Is Typical Year weather data still appropriate for Building Energy Simulation? A comparative analysis on the traditional practice of using Typical Year weather data and a modern approach in using Historical weather data in Building Energy Simulation

by

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Is Typical Year weather data still appropriate for Building Energy Simulation? A comparative analysis on the traditional practice of using Typical Year weather data and a modern approach in using Historical weather data in Building Energy Simulation

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Abstract

This research compares the use of Typical Year weather files (CWEC1990s and 2016) and Multi-Year Historical weather data (CWEEDs1998 to 2014) in Building Energy Simulation. The analysis is comprised of several components: 1) a statistical analysis on the raw weather elements - differences in the cumulative distribution of key weather elements, and relevant weather indices are compared; 2) analysis on the differences in heating and cooling energy estimations; 3) analysis on the impact of the staggered update cycles between weather data used for equipment sizing and simulation. Computer scripts created to automate tasks related to multi-year simulation are also presented. It is found that critical insights are missing when Typical Year weather files are used for simulations. Simulation with Multi-Year Historical data shows potential as a reasonable alternative, since they can be updated more frequently and contain a wider range of conditions. Repetitive tasks can also be automated with scripts.

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Chapter 1 Introduction - Building Energy Simulation and Limitations of Conventional Practices

Purpose of Building Energy Simulation (BES)

The purpose of Building Energy Simulation(BES) is to estimate potential energy usage of buildings based on a set of known parameters - this includes a set of physical building attributes such as building envelope design as well as systems design(HVAC and Lighting); and the expected operating(occupancy behavior) and environmental conditions(climate data)[1]. The current realistic goal of simulation in the industry is to provide a quantifiable way in comparing building designs under different environmental and operating conditions. While many designers rely on results of BES to justify design decisions, a full understanding in the underlying intricacy of the simulation packages is often lacking and hence not realizing the limitations of BES models.

The need for simplified simulation practices

One of the most overlooked components in BES is the basic input parameters. Most popular simulation packages used in the industry are optimized to minimize computing time, which was necessary when computing power was limited. To minimize computing time, simplifications are made on both the algorithm used for simulation and input parameters. For instance, conductive heat transfer through the building envelope - fundamental to the heat balance of the building envelope is often simplified as a transfer function using response factors as it is with Energy Plus [2]. As a consequence, the properties of building materials can only be constant to make the calculation of response factor possible, there are also limitations on the minimum simulation time step(1/4 hour time-step for energy plus) [2]. Similarly, the use of Typical Year (TY) weather files also comes from a need for simplification, old weather data were stored on tape, where gaining access to large quantities of weather data can be laborious and expensive[3].

Pushing the limits

With advancement in technology, especially the enhanced accessibility to computing power and data storage, hurdles of implementing better practices is increasingly lowered. This research has a special interest on weather data used for simulation, since the practices in acquiring and applying weather data are often influenced by technological limitations: from raw weather data collection - measured solar radiation data is hard to obtain on a large scale, therefore satellite based data is used[4]; long term data storage and data transfer to users - historical weather data are traditionally stored on tapes or other physical media until recent online database developments[3]; to the user's application – equipment is simulated at hourly time step mainly because only hourly weather data is readily available[3]. The main goal of this research is to review conventional practices related to the use of weather data in BES and determine whether there are better alternatives given the current state of availability in data access and computing power.

Context in Toronto

This research also has a focus in Toronto, Canada. This is because the population of the city and its surrounding area have been growing rapidly[5]. The population in the Greater Toronto Area is projected to grow from 6.8 million in 2018 to 10.2 million by 2046 [6]. In addition, there is indication that the surrounding "Golden Horseshoe" area will undergo further development and many building will need to be constructed [7]. While there are a lot of cities around the world undergoing rapid development, an unique challenge for Toronto and its surround cities relates to the power supply mix. In 2014, the Government of Ontario shut down the operation of all coal fired power plants, while this is generally regarded as a good policy in reducing carbon emissions, the province currently gets about 60% of its power from nuclear power generation[8]. The unique challenge at hand is the planned decommissioning of the Pickering nuclear power plant in 2028 (production stops in 2024), which currently provides about 14% of the province's electricity capacity[9]. There is also indication of a growing demand for air conditioning, in which the percentage of household with air conditioning in Toronto has grown from 81% in 2011 to 88% in 2017[10]. With an increasing demand from population growth and a reduction in electrical power supply, a good understanding of the energy usage of buildings in different weather conditions is important in preventing disastrous events such as the 2003 East Coast blackout[11], since a considerable amount of energy is used for heating and cooling.

Goal of this study

The goal of this research is to examine the practice of using Typical Year and multi Historical Year weather data in Building Energy Simulation (BES). The structure of this thesis is as follow: Chapter 2 investigates changes in relevant weather elements through statistical analysis, as well as examining the changing long term weather conditions through comparison of temperature-based weather indices; Chapter 3 analyzes the use of Typical Year and Historical Year weather files in BES for annual heating and cooling energy estimations; Chapter 4 explores the impact of the different update cycle between design weather data used for equipment sizing and simulation weather data used for simulation; Chapter 5 presents computer scripts that are created to aid the completion of this research, to highlight the progression in technology and programming literacy; Chapter 6 discusses limitation and future work; and Chapter 7 concludes this research.

Chapter 2 Conventional Practice in Creating and Using Typical Year Weather Files

2.1 Introduction

2.1.1 - The purpose and logic of Typical Year weather files

The creation of Typical Year type weather files originates from the need for a standardized weather file format for energy calculation during the 1970s, the main purpose was to aid design of solar energy systems[12]. The basic logic of Typical Year weather file is to represent the most "typical" climatic conditions with an assembly of 12 representative calendar months, where each representative month is selected from historical weather data[12][13][14]. The first Typical Year type weather file is the Typical Meteorological Year (TMY) weather files created from a research project organized by the US Department of Energy in 1981[12]. It is created using a selection method developed by the Sandia Laboratories based on Finkelstein-Schafer(F-S) Statistics[12]. The same method(or variations of the method) is still being used to create TY type weather files - including TMY[12], TMY2[13], TMY3[14] and CWEC[15].

2.1.2 -The Sandia Method

As mentioned, typical weather files are assembled with 12 representative months selected from historical weather data, usually with 10 to 30 years of the most recently available data[12]-[15]. One of the earliest challenges, as outlined in the original TMY manual[12] is how to define and select the most "typical" climatic conditions. To provide coherent meaning and process in creating Typical Year weather files, the Sandia method was developed [12]. The Sandia Method is a two-stage empirical selection method based on F-S statistics, the idea is to ensure the typical-ness of the Typical Year on a month to month basis, by selecting a representative month for each calendar month[12]-[15].

The first stage of the Sandia method is the selection of candidate months, in which cumulative distribution of the daily averages of relevant weather elements are compared with the cumulative distribution of the long-term mean. Since not all weather elements in the weather dataset have equal influence on simulation, weather elements are assigned a weight factor reflecting its relative importance. The "closeness" of candidate months is evaluated based on the weighted F-S score calculated[12]-[15].

The second stage of the Sandia method is elimination based on predefined persistence criteria. The goal of this stage is to eliminate candidate months containing weather extremities. For instance, months with longest runs, most runs and zero runs of atypical weather conditions(dry bulb temperature and global horizontal irradiation above a certain critical percentile), as well as times being affected with abnormal events such as the volcanic eruptions in Mexico in 1982 and in the Philippines in 1991 are also eliminated from selection [14]. The remaining months with the most favorable F-S score are selected as the representative months. To assemble the typical year, the 12 representative months are put together, and the transition period between the representative months are smoothened [12]-[15].

2.1.3 - Available weather data for Building Energy Simulation in Canada:

In Canada, thanks to the effort of Environment and Climate Change Canada, there is an extensive, publicly available database of weather data for energy calculations[16]. CWEEDs (Canadian Weather Energy and Engineering Datasets) refers to the Historical Year weather dataset and CWEC (Canadian Weather for Energy Calculations) refers to the Typical Year weather files[15]. There are three releases of CWEEDS- 1990s, 2005 and 2016, and two versions of CWEC - 1990s and 2016[15]. In theory, there is ample of historical weather data available, as there is access to historical data in Canada from 1953 to 2016 as indicated in [15] and [17], however in practice, the results of simulation using weather data collected in different eras are generally not recommended to be compared directly. The main issue when using vintage weather data is the methodology and instruments of weather data collection have progressed significantly, especially with the estimation of solar radiation. In order to conduct a fair analysis on changes of long-term weather conditions, one must first understand the continuous progression in weather data collection.

2.1.4 - Progression of weather data collection:

It should not be a surprise that technology/technique used in weather data collection and estimation have progressed in the past couple of decades. The purpose of this section is to highlight some major changes that are relevant to weather data used in building energy simulation.

Solar Radiation Measurement and Estimation

Solar radiation data is one of the most complicated weather elements to measure. The biggest challenge is to maintain quality measurements with consistency over long periods of time. Early solar radiation data is mainly obtained through direct ground-based measurements, this remains one of the most trusted methods today and used to verify satellite based estimations [4]. The challenge in obtaining direct ground-based measurements is the amount of resources required to maintain and operate the instruments, limiting the number of instruments that can actually be deployed [4]. Having the need to expand coverage, since vast spatial coverage is key in climate related research and in practical application such as sizing of solar panels and building design, models are developed to estimate solar radiation through cloud coverage/minutes of sun records – also known as ground based models [18][19]. The assessment of cloud coverage can be achieved two ways – human observation or ground based instruments [19]. The application of these solar radiation estimation models using ground based cloud observation fostered the expansion of the number of weather stations in North America, for example, in the first release of the National Solar Radiation Database in the United States, only 56 out of 239 weather stations have measured solar radiation data, other stations have estimated solar radiation based on cloud coverage record[18]. Similarly, in Canada the MAC 3 model developed by researchers at McMaster University is used to estimate solar radiation data used in CWEC 1990s for most weather stations, in fact, the MAC 3 model is still being used today for remote locations that are above 58 degrees north in latitude above the equator [20].

While ground based solar radiation models are sufficient in providing reasonable estimates of solar radiation, there are inherent biases that affects the overall consistency of measurements between different locations[19]. In addition, since ground based observation/measurements also requires staff maintenance and operation, there are still resource limitations on broader adaptation[4]. The full discussion on the comparison with direct ground based measurements and biases of human/instrument assessment of cloud condition is complex, and is more thoroughly addressed by experts on the topic, their findings are well discussed in [18] and [19].

To overcome the limitations of ground based solar radiation models, modern solar radiation estimations are based on models using data collected from satellite images [4][20]. In the US (also with coverage of most of North America), the National Solar Radiation database is the main source of satellite based solar radiation data[4]. In Canada, locations that are south of 58 degrees N in latitude uses SUNY solar radiation model[15]. In general, when compared with MAC3 based estimations, the SUNY solar radiation yields similar estimates of Global Horizontal Irradiance and more accurate Direct Normal Irradiance[20].

Manual to Automated systems

The implementation of modern automated weather data collection system occurred between the 1980s and 1990s [21]. One of the main changes in the automated systems is switching to time averaged based readings from instantaneous readings [19]. For instance, temperature readings at the hour is actually the 5 minute average temperature leading to the end of hour, rather than an instantaneous reading [19]. To preserve the long term integrity of weather data, some reference stations have both manual and automated systems operating closely with each other, in which the differences on the readings are being monitored and evaluated, the expectations on error and associated corrections are detailed in [19], [21] and [22]. In Toronto, Mohsin and Gough [23] completed a study in analyzing long term temperature changes, they verified based on statistical analysis of temperature data collected at weather stations across the GTA area between 1970 and 2000 that the influence from instrumental and practice changes is small(except for the Toronto Island). For the purpose of this research, it is assumed that effects of the mentioned instrumental/practice changes are small, and adjustments are made prior to the publication of the weather datasets.

2.1.5 - Progression of weather file development:

In addition to the progression in weather data collection, there also have been changes in the selection of weather data for the development of Typical Year weather files. More specifically, the weighting criteria for the selection of candidate months and the persistence criteria. Changes in the US and in Canada are also slightly different.

In the US, there has been 3 updates of the typical year weather file selection method - the original TMY released in 1981[12]; TMY2 released in 1996 [13]; and the TMY3 released in 2008 [14]. In terms of weighting used in the selection of candidate months, weight factors for solar radiation is more favored in TMY2 and TMY3 as more solar radiation elements were introduced in those weather files[13][14]. During the creation of TMY3 weather files, newer weather stations with less historical data collection were added, the selection range went from 30 years to an average of 15 years (some locations with only 10 years of weather data were also included), to accommodate the inclusion of newer weather stations, the persistence criteria is relaxed/simplified in the TMY 3 selection [14].

In Canada, because the creation of the first set of CWEC weather files is close to the creation of the TMY2 weather files, the weight factors used in CWEC 1990s and CWEC 2016 are the same[15]. Similar to the transition between TMY 2 and TMY 3, the persistence criteria in CWEC 2016 is relaxed/simplified to accommodate the inclusion of new weather stations with less historical weather data collection [15]. Table 2-1 summarizes differences between CWEC 1990s, CWEC 2016 and CWEEDs Historical weather data.

Table 2-1 Differences between CWEC 1990s, CWEC 2016 and CWEEDs Historical weather data

Weather Data Name/Data Type	Years Covered	# of Sites	Gap Filled?
CWEC 1990s (Typical)	Ranges from 1953 to 1989 (Depends on site)	75	Yes
CWEEDS 2005 (Historical)	Ranges from 1953 to 2005 (Depends on site)	145	Gap filled for sites included in CWEC 1990s from1953 to 1989; not filled for the newer weather data.
CWEC 2016 (Typical)	Depending on Site - Ranges from 1998 to 2014	492	Yes
CWEEDS 2016 (Historical)	Depending on Site - Ranges from 1998 to 2014	492	Yes

2.1.6 - Limitations of Typical Year weather files:

The limitations of Typical Year weather files lie within its foundation. First, the compilation of Typical Year is based on statistical selection of the most median weather conditions by excluding “outliers” based on predefined criteria, which may not be a good representation of the full range of actual weather conditions available in historical weather data. This may affect building design validation, where designers desire to evaluate building performance under more extreme conditions. Further, Typical Year weather file represents a predefined range of historical weather data, which the infrequent update cycle may affect its ability to sufficiently reflect changes in the overall long-term weather conditions, influenced by factors such as global climate change. This may affect the prediction of heating and cooling energy usage, since equipment operation is highly dependent on outdoor temperature.

2.1.7 - Climate change and monitoring work using weather indices in Canada:

It is generally accepted by academia, and the extended scientific community that climate is changing on a global scale[24]. While the average temperature is rising in a relatively gradual pace, it is believed that the occurrence of extreme heat events such as heat waves will very likely increase, with greater intensity and longer lengths[25]. In fact, different parts of the world have already been affected, such as Europe[26][27], Eastern China[28], and Eastern Canada[29].

One of the methods used in monitoring/analyzing the impact of global climate change is the use of weather indices. Unlike general statistical analysis, weather indices are indicators set to quantify and reflect the impact of climate change to local habitat and inhabitants, especially in relation to more extreme weather events[30]. The global development of weather indices began after an international meeting on Climate Change Detection in 1998, and it is considered to be more appropriate in monitoring impact of global climate change, since they are usually developed with implication of local context [30]. In Canada, the monitoring of climate change using weather indices is a continuous effort by Environment and Climate Change Canada, where studies have been completed to understand the impact of Global Climate Change on a regional scale [31][32].

2.2 Research Questions:

1) **What are the changes in long term weather conditions in Toronto, between the two updates of the CWEC weather files?**

   Between the two updates of CWEC weather files, there is a two-decade time gap, in which climate has changed at a global scale. The goal of this research question is to explore the differences between the two Typical Year weather files – CWEC 1990s and CWEC 2016.

2) **Is Typical Year weather file a good representation of historical conditions?**

   Typical Year weather file is a subset of a predefined range of historical weather conditions. The goal of this research question aims to explore if there are insights missing from the singular representation of Typical Year weather file.

2.3 Methodology

2.3.1 - Weather files compared

Typical and Historical Year weather files will be compared in this chapter. Two Typical Year weather files are compared – CWEC 1990s and CWEC 2016. CWEC 1990s is obtained from the EnergyPlus weather database[33]; whereas CWEC 2016 is obtained from the Environment and Climate Change Canada website [16]. The Historical Year weather data CWEEDs from 1998 to 2014 is also obtained from the Environment and Climate Change Canada website [16].

2.3.2 - Extracting weather data from CWEEDs weather files

The original CWEEDs weather files are in WYEC 3 file format, which is an old fixed width format developed by ASHRAE [34]. In order to extract relevant weather data and organize into a simulation compatible format, a custom script is written using MATLAB 2019[35]. The fixed width format is detailed in the CWEEDs technical documentation[15] and the main purpose of the script was to find relevant data in the right position, extract data, convert data into proper units/formats then export into the simulation compatible epw format [36]. A thorough description of the weather converter script is discussed in Chapter 5.

2.3.3 - Relevant Weather Elements

As shown in the Sandia selection method, not all weather elements have the same weighting, the weight factor is decided based on its relevance towards application, for example, the original application for typical year weather files is for solar system simulation[12]. In this analysis, only dry bulb temperature and global horizontal irradiance are analyzed, since their combined weight factor used in the generation of CWEC weather files is 80% [15].

To analyze change in the relevant weather elements, two comparisons are made. First, is a simple graphical comparison of hourly weather elements (dry bulb temperature and global horizontal irradiation) between the typical and historical weather data. The main goal is to determine whether there are differences in the overall distribution of weather data over a time range, as this can give a sense of when they are different. Second, is the comparison of the cumulative distribution of hourly weather elements (also with dry bulb temperature and global horizontal irradiation). The focus is to analyze the statistical distribution of the elements, this is important as there is a strong relation between the estimation of total energy usage and the distribution of the individual hourly readings of weather elements.

2.3.4 - Relevant Weather Indices

While the previous section focuses on the overall distribution of weather data, in which they are more relevant to the influence on the estimation of annual energy usage. Comparisons made in this section focuses on the occurrence of the more "extreme" weather events, which overall has greater impact on inhabitants.

In this study, a modified version of the weather indices defined by Environment and Climate Change Canada [32] is used to analyze changes in the occurrence of extreme weather events between typical and historical weather data. The modifications are necessary for this study for practical reasons. First, some of the original weather indices are calculated on a seasonal basis, and since the CWEC typical year and CWEEDs historical data are organized in a yearly format, a direct comparison will not be possible without adjustments. For example, the calculation of weather indices related to extreme cold - such as cold days, frost days, and freezing days are calculated based on the temperature records from the winter season, which spans continuously from December to February. Since typical year weather files only include weather data of one year, it is not possible to use the same method to extract a winter season continuously. Rather, the calculation will be based on winter months of the same year - January, February and December. Table 2-2 summarizes the indices used in this study.

Table 2-2 Modified weather indices used in this study

Condition	Indices	Definition
Warm	Summer Days	Number of Days with Daily Maximum Temperature above 25C - All Year
	Hot Days	Number of Days with Daily Maximum Temperature above 30C - All Year
	Hot Nights	Number of Days with Daily Minimum Temperature above 22C - All Year
	Daily Max Temperature - 95th Percentile	95th Percentile of Daily Maximum Temperature -All Year
	Daily Min Temperature - 95th Percentile	95th Percentile of Daily Minimum Temperature -All Year
Cold	Frost Days	Number of Days with Daily Minimum Temperature below or equal to 0C - All Year
	Ice Days	Number of Days with Daily Maximum Temperature below or equal to 0C - All Year
	Daily Max Temperature - 5th Percentile	5th Percentile of Daily Maximum Temperature -All Year
	Daily Min Temperature - 5th Percentile	5th Percentile of Daily Minimum Temperature -All Year
Degree Days	Cooling Degree Days	Sum of degrees when Daily Mean Temperature is above 18 C - All Year
	Heating Degree Days	Sum of degrees when Daily Mean Temperature is below 18 C - All Year

2.4 Results and Discussion

2.4.1 - Relevant Weather Statistics

Statistical Analysis

To gain a sense of how weather data is distributed historically, both dry bulb temperature and global horizontal solar radiation are graphed as shown in Figures 2-1 and 2-2. Aside from the yearly cyclical variations due to changes in season, it is hard to notice the yearly differences. For instance, by looking at the historical graph, one would not observe a noticeable increase in temperature. The global horizontal radiation data also don’t show noticeable changes, other than a short sudden spike in 2014 as seen in Figure 2-2.

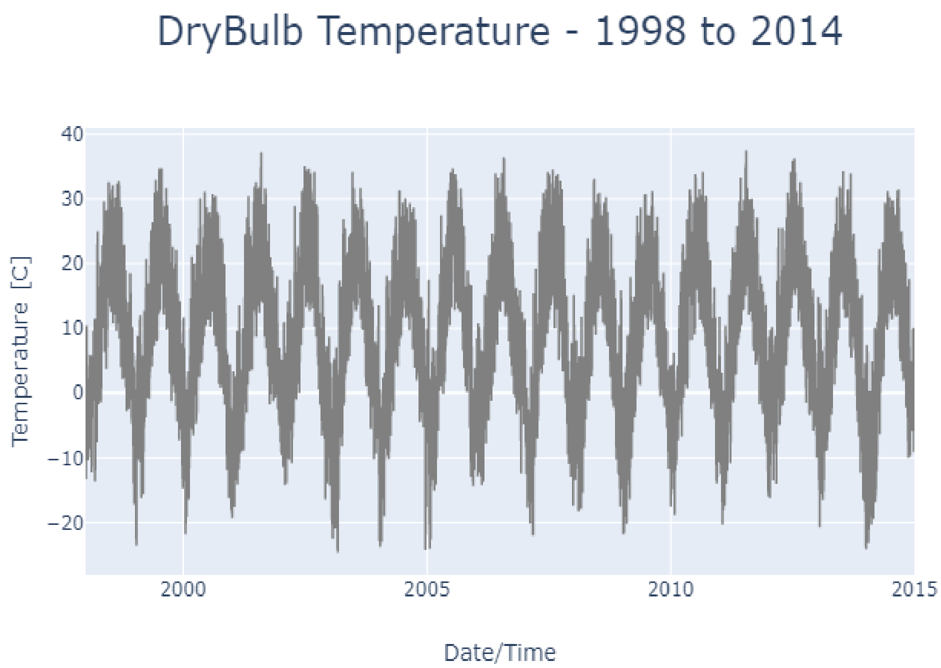


Figure 2-1 Distribution of Dry Bulb Temperature (in Years)

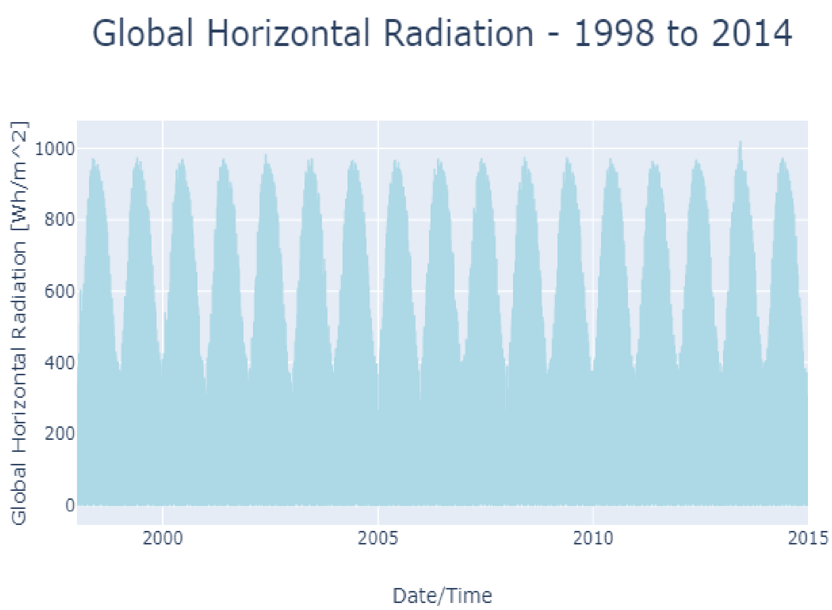


Figure 2-2 Distribution of Global Horizontal Irradiation (in Years)

To further focus on the differences in yearly data, weather data is organized in an hourly format, where the x-axis is the hour of the year. For normal years, weather data is graphed from hour 0 to hour 8760; whereas for leap years, data is graphed from hour 0 to hour 8784 as shown in Figures 2-3 and 2-4. Weather data from Typical years - CWEC 1990s and CWEC 2016 were also plotted onto the graphs, so comparisons can be drawn between Typical and Historical weather data. From the dry-bulb temperature graph, it is observed that there are larger differences in maximum and minimum temperature during winter months, whereas in the summer months the difference seems to be smaller from observation. When comparing the two typical weather files, CWEC 2016(in red) seems to have higher temperatures, especially during the summer months. When comparing typical with historical, there are no noticeable differences other than the extremities, especially during the winter months. For global horizontal solar radiation, there are no observable differences, most of the solar radiation data seems to follow the historical distributions.

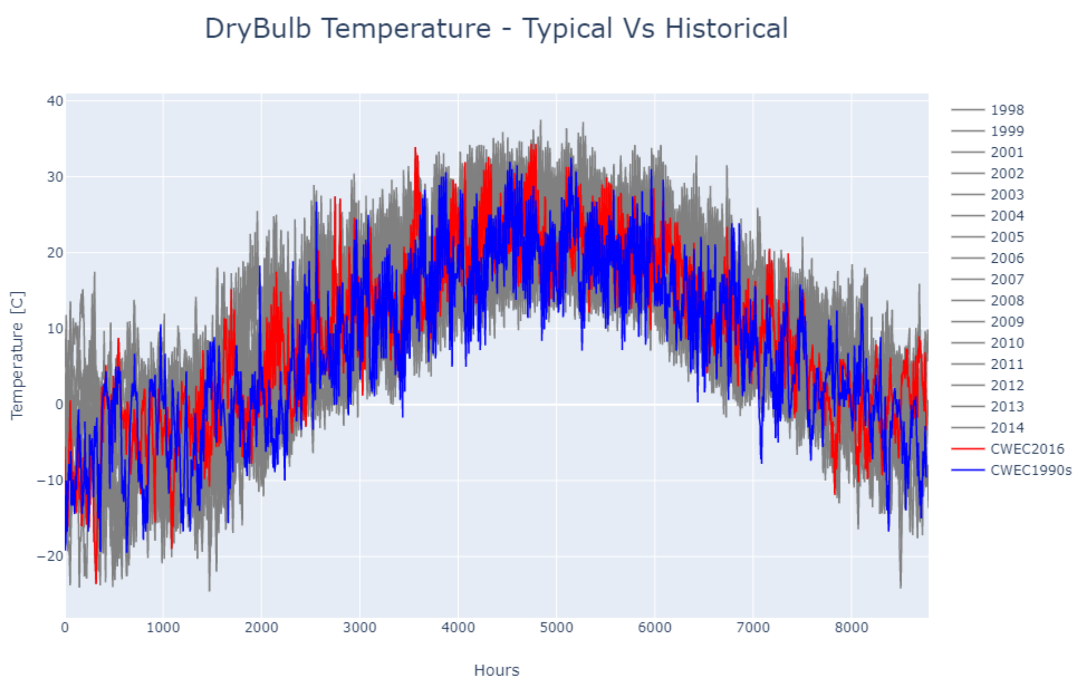


Figure 2-3 Dry-Bulb Temperature (Hourly) - Typical Vs Historical

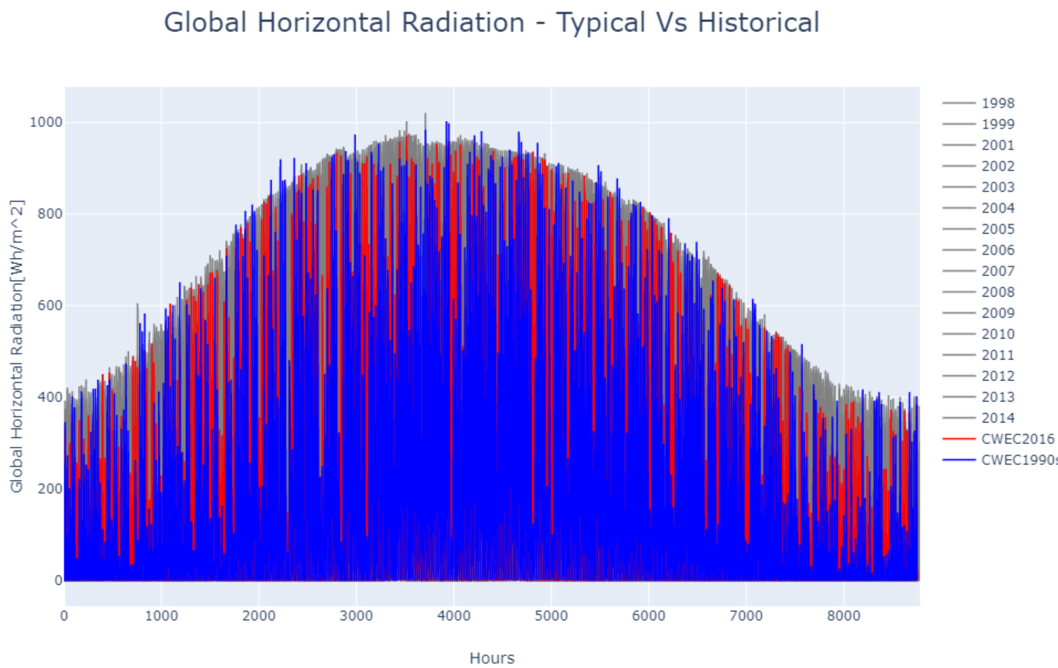


Figure 2-4 Global Horizontal Radiation (Hourly) - Typical Vs Historical

CDF Comparison

Winter Months (Heating Season) - January, February and December

During the winter months (shown in Figure 2-5), median temperature increased, ranging from 0.9 ^{o}C to 3 ^{o}C. In December, the overall distribution of dry bulb temperature shifted towards higher temperature, signifying a warmer December in CWEC 2016. The distribution in February has a steeper slope in CWEC 2016, this may indicate a moderation in temperature, since more temperature is now above -10 C. In January, the distributions of dry bulb temperature between CWEC 1990s and CWEC 2016 are similar. In terms of global horizontal irradiance, distribution in the sub-200 WH/m^2 range tend to be different – the distribution of CWEC 1990s have more hourly records in the lower end of the sub-200 WH/m^2 range, as indicated by the more rapid increase in slope on the lower end; the distribution of CWEC 2016 is more evenly distributed on the lower end, as the distribution in that range resemble a straight line; the two distribution eventually converges in all winter months.

Summer Months (Cooling Season) - June, July and August

During summer months (shown in Figure 2-6), temperatures of all CDF indicators (median, 75th percentile and 95th percentile) have increased in CWEC 2016, indicating a hotter summer season. Maximum temperatures in June and July have increased as indicated by the shift at the higher end of the distribution and the minimum temperatures have also increased for all months. The distribution of global horizontal radiation is very similar between CWEC 2016 and CWEC 1990s.

Spring Months (Shoulder Season) - March, April and May

During spring months (shown in Figure 2-7), there is also increase in all percentiles (50th, 75th and 95th) for dry bulb temperature. In March, the distribution of CWEC 1990s is generally similar to the distribution of CWEC 2016 in the Sub – 0 °C range; between 0 °C to 10 °C the slope of the distribution of CWEC 1990s is steeper, indicating that more hourly records are in the lower end of that range; the distribution of CWEC 2016 is slightly more evenly distributed in 0 °C to 10 °C range, but the higher end extends further, indicating higher maximum dry bulb temperatures. In April, there is a shift in the temperature CDF in the lower end for CWEC 2016, indicating an increase in minimum temperature.

Fall Months (Shoulder Season) - September, October and November

During fall months (shown in Figure 2-8), in September, the temperatures at the 50th and 75th percentiles increased, where there is a slight decrease in the 95th percentile. In October, there is a significant increase in minimum temperature from in CWEC 2016, and most of the lower end temperatures in CWEC 2016 are concentrated in the 0 °C to 10 °C range, the two distribution eventually meets at about 10°C and have similar distributions beyond that range. In November, the two distributions are similar, except for the slight shift of minimum temperature in November. In terms of global horizontal radiation, the distribution in both September and October are similar. In November, more hourly records are in the sub 200 WH/m^2 range.

