WHITE PAPER

MODELLING WEATHER FUTURES

TORONTO, ONTARIO

WHITE PAPER

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SUBMITTED TO

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NOMENCLATURE

ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIN = Binary file format, used for DOE-2 weather files
CWEC = Canadian Weather for Energy Calculations
CWEEDS = Canadian Weather Energy and Engineering Data Set
EPW = EnergyPlus Weather file format
HDD = Heating Degree Days, base 18°C
HVAC = Heating, Ventilation and Air Conditioning
IES-VE = Integrated Environmental Solutions – Virtual Environment software, 2016 version
MURB = Multi-unit Residential Building
TMY = Typical Meteorological Year
TMY2 = Set of TMY files developed by National Renewable Energy Laboratory
WRF = Weather Researching and Forecasting model

1 INTRODUCTION

The fundamental purpose of buildings is to provide protection for the occupants from exterior conditions. Historically, this has meant that building designers – architects and engineers – look at the typical climate conditions of the building's location, and develop their building systems to meet these conditions. In the face of climate change the building industry has been given a new challenge: design buildings that can provide thermal comfort to their occupants in the current climate, yet can also adapt and continue to provide protection from unknown future changes in the exterior environment.

Building energy simulations are used to estimate the annual energy performance of a proposed building design under a given set of annual exterior climate conditions. The simulation uses a set of input climate parameters known as a "weather file". The results from these energy models are often used to inform the design of heating, ventilation and air conditioning (HVAC) systems, or to determine the impact of different design strategies on the overall building performance. Intuition coupled with research by Huang, *et al.* highlights the importance of selecting an appropriate weather file as perhaps the most important foundational input into any energy performance analysis.

Despite this, the most commonly used weather files for buildings in Canada describe the typical climate conditions from the time period of 1959 to 1989 – data that is over 25 years old. This research paper aims to demonstrate why care must be taken to select weather files for energy modelling that best describe the climatic conditions of a location; and presents a method for using climate forecasting models to quantifiably estimate the potential outcome of climate change on a proposed building.

2 HISTORICAL WEATHER DATA

A 'typical meteorological year' (TMY) is used in building energy simulations to estimate the energy consumption of a building based on the typical local weather conditions. A TMY is a set of meteorological and solar radiation data for one year, recorded hourly. The data, however, does not relate to any one year's actual historical records. Instead, the historical records across a multi-year period are compared month-by-month to select the twelve statistically most typical months. These typical months are then concatenated to form a TMY. As such, the TMY can be considered to demonstrate the annual weather conditions that would be most typical across that multi-year period. The TMY file is then converted into a file format that is readable by whole building energy simulation tools. For EnergyPlus and IES-VE this is an EnergyPlus Weather (.EPW) format, and for eQuest and DOE-2-based software, a binary (.BIN) format is used.

Public research organizations and a growing number of private entities have developed TMY, EPW and BIN files for most major centres around the world. For Canadian locations, there are two sets of TMY files that are readily available to be used for building energy simulations: Canadian Weather for Energy Calculations (CWEC) files, and "CN2014" files. The CWEC files use data from the Canadian Weather Energy and Engineering Datasets (CWEEDS), collected by Environment Canada. This long-term data spans over 30 years, and the TMYs are selected from data for 1959 through 1989. CWEC weather files are available for free download on several sites, for example: https://energyplus.net/weather.

The CN2014 files are a new set of TMY files that have been developed by White Box Technologies for 224 Canadian cities, based on more recent recorded weather data. The Integrated Surface Data (ISD) data set from the National Centers for Environmental Information (NCEI) is used to create these TMY files from historical weather data spanning 2000 to 2014. The CN2014 can be download, for a modest price, from: http://weather.whiteboxtechnologies.com/CN2014.

To date, the CWEC files have been most commonly used for building energy simulation and studies in Canada. The files are free to download from Environment Canada, and have been well-vetted as reliable TMYs. The 30-year range of historical weather data is wide enough to provide a good basis for the selection of statistically typical months. In contrast, the CN2014 files have not yet achieved widespread use among building energy modellers. This set of TMYs was released for sale from the developer in 2015, and has not yet been thoroughly vetted. As well, the historical data only spans the 15-year period between 2000 and 2014, potentially reducing the significance of the statistics.

Nevertheless, Figure 1 suggests that despite these drawbacks, CN2014 may be the more appropriate TMY file for building energy simulation of new and proposed buildings. Figure 1 shows the historically recorded annual heating degree days (HDD) base 18°C for Toronto Pearson Airport between 1953 and 2015. The range of years used for the CWEC and CN2014 TMY files have been identified. A clear warming trend is seen over the whole time period, and the HDDs in the CN2014 range are significantly lower in comparison with the CWEC range. Further, the ASHRAE Climate Zone ranges are shown as colour bands on Figure 1, and it can be clearly seen that a shift from Climate Zone 6 to Climate Zone 5 has occurred in the Toronto climate.

