# Energy consumption of an energy efficient building envelope in the Canadian Arctic

Carsen Banister[1[0000-0002-8055-0824]], Michael Swinton[1], Travis Moore[1], Dennis Krys[1], and Iain Macdonald[1]

[1] National Research Council Canada, Ottawa ON K1K 4R7, Canada
carsen.banister@nrc.ca

**Abstract.** A demonstration house was built and commissioned in Iqaluit, Nunavut, Canada. The purpose of this work is to evaluate the energy consumption of the high performance building, while considering the unique social, economic, and logistical challenges for such a remote location. At 4.5 m by 5.4 m internal dimensions, the building has approximately 24 m$^2$ of floor area and is a 15 cm thick structural insulated panel (SIP) system with an R value of 24 (RSI 4.23) at a panel mean temperature of 0°C. A full year of monitoring has been conducted thus far, between April, 2016 and April, 2017. The cold climate required heating during all but a few hours of the year, with the outdoor ambient temperature ranging from -39°C to +21°C and a total of 9,540 Celsius heating degree days for calendar year 2016. Daily heating energy consumption ranged from a peak of 30.4 kWh in the winter down to a minimum of 0.9 kWh for a small number of days during the summer when outdoor ambient temperatures neared 20°C. The total heating electricity consumed for the period of April 25, 2016 to April 25, 2017, including electronics and lighting, was 4,945 kWh. Based on the floor area, the building had an energy use intensity of 206 kWh per m$^2$.

**Keywords:** structural insulated panel, energy performance, cold climate.

## 1 Introduction

A research house (shown in Fig. 1) was built and commissioned by Qikiqtaaluk Corporation and instrumented by National Research Council Canada (NRC) in Iqaluit, Nunavut, Canada, a city of 7,740 people which lies on Baffin Island in the Canadian Arctic at 64°N 59°W. Qikiqtaaluk Corporation is interested in housing solutions that are durable, rapidly constructed, energy efficient, and can be manufactured in the territory. The house is constructed of an innovative structural insulated panel (SIP) design which comprises the floor, walls, and roof/ceiling of the building. The primary purpose of this investigation was to assess the energy performance of the building envelope over the course of at least a full elapsed year. Monitoring began on April 25, 2016 and is ongoing at the time of writing. A counterpart publication [1] describes the in-situ R-value measurements of the building envelope over the course of the year and may provide additional background information for the work presented here.

Iqaluit is situated in a harsh northern climate, with approximately double the heating degree days of Ottawa, Ontario, Canada, which is located at 45°N 76°W. At the north end of Baffin Island is Pond Inlet at 73°N 78°W with a staggering average 12,000 HDD [2], about 30% greater than Iqaluit. This is of relevance because the energy performance in other cold climate locations is of interest.

**Fig. 1.** Qikiqtaaluk demonstration house in Iqaluit

There is little to no information on building heating energy usage in Nunavut, either in literature or in governmental reports. In fact, the Survey of Household Energy Use by Natural Resources Canada includes very detailed statistical data for all regions in Canada *except* all three Canadian territories (Yukon, Northwest Territories, and Nunavut) [3]. Thus, the results cannot readily be compared to like results in locations with similar conditions. In addition, the lack of existing information on thermal performance of buildings in the far north indicates a need for continued study and dissemination of information.

This house is taken to be energy efficient, as its air leakage is minimal at about 0.30 air changes per hour (ACH), it has minimal thermal bridging, and it can be prefabricated in northern remote communities.

## 2 Methods and Materials

### 2.1 Instrumentation

**Heat Transfer Instrumentation.** Instrumentation for measuring the heat transfer across the building envelope was installed on the wall, floor, and ceiling of the house. The primary technique used included designing and building custom instrumentation panels which consisted of a calibrated 1 in. specimen of EPS insulation, several thermocouples, and a heat flux transducer. The approach enables calculation of building envelope R-value by two methods. Details of the instrumentation for heat transfer, along with results and conclusions, are presented in the counterpart paper [1].