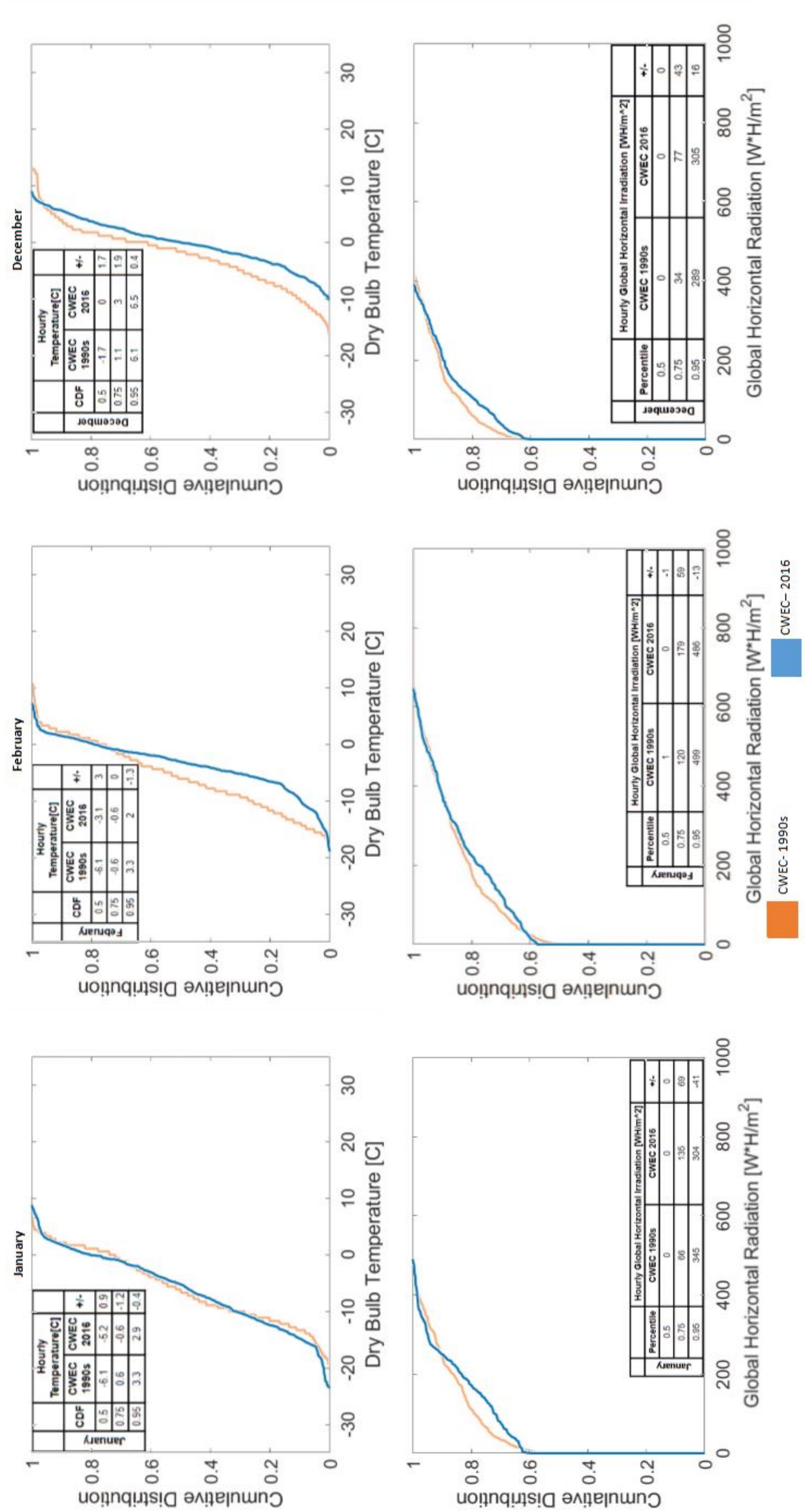


Figure 2-5 CDF of Winter Months (January, February, December)

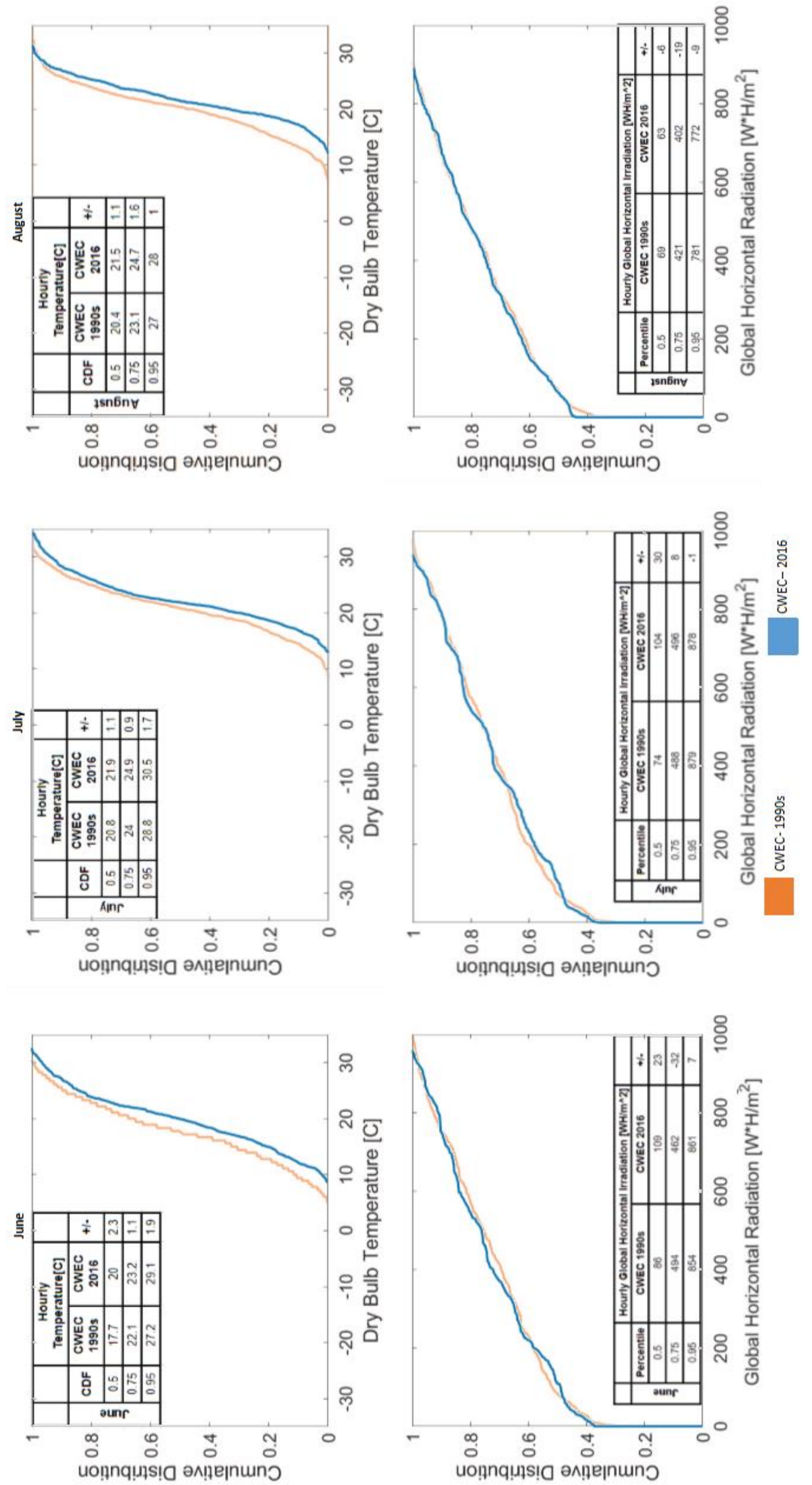


Figure 2-6 CDF of Summer Months (June, July and August)

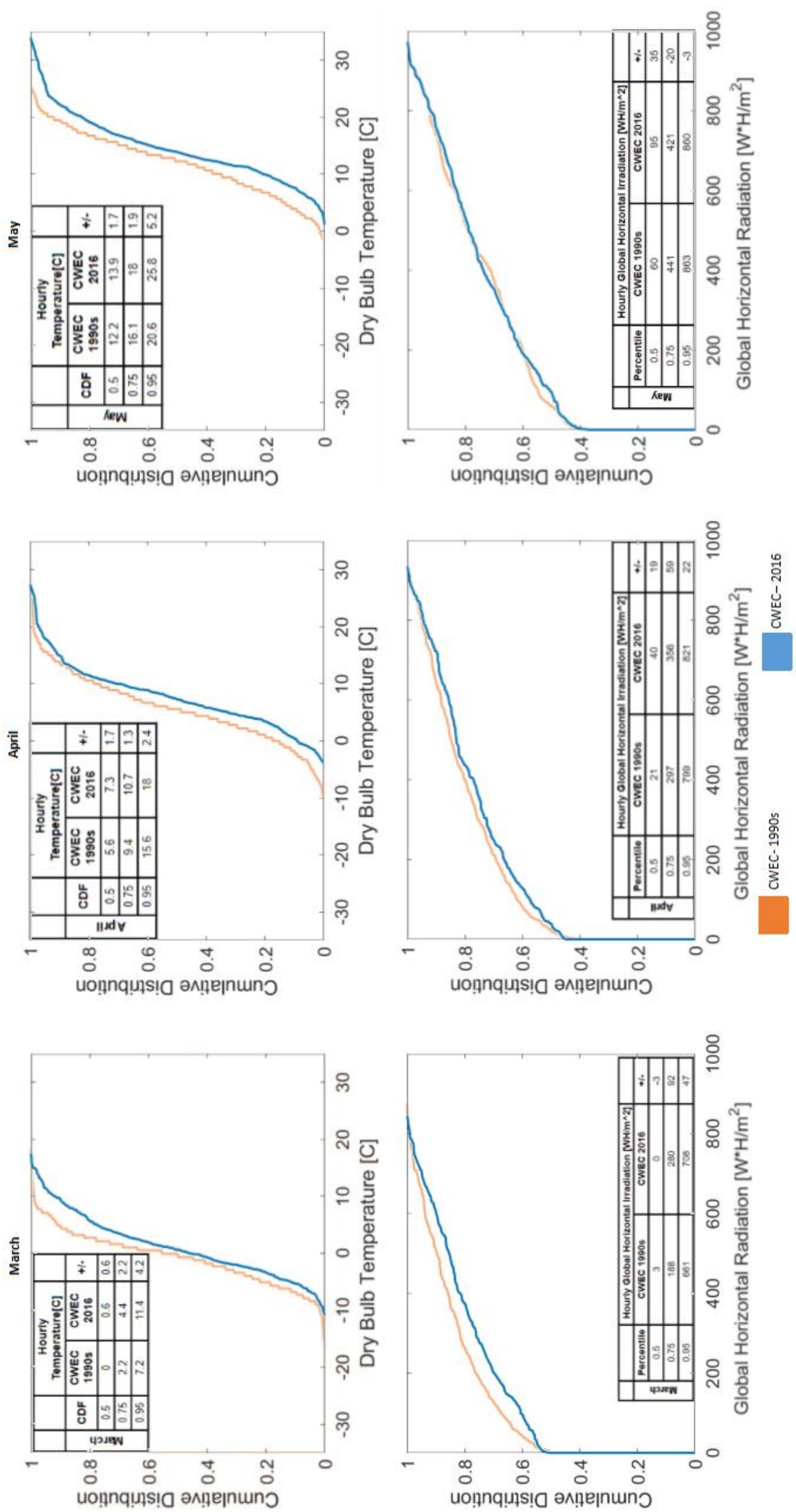


Figure 2-7 CDF of Spring Months (March, April, May)

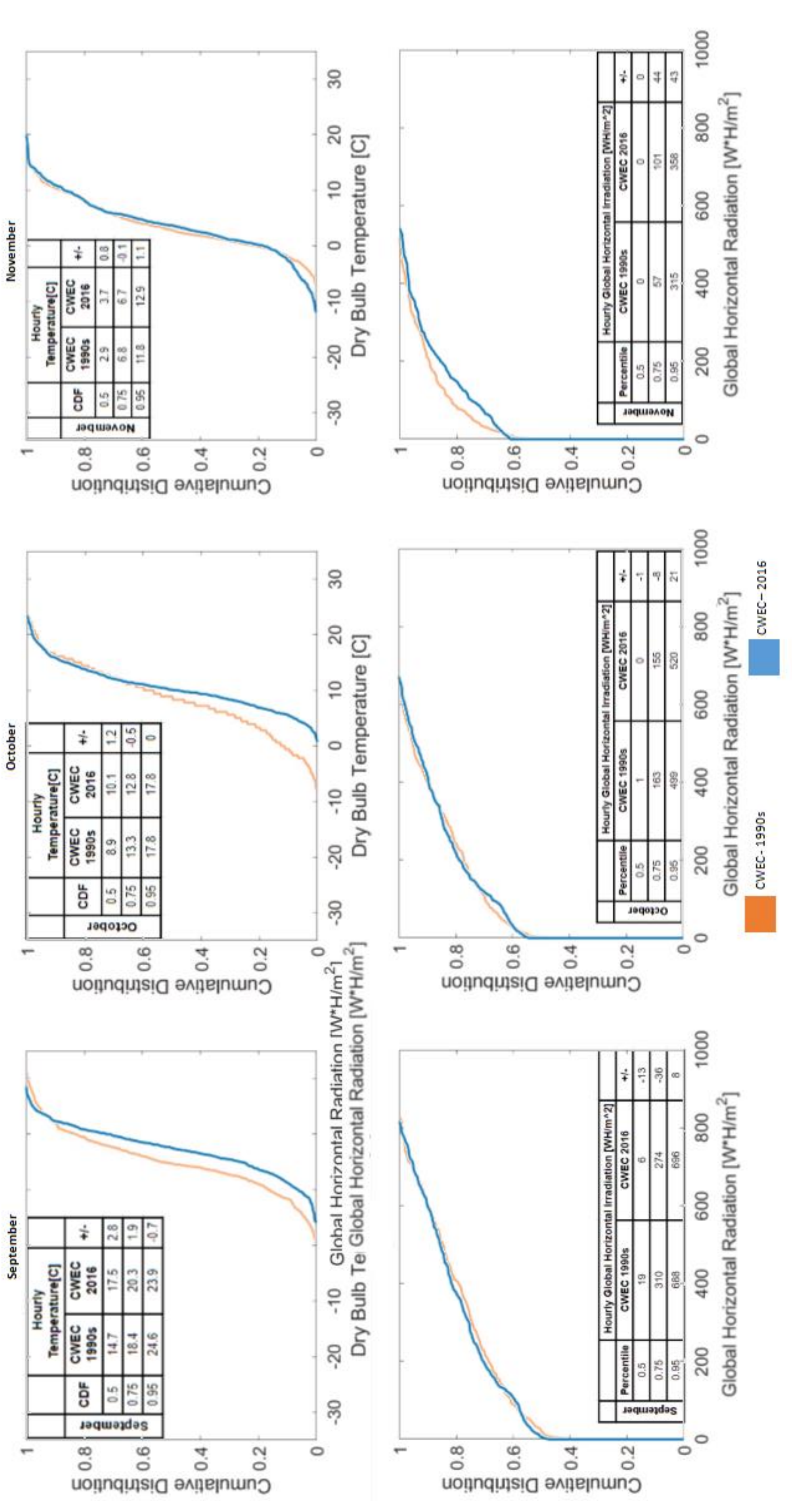


Figure 2-8 CDF of Fall Months (September, October, November)

2.4.2 - Relevant Weather Indices

Daily Maximum and Minimum Temperature (1998 to 2014)

Figure 2-9 shows the 95th and 5th percentile of the daily maximum and minimum temperature in different historical years from 1998 to 2014. As seen in the figure, there is year to year fluctuation in the temperature representing the indicated percentiles. The fluctuation in the 5th percentiles (for both maximum and minimum) seems to be greater than the 95th percentile. This may indicate that the year to year fluctuation effect have more influence on the temperature readings on the lower end of temperature spectrum, and an indication that there is more fluctuation in the occurrence of extreme cold temperatures when compared to higher temperatures

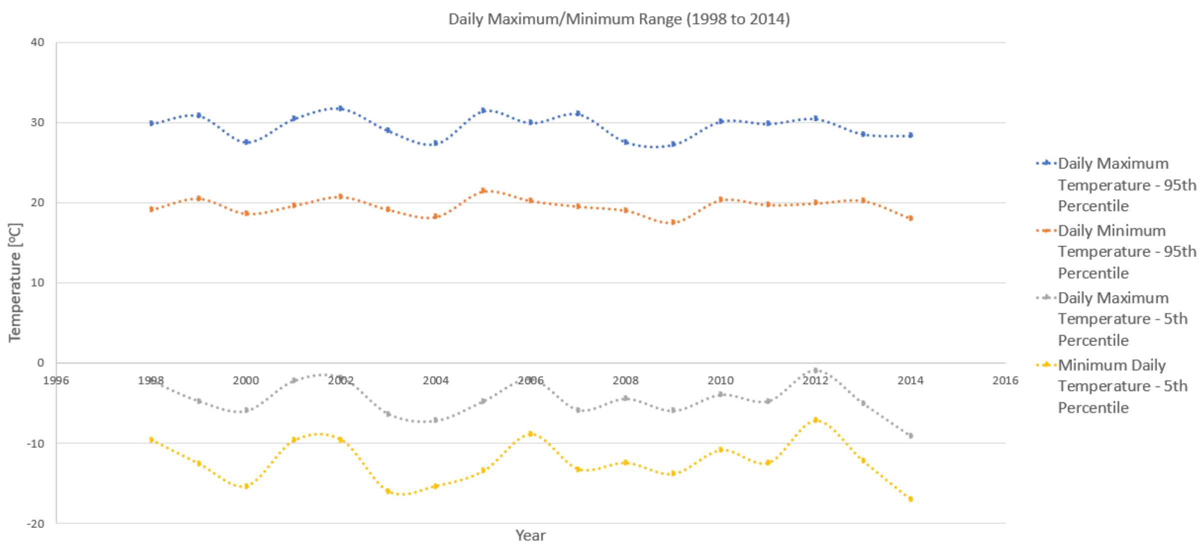


Figure 2-9 Historical Years(1998 to 2014) - 95th and 5th percentile of daily maximum and minimum temperature

Summer and Winter Characterization

The Summer and Winter characterization shows the number of days that meets the criteria for the relative "extreme" conditions. As seen in the Figures 2-10 and 2-11, there are more days meeting the winter extreme conditions than summer extreme conditions in Toronto. The numbers for both summer and winter "extreme" days fluctuate from year to year.

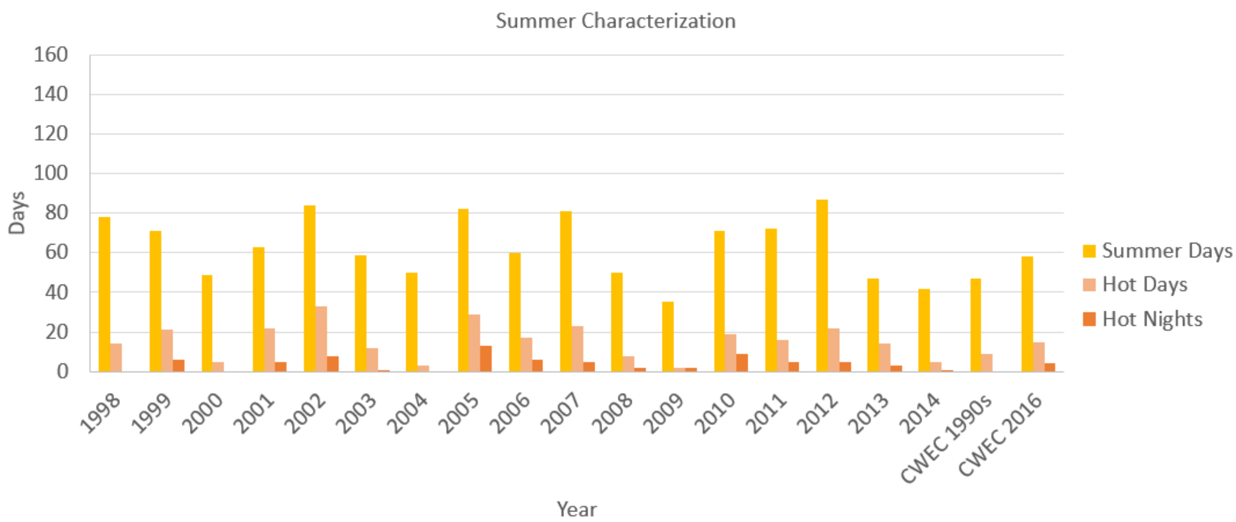


Figure 2-10 Weather Indices - Summer Characterization

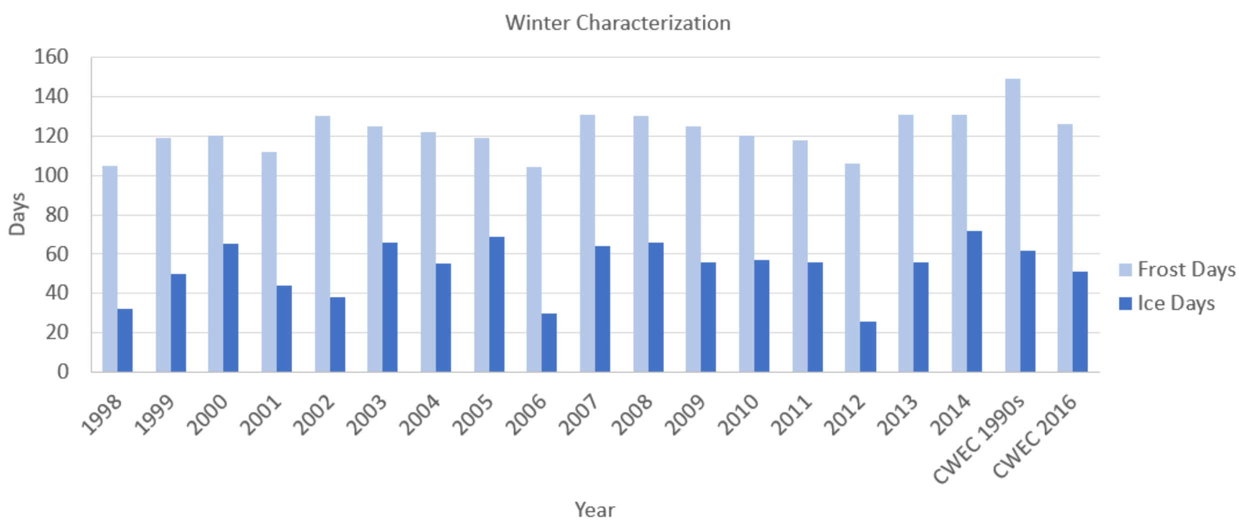


Figure 2-11Weather Indices - Winter Characterization

Heating and Cooling Degree Days (1998 to 2014)

Figure 2-12 shows the number of heating and cooling degree days from 1998 to 2014. As shown, most years fall well within the Zone 5 characterization with 3000 to 400 heating degree days[37], except for 2014, where it is only slightly above.

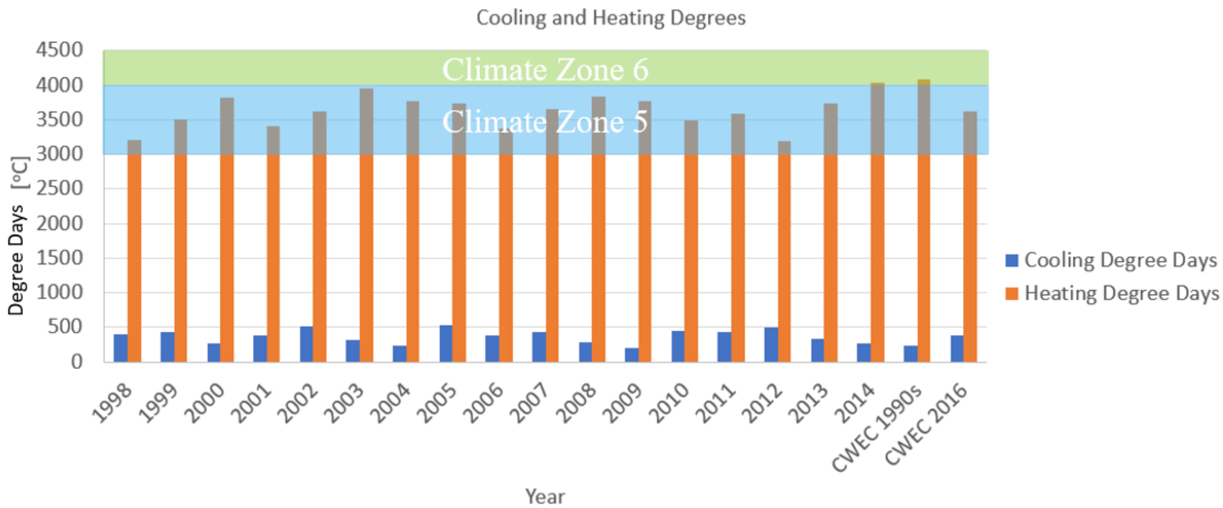


Figure 2-12 Cooling and Heating Degree Days

2.5 Concluding Remarks

This section is set out to answer two questions: 1) What are the changes from CWEC 1990s to CWEC 2016? and 2) Is Typical Year a good representation of the Historical Years, especially when they are not created under the same time range?

To answer the first question, the cumulative distribution of dry bulb temperature and global horizontal irradiation from CWEC 1990s and CWEC 2016 are analyzed. From the results it is observed that the 50th, 75th and 95th percentile of dry bulb temperature have shifted in most winter months and all the summer months. This indicates a more moderate winter and hotter summer. The analysis also shows that for the winter season (January, February and December), and the shoulder months in close proximity (November and March) the global horizontal irradiation CDF of CWEC 1990s is more skewed towards the lower end of the sub 200 WH/m^2 range.

To answer the second question, an analysis on the distribution of dry bulb temperature and solar radiation is completed. A simple look at the sequential year to year distribution of the elements does not show a drastic change. A different look into the yearly distribution on the hourly scale shows the wide band of variation in dry bulb temperature, it is also observed that more variation in dry bulb temperature in the winter months. These observations can't be seen in the Typical Year weather files, which is a singular representation of yearly conditions. In addition to the analysis on the distribution, analysis using temperature-based weather indices relevant to the well-being of inhabitants is also completed. It is observed that distribution of the 5th and 95th percentile of the yearly maximum and minimum dry bulb temperature fluctuates from year to year, it is also observed that this yearly fluctuation is greater with the 5th percentile temperatures (maximum and minimum), indicating that the yearly fluctuation have more influence on winter months. The analysis on summer and winter characterization days shows that Toronto has more winter characterization days than summer, indicating a greater number of "extreme" days in the winter. Lastly, climate zone characterization based on heating/cooling degree days show that for the majority of years, Toronto is characterized as Climate Zone 5, the only exception is 2014 where it is characterized as Climate Zone 6 by a small margin. Comparing the historical climate zone characterizations with the characterization based on Typical Year weather files, the characterization based on CWEC 1990s is climate zone 6, whereas if it is based on CWEC 2016, it is climate zone 5, which is representative of the historical year characterization.

To summarize the findings of this chapter, comparing CWEC 2016 to CWEC 1990s there is a warmer winter and hotter summer, there also seems to be warmer shoulder seasons as indicated by the shift in temperature distribution. Comparing Typical Year to Historical Years, the yearly fluctuation is not reflected in Typical Years as there is only one year of data. The wide range of maximum and minimum temperatures are not well represented in Typical Years, as this is also the general criticism indicated in literature. While the climate zone characterization based on CWEC 2016 is reflective of the characterization based on historical data, CWEC 1990s is not. This issue can be further understood by stating the fact that Typical Years are generally updated infrequently and for the duration of the Historical Years used in this study (1998 to 2014), CWEC 1990s was the best available weather file for simulation. This highlights the issue of the infrequent update cycle of Typical Year weather files, as long-term weather conditions can change over time, and more frequently updated weather files are needed for a fair representation.

Chapter 3 Conventional Transfer Function Based Simulation Using Typical and Historical Weather Files

3.1 Introduction

3.1.1 - Purpose and goal of simulation

Physical systems involved in the operation of buildings such as various heat transfer mechanisms and building system operations are complex, this is illustrated by Clarke in [38, Chapter 1, Figure 1.2]. Due to such complexity, computerized simulation programs are used to organize and manage building energy related calculations. Building Energy Simulation is a tool often used by building designers for building design validation and to estimate the amount of energy use for compliance purposes[1]. Depending on the type of building and its desired functionality, different parameters need to be evaluated within a predefined set of conditions. The full set of parameters that can be estimated by BES is vast and depends on the need of building designers, the capability of the simulation packages and post processing work. This may include estimation of energy usage, zone temperature/relative humidity and unmet hours. Ideally, it is better for simulation to yield results close to usage in actua0l building operation. However, this is difficult to achieve due to complications with factors that are hard to predict, such as occupant [39] and operator behavior [40]. To clarify, the current goal of BES is to reasonably estimate the desired parameters to aid the design process, evaluate building design, and to estimate energy use for compliance purposes.

3.1.2 - Current practice of simulation

Typical Year type weather files

One of the difficult tasks in building BES models is to make reasonable assumptions. Relating to the use of weather data, Crawley and Barnaby[3] compiled a list of required data for different building design analysis. For example, multi-year weather data is recommended for simulation of unconditioned or semi-conditioned buildings [3]. For general energy estimation and design comparison purposes, Crawley and Barnaby [3] stated that the use of "…Representative single year…" is often sufficient. The key in the statement is the interpretation of what is representative. Under general consensus amongst building designers, and also recognized by standards such as the Toronto Green Standard [41], Typical Year type weather files such as the Canadian Weather for Energy Calculations (CWEC) are generally accepted. In other regions, similar Typical Year type weather files are also accepted, such as TMY in the United States, and Typical Reference Year(TRY) in Europe[3]. It is worth noting that TRY used in Europe is not the same as the North American interpretation, the European TRY is a standardized Typical Year type weather file compiled using ISO 15924-4[3]. This is different from the North American TRY, where a complete single year is selected for simulation and is generally not considered as a good representation of historical climate [34].

The need to simplify simulation processes, and more specifically weather data used for simulation comes from a need in reducing the required computing and storage requirements during the early days of simulation [3]. Availability and access to weather data was also limited, as early weather records are stored on magnetic tapes[3]. However, with advancements in computing power and cloud storage, the accessibility to required resources have enhanced significantly. Hourly records of key weather elements from weather stations are updated hourly on the Government of Canada website[42], gridded solar radiation data from the National Solar Radiation Data Base (NSRDB) are also updated every 30 minutes, and is available for public access[43].

The main goal of this study is not to question or critique the Sandia method – methodology in creating Typical Year weather files. Rather the focus is on the practice in assuming that because the change in climate is slow and gradual, the current infrequent update of Typical Year weather files is sufficient, and it will remain a reasonable representation.

Transfer Function Based simulation

The algorithm used for simulation is also simplified to accommodate the limited computing power in the early days of simulation. For instance, in Energy Plus, the heat conduction calculation is simplified with a transfer function, which is only possible with the assumption of constant material thermal properties[2]. The goal of this discussion is not to go into the technical details of the simplifications, rather, it is to point out the general sense of need for simplification is still a prevailing thought in the building simulation community, which is bound to change in order to facilitate further advancement. For instance, moisture transfer is one of the physical components that is typically not well considered in conventional energy simulation models. Recent development of the simulation engine such as Energy Plus has added a finite element-based calculation module for Heat and Mass Transfer - the HAMT model[2]. Other more advanced simulation engines such as WUFIPlus[44] which is used for passive house certification in North

America has a more proven Heat and Mass transfer calculation-based simulation engine, however adaptation is still limited. As such, this research will focus on traditional simulation techniques with Transfer Function Based simulation.

3.1.3 - Prior work in comparing Typical Year and Multi-Year simulation

A lot of studies in the past have compared the use of Typical Year and Multi-Historical Year weather data for simulation.

Crawley[34] and Huang[45] were amongst the earliest and most prominent researchers who have conducted comprehensive comparisons on weather files used in Building Energy Simulation. Crawley completed a study on simulation of typical commercial buildings in eight cities representing different climates in the US[34], Huang[45] conducted a similar study with residential houses of different energy efficiencies. Both of them found that TMY2 yielded close average results with multi-year historical weather data, however great variations in yearly simulation results and peak load estimations. Crawley found a variation of -11% to 7% from average in yearly energy consumption estimation in Minneapolis – which represents a heating dominate climate.

More recently, Hong et al. [46] compared the use of Typical and multi-Historical Year simulation in simulating reference office buildings in 17 ASHRAE climate zones with TMY 3 weather files. The findings of their study confirmed Crawley's in which greater deviation on energy estimations with buildings operating in colder climates. In addition, by comparing the hourly results, they concluded that energy savings and peak load demands can be under or overestimated when Typical Year weather data is used. They believe that running multi-year simulation can reveal additional insight and generally recommends the practice to assess long term building performance.

Unlike other studies that are reviewed, Grudzińska and Jakusik [47] compared the use of Typical Year weather file that was created with old vintage weather data from 1971 to 2000 with multi-Historical Year weather data from 2001 to 2012. The weather data they used did not have any overlap in terms of time periods. They found significant under estimation of cooling energy when Typical Year file is used, they also observed a decreasing trend in heating demand and increasing trend in cooling demand.

As a critique to the use of Typical Year weather files for simulation, Cui et al. [48] upon comparing simulation of a prototype office building with 55 years of historical data and associated Typical Year weather files in 10 Chinese cities, believes that Typical Year weather files lack the ability in representing the variation of weather conditions that historical weather data contain. They further criticize the weighted selection method lacking flexibility in shifting emphasis on weather parameters that are relevant to specific applications. They proposed multi-year simulation as an alternative.

In understanding the potential benefits and tradeoffs in adapting multi-year simulation, Hui and Cheung[49] completed a study in Hong Kong. They concluded that insights generated from multi-year simulation are useful for operation optimization and management, however there should be evaluations on the potential cost in preparing and running multi-year simulation with the value of insight that they can generate. They believe the main hurdle is the availability of weather data, additional resources in preparing multi-year weather data, preparation of simulation files and effort in post processing additional simulation results.

3.2 Research Questions:

1) Does the use of different weather files affect conventional building energy simulation?

There are differences in the conditions represented by CWEC 1990s and CWEC 2016 as seen in Chapter 2. The goal of this research question is to explore how these differences are reflected in the results of heating and cooling energy estimation using BES.

2) Are there alternatives to current practices?

It is generally not ideal to run simulation with weather data that is out of date, since it may not be a good representation of recent long-term weather conditions. The goal of this research question is to explore whether there is alternative to the current practice of using Typical Year type weather files.

3.3 Methodology

To investigate the impact of using different weather files in conventional Building Energy Simulation, simulations of different buildings with both Typical Year weather files and Historical Year weather data are completed with Energy Plus 8.0. Energy Plus is an open source building energy simulation package published by the US Department of Energy, developed through collaboration between academia, government agencies and industry partners [50].

3.3.1 - Building models

The building models used in this study are the Department of Energy building prototypes created by the Pacific Northwest National Laboratory (PNNL)[51]. 16 buildings types are created to represent about 80% of all commercial building floor areas in the United States[51]. The purpose of the model is to aid the development and improvement of the ASHRAE energy code 90.1[51]. Due to the similarities between Canada and the United States, it is generally expected that the building types are also representative of buildings in Canada. For the purpose of this study, simulation is only completed on buildings for Toronto, therefore the prototype building models created for Climate Zone 5A (originally created for Buffalo,NY) are used, since Toronto is characterized as Climate Zone 5A in ASHARE 90.1 -2016[37]. Details of the building prototypes can be found in the accompanied scorecard, as well as examining the Energy Plus input files. The summary of the general specification of the buildings is summarized in Table 3-1.

3.3.2 - Weather data used

The weather file types that are being compared are the Typical Year and Historical Year weather files. The Typical Year weather files are the CWEC 1990s and CWEC 2016 weather files. CWEC 1990s is a weather file comprised of 12 Typical Meteorological months selected from historical weather data from 1969 to 1989 [17]; whereas Typical Meteorological months selected in CWEC 2016 are selected from historical weather data from 1998 to 2014 [15]. The Historical Year weather files are the CWEEDs 1998 to 2014, which are also used to create CWEC 2016. Design weather data used for equipment sizing is from ASHRAE Handbook of Fundamentals 2013[52], this is different from the simulation weather data described above, more is discussed in Chapter 4.

3.3.3 - Weather data format

For the weather data to be simulation compatible, conversion is needed to organize the data into proper format. Depending on the simulation engine/software used, the format needed may vary. For the purpose of this research, EPW format is needed. EPW is a weather format created for Energy Plus, however due to the relatively high adoption of Energy Plus, EPW format is also compatible with other simulation engines such as IES[53] and WUFI plus[54]. The proper format of EPW weather files is shown in[36], converting an existing EPW weather files using the Energy Plus weather converter[55] can also reveal the format required. For weather files used in this study, the older CWEC in EPW format is obtained from the EnergyPlus Weather database[33]; whereas the updated CWEC in EPW format is obtained directly on Environment and Climate Change Canada [16]. The CWEEDs weather data is obtained from the same database as the updated CWEC weather file [16].

The CWEEDS weather files are originally released in WYEC3 weather file format, which is a fixed width weather file format created by ASHRAE, and conversion to EPW is needed for simulation[15]. A script was written to convert the weather data from WYEC 3 to EPW, the methodology for the conversion is document and discussed in Chapter 4.