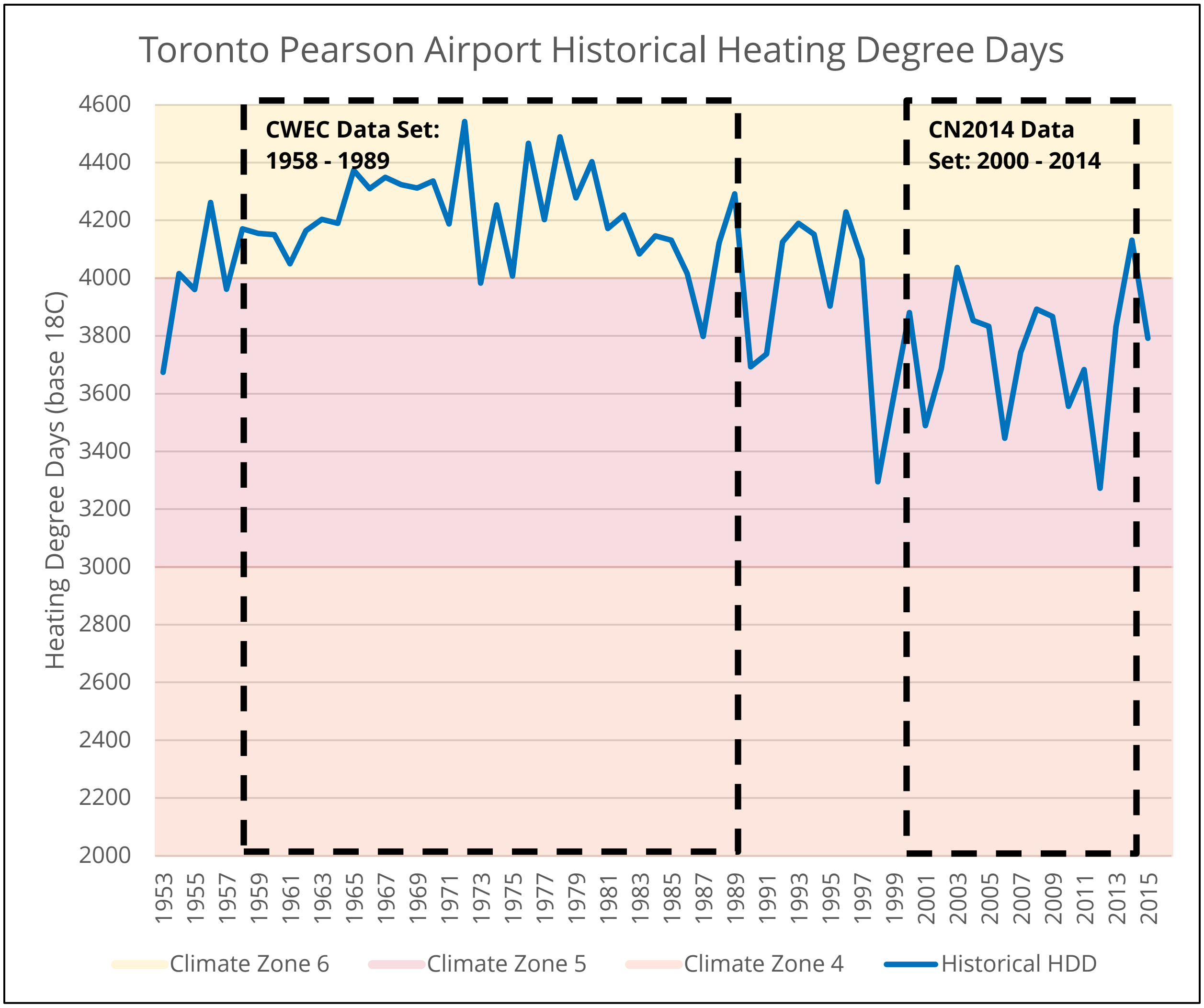

Figure 1: Annual Heating Degree Days (base 18°C), 1953 - 2015

This comparison shows that the impacts of climate change can already be seen in the Toronto context, and that continuing to assess a building's energy performance relative to the CWEC historical weather is no longer sufficiently relevant. As such, our work would suggest that the CN2014 should be used when modelling new and proposed buildings.

3 CLIMATE FORECASTING METHODS

In addition to using the more recent CN2014 TMY files when designing new buildings, given that the implications of climate change can already be seen in the historical weather records, it seems prudent to explore how climate change may continue to alter the weather, and how buildings will be impacted moving forward. This can be accomplished using climate forecasting models that estimate how the weather may change in the future.

Two methods are commonly used for forecasting future climate. A Statistical Trending or "Morphing" methodology uses historical climate data to calculate how current climate parameters are varying around the historic mean; from this calculation, a future prediction is made (ARCC, 2014). This method is relatively straightforward and cost-effective to perform, but is not suitable to predict extreme events, and arguably does not sufficiently consider the interaction among variables (Jentsch, Bahaj, & James, 2008).

