Effect of window modifications on household energy requirement for heating and cooling in Canada

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Abstract

This study evaluates the effect of window modifications on heating and cooling energy requirement of houses in Canada based on detailed energy simulations of a representative one-storey detached house. The effects of the type (glazing and frame), orientation and size of the window on heating and cooling energy requirement are investigated for five major cities (Halifax, Quebec, Toronto, Calgary, Vancouver) representing the major climatic regions in Canada (Atlantic, Quebec, Ontario, Prairies, Pacific).

It is found that it is possible to save heating energy by adding well-insulated windows to the south side of a house to make use of incident solar energy. Also, as expected, replacing low quality windows with well-insulated windows result in both heating and cooling energy savings. Since Canada has a heating dominant climate, the use of well-insulated windows with wood frame on the south side for passive solar applications is beneficial from an energy saving perspective.

1 Introduction

Direct gain is a passive heating technique generally used in cold climates. It is the most common, simple and effective approach. The basic principle is that sunlight is admitted into the living space directly through openings or glazed windows to heat the walls and floors, and thereby the air inside. In the northern hemisphere, glazed windows are generally located facing south to receive maximum sunlight during winter.

In terms of energy performance, windows play a dual role, allowing solar gains to offset the heating loads during the heating season while adding to building loads during the cooling season. Windows also represent a major source of heat loss in winter, as their insulating value can be, depending on the window type, much lower than that of the surrounding walls.

One way of achieving better performance with windows is by using advanced glazing systems. Using more than one pane for the window and high-performance low-emissivity (low-e) coated glazing (which provides better thermal performance than clear glass) can dramatically improve the energy performance of the house.

To study the effect of windows on the heating and cooling energy requirement of a building, the following factors are considered:

- **Area of windows**
  There are not adequate studies focusing on the impact of window size and its orientation for cold climates. A study about the influence of window size on the energy balance of low energy houses by Persson, et al. (2006) studied 20 terraced houses in southern Sweden which were well insulated and had modern triple-glazed windows with low-e coated glazing. To model these houses a dynamic building simulation tool was used. The results indicate that the size

of the energy efficient windows does not have a major influence on the heating demand in the winter, but is relevant for the cooling need in the summer. This suggests that instead of the traditional way of building passive houses with small northern windows (since they are a source of heat loss rather than solar gain), it is possible to enlarge the window area facing north and get better lighting conditions if high efficiency windows are used.

- **Type of windows**
  Three properties are integral to evaluating glazing energy performance: insulating performance (U-factor), solar heat gain coefficient (SHGC), and visible light transmittance (VLT or VT). The ideal properties depend on the local climate, building type, and design. For instance, while a low U-factor (less heat loss) is most important in a cold climate; a low SHGC (less solar heat gain) is a priority where overheating is a concern. Visible light transmittance is important when daylight is incorporated into the building design.
  There are three fundamental approaches to improve the energy performance of glazing products (Carmody, et al. 2007):
  - Alter the glazing material itself by changing its chemical composition or physical characteristics. An example of this is tinted glazing.
  - Apply a coating to the glazing material surface. Reflective coatings and films were developed to reduce heat gain and glare; and more recently, low-emittance coatings have been developed to improve both heating and cooling performance. Low-e coatings can combine the advantages of a reduced U-factor and SHGC while maintaining high levels of visible light transmittance.
  - Assemble various layers of glazing and control the properties of the spaces between the layers. This strategy includes the use of two or more panes or films; low conductance gas fills between the layers, and thermally improved edge spacers.

  Previous studies show that gas-filled, low-e double glazed windows are the most cost effective choice for cold climate (Sullivan & Selkowitz 1987, Karlsson, et al. 2001, Barry & Elmahdy 2007).

2 Methodology

A one-storey detached house commonly found in Canada is used as the "test case house", which was first modeled and simulated without any windows to provide the "base case" energy requirement. Then, different types of windows with different window areas were added to the model and simulated to assess the effect of window type and area on heating and cooling energy requirement. The test case house was selected from the Canadian Single-Detached and Double/Row Database (CSDDRD) (Swan, et al. 2009a) and modeled using the building energy simulation program, ESP-r, a comprehensive building modeling tool based on the finite volume technique (ESRU, 2009).

The CSDDRD contains detailed data from 16,952 actual houses in Canada and is statistically representative of the Canadian housing stock. It is a subset of the EnerGuide for Houses Database (EGHD) of Natural Resources Canada, and contains detailed data on house type, location and orientation, geometry, envelope, occupancy and air infiltration, as well as data on domestic hot water and space heating/cooling systems (SBC, 2006). The EGHD data were collected from over 200,000 requested home energy audits from 1997 through 2006 conducted by specially trained energy auditors.

The test case house was selected from the CSDDRD based on its main features (i.e. number of storeys, floor area, envelope characteristics, and space heating/cooling equipment) such that the design of the test case house is one that is commonly encountered across the country. The level of thermal insulation is in conformance to the building code.

To assess the impact of window type and area on the energy requirement of a house, it is necessary to select a well-insulated house for case study. This condition decreases the uncertainty of window influence on energy requirement of the house because in a well-insulated house window heat losses dominate the building envelope heat losses. Also, a well insulated house is a better representative of Canadian houses.

The parameters examined in this work include the type (glazing and frame), orientation and size of the window.

