Modelling the Impacts of Climate Change on Building Heating and Cooling Energy Use in Canada

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Abstract. This study describes the results of climate change impact assessment on building heating and cooling energy use in Toronto, Canada. Accordingly, three future weather data sets are generated and applied to the energy simulation of the 16 ASHRAE reference building models. Both statistical and dynamical downscaling techniques are used to generate the future weather files. The results indicate an average decrease in the range of 18-33% in heating energy use intensity, and an average increase of 16-126% in cooling energy use intensity, depending on the baseline climate and building type. In addition, the GHG emissions associated with each building models for the future climate are presented and discussed. It is concluded that the application of future weather files for building performance simulation leads to a realistic quantification of building energy demand in the future. Furthermore, the buildings energy demand forecast demonstrates the dire need to modify and adapt existing buildings and to plan future buildings according to the future climate.

1.0 Introduction

The building sector is accountable for a large share of the global energy consumption and the corresponding GHG emissions. At the same time, the ongoing changes in the outdoor climate conditions are showing major impacts on building energy demand. Buildings play an important rule between the outdoor environment that is subject to climate variables, and the indoor environment that needs to be maintained within a certain temperature range to provide comfort for the occupants. In its most recent report, the Intergovernmental Panel on Climate Change (IPCC) has predicted that the global mean surface temperature will increase, in relation to the 1986-2005 period, by a range of 2.6°C to 4.6°C by the end of the 21st century.[1] This temperature increase affects the buildings indoor environment, leading to increase in heating, ventilation, and air conditioning (HVAC) system energy demand, which is the primary control for the indoor thermal comfort and air quality. The HVAC system is a major source of energy consumption and emission in the building sector, leading to higher energy demands and emissions for space conditioning.

It is widely acknowledged that buildings account for more than 32% of total global energy consumption and contribute to 19% of greenhouse gas (GHG) emissions relating to energy processes.[1] Furthermore, the global energy-related CO_2 emissions from the building sector more than doubled between 1970 and 2010 and are also projected to increase by another twofold by 2050.[2] In Canada, the residential, commercial and institutional buildings are responsible for 17% of total GHG emissions, ranking third among industry and transportation sectors.[3] Figure 1 illustrates a categorical classification of energy consumption by end-use for both residential, commercial and institutional buildings in Ontario. The majority of energy use in the Ontario building sector are for heating and cooling purposes.[4]

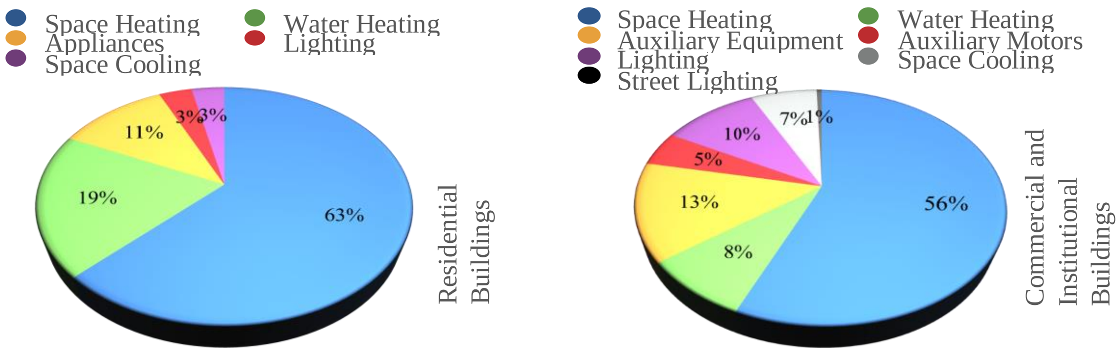

Figure 1. Classification of energy consumption for both residential and commercial buildings in Ontario.[4]

Weather data are important in assessing building energy demand and thermal comfort performance. Current practices use weather files that have been based on historical records for building simulation. But, given the scale of climate change and its impact on building heating and cooling demands, simulations using historical weather files fail to forecast the trends of building energy demand in the future. This work uses both statistical and dynamical downscaling techniques to generate future weather files. Ultimately, in order to quantify the future trends of energy demand for various building types in Canada, the generated future weather files are used to simulate several building models. These models are in compliance with ASHRAE 90.1 standards and consist of 16 buildings with various dimensions and operations. This provides reasonable information on the long-term impacts of climate change on approximately two-thirds of the commercial building stock energy performance.[5] Furthermore, the GHG emissions associated with heating and cooling for each building models for the future climate are presented and discussed.

