ON PREDICTING THE MAGNITUDE AND TEMPORAL VARIATION OF COOLING LOADS IN DETACHED RESIDENTIAL BUILDINGS

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ABSTRACT

The rapid growth in residential air conditioning (cooling) in many parts of the world is resulting in increased energy consumption, significantly affecting central electricity systems, and having adverse environmental consequences. Alternatives to conventional electrically powered vapour-compression air conditioning are emerging. Building performance simulation can be used to assess their feasibility and guide their development, but only if it can accurately characterize the magnitude and temporal variation of cooling loads, including the impact of architectural and site variables (e.g. annual weather changes) as well as the impact of occupant behaviour and interventions (e.g. setpoint temperatures, window shading, window openings). This paper demonstrates how building performance simulation can be employed to study the impact of these factors upon seasonal as well as peak daily cooling loads.

INTRODUCTION

Single-family detached housing is the dominant form of residence in Canada and accounts for 11% of the country's total secondary energy consumption and 48 Mtonnes of GHG emissions annually (NRCan, 2008). Although space cooling represents only 1.5 to 3.5% of total energy use in detached housing, this figure is growing rapidly (see Figure 1). Since 1990 the number of air conditioning (A/C) units installed in Canadian residences has increased by 140% and the electrical energy consumption for A/C has increased threefold (NRCan, 2008). By 2003 (the latest year for which statistics are available), 45% of Canadian households were equipped with A/C (NRCan, 2005). And in Ontario, a province whose regions have some of the warmest summers in Canada, almost three quarters of households had A/C. In fact, roughly 60% of Canadian residential A/C systems are installed in that province. Moreover, due to above-average temperatures since 2003 it is likely that the penetration rate of residential A/C has continued to increase. The trend towards the greater use of residential A/C is one which Canada shares with most OECD countries (IEA, 2003).

Despite the fact that A/C represents only 1.5 to 3.5% of total energy use in detached Canadian housing, it places a disproportionate demand upon the central electrical system, particularly in the late afternoon and early evening of hot summer days. High ambient temperatures and heavy loading reduce electrical conductivity leading to higher ohmic losses: marginal transmission line losses can increase by up to 200% when the central grid is peaking (OPA, 2007). Furthermore, in some parts of Canada including Ontario, GHG-intensive fuels (often coal) are used to meet marginal demands on peak days. As a result, A/C is a major and increasing contributor to the GHG burden of Canadian housing.

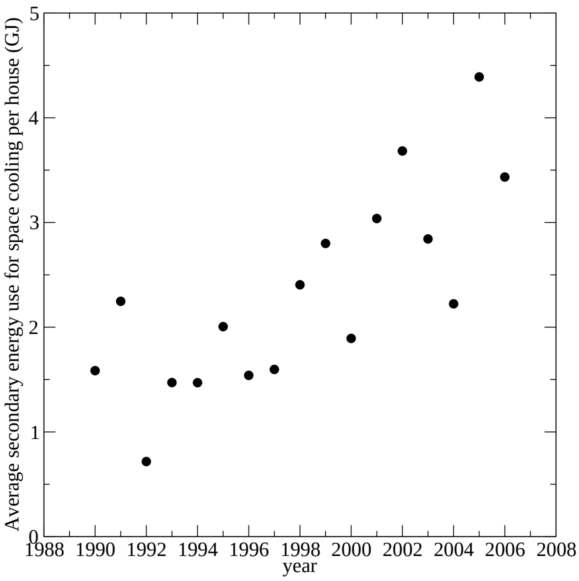

Figure 1: Growth in energy consumption for space cooling in Canadian detached housing (data source: NRCan 2008)

Alternatives to conventional electrically powered vapour-compression A/C for providing comfort cooling in residential buildings are emerging. These include thermally activated chillers (TAC) based upon closed absorption cycles. Systems based upon open or closed adsorption cycles and Rankine cyclesare other possibilities. Solar-TAC systems of a scale appropriate for cooling residential buildings are actively under development and a number of prototype and early production devices have been field tested (e.g. Henning, 2007; Kim and Infante Ferreira, 2008). Others have identified that the thermal output from micro-cogeneration devices could also be used to drive such TAC systems to provide comfort cooling (Li and Wu, 2009).

The accurate design and performance assessment of solar-TAC and micro-cogeneration-TAC for residential buildings requires an accurate understanding of the magnitude and temporal variation of thermal loads. This is because some type of thermal storage (hot and/or cold) will be required to buffer between thermal production and space cooling demands. As well, the operation of the heat generator (solar thermal or micro-cogeneration), TAC, and thermal storage will have to be controlled to respond to varying indoor and climatic conditions.

