EFFECT OF EXTERNAL SHADING ON HOUSEHOLD ENERGY CONSUMPTION FOR HEATING AND COOLING IN CANADA

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ABSTRACT

The solar energy incident on a building is influenced by shading caused by façade features, surrounding buildings and natural obstructions such as trees. Shading impacts the energy consumption of a house by reducing the amount of radiant energy absorbed and stored by the building's thermal mass. This study intends to quantify the effect of site shading on energy consumption of residential buildings in Canada.

To deal with this problem, a representative houses (one-story single detached) from the Canadian Single-Detached & Double/Row Housing Database (CSDDRD) was selected (Swan, et al. 2009). Site shading effects of neighbouring buildings on annual heating and cooling energy consumption of houses were evaluated separately and in combination using the building energy simulation program ESP-r (ESRU). The effects of house type, climate, distance of obstruction from the base house, height and width of obstruction, and number of obstructions on the energy consumption for heating and cooling are investigated. It is found that the annual heating and cooling energy requirement of a house in Canada may be significantly affected by the existence as well as the orientation, size and distance of a neighbouring house.

INTRODUCTION

The effect of shading by buildings or trees on another building may decrease or increase energy consumption depending on building characteristics and environmental conditions. A potential benefit of shading for adjacent structures is decreasing the cooling energy requirement. Negative consequences of shading include the loss of natural light for passive or active solar energy applications and the loss of warming influences, which increase the heating energy requirement during the cold season. Factors influencing the relative impact of shadow effects are site-specific such as direction, number, size and distance of neighbouring structures, building orientation, climate, time of the year and the duration of shading. Although potentially significant, the impact of neighbouring buildings and other obstructions on the heating and cooling energy requirement of houses is generally neglected in the building energy analysis. The objective of this paper is to complement the existing literature that focuses on the effect of shading on building energy consumption by studying the effect of neighbouring houses on a "typical" single storey house located in different regions in Canada.

The existing studies on shading effect due to neighbouring structures can be divided to two categories. The first category focuses on the effect of shading by neighbouring buildings, and the second category focuses on the effect of trees.

Frank, et al. (1981) developed a program to simulate the shading effect by trees and buildings in urban environments. This program was not designed to predict energy consumption. However, it is a powerful tool to calculate the view factors of building and the alignment of obstructions. This program needs to be coupled to another appropriate program to calculate energy consumption. A decade later, Ok (1992), developed a model to calculate the effect of shading due to adjacent or nearby buildings on cooling load. His model considers the solar heat gain through opaque surfaces for cooling load calculations. In the model, settlement density, building shape, distance and locations were taken to account for calculating shading area and then heat gains and losses. A multi-story residential building located in Istanbul was simulated as an example for July 21st. The results showed that the effect of shading is significant for the west-east oriented surfaces of the sample building. Since theses surfaces are vertical, the lower angle of solar radiation in the afternoon results in significant heating effect. Therefore it becomes important that these surfaces remain in the shade during the afternoon period. Lam (2000) investigates the shading effects due to neighbouring buildings on commercial buildings in seven main business districts in Hong Kong. DOE-2.1E (LBNL) was used for simulation and cooling load calculations. The results of this study showed that the reduction in cooling load due to considering shading effect is not significant for commercial buildings.

Farrar-Nagy, et al. (2000) studied a residential building in Tucson, Arizona, to evaluate opportunities for reducing cooling energy use in a hot dry climate. They studied the impact of spectrally selective windows, architectural shading, and site shading from adjacent buildings on cooling energy requirement. Building performance was modeled using a detailed hourly energy simulation tool, DOE 2, and was measured while unoccupied for a period of 12 days. It was found that ignoring shading effect due to neighbouring buildings causes overestimation in annual cooling energy requirement up to 24%, depending on the front orientation of the building, existence of overhang and type of windows.

In a paper that studied the impact of a number of parameters on heating energy requirements of houses, Purdy, et al. (2001) assessed the shading effect of surrounding objects. The study was conducted using a developmental version of the HOT3000 program (CanmetENERGY), which is based on a very detailed and capable simulation program, ESP-r. A two storey research house from the houses at the Canadian Center for Housing Technology (CCHT) was selected as the base case for this study. It was found that the shading caused by the neighbouring houses increases the annual heating load requirement by up to 5%. It was also found that the results are sensitive to the location of the neighbouring house. Furthermore, the results demonstrate that the solar shading caused by surrounding buildings, and by extension other large objects such as trees, have more impact than the shading caused by a typical roof overhang.

Li, et al. (2007) studied the daylighting performance and energy use of a commercial building shaded by nearby buildings in Hong Kong. A procedure involving computer-simulation techniques was employed to evaluate the energy performance of office buildings with daylighting controls shaded by neighbouring buildings. A detailed study of the shading effects showed that daylighting is always an energy saver. Results from a regression analysis were used to establish a number of correlation equations, which could indicate the energy savings under the impact of an external obstruction.

