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Partnership
Reconciliation in Action

Energy Model Report of a House Located in Island Lake

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1. Introduction

This report is created based on the provided data to build an energy model of a house. The report may be used to educate and assist the community to understand the impact of multiple simple measures that could reduce the energy consumption of their existing or to be built houses in northern Manitoban communities. Furthermore, building energy modeling can enable better-informed design solutions and compliance with energy codes and standards. EnergyPlus is used to develop the energy model of the proposed design of the house to be built in Island Lake. The 3D model of the house is generated based on the architectural drawing, moreover, each construction (e.g. walls, roof, and floor) is defined by specifying all the materials required in each assemble to reflect the house's design. Additionally, all the internal loads will be assigned and scheduled to reflect the average occupancy behavior and operation of a house in the community. Furthermore, the nearest weather file will be used to run the simulation to predict the energy consumption and the indoor temperature of the house. Later, the model can be utilized to optimize the proposed design by exploring several orientations and materials to minimize house energy consumption and maintain desirable indoor conditions.

There are numerous feasible retrofit alternatives with varying costs and different energy-saving potentials available for the building’s owner. According to Natural Resources of Canada (2016), even minor and major retrofit measures can make a big difference to the building’s energy consumption and lead to energy savings between 15% and 40%. The improvement of energy performance is, therefore, the result of choosing from a selection of technically favorable and cost-effective retrofit measures (Kumbaroglu et al., 2012). Thus, the report is aimed at investigating the impact of retrofit measures on the energy consumption of a house located in northern Manitoba.

The main objectives include:

1) Identification of most appropriate energy conservation measures for the single-family house.
2) Development of energy models for house retrofitting by integrating the set of measures that improve energy consumption.
3) Assessment of ‘before and after’ retrofit benefits on the house energy consumption.

4) Ranking of the retrofit measures in terms of energy-saving potential and the identification of the most effective retrofit measure.

2. Background of Retrofit Measures

2.1. Potential of energy-savings retrofit measures for residential buildings

In most countries, the energy use of the residential sector accounts for 16–50% of that consumed by all sectors nationally, and averages approximately 30% worldwide (Saidur et al., 2007). This significant consumption level warrants a detailed understanding of the residential sector's consumption characteristics to prepare for and help guide the desired reduction in energy consumption. One of the best approaches to do so would be by the utilization of building retrofit. Florentzou and Roulet (2002) defined the retrofit as a list of modifications required to upgrade to new requirements an aged or deteriorated building, which includes the evaluation of the state of all the building components as well as the information about indoor air quality, obsolescence, and energy use. Love and Bullen (2009) considered retrofitting as an effective strategy to enhance the sustainability of new and existing facilities at relatively low cost and high uptake rates. Thus providing significant opportunities for reducing global energy consumption and greenhouse gas emissions.

A significant amount of research has been carried out to develop and investigate different energy efficiency opportunities in order to improve the energy performance of houses (Chidiac et al, 2011; Xing et al., 2011; Chidiac et al., 2011; Florentzou and Roulet, 2002; Ardente et al., 2011). The results of these studies have shown that energy use in buildings can be reduced significantly through proper retrofitting. Besides the improved energy efficiency, the other benefits include better thermal comfort and reduced maintenance costs.

2.2. Analysis of available retrofit measures

There is a wide range of readily available building retrofit technologies. The set of solutions applied in residential buildings may be unique for every retrofit project. It can vary depending upon the type of building, total budget available, climate, rules, and regulations of that place, etc.

To find the optimal set of retrofit measures a literature survey of journal papers is carried out reviewing decision-making tools for energy retrofit of residential buildings (Appendix 1). According to Chidiac et al. (2011), the subject of significance is the identification of the most appropriate retrofit options based on the potential expenses and effects involved. Therefore, the following are retrofits measures identified as the most appropriate for analysis and modeling purposes:

1) Airtightness and infiltration:

Airtightness is the building property that impacts the uncontrolled infiltration and exfiltration leakage of outdoor air through cracks or unintentional openings in a building envelope, caused by pressure effects of the wind and stack effect inside the house (Limb, 1992). Simulation on a large number of building types has shown that reducing air leakage can save 5–40% of heating and cooling energy (OECD/IEA, 2013).

2) Lighting retrofit

Lighting retrofits can provide a flexible, maintainable long-term system in any type of building. Building owners can offer their occupants better light quality, improving working conditions and benefitting occupants as a whole. According to studies this retrofit could result in energy and cost savings of approximately 30% (Chow, 2012).

3) Window retrofit measure

Darwish and Gomaa (2017) indicated that window retrofit indirectly facilitated enhanced daylighting, increased insulation UV ray blockage, reduce condensation between glass panes and resulted in better occupant comfort. Low-e coated glazing was found to be clear and available for high, moderate or low solar gain (Branz, 2015). Talfeldt et al. (2013) reported that with more panes and low-emissivity coatings the energy performance will be improved. Arichi et al. (2012) indicated that the benefit of multiple pane windows is more profound in cold regions. Darwish and Gomaa (2017) showed that high-performance glazing can reduce energy demand by 8% on average. This is almost in line with the finding from Ascione et al. (2011) that this retrofit action can bring up to 12% of energy savings. However, those savings may vary depending on the location, amount of solar gains and the window-to-wall ratio of the house.