2.0 Methods

This research is divided into two streams: one focusing on the creation of future weather file, and one on the impact study of climate change on building energy performance. The future weather files developed in this paper were generated by statistical downscaling technique using two future weather generator tools, CCWorldWeatherGen and WeatherShift™. Moreover, to improve the resolution of the climate simulation outputs, the dynamical downscaling technique using the HRM3-the Hadley Regional Model 3 coupled with the HadCM3- the Hadley Climate Model 3 was used. This provides a more reliable forecast of the local boundary conditions for the future weather files.

2.1 Development of Future Weather File

Two Canadian Weather Year for Energy Calculation (CWEC) files developed by Environment and Climate Change Canada were selected as baseline climate for superimposing the changes in the future climate conditions.[6] On one hand, a CWEC file that spans a 30-year period of historical weather data (1959-1989) was selected to provide a better representation of the historical climate. Alternatively, a more recent CWEC file, which spans from 1998-2014 was selected to characterize the most current warming trends. These CWEC files are not an actual year of recorded weather data, but rather a selection of the twelve most typical months from that 30 and 15-year timeframe (Table 1).

Table 1. The Canadian Weather Year for Energy Calculation weather file breakdown for the period of 1959-1989 (CWEC file) as well as 1998-2014 (CWEC2016 file).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CWEC	1969	1965	1964	1964	1963	1970	1981	1989	1978	1969	1983	1961
CWEC2016	1999	2004	2006	2009	2006	2001	2013	2011	2003	2010	2000	2003

In this work, the original CWEC and CWEC2016 weather files were used for Toronto, Canada. Initially, the Climate Change World Weather Generator (CCWorldWeatherGen) tool was used to generate future weather files for the 2041- 2070 timeframe. The CCWorldWeatherGen tool was developed by Jentsch et al. (2013), who applied the morphing method using HadCM3 forced with IPCC A2 emission scenario to generate EnergyPlus Weather (EPW) files.[7]

Next, the changes in the future climate conditions projected by the WeatherShift tool was applied to CWEC and CWEC2016 files. This tool simulates and superimposes the changes in the future climate conditions, creating future weather files by applying the morphing technique to 14 GCMs. The weather files generated for the period of 2056-2075 were selected for the purpose of this work.

Finally, this work used a dynamically downscaled regional climate model (RCM) output developed under the North American Regional Climate Change Assessment Program (NARCCAP) to generate a future weather file by projecting climate change information based on the RCM.[8] Modelled data for the coupled GCM-RCM (HadCM3-HRM3) were downloaded for five variables including surface air temperature, surface pressure, surface specific humidity, zonal surface wind speed, and meridional surface wind speed. These variables were selected due to their significance in projecting climate conditions in building energy performance. Due to the limitations of output data availability from the NARCCAP regional model for cloud cover and solar radiation, this study chose to leave cloud cover and solar radiation of the future weather file at their original weather file values. Extraction, correction and conversion of HRM3 data from NARCCAP to the appropriate input data for building performance simulation was done by Microsoft Excel and coding in Python. Linear interpolation was applied to 3-hourly data sets, generating hourly weather data for the periods of 1970-2000 and 2040-2070. Subsequently, the proper parameters used for building performance simulation such as relative humidity, dew-point temperature, wind speed, and wind direction that are not directly available from the HRM3 output data were calculated.

3.0 Results

This chapter is divided to two main parts. The first part illustrates the results of future weather file generation. The second part consists of providing the simulation results on the impact study of climate change on building energy demand.

