Impact of typical-year and multi-year weather data on the energy performance of the residential building

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Abstract

Climate has the highest impact on the energy performance of the buildings. Therefore, it is crucial to use reliable weather data to evaluate the energy demands of the building and reduce the performance gap. Typical weather years (TWYs) have been used for the energy buildings simulation for a long time despite existing flaws. A single-family house in Winnipeg, Canada, is selected to investigate how TWYs affect energy consumption and compare them with multi-year simulations. The investigation findings revealed that a typical year could not capture the whole spectrum of year-by-year weather variations. Hence the results show that the two typical weather years (CWEC and TMY) overestimated the cooling load while underestimating the heating load compared to the last five actual weather years. Today with increased computational capacity, it is possible to use actual weather years for multi-year simulations of the buildings to improve the assessment of their energy performance.

Introduction

The building sector is accountable for around 35% of final energy consumption and approximately 39% of energy-related carbon dioxide emissions (IEA, 2019). To address this issue, code requirements for the energy performance of buildings are becoming more stringent worldwide. Building scientists and designers must investigate different design strategies and novel and advanced materials and technologies to satisfy these high standards. Dynamic building energy simulation is a robust technique that provides a pathway to test, analyze, and optimize energy efficiency measures and technologies (Al-janabi et al., 2019; Dutta & Samanta, 2018; Korolija et al., 2013; Mousa et al., 2017). However, since building energy modeling became an integral part of the building design process and compliance with energy codes and regulations, one of the most discussed issues in the design community is the energy performance gap. Several studies showed that selecting the weather file for the simulation significantly impacts the modeling predictions (Huang & Crawley, 1997). As a result, choosing appropriate weather files is critical for precise and accurate model predictions.

One of the widely used forms of weather data is typical weather year (TWY), a full-year hourly weather data derived from a long-term database through statistical processing. There are several approaches for creating TWY files, such as Typical reference year (TRY) and Typical Meteorological Year (TMY), and others with different precisions in predicting the energy performance of the building (Lee et al., 2010).

TWY has made the prediction process easy, and it is reasonably accurate in evaluating the energy performance of the building in the long term. Also, the TWY approach reduces the amount of effort and time for the energy simulations (Üner & İleri, 2000). However, there are several critical issues related to the use of TWY (Chan et al., 2006). Typical Weather Years cannot reflect the year-by-year fluctuations in the weather condition in a single year, and they usually discard the extreme conditions (Crawley & Lawrie, 2015). And as a result, they are not appropriate for estimating peak loads for sizing the heating, cooling, and ventilation equipment. In addition, TWYs are created using different procedures and methods, and consequently, they may produce different results (Bhandari et al., 2012; Skeiker, 2007).

Also, TWY files are often outdated and are not generated from recent weather data. In this respect, TWY built upon historical data might not represent the present-day climate conditions, especially considering climate change. Because Canada is heating up at approximately twice the global average, weather files should rely on recent observations to provide reliable predictions about the energy performance of the buildings (Kočí et al., 2019; Siu & Liao, 2020). For example, in a study by Yang et al. (2008), authors compared older typical weather data in Toronto city with a more recent weather file. The study shows 6-36% overestimation in heating load and 12-31% underestimation in cooling load. These results suggest significant uncertainty related to using outdated weather data.

Nowadays, with increased computational capacity, it is possible to run multiple simulations using Actual Weather Years. Evaluating multi-year actual weather data allow researchers and designers to understand the performance of the building over a long period and changing climate reflected in each year (Siu & Liao, 2020).

A few studies currently investigated the advantages of using Actual Weather Years (AWY) compared to running the

simulations with Typical Weather Years (TWY). One of the first studies was conducted by Crawley (1998), who investigated the influence of various weather data sets on annual energy consumption, peak loads, and cooling and heating demand in eight different office spaces in the U.S. The study then compared the results with 30 actual weather data showing that energy consumption varies between -11% to 7% in the 30-year actual weather data set compared to the multi-year weather dataset. Evola et al. (2021) used multi-year and typical-year approaches to investigate the energy use of an office building and a residential building in Sicily, Italy. According to the authors, TWY resulted in 10-35% and 15-25% underestimation in choosing the correct heating and cooling systems size.