4) Thermal Curtain:

In order to improve the thermal comfort of residential buildings in cold climate zones, the construction must have good insulation. The window is an important part of the building envelope, reducing the heat transfer coefficient of them is very important for building insulation. Thermal curtains are made from a thin material which helps to reduce the thermal bridging throughout the windows of the house due to their low thermal conductivity since windows are the weakest point in the envelope. A moveable external or internal over-head night-time insulating shutter has been proven through experimental tests to reduce energy consumption considerably. Arinze et al. (1986) found that the principal effect of thermal curtains is to provide additional thermal resistance, which reduces the overall rate of heat transfer to the surroundings. Rebuck et al. (1977) concluded from their experimental test results on the effect of internal curtains for energy conservation in greenhouses that the potential night-time reduction in fuel used for greenhouse heating ranged from 26% to 57% for a single-glazed glass greenhouse using various materials as internal night curtain.

5) Thermostat Set-Back point

According to Ascione et al. (2011) the modification of indoor set-points could lead to savings of around 10-11%. Especially using thermostat set-back setting during the unoccupied hours or over the night, which not only reduce the energy consumption when the house is not occupied but also does not affect the thermal comfort of occupants since they are not at home.

Table 1 Savings potential of retrofit measures according to the previous studies

	Retrofit	Energy impacts	Saving potential
1	Envelope’s Airtightness	Reduce heating and cooling demand	5%-40% (OECD/IEA, 2013)
2	Replace double-pane windows with triple pane windows	Reduce heating and cooling demand	Up to 12% (Ascione et al. 2011)
3	Lighting retrofit	Reduce electricity consumption	Up to 30% (Chow, 2012)
4	Thermal curtain	Reduce heating and cooling demand	26% -57% (Rebuck et al., 1977)
5	Thermostat set- back point	Reduce energy consumption	Up to 11% (Ascione et al., 2011)

3. Energy Modeling

3.1. EnergyPlus Software

Reliable estimation and quantification of energy benefits are essential in a sustainable building retrofit decision-support system for prioritization of retrofit measures. The performance of different retrofit measures is commonly evaluated through energy simulation and modeling. There are a number of whole-of-building energy simulation packages, such as EnergyPlus, BLAST, eQUEST, DOE-2, TRNSYS, etc., that researchers can use to simulate the energy performance of different retrofit measures. EnergyPlus is a simulation engine that integrates ASHRAE's preferred heat balance method based on actual thermodynamic equations developed by the U.S. Department of Energy’s (DOE) Building Technologies Office (BTO) and managed by the National Renewable Energy Laboratory (NREL) (BLAST, 2003). EnergyPlus also contains automated sizing of many component-specific parameters, inter-zonal airflow, and definitions of realistic heating, ventilation, and air-conditioning (HVAC) systems, and controls. Moreover, EnergyPlus is able to simulate multiple systems for a single building using a network of nodes, which offers greater flexibility to the model to incorporate most aspects of the design (Al-janabi et al., 2019) to improve the accuracy of the model. Some researchers such as Chidiac et al. (2011), Darwish and Gomaa (2017) used in their studies EnergyPlus to simulate the effectiveness of retrofit measures for buildings. EnergyPlus was used to evaluate and measure the energy performance and the estimated saving based on the prediction of an energy model of a single-story house.

The first step is to create a model of a typical house based on the architectural drawings. The model is assumed to simulate the energy consumption of a new house in Island Lake, where it will be the base model in this study. Furthermore, 6 models are created in which the models reflect the base model plus one of the proposed retrofit measures. The purpose of creating several models is to quantify the expected energy saving for each method which will enable us to further understand the impact of those measures and help us to list the measures from most effective to the least based on the model predictions.

3.2. Weather data for modeling purposes

Island Lake falls under climate zone 7B - 8 according to the climate zone designations by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) (ASHRAE, 2013). Island Lake experiences all four seasons with dramatic variation in temperature between summer and winter. Canadian Weather for Energy Calculations (CWEC) (Normals 2010) file was used in the simulation of the house model. The CWEC file is the combination of 12 typical meteorological months, contains hourly weather data records representing a typical meteorological year (TMY) specifically designed for building energy simulation, which predicts approximate average heating and cooling loads in buildings (EnergyPlus, 2017). Each meteorological month in the CWEC file is selected from a 30 years database of Canadian Weather Energy and Engineering Datasets (CWEEDS). The use of the CWEC file is required by the National Energy Code of Canada (NEC) in building energy simulation to comply with the requirements (EnergyPlus, 2017).

