Overheating risk of a single-family detached house built at different ages under current and future climate in Canada

Fuad Mutasim Baba[*,1], *Hua Ge*[1]

[1] Concordia University, Department of Building, Civil and Environmental Engineering, Montreal, Canada University, Building Engineering Department

Abstract. With the anticipated increase in temperature and solar radiation and frequency of extreme weather conditions due to climate change, buildings typically designed/built in Canadian cold climates would experience increased risks of summer overheating. This paper focuses on how these existing buildings perform under a current extreme year and projected future climates. Results show that the thermal conditions of a single-family detached house built in 1964 and 1990 are more comfortable than the house built to meet the current National Energy Code of Canada for Buildings (NECB) and high energy-efficient building (HEEB) without including natural ventilation by up to 50%. On the other hand, when natural ventilation is included, the house built to NECB and HEED are more comfortable. Sensitivity analysis is carried out to evaluate the influence of five design parameters, i.e. wall and roof insulation, airtightness, U-value and SHGC of windows. Sensitivity analysis shows that wall insulation, airtightness, and windows U-value are the three most significant parameters influencing the overheating risk without natural ventilation. With natural ventilation, the SHGC of windows is the most influencing parameter in reducing overheating risk. This paper confirms that the Canadian buildings have the overheating risk over the hot summer experienced over the past a few years and the risk will be increased in the future. Natural ventilation as a mitigation measure, which has been relied on by building designers in Canada will not be sufficient to remove excess heat or provide thermal comfort to residents. Other mitigation strategies such as shading to reduce the heat gain during the summer, are needed.

1 Introduction

The daily challenges caused by climate change are becoming evident and affecting many aspects of our lives, such as high temperatures, hurricanes, floods, and wildfires. Statistics indicate that excess heat is more responsible for weather-related deaths than any other weather phenomenon such as hurricanes or floods. Between 1992 and 2001 [1], 2190 deaths occurred in the United States due to excess temperature, compared to 880 deaths from floods and 150 deaths from hurricanes. In 2003, which was the hottest summer for Europe since the 16th century, more than 70,000 people, especially the elderly over 75 years old, died during the European heatwave [2]. However, in 2050, the number of heat-related deaths maybe three times higher due to climate change [3]. The main effect of higher temperatures will be on the thermal comfort of the buildings since people spend more than 65-90% of their time in buildings [4, 5].

Several field measurement studies concluded [6, 7] that the internal temperature of the buildings ranged between 6 to 14 ° C higher than the outdoor temperature and the peak indoor temperature could arrive to 35 ° C. According to occupant surveys in the UK [8-11], the overheating occurred in 21-44% of bedrooms and 28-29% of living rooms and 91% of homes have experienced at least one case of overheating in the past five years [11]. Meanwhile, in Estonia, 68% of the simulated residential buildings do not comply with the summer thermal comfort requirements of Estonian regulation [12]. By monitoring the temperature of 15 rooms in a student residence in the northern United Kingdom during the summer of 2014, Quigley et al. [13] found that these rooms were overheated at night during 44% of the night-time. This means that the occupants of these rooms cannot sleep continuously. In addition, they found that the severity of overheating increased with the level of the floor, where the seventh floor was less comfortable than the first floor. Passive-house buildings are designed to be more comfortable and efficient. But Mitchell et al. [14] found up to 55% of bedrooms in 82 Passive-house buildings suffered overheating during the night.

More importantly, what many studies indicate is that the high energy-efficient buildings, such as Passive-house buildings, are more uncomfortable than old buildings under certain climates [15-19]. For example, Peacock et al. [15] found that increasing the level of thermal insulation increased the risk of overheating in the southern United Kingdom, while the overheating risk was decreased in the northern United Kingdom. Similar results were obtained by Huff et al. [16], in which he concluded that increased thermal insulation contributes to an increased risk of overheating, but solar radiation and natural ventilation have the greatest impact on the thermal condition of buildings. In contrast, Fosas et al. [19] found that the insulation level did not affect the increase in the indoor temperature with sufficient ventilation under the warm climate. The idea that old buildings perform better than modern buildings is a terrifying idea for decision-makers who seek to reduce the energy consumption of buildings and reduce global greenhouse gas emissions. In fact, there are many differences between high energy efficiency building and old buildings, not only the insulation level, but also airtightness, and window properties. McLeod et al. [20] found that the most

* Corresponding author: fu_baba@live.concordia.ca

influential parameters on internal temperature were window-wall ratio, thermal mass, shading, and airtightness.