This study aims to extend the current understandings in applying different weather datasets for energy simulations and compare the impact of these datasets on the energy performance of the building exposed to extreme cold climates. It compares the energy performance of a single-family house located in Winnipeg, Canada, by applying multi-year and typical year weather datasets from a weather station. Hence two TWY files typically used by the building energy modelers and five actual weather years recorded from 2015 to 2019 were investigated and compared.

Methods

Weather data selection

Two most recent TWYs procedures were selected for the research, including Canadian Weather year for Energy Calculation (CWEC), covering the 2002 to 2017 period derived from the Canadian Weather Energy and Engineering Data Sets (CWEED), and TMYx(15), including the 2004-2018 timeframe available from the online repository climate.onebuilding.org. CWEC was developed by Environment and Climate Change Canada (previously Environment Canada) and the National Research Council as a Typical Year weather dataset for Canadian Locations. CWEC, like TMY, is a weather dataset created based on the Sandia selection method (Hall et al., 1979). The representative meteorological months are selected from the Canadian Weather Energy and Engineering Datasets (CWEEDs). TMYx files are typical meteorological data derived from hourly weather data in the ISD (US NOAA's Integrated Surface Database) using the TMY/ISO 15927-4:2005 methodologies. The authors of climate.onebuilding.org created TMYx datasets. The primary distinction between CWEC and TMY is that CWEC files are structured in the ASHRAE-developed WYEC (Weather Year for Energy Calculations) format (Siu & Liao, 2020). The selected months for constructing both typical weather years are shown in Table 1.

The nearest weather station with the requisite data for producing typical and actual weather files is the Forks weather station, located approximately 9 km from the case study near the junction of the Red and Assiniboine rivers in Winnipeg, as shown in Figure 1. Due to the dramatic changes in Canada's climate over recent years (Siu & Liao, 2020), we used current weather data. Therefore, hourly weather data was collected from the Forks weather station from 2015 to 2019. Obtained weather data contains hourly values for a variety of environmental parameters such as dry bulb temperature (°C), wind speed (m/s), relative humidity (%), wind direction, and atmospheric pressure (hPa). The obtained hourly data contain all the required parameters for energy modeling except for solar radiation. As a result, solar radiation data were obtained from (the national solar radiation database) nsrdb.nrel.gov.

EnergyPlus weather file (.epw) is one of the most widely used formats that can be read by building performance simulation (BPS) tools and is compatible with various energy simulation programs. Hence, the AWYs and TWYs of both climates were organized into the .epw format to be used in the BPS tool.

Table 1: period selection of typical weather years based on different procedures

Typical Weather Year	**TMYx(15)**	**CWEC**
Period	**2004-2018**	**2002-2017**
Jan	2015	2002
Feb	2009	2009
Mar	2017	2017
Apr	2017	2011
May	2017	2012
Jun	2011	2011
Jul	2017	2010
Aug	2015	2015
Sep	2006	2017
Oct	2008	2008
Nov	2006	2006
Dec	2018	2009

Building description and modeling

The two-storey single-family house with a total floor area of 185 m² (136.33 m² conditioned) in Winnipeg, Manitoba (see Figures.1 B and 2) was used to investigate the impact of multi-year and typical year weather datasets on its energy performance.

The house built in the 1970s is 27° west to the true north. Its layout includes three bedrooms, a kitchen and living room on the ground floor, two bathrooms, an insulated crawl space, a utility room, and ventilated open space at the basement level. Therefore, we defined nine thermal zones presented in Figure 2 B, with zone 1 (Basement) and zone 2 (utility room) below the first level.