Table 3-1 Summary of DOE Prototype buildings for Climate Zone 5A

BUILDING TYPE (Climate Zone/Standard)	FLOOR AREA (FT2)	# OF FLOORS	Window to Wall Ratio	U Value [W/m²K]				HVAC
				Wall	Roof	Foundation	Window, SHGC	
Large Office - (Climate Zone 5A /ASHRAE 90.1 - 2016)	498,600	12 plus Basement	40% of above grade wall	0.51	0.18	1.83	0.41, SHGC 0.38	**Heating:** Gas fired boiler **Cooling:** Water cooled chillers for air cooling; Water sourced fluid cooler for Data center(basment) and IT closests(each floor) **Distribution:**VAV Boxes with dampers and reheating coils
Medium Office - (Climate Zone 5A /ASHRAE 90.1 - 2016)	53,600	3	33% of above grade wall	0.31	0.18	1.83	0.41, SHGC 0.38	**Heating:** Gas Furnace inside packaged air conditioning unit **Cooling:** Packaged Air Conditioing Unit **Distribution:** VAV Boxes with dampers and reheating coils
Small Office - (Climate Zone 5A /ASHRAE 90.1 - 2016)	5,500	1	24.4% for South facing - above grade walls; remaining above grade walls 19.8%	0.29	2.45	1.83	0.41, SHGC 0.38	**Heating:** Air Sourced Heat Pump with backup gas furnace **Cooling:** Air Sourced Heat Pump **Distribution:** One unit per thermal Zone, constant air volume
Warehouse - (Climate Zone 5A /ASHRAE 90.1 - 2016)	49,495	1	0.71% of above grade wall	0.282 / 0.634	0.208	3.24	0.50, SHGC 0.40/ 0.45, SHGC 0.38 /0.98, SHGC 0.68	**Heating:** Gas Furnace inside packaged air conditioning unit **Cooling:** Packaged Air Conditioing Unit **Distribution:** Direct uncontrolled
Stand-alone Retail - (Climate Zone 5A /ASHRAE 90.1 - 2016)	24,695	1	7.1% of above grade wall	0.51	0.18	1.90	0.50, SHGC 0.40/ 0.40, SHGC 0.38	***Front entry:*** **Heating only:** Gas Furnace; ***All zones except for front entry :*** **Heating:** Gas Furnace inside packaged air conditioning unit **Cooling:** Packaged Air Conditioing Unit **Distribution**: Roof top units for each of the 4 conditioned thermal zones - constant air volume
Strip Mall - (Climate Zone 5A /ASHRAE 90.1 - 2016)	22,500	1	10.5% of above grade wall	0.31	0.18	1.90	0.40, SHGC 0.38	**Heating:** Gas Furnace inside packaged air conditioning unit **Cooling:** Packaged Air Conditioing Unit **Distribution:** One unit per store, constant air volume
Primary School - (Climate Zone 5A /ASHRAE 90.1 - 2016)	73,960	1	35% of above grade wall	0.31	0.18	1.90	0.50, SHGC 0.40/ 0.40, SHGC 0.38	**Heating:** Gas Furnace inside packaged air conditioning unit and Gas boiler to heat hot water loop **Cooling:** Packaged Air Conditioing Unit **Distribution:** Directly from packaged air conditioning unit and VAV with hot water reheating coil
Secondary School- (Climate Zone 5A /ASHRAE 90.1 - 2016)	210,900	2	33% of above grade wall	0.31	0.18	1.90	0.50, SHGC 0.40/ 0.40, SHGC 0.38	**Heating:** Gas Furnace inside packaged air conditioning unit and Gas boiler to heat hot water loop **Cooling:** Packaged Air Conditioing Unit, air cooled chiller **Distribution:** Directly from packaged air conditioning unit and VAV with hot water reheating coil
Fast Food Restaurant - (Climate Zone 5A	2,500	1	28% south facing wall 14% east facing wall	0.29	2.49	3.24	0.38, SHGC 0.30/ 0.40, SHGC 0.38	**Heating:** Gas Furnace inside packaged air conditioning unit **Cooling:** Packaged Air Conditioing Unit **Distribution:** Single zone, constant air volume

/ASHRAE 90.1 - 2016)			0% north facing wall 14% west facing wall					
Sit Down Restaurant - (Climate Zone 5A /ASHRAE 90.1 - 2016)	5,502	1 plus attic (unconditi-oned)	28% south facing wall 20.22% east facing wall 0% north facing wall 20.22% west facing wall	0.31	2.45	3.24	0.43, SHGC 0.26/ 0.40, SHGC 0.38	**Heating:** Gas Furnace inside packaged air conditioning unit **Cooling:** Packaged Air Conditioing Unit **Distribution:** Single zone, constant air volume
Hospital - (Climate Zone 5A /ASHRAE 90.1 - 2016)	241,410	5 plus basement (conditio n-ed)	12% south facing wall 13% east facing wall 15% north facing wall 24% west facing wall	0.51 / 0.45	0.18	1.83	0.40, SHGC 0.38 / 0.42, SHGC 0.40	**Heating:** Gas Boiler **Cooling:** Two water cooled chillers **Distribution:** *Medical critical zones*: 5 air handling units with hot water heating and electric steam humidifier - CAV or VAV *Non-critical zones:* 2 VAV systems for general zones, CAV for kitchen zone
Outpatient Health Care - (Climate Zone 5A /ASHRAE 90.1 - 2016)	40,950	3	20.5% south facing wall 19.1% east facing wall 24.1% north facing wall 12.9% west facing wall	0.31	0.18	1.83	0.40, SHGC 0.38	**Heating:** Gas Boiler **Cooling:** DX cooling coil **Distribution:** VAV with damper and hot water reheating coil Electrical reistance reheat in AHU-2
Small Hotel - (Climate Zone 5A /ASHRAE 90.1 - 2016)	43,200	4	3.1% south facing wall 11.4% east facing wall 4.0% north facing wall 15.2% west facing wall	0.31	0.18	1.83	0.42, SHGC 0.40	*Guest Rooms:* **Heating and Cooling:** Packaged Terminal Air Conditioner with electric resistance heating *Public Spaces:* **Heating:** Gas furnace inside packaged air conditioning unit. **Cooling:** Split system with DX cooling *Storage and stairs:* **Heating:** Electric cabinet heaters
Large Hotel - (Climate Zone 5A /ASHRAE 90.1 - 2016)	122,132	6 plus basement (Conditioned)	36.7% south facing wall 24.5% east facing wall 26.0% north facing wall 24.5% west facing wall	0.51	0.19	1.83	0.42, SHGC 0.40	**Heating:** Gas-fired boiler **Cooling:** Air-cooled chiller **Distribution:** Dedicated outside air system + 4 pipe fan-coil unit
Midrise Apartment - (Climate Zone 5A /ASHRAE 90.1 - 2016)	33,740	4	20% south facing wall 20% east facing wall 20% north facing wall 20% west facing wall	0.31	0.18	1.83	0.41, SHGC 0.38	**Heating:** Gas Furnace **Cooling**: Split System per unit **Distribution:** Constant volume
Highrise Apartment - (Climate Zone 5A /ASHRAE 90.1 - 2016)	84,360	10	30% south facing wall 30% east facing wall 30% north facing wall 30% west facing wall	0.31	0.18	1.83	0.41, SHGC 0.38	**Heating:** Water Source Heat Pump **Cooling:** Water Source Heat Pump **Distribution:** Constant volume

3.3.4 - Summary of simulation process

To clearly illustrate the preprocessing work and modifications made to models, Figure 3-1 summarizes the simulation process completed in this chapter.

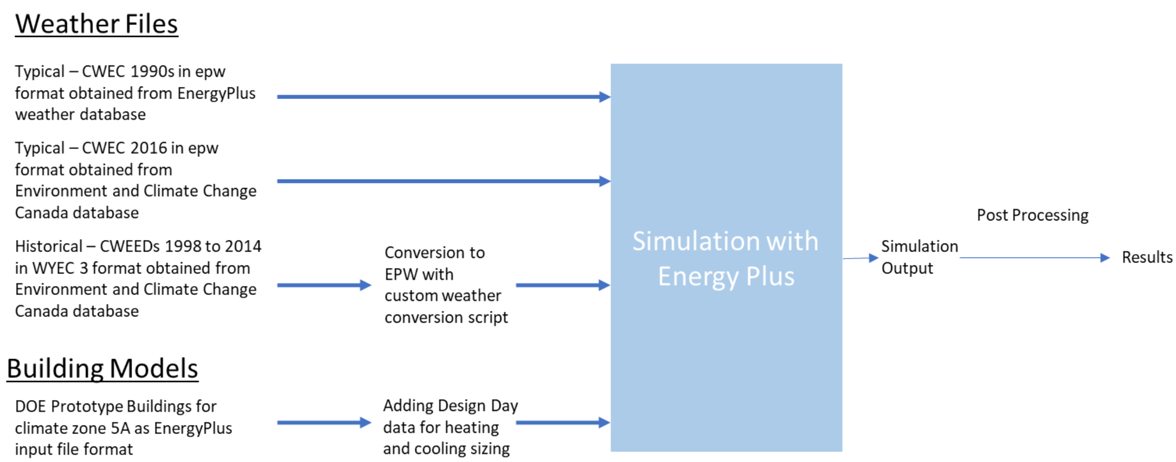


Figure 3-1 Summary of Simulation Process

3.3.5 - List of comparisons

1) Long term total heating and cooling energy usage

One of the main goals of BES is to estimate energy usage. In theory, simulation using a reasonably representative weather file should yield results close to the simulation of actual historical year weather data. The purpose of this comparison is to evaluate whether the CWEC Typical year weather files (CWEC 1990s and CWEC 2016) are reasonable representations of the CWEEDs historical year (1998 to 2014) weather data under the context of BES. Equation 3-1 shows the percentage difference calculation used in part 1:

Equation 3-1: Equation to calculate percentage difference in comparison 1

$$\%\,difference = \frac{\left(\sum E_{hist} - (E_{typ} \times 17)\right)}{0.5 \times \left(\sum E_{hist} + (E_{typ} \times 17)\right)} \times 100\% \qquad (3.1)$$

where:

$E_{hist} = Energy\ Estimation\ from\ Historical\ Year\ simulation$
$E_{typ} = Energy\ Estimation\ from\ Typical\ Year\ simulation$

2) Year to year heating and cooling energy usage estimations

The year to year heating and cooling energy usages are also of interest. As indicated in the introductory section, BES with Typical Year weather files yields a single output estimation and does not capture the year to year weather variations as illustrated in Chapter 2, and the information generated could potentially be valuable in an energy planning perspective. The goal of the comparison is to evaluate the year to year deviation between estimation of heating and cooling energy usage from simulation using Typical Year weather files and Historical weather data. Equation 3-2 shows the percentage difference calculation used in part 2:

Equation 3-2: Equation to calculate percentage difference in comparison 2

$$\%\ difference = \frac{(E_{hist} - E_{typ})}{0.5 \times (E_{hist} + E_{typ})} \times 100\% \qquad (3.2)$$

where:

$E_{hist} = Energy\ Estimation\ from\ Historical\ Year\ simulation$
$E_{typ} = Energy\ Estimation\ from\ Typical\ Year\ simulation$

3) 5, 10 and 15-year rolling average comparison

From a thorough review on the methodology used to compile Typical Year weather files in Chapter 2, it is learned that Typical Year weather files are subsets of historical weather data, further, it is identified that if Typical Year weather files are not updated frequently, they may not represent the most recent long term weather conditions. The specific interest of this comparison is to propose an alternative method in using rolling averages of historical year simulation to estimate average heating and cooling energy usage. In this comparison, rolling averages (5, 10 and 15 years) of energy estimation using historical weather data is compared with energy estimation from Typical Year weather files. The rolling averages are calculated based on the average energy estimation of the previous 5, 10 and 15 years of Historical Year estimations. Equation 3-3 shows the percentage difference calculation used in part 3:

Equation 3-3: Equation to calculate percentage difference in comparison 2

$$\%\ difference = \frac{(E_{hist,rolling\ avg} - E_{typ})}{0.5 \times (\sum E_{hist,rolling\ avg} + E_{typ})} \times 100\% \qquad (3.3)$$

where:

$E_{hist,rolling\ avg} = Average\ Energy\ Estimation\ from\ 5, 10\ and\ 15\ years\ of\ Historical\ Year\ simulation$
$E_{typ} = Energy\ Estimation\ from\ Typical\ Year\ simulation$

3.4 Results and Discussion

The estimation of heating and cooling energy usage for all DOE prototype buildings are presented in Tables 3-2 to 3-17. A color scale is added to aid the analysis of results, positive percentage differences are indicated with a red highlight, negative percentage differences are indicated by blue highlight. The intensity of the colors indicates the level of magnitude of the differences.

3.4.1 - Long term total heating and cooling energy usage comparison

The first part compares the sum of energy usage for heating and cooling in Historical Year simulations with the energy usage in Typical Year simulations multiplied by 17 years. As seen in the results, the total energy use estimated by simulation using CWEC 2016 is very close to the total estimation from simulation with Historical Years. In terms of heating energy estimation, deviation is between -1% to 2% across all building types; for cooling energy estimation, deviation is between -8% to 0%, with most building types having deviation between -1% to 0% and the warehouse having deviation at -8%. In contrast, the deviation with results from simulation using CWEC 1990s is much greater. In terms of heating energy estimation deviations are between -29% to -6%, with the high-rise apartment building having the greatest deviation; deviation in cooling energy is between -31% to -11%, with the fast food restaurant having the greatest deviation.

3.4.2 - Year to Year heating and cooling energy usage comparison

The second part compares the yearly heating and cooling energy usage estimation (from historical year simulation) with the estimation from Typical Year simulations. As seen in the results, there is great deviation in estimations from both simulation with CWEC 1990s and CWEC 2016. The estimations for heating energy with CWEC 1990s also have a general tendency of being greater than the historical year simulations, whereas the estimation for cooling energy has a tendency of being lower than the historical year simulations for most buildings type in most historical years. The deviation with CWEC 2016 is more cyclical between greater and lower than the historical year estimations, this is observed with both heating and cooling energy estimations.

3.4.3 - 5, 10 and 15 year rolling heating and cooling energy average usage comparison

The third part compares the rolling averages of historical year estimation with typical year estimations in relation to yearly historical estimations. The analysis is aided by observing the color scale applied to the estimation for each building type. As observed, the rolling average estimations did not yield better estimations of the individual Historical Years. However, it is worth noting that the differences between the individual Historical Year estimations and the rolling averages are similar to the differences between the individual Historical Year estimations and the estimations using CWEC 2016. This indicates that the rolling averages can be a good approximation of the estimation using CWEC 2016, and potentially be more appropriately used than CWEC 1990s, as CWEC 2016 is not available until 2016.

Table 3-2 Large Office - Heating and Cooling End-Use Energy

OfficeLarge

	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	3.84	2694.96	2698.8	-52%	-31%	NA	NA	NA	2807.41	21%	3%	NA	NA	NA
1999	3.47	3362.07	3365.54	-31%	-9%	NA	NA	NA	2782.51	20%	2%	NA	NA	NA
2000	3.54	3808.93	3812.47	-19%	4%	NA	NA	NA	2433.61	6%	-11%	NA	NA	NA
2001	3.3	3093.49	3096.79	-39%	-17%	NA	NA	NA	2568.42	12%	-6%	NA	NA	NA
2002	2.94	3381.98	3384.92	-30%	-8%	NA	NA	NA	2850.6	22%	5%	NA	NA	NA
2003	3.26	4341.14	4344.4	-6%	17%	28%	NA	NA	2514.49	10%	-8%	-7%	NA	NA
2004	3.55	4063.3	4066.85	-12%	10%	12%	NA	NA	2426.34	6%	-11%	-8%	NA	NA
2005	3.47	4123.85	4127.32	-11%	12%	10%	NA	NA	2971.09	26%	9%	15%	NA	NA
2006	2.93	2919.48	2922.41	-44%	-23%	-26%	NA	NA	2622.66	14%	-4%	-2%	NA	NA
2007	2.6	4283.17	4285.77	-7%	15%	13%	NA	NA	2790.01	20%	2%	4%	NA	NA
2008	3.12	4117.43	4120.55	-11%	11%	4%	13%	NA	2463.81	8%	-10%	-8%	-8%	NA
2009	3.37	3884.79	3888.16	-17%	6%	0%	4%	NA	2313.27	1%	-16%	-14%	-13%	NA
2010	2.94	3619.14	3622.08	-24%	-1%	-7%	-5%	NA	2916.69	24%	7%	10%	12%	NA
2011	2.81	3623.44	3626.25	-23%	-1%	-4%	-4%	NA	2767.95	19%	2%	5%	5%	NA
2012	2.68	2663.78	2666.46	-53%	-32%	-38%	-36%	NA	2851.77	22%	5%	7%	7%	NA
2013	2.85	3971.31	3974.16	-14%	8%	10%	5%	10%	2672.45	16%	-2%	0%	0%	0%
2014	2.96	4797.53	4800.49	4%	27%	30%	25%	26%	2485.49	9%	-9%	-8%	-8%	-7%
CWEC 1990s	3.91	4587.79	4591.7	0%	22%	NA	NA	NA	2282	0%	-18%	NA	NA	NA
CWEC 2016	3.04	3673.38	3676.42	-22%	0%	NA	NA	NA	2722.25	18%	0%	NA	NA	NA
HY - 17 Years	53.63	62749.79	62803.4	-22%	0%	NA	NA	NA	45238.57	15%	-2%	NA	NA	NA
CWEC 1990s - 17 Years	66.47	77992.43	78058.9	0%	22%	NA	NA	NA	38794	0%	-18%	NA	NA	NA
CWEC 2016 -17 Years	51.68	62447.46	62499.1	-22%	0%	NA	NA	NA	46278.25	18%	0%	NA	NA	NA

Table 3-3 Medium Office - Heating and Cooling End-Use Energy

OfficeMedium

	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	160.75	171.97	332.72	-47%	-28%	NA	NA	NA	197.32	31%	7%	NA	NA	NA
1999	192.67	211.87	404.54	-29%	-9%	NA	NA	NA	187.03	26%	2%	NA	NA	NA
2000	213.27	242.58	455.85	-17%	3%	NA	NA	NA	158.74	9%	-15%	NA	NA	NA
2001	183.4	197.17	380.57	-35%	-15%	NA	NA	NA	171.84	17%	-7%	NA	NA	NA
2002	196.8	212.56	409.36	-27%	-8%	NA	NA	NA	198.69	31%	8%	NA	NA	NA
2003	237.87	275.35	513.22	-5%	15%	26%	NA	NA	164.28	13%	-11%	-11%	NA	NA
2004	237.49	251.72	489.21	-10%	10%	12%	NA	NA	159.46	10%	-14%	-10%	NA	NA
2005	237.7	255.67	493.37	-9%	11%	9%	NA	NA	217.41	40%	17%	24%	NA	NA
2006	185.7	174.85	360.55	-40%	-20%	-24%	NA	NA	180.88	22%	-2%	-1%	NA	NA
2007	244.53	260.77	505.3	-7%	14%	11%	NA	NA	198.16	31%	7%	7%	NA	NA
2008	230.93	257.04	487.97	-10%	10%	3%	12%	NA	163.7	12%	-12%	-12%	-11%	NA
2009	225.51	236.81	462.32	-15%	5%	-1%	3%	NA	146.84	2%	-23%	-22%	-20%	NA
2010	215.79	216.97	432.76	-22%	-2%	-7%	-5%	NA	205.44	35%	11%	12%	15%	NA
2011	210.93	228.35	439.28	-21%	0%	-2%	-3%	NA	192.85	29%	5%	7%	7%	NA
2012	173.6	161.83	335.43	-47%	-27%	-32%	-31%	NA	202.3	33%	9%	11%	10%	NA
2013	225.12	247.04	472.16	-13%	7%	9%	4%	9%	181.62	23%	-1%	0%	-1%	-1%
2014	267.64	295.67	563.31	4%	24%	27%	23%	24%	160.4	10%	-14%	-15%	-14%	-13%
CWEC 1990s	268.81	270.89	539.7	0%	20%	NA	NA	NA	144.62	0%	-24%	NA	NA	NA
CWEC 2016	210.91	230.42	441.33	-20%	0%	NA	NA	NA	184.19	24%	0%	NA	NA	NA
HY - 17 Years	3639.7	3898.22	7537.9	-20%	0%	NA	NA	NA	3086.96	23%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	4569.77	4605.13	9174.9	0%	20%	NA	NA	NA	2458.54	0%	-24%	NA	NA	NA
CWEC 2016 -17 Years	3585.47	3917.14	7502.6	-20%	0%	NA	NA	NA	3131.23	24%	0%	NA	NA	NA

Table 3-4 Small Office - Heating and Cooling End-Use Energy

OfficeSmall

	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	8.62	1.9	10.52	-62%	-43%	NA	NA	NA	10.69	26%	7%	NA	NA	NA
1999	9.51	6.14	15.65	-25%	-4%	NA	NA	NA	10.09	20%	1%	NA	NA	NA
2000	10.45	6.96	17.41	-14%	6%	NA	NA	NA	8.84	7%	-12%	NA	NA	NA
2001	9.53	3.52	13.05	-42%	-23%	NA	NA	NA	9.59	15%	-4%	NA	NA	NA
2002	10.25	2.39	12.64	-45%	-26%	NA	NA	NA	10.32	22%	3%	NA	NA	NA
2003	11.02	10.63	21.65	8%	28%	44%	NA	NA	8.92	8%	-11%	-10%	NA	NA
2004	10.21	10.77	20.98	5%	25%	26%	NA	NA	8.63	5%	-15%	-10%	NA	NA
2005	11.2	8.17	19.37	-3%	17%	12%	NA	NA	11.4	32%	13%	21%	NA	NA
2006	9.07	2.23	11.3	-56%	-37%	-43%	NA	NA	9.77	17%	-2%	0%	NA	NA
2007	11.21	8.55	19.76	-1%	19%	14%	NA	NA	10.75	26%	7%	9%	NA	NA
2008	11.62	6.19	17.81	-12%	8%	-4%	9%	NA	9.24	11%	-8%	-7%	-7%	NA
2009	10.47	7.34	17.81	-12%	8%	0%	5%	NA	8.34	1%	-18%	-18%	-16%	NA
2010	10.78	5.43	16.21	-21%	-1%	-6%	-6%	NA	10.68	26%	7%	8%	11%	NA
2011	10.27	6.51	16.78	-18%	3%	1%	-2%	NA	10.14	21%	1%	4%	4%	NA
2012	8.43	2.06	10.49	-63%	-44%	-51%	-50%	NA	10.68	26%	7%	8%	8%	NA
2013	11.58	5.8	17.38	-14%	6%	9%	1%	8%	9.84	18%	-2%	0%	0%	0%
2014	11.53	12.59	24.12	18%	38%	42%	36%	37%	8.75	6%	-13%	-13%	-13%	-11%
CWEC 1990s	12.7	7.35	20.05	0%	20%	NA	NA	NA	8.25	0%	-19%	NA	NA	NA
CWEC 2016	10.36	6	16.36	-20%	0%	NA	NA	NA	10	19%	0%	NA	NA	NA
HY - 17 Years	175.75	107.18	282.93	-19%	2%	NA	NA	NA	166.67	17%	-2%	NA	NA	NA
CWEC 1990s - 17 Years	215.9	124.95	340.85	0%	20%	NA	NA	NA	140.25	0%	-19%	NA	NA	NA
CWEC 2016 -17 Years	176.12	102	278.12	-20%	0%	NA	NA	NA	170	19%	0%	NA	NA	NA

Table 3-5 Strip Mall - Heating and Cooling End-Use Energy

RetailStripmall														
				Heating					Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	477.47	477.47	-37%	-21%	NA	NA	NA	68.4	34%	7%	NA	NA	NA
1999	0	556.88	556.88	-22%	-5%	NA	NA	NA	65.93	31%	4%	NA	NA	NA
2000	0	608.79	608.79	-13%	4%	NA	NA	NA	50.9	5%	-22%	NA	NA	NA
2001	0	529.98	529.98	-26%	-10%	NA	NA	NA	60.56	22%	-5%	NA	NA	NA
2002	0	584.78	584.78	-17%	0%	NA	NA	NA	76.44	45%	19%	NA	NA	NA
2003	0	664.2	664.2	-4%	12%	19%	NA	NA	56.17	15%	-12%	-14%	NA	NA
2004	0	639.36	639.36	-8%	8%	8%	NA	NA	51.04	5%	-22%	-19%	NA	NA
2005	0	643.55	643.55	-7%	9%	6%	NA	NA	81.03	50%	24%	31%	NA	NA
2006	0	510.27	510.27	-30%	-14%	-18%	NA	NA	61.78	24%	-3%	-5%	NA	NA
2007	0	649.1	649.1	-6%	10%	6%	NA	NA	71.07	38%	11%	8%	NA	NA
2008	0	639.88	639.88	-8%	9%	3%	9%	NA	53.29	9%	-17%	-19%	-19%	NA
2009	0	606.19	606.19	-13%	3%	-2%	1%	NA	45.29	-7%	-33%	-34%	-32%	NA
2010	0	559.94	559.94	-21%	-5%	-9%	-8%	NA	71.49	38%	12%	13%	16%	NA
2011	0	593	593	-15%	1%	0%	-2%	NA	67.12	32%	6%	10%	7%	NA
2012	0	481.23	481.23	-36%	-20%	-24%	-23%	NA	72.68	40%	14%	16%	14%	NA
2013	0	633.48	633.48	-9%	8%	9%	6%	8%	60.34	22%	-5%	-3%	-4%	-5%
2014	0	714.79	714.79	3%	20%	22%	18%	19%	53.07	9%	-18%	-18%	-18%	-17%
CWEC 1990s	0	691.35	691.35	0%	16%	NA	NA	NA	48.46	0%	-27%	NA	NA	NA
CWEC 2016	0	587.49	587.49	-16%	0%	NA	NA	NA	63.48	27%	0%	NA	NA	NA
HY - 17 Years	0	10092.89	10093	-15%	1%	NA	NA	NA	1066.6	26%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	0	11752.95	11753	0%	16%	NA	NA	NA	823.82	0%	-27%	NA	NA	NA
CWEC 2016 -17 Years	0	9987.33	9987.3	-16%	0%	NA	NA	NA	1079.16	27%	0%	NA	NA	NA

Table 3-6 Retail Store - Heating and Cooling End-Use Energy

RetailStandalone														
				Heating					Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	151.42	151.42	-56%	-34%	NA	NA	NA	84.36	33%	8%	NA	NA	NA
1999	0	201.84	201.84	-28%	-6%	NA	NA	NA	81.76	30%	5%	NA	NA	NA
2000	0	210.91	210.91	-24%	-1%	NA	NA	NA	65.52	8%	-17%	NA	NA	NA
2001	0	189.24	189.24	-35%	-12%	NA	NA	NA	74.29	20%	-5%	NA	NA	NA
2002	0	193	193	-33%	-10%	NA	NA	NA	89.99	39%	14%	NA	NA	NA
2003	0	275.3	275.3	3%	25%	37%	NA	NA	69.92	14%	-11%	-12%	NA	NA
2004	0	222.16	222.16	-19%	4%	4%	NA	NA	63.94	5%	-20%	-18%	NA	NA
2005	0	230.83	230.83	-15%	8%	6%	NA	NA	96.95	46%	22%	29%	NA	NA
2006	0	165.1	165.1	-48%	-26%	-29%	NA	NA	76.05	23%	-2%	-4%	NA	NA
2007	0	228.66	228.66	-16%	7%	5%	NA	NA	85.79	34%	10%	8%	NA	NA
2008	0	219.86	219.86	-20%	3%	-2%	6%	NA	67.09	10%	-15%	-16%	-16%	NA
2009	0	235.04	235.04	-13%	9%	10%	10%	NA	58.34	-4%	-29%	-29%	-28%	NA
2010	0	226.32	226.32	-17%	6%	5%	4%	NA	86.87	36%	11%	12%	15%	NA
2011	0	196.97	196.97	-31%	-8%	-9%	-10%	NA	82.7	31%	6%	10%	7%	NA
2012	0	151.73	151.73	-55%	-34%	-37%	-36%	NA	89.04	38%	13%	16%	14%	NA
2013	0	218.59	218.59	-20%	2%	6%	2%	6%	73.81	20%	-5%	-4%	-5%	-6%
2014	0	270.18	270.18	1%	23%	27%	25%	25%	66.88	10%	-15%	-16%	-15%	-15%
CWEC 1990s	0	268.15	268.15	0%	23%	NA	NA	NA	60.55	0%	-25%	NA	NA	NA
CWEC 2016	0	213.87	213.87	-23%	0%	NA	NA	NA	77.9	25%	0%	NA	NA	NA
HY - 17 Years	0	3587.15	3587.2	-24%	-1%	NA	NA	NA	1313.3	24%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	0	4558.55	4558.6	0%	23%	NA	NA	NA	1029.35	0%	-25%	NA	NA	NA
CWEC 2016 -17 Years	0	3635.79	3635.8	-23%	0%	NA	NA	NA	1324.3	25%	0%	NA	NA	NA

Table 3-7 Small Hotel - Heating and Cooling End-Use Energy

HotelSmall														
				Heating					Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	125.45	94.29	219.74	-47%	-28%	NA	NA	NA	193.21	23%	6%	NA	NA	NA
1999	163.71	112.01	275.72	-26%	-6%	NA	NA	NA	188.31	20%	4%	NA	NA	NA
2000	187.32	124.11	311.43	-14%	6%	NA	NA	NA	169.29	9%	-7%	NA	NA	NA
2001	145.82	104.29	250.11	-35%	-15%	NA	NA	NA	178.93	15%	-1%	NA	NA	NA
2002	159.65	113.57	273.22	-26%	-7%	NA	NA	NA	187.46	20%	3%	NA	NA	NA
2003	205.37	134.17	339.54	-5%	15%	24%	NA	NA	169.17	9%	-7%	-8%	NA	NA
2004	195.95	125.93	321.88	-10%	10%	10%	NA	NA	168.37	9%	-8%	-6%	NA	NA
2005	196.94	128.5	325.44	-9%	11%	8%	NA	NA	194.69	23%	7%	11%	NA	NA
2006	138.67	98.77	237.44	-40%	-21%	-24%	NA	NA	182.74	17%	1%	2%	NA	NA
2007	202.84	128.13	330.97	-7%	13%	10%	NA	NA	187.91	20%	3%	4%	NA	NA
2008	189.4	125.4	314.8	-12%	8%	1%	9%	NA	168.21	9%	-8%	-7%	-8%	NA
2009	186.33	122.93	309.26	-14%	6%	1%	4%	NA	161.78	5%	-12%	-11%	-10%	NA
2010	170.84	111.77	282.61	-23%	-3%	-7%	-6%	NA	194.11	23%	7%	8%	9%	NA
2011	171.82	116.92	288.74	-21%	-1%	-2%	-3%	NA	187.25	19%	3%	5%	4%	NA
2012	123.71	91.25	214.96	-50%	-30%	-35%	-34%	NA	196.62	24%	8%	9%	9%	NA
2013	186.09	125.24	311.33	-14%	6%	10%	5%	8%	179.64	15%	-1%	-1%	-1%	-1%
2014	235.07	145.09	380.16	6%	26%	30%	26%	26%	165.42	7%	-9%	-11%	-10%	-9%
CWEC 1990s	217.03	139.49	356.52	0%	20%	NA	NA	NA	154.13	0%	-16%	NA	NA	NA
CWEC 2016	174.37	117.54	291.91	-20%	0%	NA	NA	NA	181.52	16%	0%	NA	NA	NA
HY - 17 Years	2984.98	2002.37	4987.4	-19%	1%	NA	NA	NA	3073.11	16%	0%	NA	NA	NA
CWEC 1990s - 17 Years	3689.51	2371.33	6060.8	0%	20%	NA	NA	NA	2620.21	0%	-16%	NA	NA	NA
CWEC 2016 -17 Years	2964.29	1998.18	4962.5	-20%	0%	NA	NA	NA	3085.84	16%	0%	NA	NA	NA

Table 3-8 : Large Hotel - Heating and Cooling End-Use Energy

HotelLarge														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	1105.69	1105.7	-39%	-20%	NA	NA	NA	956.59	28%	5%	NA	NA	NA
1999	0	1288.6	1288.6	-24%	-5%	NA	NA	NA	943.77	26%	3%	NA	NA	NA
2000	0	1440.2	1440.2	-13%	6%	NA	NA	NA	812.62	11%	-11%	NA	NA	NA
2001	0	1207.42	1207.4	-31%	-12%	NA	NA	NA	850.57	16%	-7%	NA	NA	NA
2002	0	1245.84	1245.8	-28%	-8%	NA	NA	NA	958.11	28%	5%	NA	NA	NA
2003	0	1549.2	1549.2	-6%	13%	21%	NA	NA	823.64	13%	-10%	-9%	NA	NA
2004	0	1510	1510	-9%	11%	11%	NA	NA	809.42	11%	-12%	-8%	NA	NA
2005	0	1496.7	1496.7	-9%	10%	7%	NA	NA	1007.39	33%	10%	17%	NA	NA
2006	0	1179.19	1179.2	-33%	-14%	-17%	NA	NA	900.54	22%	-1%	1%	NA	NA
2007	0	1493.41	1493.4	-10%	10%	7%	NA	NA	957.38	28%	5%	6%	NA	NA
2008	0	1445.35	1445.4	-13%	6%	0%	7%	NA	800.03	10%	-13%	-12%	-12%	NA
2009	0	1447.53	1447.5	-13%	6%	2%	4%	NA	753.43	4%	-19%	-17%	-16%	NA
2010	0	1317.01	1317	-22%	-3%	-7%	-6%	NA	1006.14	33%	10%	13%	15%	NA
2011	0	1372.52	1372.5	-18%	1%	0%	-1%	NA	939.16	26%	3%	6%	6%	NA
2012	0	1107.29	1107.3	-39%	-20%	-24%	-24%	NA	980.93	30%	7%	10%	9%	NA
2013	0	1429.77	1429.8	-14%	5%	7%	3%	6%	911.04	23%	0%	2%	1%	1%
2014	0	1695.78	1695.8	3%	22%	24%	21%	21%	811.86	11%	-12%	-12%	-11%	-10%
CWEC 1990s	0	1644.83	1644.8	0%	19%	NA	NA	NA	724.72	0%	-23%	NA	NA	NA
CWEC 2016	0	1356.43	1356.4	-19%	0%	NA	NA	NA	911.71	23%	0%	NA	NA	NA
HY - 17 Years	0	23331.5	23332	-18%	1%	NA	NA	NA	15222.62	21%	-2%	NA	NA	NA
CWEC 1990s - 17 Years	0	27962.11	27962	0%	19%	NA	NA	NA	12320.24	0%	-23%	NA	NA	NA
CWEC 2016 -17 Years	0	23059.31	23059	-19%	0%	NA	NA	NA	15499.07	23%	0%	NA	NA	NA

Table 3-9 Hospital - Heating and Cooling End-Use Energy

Hospital														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	800.86	6766.58	7567.4	-11%	-5%	NA	NA	NA	1933.43	14%	2%	NA	NA	NA
1999	846.41	6999.27	7845.7	-8%	-2%	NA	NA	NA	1897.9	13%	0%	NA	NA	NA
2000	851.85	7268.89	8120.7	-4%	2%	NA	NA	NA	1786.09	6%	-6%	NA	NA	NA
2001	855.58	6953.4	7809	-8%	-2%	NA	NA	NA	1755.16	5%	-8%	NA	NA	NA
2002	946.68	6993.83	7940.5	-7%	-1%	NA	NA	NA	1958.03	16%	3%	NA	NA	NA
2003	867.24	7421.11	8288.4	-2%	4%	5%	NA	NA	1782.86	6%	-6%	-5%	NA	NA
2004	814.72	7358.26	8173	-4%	2%	2%	NA	NA	1769	6%	-7%	-4%	NA	NA
2005	877.2	7255.32	8132.5	-4%	2%	1%	NA	NA	2017.35	19%	6%	11%	NA	NA
2006	805.27	6901.08	7706.4	-10%	-4%	-5%	NA	NA	1913.97	13%	1%	3%	NA	NA
2007	859.68	7278.85	8138.5	-4%	2%	1%	NA	NA	1903.33	13%	1%	1%	NA	NA
2008	899.52	7290.52	8190	-4%	2%	1%	3%	NA	1746.49	4%	-8%	-7%	-7%	NA
2009	859.5	7291.75	8151.3	-4%	2%	1%	1%	NA	1710.1	2%	-10%	-9%	-8%	NA
2010	828.15	7033.5	7861.7	-8%	-2%	-3%	-3%	NA	2065.47	21%	9%	11%	12%	NA
2011	810.8	7131.55	7942.4	-7%	-1%	-1%	-1%	NA	1926.23	14%	2%	3%	3%	NA
2012	768.4	6765.99	7534.4	-12%	-6%	-7%	-7%	NA	1943.96	15%	3%	4%	3%	NA
2013	901.5	7210.35	8111.9	-4%	1%	2%	1%	2%	1900.65	13%	0%	1%	1%	1%
2014	899.45	7580.53	8480	0%	6%	7%	6%	6%	1741.2	4%	-8%	-9%	-8%	-7%
CWEC 1990s	926.21	7555.97	8482.2	0%	6%	NA	NA	NA	1674.25	0%	-12%	NA	NA	NA
CWEC 2016	866.25	7125.47	7991.7	-6%	0%	NA	NA	NA	1893.14	12%	0%	NA	NA	NA
HY - 17 Years	14492.81	121500.78	135994	-6%	0%	NA	NA	NA	31751.22	11%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	15745.57	128451.49	144197	0%	6%	NA	NA	NA	28462.25	0%	-12%	NA	NA	NA
CWEC 2016 -17 Years	14726.25	121132.99	135859	-6%	0%	NA	NA	NA	32183.38	12%	0%	NA	NA	NA

