Impact of Future Climate Change on the Overheating of Canadian Housing Retrofitted to the PassiveHaus Standard: A case study

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Abstract

This paper investigates the impact of future climate changes on the indoor climate of a typical Canadian single-family house retrofitted to the PassiveHaus standard. The indoor thermal comfort of this house in terms of summer overheating risk is evaluated using current and future weather files in 2020, 2050 and 2080. The future weather files are generated using General Circulation Models (GCM) HadCM3 with the A2 emission scenario presented by the Intergovernmental Panel on Climate Change (IPCC). The simulations are carried out using IES [Ve] software. Generally, it is observed that the risk of overheating for a typical Canadian house upgraded to the PassiveHaus standard under free running conditions would significantly increase from 2020 onward. Results also show that the cooling load of the PassiveHaus retrofitted option is slightly higher than Quebec energy code (QEC) compliance option. However, the total energy consumption of the PassiveHaus option seems to be significantly lower than that of the QEC base case. Analyses also show that the application of the proposed shading systems in Montreal would not reduce the total energy consumption over future years.

Keywords: Building Envelope Retrofits, Future Climate, Overheating, Energy Simulations

1- Introduction

Potential changes in global climate would increasingly impact the built environment. Perhaps the most remarkable of these changes concerns the influence of higher air temperatures on the thermal performance of buildings (Sajjadian, et al., 2013). Observed weather records demonstrated that the global average near-surface temperature over land and sea has been increased by 0.75 °C over the 20th century (Sharpless, 2009). Sharpless, (2009) also explained that the warming rate has been greater over land regions than over the oceans and has been the greatest in higher northern latitudes. Bill Dunster Architects and Arup R&D (2005) also demonstrated the importance of mitigating climate change effects by designing homes with Energy efficiency features to balance the expected increases in air temperatures. They identified that under the UK climate conditions the energy

saving of masonry houses with the inherent thermal mass over their life time would be more than the energy saving in a lightweight timber frame house. The study demonstrated that lightweight homes would result in discomfort caused by higher internal temperature (Bill Dunster Architects, 2005). Therefore, it is important to take into account the future climate conditions so that buildings can be designed to be adaptable to their intended future environment.

Currently, the building sector aims to reduce energy consumption by increasing building envelope energy performance. Beyond various energy codes that have been set worldwide, the German standard entitled PassiveHaus (PH) is a well-known standard, which attempts to reduce energy consumption by 90% within dwellings. This high level of energy reduction requires highly insulated building envelopes and high efficiency of heat recovery ventilation systems. While the standard aims to increase both thermal comfort and energy saving, there is a potential risk and uncertainty about the performance of houses built to the PH standard under future climate conditions.

The objective of this paper is to assess the performance of a typical Canadian single-family house retrofitted to the PassiveHaus level under future climate conditions in terms of energy consumption and risks of summer overheating in comparison to the same house built to the Quebec Energy Code. The impact of shading devices on the overall energy consumption is also investigated.

PassiveHaus

Passive house (PH) is a building that demands low energy requirements but maintains appropriate comfort for occupants. In other words, a Passive house is a house that heats and cools itself. Nevertheless, most of the PH certified houses are not completely passive and have active mechanical ventilation system. According to the PassiveHaus institute in Germany, a PH tends to be 90% more energy efficient compared with a typical house (Passive House Institute, 2012). In order to achieve the PH certification, buildings have to meet the PassiveHaus standard requirements. High insulation, extremely air tight envelope, passive solar gain, heat recovery, day lighting, shading, energy efficient appliances and lighting, and high performing windows are issues that are stringently considered in the PassiveHaus standard (Straube , 2009). If active cooling is required in the PH building, the cooling demand should not exceed 15KWh/m^2year and the total energy demand target has to stay the same. Also, for a passive house that only consumes electricity or only natural gas the total onsite energy consumption should not exceed 44.4KWh/m^2/year and 109KWh/m^2/year, respectively (Passive House Institute, 2012). Table 2 shows passive house requirements.

IPCC Scenarios

The development and determination of emission scenarios are the first step in the generation of future climate change scenarios. IPCC has proposed a widely used special report on emission scenarios including six ‘Storylines’ (A1F1, A2, A1B, B2, A1T and B1) for future emissions of greenhouse gases and other anthropogenic factors. These scenarios are based on the future demographic, economic and technological growth trends. Among IPCC Scenarios, the ‘A’ group assumes the world economic growth is the key driver in a way similar to today. For the other two scenarios- ‘B’ groups, sustainability is the dominant driver (Sharpless, 2009).

Overheating

According to ASHRAE, "thermal comfort is the condition of mind which expresses satisfaction with thermal environment". This term demonstrates the complexity of thermal comfort issue and likewise overheating (ASHRAE, 2010). Study by Gupta & Gregg (2012) showed that over future climate changes the comfort temperature would increase in the summer while remains the same in the winter (Gupta & Gregg, 2012). Using the adaptive approach, Van Hoof, J et al investigated the indoor thermal comfort as a function of outdoor temperature. Results showed that the acceptable indoor temperature within thermal comfort zone for cold climates such as Canada varies between 20°C to 25°C (Halawa & Van Hoof, 2012). De Dear et al also presented an adaptive model of thermal comfort for buildings with natural ventilation. Their study showed that when the mean outdoor effective temperature changes from 5°C to 27 °C, the indoor operative temperature varies from 20°C to 25°C (De Dear & Brager, 1998).

Athienethis and santamouris (2002) indicated that the risk of overheating in highly insulated houses would not only exist in summer but also in winter (Athienitis & Santamouris, 2002). Orme et al. (2003) studied the overheating risk in a lightweight highly insulated house using IES Ve. The calibrated the dynamic thermal model using on-site measurements. Simulations showed that in a well-insulated free-running house with natural ventilation, an external temperature of 29°C may result in an internal temperature over 39°C (Orme, et al., 2003). Jenkins D.P et al (2013) investigated the overheating risks of a typical residential building over future years at different locations in the UK using Integrated Environmental Solutions Virtual Environment (IES Ve) and SAP. Simulation results from IES indicated that while the risk of indoor overheating in London would increase by about 5% between 2005 and 2030, there would be no indoor overheating risk in Edinburgh between these years. The increase in summer temperature over the future climates would increase the risks of overheating as well as the cooling energy consumption, especially in highly-insulated buildings.