A Weather Research and Forecasting (WRF) Model method is an atmospheric modelling system used for numerical weather prediction at the mesoscale. This method is significantly more complex than the Statistical Trending Method, but is considered to be the current state-of-the-art in simulating the dynamic relationship of climate variables and predicting future weather (University Corporation for Atmospheric Research, 2016). A WRF model is more expensive, but provides a weather forecast that includes consideration for extreme weather events and other impacts of climate change (SENES Consultants Limited, 2011).

3.1 Toronto Future Weather and Climate Driver Study

In 2012, the City of Toronto commissioned a study of the future weather and climate drivers. To accomplish this, a fine-resolution WRF model was performed to make projections of future climate in Toronto between the years of 2040 and 2049 (SENES Consultants Limited, 2011). This model used the Intergovernmental Panel on Climate Change (IPCC) Scenario A1B parameters, which describe a moderate-extreme future outlook within a context of rapid economic growth, changing population, and fossil fuel energy use. The study was undertaken by SENES Consultants.

The result of the study was a simulation of the hourly weather details on a 1x1 km output grid across the Greater Toronto Area for the years 2040 to 2049. The final output from the WRF model for Toronto Pearson International Airport was then specifically analyzed so that direct comparisons could be made against other climate model outputs.

In summary, the main changes expected for Toronto into the decade of 2040 to 2049 include: (SENES Consultants Limited, 2011)

- Increased temperatures throughout the year. This means both an increased number of Cooling Degree Days above 18°C, and an increased frequency and duration of heat waves.
- Increased intensity of major rain events.
- Increased frequency of freeze-thaw events.
- Increased intensity of major storms and tornados.

In Figure 2, the annual HDDs forecasted by the Toronto WRF study are appended to the historical HDDs. As in Figure 1, the ASHRAE climate zones are shown using colour bands. This figure shows that the forecasted HDDs for Toronto Pearson Airport have further shifted to Climate Zone 4.