**Heat Source Instrumentation.** The demonstration building is fitted with three infrared (IR) heating panels, each mounted to a wall of one of the three rooms in the interior space. Fuel oil heating is common practice in the locale; however, it was not used for this project for at least two reasons. First, a gravity fed heater supplied by an outdoor tank cannot be metered accurately. Second, a main goal of this work is to develop systems and methods to offset the use of fossil fuels in remote and/or Arctic communities. The electricity consumption of the components within the house was measured using power meters seen in Fig. 2.

**Fig. 2.** Installed power meters to measure electricity consumption.

### 2.2 Modelling of House Heating Consumption

A model was created in ESP-r to define the test building in Iqaluit as shown in Fig. 3. The building was modelled as an "Energy Efficient Building" with an assumed constant air leakage of 0.1 air changes per hour.

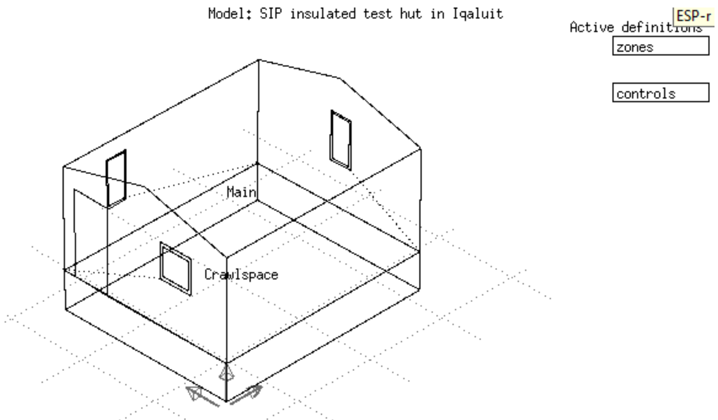


**Fig. 3.** ESP-r building energy model screenshot

**Model Description.** The model was defined in the information provided in Table 1 thru Table 4: window dimensions by location (Table 1); building dimensions (Table 2); building construction materials characterization (Table 3), and glazing configuration (Table 4).

**Table 1.** Window dimensions by location.

| Dimension Type | Orientation | West wall | South wall | North wall |
|---|---|---|---|---|
| Height from floor (mm) | | 1113 | 1029 | 895 |
| Rough opening | Width | 870 | 559 | 540 |
| | Height | 870 | 1178 | 1162 |
| Glazing area | Width | 702 | 464 | 464 |
| | Height | 702 | 1076 | 1073 |

**Table 2.** Building dimensions.

| Component | Orientation | Size (m) |
|---|---|---|
| Roof | - | 0.6 |
| | Width | 4.5 |
| Main Zone | Length | 5.4 |
| | Height | 2.5 |

**Table 3.** Building constructions.

| Component | Material | Thickness (mm) | R (BTU/hr °F ft$^2$) | RSI ($m^2$ K/W) |
|---|---|---|---|---|
| Wall | Insulation | 157 | 27.4 | 4.8 |
| | Siding | 13 | | |
| Floor | Insulation | 158 | 27.4 | 4.8 |
| Roof | Insulation | 158 | 27.4 | 4.8 |

**Table 4.** Triple glazing window construction.

| Layer | Thickness (mm) |
|---|---|
| Clear glass | 6 |
| Argon fill | 12 |

**Weather Data.** The overall weather data used for the modelling process were based on data recorded by Environment and Climate Change Canada from the Iqaluit Airport weather station [4]. Solar radiation data were not directly available for this location, as pyranometers had not been installed. Sky cover information was available, which was used in conjunction with models by Risk Sciences International, Inc. to estimate what the solar radiation component values might have been. In some periods of time on the order of a few hours, it was necessary to perform linear interpolation to provide missing data. This was seen to be an appropriate approach due to the short length of time for each occurrence of missing data. The ambient dry bulb temperature data used for modelling are shown in Fig. 4.