Canada is often associated with the cold and snowy weather and Canadian buildings are designed primarily to withstand the cold winters. With climate change and global warming, Canada's average annual temperature has increased by 1.7 ° C since 1948, with more than twice the global average temperature [21]. With Canada's commitment to reducing greenhouse gas emissions, more stringent energy efficiency requirements are stipulated in current and future energy codes. Buildings are typically designed and optimized based on historical weather data, however, with the changing climate and increased risks of overheating over the summer time, how the Canadian buildings perform under the future climates and how to design buildings that can adapt to a changing climate are the questions this paper aims to address. This paper focuses on evaluating the indoor thermal conditions for overheating risk over the summer time and the effectiveness of natural ventilation as a mitigation strategy using the single-family house as a case study. The scope of work includes: (1) evaluating four different building ages; i.e. 1964, 1990, NECB and the High Energy Efficiency Building (HEEB) under the current extreme year; 2) evaluating the effect of future climates on the thermal conditions of these buildings; 3) Since 58% of current Canadian residential buildings do not have air-conditioning and depend on natural ventilation as passive cooling during summer [22, 23], natural ventilation mitigation measure is evaluated; 4) determining the significance of varying building envelope design parameters on indoor thermal conditions by sensitivity analysis.

2 Methodology

2.1 Case study

The single-family detached houses represent 53.6% of residential buildings in Canada [24]. Montreal ranked second in the number of single-family detached houses across Canada [24]. In addition, single-family detached houses consume 17% of total energy use and contribute to 10% of Canada's greenhouse gas emissions [25]. Therefore, a single-family detached house is selected as a case study to assess the impact of climate change on the thermal conditions of residential buildings. The architecture and layout of this house are similar to those used in the CanmetENERGY Natural Resources Canada guide [26]. Figure 1 shows the first and second floor plans. This house has a 17% window-wall ratio, 84 m^2 floor area, and a ventilated attic with a roof slope of 4/12.

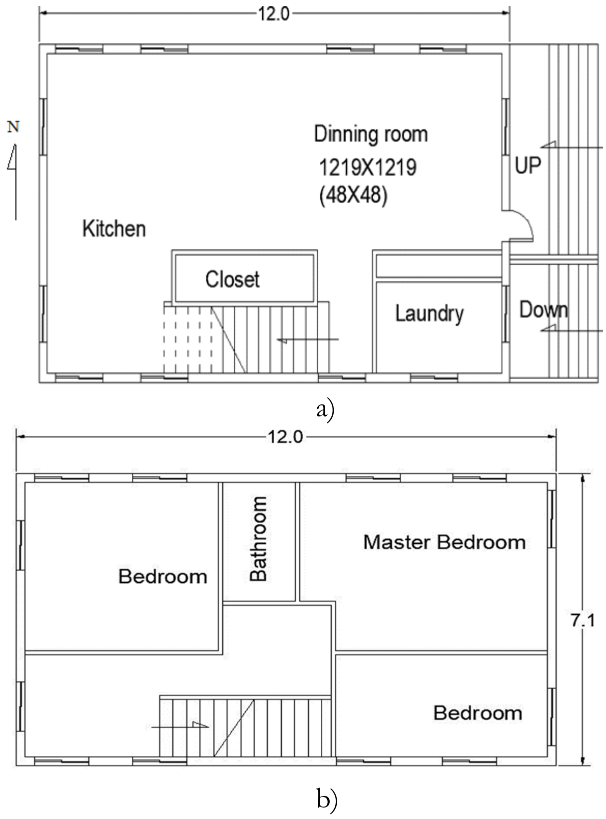


Fig. 1. Floor plan of the single-family detached house: a) first floor; b) second floor. Dimension in m.