Accurately characterizing cooling loads can be quite challenging due to the strong impact that occupant behaviour has upon the usage of cooling systems, including adjustments to thermostat setpoints. In addition many occupants take advantage of free ventilation cooling by adjusting window openings while others adjust window shading devices to reduce solar gains.

Objectives and outline of paper

This paper represents the first step in an ongoing research effort aimed at assessing the potential of solar-TAC and micro-cogeneration-TAC for cooling Canadian detached housing. In this first step, a methodology is established to explore the magnitude and temporal variation of space cooling loads in Canadian housing. The methodology is demonstrated by focusing upon a representative Canadian house and assessing its performance during the cooling season in a single climate region using building performance simulation. The next section describes the house that is the object of the study and the simulation model that has been created to represent its thermal performance. Following this, simulation predictions are presented. The initial set of simulations explore the impact of architectural and site variables, such as weather data, roof overhangs, and building orientation. Following this, a series of simulations is performed to investigate the effect of occupant interventions aimed at mitigating cooling loads, such as actuating blinds and opening and closing windows in response to indoor and outdoor conditions. Results are then discussed, conclusions drawn, and recommendations provided for future work.

MODEL OF REPRESENTATIVE HOUSE

An ESP-r (Clarke, 2001) simulation model was configured to represent a typical 30 to 50 year-old detached Canadian house. The house has 142 m^2 of floor area in its $1\frac{1}{2}$ above-ground storeys and is built upon a full-height 80 m^2 basement foundation. The envelope constructions and insulation levels are typical of this vintage of house with a moderate level of upgrades. The wood-framed walls are insulated with 89 mm of fiberglass insulation. A similar level of insulation is placed upon the internal surface of the basement's concrete walls. The ceiling under the pitched roof is insulated with 210 mm of loose-fill fiberglass while the basement floor is uninsulated.

The house contains 18.5 m^2 of clear double-glazed windows, which is slightly less than average for this vintage of building (as determined from Swan et al., 2009). These are distributed in the cardinal directions as follows: 47% north, 25% south, and 14% on each the east and west. A rendered image of the ESP-r model of the house is illustrated in Figure 2.

It is assumed that there is a constant heat gain of 580 W due to electrical appliances and lighting. The heat gains due to four occupants are also considered.

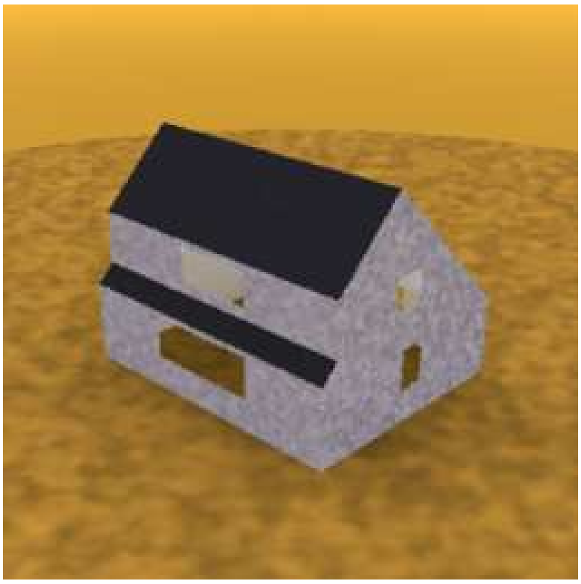

Figure 2: Rendering of ESP-r model of house

Air infiltration due to stack and wind pressures was modelled using ESP-r's optional AIM-2 model (Walker and Wilson, 1998) using airtightness and leakage areas typical for this vintage of house. The below-grade heat transfer was treated using ESP-r's optional BASESIMP model (Beausoleil-Morrison and Mitalas, 1997). The house is heated to 20^{o}C from mid-September through mid-May using an idealized zone controller. A simulation of the house conducted with ESP-r release 11.6 using the Canadian Weather for Energy Calculations (CWEC, Environment Canada 2008) climate data for Ottawa predicted an annual space heating load of 61.8 GJ, which is typical for this size and vintage of house.