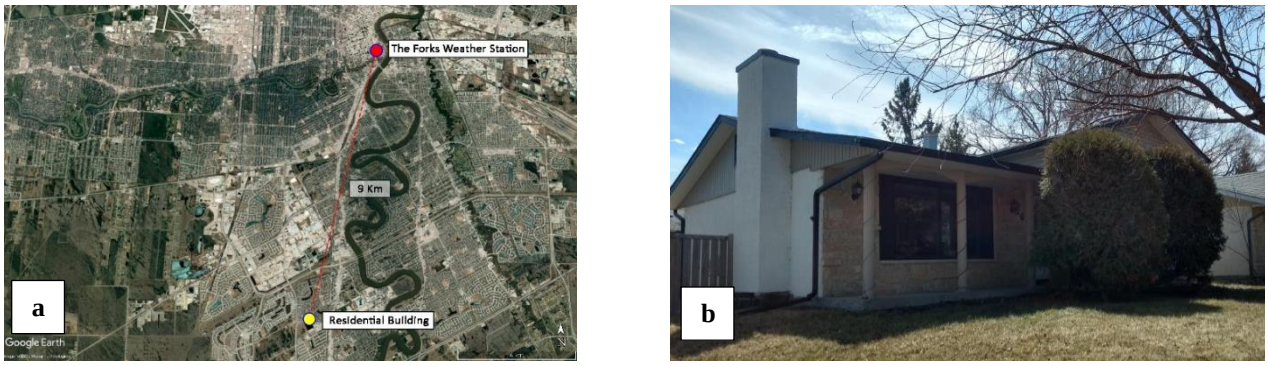

Figure 1: The location of two weather stations (A) and the actual house (B)

The house does not have any windows on the east and west exterior walls. The exterior north and south-facing walls feature 15% and 20% window-to-wall ratios. The outer wall assembly uses a conventional framing system (i.e., 2 x 4 wooden studs at 16" o.c.) and is insulated with fiberglass batt. Windows are double panes filled with air. The slab for the floor is made of 150 mm concrete covered by two layers of plywood (12mm+16mm). In the case of the roof, the plywood (16mm) and the roof sheathing (13mm) are separated by ceiling air space resistance, and also the asphalt shingles are used as the roof's outer layer. Table 2 summarizes the envelope components' thermal transmittance values (U-values).

Table 2: U-values of envelope components

	Building Components			
	Slab	**External Walls**	**Interior Walls**	**Windows**
U-Values [W/m2-K]	1.674	0.288	1.71	2.4

The first energy model for the single-family house was developed in energy plus, using the existing heating and cooling system and validated against the actual measured data. In this study, the heating and cooling loads in the building are estimated using an ideal load air system scenario. The ideal load air system is an object in EnergyPlus intended to deliver heating and cooling to a zone with 100 percent effectiveness to meet any heating or cooling requirement of the zone. This scenario allows the evaluation of the building's geometry and envelope performance without modeling heating and cooling systems (*EnergyPlus input-output*, 2021). The heating setpoint of 20 °C and cooling setpoint of 26 °C were used in the EnergyPlus model.