2.2 Building Envelope

In 2017, Montreal celebrated its 375th anniversary. Most of its buildings were built starting from 1930 [27]. To represent different ages of buildings, the thermal condition of four generations of buildings in Montreal are studied; i.e. 1964 (representing buildings built from 1959-1969), 1990 (representing buildings built from 1985-1995), NECB-2017 energy requirements (NECB), and HEEB, which has energy performance equivalent to Passive House. The thermal properties of building envelope listed in Table 1 for the years 1964 and 1990 are the average values calculated using the data provided by the Building Code of Quebec [28, 29]. Values for NECB are the prescriptive requirements by the NECB-2017, while values for HEEB are by up to 60% better than NECB values.

Table 1. Thermal proprieties of each building age [29]

Build. Enve.	Wall	Roof	**Windows**		**Air tightness**
Build. Age	U-value ($W/m^2.K$)		U-value ($W/m^2.K$)	SHGC	ACH50
1964	1.70	1.42	5.70	0.75	10
1990	0.45	0.25	5.70	0.68	5
NECB	0.24	0.18	1.50	0.56	2.5
HEEB	0.10	0.08	0.78	0.47	0.6

2.3 Generation of future weather data

Two different Representative Concentration Pathway (RCP) scenarios, i.e. RCP 4.5 and 8.5 from the AR5-IPCC report [30], are selected for the generation of future weather data. With no indications that the world is moving towards reducing carbon dioxide emissions, RCP 8.5 has been selected, which assumes the temperatures and CO_2 emissions reaching their highest level,4.9 °C and 1370 ppm, by the end of 2100. If the world decides to cut carbon dioxide emissions, we expect the climate to move in accordance with the RCP 4.5 scenario (maintaining a CO_2 level of 650 ppm). WeatherShift™ [31,32], a program developed to generate future weather files based on RCPs scenarios by Arup and Argos Analytics LLC [33, 34], is used to generate the weather files for the horizon year 2030 and 2090 based on RCP 8.5 and RCP 4.5. WeatherShift program transforms 'present-day' EnergyPlus Weather (EPW) weather files into EPW weather files for future years. WeatherShift uses 14 Global Climate Models (GCM) to generate future weather files. Cumulative distribution functions (CDF) blend these 14 GCMs and create the percentile distribution such as 10th to 95th. The percentile distribution represents the percentage of GCM models above and below the average [35].

In this paper, the 50th percentile of RCP 4.5 and 8.5 is used to generate weather files for 2030 and 2090 horizon year.

2.4 Thermal comfort criteria

The adaptive model prescribed in ASHRAE 55-2017 [36] is used to evaluate the overheating risks in naturally conditioned zones based on the operative temperature. To apply this method, the zone must be equipped with operable exterior windows that can be readily opened and adjusted by the occupants, and there must be no mechanical cooling system in the zone. Overheating occurs when the operative temperature (T_{op}) is greater than the upper threshold temperature (T_{up}). The threshold and operative temperatures are calculated using equations 1 and 2, respectively:

Upper 80% acceptable limit

$$T_{up} = 0.31*T_{op} + 21.3 \quad (1)$$

$$T_{op}= (T_r + T_{mrt})/2 \quad (2)$$

Where, T_{om} is the mean outdoor dry-bulb air temperature (°C) of seven days, T_r is the indoor air temperature (°C) and T_{mrt} is the mean radiant temperature of the zone (°C).

2.5 Simulation scenarios

Four building ages are selected in a climate zone 6 (Montreal). In total, 32 cases are modelled in DesignBuilder (EnergyPlus) for overheating risk assessment. The scenarios simulated in DesignBuilder are summarized in Table 2.