3.3. Single Story House Model (base-model)

The model of the house was created using the provided architectural drawing as shown in Figures 1, 2 and 3. The model composed of 10 thermal zones, each zone represents one of the spaces of the house. The main floor made of 3 bedrooms, washroom, main living room with the kitchen, and a porch. Each construction assembly of the house is created based on the proposed material by the designer which specifies the materials for each type of assembly (e.g. exterior walls above grade, roof, interior walls and ceiling, windows, and doors). The thermal and physical properties of the materials are taken from the database of EnergyPlus which are defined by ASHRAE. Internal loads such as dryer, washer, lighting, water heater, and stove were created and scheduled to reflect the electrical usage of a family of 15 people and also to take into account the heat gains that are produced by the operation of those equipment in the house. Energy consumptions' of the internal loads are defined based on the database available in BEopt which is developed by the National Renewable Energy Laboratory in support of the U. S. Department of Energy Building America (BEopt Building Energy Optimization Tool, 2018). The heating system used in this house is an electrical heating system to represent infrared heater in each space. Additionally, a fire stove is added to the main living room to supply heat and used for cooking. The fire stove is added to represent the wood stove commonly used in the community, due to some limitation of modeling fire stoves, a workaround was implemented to replicate the wood stove placed in the living room. The energy consumption of a fireplace was predicted by energy plus then a conversion factor was used (wood energy, 2019) to calculate the volume required of wood pellets in cubic meter. The internal loads and the heating systems schedules were created based on the occupancy of 15 people in the house, plus visitors at specific hours of the day. The high number of occupants was selected based on the inputs provided to reflect the common living conditions in the community.

Table 2 Occupancy schedules inputs

Time (hour)		weekday	weekend
0	12am	15	15
1	1am	15	15
2	2am	15	15
3	3am	15	15
4	4am	15	15
5	5am	15	15
6	6am	15	15
7	7am	15	15
8	8am	10	10
9	9am	6	10
10	10am	6	10
11	11am	6	10
12	12pm	13	13
13	1pm	8	10
14	2pm	8	12
15	3pm	8	12
16	4pm	8	12
17	5pm	15	12
18	6pm	17	15
19	7pm	17	15
20	8Pm	17	15
21	9pm	15	15
22	10pm	15	15
23	11pm	15	15