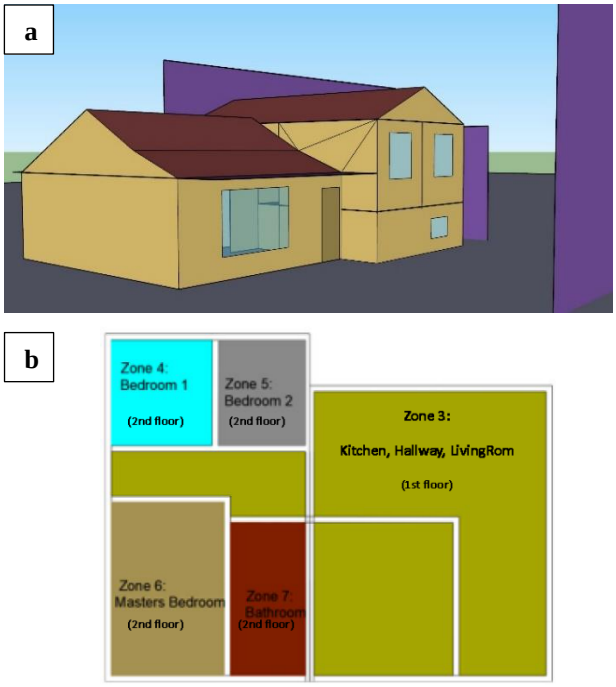

Figure 2: (a) modeled building and (b) the thermal zones

Results and discussion

Weather data

This section investigates the meteorological data recorded by the Forks weather station from 2015 to 2019 and compares it to the statistical distribution of typical weather years (TWY), CWEC, and TMY. In this respect, Table 3 summarizes their annual minimum, mean, and maximum outdoor air dry bulb temperature, relative humidity, wind speed, and global horizontal irradiance. The yearly variation between the environmental parameters, except wind speed, is not considerable between the TWY and five actual weather years (AWY). Thus, CWEC and TMY have a significantly lower annual mean wind speed of 2.1 and 2.08 m/s, respectively, than five AWYs with wind speeds ranging from 6.54 to 7.79 m/s.

Additionally, Figure 3 illustrates the distribution of dry-bulb air temperature and global horizontal irradiance in January and July. Boxplots present the results, and for conciseness, we selected the coldest month (January) and the warmest (July) for the comparison. Boxplots include a vertical box from the first quartile to the third quartile, and a horizontal line inside the box represents the median. The whiskers go from each quartile to the min and maximum of the data. Also, the green dots in the boxes demonstrate the mean of each data distribution. The length of the whiskers is limited to 1.5 times the interquartile range by varying the box and whisker plot. Thus, the whisker reaches the value farthest from the center while remaining within 1.5 times the interquartile range from the lower or higher quartile. Outliers shown as red crosses on the graph are data points outside this range.

Figure 3 shows a declining trend in both median and mean air dry-bulb temperature values in January of the last four AWY. The results also indicate that the variation range of actual weather years is between 30.96 °C and 39.15 °C in January. The temperature difference between maximum and minimum of 34.72 °C for CWEC and 33.28 °C for TMY is comparable to 2015 (33.42 °C) and 2017 (33.23 °C). The coldest January was in 2019, with the highest temperature difference from -34.65 °C to 4.50 °C. In contrast, January 2016 was the warmest, with the lowest variation in temperature between -26.50 °C and 4.46 °C. Furthermore, 2016 January appears more skewed negatively, while 2015 January is more skewed positively than the rest.

Table 3:Annual Minimum, mean, and maximum values of four environmental parameters

	Dry-bulb air temperature			**Relative humidity**			**Wind speed**			**Global horizontal irradiance**		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
Unit		°C			%			m/s			Wh/m²	
2015	-29.48	5.67	33.30	13.00	67.28	97.00	0.00	7.79	42.50	225	3730	8643
2016	-27.80	6.13	34.31	10.38	68.83	97.63	0.00	6.68	22.50	201	3683	8842
2017	-31.10	4.93	33.48	13.00	65.47	97.00	0.00	6.85	25.00	116	3706	8643
2018	-28.30	4.19	36.40	11.00	64.68	96.00	0.00	6.54	25.00	273	3667	8542
2019	-34.65	3.43	35.28	15.63	66.05	99.00	0.00	6.92	25.00	309	3702	8870
CWEC	-28.45	4.66	33.30	12.38	68.40	99.00	0.00	2.10	9.36	291	3575	8456
TMY	-28.96	4.94	33.30	13.00	66.14	100.00	0.00	2.08	11.68	206	3657	8519