3.1 Future Weather File Characteristics

The dry-bulb temperatures of the two historical weather files indicate higher temperature values for the CWEC2016 (1998-2014 years) compared to the more historical CWEC (1959-1989 years). Table 2 shows the historically recorded annual Heating Degree Days (HDDs) and Cooling Degree Days (CDDs) for the CWEC and CWEC2016 weather files and their future projections. In this paper, HDDs reflect the number of degrees that a day's average temperature is below 18.3°C, while CDDs reflect the number of degrees that a day's average temperature is above 10°C. A clear warming trend is seen between the CWEC and CWEC2016 time period. As per the future weather file results, heating and cooling degree days show a shift in Toronto's Climate Zone from the current Climate Zone 5 to a Possible Climate Zone 4 in the future.

Table 2. Heating degree day (HDD), base 18.3°C, and cooling degree day (CDD), base 10°C, for Toronto Pearson International Airport.

Weather Files	HDD	CDD	Total
CWEC (1959-1989)	4,179	1,176	5,355
CCWorldWeatherGen tool	3,427	1,721	5,148
WeatherShift tool	3,157	1,690	4,847
HRM3	3,509	1,864	5,373
CWEC2016 (1998-2014)	3,695	1,482	5,177
CCWorldWeatherGen tool	3,033	2,079	5,112
WeatherShift tool	2,769	2,239	5,008
HRM3	3,122	2,040	5,162

The future weather files project an average temperature increase of 3.7-4.5°C for the 2050s. These projections are slightly higher than the IPCC global mean surface temperature increase for the same period.

3.2 Analysis of Building Simulation Results

For the sake of harmonization, all graphs use the color yellow for historical weather files (both CWEC and CWEC2016), red for CCWorldWeatherGen tool's future weather files, blue for WeatherShift tool's future weather files, and green for the future weather files generated dynamically using HRM3. The impacts of future weather files on heating and cooling energy use per total building area, in relation to the 1959-1989 and 1998-2014 baseline climates, are illustrated in Figure 2. As per the simulation results, rises in cooling energy use intensity (EUI) and decrease in heating EUI are found in all 16 reference building models for both baseline periods due to temperature rise brought by the climate change. The magnitude of changes in heating and cooling EUI is highly dependent on baseline years and building types.

For the 1959-1989 baseline period, the results indicate an average decrease in the range of 18-33% in heating EUI, and an average increase of 16-126% in cooling EUI, depending on the building type. When the two baseline periods are compared, higher heating and lower cooling energy use were simulated for CWEC weather file mainly due to lower temperature values observed for the 1959-1989 years.