Table 3-10 Outpatient Clinic - Heating and Cooling End Use Energy

OutPatientHealthCare														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	241.5	736.58	978.08	-23%	-12%	NA	NA	NA	505.2	23%	5%	NA	NA	NA
1999	261.53	812.06	1073.6	-14%	-3%	NA	NA	NA	486.48	20%	2%	NA	NA	NA
2000	267.29	883.98	1151.3	-7%	4%	NA	NA	NA	434.24	8%	-10%	NA	NA	NA
2001	251.31	779.71	1031	-18%	-7%	NA	NA	NA	463.83	15%	-3%	NA	NA	NA
2002	259.39	797.26	1056.7	-16%	-5%	NA	NA	NA	497.68	22%	4%	NA	NA	NA
2003	275.48	930.28	1205.8	-2%	9%	13%	NA	NA	439.86	10%	-9%	-8%	NA	NA
2004	276.18	883.35	1159.5	-6%	5%	5%	NA	NA	442.7	10%	-8%	-5%	NA	NA
2005	279.53	902.4	1181.9	-4%	7%	5%	NA	NA	522.91	27%	9%	14%	NA	NA
2006	245.69	741.66	987.35	-22%	-11%	-13%	NA	NA	482.71	19%	1%	2%	NA	NA
2007	278.71	904.45	1183.2	-4%	7%	6%	NA	NA	502.46	23%	5%	5%	NA	NA
2008	271.21	886.32	1157.5	-7%	5%	1%	5%	NA	436.4	9%	-9%	-9%	-9%	NA
2009	270.61	870.37	1141	-8%	3%	1%	2%	NA	417.07	4%	-14%	-13%	-12%	NA
2010	261.98	823.78	1085.8	-13%	-2%	-4%	-4%	NA	520.68	26%	8%	10%	12%	NA
2011	256.93	856.68	1113.6	-10%	1%	0%	0%	NA	497.2	22%	4%	5%	5%	NA
2012	240.65	715.27	955.92	-26%	-15%	-17%	-16%	NA	516.76	26%	8%	8%	8%	NA
2013	269.35	886.18	1155.5	-7%	4%	6%	3%	5%	475.2	17%	-1%	-1%	-1%	-1%
2014	300.62	971.68	1272.3	3%	14%	15%	13%	14%	437.06	9%	-9%	-10%	-10%	-8%
CWEC 1990s	287.43	948.59	1236	0%	11%	NA	NA	NA	399.74	0%	-18%	NA	NA	NA
CWEC 2016	264.77	841.23	1106	-11%	0%	NA	NA	NA	479.04	18%	0%	NA	NA	NA
HY - 17 Years	4507.96	14382.01	18890	-11%	0%	NA	NA	NA	8078.44	17%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	4886.31	16126.03	21012	0%	11%	NA	NA	NA	6795.58	0%	-18%	NA	NA	NA
CWEC 2016 -17 Years	4501.09	14300.91	18802	-11%	0%	NA	NA	NA	8143.68	18%	0%	NA	NA	NA

Table 3-11 Fast Food Restaurant - Heating and Cooling End-Use Energy

RestaurantFastFood														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	528.75	528.75	-25%	-12%	NA	NA	NA	27.41	39%	6%	NA	NA	NA
1999	0	578.44	578.44	-17%	-3%	NA	NA	NA	27.64	40%	7%	NA	NA	NA
2000	0	625.84	625.84	-9%	5%	NA	NA	NA	19.07	4%	-30%	NA	NA	NA
2001	0	559.89	559.89	-20%	-7%	NA	NA	NA	24.03	26%	-7%	NA	NA	NA
2002	0	587.95	587.95	-15%	-2%	NA	NA	NA	33.26	57%	26%	NA	NA	NA
2003	0	658.04	658.04	-4%	10%	13%	NA	NA	21.66	16%	-17%	-19%	NA	NA
2004	0	631.38	631.38	-8%	5%	5%	NA	NA	18.48	0%	-33%	-31%	NA	NA
2005	0	625.77	625.77	-9%	5%	2%	NA	NA	34.92	62%	30%	40%	NA	NA
2006	0	542.03	542.03	-23%	-10%	-12%	NA	NA	25.68	33%	0%	-3%	NA	NA
2007	0	622.43	622.43	-9%	4%	2%	NA	NA	28.72	44%	11%	7%	NA	NA
2008	0	632.15	632.15	-8%	6%	3%	6%	NA	20.09	9%	-25%	-25%	-26%	NA
2009	0	623.61	623.61	-9%	4%	2%	3%	NA	16.16	-13%	-46%	-45%	-44%	NA
2010	0	571.82	571.82	-18%	-4%	-6%	-7%	NA	30.91	51%	18%	21%	24%	NA
2011	0	595.47	595.47	-14%	0%	0%	-2%	NA	27.76	41%	8%	13%	9%	NA
2012	0	514.13	514.13	-28%	-15%	-17%	-17%	NA	30.79	50%	18%	22%	18%	NA
2013	0	628.7	628.7	-8%	5%	7%	4%	6%	23.6	25%	-9%	-6%	-8%	-9%
2014	0	686.31	686.31	1%	14%	16%	14%	13%	19.54	6%	-27%	-28%	-27%	-27%
CWEC 1990s	0	682.61	682.61	0%	13%	NA	NA	NA	18.41	0%	-33%	NA	NA	NA
CWEC 2016	0	597.85	597.85	-13%	0%	NA	NA	NA	25.71	33%	0%	NA	NA	NA
HY - 17 Years	0	10212.71	10213	-13%	0%	NA	NA	NA	429.72	31%	-2%	NA	NA	NA
CWEC 1990s - 17 Years	0	11604.37	11604	0%	13%	NA	NA	NA	312.97	0%	-33%	NA	NA	NA
CWEC 2016 -17 Years	0	10163.45	10163	-13%	0%	NA	NA	NA	437.07	33%	0%	NA	NA	NA

Table 3-12 Sit Down Restaurant- Heating and Cooling End-Use Energy

RestaurantSitDown														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	744.55	744.55	-27%	-13%	NA	NA	NA	53.12	37%	6%	NA	NA	NA
1999	0	821.22	821.22	-17%	-3%	NA	NA	NA	53.2	37%	6%	NA	NA	NA
2000	0	888.63	888.63	-9%	4%	NA	NA	NA	38.69	6%	-25%	NA	NA	NA
2001	0	790.98	790.98	-21%	-7%	NA	NA	NA	46.25	23%	-8%	NA	NA	NA
2002	0	837.9	837.9	-15%	-1%	NA	NA	NA	62.05	52%	22%	NA	NA	NA
2003	0	938.65	938.65	-4%	10%	14%	NA	NA	42.59	15%	-16%	-17%	NA	NA
2004	0	895.55	895.55	-8%	5%	5%	NA	NA	37.93	4%	-27%	-25%	NA	NA
2005	0	894.42	894.42	-9%	5%	3%	NA	NA	65.57	57%	27%	36%	NA	NA
2006	0	765.72	765.72	-24%	-10%	-13%	NA	NA	49.54	30%	-1%	-3%	NA	NA
2007	0	885.79	885.79	-9%	4%	2%	NA	NA	54.86	40%	9%	6%	NA	NA
2008	0	897.8	897.8	-8%	5%	2%	6%	NA	40.07	9%	-22%	-22%	-23%	NA
2009	0	885.15	885.15	-10%	4%	2%	3%	NA	33.31	-9%	-40%	-39%	-38%	NA
2010	0	810.76	810.76	-18%	-5%	-7%	-7%	NA	58.74	46%	16%	19%	22%	NA
2011	0	846.31	846.31	-14%	0%	0%	-2%	NA	53.32	37%	6%	12%	8%	NA
2012	0	723.63	723.63	-30%	-16%	-18%	-18%	NA	58.3	46%	15%	19%	16%	NA
2013	0	892.68	892.68	-9%	5%	7%	4%	6%	46.48	24%	-7%	-5%	-6%	-7%
2014	0	979.54	979.54	1%	14%	16%	14%	14%	39.4	7%	-24%	-24%	-23%	-23%
CWEC 1990s	0	974.12	974.12	0%	14%	NA	NA	NA	36.6	0%	-31%	NA	NA	NA
CWEC 2016	0	850.45	850.45	-14%	0%	NA	NA	NA	49.98	31%	0%	NA	NA	NA
HY - 17 Years	0	14499.28	14499	-13%	0%	NA	NA	NA	833.42	29%	-2%	NA	NA	NA
CWEC 1990s - 17 Years	0	16560.04	16560	0%	14%	NA	NA	NA	622.2	0%	-31%	NA	NA	NA
CWEC 2016 -17 Years	0	14457.65	14458	-14%	0%	NA	NA	NA	849.66	31%	0%	NA	NA	NA

Table 3-13 Primary School - Heating and Cooling End-Use Energy

SchoolPrimary														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	635.18	635.18	-25%	-15%	NA	NA	NA	280.88	28%	10%	NA	NA	NA
1999	0	718.21	718.21	-13%	-3%	NA	NA	NA	261.12	21%	2%	NA	NA	NA
2000	0	765.73	765.73	-6%	3%	NA	NA	NA	227.15	7%	-12%	NA	NA	NA
2001	0	690.89	690.89	-17%	-7%	NA	NA	NA	244.08	14%	-5%	NA	NA	NA
2002	0	682.28	682.28	-18%	-8%	NA	NA	NA	267.57	24%	5%	NA	NA	NA
2003	0	832.36	832.36	2%	12%	17%	NA	NA	228.57	8%	-11%	-11%	NA	NA
2004	0	807.64	807.64	-1%	9%	9%	NA	NA	225.2	6%	-13%	-9%	NA	NA
2005	0	762.56	762.56	-7%	3%	1%	NA	NA	291.07	32%	13%	20%	NA	NA
2006	0	664.88	664.88	-20%	-11%	-13%	NA	NA	252.15	18%	-1%	0%	NA	NA
2007	0	761.44	761.44	-7%	3%	2%	NA	NA	278.04	27%	9%	9%	NA	NA
2008	0	784.1	784.1	-4%	6%	2%	7%	NA	235.59	11%	-8%	-8%	-8%	NA
2009	0	779.56	779.56	-5%	5%	3%	4%	NA	212.49	1%	-18%	-19%	-17%	NA
2010	0	719.46	719.46	-13%	-3%	-4%	-5%	NA	280.45	28%	9%	10%	13%	NA
2011	0	736.34	736.34	-10%	-1%	-1%	-2%	NA	264.63	22%	4%	5%	5%	NA
2012	0	626.73	626.73	-26%	-17%	-19%	-18%	NA	274.83	26%	7%	8%	8%	NA
2013	0	752.87	752.87	-8%	2%	3%	1%	3%	255.33	19%	0%	1%	0%	0%
2014	0	846.04	846.04	4%	13%	16%	13%	14%	221.18	5%	-14%	-15%	-15%	-14%
CWEC 1990s	0	816.12	816.12	0%	10%	NA	NA	NA	211.29	0%	-19%	NA	NA	NA
CWEC 2016	0	740.63	740.63	-10%	0%	NA	NA	NA	255.33	19%	0%	NA	NA	NA
HY - 17 Years	0	12566.27	12566	-10%	0%	NA	NA	NA	4300.33	18%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	0	13874.04	13874	0%	10%	NA	NA	NA	3591.93	0%	-19%	NA	NA	NA
CWEC 2016 -17 Years	0	12590.71	12591	-10%	0%	NA	NA	NA	4340.61	19%	0%	NA	NA	NA

Table 3-14 Secondary School - Heating and Cooling End-Use Energy

SchoolSecondary														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	1020.49	1020.49	-37%	-20%	NA	NA	NA	923.18	30%	9%	NA	NA	NA
1999	0	1204.21	1204.21	-21%	-4%	NA	NA	NA	867.6	24%	2%	NA	NA	NA
2000	0	1324.21	1324.21	-11%	6%	NA	NA	NA	742.16	8%	-13%	NA	NA	NA
2001	0	1124.57	1124.57	-27%	-11%	NA	NA	NA	809.32	17%	-5%	NA	NA	NA
2002	0	1098.18	1098.18	-30%	-13%	NA	NA	NA	896.33	27%	6%	NA	NA	NA
2003	0	1451.37	1451.37	-2%	15%	23%	NA	NA	745.34	9%	-13%	-13%	NA	NA
2004	0	1426.77	1426.77	-4%	13%	14%	NA	NA	739.44	8%	-14%	-9%	NA	NA
2005	0	1341.26	1341.26	-10%	7%	4%	NA	NA	975.11	35%	14%	21%	NA	NA
2006	0	1068.45	1068.45	-32%	-16%	-19%	NA	NA	845.71	21%	0%	2%	NA	NA
2007	0	1374.75	1374.75	-7%	9%	7%	NA	NA	924.05	30%	9%	9%	NA	NA
2008	0	1363.34	1363.34	-8%	9%	2%	9%	NA	768.36	12%	-10%	-10%	-10%	NA
2009	0	1364.13	1364.13	-8%	9%	4%	7%	NA	697.47	2%	-19%	-20%	-18%	NA
2010	0	1255.52	1255.52	-17%	0%	-4%	-3%	NA	923.77	30%	9%	9%	13%	NA
2011	0	1255.75	1255.75	-16%	0%	-2%	-2%	NA	871.96	24%	3%	5%	5%	NA
2012	0	997.35	997.35	-39%	-23%	-28%	-26%	NA	916.82	29%	8%	9%	9%	NA
2013	0	1313.22	1313.22	-12%	5%	5%	2%	5%	836.58	20%	-1%	0%	-1%	-1%
2014	0	1553.2	1553.2	5%	22%	23%	20%	21%	725.65	6%	-15%	-16%	-16%	-14%
CWEC 1990s	0	1481.4	1481.4	0%	17%	NA	NA	NA	682.68	0%	-22%	NA	NA	NA
CWEC 2016	0	1250.81	1250.81	-17%	0%	NA	NA	NA	847.15	22%	0%	NA	NA	NA
HY - 17 Years	0	21536.77	21536.8	-16%	1%	NA	NA	NA	14208.85	20%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	0	25183.8	25183.8	0%	17%	NA	NA	NA	11605.56	0%	-22%	NA	NA	NA
CWEC 2016 -17 Years	0	21263.77	21263.8	-17%	0%	NA	NA	NA	14401.55	22%	0%	NA	NA	NA

Table 3-15 Warehouse - Heating and Cooling End-Use Energy

Warehouse														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	570.56	570.56	-46%	-29%	NA	NA	NA	1.31	27%	-7%	NA	NA	NA
1999	0	738.66	738.66	-21%	-4%	NA	NA	NA	1.36	31%	-4%	NA	NA	NA
2000	0	821.5	821.5	-11%	7%	NA	NA	NA	0.96	-4%	-38%	NA	NA	NA
2001	0	673.97	673.97	-30%	-13%	NA	NA	NA	1.32	28%	-7%	NA	NA	NA
2002	0	739.15	739.15	-21%	-4%	NA	NA	NA	1.55	43%	9%	NA	NA	NA
2003	0	896.07	896.07	-2%	16%	23%	NA	NA	1.18	17%	-18%	-10%	NA	NA
2004	0	867.69	867.69	-5%	12%	11%	NA	NA	0.91	-9%	-43%	-33%	NA	NA
2005	0	844.8	844.8	-8%	10%	5%	NA	NA	1.64	48%	15%	32%	NA	NA
2006	0	666.58	666.58	-31%	-14%	-19%	NA	NA	1.44	36%	2%	9%	NA	NA
2007	0	899.09	899.09	-2%	16%	11%	NA	NA	1.41	34%	0%	5%	NA	NA
2008	0	828.25	828.25	-10%	8%	-1%	7%	NA	1.06	6%	-28%	-22%	-21%	NA
2009	0	824.16	824.16	-10%	7%	0%	3%	NA	0.92	-8%	-42%	-34%	-33%	NA
2010	0	782.37	782.37	-16%	2%	-4%	-3%	NA	1.52	41%	8%	16%	20%	NA
2011	0	756.04	756.04	-19%	-1%	-6%	-6%	NA	1.6	46%	13%	23%	21%	NA
2012	0	570.66	570.66	-46%	-29%	-36%	-35%	NA	1.54	43%	9%	17%	15%	NA
2013	0	789.62	789.62	-15%	3%	5%	0%	3%	1.37	31%	-3%	3%	4%	4%
2014	0	1001.27	1001.3	9%	27%	29%	24%	25%	0.93	-7%	-41%	-40%	-36%	-35%
CWEC 1990s	0	914.34	914.34	0%	18%	NA	NA	NA	1	0%	-34%	NA	NA	NA
CWEC 2016	0	765.98	765.98	-18%	0%	NA	NA	NA	1.41	34%	0%	NA	NA	NA
HY - 17 Years	0	13270.44	13270	-16%	2%	NA	NA	NA	22.02	26%	-8%	NA	NA	NA
CWEC 1990s - 17 Years	0	15543.78	15544	0%	18%	NA	NA	NA	17	0%	-34%	NA	NA	NA
CWEC 2016 -17 Years	0	13021.66	13022	-18%	0%	NA	NA	NA	23.97	34%	0%	NA	NA	NA

Table 3-16 High Rise Apartment - Heating and Cooling End-Use Energy

ApartmentHighRise														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	81.31	241.77	323.08	-81%	-54%	NA	NA	NA	320.89	32%	10%	NA	NA	NA
1999	116.59	371.86	488.45	-44%	-14%	NA	NA	NA	305.66	28%	5%	NA	NA	NA
2000	139.59	463.62	603.21	-23%	7%	NA	NA	NA	255.75	10%	-12%	NA	NA	NA
2001	106.4	335.55	441.95	-53%	-24%	NA	NA	NA	275.55	17%	-5%	NA	NA	NA
2002	124.71	393.5	518.21	-38%	-9%	NA	NA	NA	316.15	31%	9%	NA	NA	NA
2003	153.76	513.14	666.9	-13%	17%	34%	NA	NA	256.15	10%	-12%	-14%	NA	NA
2004	151.67	505.72	657.39	-15%	15%	19%	NA	NA	233.63	1%	-21%	-19%	NA	NA
2005	152.42	504.37	656.79	-15%	15%	13%	NA	NA	338.24	37%	16%	23%	NA	NA
2006	108.08	339	447.08	-52%	-23%	-27%	NA	NA	280.21	19%	-3%	-1%	NA	NA
2007	168.17	567.62	735.79	-3%	26%	22%	NA	NA	306.32	28%	6%	7%	NA	NA
2008	151.36	499.59	650.95	-16%	14%	3%	16%	NA	256.45	10%	-12%	-10%	-12%	NA
2009	138.63	455.54	594.17	-25%	5%	-6%	1%	NA	224.71	-3%	-25%	-23%	-23%	NA
2010	140.1	461.6	601.7	-23%	6%	-3%	1%	NA	314.87	30%	8%	11%	14%	NA
2011	125.87	405.9	531.77	-36%	-6%	-13%	-12%	NA	292.99	23%	1%	6%	4%	NA
2012	91.72	279.68	371.4	-69%	-41%	-51%	-48%	NA	332.72	36%	14%	18%	17%	NA
2013	141.98	461.61	603.59	-23%	7%	9%	2%	9%	274.07	17%	-5%	-4%	-3%	-5%
2014	184.28	623.69	807.97	6%	35%	40%	32%	34%	242.15	4%	-18%	-17%	-16%	-16%
CWEC 1990s	175.88	585.89	761.77	0%	30%	NA	NA	NA	231.57	0%	-22%	NA	NA	NA
CWEC 2016	133.16	431.4	564.56	-30%	0%	NA	NA	NA	289.42	22%	0%	NA	NA	NA
HY - 17 Years	2276.64	7423.76	9700.4	-29%	1%	NA	NA	NA	4826.51	20%	-2%	NA	NA	NA
CWEC 1990s - 17 Years	2989.96	9960.13	12950.1	0%	30%	NA	NA	NA	3936.69	0%	-22%	NA	NA	NA
CWEC 2016 -17 Years	2263.72	7333.8	9597.52	-30%	0%	NA	NA	NA	4920.14	22%	0%	NA	NA	NA

Table 3-17 Mid-Rise Apartment - Heating and Cooling End-Use Energy

ApartmentMidRise														
	Heating								Cooling					
Year	Electricity [GJ]	Natural Gas [GJ]	Total [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years	Electricity [GJ]	%Difference with CWEC 1990	%Difference with CWEC 2016	%Difference with AVG 5 Years	%Difference with AVG 10 Years	%Difference with AVG 15 Years
1998	0	112.89	112.89	-71%	-45%	NA	NA	NA	98.83	28%	8%	NA	NA	NA
1999	0	162.01	162.01	-37%	-10%	NA	NA	NA	95.64	25%	5%	NA	NA	NA
2000	0	191.59	191.59	-21%	7%	NA	NA	NA	82.45	10%	-10%	NA	NA	NA
2001	0	143.41	143.41	-49%	-22%	NA	NA	NA	88.55	17%	-3%	NA	NA	NA
2002	0	163.33	163.33	-36%	-9%	NA	NA	NA	96.96	26%	6%	NA	NA	NA
2003	0	212.42	212.42	-11%	17%	31%	NA	NA	82.68	10%	-10%	-11%	NA	NA
2004	0	208.98	208.98	-12%	15%	18%	NA	NA	79.67	7%	-14%	-11%	NA	NA
2005	0	206.85	206.85	-13%	14%	12%	NA	NA	102.54	32%	12%	17%	NA	NA
2006	0	140.89	140.89	-50%	-24%	-28%	NA	NA	89.83	19%	-2%	0%	NA	NA
2007	0	224.35	224.35	-5%	22%	18%	NA	NA	96.9	26%	6%	7%	NA	NA
2008	0	201.98	201.98	-16%	12%	2%	13%	NA	83.55	11%	-9%	-8%	-9%	NA
2009	0	192.47	192.47	-20%	7%	-2%	4%	NA	76.27	2%	-18%	-17%	-16%	NA
2010	0	186.11	186.11	-24%	4%	-4%	-1%	NA	99.36	28%	8%	10%	12%	NA
2011	0	171.81	171.81	-31%	-4%	-10%	-9%	NA	93.06	22%	2%	4%	4%	NA
2012	0	119.87	119.87	-65%	-40%	-48%	-46%	NA	100.89	30%	10%	12%	11%	NA
2013	0	191.04	191.04	-21%	6%	9%	2%	8%	90.3	19%	-1%	0%	0%	-1%
2014	0	253.42	253.42	7%	34%	38%	32%	33%	81.23	8%	-12%	-12%	-12%	-11%
CWEC 1990s	0	235.96	235.96	0%	27%	NA	NA	NA	74.61	0%	-20%	NA	NA	NA
CWEC 2016	0	179.17	179.17	-27%	0%	NA	NA	NA	91.34	20%	0%	NA	NA	NA
HY - 17 Years	0	3083.42	3083.4	-26%	1%	NA	NA	NA	1538.71	19%	-1%	NA	NA	NA
CWEC 1990s - 17 Years	0	4011.32	4011.3	0%	27%	NA	NA	NA	1268.37	0%	-20%	NA	NA	NA
CWEC 2016 -17 Years	0	3045.89	3045.9	-27%	0%	NA	NA	NA	1552.78	20%	0%	NA	NA	NA

3.5 Concluding Remarks

In the first comparison, the total (17 years) heating and cooling energy estimation using CWEC 2016 is close to the sum estimation from Historical Year simulation between 1998 to 2014. In other words, simulation based on CWEC 2016 is representative of the weather condition ranging from year 1998 to 2014 if the purpose is to compare the total heating and cooling energy usage. This can be explained by understanding the selection method for TY type weather files. CWEC 2016 is selected to represent the average conditions in CWEEDs historical weather data, in which the fluctuation between warmer and colder years as shown in the weather indices analysis in Chapter 2 cancels out, this is why Typical Year type weather files can be used in BES for average energy estimation [3]. However, an issue with current practices is that CWEC 2016 was not made available until 2016, which is 2 years after 2014 – the last year of Historical Year weather data used in this research. During 1998 to 2014, the best available "representative" weather data is CWEC 1990s. From analysis in this chapter, it is shown that there are large deviations when the sum energy estimation from historical year simulation is compared with the total energy estimation using CWEC 1990s, in which simulations using CWEC 1990s generally over estimated total heating energy use and under estimated total cooling energy use. This is an indication that it is not a good representation of the historical year from a Building Energy Simulation perspective, and there is a need for alternative.

In terms of year to year heating and cooling energy estimations, neither estimation from simulation using CWEC 1990s nor CWEC 2016 yielded consistently good estimation with Historical Year simulations. With CWEC 1990s, there is tendency of under estimation of cooling energy and over estimation of heating energy for most building types under most historical years. With CWEC 2016, the deviation with yearly historical simulation estimations are cyclical with over and under estimation. The large year to year deviation is expected, as simulation with Typical Year only yields one outcome, in which the year to year variation in actual historical year weather data is not reflected.

As a simple potential alternative, estimations based on rolling averages of 5, 10 and 15 years of historical year simulation are calculated. Based on an analysis comparing the differences with yearly historical estimation, it is found that a rolling average with 5, 10 and 15 years can yield close estimates with the estimation using CWEC 2016. This result is promising, since a rolling average estimation can be more appropriate than using a Typical Year weather file created with vintage weather data, especially if update cycles are not frequent. Further investigation is needed to determine the optimal range, and also if it is feasible to update historical year weather annually.

Chapter 4 Impact on HVAC Equipment Sizing

4.1 Introduction

The previous chapter focuses on the impact of using different weather data on the estimation of energy usage for heating and cooling in Building Energy simulation. This chapter focuses on the impact on estimation of unmet hours and peak heating & cooling energy loads. Unmet hour is an indicator that can inform designers whether the combined building design and HVAC equipment is sufficient in keeping the temperature of a space within the range of setpoint/desired temperature. Peak heating and cooling energy loads inform designers the maximum amount of end use energy required to operate the heating and cooling equipment. To reiterate, under current practice, building design is analyzed with simulation using Typical Year weather files [3]. This yields a single output and can be problematic as it is shown in Chapter 2 that long-term weather conditions vary and cannot be represented by a singular condition. This is especially applicable to equipment sizing and the associated analysis – as equipment usually needs to be tested against more extreme conditions[3], because they are expected to maintain the indoor environment even during relatively extreme events.

Currently, HVAC equipment sizing is conducted based on design day data, this is different from the hourly weather data used in typical and historical year weather files. The main purpose of the design day data is to be used for sizing of equipment based on statistically extreme situations. Current design day data used in North America is published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers(ASHRAE) and is updated every 4 years with each version of the ASHRAE Handbook of Fundamentals(HOF)[52], [56]–[58]. The details on the generation method is discussed in the climate chapter in the Handbook of Fundamentals [52], [56]–[58]. However, to provide background information and further the discussion on this study, some aspects will be discussed below.

To differentiate the different weather data used in this chapter, **design weather data** refers to the design day data used for equipment sizing, whereas **simulation weather data** refers to the typical or historical weather data used for building energy simulation.

4.1.1 - ASHRAE and OBC SB -1 design weather data

ASHRAE Design Data

In ASHRAE HOF[52], there is a list of required weather elements used for the sizing of different HVAC equipment to represent various design conditions – design day data. Similar to the selection of Typical Year weather data, the compilation of design day data is based on statistical selection [52], [56]–[58]. The fundamental logic is to select extreme conditions from the most recently available historical weather dataset, usually with 25 to 30 years of data [59][60]. Sizing of equipment is based on peak load for buildings operating in those conditions. For heating equipment sizing, the 99% and 99.6% dry bulb temperature, or in statistical terms the 1st and 0.4th quartile of a historical dataset is used. Similarly, 0.4%, 1% or 2% dry bulb temperature – 99.6th, 99th and 98th quartile is selected for cooling equipment sizing. Figure 4-1 shows the changes of design day Dry-Bulb Temperature from 2005 to 2017 for the Toronto Pearson Airport, the information is obtained from HOF 2005[56], 2009[57], 2013[52], and 2017[58]. While the changes are subtle, there is an increasing trend in dry bulb temperature used for both heating and cooling sizing.

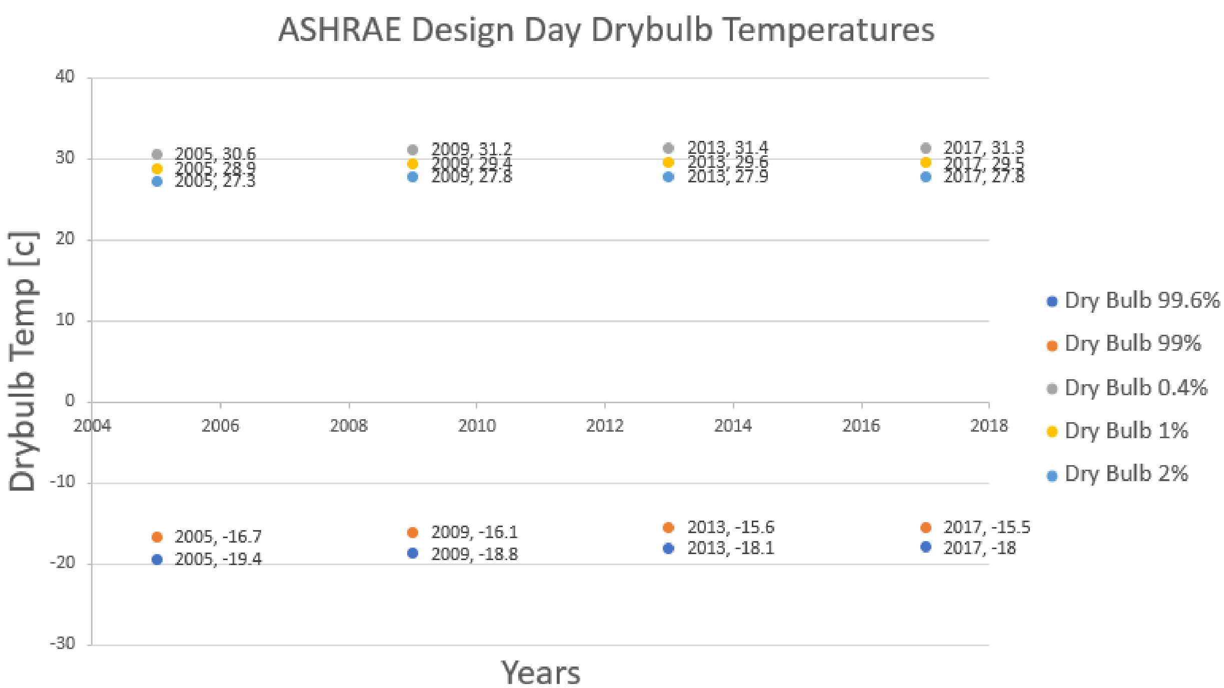


Figure 4-1 ASHRAE Design Dry Bulb Temperature 2005 to 2017

OBC SB-1 Design Data

In the province of Ontario, where Toronto is located, the Ontario Building Code is the legislation that regulates practices in building design and construction. In OBC 2012 section 9.33.3.2, it is stated that design conditions in supplementary standard SB-1 should be used for heating and cooling equipment sizing [61]. While the data source for both ASHRAE (HOF 2009 version) and SB-1 conditions share the same data source[62], the selection criteria is different. The main difference is ASHRAE design data is calculated based on annual cumulative distribution[57], whereas SB-1 is calculated based on month cumulative distribution (January for heating, July for cooling)[62]. Table 4-1 compares the difference between ASHRAE HOF 2009 design data with SB-1 design data for Toronto Pearson Airport.

Table 4-1 Comparison of ASHRAE and SB-1 Design Dry Bulb Temperatures of Toronto Pearson Airport

	SB – 1 (2014 version) [62]	ASHRAE HOF (2009 version) [57]
Dry Bulb Temperature for Cooling Equipment Sizing [^{O}C]	31 (2.5% condition)	31.2 ^{O}C (0.4% condition) 29.4 ^{O}C (1% condition) 27.8 ^{O}C (2% condition)
Dry Bulb Temperature for Heating Equipment Sizing [^{O}C]	-20^{O}C (2.5% condition) -22 ^{O}C (1% condition)	-16.1^{O}C (99% condition) -18.8 ^{O}C (99.6% condition)

For the purpose of this research, the ASHRAE HOF design data is used for simulation, since there are multiple versions of the ASHRAE design data available, which is more appropriate for analysis. In contrast, there is only one version of SB-1 design data published in 2014.

4.1.2 - Different update cycles of weather data

While the utilization of **design weather data** is generally adequate for equipment sizing – which can be conducted independent of full year simulations, the actual performance of the building is still determined from full year simulation – in which infrequently updated **simulation weather data** is used. To further emphasize, the concern at hand is whether equipment sized with more frequently updated design data perform differently in the infrequently updated Typical Year weather data?

As mentioned, the update cycle of design weather data is tied with updates of the ASHRAE Handbook of Fundamentals, which is generally updated every 4 years. In contrast, simulation weather data (for example - Typical Year Weather file) is not updated in a fixed schedule. So far in Canada, there has only been two updates, one in the 1990s and a more recent update in 2016, in which they are almost 2 decades apart. As illustrated and discussed in Chapter 2, the changes of the long-term weather conditions represented by the Typical Year weather files are different. CWEC 1990s have a colder winter and milder summer, whereas the newer CWEC 2016, due to changes of global climate and local development has warmer winter and hotter summers. The actual Historical Years also have different characteristics, which is not captured in the Typical Year weather files. Figure 4-2 shows the different update timeline of weather data, and the range of weather data source that they contain or represent.