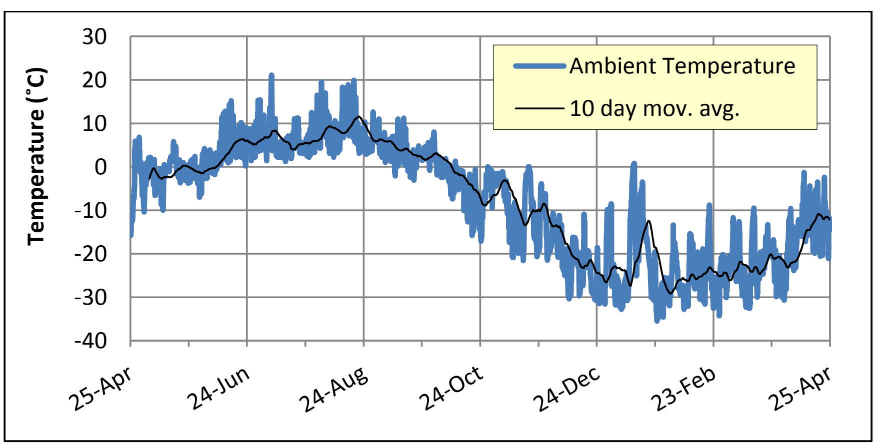


**Fig. 4.** Iqaluit ambient dry bulb temperature weather data used for modelling.

# 3 Results

## 3.1 House Electrical Consumption

The total daily electricity consumption of the Qikiqtaaluk Demonstration House is plotted in Fig. 5. The total daily consumption includes the electricity consumption for the three IR panel heaters (one in each room), lights and power outlets. The energy consumed and monitored from the outside lights has been removed from this data. Thus the values in Fig. 5 represent the energy consumed inside the house since the start of monitoring on April 25, 2016 until April 24, 2017. This energy usage represents the amount of heat required to maintain the indoor air temperature. Any energy consumed by lights or equipment inside the building contributes to heating the space, thus this energy would have to be added by either the heating system or lights and equipment, regardless.

However, it is important to note that the building was unoccupied during the monitoring period, since an active use for the space has not yet been identified. The internal heat gains due to the occupants and their activity would reduce the energy required to be delivered by the heating system. In an opposite way, the house would require ventilation air if occupied, which would increase the heating energy consumption. Future plans to continue to monitor building performance, add a ventilation system, and add occupancy of the building would enable an enhanced ability to predict the actual energy consumption of the building in use.

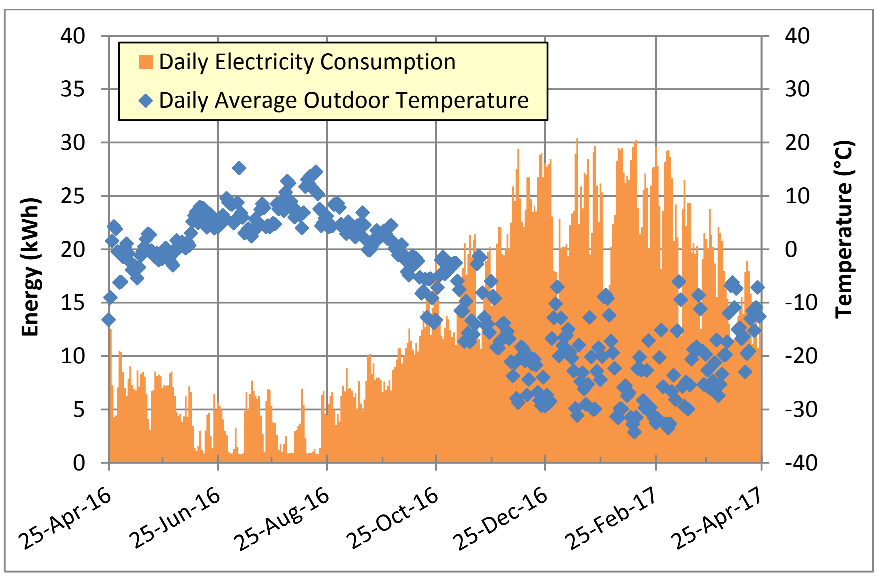


**Fig. 5.** Daily electrical consumption and corresponding daily average outdoor temperature.

From the data provided in Fig. 5 it can be seen that when this building is subjected to the Iqaluit climate, it requires heating for nearly the entire year. Indeed, there are very few days when heating is not required.