2- Methodology

The cast study house

A typical two-storey detached single-family house is considered for this research. This house, which represents a typical Canadian residential house, was built in 1998 as a research facility at the National Research Council of Canada and it is south oriented. The house is a two story detached building with a hipped roof, a two-car garage and a full basement with livable area of 210 m^2 (2260 ft^2). The total windows area is 35.0 m^2 (377 ft^2) (15% of the total wall surface area) and with 16.2 m^2 (174 $ft.^2$) South facing windows. In this paper, this house is used to investigate two scenarios. The first scenario assumes that the house is built in compliance with the Quebec Energy Code (QEC) and the actual properties of the building are used in simulations. The second scenario assumes that the house is retrofitted to the PassiveHaus (PH) standard. Table 1 compares the QEC requirements with the actual thermal performance of the house (National Research Council, 2010).

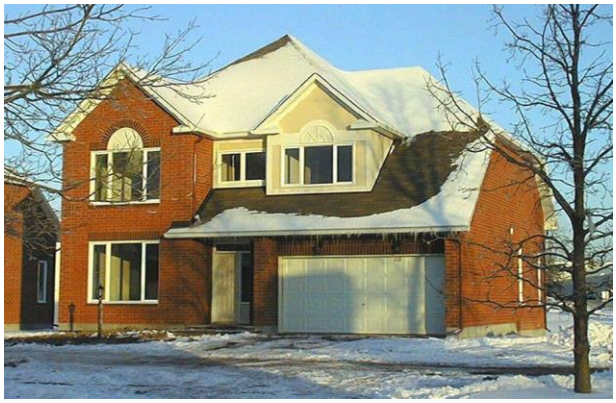


Figure 1: A typical two-storey detached Canadian house (base case) (National Research Council, 2010)

Table 1: Building properties and the Quebec Energy Code requirements (CANLII, 2013)

Component	QEC Requirements	Building Properties Description
Insulation	Attic/ceiling: Minimum R Value: 5.3 m^2k/W	Attic/Ceiling: Total R Value: 6.98 m^2k/W (Asphalt shingles, Roofing felt, Plywood, Cavity, 260mm glass wool insulation, polyethylene, Gypsum board)
	Exterior wall: Minimum R Value: 3.4 m^2k/W	Exterior Wall: Total R Value: 3.89 m^2k/W (Brick veneer, 19mm air space, Tyvak, Plywood, 140mm Batt insulation, Polyethylene, Gypsum Board)
	Foundation wall: Minimum R Value: 4.7 m^2k/W	Foundation wall: Total R-Value: 4.7 m^2k/W (Compacted soil, Plastic drainage with cementitous coating, 89mm Expanded polystyrene rigid board, damproofing, Concrete foundation wall, 89mm Batt insulation, polyethylene, Gypsum board)
Windows	Maximum U-Value: 2.85 W/m^2k	Total U-Value: 2.34 W/m^2K Small Double glazing windows- Low e-coating, 30% Glazed frame
Air-tightness	2.5 ACH @50 Pa	2.5 ACH @50 Pa
Heat recovery Ventilator (HRV)	Minimum 40% Efficiency	High Efficiency (67%)

Table 2: Comparison of the PassiveHaus Standard Requirements with PH Retrofitted Option

Component	Passive House Requirements	Passive house Retrofitted Option
Insulation	Attic/Roof: Total R-value: 9.0-16.0 m^2K/W	Attic/Roof: Total R-Value: 14.40 m^2K/W (Asphalt shingles, Roofing felt, Plywood, Cavity, 500mm Glass wool, 40mm Polyurethane, Polyethylene, Gypsum Board)
	Exterior walls: RSI 7.0–10.5 m^2K/W	Exterior Wall: Total R-Value: 10.38 m^2K/W

		(Brick veneer, 19mm air space, Tyvak, Plywood, 140mm Polyurethane, 140 mm Expanded Polystyrene, Polyethylene, Gypsum Board)
	Foundation wall: RSI 5.5–9.0 m^2K/W	Foundation wall: Total R-Value: 8.39 m^2K/W (Compacted soil, Plastic drainage with cementitous coating, 89mm Expanded polystyrene rigid board, damproofing, Concrete foundation wall, 140mm polyurethane closed cell insulation, polyethylene, Gypsum board)
Windows	Window U-values of ≤ 0.8 W/m^2k	Window U-values of ≤ 0.8 W/m^2k Low-E Triple Glazing SC=0.65
Air-tightness	0.6 ACH @50 Pa	0.6 ACH @50 Pa
Heat recovery Ventilator (HRV)	High Efficiency (80%)	High Efficiency (80%)
Heating load	< 10w/m2	-----
Cooling Load	< 8w/m2	-----

Montreal Future Climate Conditions

Future weather data files were generated using the CCWeatherGen program. This program was developed by the Sustainable Energy Research Group at the University of Southampton. The software uses the current Montreal weather file to generate future weather files by using HadCm3 model and A2 emission scenario (Figure 2). Among all IPCC scenarios, A2 is more widely used, which is categorized by a heterogeneous world with regionally oriented economic development; self-reliant nations; continuously increasing population; and slower and more fragmented technological changes (Robert & Kummert, 2012). Figure 2 shows the observed and predicted changes in global sea surface temperature. Figure 3 plots the dry bulb temperature and the global solar radiation respectively at the Montreal International Airport over future years.