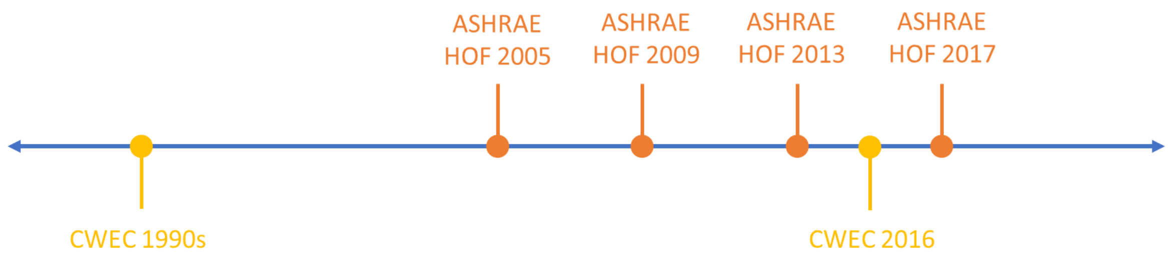


Figure 4-2 Update timeline of design and simulation weather data

4.1.3 - Comparison of design data and simulation data

With any statistical selection, the quality and quantity of the dataset is key. For weather dataset used for building energy simulation, the source and time range of the data are especially important. Fortunately for Canadians, Environment and Climate Change Canada maintains a good quality set of historical weather data with wide coverage in location and historical time range. Both the source of the weather used for design day data selection [59][60] and for simulation[15][17] are from Environment and Climate Change Canada. However, the time range used for the selection of the two different types of datasets are different. The ASHRAE Design Day Data is usually selected from 25 to 30 years of historical data – the 2005 data is selected from 1982 to 2001[59], and the 2013 data is selected from 1986 to 2010[60]; for simulation data, CWEC 1990s is generally selected from 1969 to 1989[17], CWEC 2016 is selected from 1998 to 2014[15]; and the current release of Historical CWEEDs is from 1998 to 2014[15]. A comparison is made in dry bulb temperature between the design day data (HOF 2005, HOF 2013) and the actual weather data used for simulation (CWEC 1990s, CWEC 2016 and CWEEDs 1998 to 2014).

Table 4-2 Comparison of 99.4% and 0.4% Design Condition

	Design Data		**Simulation Data**		
	Handbook of Fundamentals 2005 (Historical 1972 to 2001) [56]	**Handbook of Fundamentals 2013 (Historical 1986 to 2010)** [52]	**CWEC 1990s**	**CWEC 2016**	**CWEEDs 1998 to 2014**
0.4% Design Condition [ºC]	30.6	31.4	30.0	31.7	31.7
99.6% Design Condition [ºC]	-19.4	-18.1	-16.7	-17.0	-17.5

From Table 4-2, it is expected that the design data found in HOF 2005 should meet most of the heating demands under the conditions in simulation data, whereas there may be more unmet cooling hours due to the relatively large difference in the 0.4% condition when compared to the simulation data with CWEC 2016 and CWEEDs 1998 to 2014. The updated design data found in HOF 2013 also exceeds the 99.6% design condition for all simulated conditions and is very close to the 0.4% design condition with CWEC 2016 and CWEEDs 1998 to 2014, and hence in theory equipment sized with these conditions should meet most of the demands.

4.2 Research Questions:

The goal of this chapter is to investigate whether the use of different design and simulation weather data affect the performance of buildings with regards to heating and cooling. The research questions to be explored and their justifications are presented as follow:

1) *Do buildings with equipment sized with updated design data behave differently when simulated with simulation weather data created to represent weather conditions of different time periods?*

The first research question is a practical one that aims to explore the impact related to the current "out of sync" update and release cycle of weather data. As seen in Figure 4-2 the update cycle of ASHRAE HOF is not in sync with Typical Year Weather files. There are time periods where building design with equipment sized with more updated design day data is simulated with older Typical Year weather file, which is created to represent historical weather years from an older time period. The interest of this research topic is to investigate how design analysis differ between the use of CWEC 2016 and CWEC 1990s when equipment sizing is completed with design data from ASHRAE HOF 2013. This is especially interesting as buildings designs evaluated between 2013 and 2015 can potentially have different results than buildings designed between 2016 and 2017, just based on the weather data made available for designers to use.

2) Do buildings with equipment sized with updated weather data perform better?

The second question is an exploration to investigate whether sizing equipment with updated design data leads to better performing buildings in simulation. As well as whether there are differences in analysis when different Typical Year weather files are used.

3) ***How does equipment sized with different design data perform in simulation using historical CWEEDs weather data?***

Finally, the last research question of this chapter explores the differences between simulation using Historical and Typical weather data, when different design data is used for heating and cooling equipment sizing. The goal is to potentially identify and highlight insights that are not captured from a singular output condition, in which multi-year simulation can provide.

4.3 Methodology

The logic of the methodology for this chapter is as follow: it involves sizing of heating and cooling equipment with different sets of design data – ASHRAE HOF 2005 and HOF2013; buildings with the sized equipment is then simulated under different simulation weather data CWEC 1990s, CWEC 2016 and CWEEDs 1998 to 2014. Finally, analysis is conducted by comparing different simulation results.

4.3.1 - Building model and simulation weather data:

Building models used in this study is the same as the previous chapter – DOE prototype buildings designed to meet ASHRAE 90.1 – 2016[51]. Weather data used for simulation are CWEC 2016 (statistically selected to represent long term weather conditions between 1998 to 2014), CWEC 1990s (statistically selected to represent long term weather conditions between 1953 to 1989) and CWEEDs 1998 to 2014. EnergyPlus 8.0 is used to run the simulations.

4.3.2 - Design weather data:

Simulation is conducted with design data from the 2005 and 2013 version of the ASHRAE Handbook of Fundamentals. For the purpose of this study, only two design day conditions are used – one for winter heating (99.6%) and the other for summer cooling (0.4%). This is to be consistent with sizing conditions used in the DOE prototype building models. Figure 4-3 to 4-6 shows the design day configuration setup in Energy Plus for reference.

2005 HOF Design Day for heating and cooling equipment sizing

```
SizingPeriod:DesignDay,
    Toronto_International_Ann Htg 99.6% Condns DB,  !- Name
    1,                       !- Month
    21,                      !- Day of Month
    WinterDesignDay,         !- Day Type
    -19.4,                   !- Maximum Dry-Bulb Temperature {C}
    0.0,                     !- Daily Dry-Bulb Temperature Range {deltaC}
    DefaultMultipliers,      !- Dry-Bulb Temperature Range Modifier Type
    ,                        !- Dry-Bulb Temperature Range Modifier Day Schedule Name
    DewPoint,                !- Humidity Condition Type
    -23.4,                   !- Wetbulb or DewPoint at Maximum Dry-Bulb {C}
    ,                        !- Humidity Condition Day Schedule Name
    ,                        !- Humidity Ratio at Maximum Dry-Bulb {kgWater/kgDryAir}
    ,                        !- Enthalpy at Maximum Dry-Bulb {J/kg}
    ,                        !- Daily Wet-Bulb Temperature Range {deltaC}
    99260,                   !- Barometric Pressure {Pa}
    4.2,                     !- Wind Speed {m/s}
    340,                     !- Wind Direction {deg}
    No,                      !- Rain Indicator
    No,                      !- Snow Indicator
    No,                      !- Daylight Saving Time Indicator
    ASHRAEClearSky,          !- Solar Model Indicator
    ,                        !- Beam Solar Day Schedule Name
    ,                        !- Diffuse Solar Day Schedule Name
    ,                        !- ASHRAE Clear Sky Optical Depth for Beam Irradiance (taub) {dimensionless}
    ,                        !- ASHRAE Clear Sky Optical Depth for Diffuse Irradiance (taud) {dimensionless}
    0.00;                    !- Sky Clearness
```

Figure 4-3 EnergyPlus Design Day Setup with data from 2005 ASHRAE Handbook of Fundamentals (Winter Heating)

```
SizingPeriod:DesignDay,
    Toronto_International_Ann Clg .4% Condns DB=>MWB,  !- Name
    7,                       !- Month
    21,                      !- Day of Month
    SummerDesignDay,         !- Day Type
    30.6,                    !- Maximum Dry-Bulb Temperature {C}
    10.6,                    !- Daily Dry-Bulb Temperature Range {deltaC}
    DefaultMultipliers,      !- Dry-Bulb Temperature Range Modifier Type
    ,                        !- Dry-Bulb Temperature Range Modifier Day Schedule Name
    Wetbulb,                 !- Humidity Condition Type
    21.9,                    !- Wetbulb or DewPoint at Maximum Dry-Bulb {C}
    ,                        !- Humidity Condition Day Schedule Name
    ,                        !- Humidity Ratio at Maximum Dry-Bulb {kgWater/kgDryAir}
    ,                        !- Enthalpy at Maximum Dry-Bulb {J/kg}
    ,                        !- Daily Wet-Bulb Temperature Range {deltaC}
    99260,                   !- Barometric Pressure {Pa}
    5.5,                     !- Wind Speed {m/s}
    270,                     !- Wind Direction {deg}
    No,                      !- Rain Indicator
    No,                      !- Snow Indicator
    No,                      !- Daylight Saving Time Indicator
    ASHRAETau,               !- Solar Model Indicator
    ,                        !- Beam Solar Day Schedule Name
    ,                        !- Diffuse Solar Day Schedule Name
    0.473,                   !- ASHRAE Clear Sky Optical Depth for Beam Irradiance (taub) {dimensionless}
    1.952;                   !- ASHRAE Clear Sky Optical Depth for Diffuse Irradiance (taud) {dimensionless}
```

Figure 4-4 EnergyPlus Design Day Setup with data from 2005 ASHRAE Handbook of Fundamentals (Summer Cooling)

2013 HOF Design Day for heating and cooling equipment sizing

```
SizingPeriod:DesignDay,
    Toronto_International_Ann Htg 99.6% Condns DB,  !- Name
    1,                        !- Month
    21,                       !- Day of Month
    WinterDesignDay,          !- Day Type
    -18.1,                    !- Maximum Dry-Bulb Temperature {C}
    0.0,                      !- Daily Dry-Bulb Temperature Range {deltaC}
    DefaultMultipliers,       !- Dry-Bulb Temperature Range Modifier Type
    ,                         !- Dry-Bulb Temperature Range Modifier Day Schedule Name
    DewPoint,                 !- Humidity Condition Type
    -23.3,                    !- Wetbulb or DewPoint at Maximum Dry-Bulb {C}
    ,                         !- Humidity Condition Day Schedule Name
    ,                         !- Humidity Ratio at Maximum Dry-Bulb {kgWater/kgDryAir}
    ,                         !- Enthalpy at Maximum Dry-Bulb {J/kg}
    ,                         !- Daily Wet-Bulb Temperature Range {deltaC}
    99260,                    !- Barometric Pressure {Pa}
    4.8,                      !- Wind Speed {m/s}
    0,                        !- Wind Direction {deg}
    No,                       !- Rain Indicator
    No,                       !- Snow Indicator
    No,                       !- Daylight Saving Time Indicator
    ASHRAEClearSky,           !- Solar Model Indicator
    ,                         !- Beam Solar Day Schedule Name
    ,                         !- Diffuse Solar Day Schedule Name
    ,                         !- ASHRAE Clear Sky Optical Depth for Beam Irradiance (taub) {dimensionless}
    ,                         !- ASHRAE Clear Sky Optical Depth for Diffuse Irradiance (taud) {dimensionless}
    0.00;                     !- Sky Clearness
```

Figure 4-5 EnergyPlus Design Day Setup with data from 2013 ASHRAE Handbook of Fundamentals (Winter Heating)

```
SizingPeriod:DesignDay,
    Toronto_International_Ann Clg .4% Condns DB=>MWB,  !- Name
    7,                        !- Month
    21,                       !- Day of Month
    SummerDesignDay,          !- Day Type
    31.4,                     !- Maximum Dry-Bulb Temperature {C}
    9.9,                      !- Daily Dry-Bulb Temperature Range {deltaC}
    DefaultMultipliers,       !- Dry-Bulb Temperature Range Modifier Type
    ,                         !- Dry-Bulb Temperature Range Modifier Day Schedule Name
    Wetbulb,                  !- Humidity Condition Type
    22.4,                     !- Wetbulb or DewPoint at Maximum Dry-Bulb {C}
    ,                         !- Humidity Condition Day Schedule Name
    ,                         !- Humidity Ratio at Maximum Dry-Bulb {kgWater/kgDryAir}
    ,                         !- Enthalpy at Maximum Dry-Bulb {J/kg}
    ,                         !- Daily Wet-Bulb Temperature Range {deltaC}
    99260,                    !- Barometric Pressure {Pa}
    5.8,                      !- Wind Speed {m/s}
    270,                      !- Wind Direction {deg}
    No,                       !- Rain Indicator
    No,                       !- Snow Indicator
    No,                       !- Daylight Saving Time Indicator
    ASHRAETau,                !- Solar Model Indicator
    ,                         !- Beam Solar Day Schedule Name
    ,                         !- Diffuse Solar Day Schedule Name
    0.386,                    !- ASHRAE Clear Sky Optical Depth for Beam Irradiance (taub) {dimensionless}
    2.282;                    !- ASHRAE Clear Sky Optical Depth for Diffuse Irradiance (taud) {dimensionless}
```

Figure 4-6 EnergyPlus Design Day Setup with data from 2013 ASHRAE Handbook of Fundamentals (Summer Cooling)

4.3.3 - Simulation sets:

The analysis completed in this chapter involves the comparison of simulation using different combinations of design and simulation data. Since there are different versions of weather data, the comparisons can be confusing. Table 4-3 lists the simulation sets and states the conditions they are set to represent.

Table 4-3 Simulation Sets

Simulation sets completed	Represented Conditions
Typical Year Simulations	
CWEC 1990s with HOF 2005	Best practice with available information between 2005 to 2009
CWEC 1990s with HOF 2013	Best practice with available information between 2013 to 2016
CWEC 2016 with HOF 2005	Investigating how equipment sized in 2005 would perform in the updated weather file that is statistically representing the long-term weather between 1998 to 2014
CWEC 2016 with HOF 2013	Best practice with available information in 2016
Historical Years Simulations	
CWEEDs 1998 to 2014 with HOF 2005	Simulation with equipment sized with older design data under actual operating condition
CWEEDs 1998 to 2014 with HOF 2013	Simulation with equipment sized with updated design data under historical condition.

4.3.4 - Comparison of simulation sets

1) Comparison between simulation using CWEC 1990s and CWEC 2016 (HOF 2013)

This comparison is hoping to address the first research question of whether buildings with equipment sized with updated design data perform differently when Typical Year weather files created with data from different time periods are used. This is a common scenario due to the “out of sync” update cycle of sizing design and simulation weather data. Results from simulation using CWEC 1990s and CWEC 2016 with equipment sized using ASHRAE HOF 2013 are compared.

2) Comparison between simulation under CWEC 1990s and CWEC 2016 (HOF 2005 and HOF 2013)

This comparison is hoping to answer the second research question. The goal is to determine if sizing equipment with updated design weather data would actually lead to better performing buildings? And whether the use of different simulation weather files would change the analysis.

This comparison is divided into two parts. The first part is the comparison of buildings with equipment sized with HOF 2005 and HOF 2013 respectively and simulated under CWEC 1990s. This comparison is of interest, since the update of design data is supposedly to have equipment sized under the most recent design conditions, and theoretically expected to perform better. However, if the simulation data remains the same, in this case a representation of older weather conditions, does this expectation still hold?

The second part compares buildings with equipment sized with HOF 2005 and HOF 2013 and simulated under CWEC 2016. This comparison would be used to contrast the results from part 1, as it is generally expected that the design condition in HOF 2013 is a good representation of the extreme conditions presented in CWEC 2016.

3) Comparison between Typical Year simulation and Multi Historical Year simulation

As seen in Chapter 2, there are year to year differences in historical year weather data. The goal of this comparison is to highlight the range of simulation results that are not captured by Typical Year simulation. Figure 4-7 shows the organization of the analysis of results. To briefly summarize, the comparison is separated into unmet hour and peak load estimations, since they serve very different purposes and the effects of different weather inputs can be different. Then the comparison is separated into different design day data. Finally, comparison is made across different weather files – CWEC 1990s, CWEC 2016 and Historical simulations.

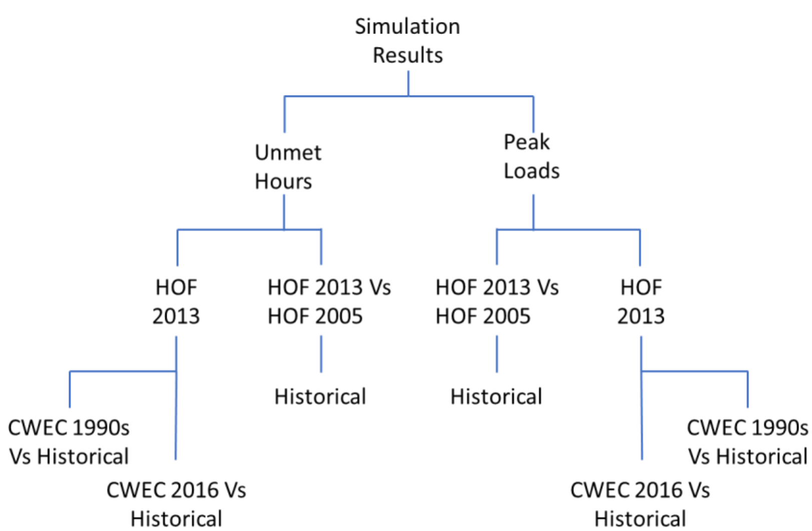


Figure 4-7 Organization of Historical Simulation

4.3.5 - Metrics compared:

To evaluate the impact of different weather datasets on HVAC systems, two metrics are evaluated – ***Unmet Hours*** and ***Peak Load Demands*** used for heating and cooling.

1) ***Unmet hours*** – for heating and cooling during occupied hours.

Unmet hours as defined in the ASHRAE energy standard 90.1 -2016 is any hour where the temperature of 1 or more zones does not meet the setpoint temperature [37]. While this is not hard to understand in theoretical sense, and ideally there should be equipment that can supplement heating and cooling loads on demand. In practice however, the temperature of a space/zone is not always static, as the sensing and controls of HVAC equipment are not instantaneous. Therefore, a level of tolerance is often allowed for the calculation of unmet hours. In ASHRAE 90.1 it is stated that the tolerance used should be no more than 0.5 ^{o}C [37], whereas the default tolerance used in EnergyPlus and the DOE prototype models is 0.2 ^{o}C. This difference can have large impact on the results, which is further discussed in section 4.4.4.

2) ***Peak Loads***– for heating and cooling

Peak Loads considered in this chapter are the subcategorized demands based on end use applications. The peak loads compared are natural gas and electricity load for heating, and electricity load for cooling.

4.4 Results and Discussion

4.4.1 - Comparison between simulation using CWEC 1990s and CWEC 2016 (HOF 2013):

From the analysis in Chapter 2, it is generally expected that CWEC 1990s represents a year with a colder winter and milder summer when compared to CWEC 2016. Of all the ASHRAE design data compared, design data from HOF 2013 has the highest 0.4% summer design day dry bulb temperature, and the second highest 99.6% winter heating design day dry bulb temperature. Logically speaking, it is expected that sizing with HOF 2013 design data would yield larger cooling equipment capacity and smaller heating equipment capacity when compared to equipment sized with older Design Data. Further, Table 4-2 shows that the sizing data generally fits closely to the 99.6% and 0.4% sizing criteria calculated from the CWEC 2016 and CWEEDs 1998 to 2014 weather data, in which the expectation is that the buildings with equipment sized with HOF 2013 should meet most of the demands with CWEC 2016, and perhaps not meet as much heating demands in CWEC 1990s due to the differences in the 99.6% heating design condition.

Unmet Hours

Comparing the estimation of unmet hours from simulation using CWEC 1990s (Table 4-4) and CWEC 2016(Table 4-5), more building types met the 300-hour standard with CWEC 1990s than CWEC 2016. To further examine the differenes, the difference in unmet heating and cooling hours are calculated and summarized in Table 4-6.

Table 4-4 Unmet Hours - CWEC 1990S - HOF 2013

CWEC 1990s		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013
Unmet Hours	Unmet Heating - During Occupied [Hrs]	0.0	0.0	4899.0	59.8	665.8	216.8	444.3	22.3	10.2	3.2	0.0	1951.8	90.3	7.5	3.0	445.3
	Unmet Cooling - During Occupied [Hrs]	367.8	281.8	603.0	335.2	2471.5	168.5	62.3	2.3	1574.5	4.3	24.5	0.0	629.7	251.0	923.3	0.0
	Total Unmet Hours [Hrs]	367.8	281.8	5502.0	395.0	3137.3	385.3	506.5	24.7	1584.7	7.5	24.5	1951.8	720.0	258.5	926.3	445.3

Table 4-5 Unmet Hours - CWEC 2016 - HOF 2013

CWEC 2016		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013
Unmet Hours	Unmet Heating - During Occupied [Hrs]	0.0	0.0	4899.5	54.8	529.0	145.0	362.3	19.7	11.8	4.2	0.0	2038.2	102.5	9.7	1.8	413.3
	Unmet Cooling - During Occupied [Hrs]	464.3	308.8	677.0	384.2	2730.3	221.3	80.3	9.8	1514.7	15.2	51.8	0.0	679.3	353.0	1082.8	0.0
	Total Unmet Hours [Hrs]	464.3	308.8	5576.5	439.0	3259.3	366.3	442.5	29.5	1526.5	19.3	51.8	2038.2	781.8	362.7	1084.7	413.3

Table 4-6 Unmet Hours - CWEC 1990s Vs 2016- HOF 2013

Typical 1990s Vs Typical 2016		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]	HOF 2013 [2016-1990s]
Unmet Hours	Unmet Heating - During Occupied [Hrs]	0.0	0.0	0.5	-5.0	-136.8	-71.8	-82.0	-2.7	1.7	1.0	0.0	86.3	12.2	2.2	-1.2	-32.0
	Unmet Cooling - During Occupied [Hrs]	96.5	27.0	74.0	49.0	258.8	52.8	18.0	7.5	-59.8	10.8	27.3	0.0	49.7	102.0	159.5	0.0
	Total Unmet Hours [Hrs]	96.5	27.0	74.5	44.0	122.0	-19.0	-64.0	4.8	-58.2	11.8	27.3	86.3	61.8	104.2	158.3	-32.0

For most building types simulated using CWEC 2016 as weather data input, there are the same or fewer numbers of unmet heating hours estimated, the difference ranges from **-0 to -136.8** hours. This is mostly expected as the long-term weather conditions represented by CWEC 2016 generally has milder winters. There are a few exceptions where more numbers of unmet heating hours are estimated, the difference ranges from **0.5 to 86.3** hours. Unlike the estimation of unmet heating hours, simulation using CWEC 2016 estimated higher numbers of unmet cooling hours for most building types, the difference ranges from **7.5 to 258.8** hours. The only exception is Outpatient Healthcare Clinic, where **59.8** fewer hours are estimated.

In general, the total number of unmet hours have increased for most buildings types with equipment sized with HOF 2013 and when CWEC 2016 is used in place of CWEC 1990s, the difference ranges from **4.8 to 158.3** hours. The exceptions are the large office building, medium office building, outpatient clinic, and warehouse, the differences range from **-19 to -64** hours.

Peak Load Demands

In terms of peak load energy demands, simulation using CWEC 2016 estimated both higher heating and cooling peak loads for most building types. This result is not surprising given that the hottest and coldest hours in CWEC 2016 are more extreme than conditions in CWEC 1990s – refer to Figures 4-8 and 4-9 where the hourly temperature of each day are graphed for the winter and summer season. As seen in Table 4-7, the main exception is the Large office building where peak load estimations are lower - peak heating electrical load is **200%** less, peak heating natural gas load is **1.48%** less and peak cooling electrical load is **9.56%** less. The large percentage difference for peak heating electrical load is mainly because there is no electrical load attributed to heating with simulation using CWEC 2016. Other exceptions are the small and medium office building with slightly lower peak electrical for heating, as well as outpatient health clinic and warehouse with lower peak natural gas load for heating.

Table 4-7 Peak Loads - CWEC 1990s Vs 2016- HOF 2013

Typical 1990s Vs Typical 2016		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016	% Diff HOF 2013 -Typical 1990s Vs Typical 2016
Peak Loads	Heating - Electrical [W]	76.34%		0.03%		17.01%	-200.00%	-0.94%	-0.52%	4.01%							
	Heating - Natural Gas [W]	37.87%	32.55%	4.86%	61.02%	23.27%	-1.48%	12.59%	3.37%	-3.37%	6.70%	22.37%	27.24%	6.11%	18.05%	4.12%	-0.07%
	Cooling - Electrical [W]	1.27%	8.29%	11.74%	9.65%	15.92%	-9.56%	19.11%	14.24%	18.87%	21.13%	20.91%	15.54%	16.02%	11.90%	32.32%	186.41%

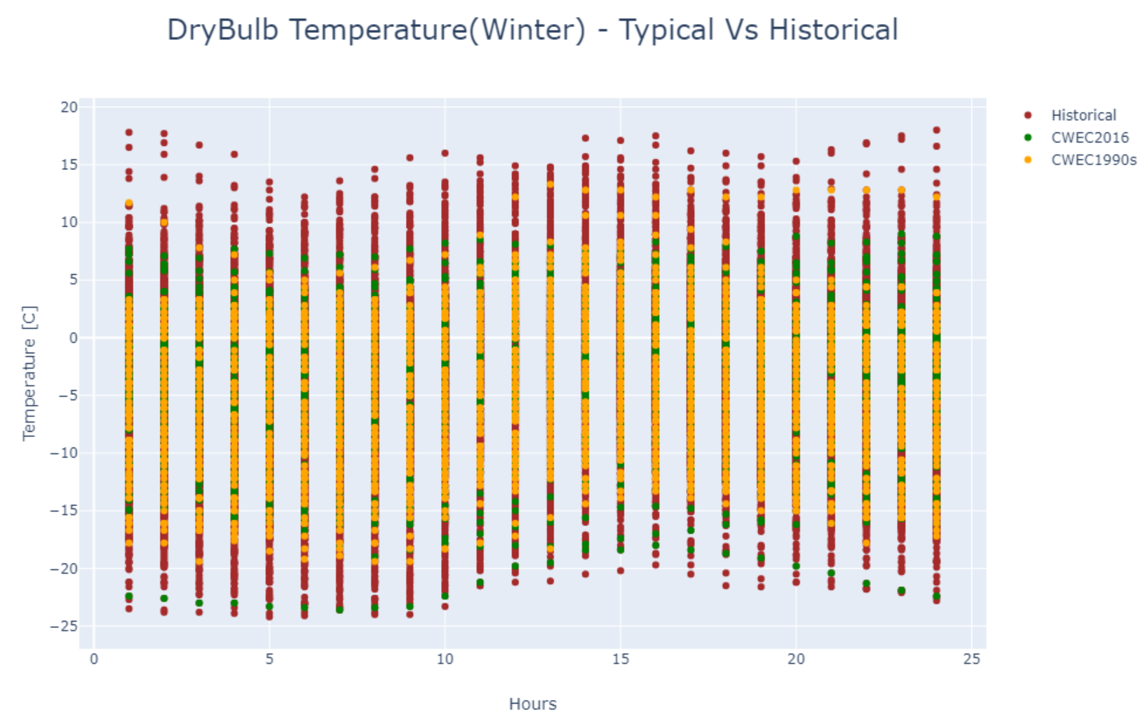


Figure 4-8 Dry Bulb Temperature (Winter) Typical Vs Historical

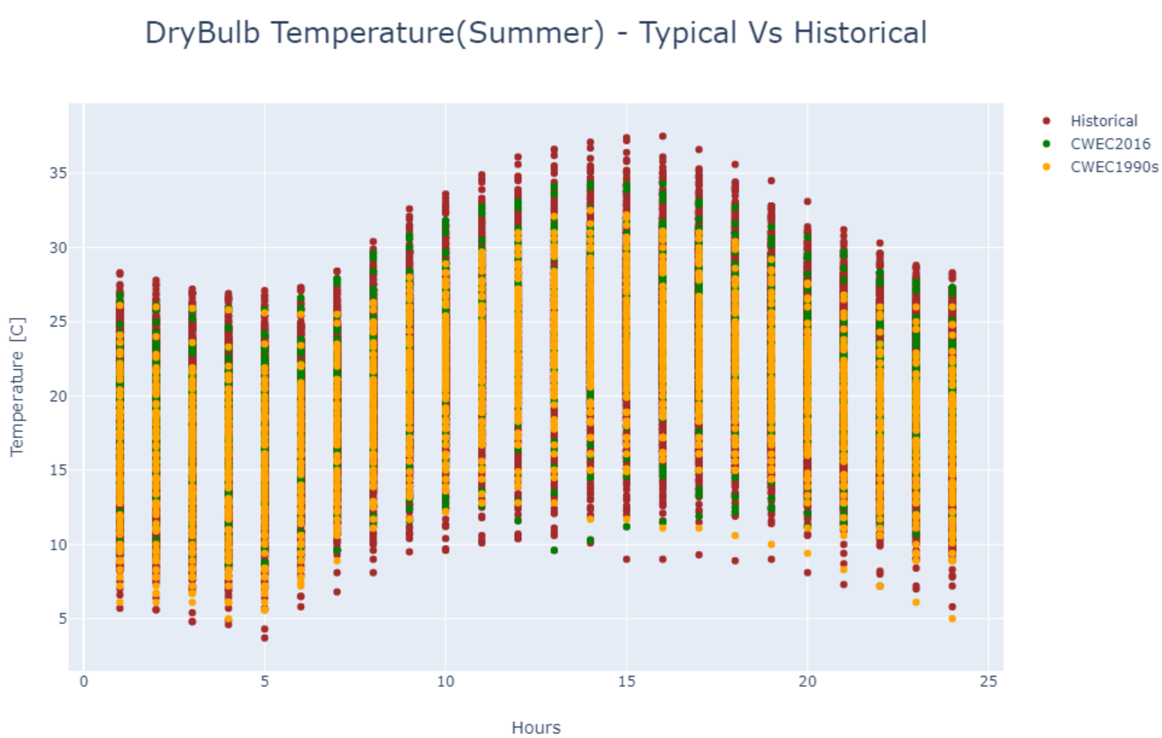


Figure 4-9 Dry Bulb Temperature (Summer) Typical Vs Historical

4.4.2 - Comparison between HOF 2013 and HOF 2005 when simulated under CWEC 1990s and CWEC 2016

Unmet Hours

Comparing the analysis using CWEC 1990s with different design data(Table 4-8), the deviation in the estimation of unmet heating hours is low ranging from **-4.5 to 8.8** hours, indicating that the impact of using different design data under the simulation weather represented by CWEC 1990s for unmet heating hour estimation is relatively low. The impact of unmet cooling hours is greater, in which deviation ranges from **-49.8 to 12.8** hours.

Table 4-8 Unmet Hours - CWEC 1990s - HOF 2013 Vs HOF 2005

CWEC 1990s		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005
Unmet Hours	Unmet Heating - During Occupied [Hrs]	0.0	0.0	-3.5	8.8	-4.5	-3.0	4.5	0.2	3.0	0.2	0.0	0.0	-2.5	-2.8	-0.5	-2.8
	Unmet Cooling - During Occupied [Hrs]	-49.8	-30.5	-20.0	-27.3	12.8	-8.0	-3.3	-0.8	-7.7	0.0	0.0	0.0	0.2	-15.8	-10.5	0.0

Table 4-9 Unmet Hours - CWEC 2016- HOF 2013 Vs HOF 2005

CWEC 2016		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005	Diff - HOF 2013-2005
Unmet Hours	Unmet Heating - During Occupied [Hrs]	0.0	0.0	-2.8	5.0	-6.0	-9.0	4.3	0.2	-0.5	0.0	0.0	0.0	-4.7	3.7	0.0	-1.3
	Unmet Cooling - During Occupied [Hrs]	-91.8	-45.8	-18.0	-26.8	7.5	-5.0	-9.0	-5.2	-7.5	0.0	0.0	0.0	0.7	-17.2	-9.0	0.0

When simulated under CWEC 2016 the differences in unmet heating hours is again relatively small as seen in Table 4-9, with deviations ranging from **-9.0 to 5.0** hours. The range of deviation with estimated unmet cooling hours when all building types are considered is wider, ranging from **-91.8 to 7.5** hours. However, this is mainly skewed by changes with both the Highrise and Midrise apartment building, where the differences grew from **-49.8 to -91.8** hours; and **-30.5 to -45.8** hours respectively.

Peak Load Demands

There is little deviation in peak heating and gas load estimations when comparing CWEC 1990s simulation with equipment sized with HOF 2005 and 2013(Table 4-10). The deviation ranges from **-1.29% to 2.14%** with heating electrical peak load; and **-6.67% to 2.93%** with heating natural gas peak load. There are more building types with lower peak heating loads when HOF 2013 is used for sizing. The deviation in peak cooling electrical load is wider, ranging from **-11.76% to 6.17%**. Generally, there are more building types with higher peak cooling loads when HOF 2013 is used for sizing.

Table 4-10 Peak Loads - CWEC 1990s - HOF 2013 Vs HOF 2005

	CWEC 1990s	Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005
Peak Loads	Heating - Electrical [W]	0.31%		-0.29%		-1.29%	0.09%	-0.36%	2.14%	0.32%							
	Heating - Natural Gas [W]	-0.51%	-0.28%	-0.58%	-6.67%	-0.30%	-0.40%	-0.62%	-0.45%	0.26%	-0.07%	-0.05%	0.96%	1.77%	0.58%	2.93%	1.41%
	Cooling - Electrical [W]	6.17%	2.50%	4.08%	-11.76%	0.07%	6.28%	2.91%	1.16%	-0.93%	0.02%	0.02%	-0.05%	-0.41%	0.76%	-0.01%	1.07%

Table 4-11 Peak Loads - CWEC 2016 - HOF 2013 Vs HOF 2005

	CWEC 2016	Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005	%Diff - HOF 2013-2005
Peak Loads	Heating - Electrical [W]	-18.16%		0.10%		-0.78%		-0.29%	2.36%	3.87%							
	Heating - Natural Gas [W]	3.11%	-0.28%	-0.45%	-0.20%	-0.11%	0.06%	-0.40%	-1.48%	-2.65%	-0.06%	-0.05%	0.09%	2.56%	0.57%	-1.40%	1.96%
	Cooling - Electrical [W]	7.12%	-3.80%	-1.85%	0.02%	0.08%	0.45%	3.88%	2.41%	2.12%	-0.12%	0.04%	-0.09%	0.05%	1.80%	1.27%	0.19%

As seen in Table 4-11, when simulation is completed with CWEC 2016, the overall analysis of all building types remains relatively similar to the results from CWEC 1990s, aside from some exceptions. Notably, the high-rise apartment building behaves very differently when different sizing data is used. Going from HOF 2005 to HOF 2013, instead of a slight increase in heating electrical peak energy and a slight decrease in heating gas energy, as seen in simulation with CWEC 1990s; there is an **-18.16%** decrease in heating electrical peak energy, and a **3.11%** increase in heating natural gas peak energy. The are other minor deviations, but they are generally not that significant. Unlike the analysis of unmet hours, it’s harder to draw a clear connection between changes to sizing with peak load demands in different typical year simulation.

4.4.3 - Comparison between HOF 2005 and HOF 2013 in historical simulation

The purpose of this section is to compare unmet hour and peak load estimations from simulation using Typical Year weather files and Historical Year weather data. Bar graphs of historical unmet hours and peak loads for each building type can be found in Appendix A and B.

Unmet Hours (with HOF 2013)

CWEC 1990s vs Historical

This comparison is of interest, since CWEC 1990s is used before the release of CWEC 2016. Which means buildings designed based on analysis of simulation using CWEC 1990s is operated in the conditions contained in CWEEDs 1998 to 2014. As seen in Table 4-12, the unmet cooling hour estimation using CWEC 1990s is skewed towards the lower end of estimation from historical simulations for unmet cooling hours, with 8 out of 16 building types having an estimated number of unmet cooling hours that are out of the range from the historical simulations. This means the condition contained in the typical weather file is not actually representative of the historical conditions. For unmet heating hours, the estimation using CWEC 1990s is generally skewed towards the higher end of the historical estimation, but within range.