Trees are the other major focus of external obstruction considered in studies. Trees affect the microclimate via three major processes: shading, wind speed reduction and evapotranspiration (Akbari, 1992, Simpson, 1998). Some studies consider all of these effects while some are limited to one or two. Since this focus of this study is on the shading effect, papers that focus on the other effects are neglected.

Akbari, et al. (1992) studied all three effects of tree and the impact of high-albedo (white surfaces) on residential heating and cooling energy use in four Canadian cities. For this purpose, three different building prototypes were simulated by an energy simulation program, DOE-2.1D, for Vancouver, Montreal, Edmonton and Toronto. The building prototypes included a detached one-story as well as a detached two-story single family house, and a row house. It was found that by increasing the vegetative cover of the neighbourhood by 30% (corresponding to about three trees per house), considering only the shading effect, increases the annual heating energy consumption in Toronto by up to 1% in urban houses, whereas cooling energy can be reduced by up to 30%. Considering the vegetative cover of the neighbourhood and increasing the albedo of the houses by 20%, the heating energy in Toronto can be reduced about 10% in urban houses and 20% in rural houses, whereas cooling energy can be reduced 40 to 30%, respectively. In urban houses of Edmonton, Montreal and Vancouver, savings in heating energy use were about 10%. Cooling energy can be totally offset in Edmonton and Vancouver, and average savings of 35% can be achieved in Montreal.

Simpson, et al. (1996) studied the tree-shade effect on the energy use of energy efficient, attic insulated and uninsulated houses in eleven California climate zones. In this study the effect of wind speed reduction and evapotranspiration from trees were not considered. Trees shading a west exposure, southwest and east were found to produce the largest annual energy savings for all climate zones and insulation levels considered. Depending on climate zone, tree mature trees (two on the west, one on the east side) reduced annual energy use for cooling up to 50%. Trees planted on the south and southeast exposures are advantageous for cooling, but increased heating loads due to reduced solar thermal gains in winter may substantially reduce or eliminate any savings from cooling energy reduction. Trees to the northwest may reduce peak load, while those to the north and northeast of a structure have minimal energy impacts in terms of direct shade.

Akbari, et al. (1997) studied the impact of all three effects of trees on cooling energy use. For this study, two houses in Sacramento, CA were set up for a detailed experimental design. These houses shaded directly from south and west with sixteen trees, eight tall (~6m) and eight short (~2.4m). These houses were simulated by DOE-2.1E program to compare the results of measurement and simulation. It was found that saving in these houses during the shaded periods were, 47% and 26%.

Another study by Simpson, et al. (1998) on the 254 residential properties in Sacramento, California indicated that planting an average of three trees per property reduces annual and peak cooling energy use by 7.1% and 2.3%, respectively.

Literature shows that shading caused by nearby structure has a significant impact on energy consumption of a building. However, there is a need for a detailed study on the effect of nearby structures on residential energy consumption in cold climates like Canada. This study intends to address this issue.

METHODOLOGY

This study is conducted using a “typical” one-storey single detached house designed commonly in Canada. The test case house is modeled using an energy simulation program, ESP-r, a comprehensive building modelling tool based on the finite volume technique. Since this work is intended to be used in the “New Comprehensive Hybrid Energy Model and GHG Emissions Model of the Canadian Housing Stock” (Swan, et al. 2008), the house used as case study house was selected from the Canadian Single-Detached and Double/Row Database (CSDDRD) (Swan, et al., 2009). After creating and simulating the base case model, one or more obstructions were added to the model to assess the impact of shading from surrounding objects. A number of parameters are examined in this work such as, location of the neighbouring house, its size and distance from the modeled house. The following section describes the base case building for this study.

Base Case Model

The single storey base case house is located in Toronto, Ontario. It is composed of one above-grade storey, a conditioned basement and a non-conditioned attic. Characteristics of this house are shown in Table 1. Figure 1 shows the geometry of the base case model.

Table 1
Characteristics of the base case house

Region	Ontario
City	Toronto
Built year	1962
Floor-Area (m^2)	94.3
Width (m)	9.71
Depth (m)	9.71
Height (including attic) (m)	4.46
U-value Above-grade walls ($W/m^2 K$)	0.44
U-value Above-grade ceiling ($W/m^2 K$)	0.21
U-value Basement walls ($W/m^2 K$)	1.44
U-value windows ($W/m^2 K$)	2.73
Number of windows	4 (one each side)
Dimensions of windows (m)	2 x 2

Three thermal zones were used to represent the house. The basement, the attic and the one-storey of living space were each represented as thermal zones. In the model, the living space and basement were conditioned by the HVAC system while the attic is “free floating”, varying in response to the thermal contact with the other zones and the outdoors. The contact between the basement zone and the ground was modeled with the BASESIMP model (Beausoleil-Morrison, et al. 1997) and the air infiltration was modeled with the AIM-2 model (Walker, et al. 1990).

