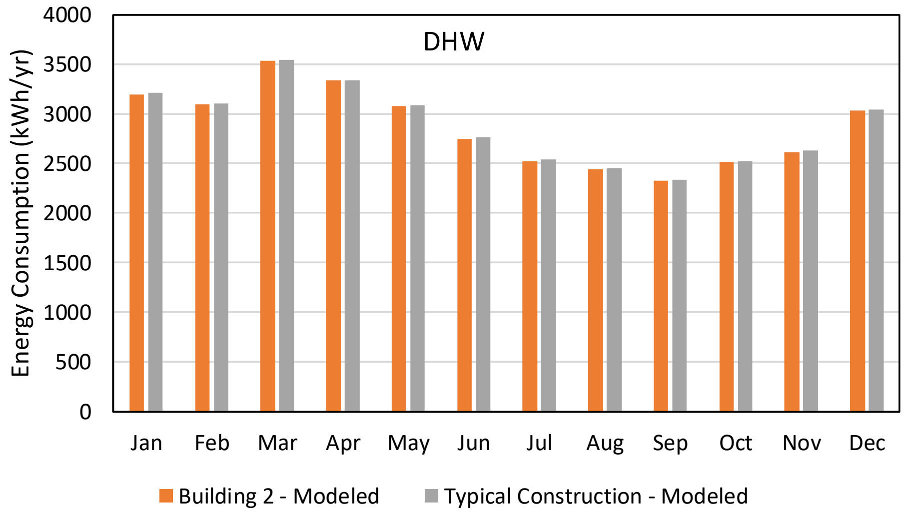


Figure 4.22 Comparison of Building 2 monthly modeled and baseline (Typical Construction) whole building DHW energy use

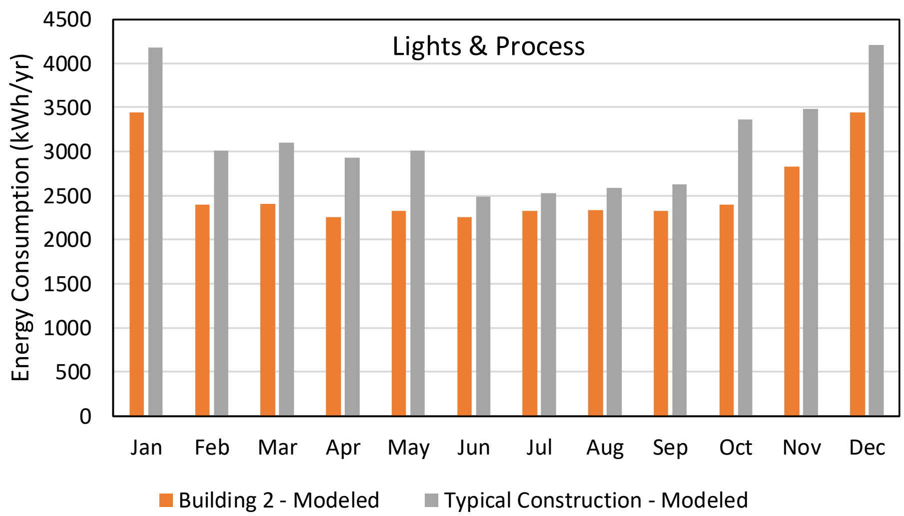


Figure 4.23 Comparison of Building 2 monthly modeled and baseline (Typical Construction) whole building Process & Lights energy use

The annual operation energy and GHG savings from the design of Building 2 with improved energy efficiency features (Table 4.1) compared to the typical baseline in Whitehorse (Table 4.2) are shown in Table 4.3. The emissions factors used for Whitehorse were 2.74 kg/L (0.254 kg CO_2e/kWh) for Fuel Oil and 0.05 kg CO_2e/kWh electricity[10].The energy efficiency improvements included in the building construction result in 31.6 kWh/m²/yr (18.1%) of energy savings and 20.6 kg/m²/yr (74.6%) of GHG savings per year. This is predominantly a result of the reduction in space heating energy use and a switch from fossil fuel burning in an oil-fired furnace for the baseline to the use of electric baseboard heating in the actual building. Building 2 as constructed uses approximately 26% less energy for heating than comparable building of typical construction in

[10] Emission factors obtained from City of Whitehorse Corporate Milestone 5 Report (https://www.fcm.ca/Documents/reports/PCP/Whitehorse_Corporate_Milestone5_Report.pdf) Table 1. Note, the emissions factors indicted in the table should be in units kg/L or kg/kWh to align with actual energy densities.

Whitehorse. The modest GHG savings resulting from Equipment & Lights are a result of not having a furnace fan in the actual building.