CWEC 2016 vs Historical

The unmet hour estimation is generally situated in between the maximum and minimum conditions, which is expected since CWEC 2016 is statistically created to represent the conditions of CWEEDs 1998 to 2014. However, it is worth noting that the estimate of unmet hours can be very different within the estimations made from simulation using historical weather files. The largest difference is with Standalone Retail Store, in which the difference between the maximum and minimum unmet hour estimations from historical simulation is **1026.33** hours.

Table 4-12: Unmet Hours (HOF 2013) - Typical Vs Historical Simulation

BuildingType	CWEC 1990s			CWEC 2016			Historical						Difference between Max &Min	CWEC 1990s		
	Unmet Heating	Unmet Cooling	Unmet Total	Unmet Heating	Unmet Cooling	Unmet Total	Max Unmet Heating	Max Unmet Cooling	Max Unmet Total	Min Unmet Heating	Min Unmet Cooling	Min Unmet Total		Out of Range - Unmet Heating	Out of Range - Unmet Cooling	Out of Range - Unmet Total
ApartmentHighRise	0	367.75	367.75	0	464.25	464.25	0	605.5	605.5	0	359.75	359.75	245.75	No	No	No
ApartmentMidRise	0	281.75	281.75	0	308.75	308.75	3.25	386.25	386.25	0	272.75	272.75	113.5	No	No	No
Hospital	4899	603	5502	4899.5	677	5576.5	4966	740.25	5633	4885.75	630.75	5536	97	No	Yes	Yes
HotelLarge	59.83	335.17	395	54.83	384.17	439	159.83	421.83	515.34	10.17	349	384.83	130.51	No	Yes	No
HotelSmall	665.75	2471.5	3137.25	529	2730.25	3259.25	851.75	2949	3474.75	327.25	2520	3133.5	341.25	No	Yes	No
OfficeLarge	216.75	168.5	385.25	145	221.25	366.25	245.5	286.25	423.25	88	177.75	302.25	121	No	Yes	No
OfficeMedium	444.25	62.25	506.5	362.25	80.25	442.5	448	116.5	522	313.25	43	405.5	116.5	No	No	No
OfficeSmall	22.33	2.33	24.66	19.67	9.83	29.5	43.67	23.83	50.84	7	2.5	16.5	34.34	No	Yes	No
OutPatientHealthCare	10.17	1574.5	1584.67	11.83	1514.67	1526.5	48.83	1569	1598.83	0.33	1418.67	1432	166.83	No	Yes	No
RestaurantFastFood	3.17	4.33	7.5	4.17	15.17	19.34	4.33	39.67	42.5	2.5	0	2.83	39.67	No	No	No
RestaurantSitDown	0	24.5	24.5	0	51.83	51.83	0	118.83	118.83	0	3.83	3.83	115	No	No	No
RetailStandalone	1951.83	0	1951.83	2038.17	0	2038.17	2384.33	3.67	2384.33	1358	0	1358	1026.33	No	No	No
RetailStripmall	90.33	629.67	720	102.5	679.33	781.83	145.5	750	840.17	82.33	628.83	717.33	122.84	No	No	No
SchoolPrimary	7.5	251	258.5	9.67	353	362.67	13.5	424.83	435.66	4.17	273.83	287.33	148.33	No	Yes	Yes
SchoolSecondary	3	923.33	926.33	1.83	1082.83	1084.66	6	1196.17	1196.17	0	938.83	943	253.17	No	Yes	Yes
Warehouse	445.25	0	445.25	413.25	0	413.25	464.75	0	464.75	367.25	0	367.25	97.5	No	No	No

Unmet Hours (Comparing HOF 2005 with HOF 2013)

Comparing the estimation of unmet hours using HOF 2013 with estimation using HOF 2005(Table4-13), the deviation on maximum unmet heating hours ranges from **-12.25** hours to **20.25** hours with 7 building types having greater number of unmet heating hours when simulated with HOF 2013, 5 building types with unchanged max unmet heating hours and 4 building types with fewer, ranging from **-0.67** to **-12.25** hours. With minimum unmet heating hours, the deviations are smaller, ranging from **-9.74** hours to **7.83** hours, with most building types having unchanged number of minimum unmet heating hours. These deviations are relatively small compared to differences with unmet cooling hours.

With maximum unmet cooling hours, 11 out of 16 building types have fewer unmet cooling hours, the differences range from **-92** to **-0.16** hours; 3 building types with unchanged numbers; and only 2 building types with slightly more unmet cooling hours at **0.5** and **8.5** hours more respectively. With minimum unmet cooling hours, the trend continues. There are 11 building types with fewer minimum unmet cooling hours, difference ranges from **-0.67** hours to **-36.25** hours; 4 building types remain unchanged; and only 1 building type with **7** more unmet cooling hours.

Simulation with buildings having heating and cooling equipment sized with HOF 2013 generally estimated fewer unmet heating and cooling hours in historical year simulation between 1998 to 2014. The difference ranges from -**0.33** to **-36.25** hours. The only exception is the small hotel with **12.75** more total unmet hours.

Table 4-13 Unmet Hours - HOF 2005 Vs HOF 2013 in Historical Simulation

BuildingType	Historical - HOF 2005						Historical - HOF 2013						Difference					
	Max Unmet Heating	Max Unmet Cooling	Max Unmet Total	Min Unmet Heating	Min Unmet Cooling	Min Unmet Total	Max Unmet Heating	Max Unmet Cooling	Max Unmet Total	Min Unmet Heating	Min Unmet Cooling	Min Unmet Total	Diff - Max Unmet Heating	Diff - Max Unmet Cooling	Diff - Max Unmet Total	Diff - Min Unmet Heating	Diff - Min Unmet Cooling	Diff - Min Unmet Total
ApartmentHighRise	0	697.5	697.5	0	396	396	0	605.5	605.5	0	359.75	359.75	0.00	-92.00	-92.00	0.00	-36.25	-36.25
ApartmentMidRise	3.25	427	427	0	299.25	299.25	3.25	386.25	386.25	0	272.75	272.75	0.00	-40.75	-40.75	0.00	-26.50	-26.50
Hospital	4953	758	5650.25	4885.75	648.5	5549.75	4966	740.25	5633	4885.75	630.75	5536	13.00	-17.75	-17.25	0.00	-17.75	-13.75
HotelLarge	141	451.83	543.83	8.83	369.83	411.67	159.83	421.83	515.34	10.17	349	384.83	18.83	-30.00	-28.49	1.34	-20.83	-26.84
HotelSmall	831.5	2940.5	3462.75	337	2513	3120.75	851.75	2949	3474.75	327.25	2520	3133.5	20.25	8.50	12.00	-9.75	7.00	12.75
OfficeLarge	257.75	294.25	445	91.25	186	316.5	245.5	286.25	423.25	88	177.75	302.25	-12.25	-8.00	-21.75	-3.25	-8.25	-14.25
OfficeMedium	443	125.25	523.25	307.75	47	407.25	448	116.5	522	313.25	43	405.5	5.00	-8.75	-1.25	5.50	-4.00	-1.75
OfficeSmall	43.33	29.83	52	7	3.17	17.17	43.67	23.83	50.84	7	2.5	16.5	0.34	-6.00	-1.16	0.00	-0.67	-0.67
OutPatientHealthCare	49.67	1574.33	1606.33	0.33	1425	1434.83	48.83	1569	1598.83	0.33	1418.67	1432	-0.84	-5.33	-7.50	0.00	-6.33	-2.83
RestaurantFastFood	4.33	39.67	42.34	2.5	0	2.83	4.33	39.67	42.5	2.5	0	2.83	0.00	0.00	0.16	0.00	0.00	0.00
RestaurantSitDown	0	118.83	118.83	0	3.83	3.83	0	118.83	118.83	0	3.83	3.83	0.00	0.00	0.00	0.00	0.00	0.00
RetailStandalone	2384.33	3.83	2384.33	1358.33	0	1358.33	2384.33	3.67	2384.33	1358	0	1358	0.00	-0.16	0.00	-0.33	0.00	-0.33
RetailStripmall	143.67	749.5	836.83	74.5	629.5	725.67	145.5	750	840.17	82.33	628.83	717.33	1.83	0.50	3.34	7.83	-0.67	-8.34
SchoolPrimary	10.67	440.17	448.5	1.83	294.5	303.34	13.5	424.83	435.66	4.17	273.83	287.33	2.83	-15.34	-12.84	2.34	-20.67	-16.01
SchoolSecondary	6.67	1205.17	1205.34	0	946	950.83	6	1196.17	1196.17	0	938.83	943	-0.67	-9.00	-9.17	0.00	-7.17	-7.83
Warehouse	466.5	0	466.5	368.5	0	368.5	464.75	0	464.75	367.25	0	367.25	-1.75	0.00	-1.75	-1.25	0.00	-1.25

Peak Loads (with HOF 2013)

When building equipment is sized with data from HOF 2013(Table 4-14), simulation using CWEC 2016 yields peak load estimations that are within the range of the Historical simulations. This can be explained by the fact that CWEC 2016 is selected from CWEEDs 1998 to 2014. Simulation using CWEC 1990s however, yields cooling peak loads that are skewed towards the lower end, in which for 7 out of 16 building types peak load estimations are actually below the minimum peak loads from historical simulations, indicating it's not a good representation of the demands from historical simualtions, and hence probably not a good representation of actual demands from operation. Estimation of peak heating load tends to be in the middle range, relative to the historical range. The exceptions are the peak estimation of natural gas load for heating with the large office building in which it is higher than the maximum peak load from historical simulation; and the estimation of peak heating electrical of the out patient healthcare clinic, which is also higher than the maximum peak load from historical simualtion.

Table 4-14 - Peak Load (HOF 2013) - Typical Vs Historical Simulation

BuildingType	CWEC 1990s			CWEC 2016			Historical						CWEC 1990s		
	Peak Heating - Natural Gas [W]	Peak Heating - Electrical [W]	Peak Cooling - Electrical [W]	Peak Heating - Natural Gas [W]	Peak Heating - Electrical [W]	Peak Cooling - Electrical [W]	Max Peak Heating - Natural Gas [W]	Max Peak Heating - Electrical [W]	Max Peak Cooling - Electrical [W]	Min Peak Heating - Natural Gas [W]	Min Peak Heating - Electrical [W]	Min Peak Cooling - Electrical [W]	Peak Heating NG - Out of Range	Peak Heating Elec - Out of Range	Peak Cooling Elec - Out of Range
ApartmentHighRise	170876	34033	64832	250704	76053	65660	270182	118348	67100	125426	25068	64882	No	No	Yes
ApartmentMidRise	81305	0	19308	112917	0	20978	116809	0	24691	57739	0	18111	No	No	No
Hospital	1255423	51190	303200	1317943	51205	341025	1549126	51328	342682	849486	50561	305430	No	No	Yes
HotelLarge	322406	0	154460	605506	0	170115	727194	0	204515	294754	0	150195	No	No	No
HotelSmall	20277	81187	23652	25618	96283	27744	25619	96960	40370	17935	61902	21731	No	No	No
OfficeLarge	2119814	35694	538862	2088769	0	489690	2115650	54473	559441	2088774	0	456376	Yes	No	No
OfficeMedium	110929	192773	67113	125827	190977	81295	127876	195069	87002	87977	160349	64556	No	No	No
OfficeSmall	28596	5382	4957	29577	5354	5717	29577	5367	6113	21959	4622	4743	No	Yes	No
OutPatientHealthCare	151146	75042	98476	146134	78112	118990	151330	102270	126081	146133	61975	99329	No	No	Yes
RestaurantFastFood	90613	0	11362	96895	0	14047	109994	0	15490	70498	0	11935	No	No	Yes
RestaurantSitDown	145578	0	18999	182243	0	23436	182248	0	25146	109648	0	20777	No	No	Yes
RetailStandalone	173525	0	32472	228247	0	37944	255234	0	41526	143542	0	29859	No	No	No
RetailStripmall	236211	0	36398	251090	0	42735	259998	0	44567	188810	0	34044	No	No	No
SchoolPrimary	469248	0	89159	562374	0	100437	729626	0	105118	375359	0	83400	No	No	No
SchoolSecondary	1230559	0	289513	1282330	0	401113	2337652	0	405679	955310	0	292792	No	No	Yes
Warehouse	0.28	0.00	0.00	0.28	0.00	0.00	0.30	0.00	0.01	0.21	0.00	0.00	No	No	Yes

Peak Loads (Comparing HOF 2005 with HOF 2013)

The differences on peak heating load estimation between simulation using HOF 2005 and HOF 2013 are generally not great as shown in Table 4-15. For peak heating with natural gas, HOF 2013 generally have lower estimations of maximum peak demand ranging from **-0.05%** to **-1.55%** for 12 out of 16 building types; 4 building types have higher demand estimations, the difference is from **0.01%** to **4.52%**. Similarly, the estimation of minimum peak demand on peak heating with natural gas is generally lower with HOF 2013, 10 of 16 buildings yielded lower estimations, difference is between **-0.05%** to **-6.33%**. 5 of 16 buildings have higher minimum peak demands, ranging from **0.01%** to **2.56%**. Not all building types use electricity for heating, but the differences are between **-9.91%** and **2.36%** for max peak heating electrical load, and **-0.29%** to **1.89%** for min peak heating electrical load.

For peak cooling load demand, more building types have higher estimation with HOF2013. With maximum cooling load demand, 10 of 16 buildings have higher max cooling load demand estimation ranging from **0.08%** to **8.98%**; 5 of 16 buildings have lower max peak load estimation ranging from **-0.01%** to **-1.21%**. With minimum cooling load demand, the difference is between **-6.4%** to **6.27%**.

Table 4-15 Peak Loads HOF 2005 Vs HOF 2013 in Historical Simulation

BuildingType	Historical - HOF 2005						Historical - HOF 2013						Differences					
	Max Peak Heating - Natural Gas [W]	Max Peak Heating - Electrical [W]	Max Peak Cooling - Electrical [W]	Min Peak Heating - Natural Gas [W]	Min Peak Heating - Electrical [W]	Min Peak Cooling - Electrical [W]	Max Peak Heating - Natural Gas [W]	Max Peak Heating - Electrical [W]	Max Peak Cooling - Electrical [W]	Min Peak Heating - Natural Gas [W]	Min Peak Heating - Electrical [W]	Min Peak Cooling - Electrical [W]	% DIFF Max Peak Heating - Natural Gas	% DIFF Max Peak Heating - Electrical	% DIFF Max Peak Cooling - Electrical	% DIFF Min Peak Heating - Natural Gas	% DIFF Min Peak Heating - Electrical	% DIFF Min Peak Cooling - Electrical
ApartmentHighRise	258239	130685	63368	126618	25068	60935	270182	118348	67100	125426	25068	64882	4.52%	-9.91%	5.72%	-0.95%	0.00%	6.27%
ApartmentMidRise	117795	0	22568	57970	0	19309	116809	0	24691	57739	0	18111	-0.84%		8.98%	-0.40%		-6.40%
Hospital	1573403	51279	338893	828052	50711	300843	1549126	51328	342682	849486	50561	305430	-1.55%	0.10%	1.11%	2.56%	-0.29%	1.51%
HotelLarge	730416	0	204576	297997	0	149925	727194	0	204515	294754	0	150195	-0.44%		-0.03%	-1.09%		0.18%
HotelSmall	25647	97719	40338	17989	61880	21714	25619	96960	40370	17935	61902	21731	-0.11%	-0.78%	0.08%	-0.30%	0.04%	0.08%
OfficeLarge	2131524	54352	549243	2088610	0	485576	2115650	54473	559441	2088774	0	456376	-0.75%	0.22%	1.84%	0.01%		-6.20%
OfficeMedium	128499	196584	83630	88635	160300	63980	127876	195069	87002	87977	160349	64556	-0.49%	-0.77%	3.95%	-0.74%	0.03%	0.90%
OfficeSmall	30016	5242	5955	22090	4535	4706	29577	5367	6113	21959	4622	4743	-1.48%	2.36%	2.61%	-0.59%	1.89%	0.78%
OutPatientHealthCare	150914	100844	123116	148941	61606	100274	151330	102270	126081	146133	61975	99329	0.28%	1.40%	2.38%	-1.90%	0.60%	-0.95%
RestaurantFastFood	110061	0	15505	70550	0	11943	109994	0	15490	70498	0	11935	-0.06%		-0.10%	-0.07%		-0.06%
RestaurantSitDown	182347	0	25149	109700	0	20771	182248	0	25146	109648	0	20777	-0.05%		-0.01%	-0.05%		0.03%
RetailStandalone	255377	0	41552	143547	0	29862	255234	0	41526	143542	0	29859	-0.06%		-0.06%	0.00%		-0.01%
RetailStripmall	260730	0	45110	186805	0	34156	259998	0	44567	188810	0	34044	-0.28%		-1.21%	1.07%		-0.33%
SchoolPrimary	729587	0	103269	370515	0	84110	729626	0	105118	375359	0	83400	0.01%		1.77%	1.30%		-0.85%
SchoolSecondary	2338289	0	401805	1017711	0	290809	2337652	0	405679	955310	0	292792	-0.03%		0.96%	-6.33%		0.68%
Warehouse	0.30	0.00	0.01	0.21	0.00	0.00	0.30	0.00	0.01	0.21	0.00	0.00	1.76%		0.00%	0.46%		0.00%

4.4.4 - Tolerances used for unmet hours calculation:

This section is dedicated to the tolerances used in the calculation of unmet hours in BES, and more specifically the settings in EnergyPlus. As mentioned earlier in this chapter, a tolerance is usually allowed to be used in BES for unmet hour calculations, in ASHRAE 90.1[37], the allowed tolerance is 0.5 °C . The goal of this section is to understand how using different tolerances affect simulation results.

From analyzing unmet hour estimations from the first batch of simulation results, it is learned that because the tolerance value was not explicitly defined in the original DOE prototype models [51], the default EnergyPlus temperature tolerance of 0.2 °C is applied instead. This is a more stringent tolerance value, considering that the allowed tolerance from ASHRAE 90.1[37] is 0.5 °C, as such, large amounts of unmet hours were estimated in the initial batch of simulation shown in Tables 4-16 and 4-17. For the purpose of this research, these are labelled as preliminary results, as they are not used for in depth analysis.

Table 4-16 Preliminary Results - CWEC 2016 and HOF 2013

	CWEC 2016	Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013
Unmet Hours	Unmet Heating - During Occupied [Hrs]	4.3	1.5	4899.5	133.2	736.0	221.0	454.8	30.3	19.5	10.8	0.7	2436.0	1140.3	11.2	3.2	495.5
	Unmet Cooling - During Occupied [Hrs]	606.8	615.3	1192.8	976.0	3346.0	376.3	164.0	25.8	1797.3	26.0	66.7	0.2	727.8	521.2	1308.7	0.0

Table 4-17 Preliminary Results - CWEC 1990s and HOF 2005

	CWEC 1990s	Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005
Unmet Hours	Unmet Heating - During Occupied [Hrs]	2.3	0.0	4902.5	138.0	993.5	321.3	553.3	36.5	21.3	11.0	0.5	2507.3	1118.2	13.8	6.8	525.8
	Unmet Cooling - During Occupied [Hrs]	530.3	558.8	1162.5	956.2	3050.8	316.0	128.8	11.8	1945.8	9.0	33.3	0.0	660.2	413.5	1193.8	0.0

To investigate whether loosening the tolerance leads to fewer numbers of unmet hours, simulation is completed with the tolerance set to 0.5 °C – which is a more reasonable level. The results are shown in Tables 4-18 and 4-19.

Table 4-18 Revised Results - CWEC 1990s and HOF 2005

CWEC 1990s		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005	HOF 2005
Unmet Hours	Unmet Heating - During Occupied [Hrs]	0.0	0.0	4902.5	51.0	670.3	219.8	439.8	22.2	7.2	3.0	0.0	1951.8	92.8	10.3	3.5	448.0
	Unmet Cooling - During Occupied [Hrs]	417.5	312.3	623.0	362.5	2458.8	176.5	65.5	3.2	1582.2	4.3	24.5	0.0	629.5	266.8	933.8	0.0

Table 4-19 Revised Results - CWEC 2016 and HOF 2013

CWEC 2016		Apartment HighRise	Apartment MidRise	Hospital	Hotel Large	Hotel Small	Office Large	Office Medium	Office Small	OutPatient HealthCare	Restaurant FastFood	Restaurant SitDown	Retail Standalone	Retail Stripmall	School Primary	School Secondary	Warehouse
		HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013	HOF 2013
Unmet Hours	Unmet Heating - During Occupied [Hrs]	0.0	0.0	4899.5	54.8	529.0	145.0	362.3	19.7	11.8	4.2	0.0	2038.2	102.5	9.7	1.8	413.3
	Unmet Cooling - During Occupied [Hrs]	464.3	308.8	677.0	384.2	2730.3	221.3	80.3	9.8	1514.7	15.2	51.8	0.0	679.3	353.0	1082.8	0.0

As shown, there are fewer total unmet hours for most building types in both simulation scenarios. More buildings passed the 300-hour limit with the increased tolerance, even though changing the tolerance alone did not bring all building types below the 300 unmet hour limit.

Ideally, all prototype buildings should be meeting the unmet hour limit in ASHRAE 90.1[37]. However, it is expected that this should not greatly interfere with the analysis completed in this chapter, since the focus is on comparing the relative differences on using different weather data. That being said, there are attempts in further lowering the number of unmet hours for buildings that did not pass the 300-hour limit. The effort is discussed in section 4.4.5.

4.4.5 - Adjustments to lower unmet hours

As seen in the previous sections of this chapter, a lot of building types did not meet the 300-hour unmet hours limit stated in ASHRAE 90.1 - 2016[37]. An analysis is completed to explore ways to further reduce the number of unmet hours for buildings that did not pass the 300-hour limit. The Hospital model is used as an example, since it has large numbers of unmet heating hours, and adjusting the tolerances level alone did not reduce the numbers as shown in the previous section.

<u>Hospital</u>

Unlike other building type models, the number of unmet hours did not reduce much when the tolerance is increased for the Hospital model. Upon further investigation, it is found that one of the zones (OR4_2NDFloor) has a heating coil sized with zero heat load. While this may occur if there is indeed no need for heating in some cases, a simple check on the average zone temperature showing the zone temperature is consistently lower than the set point temperature suggests otherwise.

To troubleshoot the issue, a comparison is made with the original DOE prototype models found in [51]. It is found that the heating coils in OR4_2NDFloor in the 2016 and 2013 models are sized with zero load, which resulted in large numbers of unmet cooling hours. This is not the case with the older 2004 model, where the heating coils are sized correctly. Upon further comparison, it is found that one of the main differences between the models is the zone minimum airflow input method. The control of airflow is scheduled based in the 2016 and 2013 models, whereas the 2004 model is set as a constant flow. Based on the schedule logic in the 2016 and 2013 models, the airflow should be at 20% of the maximum airflow during the heating design day when sizing of the heating coil takes place. However, for unknown reasons, the heating load sizing for zone OR4_2NDFloor did not start correctly, and a zero-load coil is sized for the zone. To remedy this issue, the minimum flowrate for the fan coil is set to 100%, constant for all times, Figure 4-10 shows the changes. It's worth noting that this change is expected affect the overall energy efficiency of the building, as the original schedule based control was to conserve energy during unoccupied times, however, the focus on this change for the purpose of this study is to trigger zone sizing to minimize the number of unmet hours. The summary of results from the modified simulation is shown in Table 4-20.

Table 4-20 Hospital modified model results

Model	Heating Energy - Natural Gas [GJ]	Heating Energy - Electricity [GJ]	Heating Energy - Total	Cooling Energy - Electricity [GJ]	Unmet Heating Hours [hrs]	Unmet Cooling Hours [Hrs]	Peak Heating Load - Natural Gas [W]	Peak Heating Load - Electricity [W]	Peak Cooling Load - Electricity [W]
Original	7125.47	866.25	7991.72	1893.14	4899.5	1192.75	1317943.098	51204.793	341024.783
Adjusted	8227.34	756.78	8984.12	1962.27	144.25	676.75	1358053.078	50877.153	339603.498

As seen in the results, the number of unmet heating and cooling hours decreased, while the amount of energy for heating and cooling increased.

Original

```
AirTerminal:SingleDuct:VAV:Reheat,
    OR4_Flr_2 VAV Box Component,    !- Name
    ALWAYS_ON,                 !- Availability Schedule Name
    OR4_Flr_2 VAV Box Damper Node,    !- Damper Air Outlet Node Name
    OR4_Flr_2 VAV Box Inlet Node,    !- Air Inlet Node Name
    AUTOSIZE,                  !- Maximum Air Flow Rate {m3/s}
    Scheduled,                 !- Zone Minimum Air Flow Input Method
    0.0000,                    !- Constant Minimum Air Flow Fraction
    ,                          !- Fixed Minimum Air Flow Rate {m3/s}
    OR_MinSA_Sched,            !- Minimum Air Flow Fraction Schedule Name
    Coil:Heating:Water,        !- Reheat Coil Object Type
    OR4_Flr_2 VAV Box Reheat Coil,    !- Reheat Coil Name
    AUTOSIZE,                  !- Maximum Hot Water or Steam Flow Rate {m3/s}
    0.0,                       !- Minimum Hot Water or Steam Flow Rate {m3/s}
    OR4_Flr_2 VAV Box Outlet Node,    !- Air Outlet Node Name
    0.001,                     !- Convergence Tolerance
    REVERSE,                    !- Damper Heating Action
    ,                         !- Maximum Flow per Zone Floor Area During Reheat {m3/s-m2}
    0.5,                      !- Maximum Flow Fraction During Reheat
    40;                       !- Maximum Reheat Air Temperature {C}
```

Modified

```
AirTerminal:SingleDuct:VAV:Reheat,
    OR4_Flr_2 VAV Box Component,    !- Name
    ALWAYS_ON,                 !- Availability Schedule Name
    OR4_Flr_2 VAV Box Damper Node,    !- Damper Air Outlet Node Name
    OR4_Flr_2 VAV Box Inlet Node,    !- Air Inlet Node Name
    AUTOSIZE,                  !- Maximum Air Flow Rate {m3/s}
    Constant,                 !- Zone Minimum Air Flow Input Method
    1.0,                    !- Constant Minimum Air Flow Fraction
    ,                          !- Fixed Minimum Air Flow Rate {m3/s}
    OR_MinSA_Sched,            !- Minimum Air Flow Fraction Schedule Name
    Coil:Heating:Water,        !- Reheat Coil Object Type
    OR4_Flr_2 VAV Box Reheat Coil,    !- Reheat Coil Name
    AUTOSIZE,                  !- Maximum Hot Water or Steam Flow Rate {m3/s}
    0.0,                       !- Minimum Hot Water or Steam Flow Rate {m3/s}
    OR4_Flr_2 VAV Box Outlet Node,    !- Air Outlet Node Name
    0.001,                     !- Convergence Tolerance
    REVERSE,                    !- Damper Heating Action
    ,                         !- Maximum Flow per Zone Floor Area During Reheat {m3/s-m2}
    0.5,                      !- Maximum Flow Fraction During Reheat
    40;                       !- Maximum Reheat Air Temperature {C}
```

Figure 4-10 Changes to hospital model - heating coil operation

4.5 Concluding Remarks

In part 1, buildings with equipment sized with design data from HOF 2013 is simulated with Typical Year weather files CWEC 2016 and CWEC 1990s. The simulation with CWEC 2016 when compared to simulation with CWEC 1990s estimated fewer unmet heating hours(10 out of 16 building types); more unmet cooling hours (13 out of 16 building types); and higher total unmet hours (with heating and cooling combined, for 12 out of 16 building types). Aside from some exceptions, peak loads for heating and cooling are also higher when simulation is completed with CWEC 2016. For designers, this means if simulation is completed with the older Typical Year weather file(CWEC 1990s) instead of the updated version(CWEC

2016) in Toronto, there could be underestimations of unmet cooling hours; over estimation of heating hours, and under estimation of total unmet hours. While it is generally not recommended to use Typical Year type weather files for peak load estimation. The relative comparison of peak load can be useful when comparing different building designs. In general, peak loads for heating and cooling are higher when simulation is completed with CWEC 2016. This can be explained by the more "extreme" summer and winter conditions contained in the weather file shown in Figures 4-8 and 4-9. It is worth noting that weather outliers are generally excluded from Typical Year weather files, and the "extreme" conditions may not be representative. Designers should be aware of the conditions that are contained in weather files and determine whether the conditions in Typical Weather files are sufficiently challenging.

In part 2, buildings with equipment sized with design data from HOF 2013 and HOF 2005 are compared. To see if the comparison is different when different versions of Typical Year weather files are used, simulation is also completed under both CWEC 1990s and CWEC 2016. In general, switching from HOF 2005 to HOF2013 for heating and cooling equipment sizing lead to small deviation in unmet heating hours; slightly greater deviation is seen in unmet cooling hour estimations where buildings with cooling equipment sized with HOF 2013 had fewer unmet cooling hours. Considering the change in design data (HOF 2005 to HOF 2013) under different Typical Year simulation weather data(CWEC 1990s and CWEC 2016), the relative comparison of unmet heating hours generally does not change when switching from CWEC 1990s to CWEC 2016; the relative comparison is more affected in the estimation of unmet cooling hours, in which a greater deviation in unmet cooling hours is seen when simulating under CWEC 2016. This can be associated with the hotter summer represented in CWEC 2016, in which updating the design data from HOF 2005 to HOF 2013 generally lead to greater reduction in unmet cooling hours. The reduction is especially large with the high-rise and mid-rise apartment buildings when compared to the rest of the building types, the main exception is the small hotel, where more unmet cooling hours are estimated. For designers, sizing equipment with the more updated design data should generally lead to fewer unmet cooling hours, and the most updated weather data should be used to properly reflect the effects of the change in design data.

In part 3, two comparisons are made with simulation using Historical Year weather data (CWEEDs 1998 to 2014) in estimating unmet hours and peak loads. First, estimations using Historical Year simulation is compared with results from simulation using two different Typical Year weather files (CWEC 1990s and CWEC 2016), the focus is how singular estimations from Typical Year simulation compares with the range of results from multi Historical Year simulation. Second, comparisons are made between estimations from Historical Year simulation of buildings with heating and cooling equipment sized with different design weather data (HOF 2005 and HOF 2013), the focus is on comparing the range of estimations in Historical Year simulation due to differences in design data. In general, there are large variations shown in historical simulation in both unmet hour and peak load estimations. In the first comparison, estimations using CWEC 2016 falls within the range of estimations from Historical Year simulations, this can be explained by the fact that CWEC 2016 is a subset of conditions in CWEEDs 1998 to 2014. On the other hand, estimations from simulation using CWEC 1990s generally underestimated the number of unmet cooling hours, where 8 out of 16 building types had estimations that are not in the range from Historical Year simulation. Similar findings are seen in peak loads, where estimations using CWEC 1990s are generally skewed towards the lower end of estimations, and 7 out of 16 building types have estimations that are not in the range from Historical Year simulation. In the second comparison, there are only small differences in unmet heating hour estimation between buildings with heating equipment sized using design data from HOF 2005 and HOF 2013, for some building types, there is slight increase in maximum unmet heating hours from historical year estimations. The impact of using more updated design data on the estimation of unmet cooling hours is greater, for most building types, there are there are fewer number of maximum unmet cooling hours when HOF 2013 is used for equipment sizing, which also lead to a general reduction in of total unmet hours. In terms of peak load, the differences between simulation using HOF 2005 and HOF 2013 is not great. In general, when HOF 2013 is used, the maximum natural gas peak load for heating is slightly higher, while the maximum electrical peak load for cooling is generally lower. The greatest difference can be seen with the high-rise and mid-rise apartment buildings.

To conclude this chapter, designers should be aware of the weather data that is available for use. To answer the first research question, the weather conditions represented in different versions of simulation weather files can be very different, in which older Typical Year weather files(CWEC 1990s) may not be representative of the weather conditions in recent years, the impact on unmet hour and peak load estimations can be seen in the comparisons made in this chapter. To answer the second research question, the effects on updating design weather data used for equipment sizing is different when simulated in different Typical year weather files, buildings using the updated design data(HOF 2013) generally performed better under the newer Typical Year weather file(CWEC 2016), with fewer numbers of unmet cooling hours estimated. To answer the third research question, buildings with equipment sized with the updated design data (HOF 2013) generally performed better in Historical Year simulation between 1998 to 2014, with fewer numbers of maximum unmet (heating and cooling combined) hours estimated.

Chapter 5 Preprocessing and Post Processing Tools for Multi-Year Simulation

5.1 Introduction

One of the main challenges in conducting multiyear simulation is dealing with additional amounts of input and output data. While there is abundant weather data available in Canada, not all are organized in formats suitable for energy simulation. Different simulation programs accept different types of weather file formats, for example Energy Plus accepts EPW format[36], eQuest accepts bin format[63], etc. When converting in-between formats, weather convertors are often used, for example EnergyPlus has a built-in weather convertor[55] that can convert custom user defined weather file from a structured csv file to EPW format, elements is a weather file compiler with built in physical relationships between parameters[64]. While the formatting of weather format is often clearly stated in technical manuals, the actual organizing work which involves gathering appropriate weather data, converting data to proper units and reorganizing into proper format can be laborious, and potentially lead to errors during compilation, especially when large quantities of weather files need to be made. Similar issues arise with post processing tasks such as extracting simulation results and generating graphs.

As it is clear from previous sections, conducting multi-year simulation does generate insights that would normally be neglected in simulation with Typical Year weather files. Crawley and Barnaby[3] recommended a list of tools including Dview[65] and Climate consultant[66] that building designers can use to analyze and generate insight from weather data. However, it can be difficult for building designers to effectively extract and conduct analysis on multi-year simulation as most simulation engines and related analysis tools are designed to conduct single year analysis, getting familiar to different pre-built computer tools created by different programmers can also be time consuming.

While pre-processing and post processing tasks may seem very different for building professionals without a strong programming background, the logic and skills required in reality is not that different, and can be easily created with modern scripting tools such as MATLAB and Python. The goal of this chapter is to present some of the computer scripts created to complete this research work, as an illustration of the benefits of acquiring scripting as a part of a building designer's professional skillset.

The application of computer programming and scripting is not a novelty in the academia, researchers from a wide spectrum of fields have been using them actively for research. There also exists other programming languages such as C/C++ and Java, and the application is more related to the preference of the user, the capabilities of the languages and other compatibility factors.

Both MATLAB and Python are used extensively in academia and in industry, however, there are great differences between the two. MATLAB requires paid licenses, but have specialized tool packages for different application purposes, for example, Simulink is a powerful simulation package for control systems. Python on the other hand is open source and has gained popularity in recent years due to its intuitive use, as well as strong development and support community. The combination of factors makes Python an ideal language for data related applications.

The building industry is an interesting intersection of different profession and trades with unique skillsets. This chapter is hoping to provide sufficient background and relatable examples of how building designers can leverage the computing efficiency and flexibility of computer scripts to automate mundane tasks. As this can save time, ensure consistency and repeatability, as well as minimizing the associated human errors.

5.2 Methodology

To understand the role of computer scripts in the context of this research, Figure 3-1 from Chapter 3 is revisited with added highlights on tasks that are completed with scripts (refer to Figure 5-1).