To simplify the model, all windows were placed near the geometric center of the wall for each side of the house. Based on the work by Purdy, et al. (2001), this assumption will not affect the results significantly. The windows are not sealed and it is assumed that they have no blinds.

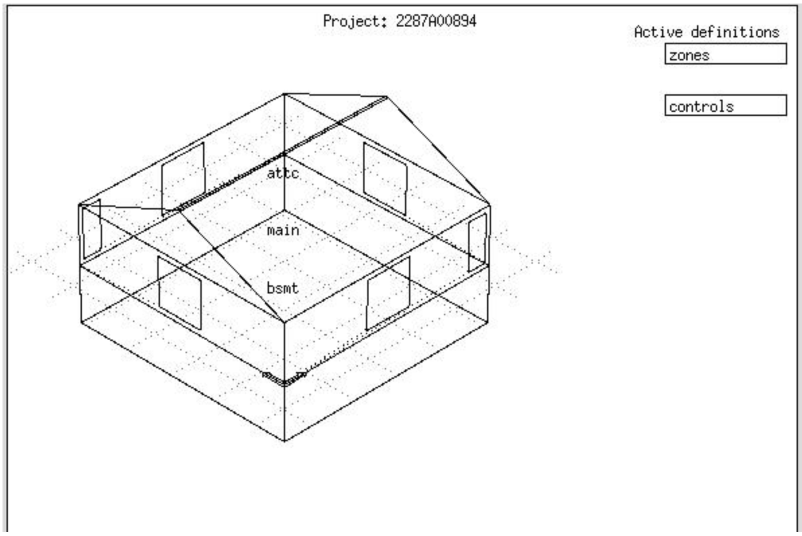

Figure 1. One-story house (base case model)

RESULTS AND DISCUSSION

To assess the effect of shading due to nearby houses a number of simulations were performed. Shading by nearby houses was ignored in the base case. In every other case one or more obstructions were added to the base case model to examine the following factors:

- Location and number of neighbouring houses
- Size of neighbouring houses
- Distance of neighbouring houses from the house
- Climate

In all cases it is assumed that there is no obstruction in the front orientation. While this study considered the effect of neighbouring buildings only, the effect of trees will be studied in the near future.

Location and number of neighbouring houses

The first factor considered is location of the neighbouring house regarding to the base house. An obstruction which is a representative of a nearby building is added to the base case model. Figure 2 shows the schematic of the house with an obstruction. The obstruction is 4.9m (half of the width of the house) away from the house under consideration. It has the same width and height of the house. Four scenarios were examined, with the neighbouring house located north, south, east and west. As can be seen in Figure 3, the shading caused by the neighbouring house increases heating load by up to 2.5% when it is located in the south and decreases cooling load up to 18% when it is located in the west. The results are sensitive to the location of the neighbouring building which confirms Purdy, results on the shading by surrounding objects (Purdy, et al. 2001). Since solar azimuth is high in the summer the obstruction does more shade on the east and west exposure. Therefore, the cooling energy requirement decreases more if the neighbouring house is on the east or west side. Similarly, the heating energy requirement decreases more if the neighbouring building is on the south side since the solar radiation is highest on the south exposure during the heating season.