Test case house

The one-storey test case house is composed of an above-grade storey, a conditioned basement and a non-conditioned attic. It is occupied by four adults, and has a set of appliances including a refrigerator, washer and dryer, dishwasher and TV[1]. The thermal characteristics of the house are given in Table 1, while Figure 1 shows the geometry.

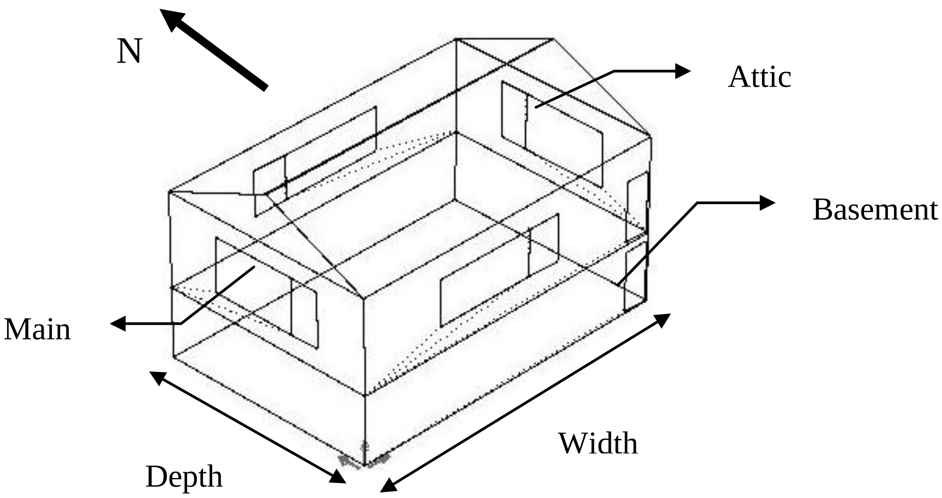


Figure 1. Case study house

Three thermal zones representing the basement, the attic and the one-storey living space were used to model the house in the ESP-r energy simulations. In the thermal model, the living space and basement are conditioned by the HVAC system while the attic is “free floating” in response to the thermal contact with the other zones and the outdoors. The space heating and cooling temperature setpoints were specified as 21 and 25, respectively. As shown in Table 2, to consider occupant behavior and different climates in Canada five control periods is defined (Swan, 2010). The contact between the basement zone and the ground is modeled with the BASESIMP model (Beausoleil-Morrison and Mitalas 1997) and the air in-

[1] The number of occupant is based on the CSDDRD input data which is typical occupancy for Canadian residential houses.

filtration is modeled with the AIM-2 model[1] (Walker, et al. 1990). To simplify the model, windows are placed at the geometric center of the walls. This is a reasonable assumption based on the findings of Purdy and Beausoleil-Morrison (2001). It is assumed there is no obstruction around the house to block solar gain.

According to literature (Purdy & Beausoleil-Morrison 2001, Mitchell, et. al 2003 and Carmody, et. al 2007) frame type can have a significant effect on the energy requirement of the building. Since the window area listed in CSDDRD corresponds to the "roughed-in" window area, it has been divided proportionally to consider both center-of-glass and frame. Canadian Hybrid Residential End-use Energy and Emission model (CHREM) assumes that center-of-glass occupies 75% of the roughed-in-area which is a reasonable assumption based on Mitchell, et. al (2003) and Carmody, et al. (2007). Although in reality the frame surrounds the aperture area, the frame area was placed to the right-hand-side of the aperture area to simplify the model since this simplification does not significantly alter the energy requirement (Swan, 2010). An illustration of the CHREM window representation is shown in Figure 2.

Table 1. Characteristics of the "test case house"

Built year	1981
Floor-Area (m^2)	96
Width (m)	12
Depth (m)	8
Height (including attic) (m)	7.5
U-value above-grade walls ($W/m^2.K$)	0.226
R-value above-grade walls ($ft^2.^{\circ}F.h/BTU$)	25
U-value ceiling ($W/m^2.K$)	0.132
R-value ceiling ($ft^2.^{\circ}F.h/BTU$)	43
U-value basement walls ($W/m^2.K$)	0.877
R-value basement walls ($ft^2.^{\circ}F.h/BTU$)	6.5
U-value basement floor ($W/m^2.K$) (no insulation)	5
Number of windows	4 (one each side)
Window area (m^2/side)	8
Front side	South

Table 2. Five periods space heating and cooling available

Period	Date	Space heating available	Space cooling available
1	Jan1 – Apr 1	✓	
2	Apr2 – Jun 3	✓	✓
3	Jun 4 – Sep 16		✓
4	Sep 17 – Oct 7	✓	✓
5	Oct 8 – Dec 31	✓	

Case studies conducted

The effect of window type, orientation and size on heating and cooling energy requirement was assessed by conducting a series of building energy simulations, and comparing the results with those obtained from the simulation of the base case house.

Since the effect of window type modification and window enlargement on heating and cooling energy requirement varies substantially based on the climate and the geographical lo-

[1] The AIM-2 model calculates the infiltration rate for each time step. The implementation can be found in Beausoleil-Morrison (2000) and Wang et al. (2009).

cation of a house, five cities, namely Halifax, Quebec, Toronto, Calgary and Vancouver, were selected to represent the five major climatic regions in Canada, namely Atlantic, Quebec, Ontario, Prairies and Pacific.