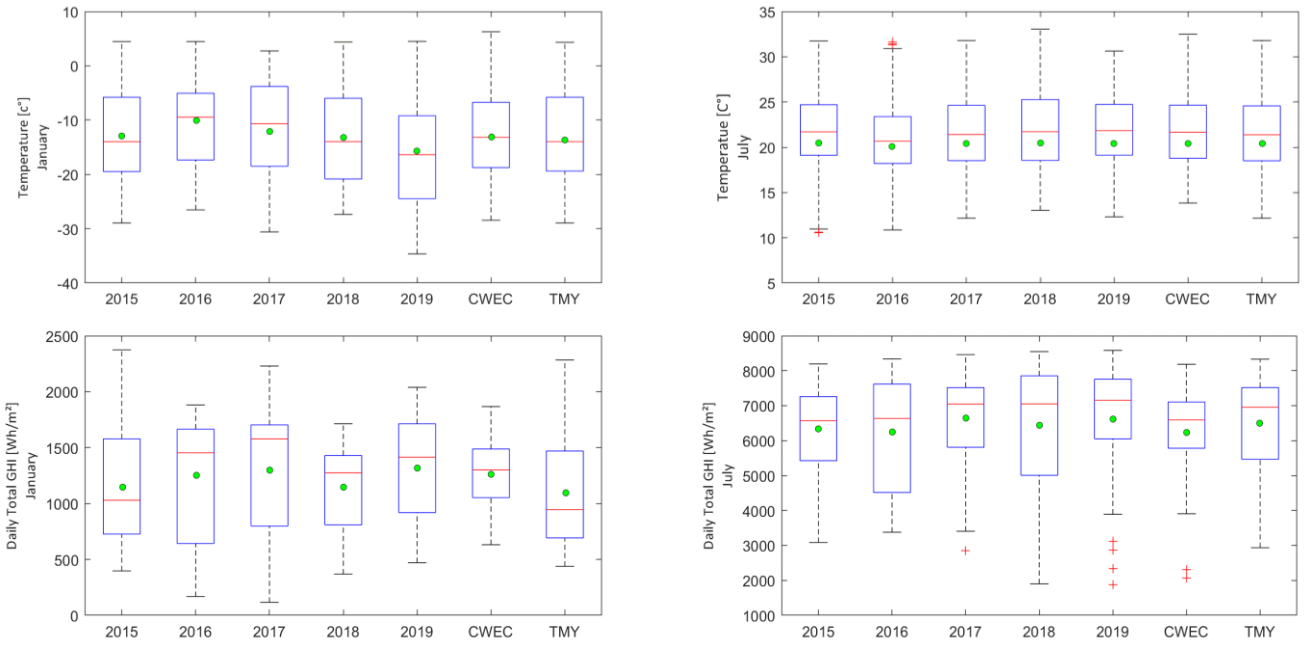

Figure 3: Distribution of the dry-bulb air temperature and global horizontal irradiance in January and July

In the case of global horizontal irradiance (GHI), the average variation over the five years ranges between 1125 Wh/m² to 1375 Wh/m² in January and 6226 Wh/m² to 6575 Wh/m² in July. There is a significant variation in GHI between two typical weather years. In this respect, the distribution of January and July GHI of CWEC is considerably lower than TMY. January 2016 had the most extensive distribution of GHI, followed by 2017. Also, 2016 and 2017 are negatively skewed, similar to 2018, whereas the 2015 and TMY distributions are skewed positively. July 2016 also had the most extensive distribution of GHI, followed by 2018. Global horizontal irradiances in July 2017, 2019, CWEC, and TMY appear skewed negatively.