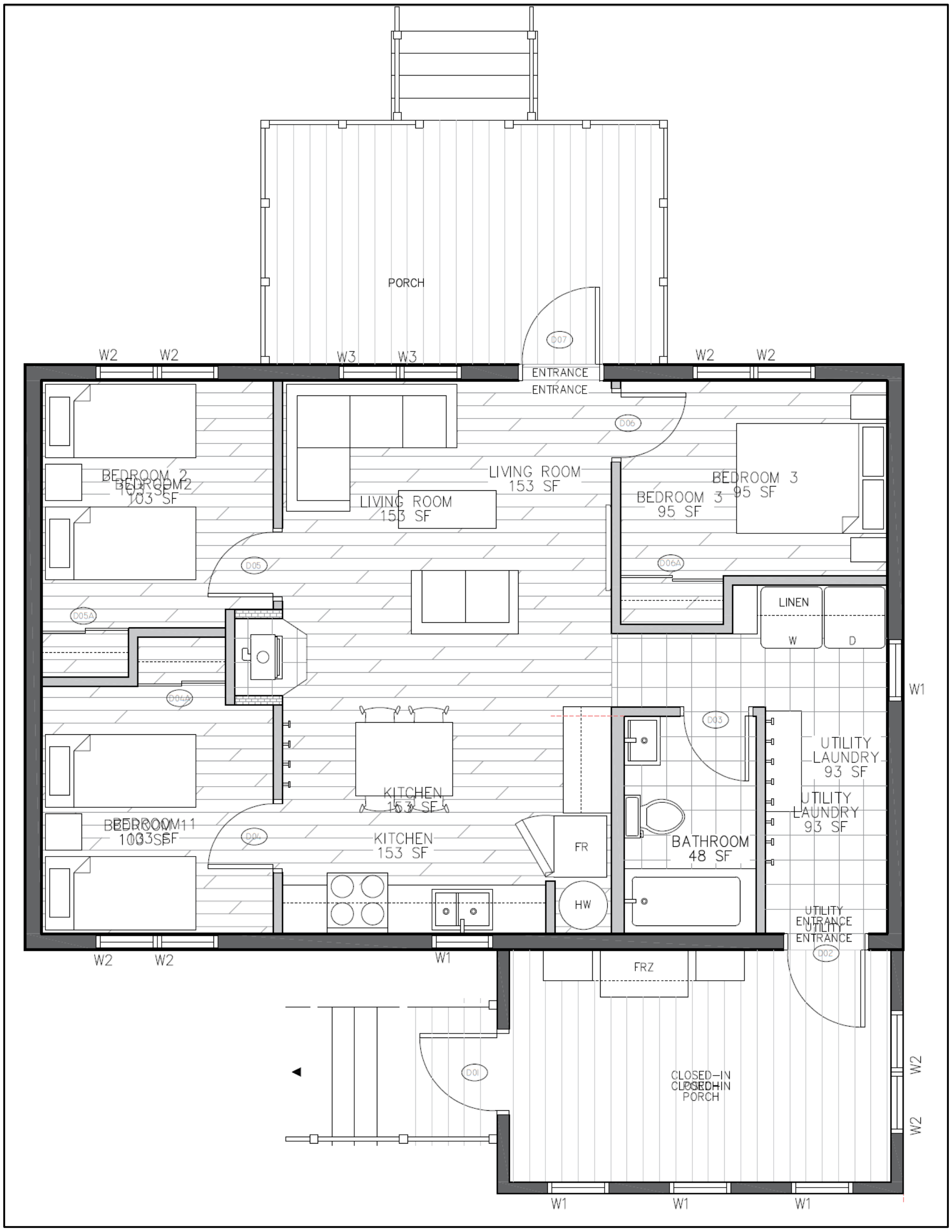

Figure 1 House's floor layout

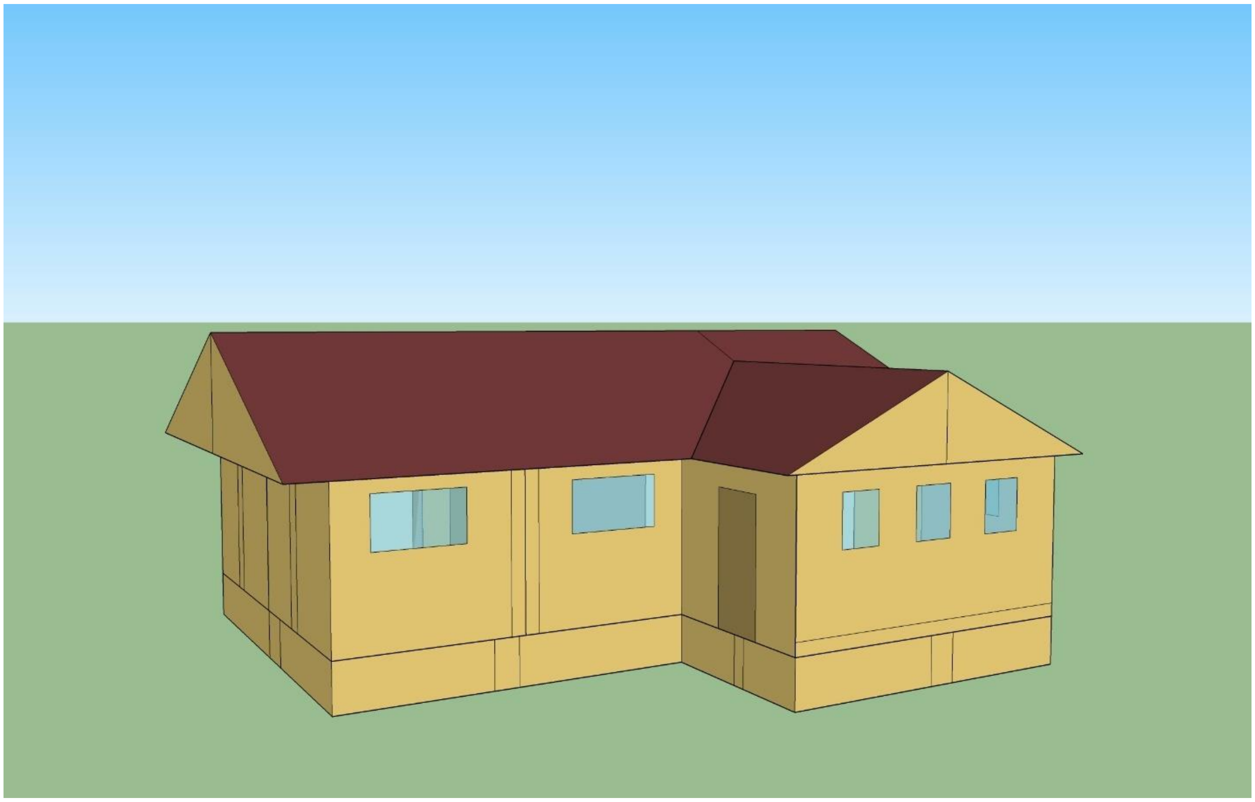

Figure 2 Energy model front view

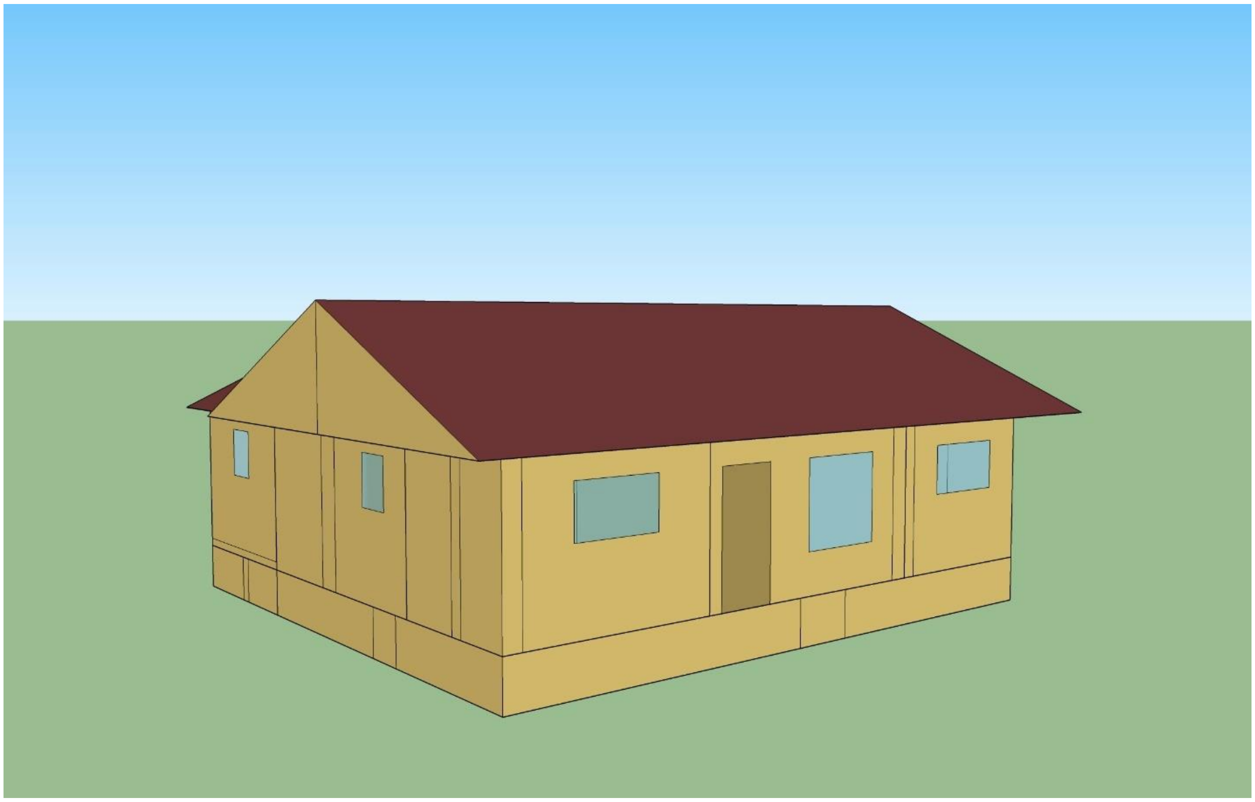

Figure 3 Energy model back view

3.4. LED Lighting Model

In the base model typical halogen light bulbs were used for the purpose of lighting. There is a total of 16 halogen light bulbs distributed around the house, each bulb is a 40Watt bulb. Table 3 shows the bulbs distribution in the house. All bulbs were replaced with light-emitting diodes (LEDs) of 11watt each to reduce electrical energy consumption.

Table 3 Bulbs distribution in the house

Number of Bulbs	Location
8	Main Living Room and Kitchen
2	In each bedroom and washroom
2	Porch

3.5. Airtightness Model

The Natural Resources Canada requires houses to have a total airtightness equal to or less than 2.5 air change per hour (ACH) (NRCan, 2016). The base model was created with the maximum allowed value of 2.5 ACH (NRCan, 2016) assuming that the house at least meets the maximum allowed value. The model with the improved airtightness value was created with a value of 1.75 to reflect an improvement of 30% only. However, the airtightness of a house should not be less than 0.6 ACH as recommended.

3.6. Thermal Curtain Model