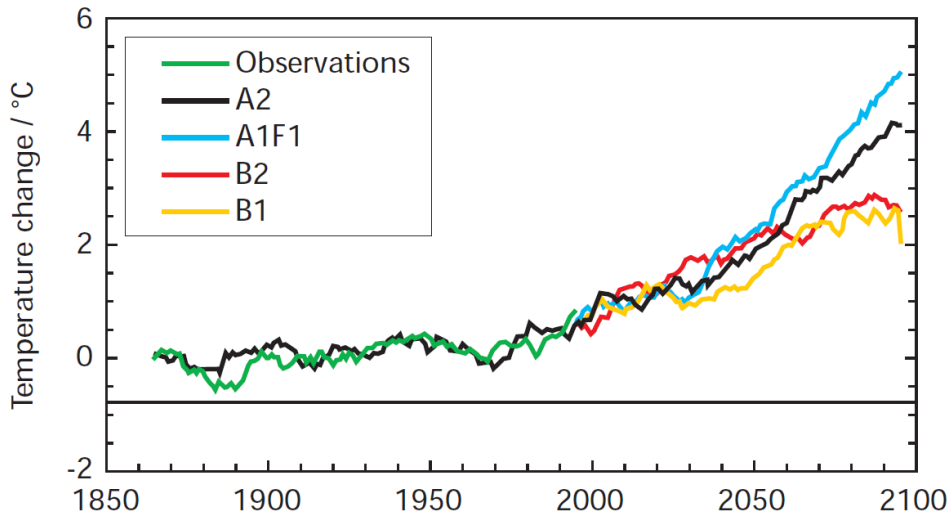
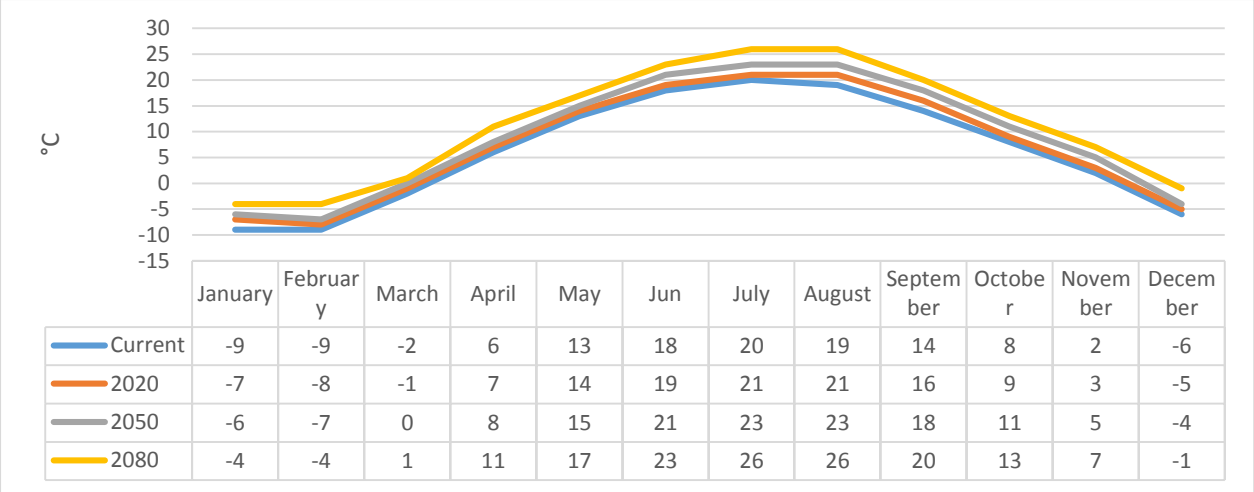


Figure 2: Observed changes in global average land and sea surface temperature (Hulme, et al., 2002)



	January	February	March	April	May	Jun	July	August	September	October	November	December
Current	-9	-9	-2	6	13	18	20	19	14	8	2	-6
2020	-7	-8	-1	7	14	19	21	21	16	9	3	-5
2050	-6	-7	0	8	15	21	23	23	18	11	5	-4
2080	-4	-4	1	11	17	23	26	26	20	13	7	-1

Figure 3: Dry bulb temperature at Montreal International Airport in current year, 2020, 2050, and 2080

As shown in Figure 3, the dry bulb temperature in Montreal would increase over future years. Therefore, the risk of overheating within buildings would potentially increase in the future.

Range for Overheating

While thermal comfort is a complex term defined by different parameters, taking all these parameters into account is out of the scope of this research. A simplified approach is adopted, which considers an indoor air temperature of 26°C or greater as overheating (McLeod, et al., 2013; Sajjadian, et al., 2013; Kwong, et al., 2014).

Whole Building Energy Simulation Using IES Ve

In this study, the excessive number of corners on the north and south facades and roof have been eliminated in building the model to shorten simulation time. Table 3 shows the components that are varied for different simulation scenarios.

Table 3: Components that are varied for different simulation scenarios

Components	Description
Weather files	Current year, 2020, 2050 and 2080
Opaque building envelope thermal characteristic	QEC house and retrofitted option to PH (refer to table 1 and 2)
Maximum infiltration rate	2.5ACH for QEC, 0.6ACH for retrofitted option to PH
Solar shading components	No shading, shading with 0.5m overhang, shading with 1m overhang

Solar radiation is the main parameter that influences the variation of indoor temperatures in different rooms in the building and contributes to the overheating. To simplify simulations only one bedroom located at the south west of the second floor is considered for indoor temperature analysis. This room is highlighted in the model shown in Figure 4. As for heating and cooling loads and the total energy consumption, the whole building is considered.