As previously stated, this research is aimed at assessing the potential of solar-TAC and micro-cogeneration-TAC for space cooling. Consequently, a detailed explicit plant model was configured to represent the cooling system. Figure 3 illustrates one possible configuration of a solar-TAC system. As little information is currently available on the performance characteristics of the TAC itself, this component and the others shown in grey in the figure are excluded from the current model. Rather, the model explicitly represents the chilled water storage tank and the pump, fan, and cooling coil that comprise the secondary system that cools and dehumidifies the air that is recirculated through the building's ducting and air terminals to condition the house. In this way, the simulation accurately predicts the chilled water production required by the TAC and the other components shown in grey. To represent the system in the ESP-r model, pump, fan, and cooling coil plant components were configured and controlled such that the pump and fan cycle on and off to maintain the house at 25 ± 0.5^oC from mid-May through mid-September. Throughout the simulation period, the tank is held at a constant 10^{o}C.

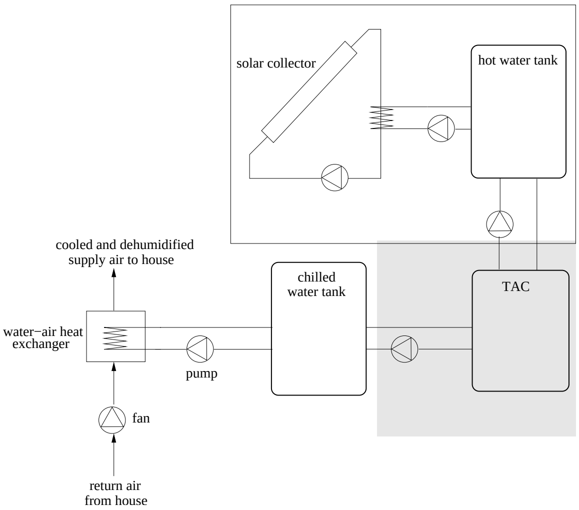

Figure 3: Solar-TAC cooling system

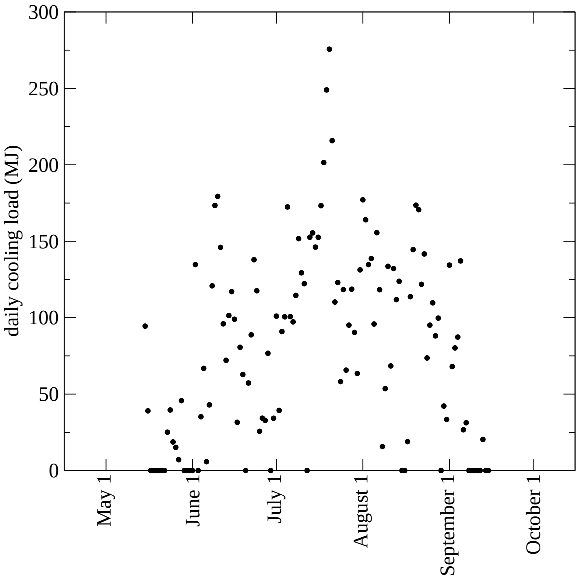

Figure 4: Daily integrated cooling loads for unshaded house with no occupant interventions

ARCHITECTURAL AND SITE VARIABLES

Simulations were conducted with the model described in the previous section for the period of May 15 through September 15 using 5-minute time-steps. In this set of simulations it was assumed that the occupants took no action to mitigate cooling loads: the windows were never shaded with blinds and the windows remained closed throughout the summer.

Weather data

When simulated with the Ottawa CWEC weather data, the total cooling load (sensible plus latent) placed upon the chilled water tank over the cooling season was found to be 10.0 GJ. The daily integrated cooling load for each day of the summer is plotted in Figure 4. The cooling system was required to operate on 100 days of the 124 days of the cooling period. The peak daily load, an important consideration in sizing the components of the system, was found to be 276 MJ. It is worth noting that 276 MJ of cooling represents a significant load for a TAC system. For a nominal coefficient of performance of 0.6 and neglecting parasitic loads, the TAC device would require a thermal input of 460 MJ. This could be provided by a micro-cogeneration device operating with a constant 5.3 kW of thermal output over the course of a day. Alternatively, approximately 43 m^2 of solar thermal collectors with a nominal efficiency of 0.5 would be required to provide this thermal input on a typical July day in Ottawa (21.6 $\mathrm{MJ/m^2}/day$ of global horizontal irradiance).

It is important to note that these simulation results were generated with the CWEC weather data. CWEC weather files are derived from long-term climate observations using a Typical Meteorological Year (TMY) methodology. With this, a monthly composite weighting of average solar radiation and average and extreme dry bulb temperature, dew point temperature, and wind velocity are compared to the long-term distribution of these values. Months closest to the long-term distribution are selected and concatenated to form a CWEC file containing data for actual months from a number of different years. Crawley (1998) has demonstrated that such composite weather files are appropriate for predicting the long-term energy performance of buildings. However, they do not necessarily capture normal year-to-year weather variations and extremes. Additionally, they may lead to significant errors in studies such as the current one that are focused upon one aspect of performance, in this case cooling.