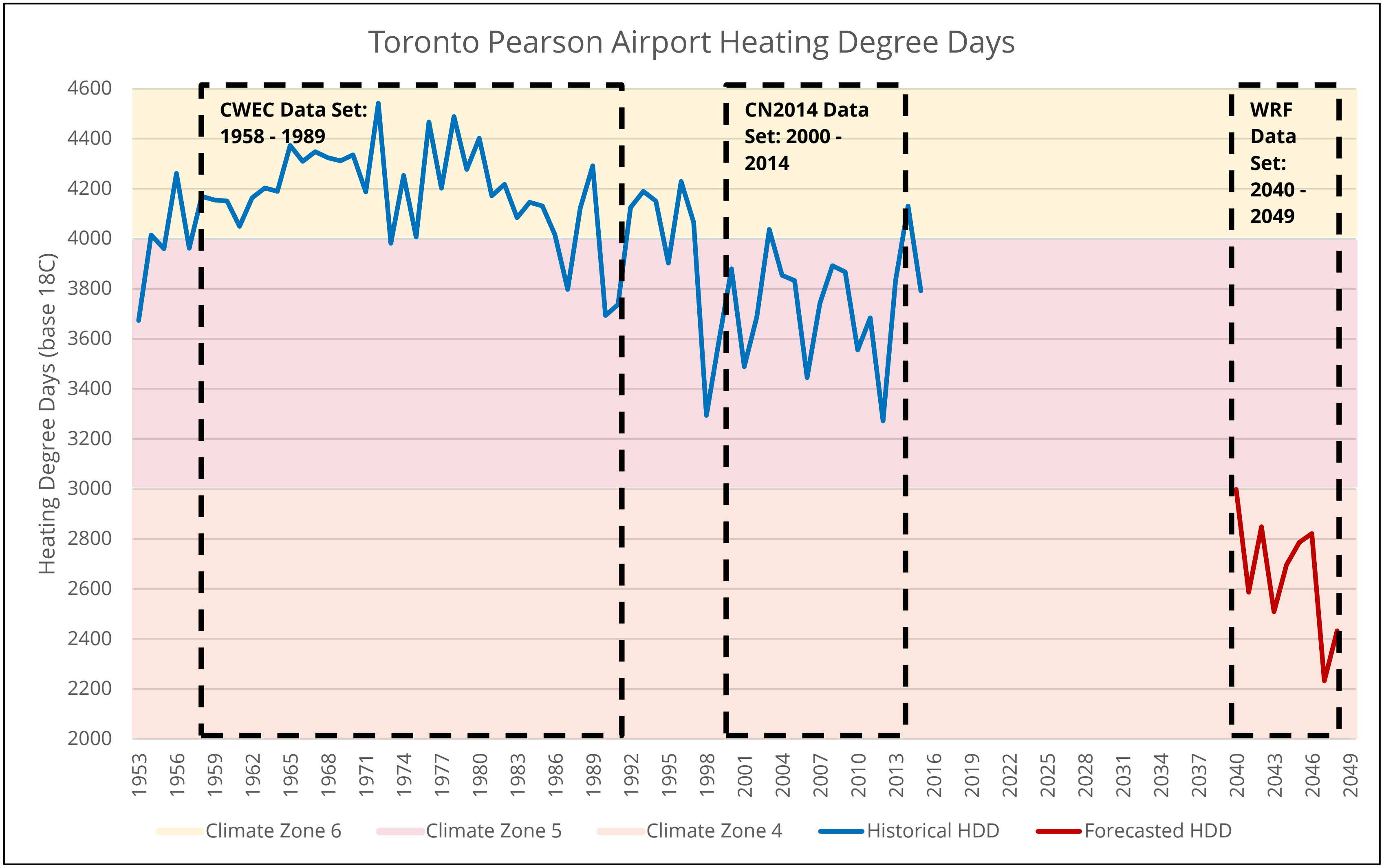

Figure 2: Heating Degree Days, Historical and Forecasted

4 RWDI CASE STUDY

As building energy consultants and climate engineers, RWDI wanted to explore the implications of the future weather on Toronto buildings. To do this, the projected hourly weather data was acquired from SENES Consultants for Toronto Pearson Airport for the years 2040 through 2049. From this data, a TMY was created and converted into a format appropriate for energy modelling software to use in a building energy simulation. The resultant Weather Future (WF) files will be made freely available as WF2040s.EPW and WF2040s.BIN files for use in EnergyPlus, IES-VE and eQuest energy simulations.

This new TMY was compared to the existing CWEC and CN2014 files, and used in a sample building energy simulation, to demonstrate the differences between these TMY files.

4.1 TMY Creation Methodology

The process we used for creating a TMY from the 2040-2049 data was adapted from the methodology used by the National Renewable Energy Laboratory (NREL) in developing their "TMY2" data sets. The TMY2 methodology uses the Sandia Method to select individual months which are concatenated into one TMY. The Sandia Method is a statistical comparison of a number of weighted indices, including maximum, minimum and mean dry bulb and dew point temperatures, maximum and mean wind velocities, and global and direct solar radiation.

The TMY2 methodology was used to create the CN2014 files (Huang, Su, Seo, & Krarti, 2014). The adoption of this methodology by RWDI, therefore, is intended to create a TMY that can be compared to the CN2014 files. However, since the TMY2 methodology is designed to assess 30 years of data, RWDI adjusted the process slightly to better suit the smaller 10-year future weather data set. It is worth noting that while the CWEC files also use the TMY2 methodology, the weighting of indices was adjusted and does not match with those used in the TMY2, CN2014 or RWDI files (Environment Canada, 2010). However, research by Huang *et al.* (2014) suggests that the impact of using different weightings on the resultant weather file is minimal; as such, the CWEC files are still considered comparable.

4.2 TMY Comparison

RWDI compared the resulting TMY, referred to as the "2040s TMY," with the CWEC and CN2014 TMY files to discover general trends in the projected weather data.

Figure 3 compares the average monthly dry bulb temperature between the CWEC, CN2014 and 2040s TMY files. Figures 4 and 5 show the monthly heating and cooling degree days, respectively, for the each TMY file. As may be expected, the 2040s TMY features increased average dry bulb temperatures, increased cooling degree days, and decreased heating degree days when compared to the historical TMYs.