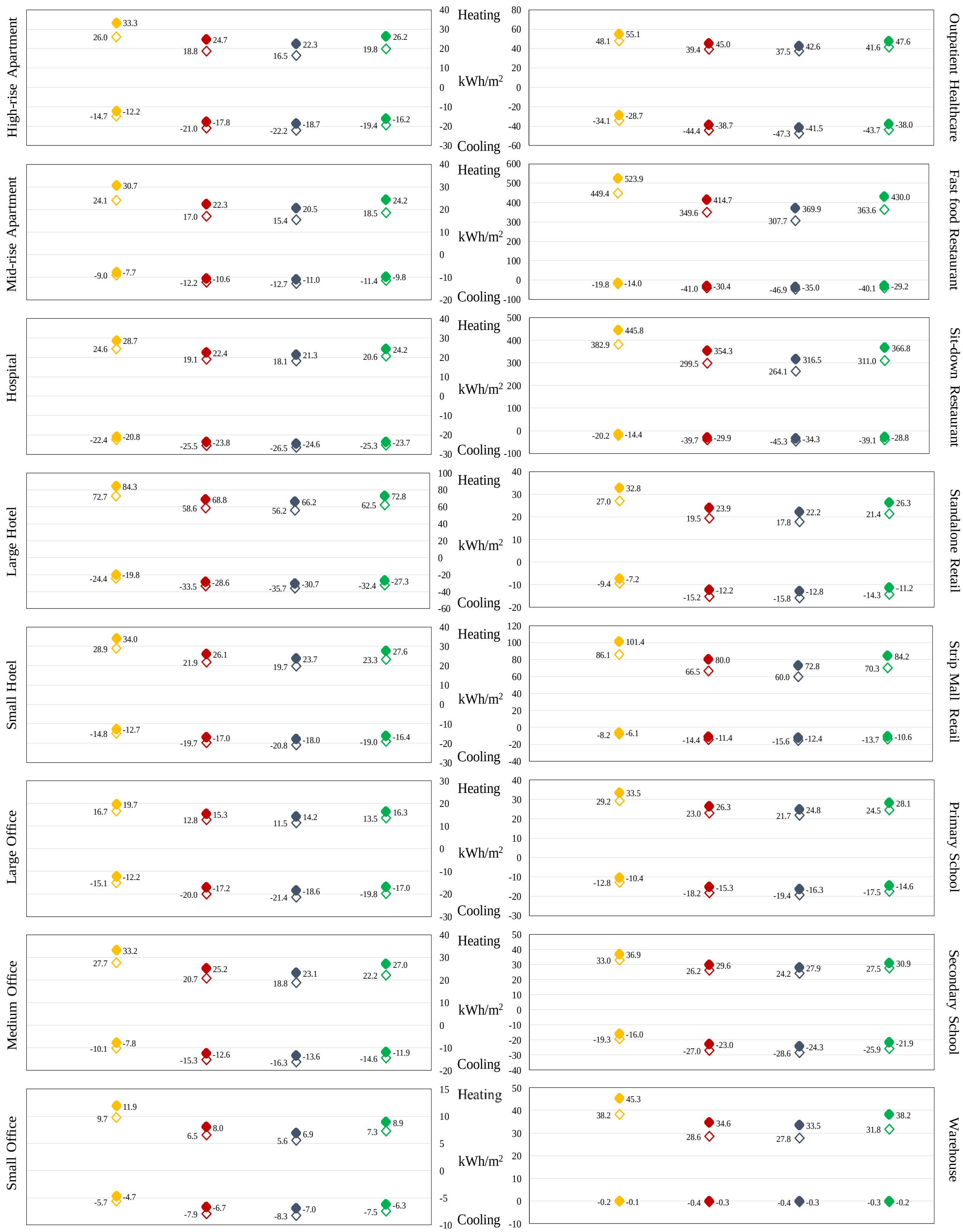

Figure 2. The scatterplots showing the distribution of values for the annual heating energy (positive values) and cooling energy (negative values) under historical and future weather data sets for all 16 reference buildings. Values for the 1959-1989 baseline period are presented in solid color markers and the 1998-2014 baseline period in hollow color markers.

Heating and cooling energy use for all 16 reference buildings are found to be extremely susceptible to the effects of climate change. However, this study determined that the heating load of large buildings is not as sensitive to changes in climate conditions as small buildings. These findings correspond to Xu et al. (2012) conclusion that certain types of buildings are more sensitive to climate change than others due to envelop heat loss/gain accounting for a larger portion of heating and cooling loads.[9] Moreover, buildings with higher insulation level, greater zone ratio, smaller window-to-wall ratio, and lower outdoor air supply are less affected by the outdoor conditions and thus climate change.

The rise in cooling demand in hot summer months suggests that the summer peak load electricity will place enormous pressure on the electricity grid. From the results of the analysis, it is evident that mitigations measures related to HVAC operations such as changes to the room temperature setpoints, HVAC system's operation hours will be required in the future. Apart from HVAC systems, other methods including addition of thermal mass, improvements in glazing and envelop insulation are recommended to help tackle some of the climate change challenges in the building sector.