To explore the significance of weather data selection, 10 additional simulations were performed using the most recent decade's worth of observed and modelled weather data from the Canadian Weather Energy and Engineering Data Sets (CWEEDS, Environment Canada 2008). Three performance metrics were selected to compare predictions from the 11 simulations (1992 through 2001 CWEEDS plus CWEC):

- The total cooling load placed upon the chilled water tank over the cooling season. This is indicative of the system's energy consumption over the summer.
- The peak daily load placed upon the chilled water tank. This is an important indicator for the sizing and control of system components, such as the TAC, thermal generator (micro-cogenerator or solar thermal collector), and storage tanks.
- The number of days of system operation. This is indicative of the frequency at which the system must function.

The values for these three parameters were determined from each of the 10 CWEEDS simulations and then contrasted to the predictions achieved with the CWEC weather data. These results, normalized to the CWEC results, are plotted in Figure 5. As can be seen, in 8 of the 10 years analyzed the total cooling load over the summer was greater than that predicted with the

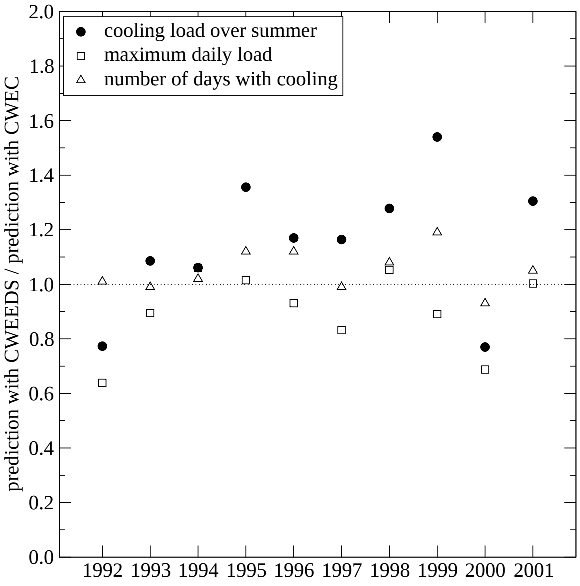

Figure 5: Contrast of predictions using actual year CWEEDS weather data versus using CWEC weather data

CWEC weather data. In fact, in one year (1999) the load exceeds the CWEC prediction by more than 50%. There was less variability, however, in the peak daily loads: in 8 out of 10 years the predictions were within 20% of the value predicted with the CWEC data. There was even less variation in the number of days during which the cooling system functioned.

Roof overhangs

The previous simulations assumed there was no shading of the windows. To explore the impact that roof overhangs (a common architectural feature for reducing summer solar gains) could have, the model was reconfigured with external blockages representing overhangs that extend 0.4 m from the window surface.

Another simulation was conducted using the CWEC weather file. Figure 6 examines the impact of the overhangs upon the daily integrated cooling load by contrasting the results of this simulation with the results of the previously reported CWEC simulation. Each data point in the figure represents the load for a single summer day and equals the ratio of the cooling load when the overhangs are present relative to the cooling load when they are absent. All data points lie below the dashed line (except those with zero cooling load), indicating that the overhangs reduced the cooling load on each day the system operated. The addition of the roof overhangs was found to reduce the cooling load over the summer by 22%. However, they reduced the peak daily load by only 9% and eliminated the need for the cooling system for only 4 additional days.

Building orientation

The previous section indicated that the house's dominant solar exposure was to the north: 47% of the window area faced north whereas 25% faced south. Another simulation using the CWEC weather data was conducted wherein the house was rotated 180^o so that its window area was predominantly south facing. The roof overhangs were absent during this simulation.