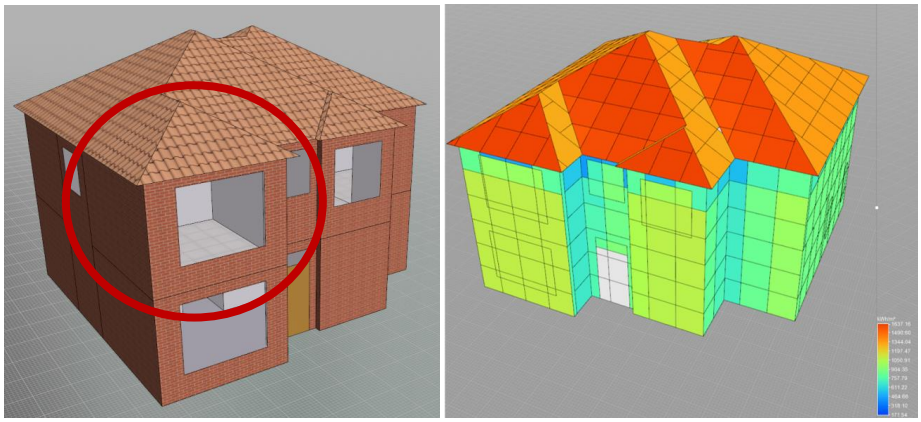


Figure 4: Building modeled in IES [VE]

A central natural gas-fired furnace system with an efficiency of 89%, and a cooling system with a Coefficient of Performance (COP) of 3.6 are specified. An internal gain of 10.76W/m^2, which represents a family of five person with typical lighting and appliance profiles, is specified. The heating set point of 20°C and cooling set point of 25°C are specified in simulations, which means that when the internal temperature is lower than 20°C or higher than 25°C, the mechanical system will be turned on to maintain the desired indoor temperature range.

Natural Ventilation Control

In simulations, windows are set to have a 30% openable area. It is assumed that openable windows are side hung with a maximum opening angle of 20°. To control natural ventilation the opening threshold of 20°C, which is the lower temperature limit of desired internal temperature, is specified for this study.

Impact of Shading Systems

The impact of shading systems on the internal temperature and energy consumption is also investigated by considering no shading, shading with 0.5m overhang and shading with 1m overhang above the windows. Figure 5 shows the locations of shadings added on the top of windows.

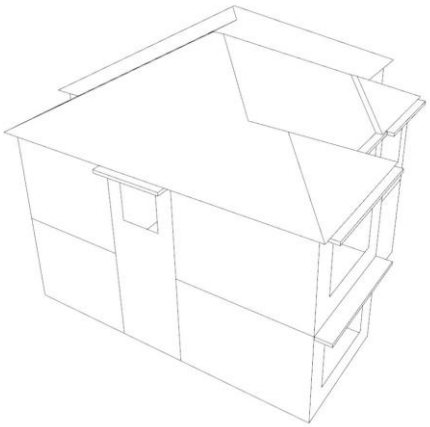


Figure 5: Location of proposed shadings

3- Result analysis and discussion

Figure 6 and Figure 7 show the internal hourly temperature of the free running base-case and the free-running PassiveHaus retrofitted option over different years, respectively. It is observed that the risk of overheating would likely increase in the future years. Although the QEC-compliance house is more sensitive to the changes in outdoor temperature, the overheating risk of the PassiveHaus option is likely greater that that in the QEC. Simulations show that the indoor air temperature will reach as high as 32°C in the QEC house while about 38°C in the PassiveHaus by 2080. Figure 8 also compares the daily indoor mean temperature of mentioned cases.

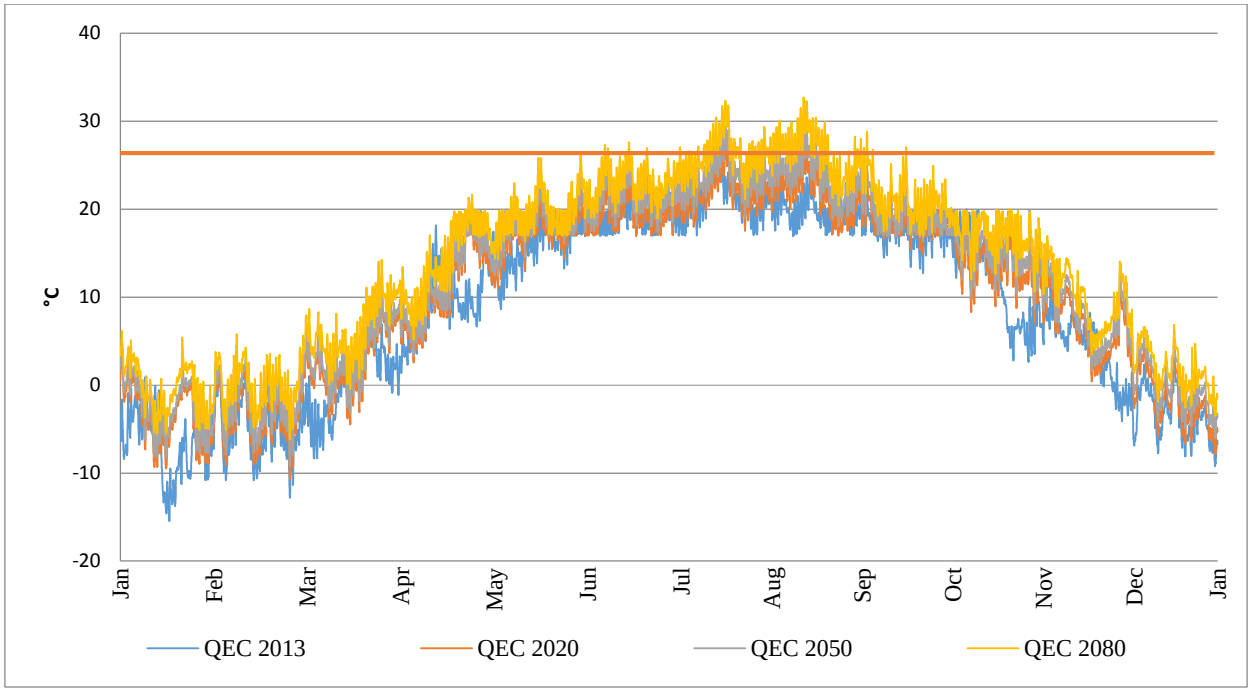


Figure 6: Hourly Indoor Temperature of the free running Base Case (QEC) over different years