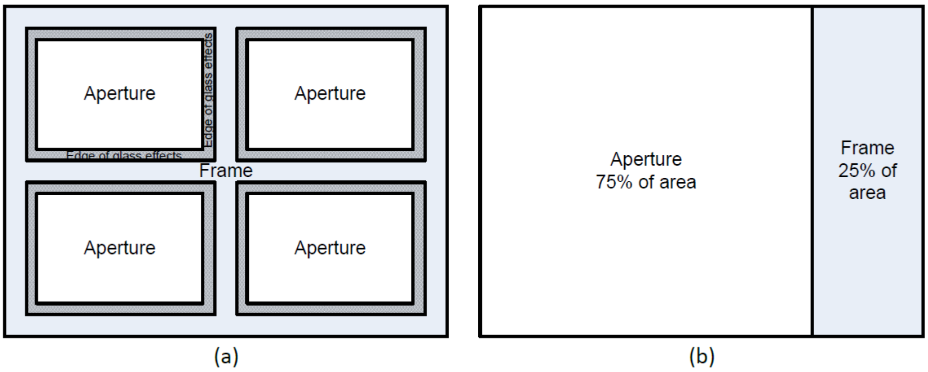


Figure 2. Window aperture and frame relationships for (a) the realistic layout showing the aperture, frame, and "edge of glass effects", and (b) the CHREM modeling representation (Swan, 2010)

The weather data files used in the simulations are from the Canadian Weather Year for Energy Calculation (CWEC) files (Numerical Logics, 2010). These files are 'typical year' weather files which are obtained by concatenating twelve Typical Meteorological Months selected from a database of, in most cases, 30 years of data. The months are chosen based on statistical criteria (representing mostly solar and dry bulb temperature). The climatic characteristics of selected cities are summarized in Table 3.

Table 3. Climatic characteristics of selected cities

City	Latitude	Longitude	HDD (Based on 18˚C)	CDD (Based on 18˚C)
Halifax	44˚ 54' N	63˚ 34' W	4031	105
Quebec city	46˚ 48' N	71˚ 24' W	5202	133
Toronto	43˚ 41' N	79˚ 24' W	3570	359
Calgary	51˚ 6' N	114˚ W	5108	40
Vancouver	49˚ 11' N	123˚ 10' W	2926	44

In the CHREM three window parameters available in the CSDDRD were used to describe the thermal and optical properties of the windows. These are glazing type, coating, and gap-width/fill-gas (Swan, et al. 2009b). Each window type is described in the CSDDRD with a three-digit code, as shown in Table 4.

Table 4. Window parameters with the three-digit code used in CSDDRD

Code digit value	Glazing type (digit 1)	Coating* (digit 2)	Gap width and Fill gas (digit 3)
0	-	Clear Glass	13 mm – Air
1	Single Glazed (SG)	Low_e (0.04**)	9 mm – Air
2	Double Glazed (DG)	Low_e (0.10**)	6 mm – Air
3	Triple Glazed (TG)	Low_e (0.20**)	13 mm – Argon
4	-	Low_e (0.40**)	9 mm – Argon

* The low-e coating is applied to the gap facing side of the innermost glazing layer
** The numbers show the emissivity of the glazing

Since using the same digit to represent both the gap-width and the fill gas is not appropriate for the current assessment, a fourth digit is added to the code to separate fill gas and gap size. Therefore, each window type is described with a four-digit code in this work. The coding key for constructing each window type is summarized in Table 5.

Table 5. Key code of window parameters

Code digit value	Glazing type (digit 1)	Coating* (digit 2)	Fill gas (digit 3)	Gap width (digit 4)
0	-	Clear Glass	Air	13 mm
1	Single Glazed (SG)	Low_e (0.04**)	Argon	9 mm
2	Double Glazed (DG)	Low_e (0.10**)	-	6 mm
3	Triple Glazed (TG)	Low_e (0.20**)	-	-
4	-	Low_e (0.40**)	-	-

* The low-e coating is applied to the gap facing side of the innermost glazing layer
** The numbers show the emissivity of the glazing

According to a study by Swan et al. (2009b) 25 unique window types are found in the CSDDRD. Table 6 shows all window descriptions in the CHREM with both the original CSDDRD code and the modified four-digit code used here. Since ESP-r calculates the window thermal and solar properties at each time-step, the approximate SHGCs and U-values for each window type are presented only for comparison purposes.

Since Canada has a heating dominated climate, the low emissivity coating is applied to the outside of the inner glazing layer to reduce the long-wave radiation exchange between the glazing layers and the surroundings.

To evaluate the effect of window upgrades on energy requirement, the following analyses were conducted:

- Effect of window glazing type: To study the effect of window glazing upgrades, different types of window glazing, according to table 6, were placed on all four sides of the test house. All windows are 8 m^2 per side and with wood frame.
- Effect of window frame type: To study the effect of window frame upgrades, different types of frames were placed on all four sides of the test house. The six types of frames that are represented in the CSDDRD are used in the simulations:
  - Aluminum window frame without thermal break
  - Aluminum window frame with thermal break
  - Wood window frame
  - Aluminum clad wood window frame
  - Vinyl window frame
  - Fiberglass window frame
- Effect of window orientation: To study the effect of window orientation, a 8 m^2, triple glazed, low-e (0.2), 13 mm argon filled window (type 3310) with wood frame was added to each side of the base case house (that has no windows).
- Effect of window size: To study the effect of window size, one window was added to the south side of the test case house. The size of window was increased to cover 10% to 80% of wall area in increments of 10%. This analysis was done for all window types given in Table 6.