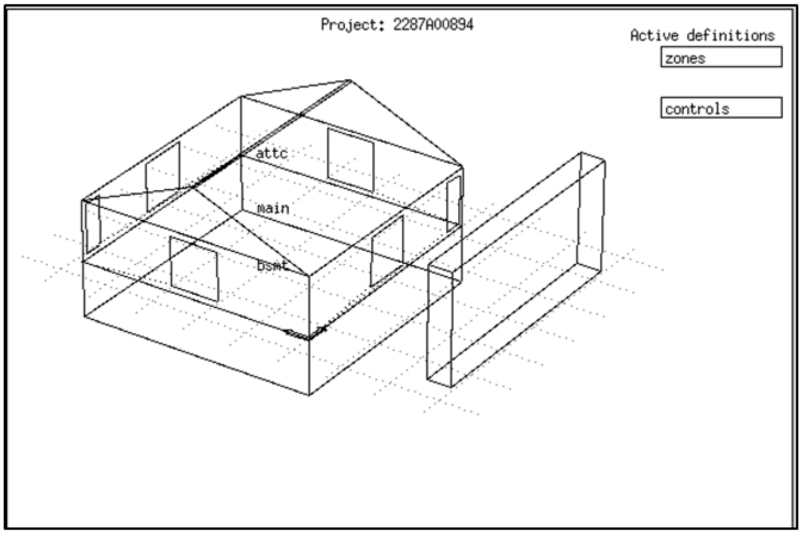

Figure 2. One-story house with an obstruction in the south side

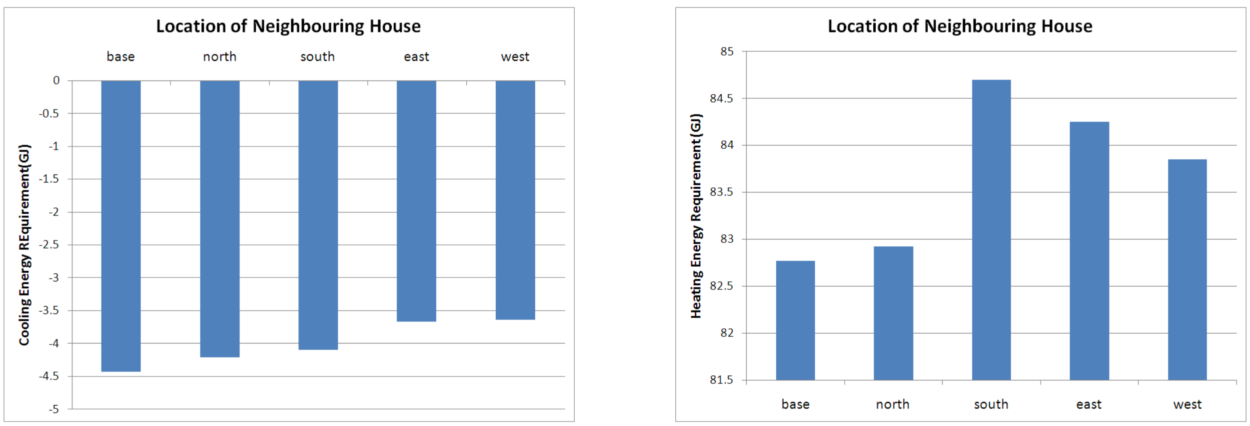

Figure 3. Sensitivity to location of neighbouring house

The second factor is the number of obstructions and orientation of each obstruction. To assess this effect Two obstructions were added to different sides of the house (Figure 4).

As can be seen in Figure 4, adding two obstructions to the east and west sides have a significant effect on the cooling load (37% reduction), which is similar to Ok's findings (Ok, 1992). Adding two obstructions to the east and south sides have the most impact on heating load (4% increase). Figure 5 shows the result of different combinations of three obstructions. South-east-west combination has the lowest cooling load (45%) reduction and the highest heating load (7%) increase.

Size of neighbouring houses

Another important factor is dimensions of the neighbouring houses. For assessing this effect, the width and height of neighbouring houses located to the south and to the west of the house under consideration were changed.

As seen in Figures 6 and 7, increasing sizes of the neighbouring house decreases cooling load by up to 44% and increases heating load by up to 6.3%.

Distance of neighbouring house

Two houses were added to the west and the south of the house and their distances were changed from one-fourth of width of the modeled house to one and a half of that width. The results are shown in Figures 8 and 9 for south and west added obstructions, respectively.

The results indicate that cooling energy is decreased by up to 35% when the neighbouring house is located 3m away from the house and towards the west. Heating energy is increased by up to 5% when the neighbouring house is located 3m away from the house and towards the south. These results are in a good agreement with those reported by Purdy, et al. (2001).

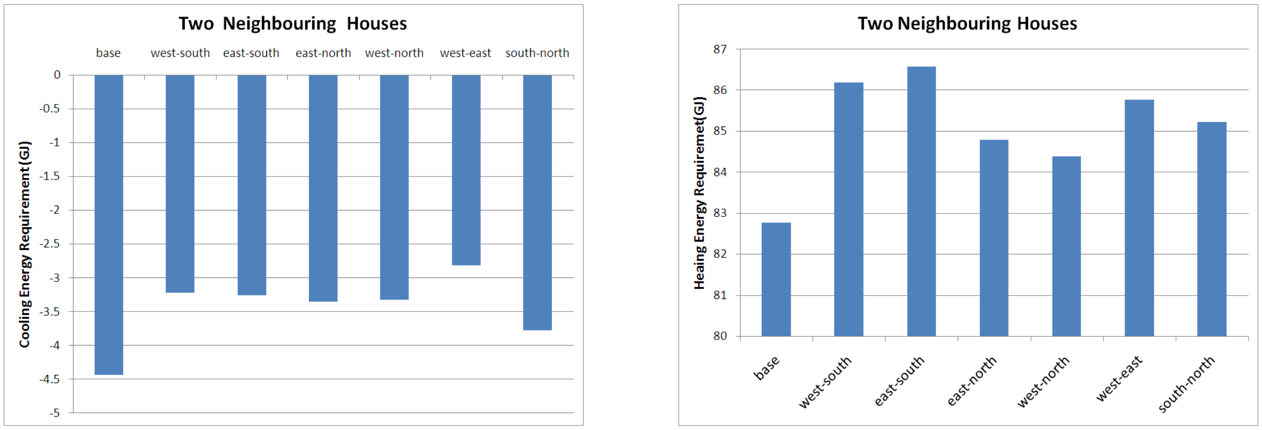

Figure 4. Sensitivity to the location of neighbouring houses (two neighbouring houses considered)