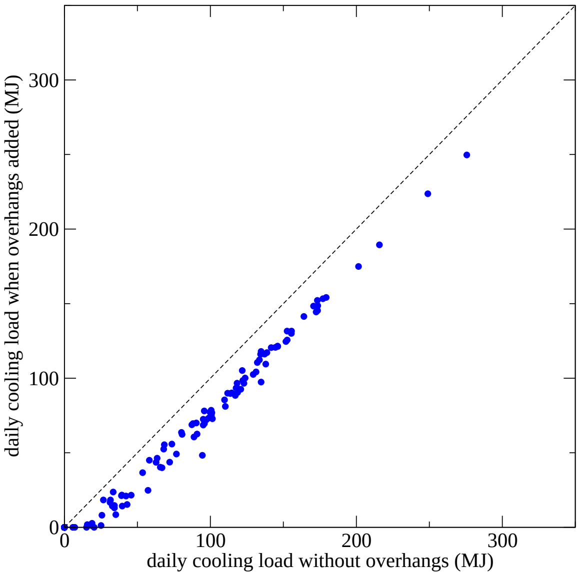

Figure 6: Impact of adding roof overhangs

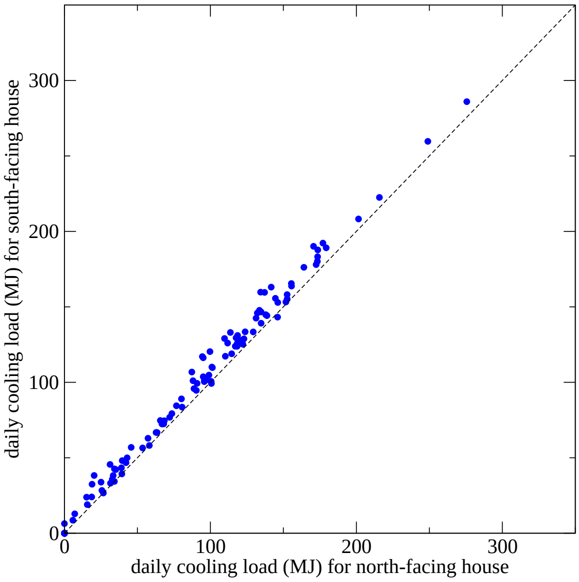

Figure 7: Impact of building orientation

Figure 7 examines the impact of building orientation. Each data point in the figure represents the load for a single summer day and equals the ratio of the cooling load when the house is south facing relative to the load when the house is north facing. All but 5 data points lie above the dashed line (discounting those with zero cooling load), illustrating the influence of the greater solar fenestration on most days. Rotating the building to face south was found to increase the cooling load over the summer by 8% (to 10.8 GJ) but only increased the peak daily load by less than 4% and required the cooling system to operate an additional 1 day.

Shading by trees

The previous simulations neglected the shading that might be caused by surrounding objects such as other buildings and trees. To assess the potential impact of this, another simulation was performed on the north-facing house without overhangs. In this case a solar obstruction was added to the ESP-r model to approximate the shading that would be caused by a 4 m diameter tree located 10 m south of the house. This was found to reduce the cooling load over the summer by almost 5%, although the reduction in the peak daily cooling load was less than 2%.

The simulation results presented in this section have examined the significance of a number of architectural and site variables. Although this study is not exhaustive, the factors that can vary for a given house design and that are felt to have the greatest influence on cooling loads have been examined. The next section studies the influence of occupant behaviour upon these loads.

OCCUPANT INTERVENTIONS

Setpoint temperature

The impact of cooling setpoint temperature was explored by conducting another simulation of the unshaded house with no occupant interventions and by using the CWEC weather file. Previously the cooling system was operated to maintain the house at 25 ± 0.5^oC. This setpoint temperature was raised by 1^oC to maintain the house at 26 ± 0.5^oC. As expected, raising the setpoint temperature results in a lower cooling load each day the system is operated. This was found to reduce the cooling load over the summer by 17% (to 8.3 GJ). However, the peak daily load was reduced by only 7% and the need for cooling was eliminated by only 3 days.

Window shades

In the previous simulations the windows were assumed to have no blinds. If such shading devices are present they could be operated by the occupants to reflect incoming solar radiation at certain times in an attempt to reduce cooling loads placed upon the A/C system. A number of simulations were conducted to explore the potential impact of this occupant intervention.

Three types of blinds were considered: light-coloured venetian blinds, light-coloured translucent roller blinds, and white opaque roller blinds. The optical property data of the windows were altered in the ESP-r model to account for the impact of absorption, transmission, and reflection of the shading layer using representative data provided by ASHRAE (2005). In the case of the light-coloured venetian blinds, for example, it was assumed that only 5% of the solar radiation reaching the window's inside pane would be transmitted to the house interior, where it would be absorbed and eventually convected to the room air to affect the indoor air temperature and become a load on the A/C system. Whereas 55% of the solar radation reaching the window's inside pane would be reflected towards the outside pane. The remaining 40% would be absorbed at the interior surface of the window and thus elevate its temperature. This elevated temperature would augment the convective heat transfer from the window to the room air and the radiant exchange with the house's other interior surfaces (eventually affecting the room air temperature), which would again affect the load placed upon the A/C system. (A more detailed treatment of the optical and thermal performance of the shading layer could be accomplished in the future using the methodologies proposed by Lomanowski 2008.)