Daily average outdoor temperatures were calculated from the data measured at the Iqaluit Airport are also shown to highlight the dependence of total consumption on outdoor temperature. The relationship between daily total consumption and daily average outdoor temperature is shown explicitly in Fig. 6. The maximum daily consumption is about 30 kWh per day at a daily average outdoor temperature of just under -30°C. The minimum daily consumption at the bottom right of the graph when there is no heating load is about 0.88 kWh per day, which is what is consumed by the data acquisition system (including computer, modem, and other devices). This represents about 37 Watts of continuously connected power.

The total electrical energy consumed inside the house for the period of April 25, 2016 to April 24, 2017 was 4,945 kWh. At an assumed rate of CAD$0.60 per kWh [5], the cost of heating for this period is CAD$2,967. It was necessary to use electrical energy to heat the house rather than oil, since the gravity-fed oil heater could not be accurately metered. Ideally, renewable resources such as solar and wind energy could be used to reduce cost, increase self-sufficiency, and reduce environmental impact. An alternative energy source, such as small wind power would be less expensive per unit of heating energy delivered [6], therefore reducing this cost.

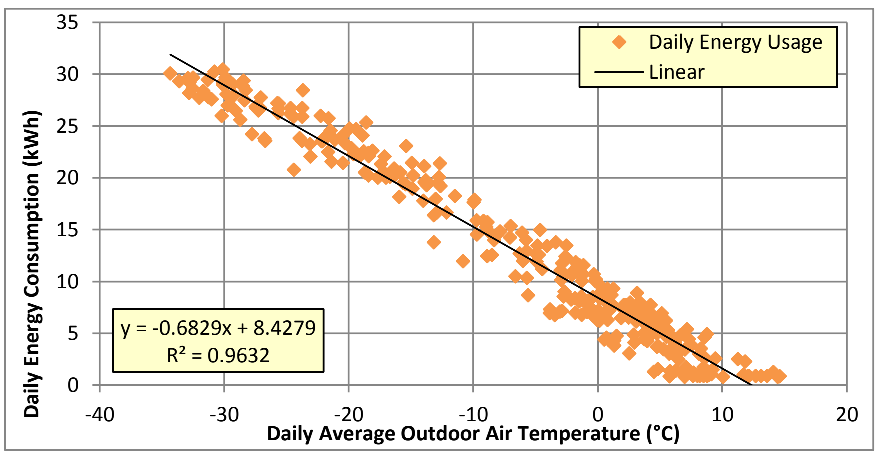


**Fig. 6.** Relationship between daily energy consumption and daily average outdoor temperature.

Based on the floor area of 24.3 $m^2$, the energy use intensity (EUI) of the building for the monitoring period in Iqaluit was 203 kWh/$m^2$/yr or 0.73 GJ/$m^2$/yr. As anticipated, this compares favourably to typical construction in Canada. The 2011 Survey of Household Energy Use by Natural Resources Canada was consulted for comparison [8], which is a very detailed analysis of residential buildings and their energy use. Values for EUI are available for many regions of Canada, but does not include the three territories. For buildings under 56 $m^2$, the average EUI in Québec was estimated at 0.98 GJ/m2/yr and for Ontario was 0.83 GJ/$m^2$/yr.

It must be noted that these figures are not adjusted based on climate. Although the provincial figures are averages, it is reasonable to estimate that the climatic load in these two provinces is on the order of half that of Iqaluit, supported by this being true for Ottawa in comparison to Iqaluit, as noted earlier in this report.

## 3.2 Modelling Results

The total modelled heat loss for Iqaluit was 4,801 kWh, whereas the actual measured consumption was 4,935 kWh. This represents a 3% under-prediction of the energy consumption by the model. This is quite good agreement between the total annual energy consumption between the modelled and measured test house. However, the agreement should be accompanied with a reasonable amount of skepticism, as it is possible the errors of some effects are counterbalancing each other. Potential factors contributing to the uncertainty of the model are presented later in this section. Despite these possibilities, it is evident that the building energy model is representative of the overall performance of the house.