Initially, the house did not have any thermal curtains. The curtains were created in the model to cover the whole windows during the nighttime which will significantly reduce the amount of energy exchange with the outdoors through windows. The defined curtain has a thickness of 0.5cm and thermal conductivity of 0.04W/m.k.

3.7. Windows Improvement Model

The action required the replacement of the clear double pane argon filled windows which are commonly used type of windows in houses with the high-performance windows comprise of 3 clear panes filled with argon. The base model of the house was created with a clear double-pane window. Each pane is 3mm thick in both cases.

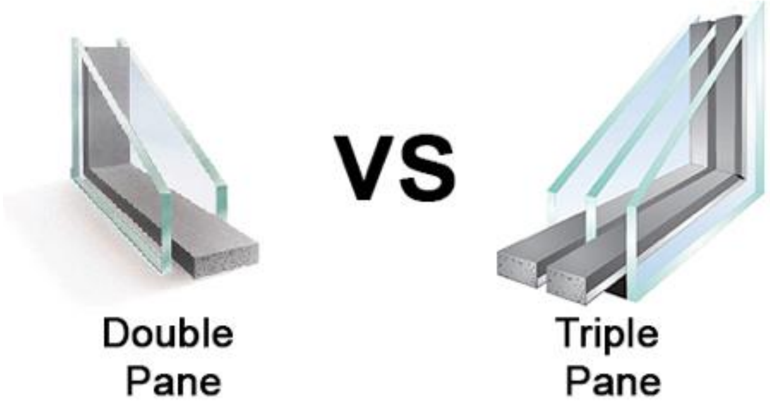

Figure 4 double pan V.S. triple pane window (BoP, 2018)

3.8. Thermostat Set-Back Point Model

The base model thermostat temperature set-point and set-back were created based on the data provided by the community to integrate it into the model. The provided data shows that the family uses a fixed heating set-point for heating (23 °C) during the heating season. The improved model was created to follow a slightly lower set-point (22 °C) during the day and occupied hours. Furthermore, a set-back temperature (20 °C) was implemented over the night to reduce the energy consumption between 11:00 pm to 6:00 am.

Table 4 summarizes the base-model inputs and the changes implemented to the improved model inputs.