Table 2. Simulated scenarios

	Scenarios
Building age	1. 1964 2. 1990 3. NECB 4. HEEB
Climates	Montreal (zone 6)
Ventilation scenarios	1. With natural ventilation (NV): by opening 40% of the window area 2. No natural ventilation (NNV): by keeping the windows closed
Weather files	1. Historical database (1960-1990) 2. 2016 current year 3. 2030 (2026-2045) 50th (RCP 4.5 &8.5) 4. 2090 (2080-2099) 50th (RCP 4.5 &8.5)

The NV scenario without any mechanical system is studied for two reasons: 1) As discussed in section 1, 58% of residential buildings in Canada do not have an air-conditioning system [22, 23] and 2) Most heat waves were accompanied by an electricity outage, therefore, mechanical systems may not be available during the "heat wave" [37]. The NNV scenario is chosen as the worst-case given that 46% of occupants in north England do not open their windows when they are out of the house or at night due to a security concern [38]. While 30% of the occupants keep their windows open 10 to 15 cm, during "heat waves" it may not be favorable to keep windows open [38, 39]. Since there is an infinite number of possibilities between the closed window and 40% opening as the best scenario, the relationship between the window opening ratio (WOR) and the risks of overheating is studied.

2.6 Sensitivity analysis

To determine the significance of varying building envelope design parameters that influences the indoor thermal conditions of buildings, a global sensitivity analysis is carried out. The building design parameters studied include thermal insulation values of wall and roof, airtightness, window SHGC, and window U-value, with and without natural ventilation. A uniform distribution is assumed for each parameter and their ranges are listed in Table 3.

Table 3. Range of building design parameters

	Parameters	**Unit**	**Uniform distribution range**
P1	**Airtightness**	ACH50	**0.6-5**
P2	**Window Properties**	SHGC	**0.26-0.75**
P3		U-value (W/m^2. K)	**1.5-5.5**
P4	**Wall insulation**	W/m^2. K	**0.1-0.45**
P5	**Roof Insuloation**	W/m^2. K	**0.08-0.25**

SIMLAB program [40] that has been developed by the Joint Research Centre (JRC) of the European Commission is used to generate 1280 samples by using the Sobol sampling method. These samples are simulated using the jEPlus tool [41], which provides a Graphical User Interface (GUI) for defining the five design parameters, editing models, managing simulation samples, and collecting results of the indoor temperature from June 1st to October 1st. Sobol sensitivity indices are calculated based on the results of 1280 samples to determine the contribution effect of each parameter on the indoor temperature using the SIMLAB program.

Sobol method [42] is a variance-based sensitivity analysis, which measures the sensitivity across the whole input area by finding the effect of interactions among parameters in a non-additive mode. It can handle nonlinear and non-monotonic models. The output sensitivity to an input variable is measured by the amount of variance in the output that has been caused by this input and then the contribution of each input to the output is found. For example, for a model having two inputs and one output. One may find that 60% of the output variance is caused by the variance in the first input, 30% by the variance in the second input, and 10% due to interactions between the two inputs. These percentages are interpreted directly as sensitivity indices. Sobol indices are calculated based on equations 3 and 4. Equations 3 and 4 calculates the first order and total order indices respectively:

$$S_i = \frac{V_{X_i}}{V(Y)} \quad (3)$$

$$S_{Ti} = 1 - \frac{V_{X\sim i}}{V(Y)} \quad (4)$$

Where V_{X_i} measures the effect of parameter X_i on the model output, V(Y) is the total variance of the model output (variance of expected all parameters with all interactions). $V_{X\sim i}$ measures the effect of all parameters except X_i on the model output.

2.7 Settings in EnergyPlus simulations

DesignBuilder (EnergyPlus) program is used to assess the thermal conditions of the single-family detached house under the historical typical year and predicted future weather data of 2030 and 2090. As a whole building energy simulation program, EnergyPlus outputs indoor temperature, which can be used for assessing the thermal conditions of the whole building. The settings in EnergyPlus simulations are listed in Table 4.