The results for heating energy requirement are compared with those obtained from a house with no windows. Due to the big difference between the cooling energy requirement of a house with no windows and a house with any kind of window, the results for cooling energy requirement are compared to a house with single glazed windows.

Table 6. CHREM window database

Digits 1-3 (CHREM)	Glazing layers	Coating	Fill gas	Gap size	Digits 1-4 (modified)	SHGCs	U-value (W/m^2K)
100	SG[1]	Clear Glass			1000	0.86	5.91
200	DG[2]	Clear Glass	Air	13 mm	2000	0.76	2.73
201	DG	Clear Glass	Air	9 mm	2001	0.76	2.88
202	DG	Clear Glass	Air	6 mm	2002	0.76	3.17
203	DG	Clear Glass	Argon	13 mm	2010	0.76	2.57
210	DG	Low_e (0.04)	Air	13 mm	2100	0.52	1.70
213	DG	Low_e (0.04)	Argon	13 mm	2110	0.52	1.36
220	DG	Low_e (0.10)	Air	13 mm	2200	0.64	2.10
223	DG	Low_e (0.10)	Argon	13 mm	2210	0.64	1.99
224	DG	Low_e (0.10)	Argon	9 mm	2211	0.64	2.10
230	DG	Low_e (0.20)	Air	13 mm	2300	0.73	2.21
231	DG	Low_e (0.20)	Air	9 mm	2301	0.73	2.33
233	DG	Low_e (0.20)	Argon	13 mm	2310	0.73	2.10
234	DG	Low_e (0.20)	Argon	9 mm	2311	0.76	2.21
240	DG	Low_e (0.40)	Air	13 mm	2400	0.73	2.44
243	DG	Low_e (0.40)	Argon	13 mm	2410	0.73	2.27
244	DG	Low_e (0.40)	Argon	9 mm	2411	0.73	2.38
300	TG[3]	Clear Glass	Air	13 mm	3000	0.68	1.82
301	TG	Clear Glass	Air	9 mm	3001	0.68	1.98
320	TG	Low_e (0.10)	Air	13 mm	3200	0.58	1.48
323	TG	Low_e (0.10)	Argon	13 mm	3210	0.58	1.36
330	TG	Low_e (0.20)	Air	13 mm	3300	0.65	1.53
331	TG	Low_e (0.20)	Air	9 mm	3301	0.65	1.64
333	TG	Low_e (0.20)	Argon	13 mm	3310	0.65	1.42
334	TG	Low_e (0.20)	Argon	9 mm	3311	0.65	1.48

[1] SG = Single Glazed, [2] DG = Double Glazed, [3] TG = Triple Glazed

3 Results and discussion

Effect of window glazing type

The effect of window glazing type modification on annual heating and cooling energy requirement are summarized in Figures 3 and 4 where the changes are given as a percentage of the annual values of the base case house. Since the base case house energy requirement varies from location to location, the base case house energy requirement is included in each figure.

Effect on heating energy requirement

As seen in Figure 3(a), in comparison with a house that has no windows, the addition of single glazed window increases the annual heating energy requirement substantially. Addition of glazing layers, low emissivity (low-e) coating, less conductive fill gas and larger gap size increases the effective thermal resistance of the window. As the thermal resistance of the window increases with these features, the heat loss through the window approaches the heat loss through the same area of surrounding wall. The results shown in Figure 3(a) indicate that:

- Increasing the number of glazing reduces heating energy requirement,
- Increasing gap size from 6 mm to 9 mm and further to 13 mm reduces heating energy requirement,

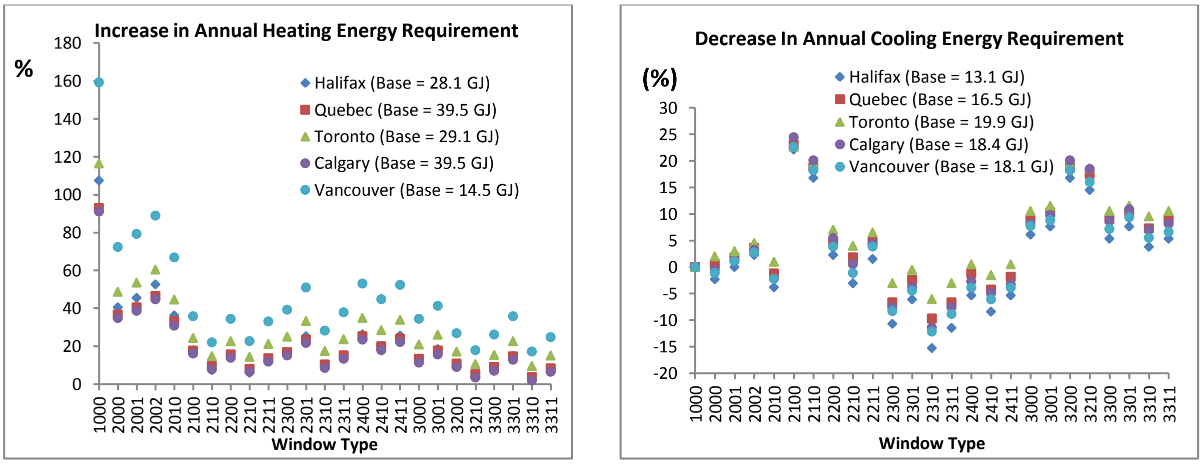
- Replacing air with argon as the fill gas reduces heating energy requirement,
- Increasing the emissivity of the coating applied to the outside of the inner glazing layer reduces heating energy requirement.