Table 4 Base-model inputs V.S. Improved model Inputs

Retrofit Measure	**Base-model input**	**Improved model input**	**Reference**
Airtightness	2.5 Air Change per Hour	1.75 Air Change per Hour	(NRCan, 2016)
Thermostat set-back	Fixed Set-point for heating and cooling, for heating (23 °C)	Set-point is (22 °C) for heating during the day, Set-back applied over the night, (20 °C) for heating	N/A
Improved windows	Clear double pane argon filled windows	Clear triple panes filled with argon	(ASHRAE HOF, 2005)
Thermal Curtains	No insulation curtains	Insulation curtains applied during the night only	(AmCraft, 2018)
LED Lights	40Watt halogen light bulb	11Watt Ikea LED light E26-1000-lum	(Ikea, 2018)

4. Results

The base-model was run for a full meteorological year which provides an estimate of the expected energy consumption of the modeled house. Table 5 and figure 5 illustrate the total and breakdown energy consumption predictions of the base model. The results show that heating energy consumption is the highest due to the extremely cold winters in Island Lake. Moreover, the interior equipment includes the energy consumption of the fridge, freezer, stove, cloth washer, cloth dryer, and plug loads. The heating energy by fire is approximately equal to the volume of 5m^3 of Wood pellets a year (wood energy, 2019).

Table 5 End-use energy consumption of the base-model

Type	Energy consumption (kWh)
Heating (Electrical)	25121
Heating (Fire)	13560
Lighting	4000
Interior Equipment	3068
Water heater	10252
Total	56001

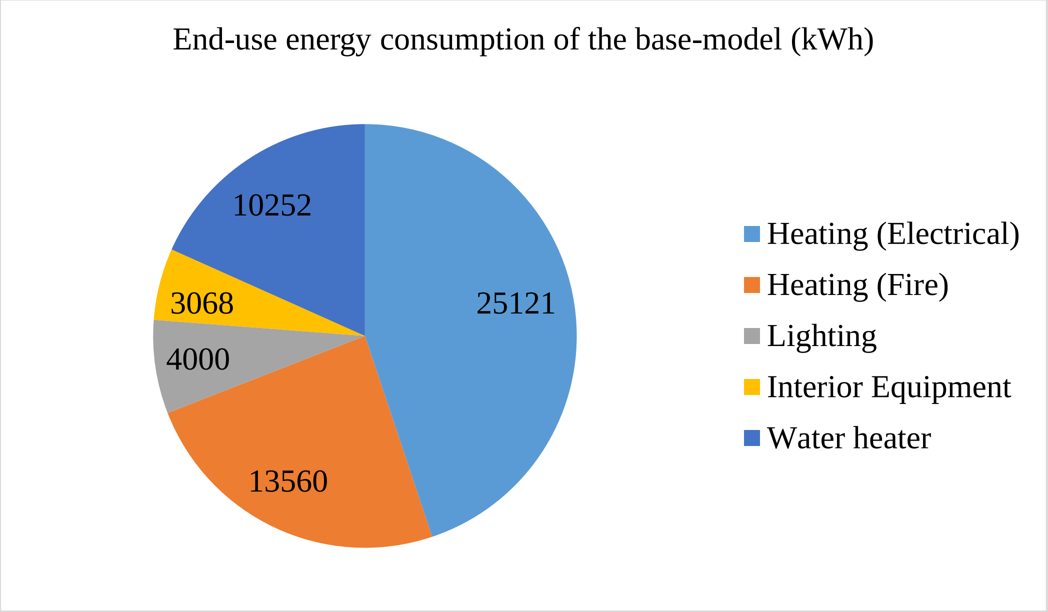

Figure 5 End-use energy consumption of the base-model

Table 6 shows the predicted energy savings of each retrofit measure implemented from highest to lowest savings. The results suggested that the highest savings could be achieved by improving the airtightness of the house. Around 20% reduction in energy consumption was accomplished by improving the airtightness of the house by 30% only. Moreover, this finding actually demonstrates why the Net-Zero Energy Residential Test Facility (NZERTF) lists building envelope airtightness as a key design goal of the NZERTF to decrease the heating and cooling energy consumption in residential buildings (Thompson, 2017). Surprisingly, the second most effective measure is defining a set-back point temperature during the nighttime. Approximately 8.2% of energy saving could be achieved by homes' owners without any additional cost. Figure 6 presents the indoor air temperature of the base-model vs. the improved model over the period of one day.