Table 4. Whole Building Energy Simulation Settings

Building Envelope Components	**Units**	**Value**	**Notes and References**
Heating set point	°C	21	NBC 9.36.5.4. (5)
Heating set back	°C	18	NEBC Table A-8.4.3.2.(1)
Cooling set point	°C	Free cooling	
Appliances & plug loads	W/m^2	2.5	NEBC Table A-8.4.3.3 (2) A.
Lighting density	W/m^2	5	NEBC8.4.4.6.
Natural ventilation (NV)set point	°C	24	NV works if $T_{room} > T_{setpoint}$ & $T_{room} > T_{outdoor}$

3 Results and discussion

3.1 Overheating risk

Figure 2 shows the seasonal thermal conditions of four building ages in 2016 in Montreal. The NECB building is considered as the base-case for comparison with other buildings. The number of overheating hours in NECB building is 71% (3681 hrs) of the period studied from April 1st to Oct. 31st if occupants could not open windows. Due to climate change and temperature increase in the spring and autumn seasons, there are potential overheating risks in spring and autumn seasons, as shown in Figure 2, therefore an extended period is used in this study. While the old buildings performed better than NECB by 41% (2179 hr) and 22% (2883 hr) for 1964 and 1990 buildings respectively. However, HEEB is the worst among these buildings with overheating hours represent 80% (4123 hrs) of the study period.

If occupants are able to open 40% of the windows area, the cases with NV, the overheating hours in NECB building can be reduced to 274 hr (5% of summer time). The performance of HEEB building was slightly better than NECB by 4%, while the 1990 and 1964 buildings are worse with 8% (431 hr) and 10% (501 hr), respectively.
Figure 3 shows the effect of climate change on the thermal conditions of four buildings built at different ages. Similar results are obtained under future climates, where the old buildings would perform better than energy-efficient buildings if there is no natural ventilation. However, the number of overheating hours may increase up to 91% (4697 hr) of summer time by 2090 under the RCP 8.5 scenario for HEEB building. Under future climates, natural ventilation may be insufficient to mitigate the risks of overheating, as the overheating hours could reach 11% (570 hours) of summer time in 2090 in the HEEB (the best scenario) and 18% (92 1hr) in 1964 building (worst scenario).

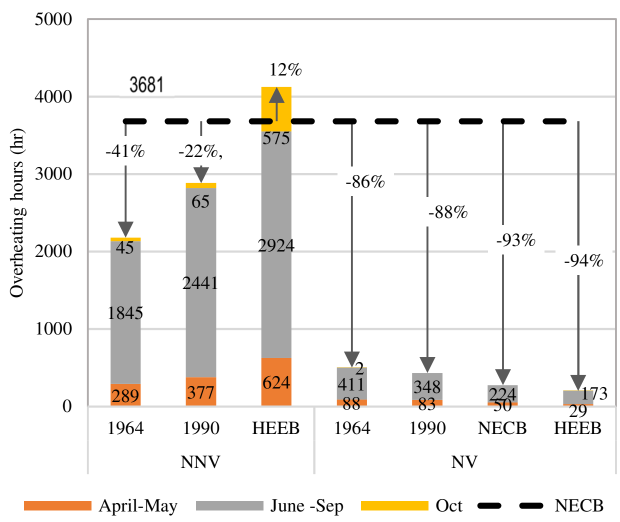
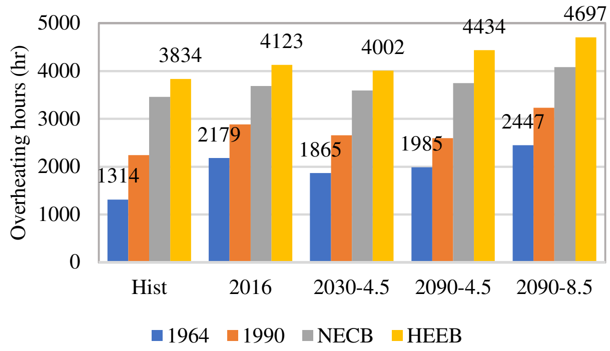
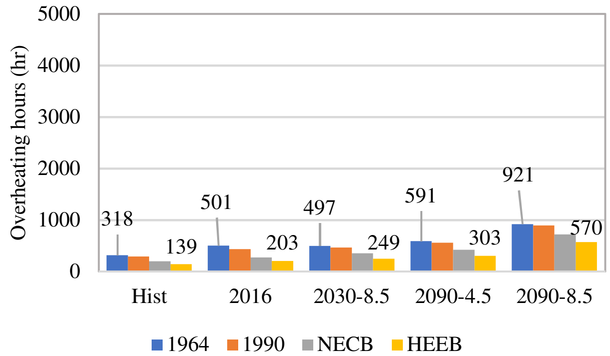


Fig. 2. Seasonal overheating hours for1964, 1990, NECB and HEEB buildings under 2016 weather



a) NNV



b) NV

Fig. 3. Overheating hours during the study period for whole single-family detached house; a) NNV; b) NV.