Heating degree days and cooling degree days

Figure 4 presents the annual heating degree days based on 18 °C (HDD18) and cooling degree days based on 23 °C (CDD23) to provide a detailed look at the variation in actual weather data for recording years from 2015 to 2019. Considering the HDD, the TMY weather data is very close to the median of the five-year actual weather data, while the CWEC exceeds by 3% the median (HDD= 5172°C.day). Regarding the CDD, the TMY year aligns with the median of the five-year actual weather data, whereas the CWEC year surpasses by 19% the median of the actual weather years (CDD = 30°C.day). These findings suggest that TMY better describes the current weather conditions than CWEC weather data in dynamic simulation of the building for predicting the cooling and heating demand of the building. Nevertheless, conclusive conclusions require further analysis of heating and cooling energy simulations.

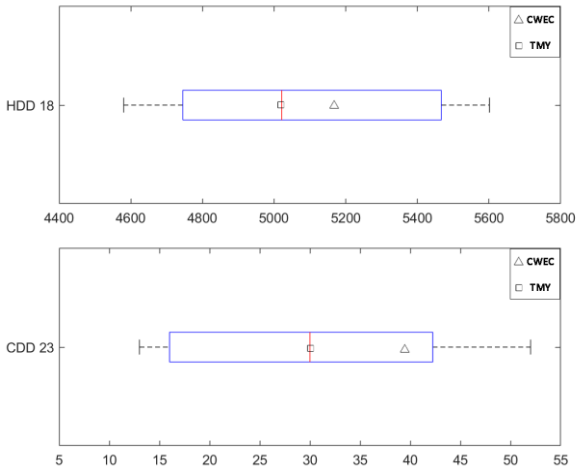

Figure 4: Heating and cooling degree days. Notes: the boxplots represent the multi-year distribution, and the shapes on the charts show the actual value for the typical weather year data.

Energy simulation of the residential building

This section seeks to investigate the impact of typical and actual weather years on the energy performance of the building. Figure 5 illustrates that the annual energy demand and peak energy demand computed using the actual weather year simulations fluctuate across a broad range, especially heating demand and peak. Thus, the heating demand distribution appears positively skewed, with the amplitude range between minimum and maximum values for heating demand being around 15 kWh/m². similarly, the distribution of cooling demand is skewed positively, ranging from 2.6 to 3.4 kWh/m².

The two typical weather years produce values close to one another and the median of the heating demand. However, the comparison of median values shows that TWY resulted in around 35% overestimated cooling load compared to the AWY.

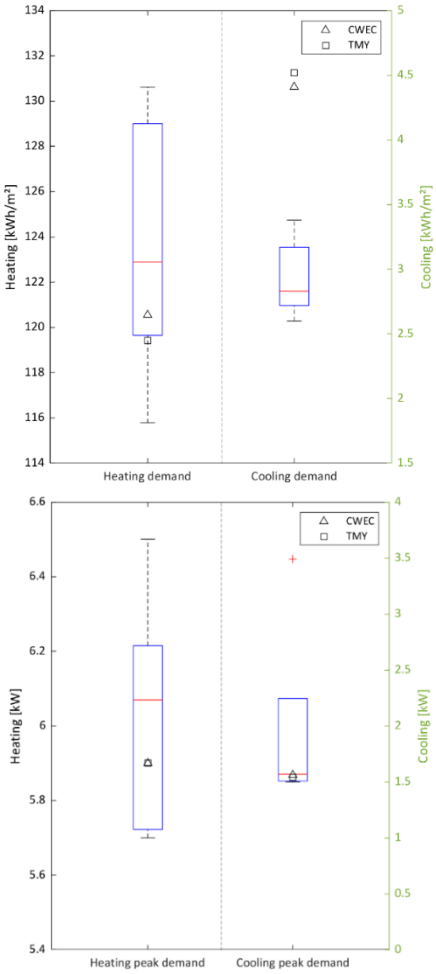

Figure 5: Heating and cooling loads and peak loads. Notes: the boxplots represent the multi-year distribution, and the shapes on the charts show the actual value for the typical weather year data.