3.3 Greenhouse Gas Emissions Due to Climate Change

The energy use breakdown for the 16 reference building models indicated that heating uses primarily natural gas while cooling is generated entirely from electricity. Using total energy use and the emission factors for electricity (36 grams of CO_2 per equivalent kWh) and natural gas (179.95 grams of CO_2 per equivalent kWh), the total GHG emissions associated with each building model was calculated.[10] It is worth noting that in province of Ontario, the baseload electricity is provided primarily with clean sources of energy such as wind, nuclear and hydro, and the peak load energy demand is fulfilled in large with natural gas. Figure 3 details the total energy use emissions for the 16 reference building models. It is evident that the buildings are accountable for a large share of energy consumption and the corresponding GHG emissions.

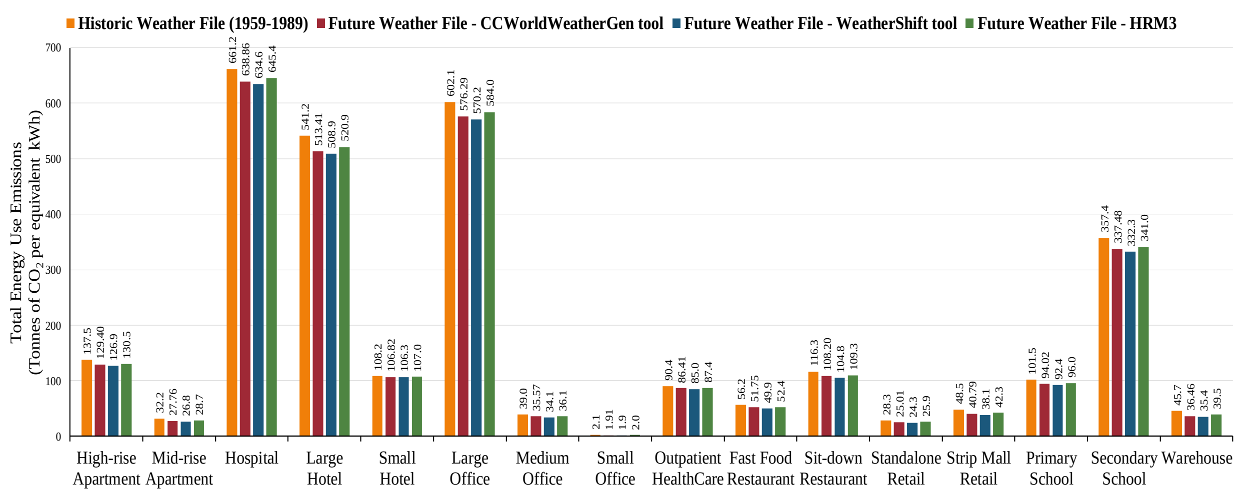

Figure 3. The total energy use emissions for the 16 reference building models, 1959-1989 baseline period.

4.0 Conclusions

The results described in this paper establishes the importance of considering future weather file for building energy simulation. Both statistical and dynamical downscaling techniques provide reasonable information on the long-term impacts of climate change on building energy demand. However, in statistical downscaling, it is evident that different TMY selected for the baseline period can project diverse future climate conditions. In dynamical downscaling, finer spatial resolution generated by RCM present a better representation of the local climate conditions. Thus, the impacts of climate change on building energy demand, that tends to focus on local level, is better quantified.

For a Canadian climate, the more heating energy a building consumes in the winter, the greater potential it has in magnitude of decrease in energy use in the future. Therefore, making it capable of saving more energy in the future climate. Nevertheless, the potential increase in cooling energy demand and summer peak load electricity in summer months offer a warning sign to the local governments and electricity providers. The buildings energy demand forecast demonstrates the dire need to modify and adapt existing buildings and to plan future buildings according to the future climate.

In future work, it is suggested to use the generated weather files to assess the climate change mitigation measures on various building types. In addition, future studies should include multiple cities across Canada with different climate conditions, as building energy use as well as GHG emissions vary significantly across the region. Finally, it is necessary to consider the effects of urban climate along with extreme conditions to fully understand the impacts of climate change on buildings energy demand.

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Notes

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