The results in Figure 2 show two cases only; i.e. no natural ventilation (closed windows) and natural ventilation by opening 40% of the window area.

Figure 4 shows an exponential relationship between WOR and overheating hours in NECB building. The same relation is found in other buildings. Therefore, if the windows are opened by 5% of their area, the overheating risk can be reduced by 68%, while with a 40% of WOR, the overheating can be reduced by 93% under 2016 weather in Montreal.

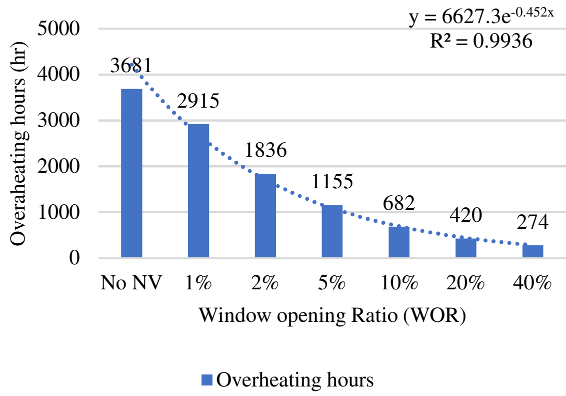


Fig. 4. Overheating hours in NECB based on WOR under 2016 weather

3.2 Sensitivity analysis

Table 5 shows the results of global sensitivity analysis. It can be seen that the sensitivity index of SHGC of window (0.42), insulation level of the wall (0.27), airtightness (0.18) and U-value of windows (0.13) have a more significant influence on the indoor temperature without natural ventilation. Since the indoor temperature is higher than the outdoor temperature without natural ventilation, the heat tries to move from the inside out. However, with the high level of insulation, airtightness, and the window U-value that prevents this, the importance of these factors increases to form 0.58. The old buildings that have a high infiltration rate, low insulation level and low U-value of windows were more comfortable.

Whereas, with natural ventilation, SHGC of windows becomes the most significant parameter, which has a 0.90 of impact on the indoor thermal conditions, since it works to reduce the solar gain. Therefore, the HEEB building was less likely to have overheating risk with natural ventilation.

Table 5. Sensitivity index of each parameter with and without natural ventilation

	NNV	NV
P1: Airtightness	0.18	0.00
P2: Window SHGC	0.42	0.90
P3: Window U-value	0.13	0.06
P4 Wall Insulation	0.27	0.04
P5: Roof Insulation	0.00	0.00

4 Conclusion

Thermal conditions of a single-family house built at different ages in Montreal are studied under the current hottest year recorded in 2016 and future climates through simulations. Future weather data for horizon years 2030 and 2090 are generated based on two emission scenarios, namely, RCP 4.5, and RCP 8.5. ASHRAE -55 adaptive model is used to evaluate the severity and occurrence of overheating.

Simulation results show that, without natural ventilation under 2016 weather, the old building (built in1964) with low energy efficiency was more comfortable compared to houses built to NECB, while the high energy-efficient building was the most uncomfortable among the buildings. However, these results change completely when natural ventilation is included, under which scenario the energy-efficient buildings (NECB and HEEB) provide more comfortable indoor thermal conditions. While natural ventilation plays an important role in improving the indoor environment, it is insufficient to mitigate overheating. 10% of summer time was overheating in HEEB, and this number could reach 18% in 2090, as in the 1964 building.

A global sensitivity analysis indicated that without natural ventilation, improving the wall insulation level, building airtightness and thermal performance of windows increases the internal temperature. With natural ventilation, the SHGC of windows becomes the most significant influencing parameter. Therefore, HEEB having a low SHGC value is the most comfortable building.