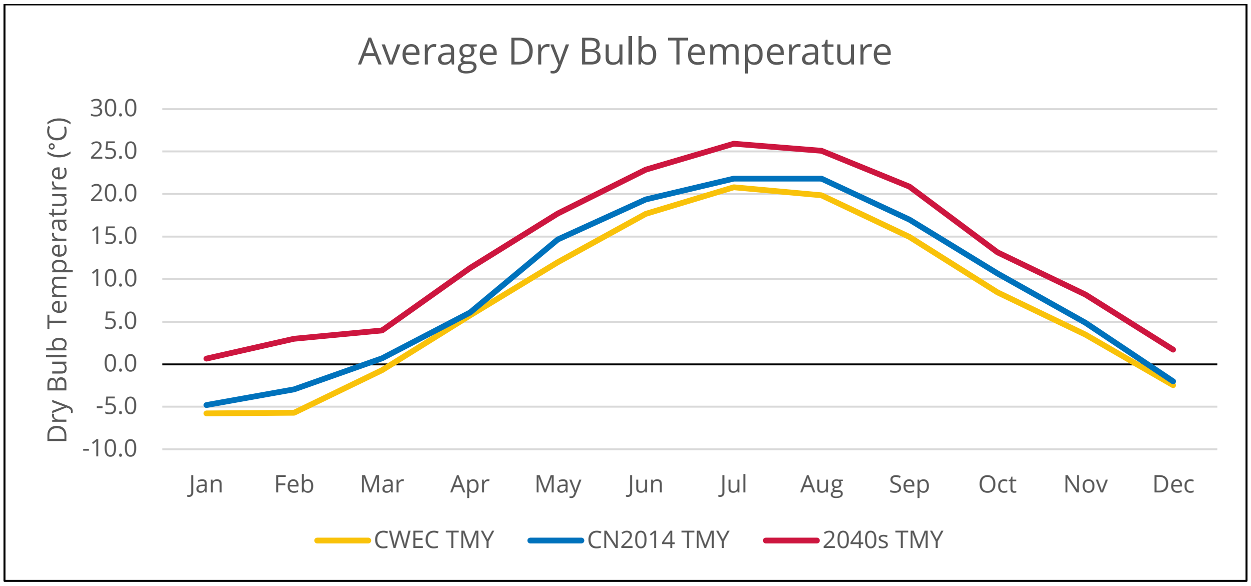

Figure 3: Average Dry Bulb Temperature

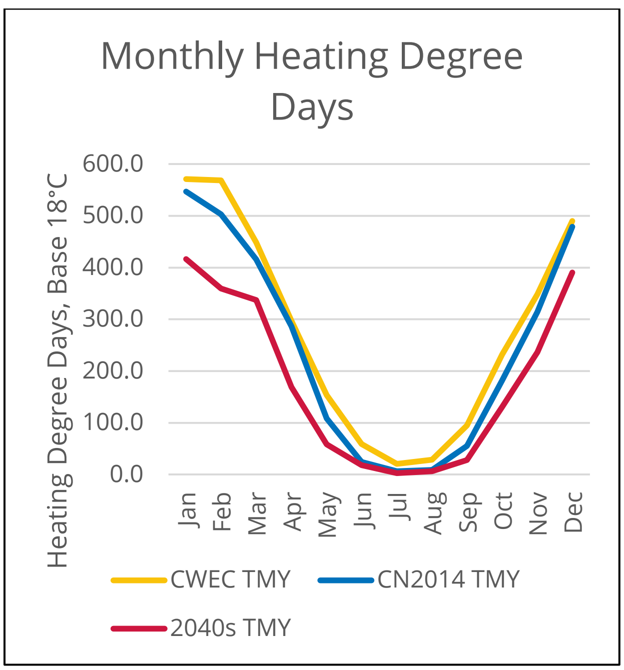

Figure 4: Heating Degree Days (base 18°C) per Month

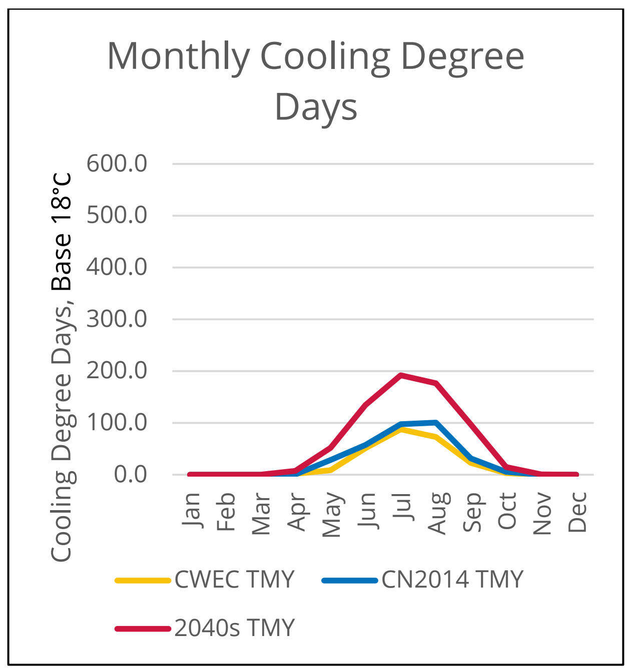

Figure 5: Cooling Degree Days (base 18°C) per Month

This can be put into the context of thermal comfort using psychrometric charts, see Figures 6 and 7, that were generated using Climate Consultant Version 6.0 (UCLA Energy Design Tools Group, 2016). The blue rectangles outline the thermal comfort zones for heating and cooling seasons, as defined by ASHRAE Standard 55. Figure 6, which plots the CN2014 TMY data, shows that there are 922 hours in which the exterior conditions fall within the thermal comfort zones. The other hours appear most heavily distributed in the dry bulb temperature range of -10°C through 5°C, with few uncomfortable hours at hotter temperatures.

In contrast, the 2040s TMY data, shown in Figure 7, has fewer hours that fall within the thermal comfort zones (759 hours) and shows a different distribution of hours across the dry bulb temperature range. Though most heavily found between -5°C and 10°C, there are several uncomfortable hours noted with dry-bulb temperatures and/or humidity levels that are higher than the defined comfort conditions. While the CN2014 TMY (Figure 6) does not show any hours reaching 35°C, the 2040s TMY (Figure 7) shows dry bulb temperatures rising up to 40°C.