The calculated heating demands using TWY fall in the interquartile range. Yet, there is a slight underestimation of approximately 2% when using TWY compared to the AWY. Figure 5 also shows that the two methods of typical weather years, CWEC and TMY, underestimate the heating peak loads by around 3 % of the median. Regarding the cooling peak load, CWEC and TMY weather data underestimate the peak loads by approximately -1%. Since mechanical systems must provide thermal comfort even in extreme weather conditions, these results suggest that using typical weather years might result in inappropriate heating and cooling equipment sizing. Figure 6 compares year-by-year fluctuations of the heating demand and the cooling demand, predicted by actual weather years' simulation against the predictions of two versions of typical weather years. Among actual weather years, 2019 has the highest heating demand of approximately 130 kWh/m², closely followed by 2018 with 128 kWh/m². The weather years 2017 and 2015 have similar heating demand of around 120 kWh/m², while 2016, with around 115 kWh/m², has the lowest. Typical weather years CWEC and TMY have similar heating energy consumptions of 120.6 kWh/m² and 119.4 kWh/m², respectively. Figure 6 also shows a considerable difference between cooling energy demand between two TWY and five AWY. Thus, the cooling needs of AWY range between 2.6 kWh/m² and 3.38 kWh/m², whereas they are 4.41 kWh/m² and 4.52 kWh/m² for CWEC and TMY, respectively.

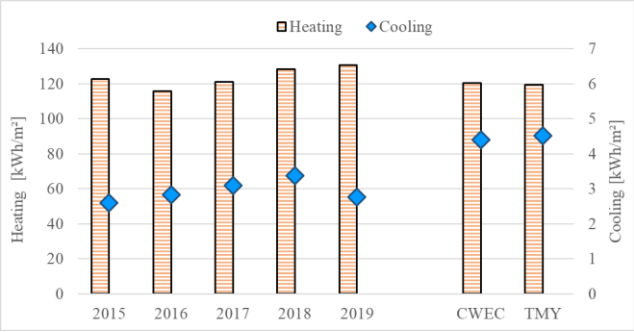

Figure 6: Year-by-year heating and cooling loads for five actual and two typical weather years.

Furthermore, Figure 7 shows the year-by-year variation for heating and cooling demands based on the multi-year simulation approach compared to single-year simulations. The percent variation is based on the average value of all AWYs from 2015 to 2019. Overall, the heating energy demand ranges from -6% in 2016 to 5% in 2019. The values calculated by the typical years approach were around 2% for CWEC and -3% for TMY. In contrast, the cooling load shows a significant variation compared to the mean of the multi-year simulation. Hence, CWEC and TMY overestimate the space cooling load by 50% and 54%, respectively. The likely explanation for differences in cooling energy demands between the weather years is a significantly higher wind speed (~70%) of five AWY than the two TWY (see Table 3). Similarly, because of the highest wind speed, 2015 has the lowest cooling demand among the five AWYs. Therefore, wind through the convection promotes heat dissipation from the house and reduces the cooling energy demand under AWYs compared to TWYs.

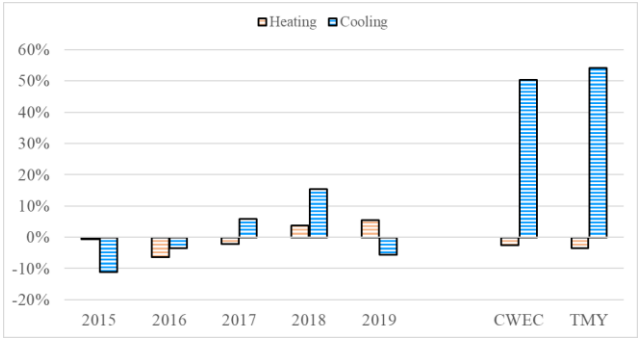

Figure 7: Year-by-year heating and cooling loads variation for five actual and two typical weather years.