In conclusion, Canadian buildings traditionally designed to withstand the severely cold winter began to experience overheating during the summer time periodically and at a faster rate. With good ventilation, improving the thermal performance of the building envelope for better energy efficiency does not compromise its indoor thermal conditions. However, natural ventilation alone is insufficient especially during "heat wave" for future climates. Other mitigation strategies such as shading and solar control during the summer time need to be considered. Therefore, future studies should focus on innovative passive mitigation solutions to improve the indoor environment without increasing energy consumption.

We gratefully acknowledge the financial supports received from NSERC Discovery Grant and Gina Cody School of Engineering and Computer Science, Concordia University.

References

1. R. Basu, J.M. Samet. Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence. Epidemiologic Reviews, 24 (2002); 190–202.
2. J.M. Robine, S.L. Cheung, S. L. Roy, H. V. Oyen, F.R. Herrmann. Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies. 331(2008); 171-178
3. Zero Carbon Hub. Overheating in Homes, the Big Picture. Full Report; Zero Carbon Hub: London, UK. (2015).
4. N.E. Klepeis, W.C. Nelson, J.P. Robinson, et al. The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. Exposure Analysis and Environmental Epidemiology 11(2001); 231–52.
5. J.A. Leech, W.C. Nelson, R.T. Burnett, S. Aaron,M.E. Raizenne. It's about time: A comparison of Canadian and American time-activity patterns. Exposure Analysis and Environmental Epidemiology 12(2002); 427–32
6. J. L.White-Newsome, B. N. Sanchez, O. Jolliet, Z. Zhang, E. A. Parker, J. T. Dvonch. Climate change and health: indoor heat exposure in vulnerable populations. Environmental Research. 112(2012); 20-27
7. M. Hamdy, S. Carluccia, P. Hoes, J. Hensen. The impact of climate change on the overheating risk in dwellings-A Dutch case study. Building and Environment. 122(2017); 307-323
8. A. Beizaee, K. J. Lomas, S. K. Firth. National survey of summertime temperature and overheating risk in English homes. Building and Environment. 65(2013); 1-17.
9. M. Baborska-Marozny, F. Stevenson, M. Grudzinska. Overheating in retrofitted flats: occupant practices, learning and interventions. Building and Research and Information. 45(2017); 40-59.
10. A. Pathan, A. Mavrogianni, A. Summerfield, T. Oreszczyn, M. Davies. Monitoring summer indoor overheating in the London housing stock. Energy and Buildings. 141(2017); 361-378.
11. Zero Carbon Hub. Overheating in homes- the big picture. Full report. (2015); 91.
12. R. Simson, J. Kurnitski, M. Maivel. Summer thermal comfort: Compliance assessment and overheating prevention in new apartment building in Estonia. Building Performance Simulation. 10 (2017); 378-391.
13. E. S. Quigley, K. J. Lomas. Performance of medium-rise, thermally lightweight apartment buildings during a heat wave. Proceedings of 10th Windsor Conference: Rethinking Comfort, Windsor, London, UK. (2018). 32-47.
14. R. Mitchell, S. Natarajan. Overheating risk in Passivhaus dwellings. Building Services Engineering Research Technology. 40(2019); 446–469.
15. A. D. Peacock, D. P. Jenkins, D. Kane. Investigating the potential of overheating in UK dwellings as a consequence of extant climate change. Energy Policy. 38(2010); 3277-3288
16. R. Gupta, M. Kapsali. Empirical assessment of indoor air quality and overheating in low-carbon social housing dwellings in England, UK. Advances in Building Energy Research. (2015); 1-23
17. S.M. Sameni, M. Gaterell, A. Montazami, A. Ahmed. Overheating investigation in UK social housing flats built to the Passivhaus standard. Building and Environment. 92 (2015); 222-235
18. M.J. Fletcher, D.K. Johnston, D.W. Glew, J.M. Parker. An empirical evaluation of temporal overheating in an assisted living Passivhaus dwelling in the UK. Build. Environ. 121 (2017); 106-118
19. D. Fosas, D. A. Coley, S. Natarajan et al. Mitigation versus adaptation: Does insulating dwellings increase overheating risk? Building and Environment. 143(2018); 740–759.
20. R.S. McLeod, C.J. Hopfe, A. Kwan. An investigation into future performance and overheating risks in