For example, upgrading a single glazed (type 1000) window to a double glazed window with low-e coating (0.04) and 13 mm argon filled air gap (type 2110) results in a reduction of 53% (from 37.6 GJ/year to 17.7 GJ/year) in the heating energy requirement of a house located in Vancouver, and 43% (from 76.2 GJ/year to 43.3 GJ/year) for a house located in Quebec, representing savings of 19.9 GJ/year and 32.9 GJ/year, respectively.

As the quality of the existing window increases, the benefit from an upgrade decreases. For example, upgrading from a well insulated double glazed window (low-e coated (0.04), 13 mm argon filled – type 2110) to a well insulated triple glazed window (low-e coated (0.2), 13 mm argon filled – type 3310) results in a small decrease in the heating energy requirement, which varies from 5.4% for a house located in Calgary (from 42.6 GJ/year to 40.3 GJ/year) to 4% for a house located in Vancouver (from 17.7 GJ/year to 17 GJ/year). The results also indicate that a high quality insulated window (type 3310) has an effective thermal resistance similar to that of the surrounding wall.

Effect on cooling energy requirement

Solar heat gain is the dominant cause for the cooling load of a house. Thus, when a window is added to a house that has no windows, the cooling load, and consequently cooling energy requirement, may increase by as much as 10 times or more. Therefore, rather than using a windowless house as the base case house to compare changes in the cooling energy requirement due to window upgrades, a house with single glazed windows is used as the base case house.



(a) (b)

Figure 3. Effect of window glazing upgrades: (a) Increase in annual heating energy requirement (%) compared to the base case house with no window; b) Decrease in annual cooling energy requirement (%) compared to the base case house with single glazed windows

As seen in Figure 3(b), in comparison to a house with single glazed windows, addition of glazing layers, low emissivity (low-e) coating, different gap fill gas and size may result in decrease or increase in cooling energy requirement. Additions of these features to the window results in lower U-value for the window which may increases the cooling energy requirement by blocking long-wave radiation from inside to outside or decrease it by transferring less heat from outside to inside. However, this also results in solar gain reduction, which decreases the cooling energy requirement. Therefore, a trade off between heat loss and solar heat gain may increase or decrease the cooling energy requirement. The results shown in Figure 3(b) indicate that:

- Increasing the number of glazing reduces cooling energy requirement,
- Decreasing gap size from 13 mm to 9 mm and further to 6 mm reduces cooling energy requirement,
- Replacing air with argon as the fill gas increases cooling energy requirement,
- Increasing the emissivity of the coating applied to the outside of the inner glazing layer increases cooling energy requirement.

For example, upgrading single glazed (type 1000) windows to double glazed, low-e coated (0.04), 13 mm air filled gap (type 2100) windows results in a reduction of cooling energy requirement, which varies from 24.4% (from 18.4 GJ/year to 13.9 GJ/year) for a house located in Calgary to 22.1% (from 13.1 GJ/year to 10.2 GJ/year) for a house located in Halifax, representing 4.5 GJ/year and 2.9 GJ/year, respectively.

As seen in Figure 3(b), double-glazed, low-e coated (0.04), 13 mm air filled gap (type 2100) results in the largest decrease in cooling energy requirement. Also all triple glazed windows decrease cooling energy requirement more than double glazed windows. To explain this trend the annual solar gain through the windows is shown in Figure 4. Since the solar heat gain through the windows is the dominant heat gain during the cooling season, the cooling energy requirement is mainly due to the solar heat gain. Figure 4 indicates that:

- Double glazed, low-e (0.04), 13 mm air/argon filled window has the lowest solar gain,
- All triple glazed windows have lower solar gain compared to all double glazed windows except for double glazed windows with the low emissivity coating of 0.04 and 0.1.

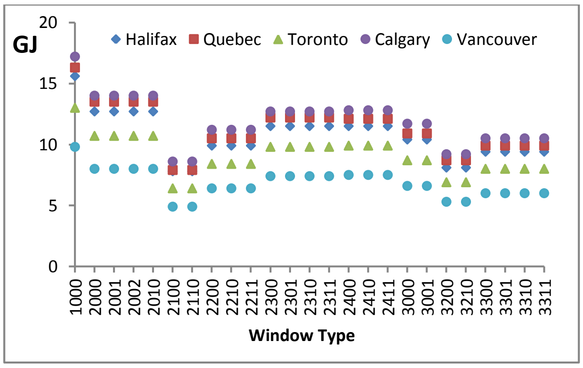


Figure 4. Annual solar heat gain through windows (GJ)

Effect of window frame type

The effect of window frame type modifications on annual heating and cooling energy requirement is summarized in Figures 5(a) and (b) as a percentage of the annual values of the base case house that has triple glazed, low-e coated (0.2), 13 mm argon filled (type 3310) windows with aluminum frame. A window with high glazing insulation and low frame insulation is chosen as the base case to accentuate the effect of changing frame insulation. The base case house energy requirement is included in each figure.

Effect on heating energy requirement

As seen in Figure 5(a), in comparison with a house that has windows with aluminum frame, using more insulated frame decreases annual heating energy requirement substantially. Since the frame covers 25% of the window area, improving the thermal resistance of the frame has a major impact on reducing the heat loss through the window.