Table 1: Occupant control actions over window shading

type of blind	**case**	**control action**
light-coloured venetian blinds	A	close when $T_a > 28^oC$
	B	close when $T_{house} > 24^oC$
	C	close when $I_{window} > 500W/m^2$
light-coloured translucent roller blinds	D	close when $T_a > 28^oC$
	E	close when $T_{house} > 24^oC$
	F	close when $I_{window} > 500W/m^2$
white opaque roller blinds	G	close when $T_a > 28^oC$
	H	close when $T_{house} > 24^oC$
	I	close when $I_{window} > 500W/m^2$

The light-coloured translucent roller blinds were treated in a similar fashion. But in this case the solar transmittance, reflectance, and absorptance were taken to be 25%, 60%, and 15%. And the white opaque roller blinds were treated with values of 0%, 65%, and 35%.

A control algorithm was established to mimic occupant control of the blinds. In one scenario, for example, the occupants would close the blinds when the ambient temperature rose above 28^oC. In another scenario the occupants would close the blinds when the room air temperature rose to 24^oC, thus mimicking a control action that took place prior to the A/C system being called upon to cool. In the third scenario the occupants would close the blinds when the solar radiation incident upon the outside pane of the window exceeded 500 W/m^2. In all instances control was assumed to be perfect: the occupants were always home and always took action to draw the blinds to mitigate the cooing loads caused by solar gain. As such, this analysis provides an upper bound on the effectiveness these occupant interventions actions might be in mitigating solar gains and thus reducing the burden upon the A/C system. The 9 combinations of blind type and control behaviour are given in Table 1.

Figure 8 illustrates the impact of these 9 scenarios. The labels used in the figure to identify each case correspond to the classification given in Table 1. These simulations were conducted with the CWEC weather data and without the roof overhangs.

Despite considerable variation in optical properties, the results are quite consistent for the three types of blinds. Drawing the blinds when the ambient temperature rises above 28^oC (cases A, D, and G) has only a small impact (2 to 3%) upon the cooling load over the summer

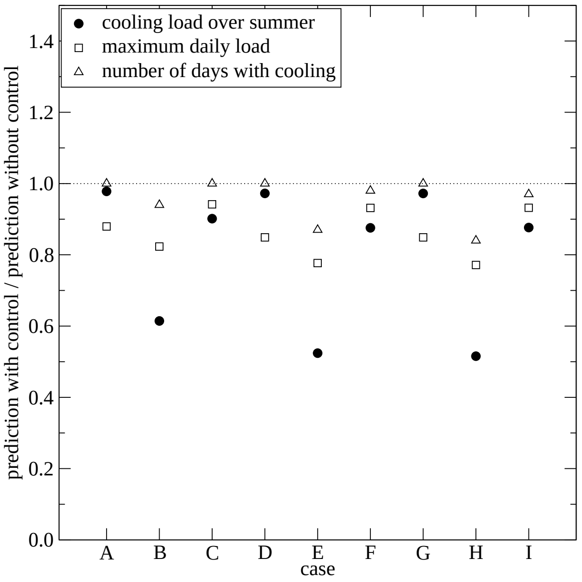

Figure 8: Impact of occupant controlled shading devices (refer to Table 1)

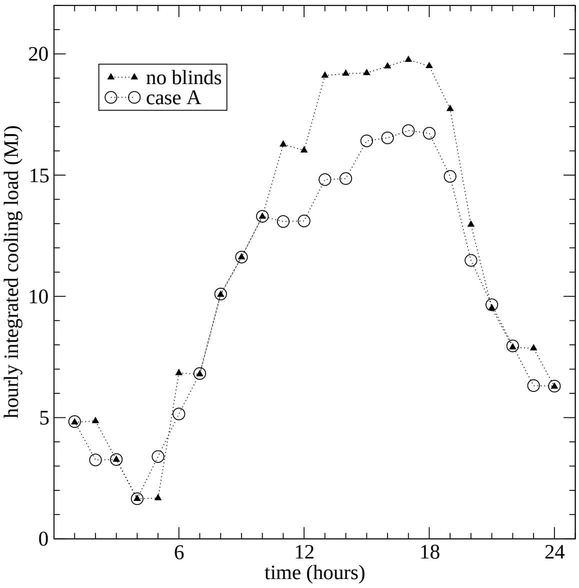

Figure 9: Impact of blinds during peak cooling day

and has no impact upon the number of days in which the A/C system operates. However, this strategy can reduce the peak daily cooling load by 11 to 15%. Figure 9 illustrates the hourly integrated cooling load for case A over the day with the highest cooling load (July 20). By contrasting the case A results to those for the house without blinds, this figure illustrates the impact that drawing the blinds has upon reducing the cooling load on this day from mid-morning to early evening.