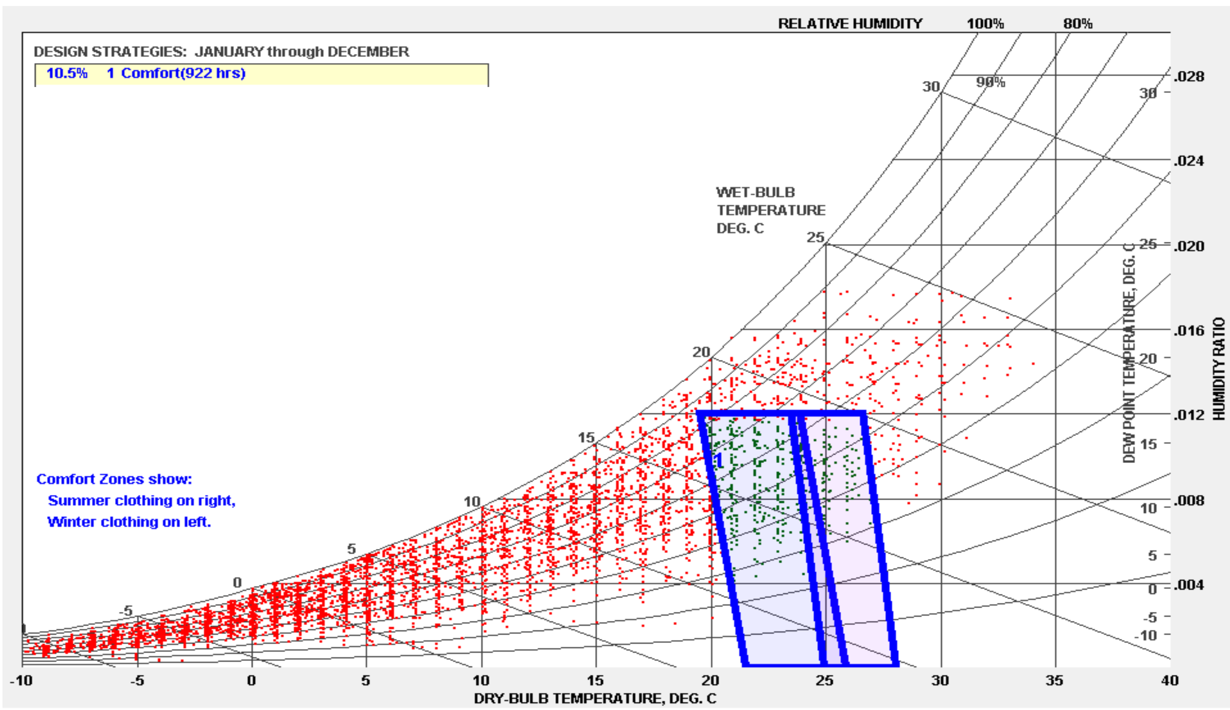

Figure 6: Psychrometric Chart of CN2014 TMY (UCLA Energy Design Tools Group, 2016)