Upgrading aluminum to wood frame results in the largest decrease in heating energy requirement, which varies from 19% for a house located in Vancouver (from 21 GJ/year to 17 GJ/year) to 14.7% for a house located in Quebec (from 48.1 GJ/year to 41 GJ/year).

Effect on cooling energy requirement

As seen in Figure 5(b), in comparison with a house that has windows with aluminum frame, using more insulated frame increases annual cooling energy requirement due to reduced heat loss from the zone to the outdoors through the window frame since the indoor temperature is not much different from the outdoor temperature most of the time during the cooling season. However, compared to the impact on heating energy requirement, the reduction in cooling energy requirement is negligible.

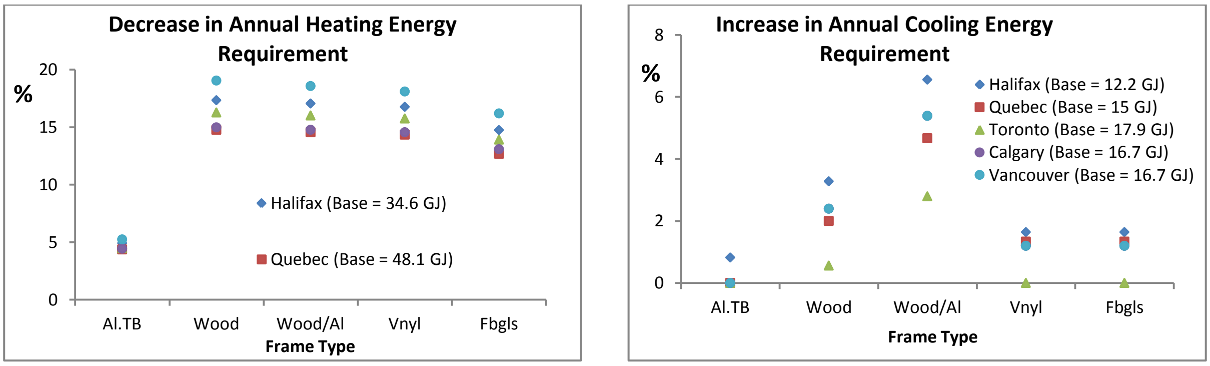


Figure 5. Effect of window frame upgrades: (a) Decrease in annual heating energy requirement (%), (b) Increase in annual cooling energy requirement (%) compared to base case house with aluminum window frame

Effect of window orientation

The effect of window orientation on annual heating and cooling energy requirement is summarized in Figures 6 (a) and (b). In these figures, the changes are given as a percentage of the annual values of the base case house that has no windows. The base case house energy requirement is included in each figure.

Effect on heating energy requirement

As seen in Figure 6(a), in comparison with a house that has no windows, addition of a well insulated window to the south side results in a decrease in annual heating energy requirement. Since the solar radiation is highest on the south exposure during the heating season, addition of a well insulated window to this side can increase the solar gain through the window while keeping the increase in heat loss to a minimum. In other words, there is a net heat gain since the benefit from the solar heat gain eclipses the increased heat loss.

Addition of a triple glazed, low-e coated (0.2), 13 mm argon filled (type 3310) window with wood frame to the south side of a house decreases annual heating energy requirement which varies from 13.7% for a house located in Calgary (from 39.5 GJ/year to 34.1 GJ/year) to 8.6% for a house located in Toronto (from 29.1 GJ/year to 26.6 GJ/year).

Effect on cooling energy requirement

As seen in Figure 6(b), in comparison with a house that has no windows, addition of a well insulated window to the west side results in the highest increase in annual cooling energy requirement. Since the solar azimuth arc is longer in the summer than in winter, the solar gain from west and east side is higher than the solar heat gain through the south side in summer. On the other hand, addition of a window to the north side results in the least increase in cooling energy requirement due to the fact that north side gains the least solar radiation through the year.

Addition of a well insulated window (type 3310) to the west side results in the highest increase in cooling energy requirement which varies from 637% for a house located in Vancouver (from 0.8 GJ/year to 5.9 GJ/year) to 187% for a house located in Toronto (from 2.4 GJ/year to 6.9 GJ/year), representing 5.1 GJ/year and 4.5 GJ/year.

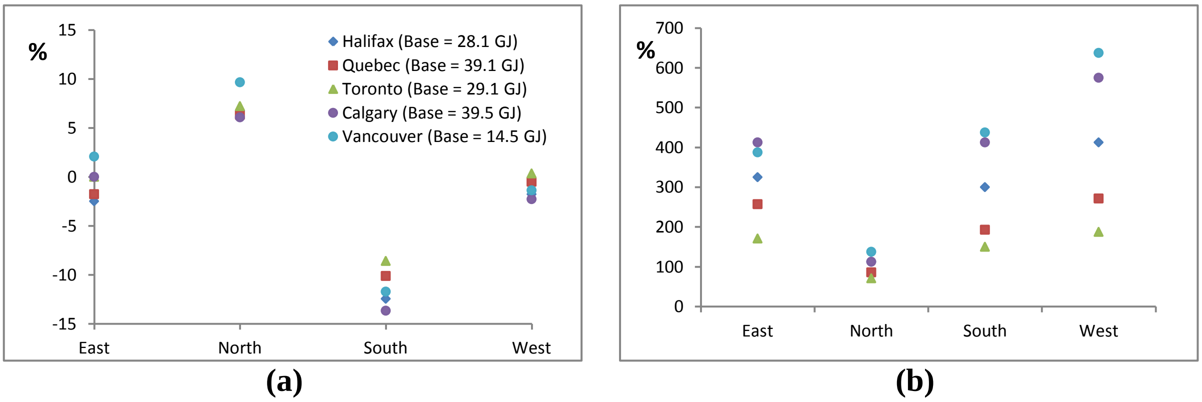


Figure 6. Effect of adding a triple-glazed window to different orientations compared to the base case house (no window) (a) Increase in annual heating energy requirement (%), (b) Increase in annual cooling energy requirement (%)