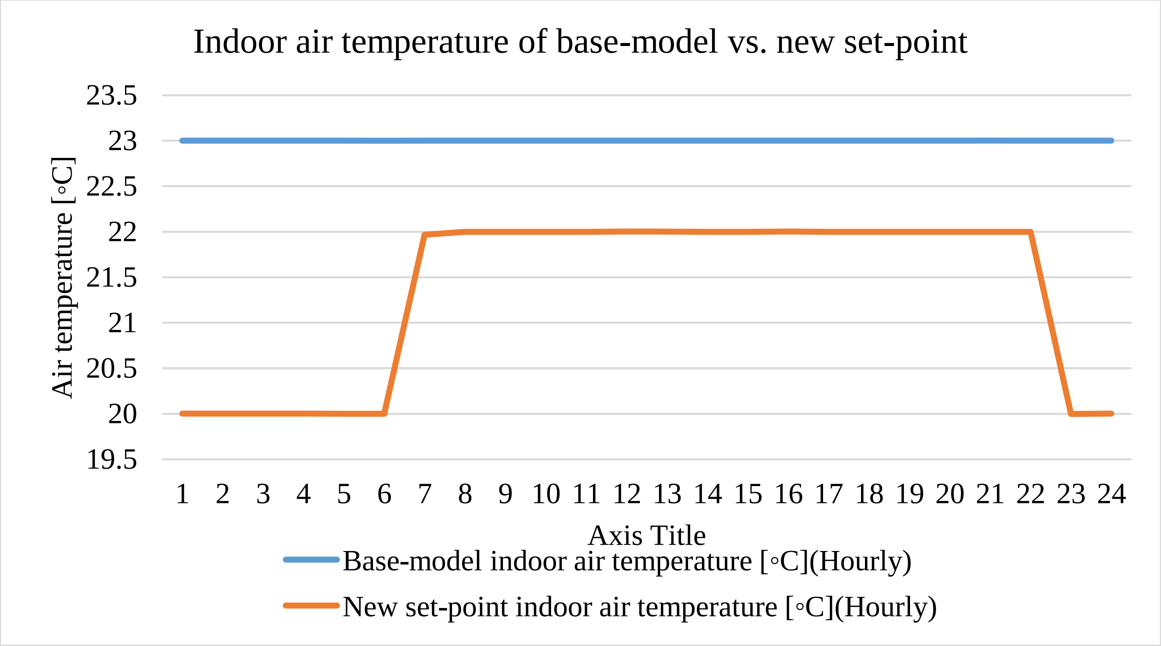

Figure 6 Indoor air temperature of base-model vs. new set-point

The third is replacing halogen light bulbs with LED lights to reduce the electricity consumption of lights in the house. Around 6% of saving was predicted by the model. Also, it is worth mentioning that LED light lifespan is about 25-50 times longer than a halogen light, which also can be considered as saving on maintenance cost over time. Fourth, is improving the windows of the house by using triple pane windows instead of clear double pan windows to mitigate energy loss through them. Almost a 1.9% energy reduction can be achieved by upgrading the windows to improve the energy performance of the house since windows have a much lower thermal resistance value than walls. Fifth, the installation of thermal curtains to control the heat loss through windows during the night time by reducing the thermal conductivity of the window when adding an insulation layer (thermal curtain), which may save around 1.9% of the yearly energy consumption of the house. Around 37% reduction of the total energy consumption can be obtained when implementing the five retrofit measures in the house by reducing the yearly end-use of the house from 56001kW/h to 35262 kWh based on the model results. Figure 7 illustrates the total energy consumption of the base-model vs. the improved models.

Table 6 Energy savings prediction of the implemented energy retrofit measures

Retrofit Measure	Base-Model Total Energy usage (kWh)	Total energy usage (kWh)	Energy-saving (kWh)	Yearly energy savings %
Air tightness	56001	45221	10780	19
Thermostat set-back	56001	51425	4576	8.2
LED Lights	56001	52651	3350	6
Improved windows	56001	54961	1040	1.9
Thermal Curtains	56001	55008	993	1.9
Total savings	56001	35262	20739	37

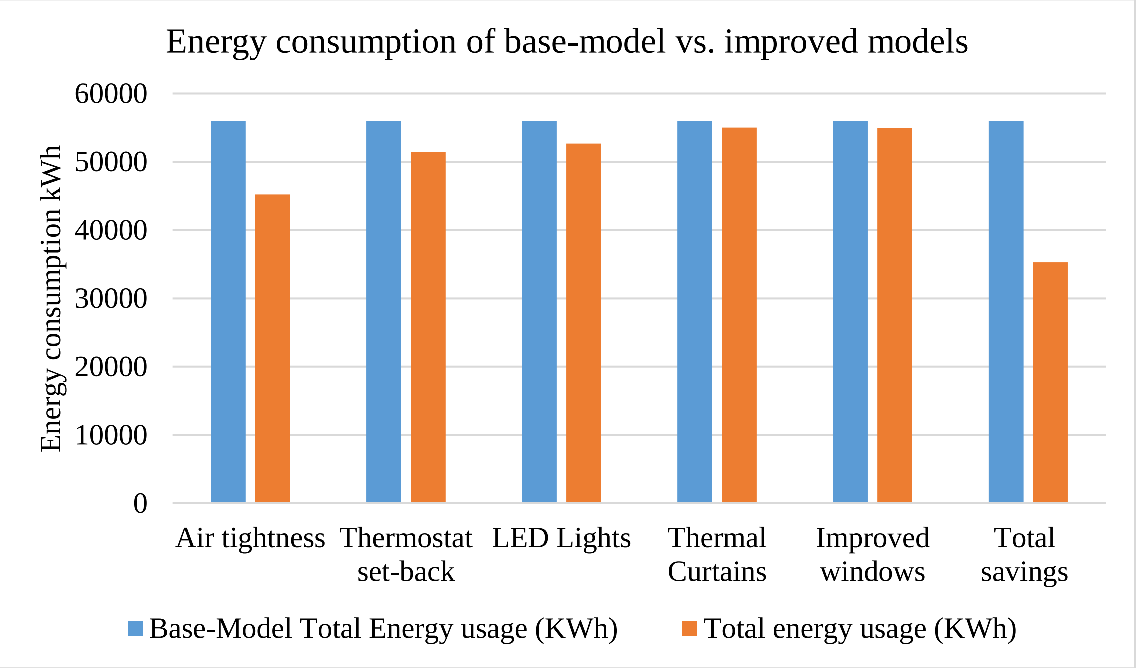

Figure 7 Energy consumption of base-model vs. improved models

5. Conclusion

From previous studies, it was found that energy consumption reduction can be achieved by implementing or adding modifications to new or previously constructed buildings. This project presents an energy model to assist residential house occupants in the definition of savings measures aimed at minimizing the energy use in the building.