Fig. 7 shows the relationship between the modelled energy consumption and the outdoor temperature. The annual model results are presented in comparison to the measured results in Fig. 8.

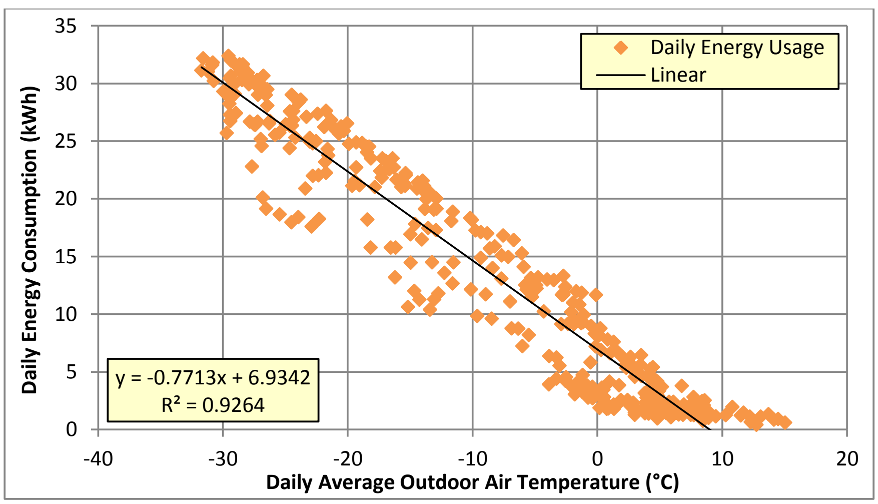


**Fig. 7.** Modelled daily energy consumption versus daily average outdoor air temperature.

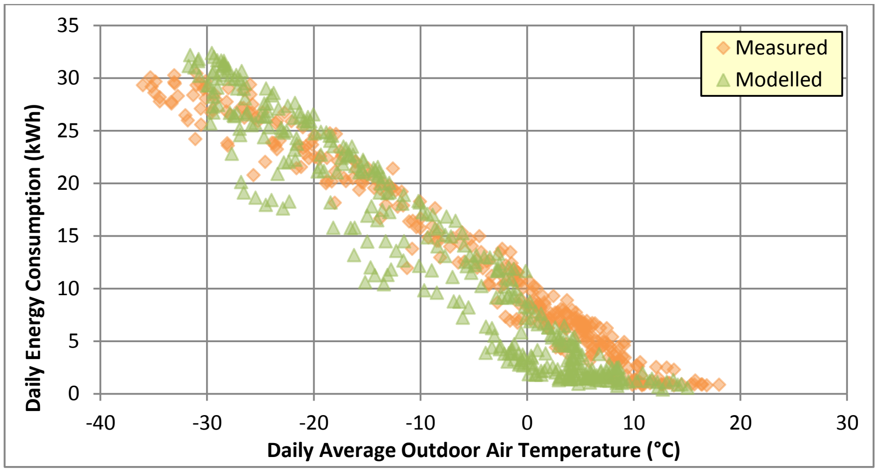


**Fig. 8.** Comparison of modelled and measured daily energy consumption data.

As can be seen in Fig. 7 and Fig. 8, the model underestimates the energy consumption of the prefabricated house on milder days by a small degree (i.e. < 5%). It then overestimates the energy consumption during colder days, i.e., those below approximately -25°C daily average outdoor air temperature. As a result, the slope of the linear trendline for the model is steeper than that of the measured data.

This indicates that for climates with milder annual average weather, the model might be expected to under predict energy consumption slightly more, and for colder annual average weather, the model might be expected to over predict energy consumption slightly. Despite this, the already good accuracy enables a reasonable prediction of energy usage performance via parametric studies.

The same modelling results data are shown in Fig. 9, but presented chronologically over the monitoring period.