TABLE 4.3 COMPARISON OF ANNUAL ENERGY AND GHG SAVINGS FROM BUILDING 2 VERSUS THE TYPICAL WHITEHORSE BUILDING CONSTRUCTION						
	Baseline		**Building 2**		**Savings**	
End Use	**Energy (kWh/m^2)**	**GHG (kg/m^2)**	**Energy (kWh/m^2)**	**GHG (kg/m^2)**	**Energy (kWh/m^2)**	**GHG (kg/m^2)**
Space Heating	108.5	27.6	67.9	3.4	40.6 (37.4%)	24.2 (87.7%)
DHW	38.4	1.9	38.2	1.9	0.2 (0.4%)	0.0 (0.4%)
Equip. & Lights	41.6	2.1	34.1	1.7	7.5 (18.1%)	0.4 (18.1%)
Total	188.4	31.6	140.2	7.0	48.3 (25.6%)	24.6 (77.8%)

Note: The space heating in the baseline model uses fuel oil whereas the space heating in the Building 2 model uses electricity.

5 Conclusions

Buildings located in northern regions of Canada are exposed to significantly colder weather than in more Southern locations which can result in higher annual energy consumption than the national average. Understanding and reducing energy consumption by buildings in the North is of increasing interest to a number of parties. Yukon Housing Corporation has supported the design and construction of energy efficient residential buildings in northern Canada with the aim of identifying technologies and design practices that lead to reduced energy consumption. The Yukon Housing Corporation has recently constructed buildings with energy efficient features to test the impact on energy consumption and has equipped these buildings with sensors to monitor building operation and energy consumption. This work provides an analysis of the data from two such buildings to understand the impact of the designs on energy use in the North and identify performance trends.

The main energy efficiency improvements made over typical Whitehorse construction in both buildings were the use of greater levels of enclosure insulation, higher performance windows (triple or quad pane), and increased heat recovery efficiency in the ventilation system. Heating was also provided by electric baseboards instead of fossil fuel furnaces. This design allows for a reduction in heating demand while simultaneously moving away from fossil fuel use eliminating the need for fuel oil delivery to the building. Both Building 1 (18.4 MWh/yr/unit) and Building 2 (15.6 MWh/yr/unit) were found to use less energy than the typical Whitehorse dwelling (26.6 MWh/yr/unit) but this is likely due in part to small floor areas from rowhouses and apartment buildings compared to the standard.

Occupant behaviour was found to have a significant impact on the energy use of units within both buildings. Occupants can affect energy use through operation choices such as thermostat temperature settings, behaviour patterns such as window opening or lighting use, and hot water consumption practices. Comparison between units in Building 1 showed that the highest energy consuming unit used 63% more energy per dwelling unit (34% when normalized by floor area) than the lowest energy consuming unit. There was also significant variability between units for energy end use. The highest energy consuming units used 162%, 165%, and 92% more energy than the lowest energy consuming units for DHW, space heating, and Lights & Process loads, respectively. When normalized by building floor area the differences in consumption persist though to a smaller degree with the highest consuming units using 116%, 147%, and 77%% more energy than the lowest energy consuming units for DHW, space heating, and Lights & Process loads, respectively. Sub metering of the space heating energy in Building 2 showed large variability between units with the greatest using 390% more energy than the least consuming unit (on a per unit and per floor area basis). Other factors likely account for some (but not all) of this variation include differences in enclosure area of the suits as well as the number of occupants and associated internal equipment which could not be determined from the available data.

Energy modeling was used to compare the energy use from the actual buildings to a theoretical baseline with the same operating characteristics but with construction characteristics of typical new buildings in Whitehorse. The energy efficiency improvements included in Building 1 resulted in 46.1 kWh/m^2/yr (27.8%) of energy savings and 19.6 kg/m^2/yr (76.6%) of GHG savings per year compared to the baseline model. The energy efficiency improvements included in Building 2 resulted in 48.3 kWh/m^2/yr (25.6%) of energy savings and 24.6 kg/m^2/yr (77.8%) of GHG savings per year compared to the baseline model. These savings are predominantly a result of the reduction in space heating energy use and a switch from fossil fuel burning in an oil-fired furnace for the baseline to the use of electric baseboard heating in the actual building.

Comparison of measured and modeled data for these two buildings constructed in Whitehorse shows that constructing housing with improved building enclosure performance can result in lower energy consumption relative to typical construction practices. The amount of energy use within the units of the buildings varied substantially indicating that differences in number and characteristics of occupant can influence overall building energy consumption. The difference in measured energy use between units shows that there is potential for further energy reduction in the building by influencing occupant choices. Benefits could potentially be gained through educational efforts to highlight the impact of occupant choices on the overall building performance.

Yours truly,

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