Passivhaus dwellings. Building and Environment. 70 (2013); 189-209

21. X. Zhang, G. Flato, M. Kirchmeier-Young, et al. Changes in Temperature and Precipitation Across Canada. In Canada's Changing Climate Report; Bush, E., Lemmen, D.S., Eds.; Government of Canada: Ottawa, ON, Canada. (2019); 112–193.
22. Natural Resources Canada (NRCan). Survey of Household Energy Use 2011. Detailed Statistical Report. Office of Energy Efficiency. Natural Resources Canada. Ottawa, Ontario. (2011).
23. Natural Resources Canada (NRCan). Survey of commercial and institutional energy use – buildings 2009. Detailed Statistical Report. Office of Energy Efficiency. Natural Resources Canada. Ottawa, Ontario. (2012).
24. Statistics Canada. Census in Brief Dwellings in Canada. Revised by May-2019. (2017) https://www12.statcan.gc.ca/census-recensement/2016/as-sa/98-200-x/2016005/98-200-x2016005-eng.pdf
25. Natural Resources Canada (NRCan). Energy efficiency trends in Canada 1990-2013. Office of Energy Efficiency. Natural Resources Canada. Ottawa, Ontario. (2013).
26. A. Parekh, K. Chris. Thermal and Mechanical Systems Descriptors for Simplified Energy Use Evaluation of Canadian Houses. Proceedings of SimBuild. 5(2012); 279-286.
27. R. Rocha. Montreal Building Age Story Map. (2018). https://www.cbc.ca/news2/interactives/montreal-375-buildings/ (accessed December 24, 2019).
28. RBQ. Construction Code and Safety Code - Régie du bâtiment du Québec 2018. https://www.rbq.gouv.qc.ca/en/laws-regulations-and-codes/construction-code-and-safety-code.html (accessed December 24, 2019).
29. A. Katal, M. Mortezazadeh, L. Wang. Modeling building resilience against extreme weather by integrated CityFFD and CityBEM simulations. Applied Energy. 250 (2019); 1402-1417
30. R. Pachauri, M. Allen, V. Barros, et al. Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental panel on climate change. IPCC. (2014)
31. A. Moazami, S. Carlucci S, Geving. Critical analysis of software tools aimed at generating future weather files with a view to their use in building performance simulation. Energy Procedia 132 (2017); 640-645.
32. WeatherShift. (2016). http://www.weather-shift.com/
33. S.E. Belcher, J.N. Hacker, J.N. Hacker. Constructing design weather data for future climates. Article in Building Service Engineering. 26(2005); 49-61
34. U. Berardi. Book: Sustainability Assessments of Buildings. published in Sustainability. (2017).
35. L. Troup, D. Fannon. Morphing Climate Data to Simulate Building Energy Consumption. ASHRAE and IBPSA-USA SimBuild 2016. Building Performance Modeling Conference, Salt Lake City, UT, August 8-12, (2016).
36. ANSI/ASHRAE Standard 55. Thermal Environmental Conditions for Human Occupancy. (2017)
37. Institute of Medicine (IOM). Climate Change. The Indoor Environment, and Health. Institute of Medicine of the National Academies Press, Washington, DC. (2011).
38. M. Baborska-Marozny, F. Stevenson, M. Grudzinska. Overheating in retrofitted flats: occupant practices, learning and interventions. Building and Research and Information. 45(2017); 40-59.
39. E.S. Quigley, K. J. Lomas. 2018. Performance of medium-rise, thermally lightweight apartment buildings during a heat wave. Proceedings of 10th Windsor Conference: Rethinking Comfort, Windsor, London, UK. (2018); 32-47.
40. European Commission SIMLAB: Sensitivity analysis software – Joint Research Centre. https:// ec.europa.eu/jrc/en/samo/simlab (2015)
42. Zhang Y, Korolija I. jEPlus - An EnergyPlus simulation manager for parametric. http://www.jeplus.org/wiki/doku.php
43. I. M. Sobol. Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. Mathematics and Computers in Simulation, 55(2001); 271-280