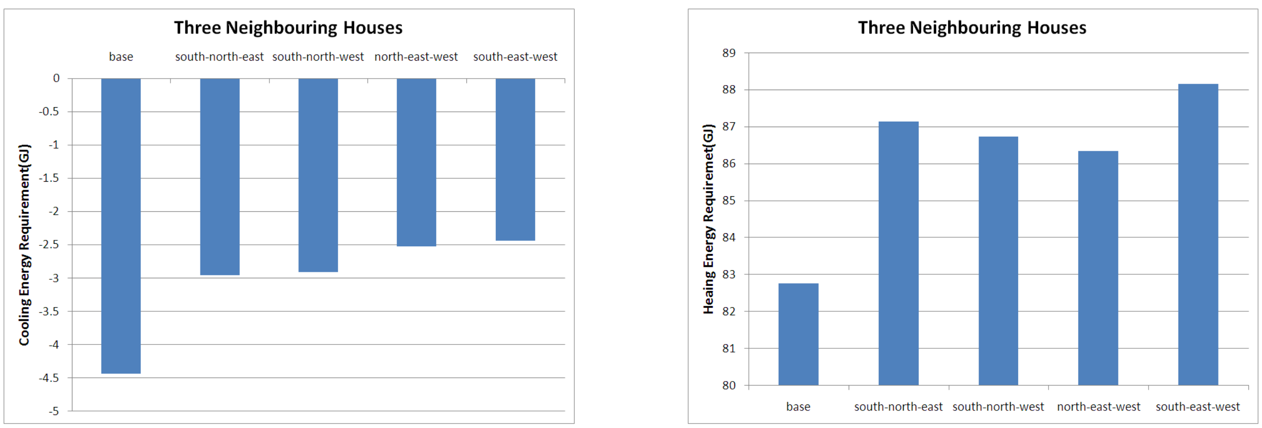

Figure 5. Sensitivity to the location of neighbouring houses (three neighbouring houses considered)

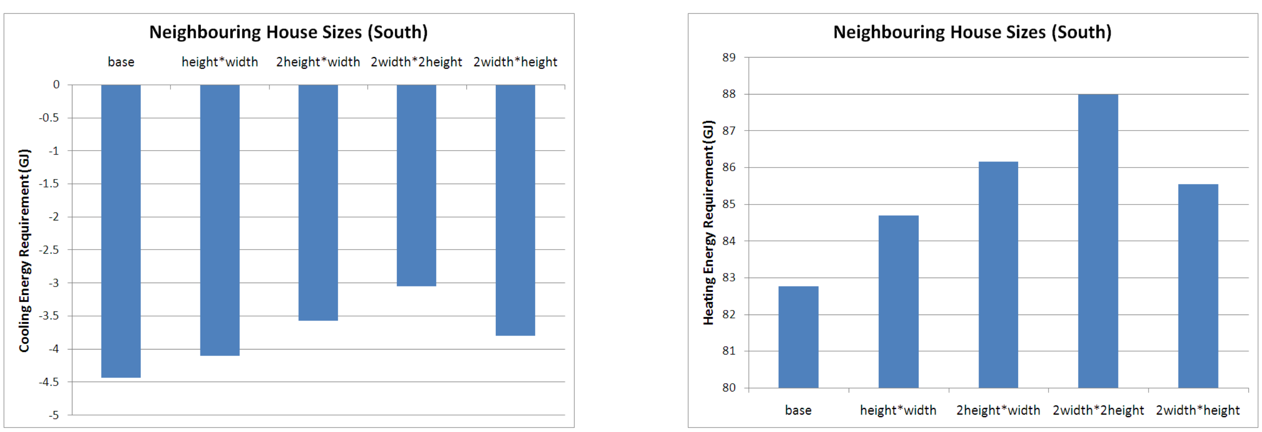

Figure 6. Sensitivity to the neighbouring house size (Added to the South)