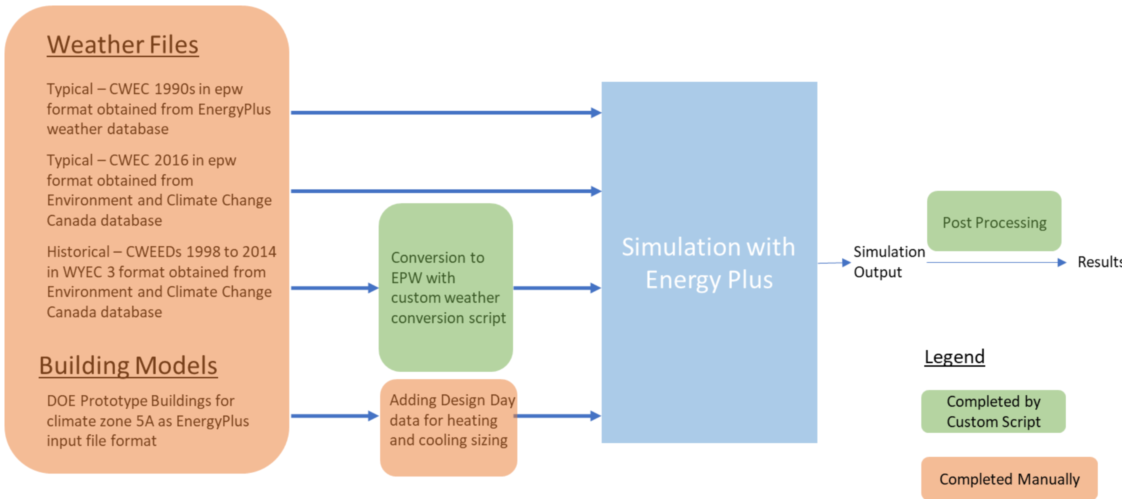


Figure 5-1 Simulation process with highlight on automated processes

In this chapter, three computer scripts are presented, each designed to handle a labor-intensive task in association to completing this research. The first script written in MATLAB 2019[35] is a weather conversion tool used to convert historical weather data from WYEC 3 format to EPW format; the second script written in Python is an output data extraction tool ;and the third script written also in Python is a graphing script used to create daily distribution of hourly dry bulb temperature.

5.2.1 - Basics: matrices/arrays and time-based indexing

While it is not within the scope of this work to outline all the basic computer programming knowledge needed to understand the scripts presented, it is worthwhile to briefly discuss some critical concepts and highlight features that make the scripts work.

For those with a background with linear algebra, matrices and arrays should not be a foreign concept. To provide a simplistic description, matrices and arrays can be seen as data organization structures for data storage, in which stored data can be accessed through location-based indices.

In modern programming languages, more advanced matrices/ arrays with labelled variables are used for data storage. With labelled variables, data can be accessed based on the labelled tags assigned for each column. An indexing column can also be assigned so that data can be located based on row indices, for example if the data has a column with time, it can be used as a time-based index column, in which the row data can be accessed based on the specified time tags. Different programming languages uses different names for label-based matrices/arrays, in MATLAB, it is called tables [67], which is essentially a collection of arrays with variable tags; in Python, the pandas library[68] has a data storage structure called dataframe[69]. The use of tables and dataframes with time-based indices forms the basis for most scripts described below.

5.2.2 - Script 1: Weather converter

The weather file converter is used to convert CWEEDs weather data from WYEC 3 format to EPW format which is compatible for energy simulation. The script is written in MATLAB, so it can be easily modified and used with MATLAB Simulink for further research work. Figure 5-2 shows the general process completed by the script. The script needs to be placed in the folder where the weather files being converted are stored, then by running the script, the files are processed and converted.

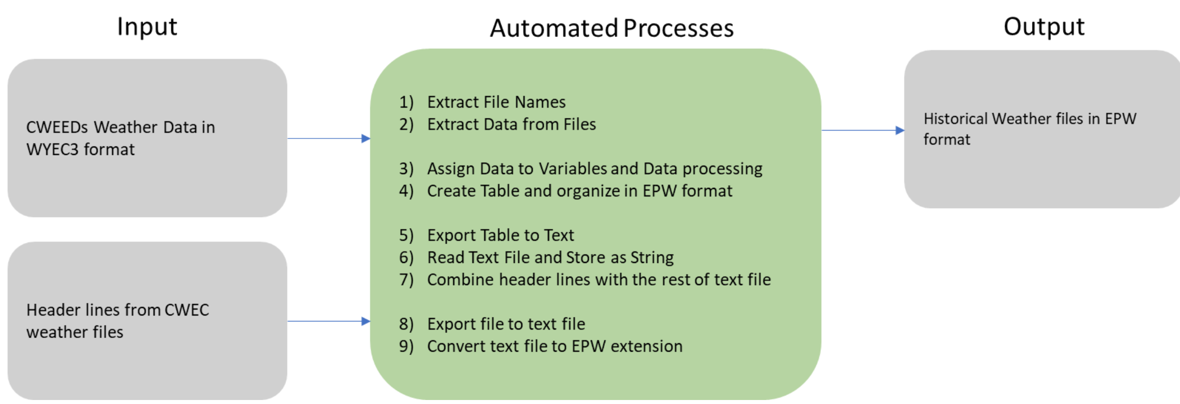


Figure 5-2 Script 1 Weather converter process

5.2.3 - Script 2: Graphing scripts:

This graphing script is used to analyze weather data in EPW file format by creating interactive graphical representation of the data. The script is written in Python because 1) it is open source, in which anyone with access to a modern computer can replicate and run the script; 2) interactive graphs can be created easily by using one of the libraries named Plotly [70], which is useful for weather data analysis. In this script, the file directory of the weather files being analyzed has to be specified. Figure 5-3 shows the general process completed by the script.

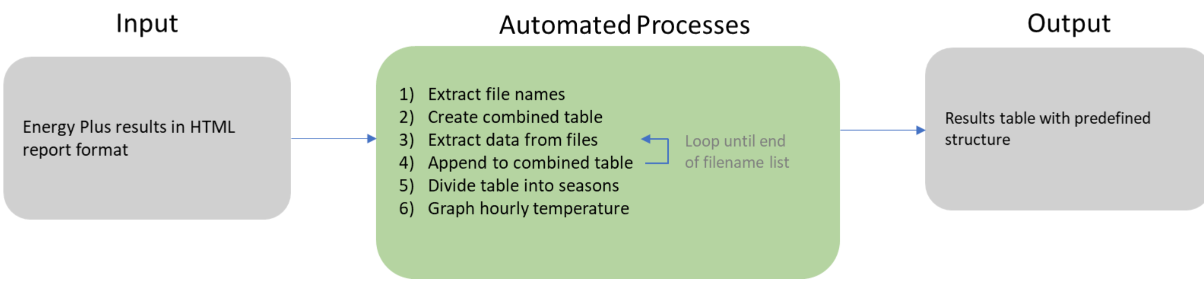


Figure 5-3 Script 2 Graphing script process

5.2.4 - Script 3: Results extraction tool:

This data extraction script is used to extract simulation results from Energy Plus simulation reports in HTML format. The goal is to extract relevant fields from the simulation reports and consolidate results from multi-year/multi-building design simulation. This script is also written in Python because 1) it is open source, where more users can utilize the tool; 2) the eppy library[71] has a function that can read HTML files and recognize titles/description of tables which allows for term based table search and extraction. In this script, the file directory of the weather files being analyzed does not have to be specified, but the script has to be placed in the folder where the reports are being stored. Figure 5-4 shows the general process completed by the script.

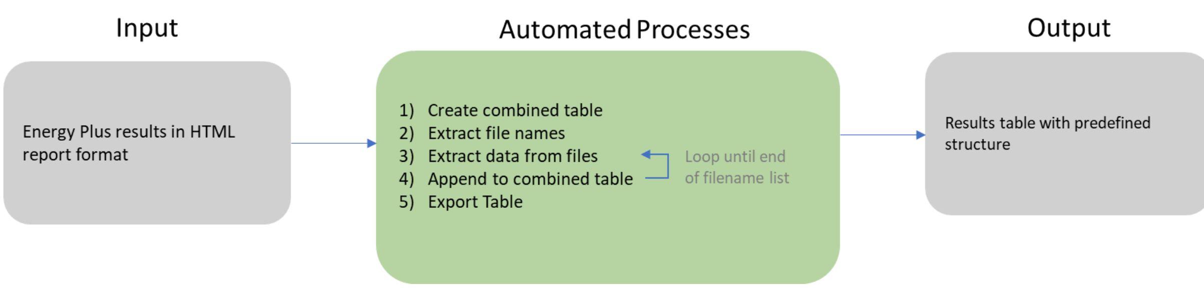


Figure 5-4 Script 3 Results extraction tool

5.3 Results and discussion

5.3.1 - Script 1: Weather converter

The full script is attached in Appendix C, the following is an overview of the function and rationale for each step.

Input

There are two inputs in the script – 1) CWEEDs weather data in WYEC3 format, which can be obtained from Environment and Climate Change Canada [16], and 2)Header lines from CWEC weather files, which can also be obtained from [16]. Both inputs are needed since EPW weather files are comprised of simulation weather data – which are the hourly weather conditions; and header lines containing other crucial information such as location and design day data. The proper format of EPW weather files are documented in [36].

The CWEEDs Historical weather data are stored in WYEC 3 format, which is a fixed width file format, in which each line of data, representing hourly records of weather elements have the same length, and each weather element is stored in a fixed location. The CWEEDs/CWEC documentation [15] outlines the format, units and location of each weather element for CWEEDs weather data, which is crucial information for the data extraction process.

The format of header-lines for EPW weather files can be found in [36], for simplicity, since each location in CWEEDs has a corresponding CWEC weather file in EPW format, the header lines are obtained from the CWEC weather files.

Automated Process by Script

The commented script is attached in Appendix C. The following section outlines a short description of the functionality of each part.

1) Extract file names

First part of the script is to create a list of names of the files with .WY3 extension in the folder where the script is located in. The files in the list are files that will be converted. A "*for"* loop is initiated after the file name extraction and will convert the files on the list one by one by iterating the following steps.

2) Extract data from files

Second part of the script is to create a table to temporarily store weather elements extracted from the CWEEDs weather files. The organization of the table is based on the WYEC3 format as indicated in [15].

3) Assign Data to Variables and Data processing

In preparation for the reorganized EPW table, each relevant weather element from CWEEDs is stored in arrays of appropriate data type. In general, numbers are stored in "*double*" arrays, which allows for math operations and text are stored in "*string*" arrays, in which in theory can be used to store numbers or characters.One thing to note is that weather data stored in CWEEDs generally can't be used directly in

EPW, due to differences in units. The details on the unit conversion completed is summarized in Table 5-1.

Table 5-1 Unit conversion needed for Script 1

Elements in EPW {units} [36]	**Equivalent Elements in CWEEDs WYEC3 {units}**[15]	**Processing Completed**	**Used in Energy Plus** [36]
Date - Year	Date - Year		Yes
Date - Month	Date - Month		Yes
Date - Day	Date - Day		Yes
Time -Hour	Time -Hour		Yes
Time- Minute		Minutes are set to 0 since all recordings are at the hour	
Data Source and Uncertainty Flag		Used the generic Source flag from CWEC 2016 found in [16]	
Dry bulb temperature{C}	Dry bulb temperature {0.1 C}	Conversion to C – conversion factor: 0.1	Yes
Dew point temperature{C}	Dew point temperature {0.1 C}	Conversion to C – conversion factor: 0.1	Yes
Relative Humidity {%}		Calculated based on psychrometric relationships found in [72]	Yes
Atmospheric Pressure {Pa}	Station pressure {10 Pa}	Conversion to Pa – Conversion factor: 10	Yes
Extraterrestrial Horizontal Radiation {Wh/m^2}	Extraterrestrial irradiance {kJ/m2}	Conversion from irradiance to radiation – conversion factor: 1/3.6	No
Extraterrestrial Direct Radiation {Wh/m^2}		Conversion from irradiance to radiation – conversion factor: 1/3.6	No
Horizontal Infrared Radiation Intensity {Wh/m^2}		Missing flag is used to trigger estimation in Energy Plus	Yes

Global Horizontal Radiation {Wh/m^2}	Global horizontal irradiance {kJ/m2}	Conversion from irradiance to radiation – conversion factor: 1/3.6	No
Direct Normal Radiation {Wh/m^2}	Direct normal irradiance {kJ/m2}	Conversion from irradiance to radiation – conversion factor: 1/3.6	Yes
Diffuse Horizontal Radiation {Wh/m^2}	Diffuse horizontal irradiance {kJ/m2}	Conversion from irradiance to radiation – conversion factor: 1/3.6	Yes
Global Horizontal Illuminance {lux}	Global horizontal illuminance {100 lux}	Conversion to lux – conversion factor: 100	No
Direct Normal Illuminance {lux}	Direct normal illuminance {100 lux}	Conversion to lux – conversion factor: 100	No
Diffuse Horizontal Illuminance {lux}	Diffuse horizontal illuminance {100 lux}	Conversion to lux – conversion factor: 100	No
Zenith Luminance {Cd/m2}	Zenith luminance {100 Cd/m2}	Conversion to Cd/m^2 conversion factor: 100	No
Wind Direction {Degrees}	Wind direction {0-359 degrees}		Yes
Wind Speed {m/s}	Wind speed {0.1 m/s}	Conversion to m/s – conversion factor: 0.1	Yes
Total Sky Cover {0 to 10}	Total sky cover {0-10 in tenths}		Yes
Opaque Sky Cover {0 to 10}	Opaque sky cover {0-10 in tenths}		Yes
Visibility {km}	Visibility {100 m}	Conversion to km – conversion factor:0.1	No
Ceiling Height {m}	Ceiling height {10 m}	Conversion to m– conversion factor:10	No
Present Weather Observation		9 → Missing Flag	Yes
Present Weather Codes	Present Weather *not used if previous field is 9		Yes

Precipitable Water {mm}		Missing Flag	No
Aerosol Optical Depth {thousandths}		Missing Flag	No
Snow Depth {cm}	Snow Cover	The original CWEC snow depth records only indicate snow coverage as snow cover (1) or no snow cover (0)[15]. In EPW weather files, snow cover should be a measurement of depth[36]. Upon inspecting convention used in CWEC, it is found that snow coverage is used directly in the EPW version, therefore conversion is not completed	Yes
Days Since Last Snowfall		Missing Flag	No
Albedo		Missing Flag	No
Liquid Precipitation Depth{mm}		Missing Flag	Yes
Liquid Precipitation Quantity {hr}		Missing Flag	No

4) Create Table and organize in EPW format

A new table is created with the EPW format, in which the arrays created from the previous step are organized into the appropriate columns. Depending on the Mode selected, the weather files can be packaged into different time frames. The “standard” mode, which is what is used in this research, divides the continuous record of weather data into individual year. The custom mode, which is not used in this research can package the weather data into different custom time ranges.

5) Export Table to Text

This step exports the table into text file.

6) Read Text File and Store as String

The text file is imported back and stored as a single string. This seemingly redundant step is needed in preparation for the next step.

7) Combine header lines with the rest of text file

The “*concat”* function is used to combine the header-lines to the rest of the simulation weather data. The previous step is needed since “*concat”* only works with two arrays that have the same size, hence it was needed to store the text file as a single string.

8) Export file to text file

The file is then exported to a text file(.txt).

9) Convert text file to EPW extension

The final step is to convert the .txt extension to .epw extension.

5.3.2 - Script 2: Graphing scripts:

The commented script is attached in Appendix D. The following section outlines a short description of the functionality of each part.

1) Extract file names

This part of the script extracts the filenames with .epw extensions from the specified path. A specified path method is used here because simulation ready weather files are often stored in dedicated folders and might not be good practice to place a script in individual folders containing weather files. The goal of this step is to create a name list of files that needs to be graphed. The pathlib library is used to convert the user defined text string into a recognizable path by functions in the os library.

2) Convert all epw files into csv

Since the epw file is not a recognized format, conversion to csv is needed to allow data extraction functions to work properly. The Shutil function library is used to copy the epw files and change the extension to csv.

3) Create dataframe

Dataframe in python is similar to Table in MATLAB. The Pandas library[69] is used to create the dataframes, and the structure of the dataframes are organized in EPW format. The objective of this step is to create a common dataframe to hold all the historical weather data of the same location together.

4) Extract data from files and append to combined dataframe

This step is to extract weather data from all the historical weather files placed in the specified folder through a loop. Each iteration of the loop extracts weather data from a historical weather file, the data is then being appended onto the combined dataframe, which is meant to serve as master storage for all historical weather data for the specified location. A similar strategy is used to extract typical year weather data with a different script.

5) Divide Data into seasons

This step is specific to the analysis being conducted. The goal is to divide data into seasons, so seasonal distributions of dry bulb temperature can be graphed. The division can be accomplished in different ways, a time column is created which can be easily assigned to a time index column, so data extraction can be accomplished by specifying a time range, for example extracting data between June 1 and August 31 for the summer season. However, the current script uses a different data extraction strategy, it is actually more straightforward in this case to just extract data based on the months column, since the dates are already separated in the EPW file format. For example, to extract summer months data, entries with months labelled as 6, 7 and 8 are extracted. Same strategy is used to extract data for other seasons. The extracted data for each season is assigned to a new variable, this is to keep data integrity of the master dataframe with all the historical weather data, so it can be easily used for data extraction for other analysis.

6) Graph hourly temperature

Finally, the extracted data is graphed with functions from the Plotly library[70]. A distinctive feature with the Plotly library [70] is its interactive abilities, which is useful for analyzing weather data and building simulation results. To illustrate these abilities, the interactive features used to analyze Figure 4-8 are shown in Figures 5-5 and 5-6. From Figure 4-8, it is seen that there are relatively high temperatures in the early hours, however, it is hard to know the exact temperature values just by examining the graph as a static image or to quickly compare two specific data series directly. Figure 5-5 shows the functionality where the temperature of the point of interest is highlighted when the cursor is hovering over; Figure 5-6 shows the series toggling functionality, where a certain data series can be hidden and cross comparison of other data series can be completed.

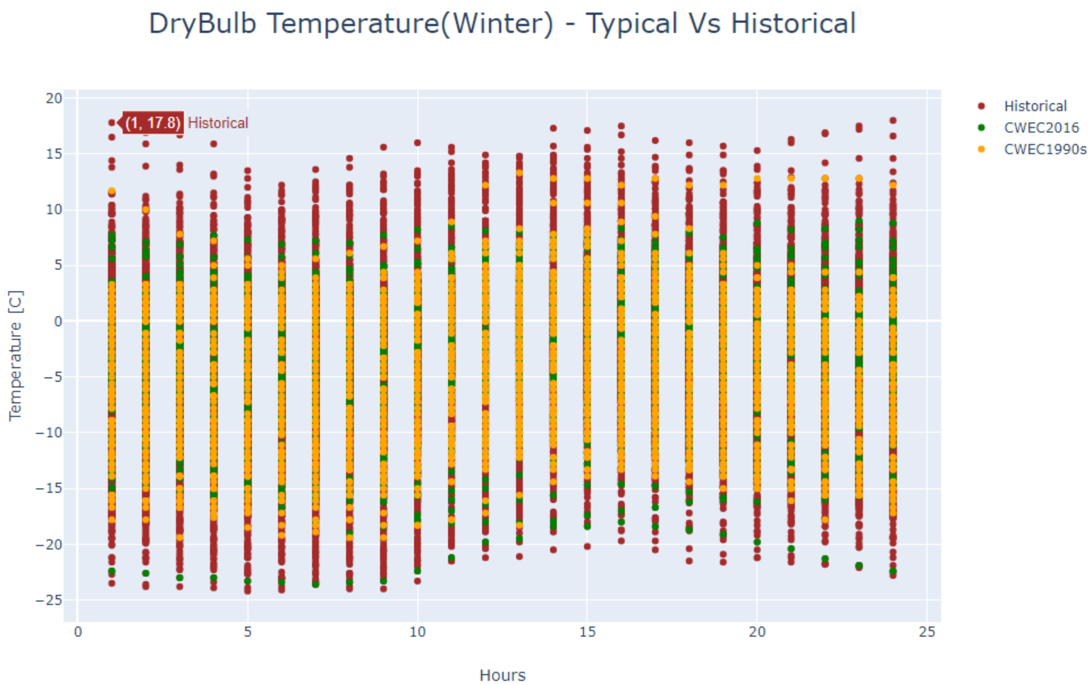


Figure 5-5 Dry Bulb Temperature Typical Vs Historical (Interactive Tag)

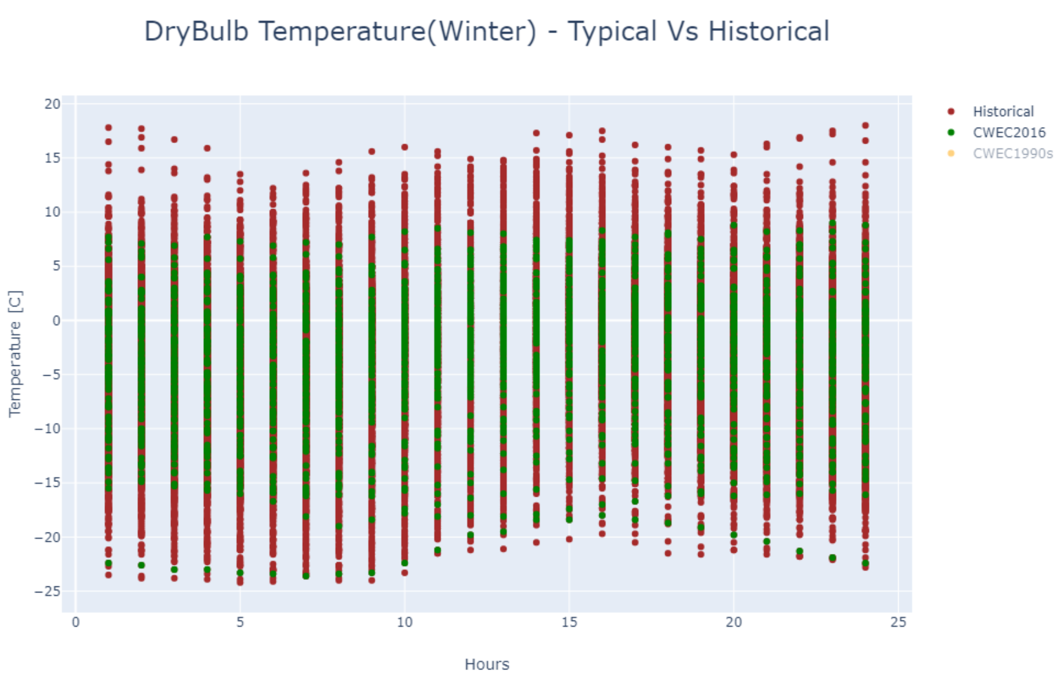


Figure 5-6 Dry Bulb Temperature Typical Vs Historical (Toggled Series)

5.3.3 - Script 3: Results extraction tool:

The commented script is attached in Appendix E. The following section outlines a short description of the functionality of each part.

1) Create combined table

This step is to create a pandas dataframe with a user defined structure for data storage purposes.

2) Extract file names

This is to create a name list with all the files with HTML extension in the folder that the script is located in. In this case, they are the EnergyPlus reports in HTML format. Reasons of why the csv version of the report which is much more accessible for data extraction is not used will be discussed below.

3) Extract data from files

The data extraction for this script is conducted differently than the previous two scripts presented in this chapter. In the previous two scripts, weather data is being analyzed, in which other than the header lines, the rest of the data has the same formatting. The reports created from EnergyPlus is not the case, in which the reports are more like a collective of tables where some may have different sizes depending on the number of equipment or the number of zones in the simulation model. Since EnergyPlus allows for user defined output reports, the structure of the reports can change. In this case, the location of the data that needs to be extracted may change, making the use of location-based indexing difficult. In theory, users can create templates, in which they can fixate the location of key parameters that needs to be extracted. However, that might not be practical in all cases. For example, analyzing the HTML reports of DOE prototype buildings published with the building models found in [51].

To analyze relatively unstructured data, eppy – a library of tools developed for the manipulation and analysis of EnergyPlus simulation is used. One of the tools is an HTML report reader[71] that is able to extract tables based on two different types of tags. The first one is based on the extraction of the bolded titles used in the HTML reports, in which the function will create a list of tags of bolded header lines in the HTML report and the associated location, so it could be used to locate the tables. The second one is based on the extraction of all the header-lines leading up to the table and again the associated table location.

The proper application of the functions can enable searching of tables based on key words in the table of interest from the collection of tables in the Energy Plus output reports.

4) Append to combined table

The extracted data is organized and stored in the combined dataframe, which is meant to store the information from all the reports in the folder so they can be used for comparison.

5) Export Table

The combined dataframe is exported into a csv file and can be used for further post processing.

5.4 Concluding Remarks

The use of computer scripts enhanced the quality of this research by ensuring data can be presented the way it is intended to. For repetitive tasks, the use of scripts ensured consistent quality, and traceability of the processes completed, for example the algorithm used in the scripts can be further examined and corrected if errors are found.

To be clear, the scripts presented in this chapter are not optimized for performance, in which the objective in mind is to achieve the goal of presenting data the way intended with the most simplistic logic and the least amount of time spent on coding. The amount of time spent on coding depends highly on the experience and skills of the user, and often a simple time cost/ benefit analysis should be completed to justify such endeavor. For example, script 3 is meant to extract data from about 1200 simulation, 2 days were spent on scripting and troubleshooting, where the processing time took about 2 hours. However, if the script is not written and data is extracted manually, assuming 60 reports can be opened and documented in an hour, it will at least take 20 continuous hours of manual labor to complete the work, assuming that no errors are made in the process. It is clear in this example that scripting is the better way.

There are also added benefits to the efficiency of coding once a library of scripts is being built by the user, in which code blocks can be used interchangeably with minor modifications. This is what happened with the progression of this research, much of the code created for script 1, 2 and 3 are reused (for example, the file name extraction code block, and the graphing code block) for other purposes. The combination of code blocks/functions can also be used in more sophisticated applications.

Chapter 6 Limitations and Future Work

6.1 Expanding geographical representativeness

This research work only considered the Toronto Pearson Airport weather station. Further work should be conducted on other major cities in Canada to expand geographical representativeness of the claims made from the results of this research. The computer scripts created in completing this research can be used to expedite any further exploration in the subject.

6.2 Effective conductivity of building thermal insulation materials

The main theme of this thesis is on reviewing current practices and questioning whether the limitations that are identified in the past still exist with current advancements in knowledge and technologies. Similar to the practice of using Typical Year weather files, the use of constant thermal conductivity is mainly due to 2 reasons: 1) an industry reporting rule introduced by the Federal Trade Commission in the 1970s stating that manufacturers have to report thermal conductivity of building insulation materials measured at a mean temperature of 24 degrees at dry state[73], and the practice continues till today; 2) as mentioned in Chapter 3, simplifications are made to the conductive algorithm in the early days of Building Energy Simulation, and much of today's BES packages such as Energy Plus still uses transfer function, in which material properties have to constant. In reality, thermal conductivity is influenced by factors such as temperature and moisture content, which is recognized by other studies [74][75]. A preliminary study [76] is completed by the author of this thesis in exploring the impact of the use of Typical and Historical year weather files in simulation using WUFIPlus[44] - a BES package that has capability in accounting for heat and mass transfer, as well as temperature and moisture dependent conductivity. The results showed small differences when temperature and moisture dependent properties are accounted for with cellulose insulation materials applied in a house in Toronto. However, one of the limitations of that study is the lack of rain data which can potentially limit the amount of moisture in the insulation material. Future studies can include rain data into the weather data and further investigate the impact it has on BES when both temperature and moisture properties of building materials are accounted for, further organization work is also needed in gathering thermal conductivity data with temperature and moisture dependent effects.

Chapter 7 Conclusions

The goal of this research is to thoroughly examine the practice of using Typical Year and multi-Historical Year weather data in Building Energy Simulation (BES).

In Chapter 2, through the analysis of the statistical distribution of relevant weather elements, from two versions of Typical Year weather files(CWEC 1990s and CWEC 2016), it is observed that there is change in the distribution of dry bulb temperature, in which CWEC 2016 generally has warmer temperature in most months. Signifying a warming trend between the creation of the two typical year weather files, and the long-term weather conditions represented in those files may not be the same. From the analysis of weather indices with Historical Year weather data (CWEEDs 1998 to 2014), the yearly occurrences of extreme weather events is not similar and tend to cycle between periods of hotter years and colder years. This fluctuation is not represented by a singular representative by Typical Year weather files.

In Chapter 3, the total energy estimation for heating and cooling using Typical and Historical Year weather data are compared. In general, the total estimation of heating and cooling energy using CWEC 2016 is similar to the sum of the 17 years of Historical Year simulations, whereas the estimation from simulation using CWEC 1990s generally under-estimated cooling energy and over-estimated heating energy. In terms of estimating yearly energy usage for heating and cooling, neither simulation using CWEC 2016 nor CWEC1990s yielded consistent results close to the yearly historical estimation, as the yearly weather fluctuation cannot be reflected in a singular weather year representation. The problem identified with the practice of using Typical Year weather files for simulation is that they are always created with past weather data and may potentially not be a good representation of long-term weather conditions if not updated frequently. Even though simulation using CWEC 2016 can yield close estimates of total energy usage with simulation using Historical Year that it is selected to represent, as soon as it is created, the present weather year is already out of that historical range, which can make the Typical Year increasingly less representative as with the older CWEC 1990s weather file. A simple alternative using a rolling average of historical year is presented, and while it also does not yield a good estimation of the yearly historical estimations, the estimation yielded is close to the estimations with CWEC 2016, showing potential that it can be used as an alternative, especially considering that CWEC 2016 can only be compiled after 2014.

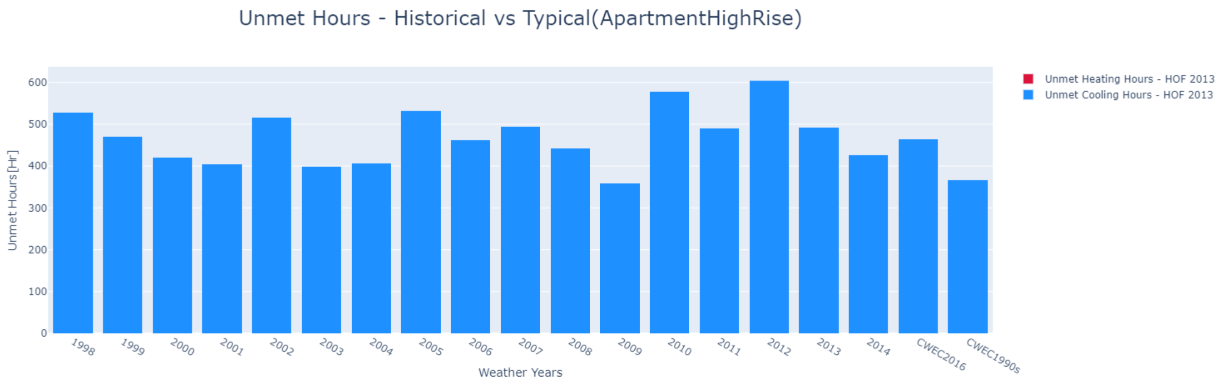
In Chapter 4, the effects of simulating buildings with equipment sized with different design data (from ASHRAE HOF 2005 and HOF 2013) are compared under different weather conditions (CWEC 1990s, CWEC 2016, and CWEEDs 1998 to 2014). From the analysis it is found that no matter which design data is used, simulation with CWEC 1990s generally have fewer unmet hours estimated and more building type passes the ASHRAE 300-hour rule on unmet hours. This indicates that simulation with the older CWEC 1990s weather file may lead to under estimation of unmet hours. For peak load estimations, it is found that simulation using CWEC 2016 generally estimated higher heating and cooling peak loads, this is mainly because the conditions in the selected months contained the relatively more extreme conditions. Since the selection of Typical Year weather data does not actively use extreme conditions as a selection criterion (there is however persistence criteria excluding the most extreme conditions), there is no guarantee of whether the selected months contain the relatively more extreme conditions. As suggested by literature, it is generally not encouraged to use Typical Year weather files to evaluate peak loads. In terms the effects of using different design data for equipment sizing, there is generally fewer unmet cooling hours estimated when data from HOF 2013 is used, for unmet heating hour estimation the difference between sizing with HOF 2005 and HOF 2013 is not great. The estimations using CWEC 2016 tends to stay within the range estimated from historical year simulation; whereas the estimation of unmet cooling hours and peak loads using CWEC 1990s tends be on the lower range of the historical estimations, with some buildings being out of range, indicating that it is not a good representation of the weather conditions in the Historical Year weather data. When comparing the results of using different design data, it is found that there tends to be fewer unmet hours when HOF 2013 is used in historical simulation, this is mainly a decrease in unmet cooling hours for most building types and only a slight increase in unmet heating hours for some building types. The difference in peak load estimations are not great.

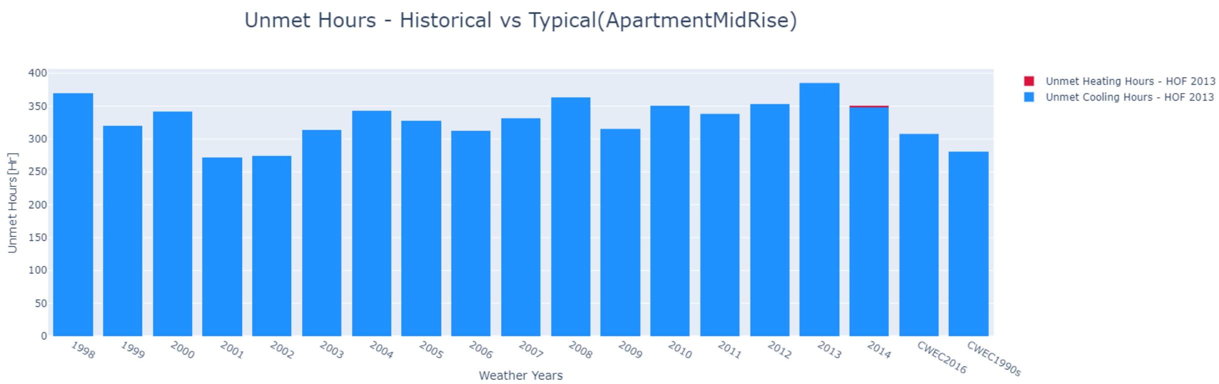
In Chapter 5, three computer scripts are presented to show that the labor-intensive work in preparing and analyzing multi-year simulations can indeed be automated, as literacy in computer programming and access to computing power and storage are enhancing rapidly. The continuous development of tools specific to building related analysis can also further inspire development of more advanced tools.