However, to further investigate this assumption, we created two hypothetical typical weather files by replacing wind speeds in the CWEC and TMY files with the values from 2018. We selected 2018 due to its lower wind speed than other AWY (see Table 3). Figure 8 illustrates that an increase in the wind speed of hypothetical weather years resulted in an approximately 23% reduction of their cooling energy demands compared to their counterparts and almost equated to the cooling energy demand of 2018. In contrast, as expected, the heating energy demand for the hypothetical years slightly increased (≈2%). The higher indoor-outdoor temperature difference during winter could explain the more pronounced impact of wind speed on cooling than heating energy demand during the winter months, which is the primary driver of heat transfer.

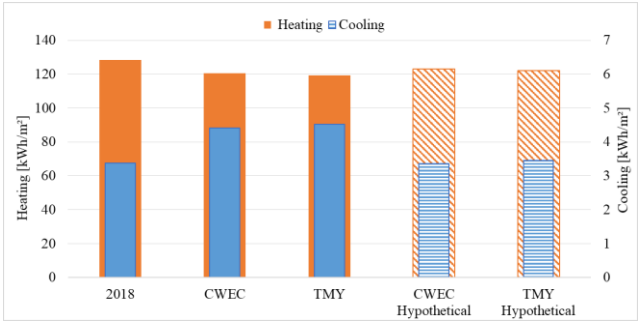

Figure 8: Year-by-year heating and cooling loads for 2018, two typical and two hypothetical weather years

Conclusions

This study investigated the impact of different weather data files on the energy predictions of the EnergyPlus energy simulation tool for a single-family house in Winnipeg, Manitoba. To explore and explain differences in energy predictions, we also analyzed variations in four main weather parameters, HDD and CDD. The annual variation between outdoor air temperature, relative humidity, and global horizontal irradiance was relatively low between the TWY and five AWY. For example, the percent difference between the mean values of these three environmental parameters ranged from 1.1% for the GHI to 4.31% for the dry-bulb air temperature. In contrast, TWY had approximately 70% lower annual average wind speed than AWY.

The findings also show significantly higher variation in cooling than heating energy predictions between the actual and typical weather years. Thus, CWEC and TMY predicted around 3% lower heating energy demand than the average of AWYs. On the other hand, two typical years calculated around 36% higher cooling energy demand than the AWYs' average. The discrepancy in the cooling predictions is due to the significantly lower wind velocities of TWY than AWY, which resulted in lower heat dissipation during the summer months.

Moreover, the results suggest that relying only on HDD and CDD to predict heating and cooling energy demand is inappropriate. For example, even though HDD and CDD of TMY are closer to the median of the five-year actual weather data than CWEC, the year-by-year analysis showed a more significant discrepancy between heating and cooling predictions of TMY and AWY compared to the CWEC. The difference was particularly notable for the projections of the cooling energy demand. These results are not surprising considering that the cooling energy demand calculations are inherently more complicated as they involve solving unsteady equations with unsteady boundary conditions and internal heat sources.

The findings from this study provide additional support that only the use of TWY is inappropriate for the sizing of the heating, cooling, and ventilation equipment. Therefore, using both actual weather years and typical weather years in building energy simulation should be a must to estimate peak heating and cooling load and annual energy demand. Furthermore, the observations of the year-by-year variation in energy demand indicate that a single value could not adequately reflect the energy performance of the single-family house. Consequently, the building's energy demand prediction should be a range of values derived from running the model using multi-year weather data. Further research should investigate the implications of different weather files on the energy predictions of more complex commercial and institutional buildings exposed to cold climates. Additional studies should examine the impact on buildings with different envelope types, including enclosures with high thermal mass. Future research should also investigate the effects of weather files on heating and cooling energy predictions generated using other building performance simulation tools such as TRNSYS and IES.

Acknowledgement

The authors gratefully acknowledge the financial support received from the Natural Sciences and Engineering Council of Canada (NSERC).

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