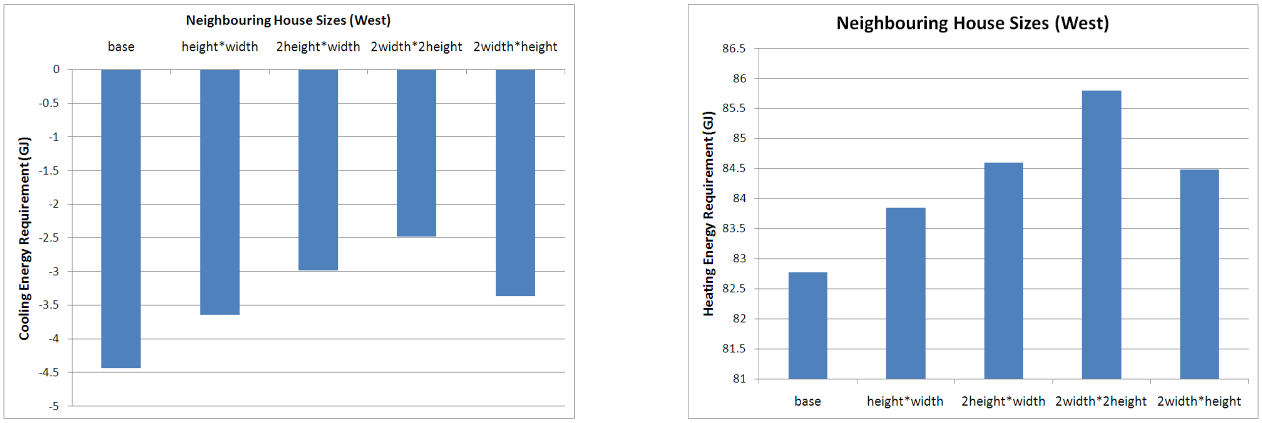

Figure 7. Sensitivity to the neighbouring house size (Added to the West)

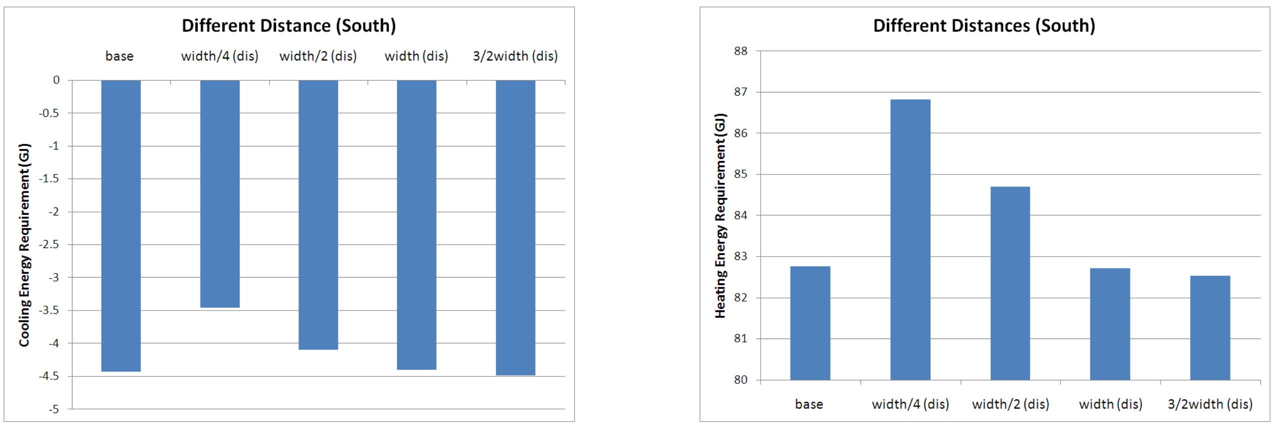

Figure 8. Sensitivity to the distance of neighbouring house (Added to the South)

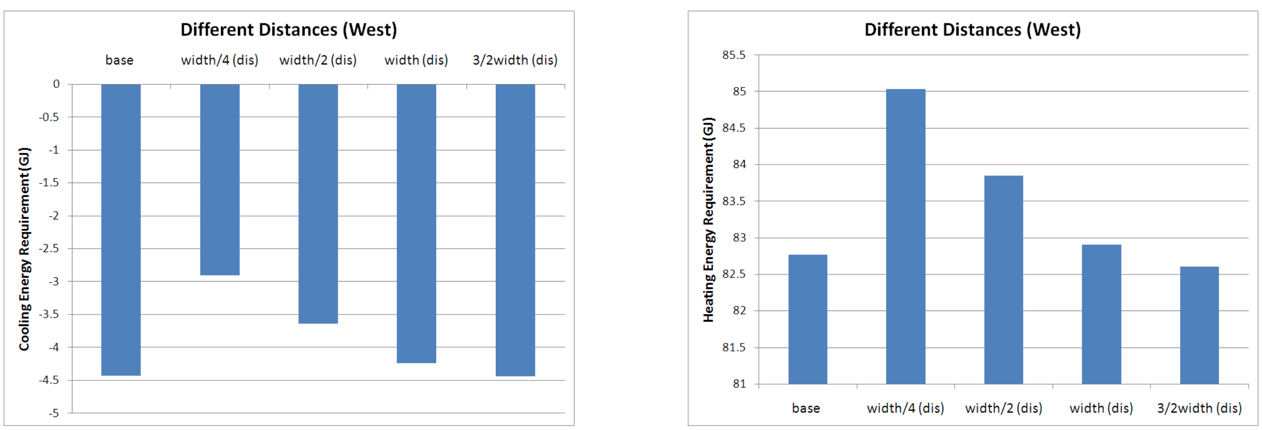

Figure 9. Sensitivity to the distance of neighbouring house (Added to the West)

Climate

To assess the impact of climate on the shading effect due to nearby houses, six cities were selected. These cities are selected from the east coast to the west coast: Halifax, Montreal, Toronto, Regina, Calgary and Vancouver. Two neighbouring houses were added to the west and south side of the building. The results show that cooling energy reduction varies from 7% to 32%. The most significant effect occurs in Regina when the neighbouring house is located on the west side of the house. Figure 10 (a) shows the cooling energy reduction percentage in different regions with a house added on the west side of the house. Figure 10 (b) shows the heating load increase percentage in different region with an obstruction added on the south side of the house. It is found that heating energy increases by up to 4% for the house located in Calgary.