Effect of window size

The effect of window size on annual heating and cooling energy requirement are summarized in Figures 7 and 8. In these figures, the changes are given as a percentage of the annual values of the base case house. Since the base case house energy requirement varies from location to location, the base case house energy requirement is included in each figure.

Effect on heating energy requirement

The effect of window area enlargement on annual heating energy requirement for four different window types is summarized in Figures 7(a) – (d).

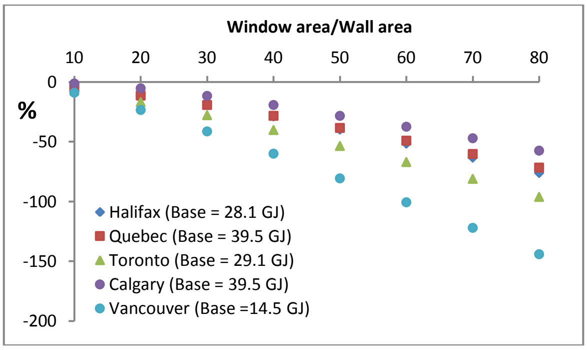
As seen in Figure 7, in comparison with a house that has no windows, upgrading single glazed (type 1000) to a better insulated window results in decrease in annual heating energy requirement for larger windows. As it was concluded earlier, by improving the thermal resistance of the window, the heat loss through the window approaches the heat loss through the same area of surrounding wall. Therefore, increasing the window area of a very well insulated window only increases the solar heat gain while the heat loss does not change significantly. In other words, by increasing the window area of a well insulated window, there is a net increase in heat gain as the increase in solar heat gain is larger than the increase in transmission heat loss. From Figure 7, the following can be concluded:

- Upgrading a window to a better insulated one allows to have a larger window,
- For climates with higher HDD, benefit from solar gain for a well insulated window becomes almost constant for window area/wall area ratios higher than 50%,

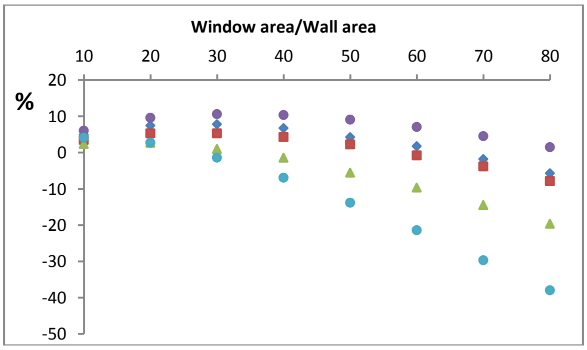
- Enlarging well-insulated windows has more benefit for climates with higher HDD.

For example, addition of a triple glazed window, low-e coating (0.1), 13 mm argon filled (type 3210) and window area/wall area ratio of 50% results in a reduction of 20% (from 39.5 GJ/year to 31.6 GJ/year) in the annual heating energy requirement of a house located in Calgary, and 10.3% (from 14.5 GJ/year to 13 GJ/year) for a house located in Vancouver, representing savings of 7.9 GJ/year and 1.5 GJ/year, respectively.

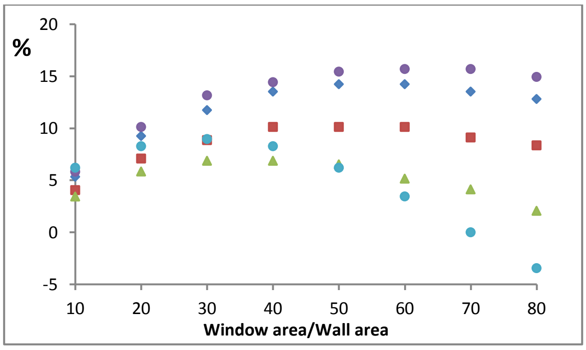
As the area of a window increases, the benefit from an upgrade decreases or may reverse. For example, upgrading from 50% to 80% of wall area for a well insulated triple glazed window (low-e coated (0.1), 13 mm argon filled – type 3210) results in a small reduction of 1.9% (from 31.6 GJ/year to 31 GJ/year) for a house located in Calgary and an increase of 7.7% (from 13 GJ/year to 14 GJ/year) for a house located in Vancouver.