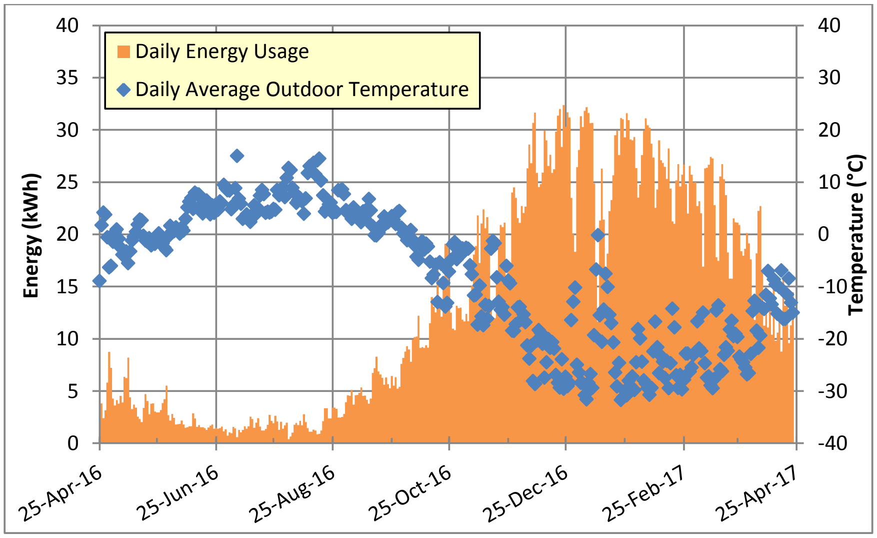


**Fig. 9.** Modelled daily electricity consumption and average outdoor air temperature.

**Differences Between Measured and Modelled.** The model results were found to agree with the measured data to a reasonably high accuracy (i.e. $< 5\%$ deviation). As with all modelling, there is always deviation from actual results due to many factors, in this case, such as:

- Uncertainty in values for solar radiation;
- Exactness of orientation;
- Deviations between actual material properties and modelled properties;
- Underlying assumptions of or in model governing equations; and
- Other unknown factors to be discovered;

Despite these limitations, there is opportunity to adjust the model to provide more accurate results given some additional information in respect to climate loads, building orientation and variations in material properties. Accurate solar radiation measurements on site would help correct some potential uncertainty, as high differences between modelled and measured were seen on cold days having significant solar radiation.

Given that it is impossible to model a building to perfection, the deviation between the model and measured values for a given location can be noted and used to adjust for results in a different location if reasonable understanding of the reasons for deviation is thought to be known and this knowledge can be applied to the transformation.

## 4 Summary and Conclusions

A demonstration house was built in Iqaluit and instrumented to monitor the energy performance of the structural insulated panel technology from which it is built. To date, over a year of elapsed monitoring has been conducted, and is still ongoing at the time of writing. The energy consumption results of the house have been presented, along with a comparison to the results from a building energy model.

The total energy consumed by the house from April 25, 2016 to April 24, 2017 was 4,935 kWh, which is an energy use intensity of 203 kWh/m$^2$/yr or 0.73 GJ/m$^2$/yr. Lack of data for residential energy consumption in such climates makes comparison to other technologies difficult. In addition, it is important to note that the house was unoccupied during the period monitored thus far, therefore energy consumption is expected to be higher during occupancy due to the need for mechanical, heat recovery ventilation.

The building configuration was replicated in ESP-r to develop a model for future work and was benchmarked against the measured annual energy consumption. The model underestimated energy consumption slightly at mild outdoor temperatures and overestimated at cold outdoor temperatures, but was within 3% of measured consumption overall, demonstrating excellent agreement. The benchmarked model will be used to support further development of this residential building solution in harsh cold climates.

Building physics, energy systems, and mechanical systems modelling can be used in the future to advance the design and functionality of this building solution. Some potential investigations or advancements include: various locations; optimization, e.g., window placement, adding a vestibule, adding insulation; ventilation strategy; occupancy scenarios; humidity loads, e.g., from cooking; predicting thermal comfort; interactions with energy system(s); and alternate heating system(s).

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