CONCLUSION

The findings of this study indicate that the annual heating and cooling energy requirement of a house in Canada may be significantly affected by the existence as well as the orientation, size and distance of a neighbouring house.

According to findings of this study, a nearby house located on the *south* side of the house under consideration has the most impact on the annual heating energy requirement, while a nearby house located on the *west* side has the most impact on the annual cooling energy requirement. The highest impact on energy requirement is with three obstructions located on the south, east and west sides of the house, in which case the cooling energy requirement decreases by 45% and the heating energy requirement increases by 7% which is more than other combination.

A neighbouring building which is twice as big as the house decreases cooling energy requirement by up to 44% and increases heating energy requirement by up to 6.3%.

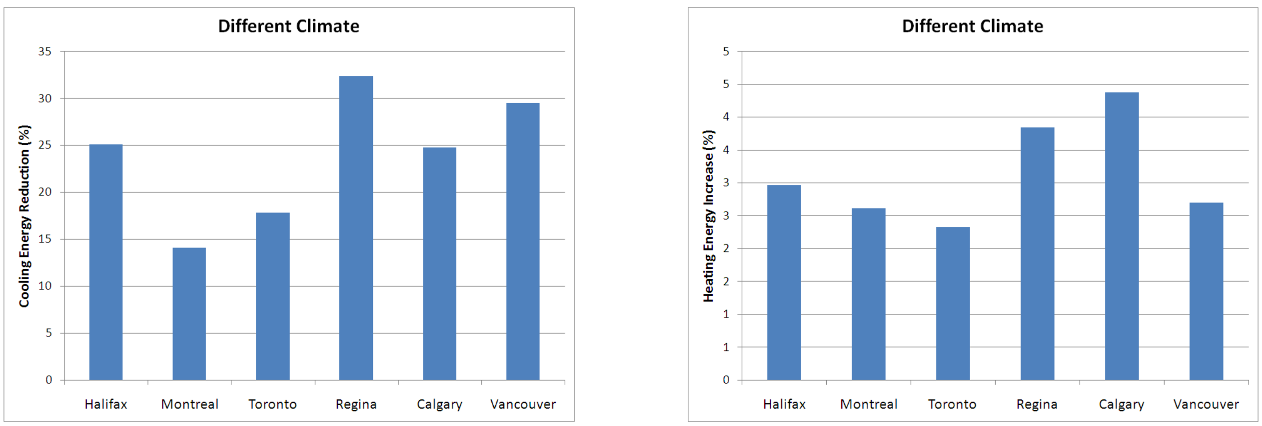

Figure 10. Sensitivity to the climate (a) cooling energy reduction, (b) heating energy increase

Distance of the nearby houses from the house under consideration is another important factor that has impact on heating and cooling energy requirements of a house. The results indicate that cooling energy is decreased by up to 35% when the neighbouring house is located 3m away from the house and towards the west. Heating energy is increased by up to 5% when the neighbouring house is located 3m away from the house and towards the south.

The overall findings which are summarized in Figure 11 show that the total annual heating and cooling energy consumption could increase by 4.5% for a house in Toronto shaded by a neighbouring house which is twice as big as itself and located on the south side. For the same type of shading, the increase in energy requirement varies from 4.4% in Toronto to 6.8% in Calgary.

Considering the substantial impact of external shading by nearby buildings on energy requirement for heating and cooling, it is recommended that external shading effects need to be accounted for in residential sector energy models. The results of this study can also be used in city development strategies. As a continuation of this work, the impact of shading of trees on the energy consumption will be investigated.