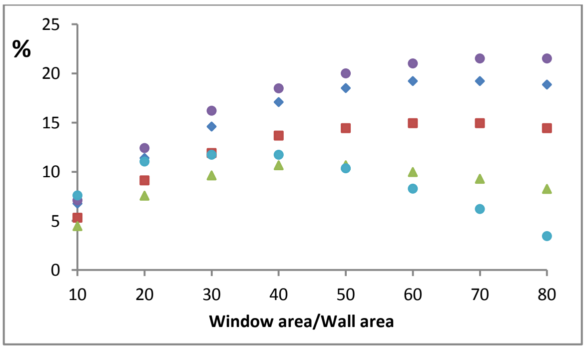
(a) window type 1000



(b) window type 2000



(c) window type 2110



(d) window type 3210

Figure 7. Decrease in annual heating energy requirement (%) due to window enlargement compared to the base case house that has no windows

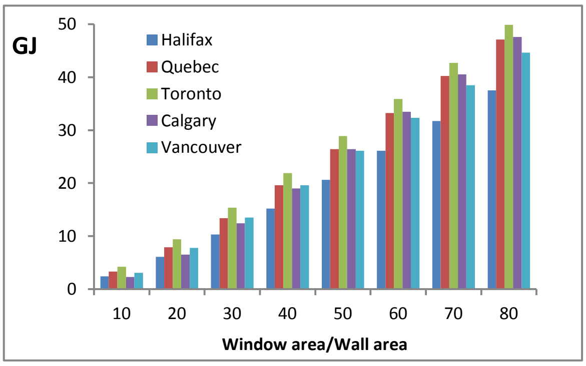
<u>Effect on cooling energy requirement</u>

As discussed earlier, in comparison to a house with no windows, addition of a window increases the cooling energy requirement dramatically. However, in heating dominant climates, by using the appropriate window type and area, the benefit of reducing the heating energy requirement can overcome the disadvantage of increasing the cooling energy requirement. Since the trade off between cooling and heating energy requirement is a matter of interest in this part, the difference between the reduction in heating and the increase in cooling energy requirement due to window enlargement is shown in Figure 8. Figures 8(a)-(d) show that:

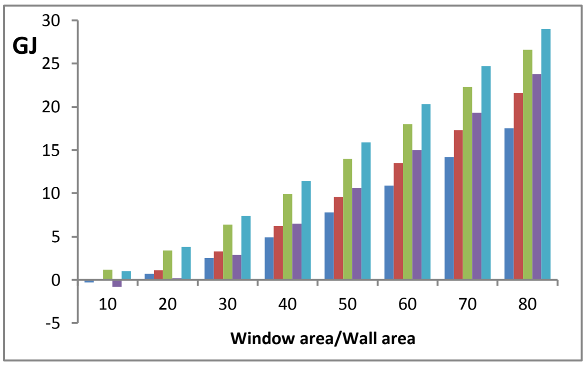
- Enlarging window area increases the annual space energy requirement. In other words, the increase in cooling energy requirement minus the decrease in heating energy requirement is greater than zero.

- Using a more insulated window type decreases the increase in annual space energy requirement.

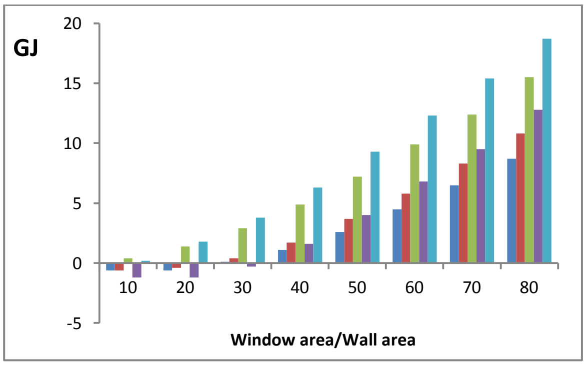
For example, addition of a triple glazed window, low-e coating (0.1), 13 mm argon filled (type 3210) and window area/wall area ratio of 30% results in 1.2 GJ/year saving in space energy requirement for a house located in Calgary while it increases space energy requirement by 3.7 GJ/year for a house located in Vancouver.



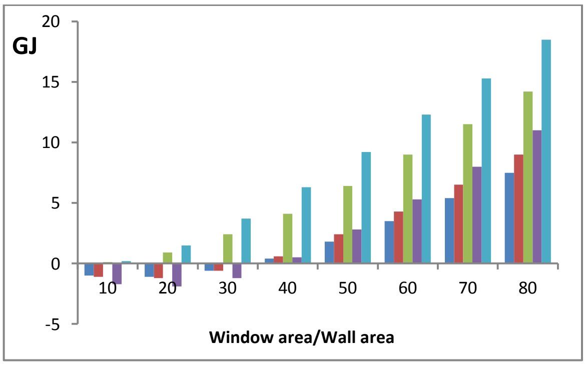
(a) window type 1000



(b) window type 2000



(c) window type 2110



(d) window type 3210

Figure 8. Effect of window enlargement: annual increase in space energy requirement (GJ) (i.e. difference between the increase in cooling energy requirement and the decrease in heating energy requirement) due to window enlargement

4 Conclusion

The analysis conducted in this study to evaluate the impact of window modifications on heating and cooling energy requirement of houses in Canada indicate that it is possible to reduce the annual energy requirement by carefully choosing the modifications taking into consideration the location of the house and the characteristics as well as the size of the existing windows. Using a comprehensive building energy simulation tool as it is done here; it is possible to quantify the impact of window modifications. The next steps in this study are to conduct a similar analysis for the Canadian housing stock using the CHREM as well as to incorporate an economic analysis along with a GHG emissions analysis. Once these are completed it will be possible to identify economically and technically feasible approaches to reduce the energy consumption and GHG emissions in the Canadian housing stock through window modifications.

5 Acknowledgement

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