The project results showed that simple retrofit strategies such as airtightness, thermosets control setting, and using LED lights could significantly reduce energy consumption in the cold climate of northern Manitoba. The predicted saving potential could be up to 37%, therefore, the results presented in this project fall within the range of savings according to Natural Resources of Canada (2016), which indicates that retrofit measures could reduce the energy consumption by 15-40%. The retrofit measures showed that the most effective measure in terms of saving potential is airtightness (19%) which is aligned with the previous studies' findings indicated that reducing air leakage could save from 5% to 40% of energy (OECD/IEA, 2013).

However, there is a range of factors that influence the results of the project. Firstly, the measures were limited to those from previous studies. Secondly, the measures that were included in this study are limited to those low cost, climate appropriate, and low disturbance factors for occupants.

6. Recommendations

The concluding recommendations for future work in this area are as follows. Appropriate selection criteria are essential in the procedure to select the most cost-effective retrofit strategies. Major concerns of building owners should be taken into consideration during this procedure. The occupant's behavior is a significant factor that heavily affects energy consumption during operation. More comprehensive research associated with investigating human factors on building retrofits is needed.

Appendix 1

Table 1 Summary of findings from previous studies

	Major retrofit technologies used	**Savings determination method**	**Major results**
Chidiac et al. (2011)	Heat recovery; Day-lighting; Boiler efficiency economizer; Preheat upgrade; Lighting load reduction.	Simulation program, EnergyPlus	The use of five retrofit options could achieve a 20% reduction in electricity consumption for Edmonton, Ottawa and Vancouver, and 30%, 32% and 19% reduction in natural gas for each of the respective cities.
Ascione et al. (2011)	Modification of indoor temperature set-point; Infiltration reduction; Increase of the vertical wall thermal insulation; Replacement of the old boiler with a condensation gas heater.	Numerical model calibrated by experimental data	Could achieve 22% primary energy savings. The total cost of the refurbishment would be 53,280 € with a discounted payback period of 11 years and a net present value of 30,748 €.
Verbeeck and Hens (2005)	Insulation measures; Glazing measures; Solar collectors and PV cells.	Building simulation model and net present value	Roof insulation, better performing glazing and efficient heating system appeared to be the most effective measures. Floor insulation appeared to be profitable in most cases
Dascalaki and Santamouri (2002)	Building envelope improvement; Using passive systems and techniques; Installation of energy saving lighting systems and use of daylight; Improvement of heating, cooling and ventilation systems.	Simulation model developed	For enclosed/light/skin dependent/cellular office buildings, the combination of all retrofit options resulted in a reduction of total energy use ranging from 48% in the North Coastal to 56% in the North European climatic regions.
Fluhrer et al. (2010)	Windows upgrading; Insulated reflective barriers; Tenant day-lighting, lighting and plugs; Chiller plant retrofit; Using a new air handling layout unit; Demand control ventilation; Balance of direct digital controls; Tenant energy management.	Energy and financial modeling	Can achieve a 38% reduction in energy use, save 105,000 metric tonnes of CO_2 over the next 15 years, and has an incremental net present value of approximately $22 million.
Goldman et al. (1988)	Heating controls and heating system equipment retrofits (for fuel-heat buildings); Window retrofits and insulation of water heat tank and installation of low-flow showerheads (for electric-heat buildings).	Analysis of measurement data from the database	Energy consumption after the retrofits decreased by 12–15 MBtu/unit in fuel-heat buildings and by 1450 kWh/unit in electric-heat buildings. Energy savings were between 10% and 30% of pre-retrofit energy use in 60% of the buildings studied.
Bin and Parker (2012)	A high level insulation of the roof, walls, foundation and basement floor; Air sealing and replacement of windows and doors; The adoption of renewable energy and energy efficient appliances.	Life cycle energy analysis	The environmental upfront cost of the retrofits will be offset within 2 years although the renovations resulted in additional embodied environmental impacts.

Mahlia et al. (2005)	Retrofitting incandescent lamps with more efficient compact fluorescent lamps (CFL).	Simple energy calculation	The potential monetary savings were $37 million, $74 million and $111 million for 25%, 50% and 75% replacement of the lamps (for 5000 operation hours of efficient lighting), respectively.
Darwish and Gomaa (2017)	Retrofit measures (double glazing, airtightness, external wall insulation and solar shading)	EnergyPlus	The study results show that retrofit strategies such as solar shading, window glazing, airtightness then insulation can reduce energy consumption of an average of 33%. Retrofit strategies such as solar shading can reduce energy up to 23% on average, followed is glazing strategy by 8% on average. Airtightness had little effect in energy reduction on the studies samples as it reduced energy only 2% on average.

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