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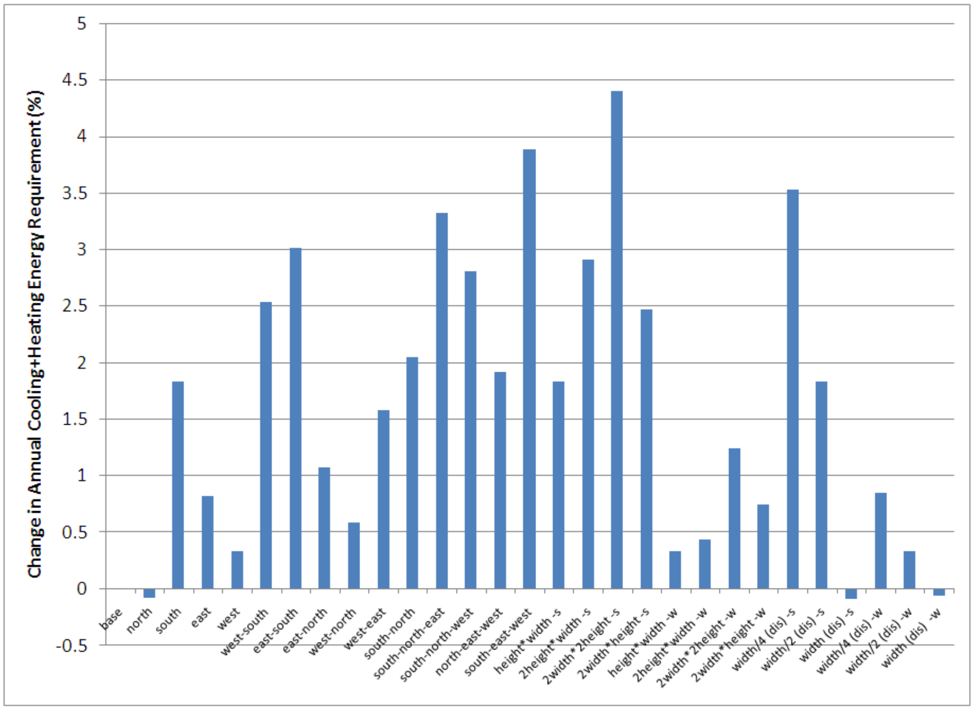

Figure 11. Change in total annual energy requirement due to shading by neighbouring houses

REFERENCES

Akbari, H., Kurn, D. M., Bretz, S. E., & Hanford, J. W. 1997. Peak power and cooling energy savings of shade trees, Energy and Buildings, 25(2), 139-148.

Akbari, H., & Taha, H. 1992. The impact of trees and white surfaces on residential heating and cooling energy use in four canadian cities. Energy, 17(2), 141-149.

Beausoleil-Morrison, I., Mitalas G. 1997. BASESIMP: a residential-foundation heat-loss algorithm for incorporating into whole-building energy-analysis programs", Proceedings of Building Simulation '97(2), 1-8, Int Building Performance Simulation Association, Prague, Czech Republic.

ESRU, Energy Systems Research Unit's (ESRU) Web site, http://www.esru.strath.ac.uk/

Farrar-Nagy, S., Reeves, P., Anderson, R., & Hancock, C. E. 2000. Impacts of shading and glazing combinations on residential energy use in a hot dry climate, Proceedings ACEEE Summer Study on Energy Efficiency in Buildings, 1, 163-176.

Frank, R. S., Gerding, R. B., O'Rourke, P. A., & Terjung, W. H. 1981. Simulating urban obstructions, Simulation, 36(3), 83-92.

Lam, J. C. 2000. Shading effects due to nearby buildings and energy implications, Energy Conversion and Management, 41(7), 647-659.

LBNL, Lawrence Berkeley National Laboratory, http://gundog.lbl.gov/

Li, D. H. W., & Wong, S. L. 2007. Daylighting and energy implications due to shading effects from nearby buildings, Applied Energy, 84(12), 1199-1209.

CanmetENERGY, Natural Resource's Canada CanmetENERGY, http://canmetenergy.nrcan.gc.ca/eng/index.html

Ok, V. 1992. Procedure for calculating cooling load due to solar radiation: The shading effects from adjacent or nearby buildings, Energy and Buildings, 19(1), 11-20.

Purdy, J., & Beausoleil-Morrison, I. 2001. The significant factors in modeling residential buildings, Seventh International IBPSA Conference, Rio de Janeiro, Brazil, Aug. 13-15, 2001. 207-214.

Simpson, J. R., & McPherson, E. G. 1998. Simulation of tree shade impacts on residential energy use for space conditioning in sacramento, Atmospheric Environment, 32(1), 69-74.

Simpson, J. R., & McPherson, E. G. 1996. Potential of tree shade for reducing residential energy use in california, Arboriculture & Urban Forestry, 22(1), 10-18.

Swan, L., Ugursal, V. I., Beausoleil-Morrison, I. In press. A database of house descriptions representative of the Canadian housing stock for coupling to building energy performance simulation, Building Performance Simulation.

Swan, L., Ugursal, V. I., Beausoleil-Morrison, I. 2008. A new hybrid end-use energy and emissions model of the Canadian housing stock, 3rd Canadian Solar Buildings Conference, Fredericton, N.B., Aug. 20-22, 2008, 109-116.

Walker I.S., Wilson D.J. 1990, The alberta air infiltration model: AIM-2, University of Alberta, Dept. of Mech. Eng, Report 71, Edmonton Canada.