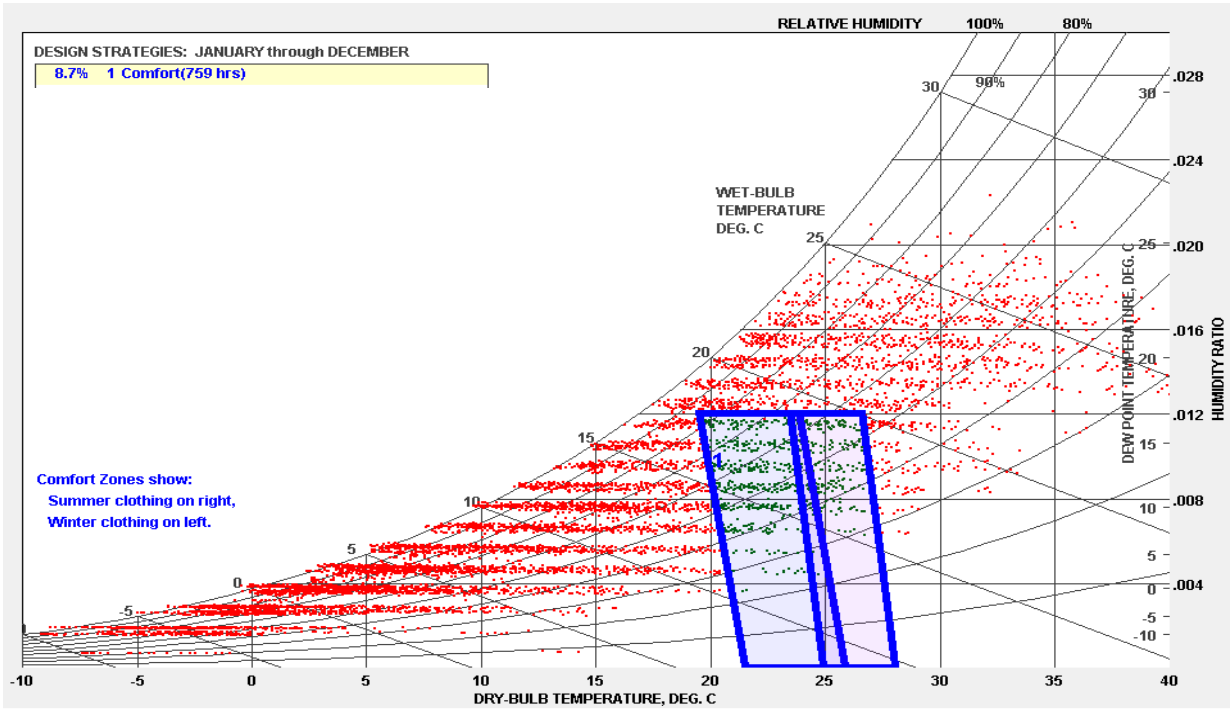

Figure 7: Psychrometric Chart of 2040s TMY (UCLA Energy Design Tools Group, 2016)

Finally, the full future weather data was used to determine the annual climatic design conditions, following the protocol outlined in ASHRAE Fundamentals 2013, Chapter 14. These design conditions describe the dry bulb temperature extremes, and are used to size building mechanical equipment. A dramatic change can be seen between the current values, provided by ASHRAE for Toronto Pearson Airport (WMO# 716240), and the projected future case.

Table 1: Annual Climatic Design Conditions

	Heating Dry Bulb Temperature (°C)		Cooling Dry Bulb Temperature (°C)		
Percentile	**99.6%**	**99%**	**0.4%**	**1%**	**2%**
ASHRAE	-18.1	-15.6	31.4	29.6	27.9
2040-2049	-6.8	-5.3	37.2	34.9	32.9

4.3 Sample Building Energy Simulation

To put the projected future weather into the context of the built environment, RWDI performed three sample building energy simulations, comparing the CWEC, CN2014 and 2040s TMY files.

Integrated Environmental Solutions – Virtual Environment 2016 (IES-VE 2016) software was used to create an energy model of an archetypal high-rise multi-unit residential building (MURB) in Toronto, Ontario. The archetype building represents a 45,000 m^2 building with 33 storeys – 16 apartment suites and 1 core zone per floor. The archetype has a window to wall ratio of 40% and is enclosed by an envelope with thermal characteristics equivalent to the Ontario Building Code 2012. The HVAC system is a fan coil system servicing the apartments, and a hydronically heated and cooled make-up air unit providing fresh air to the core zones. Fresh air infiltrates into the suites from the core zone via the door undercut. The fan coils are supplied by natural gas boilers and water-cooled chillers. This system is typical for high-rise residential market in the Toronto market.

The model was initially run using the CWEC TMY file as the climate file – currently the CWEC TMY is most commonly used for building energy modelling in Canada. The HVAC systems were auto-sized by IES-VE to meet the loads required by each zone. RWDI then ran the model twice more, first using the CN2014 TMY file, and then the 2040s TMY file, but maintained the equipment sizing that was determined in the initial model run. Table 2 compares the results of these three simulations, and the end-use energy usage for the models is shown in Figure 8.

Table 2: Total Annual Energy Use Results

	Total Energy (MWh)	**Energy Use Intensity** ($kWh/m^2/yr$)	**Total Electricity** (MWh)	**Total Natural Gas** (MWh)	**Unmet Heating Hours**	**Unmet Cooling Hours**
CWEC TMY	8,681.3	192.7	2,689.1	5,992.1	11	149
CN2014 TMY	8,289.5	184.0	2,721.3	5,568.2	1	216
2040s TMY	7,696.4	170.8	3,111.5	4,584.9	0	728
Variance CN2014 to CWEC	-5%		+1%	-7%	1 hour	67 hours
Variance 2040s to CWEC	-11%		+16%	-23%	11 hours	579 hours