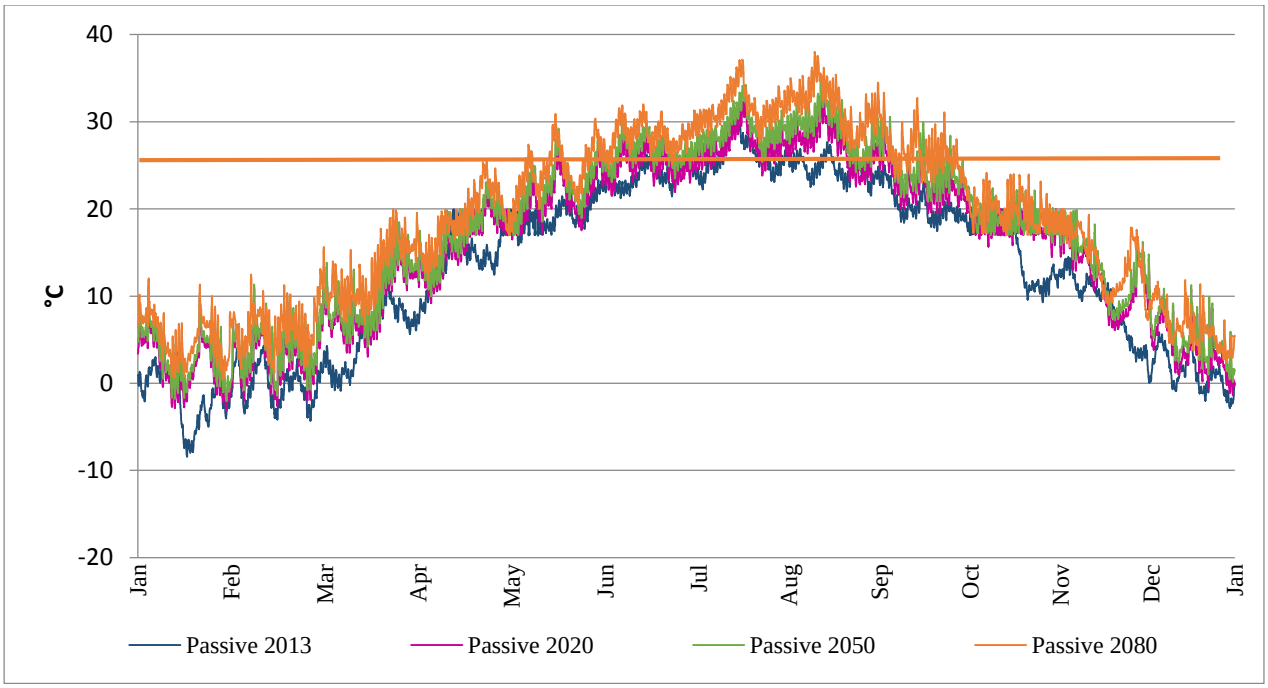


Figure 7: Hourly Indoor Temperature of the free running Building retrofitted to the PassiveHaus standard over different years

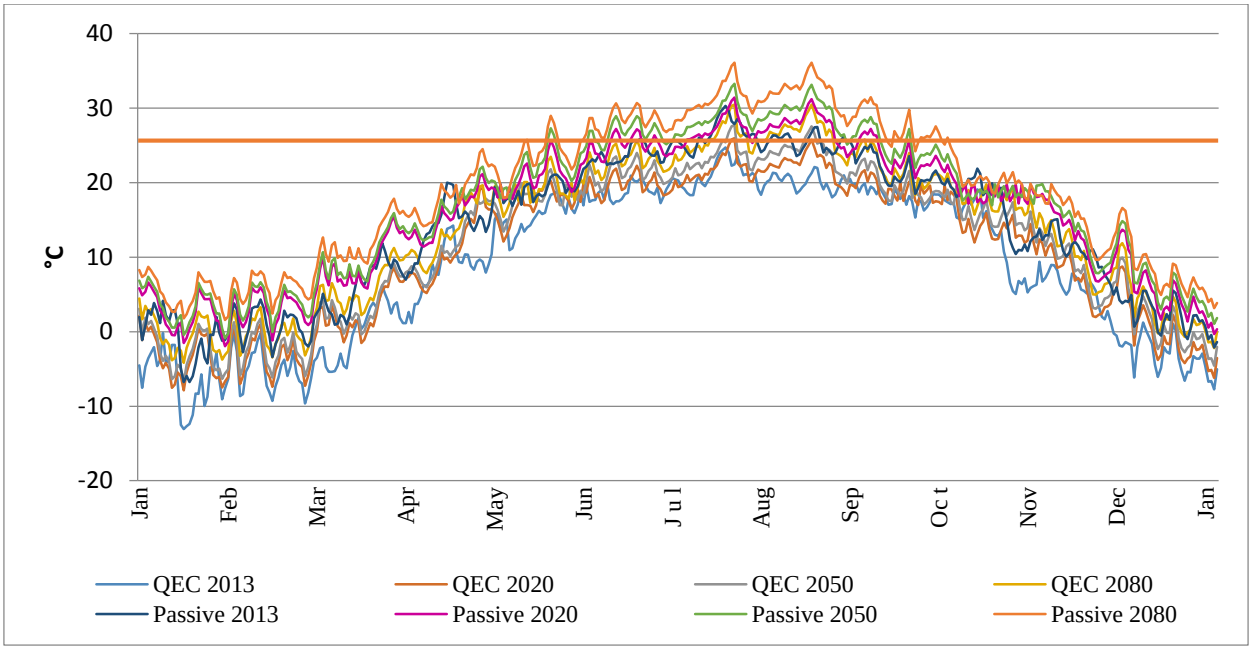


Figure 8: Comparison of the Daily Indoor Mean Temperature between the Base Case and the Retrofitted PassiveHaus Option over current and future years

Figure 9 shows the percentage of time when the internal temperature is over 26°C, specified as overheating. The overheating risk of the PH retrofitted option is likely higher than a typical QEC building over future years under free running conditions with natural ventilation. By 2080, the percentage of time within a year that the internal air temperature is over 26°C for the QEC house and for the PH retrofitted option would be around 10.0% and 31.4%, respectively.