Drawing the blinds before the A/C is required (cases B, E, and H) was seen to be the most effective strategy. This significantly reduced the cooling load over the summer (by 38 to 48%) and eliminated the need for A/C between 7 and 13 days. However, this strategy only reduced the peak daily load by about 20%.

When the occupants draw the blinds in response to high solar radiation levels (500 W/m^2 at the outside pane of the window, cases C, F, and I) this reduced the cooling load over the summer by 10 to 12%. However, this strategy had a smaller impact upon the peak daily cooling load (5 to 7%) and a negligible impact upon the number of days of A/C system operation.

Opening windows

In the previous simulations the windows were assumed to be closed at all times. In other words, the occupants did not open and close the windows in response to indoor and outdoor conditions to take advantage of free ventilative cooling. A number of simulations were conducted to explore the potential impact this occupant intervention might have.

Numerous algorithms have been developed to represent occupant behaviour in regards to opening windows in response to thermal conditions to provide ventilative cooling (e.g. Bourgeois, 2005; Herkel et al., 2008; Rijal et al., 2008; Yun et al., 2009)). However, these are not readily applicable to residential buildings or the Canadian context. Consequently, the impact of window openings is quantified here using a simplified method.

As described earlier, ESP-r is calculating the infiltration to the house due to stack and wind pressures using the AIM-2 model. This is an appropriate approach when the windows are closed as it calculates the infiltration through unintended openings. An alternate approach is employed when the windows are open. With this, ESP-r's nodal network method (Clarke, 2001) is used to calculate the air flow rate through open windows due to indoor-outdoor pressure differences. The window openings are characterized using ESP-r's *specific air flow opening* which relates the air flow through each window to the pressure difference according to,

$$\dot{m}_{air} = 0.65 \cdot A_{opening} \cdot (2\rho\Delta P)^{1/2} \qquad (1)$$

Where $\dot{m}_{air}$ is the air flow through the open window (kg/s), ρ is the air density (kg/m^3, calculated as a function of temperature), and ΔP is the pressure difference (Pa) between the outside surface of the window and the house interior. The opening area, $A_{opening}$ (m^2), is taken here to be 10% of the total area of the window. This assumption is based upon a number of approximations and judgments, such as the presence of insect screens, non-openable portions of windows, and the fact that it is unlikely that all windows would be fully opened by the occupants at any given point in time. Clearly these assumptions introduce significant uncertainly into the analysis. Notwithstanding, it is felt that this method provides an indication of the potential for this intervention to mitigate cooling loads.

The ΔP term in equation (1) is calculated for each window given its orientation and the wind speed data from the weather file. The pressure exerted by the wind on the outside surface of each window is calculated by

Table 2: Occupant control actions over window openings

case	close windows when either condition occurs	
a	$T_{house} < 20^oC$	$T_{house} - T_a < 3^oC$
b	$T_{house} < 19^oC$	$T_{house} - T_a < 3^oC$
c	$T_{house} < 21^oC$	$T_{house} - T_a < 3^oC$
d	$T_{house} < 20^oC$	$T_{house} - T_a < 2^oC$
e	$T_{house} < 20^oC$	$T_{house} - T_a < 1^oC$

(Clarke, 2001),

$$P_i = R \cdot C_P \cdot \left(\frac{\rho V_{wind}^2}{2} \right) \tag{2}$$

Where (V_{wind} is the wind velocity (m/s) at the weather station in the direction of the surface under consideration. R is the wind reduction factor (-) that relates the wind velocity at the building site to that at the weather station. It is taken here to be 0.526, a value corresponding to urban locations. C_P a pressure coefficient (-) for the surface under consideration. The values recommended by Clarke (2001) for a sheltered wall are used here.

Five window control scenarios were examined, as detailed in Table 2. For example, in scenario *a*, the occupants left the windows open at all times except when the house temperature dropped below 20^{o}C or when the indoor-outdoor temperature difference dropped below 3^{o}C. When the windows were open the air infiltration (including moisture) was calculated with equations (1) and (2). And when the windows were closed the air infiltration was calculated with the AIM-2 model as in the previous simulations. In all instances control was assumed to be perfect: the occupants were always home and always took action to open and close the windows according to the strategies described in Table 2. As such, this analysis provides an indication of the potential impact window operation might have upon reducing the load placed upon the A/C system.