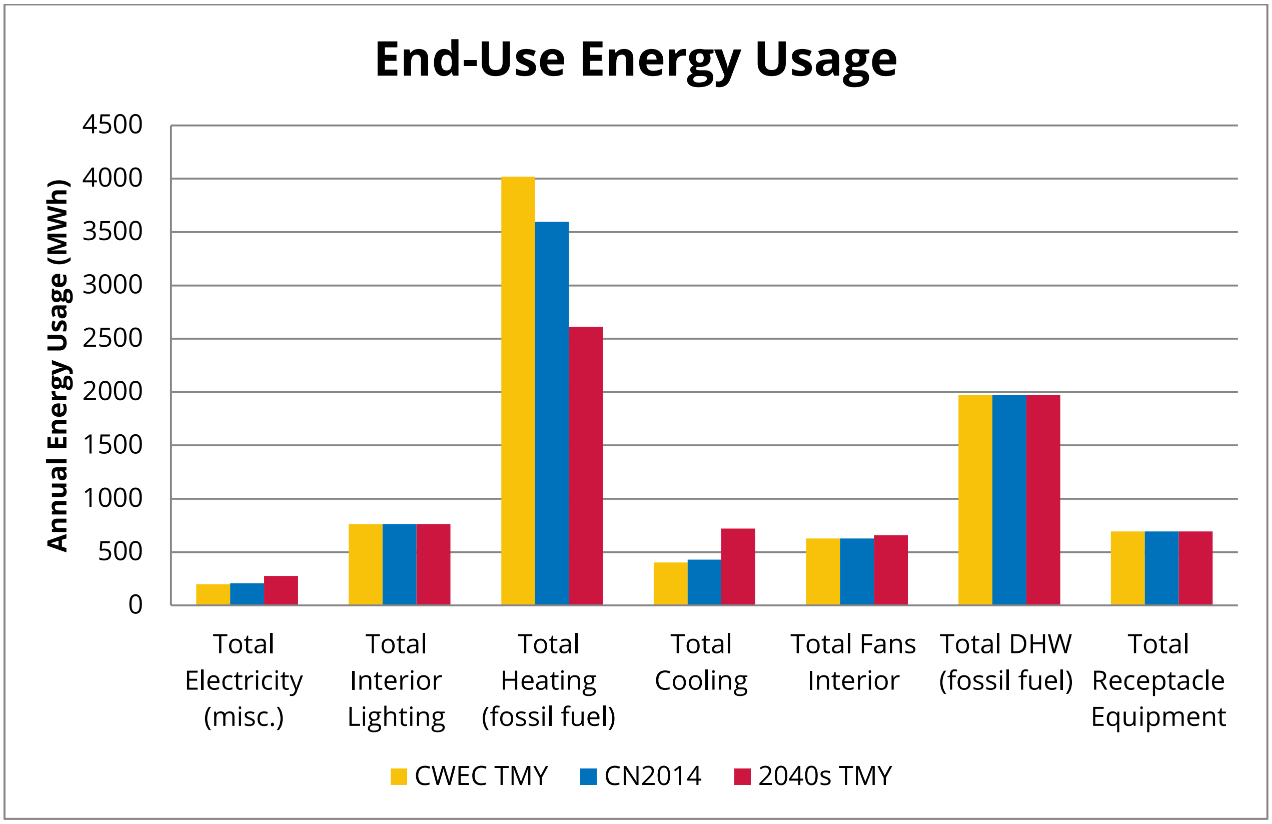

Figure 8: Annual Energy End-Use Breakdown, Archetype MURB Energy Simulation

For the most part, these total energy use and end-use results align with the climate projections discussed above – an increase in the number of cooling degree days results in an increase in building cooling energy use and total electricity use; a decrease in heating degree days results in a decrease in building heating energy use, and therefore lowered natural gas use. The total energy use is reduced in the 2040s model, since the efficiency of the cooling systems is better than that of the heating systems.

An unmet hour can be defined as an hour when the HVAC system of the building is unable to bring the conditioned spaces of the building to within the thermal comfort range, typically defined by ASHRAE Standard 55. For unmet cooling hours, this means that the space is more warm and/or humid than can be considered comfortable for occupants.

There is no regulated maximum allowable number of unmet cooling hours for a building; however, the unmet cooling hours for the 2040s TMY are cause for concern. When considering that the 728 unmet cooling hours are likely to occur during the middle 8 hours of the day (between 10h00 and 18h00), this model suggests there will be 91 days each year (3 months) where the HVAC system is unable to condition the spaces to meet the required thermal comfort conditions during the hottest part of the day.

5 CONCLUSION

The research described in this report has demonstrated three important considerations for building energy simulations in the context of climate change:

1. It is important to consider the historical data that is represented by a TMY – what period of time does the TMY represent, and how does it compare to the current climate conditions – and determine which TMY file is most appropriate for use in building energy modelling. In particular, code officials, city planning departments, and green building councils should take note and consider requiring that current TMY files be used for energy performance studies.

2. A “future” TMY file can offer further insight into the capability of a building’s design to continue to perform as intended, despite a changing climate.

3. The ‘resiliency’ of the built environment to the changing climate is of increasing concern. To date, resiliency studies have largely been qualitative; building performance studies based on future weather files allow quantified metrics (e.g. unmet cooling hours) to be calculated, and the relative merit of design considerations to be estimated accordingly.

Another important outcome from this study is the now freely available WF2040s_YYZ.bin and WF2040s_YYZ.epw future weather files that present an opportunity for the energy consulting and simulation community to begin to quantifiably consider future weather impacts on building designs.

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