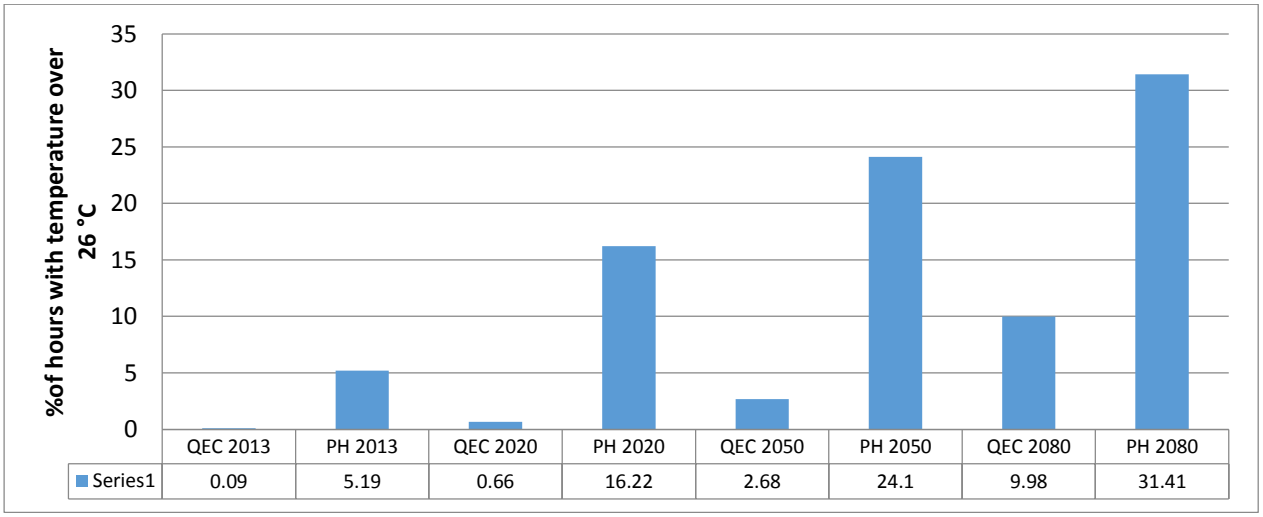


Figure 9: Percentage of time with temperature over 26°C (free running scenario)

To maintain the indoor temperature within 20°C and 25°C, the mechanical system will be turned on when the internal temperature is lower than 20°C or higher than 25°C. Figure 10 and Figure 11 compare the heating and cooling loads of the base case to the PH retrofitted option, respectively. It is observed that the heating load of the base case (QEC) and the PH retrofitted house would decrease by 45.1% and 34.1% between current year and 2080, respectively. Although the internal

temperature of the PH retrofitted house under free running scenario is higher than that in the house built to QEC, the cooling load of PH retrofitted house would be lower than that in the QEC house; particularly by 2050 onward.

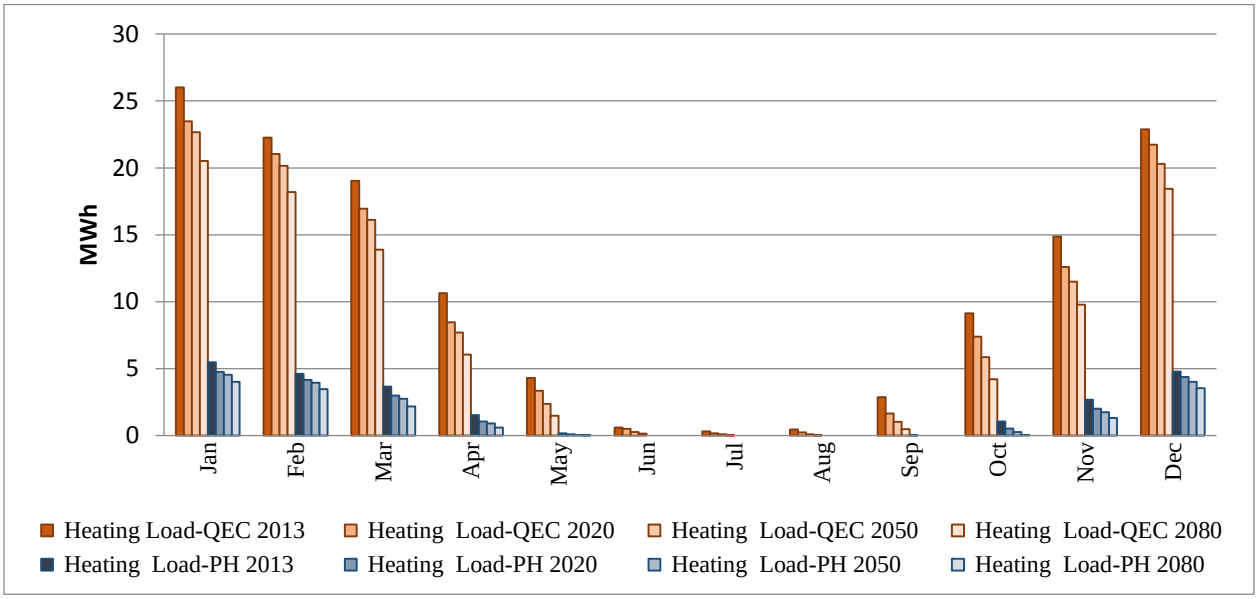


Figure 10: Comparison in heating load between the QEC house and the PH retrofitted option over current and future years