Figure 10 illustrates the impact of the 5 occupant behaviour scenarios. The labels used in the figure to identify each case correspond to the classification given in Table 2. These simulations were conducted with the CWEC weather data and with the house without roof overhangs. As can be seen, controlling the windows to provide ventilative cooling can have a major impact upon the cooling load over the summer. The 5 scenarios reduce this load by 49 to 55%. Additionally, these strategies can eliminate the need for A/C system operation by 36 to 40 days. The impact upon the peak daily cooling load, however, is much more modest. These strategies reduced this load by only 6 to 10%.

CONCLUDING REMARKS

The first step of an ongoing research effort aimed at assessing the potential for cooling Canadian detached houses using thermally activated chillers (TAC) powered by the thermal output of solar collectors or micro-cogeneration has been completed. In this, methods have been developed and demonstrated for exploring the magnitude and temporal variation of space cooling loads in Canadian housing. The results from the application of the methodology for a representative 30 to 50 year-old detached house are presented.

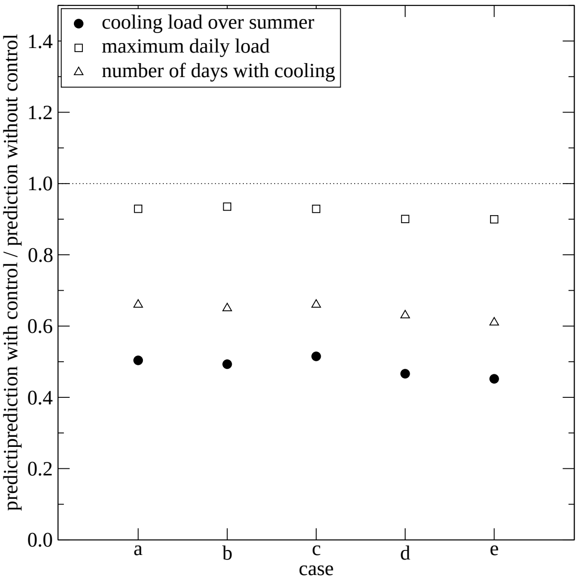

Figure 10: Impact of occupant controlled window openings (refer to Table 2)

It was found that the total cooling load over the summer can vary significantly from one year to the next due to weather conditions. However, the annual variation in the peak cooling load was found to be much less significant. These observations lead to the preliminary conclusion that although year-to-year weather variations may have a significant impact upon the cooling system's energy consumption, the use of representative weather data (CWEC in this case) may be adequate for the purposes of dimensioning system components and for assessing the feasibility of the system under peak operating conditions.

The presence of roof overhangs that shade windows was found to significantly reduce the cooling load over the summer (by 22%) but only reduced the peak daily cooling load by 9%. For this particular building and climate combination, window orientation and the presence of trees that shaded south-facing windows were found to be less significant factors than the presence of roof overhangs.

A number of simulations were conducted to assess the impact of occupant behaviour and interventions to reduce cooling loads. Raising the cooling setpoint temperature 1^{o}C was found to have an important impact upon the cooling load over the summer but only reduced the peak daily load by 7%.

It was found that when occupants draw internal blinds in response to high outdoor air temperatures this has a minor impact upon the cooling load over the summer, although it is moderately effective at reducing the peak daily cooling load (by 12 to 15%). In contrast, when occupants draw internal blinds in response to high solar insolation levels, this has a moderate impact upon the cooling load over the summer, but only a minor impact upon the peak daily cooling load. The most effective occupant blind control was found to be when occupants closed the blinds as the indoor temperature rose and before the A/C system turned on. This was found to reduce the cooling load over the summer by 38 to 48% and was found to reduce the peak daily cooling load by 18 to 23%. These results were found to be fairly insensitive to the type of internal blind employed.

The opening and closing of windows to take advantage of ventilative cooling was found to be the most effective occupant intervention. Various scenarios were examined for the window control behaviour and all led to significant reductions (48 to 55%) in the cooling load over the summer. However, the opening of windows had only a minor impact upon the peak daily cooling load (6 to 10%).

In the future, the combined impact of a number of the occupant interventions and site variables will be examined, as will be the influence of different internal heat gain scenarios. This will provide a range on the possible peak daily cooling loads as well as the temporal distribution of these loads over the day. The monitoring of the A/C electrical consumption of a limited number of residences will be performed to corroborate some of the assumptions required for modelling the occupant behaviour.

Following an experimental investigation of a prototype TAC device, the modelling will be extended to include the TAC and other components shown in grey in Figure 3. In this way, the temperature of the chilled water tank will respond to the climate and building conditions as well as the functioning of the other system components. The methodology demonstrated here will also be extended to other representative Canadian houses and climate regions.

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