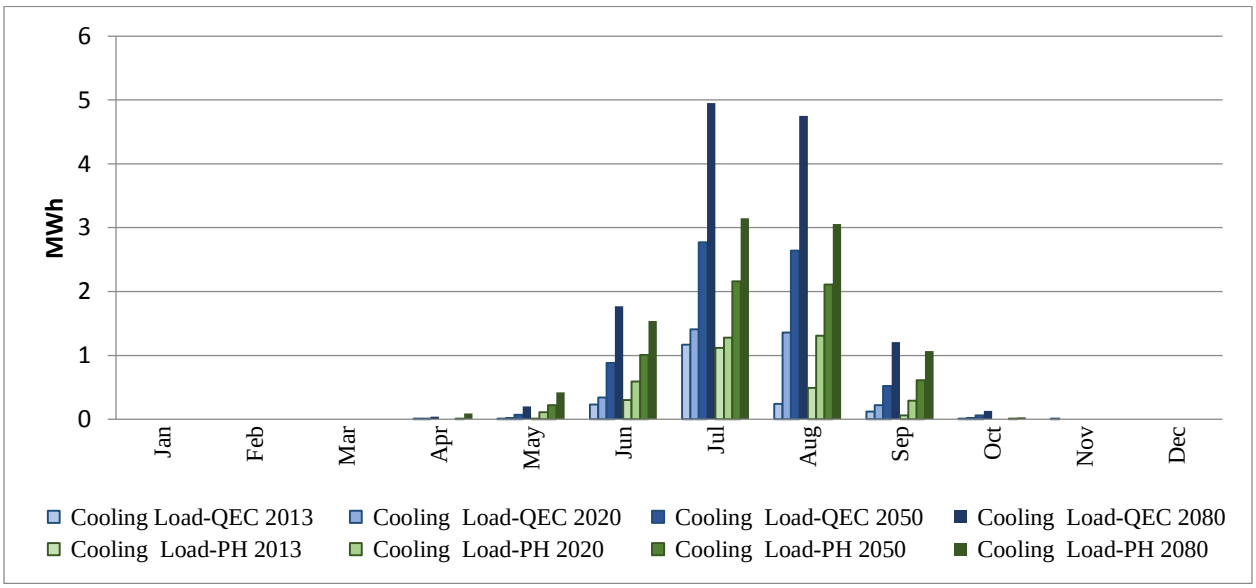


Figure 31: Comparison in cooling load between the QEC and the PH retrofitted option over current and future years

Application of shading systems for buildings built to the PH standard is essential in warm climates (IPHA, 2010). However, for cold climates studies have shown that the provision of external shading devices would increase the total energy consumption of any building (Palmero-Marrero & Oliveira, 2010; Nikoofard, et al., 2014). In this study, the impact of simplified shading systems with 0.5m and 1m overhang on the heating load and the cooling load are investigated. Figure 12 and 13 compare the monthly heating and cooling loads between different shading systems added

to the PH retrofitted house for the year 2013 and 2080, respectively. Results show that while the cooling loads of the PH option with 1m overhang is 12.6% lower than that in the PH option with no shading in 2013, the heating load would be 1.9% higher. By 2080 these values would be 7.2% and 2.3% respectively. However, the total energy consumption of both scenarios in current year and 2080 are likely the same.

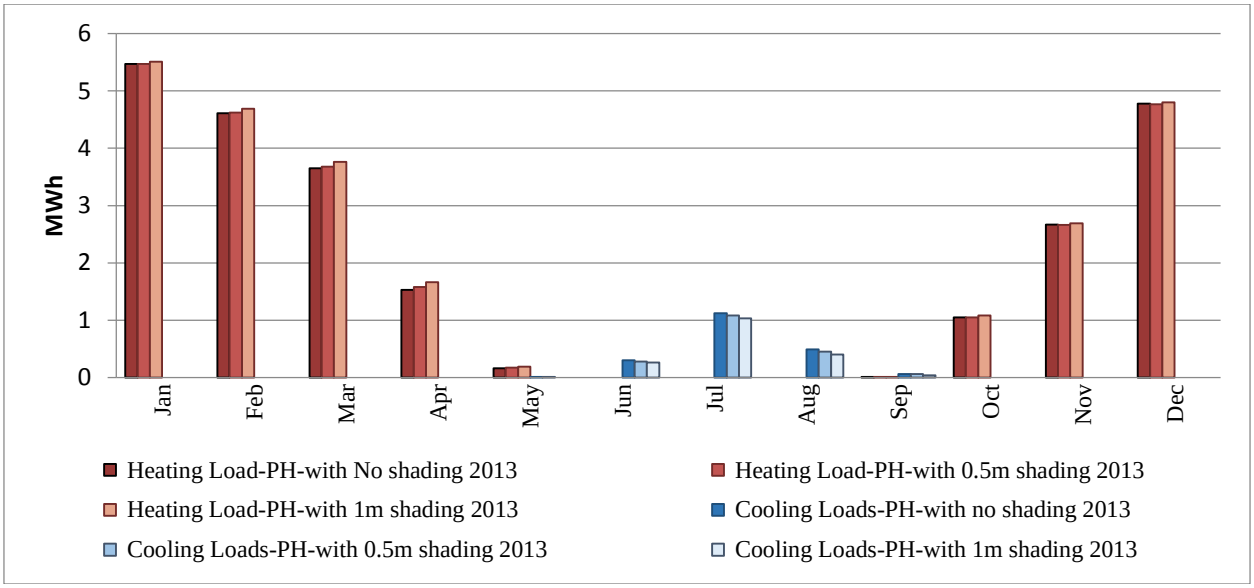


Figure 42: Impact of shading systems on the monthly heating and cooling loads of the PH retrofitted option in 2013

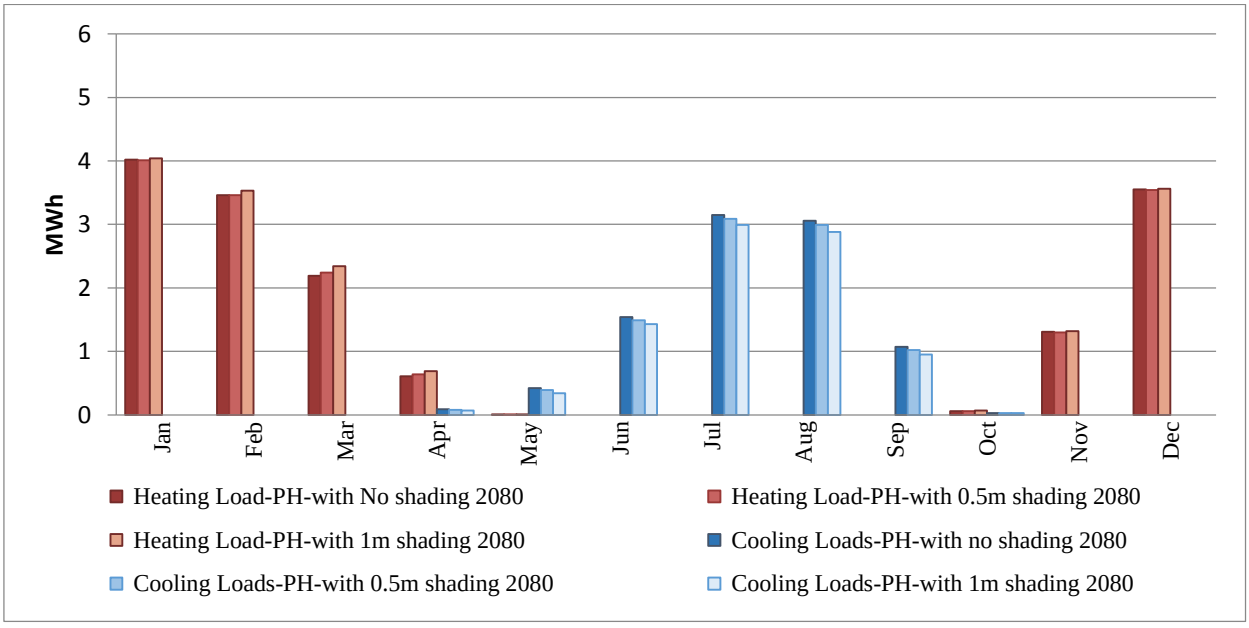


Figure 53: Impact of shading on the monthly heating and cooling loads of the PH retrofitted option in 2080

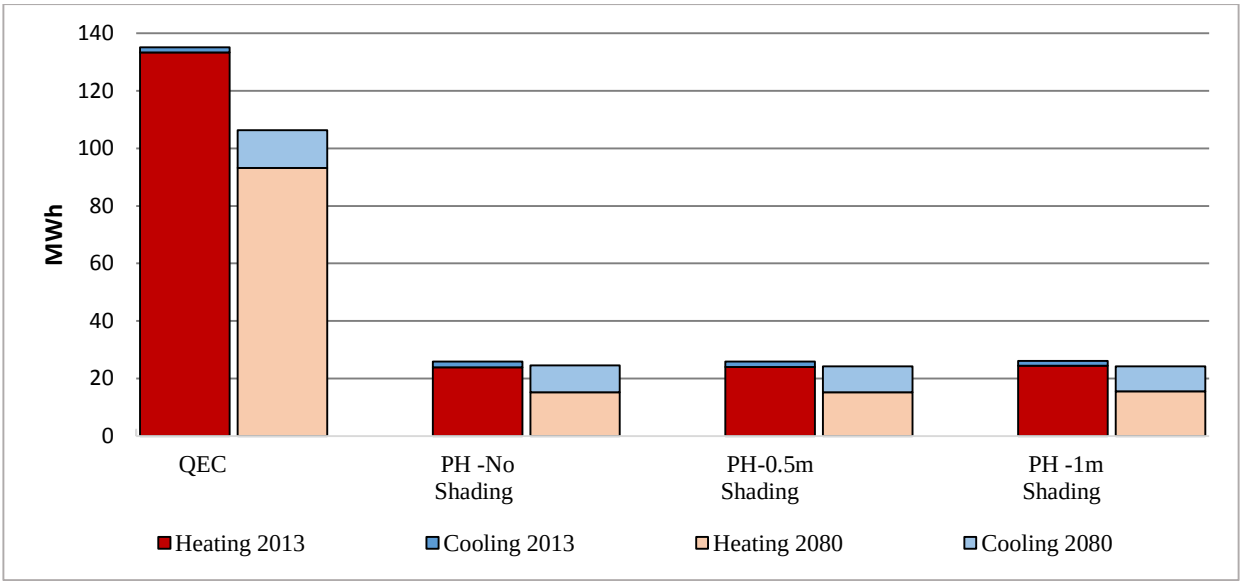


Figure 14: Comparison of the annual heating and cooling loads between QEC case and the PH retrofitted options in 2013 and 2080

Figure 14 compares the annual heating and cooling loads between QEC case and the PH retrofitted options. Results demonstrate that for the Canadian climate the proposed shading system would likely increase the total annual energy consumption by around 0.8% in 2013. While it would decrease the total annual energy consumption by 1.3% in 2080

4- Conclusion

In this paper, the potential overheating risk of a typical Canadian single-family house retrofitted to the PassiveHaus under future climate conditions is investigated. Weather data for future years are generated using HasCM3 general circulation model with the A2 emission scenario. IES is used for the whole building energy simulations. The hourly internal temperature in a south-oriented room is used to evaluate the overheating risks. Simulation results show that compared to the base case, the PH retrofitted option has higher risks of overheating. It is observed that in the house built to the QEC with natural ventilation the overheating (indoor temperature greater than 26°C) is around 0.1% and 10.0% of the time within a year in 2013 and year 2080, respectively. However, for the same house retrofitted to the PassiveHaus standard, the overheating risks would increase to 5.2% and 31.4% in 2013 and 2080, respectively.

Simulation results also show that in 2013 the annual energy required to moderate internal temperature of QEC and PH retrofitted option would be approximately 135MWh and 26MWh, respectively. Nevertheless in 2080, these amounts would likely decrease to about 106MWh and 24.5MWh, respectively. The application of shading with 0.5 width overhang in the PH retrofitted house would not impact on the total annual energy consumption over the future years. However, the application of shading system with 1m width overhang would likely increase the total annual energy consumption by 0.8% in 2013 and decrease the total annual energy demands by 1.3% in 2080. It is concluded that the impact of proposed shading devices is insignificant for the PH retrofitted option in Montreal for this particular case studied over the current and the future climate.

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