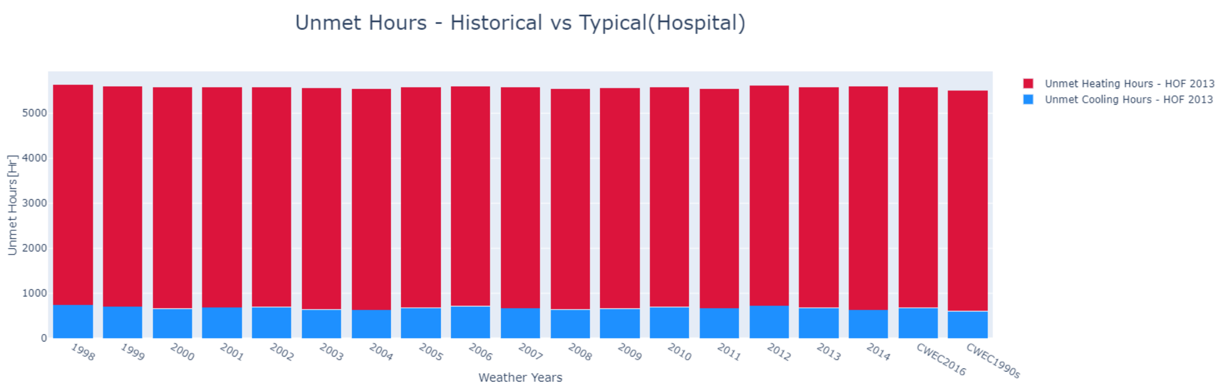
In conclusion, the analysis work completed in chapters 2 to 4 shows that there are critical insights missing from conventional Building Energy Simulation with Typical Year weather files. The general infrequent update cycle of Typical Year weather files is especially problematic, since the selection method can only generate weather files that are statistically representative of a certain historical time range. In Toronto, this can be an issue if the designer is not aware of the different versions of weather data available, since the Toronto Green Standard[41](which mandates energy modelling for new building design) only asks for a CWEC weather file to be used in simulation and does not specify the version to be used. In fact, the CWEC 1990s weather file is still readily accessible from the Energy Plus weather database [33], which can be easily mistaken if the designer does not open and check the weather data being included. It is recommended that designers should always double check the weather data being used prior to simulation. Simulation with Historical Year data while is also not ideal as they are products of the past, has shown potential as a reasonable alternative to simulation with Typical Year weather, since they can be updated more frequently and contain a wider range of conditions. Chapter 5 shows that tasks that are laborious or resource prohibited in the past can be simplified with relative ease, hindered mainly only on the general computer programming literacy amongst building designers. Future work can focus on analyzing other cities in Canada, as well as investigating the application of multi-year simulation in more advanced simulation applications such as incorporating effective thermal conductivity in simulation.

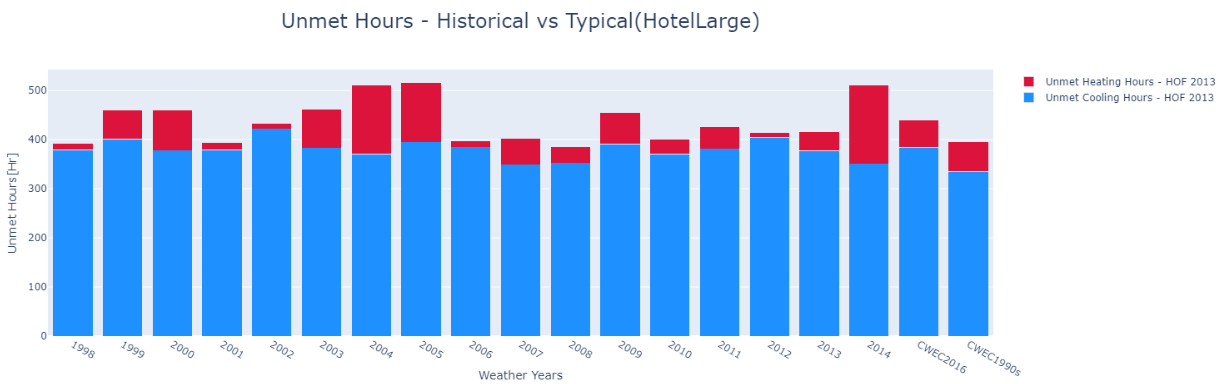
Appendices

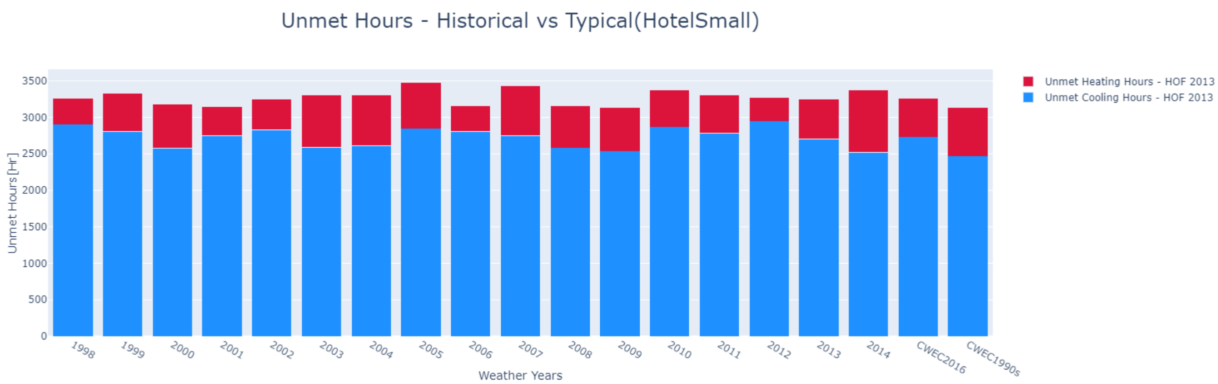
Appendix A - Unmet hours from Historical Simulation

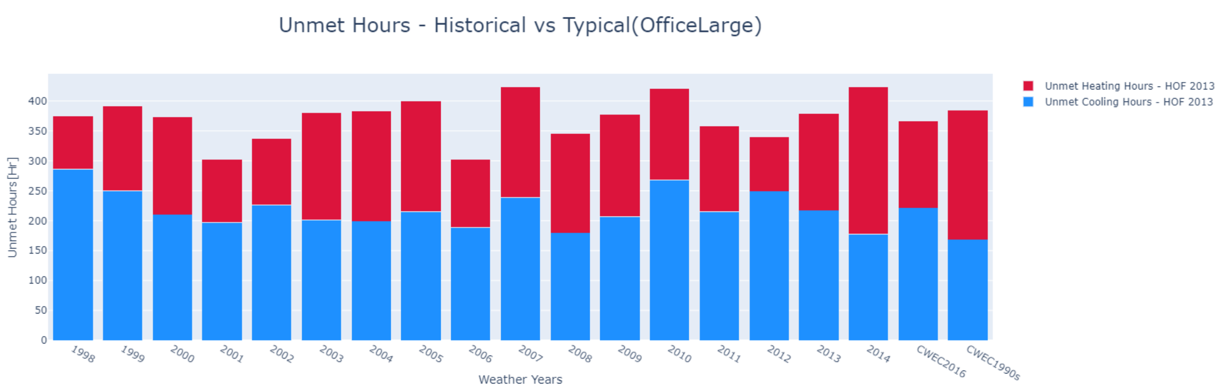


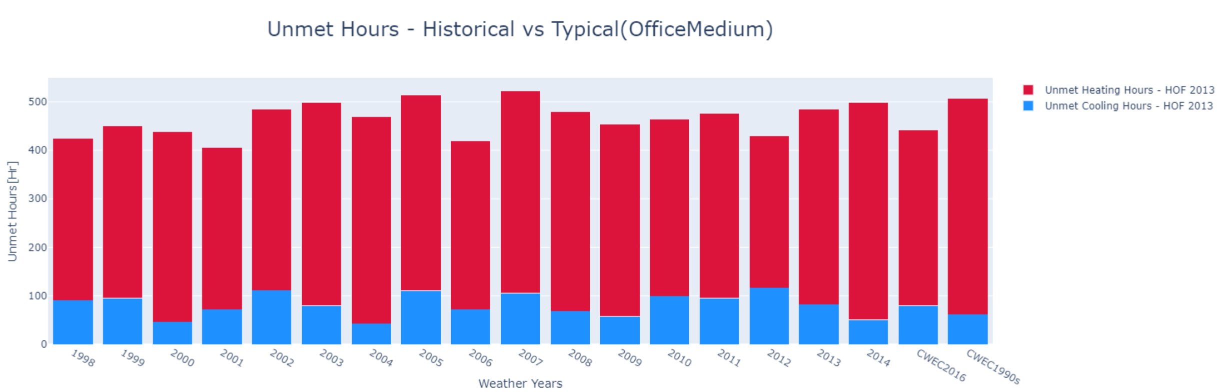




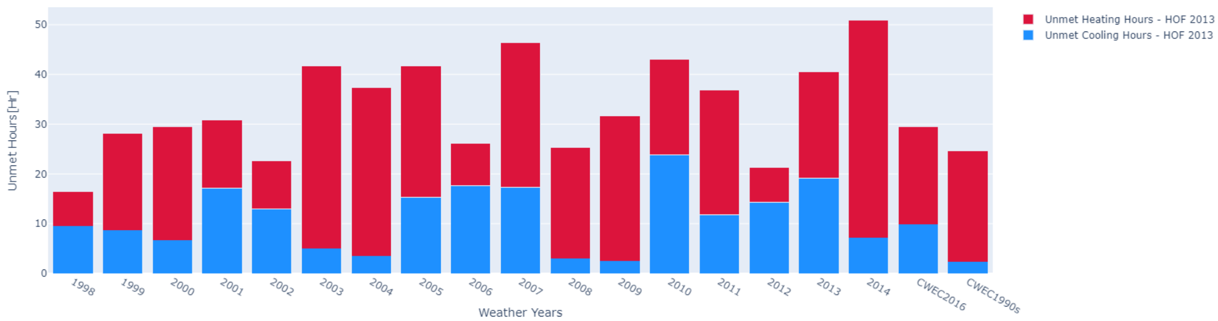

Unmet Hours - Historical vs Typical(HotelLarge)
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013
Unmet Hours[Hr]
Weather Years
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s


Unmet Hours - Historical vs Typical(HotelSmall)
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013
Unmet Hours[Hr]
Weather Years

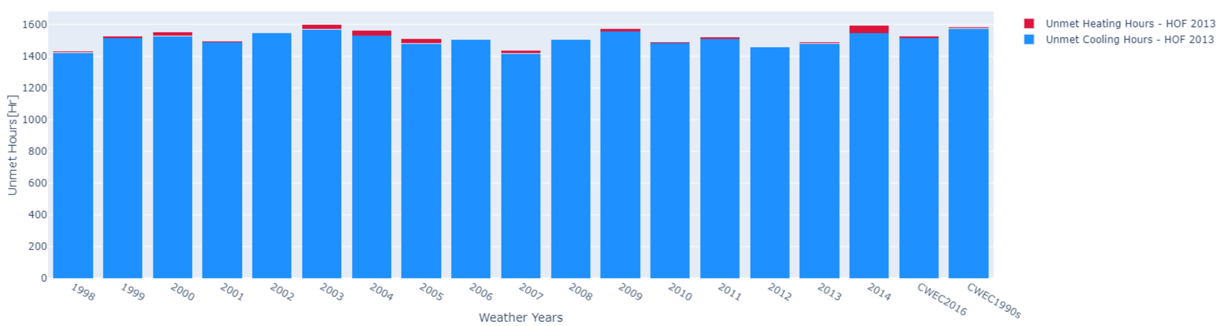

Unmet Hours - Historical vs Typical(OfficeLarge)
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013
Unmet Hours[Hr]
Weather Years


Unmet Hours - Historical vs Typical(OfficeMedium)
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013
Unmet Hours[Hr]
Weather Years

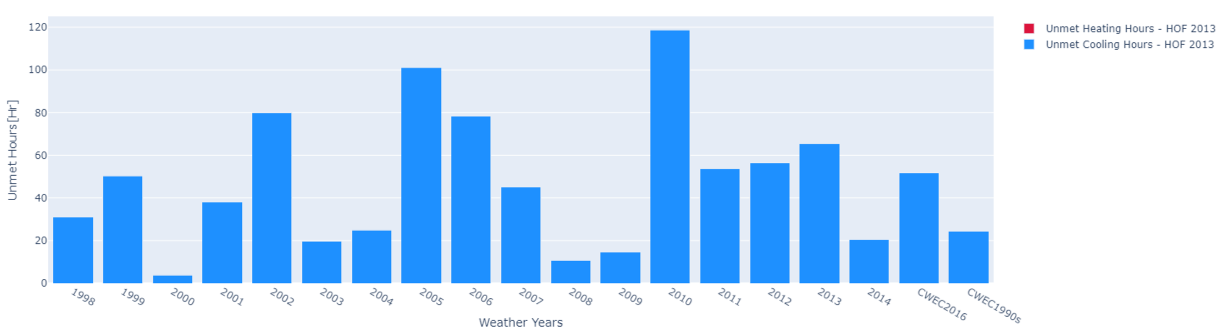
Unmet Hours - Historical vs Typical(OfficeSmall)



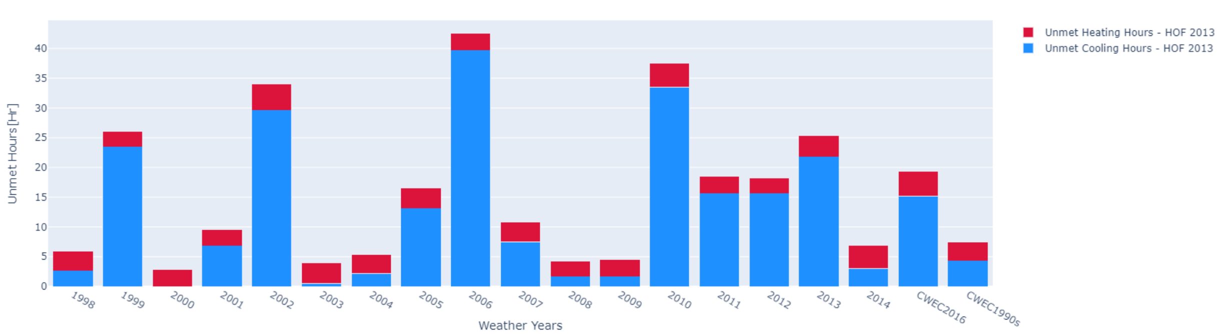
Unmet Hours - Historical vs Typical(OutPatientHealthCare)

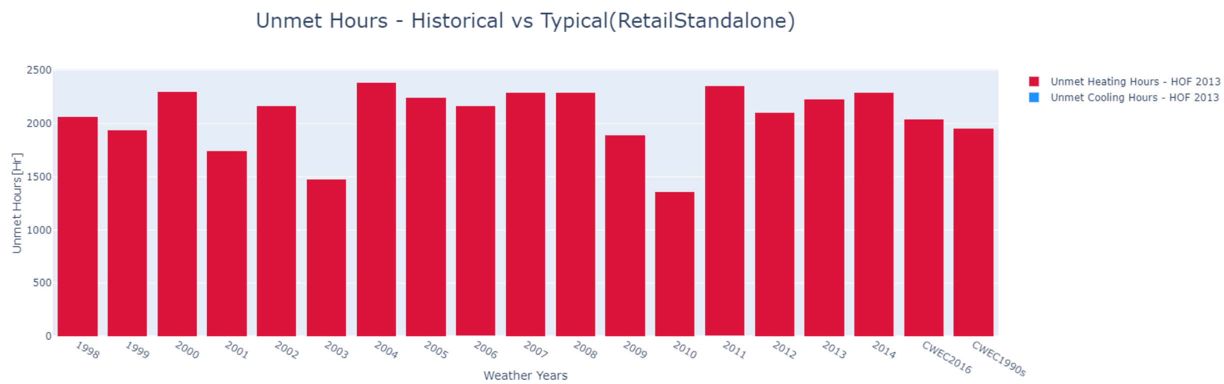


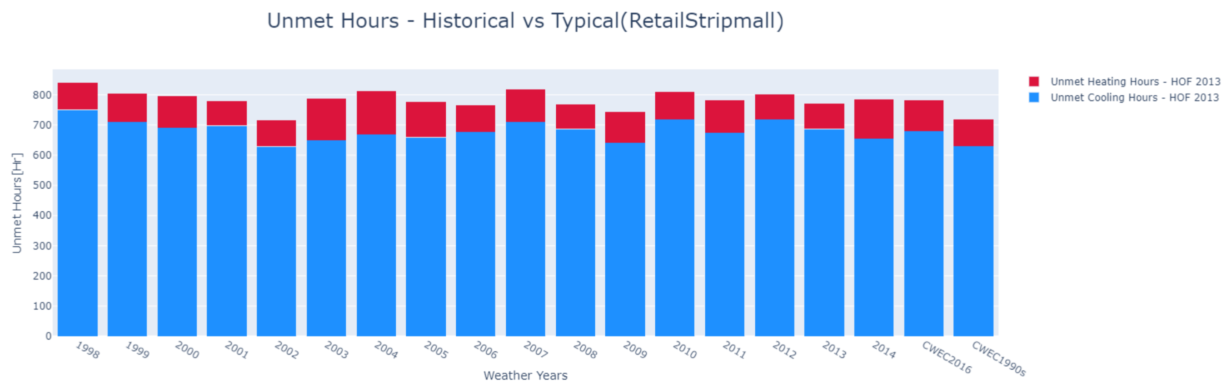
Unmet Hours - Historical vs Typical(RestaurantSitDown)

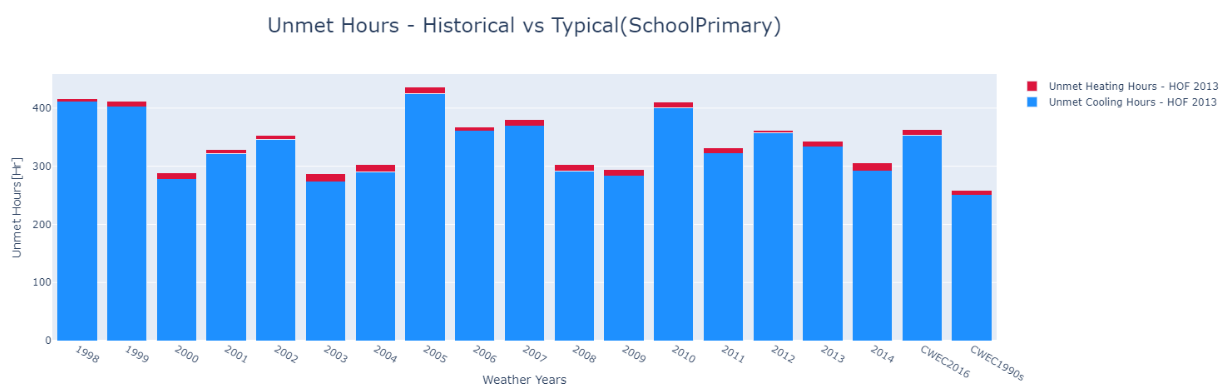


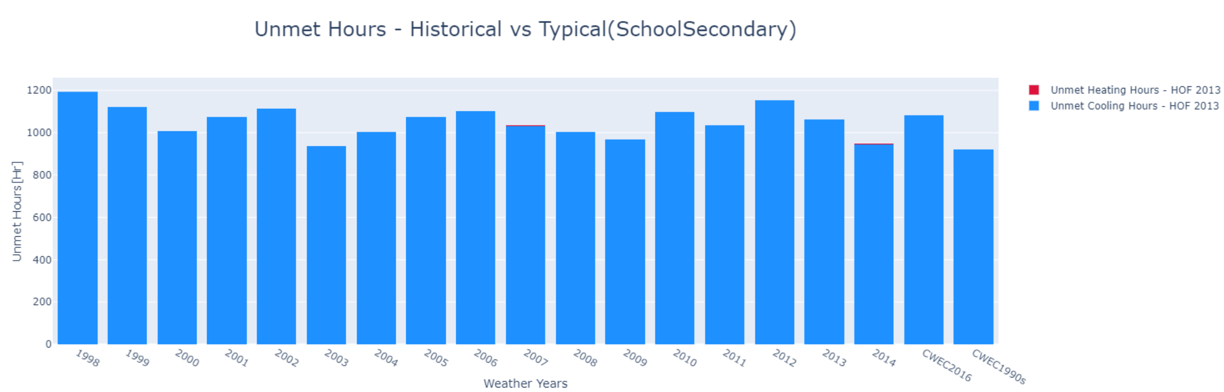
Unmet Hours - Historical vs Typical(RestaurantFastFood)

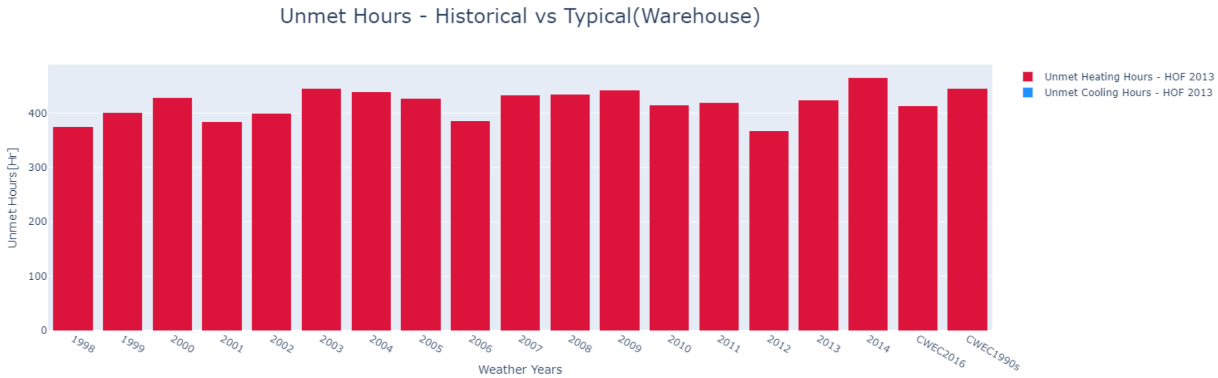



Unmet Hours - Historical vs Typical(RetailStandalone)
Unmet Hours[Hr]
Weather Years
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013

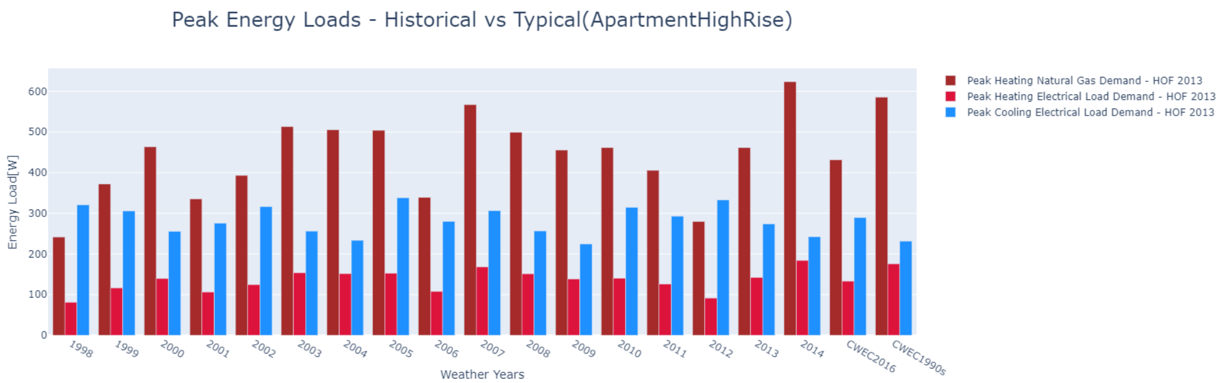

Unmet Hours - Historical vs Typical(RetailStripmall)
Unmet Hours[Hr]
Weather Years
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013

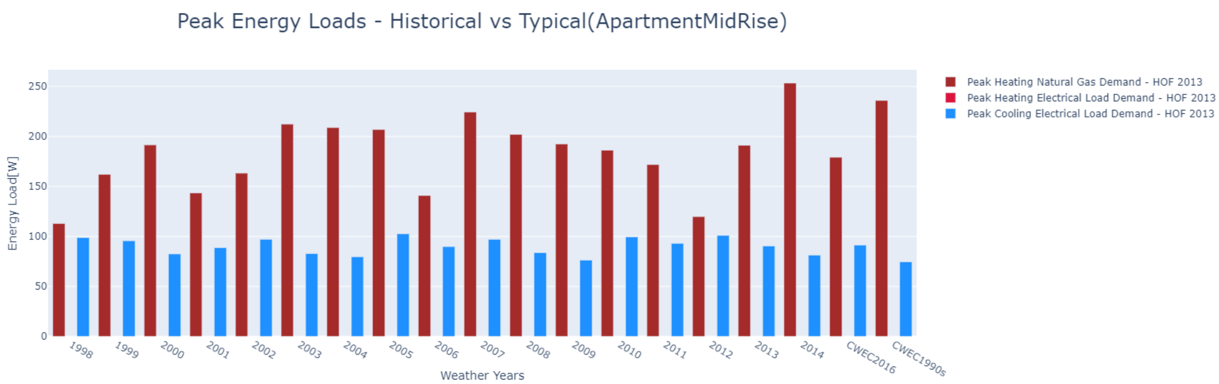

Unmet Hours - Historical vs Typical(SchoolPrimary)
Unmet Hours[Hr]
Weather Years
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013

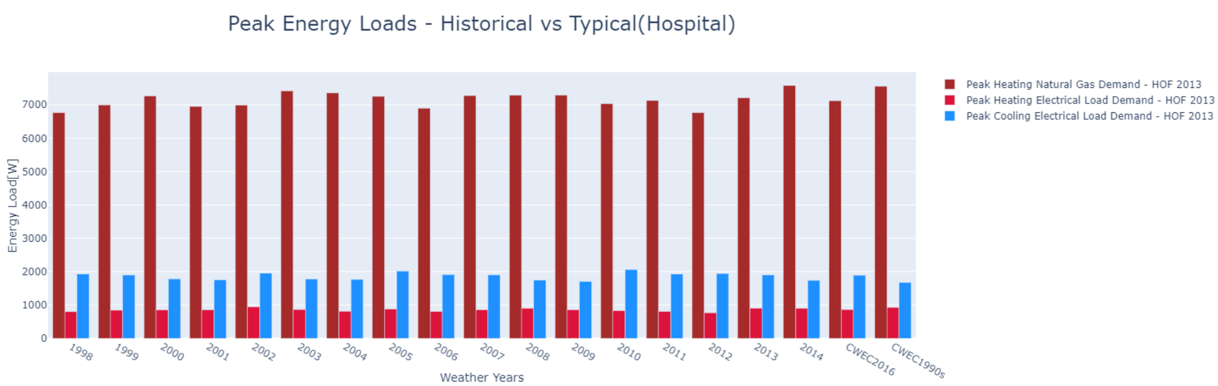

Unmet Hours - Historical vs Typical(SchoolSecondary)
Unmet Hours[Hr]
Weather Years
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013

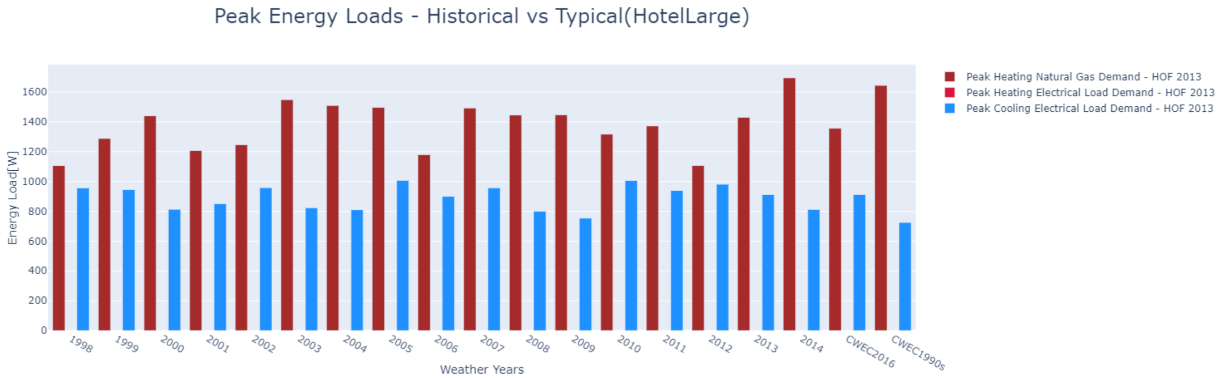

Unmet Hours - Historical vs Typical(Warehouse)
Unmet Heating Hours - HOF 2013
Unmet Cooling Hours - HOF 2013
Unmet Hours[Hr]
0
100
200
300
400
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s
Weather Years

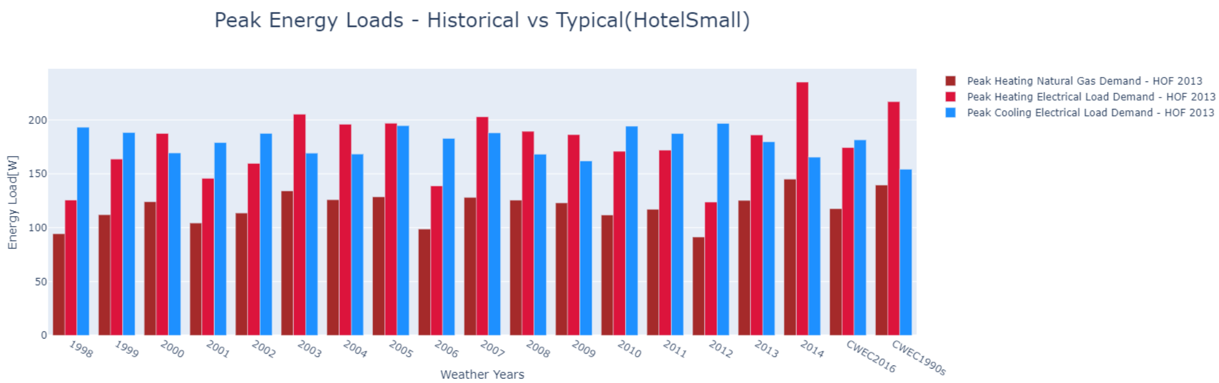
Appendix B - Peak Energy Loads from Historical Simulation

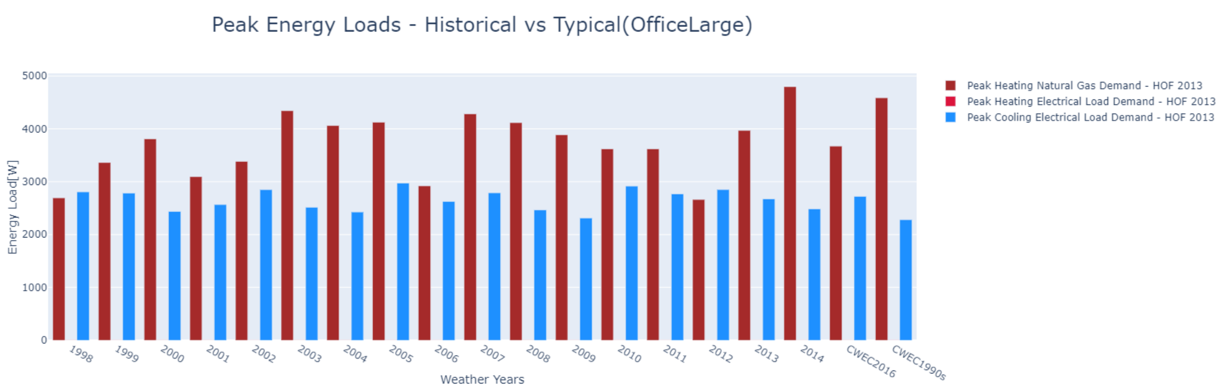


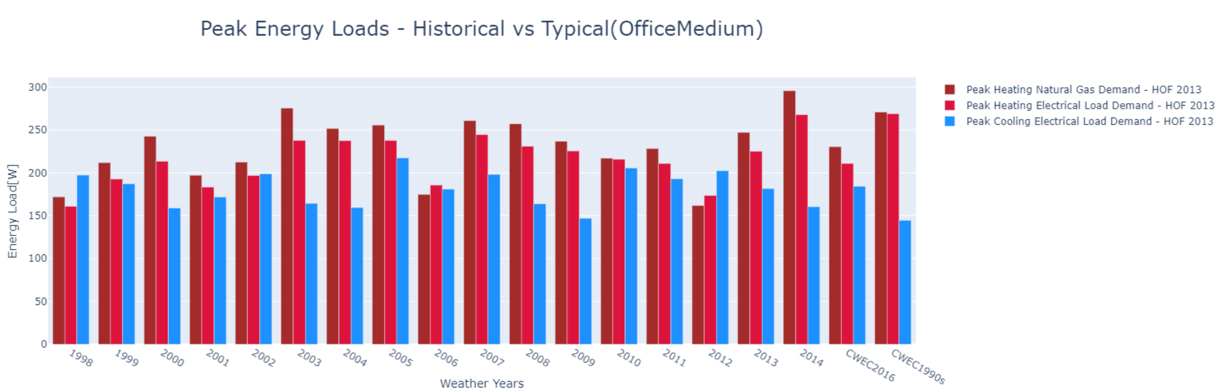




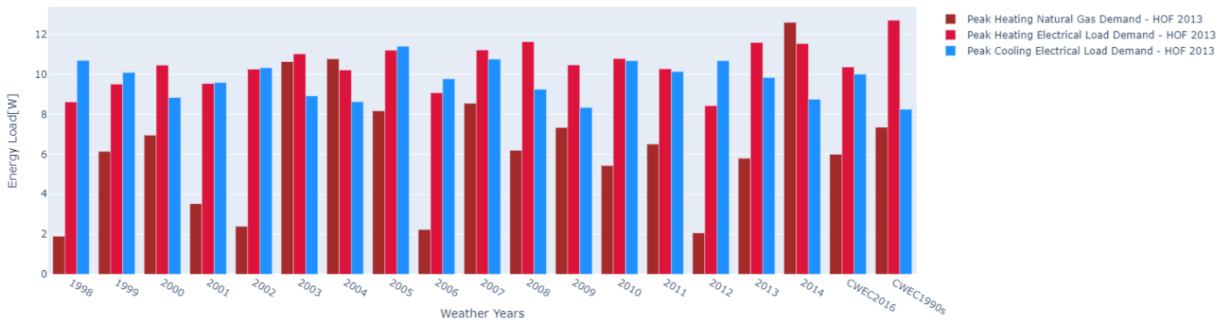

Peak Energy Loads - Historical vs Typical(HotelLarge)
Energy Load[W]
Weather Years
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013


Peak Energy Loads - Historical vs Typical(HotelSmall)
Energy Load[W]
Weather Years
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013

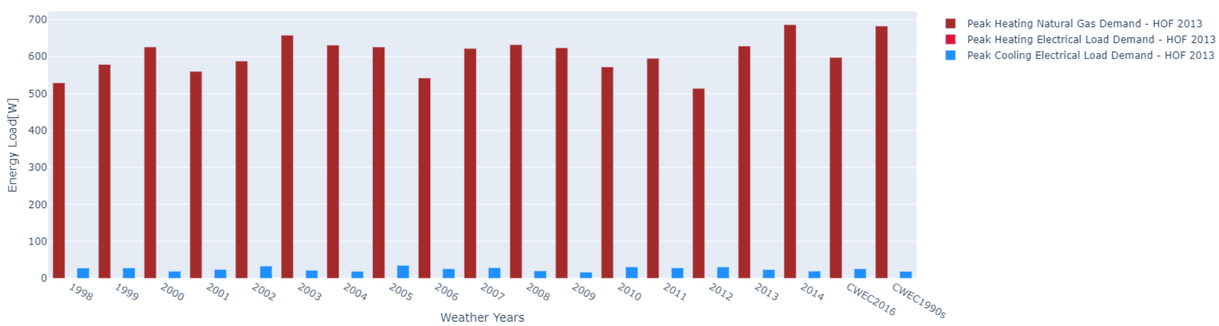

Peak Energy Loads - Historical vs Typical(OfficeLarge)
Energy Load[W]
Weather Years
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013


Peak Energy Loads - Historical vs Typical(OfficeMedium)
Energy Load[W]
Weather Years
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013

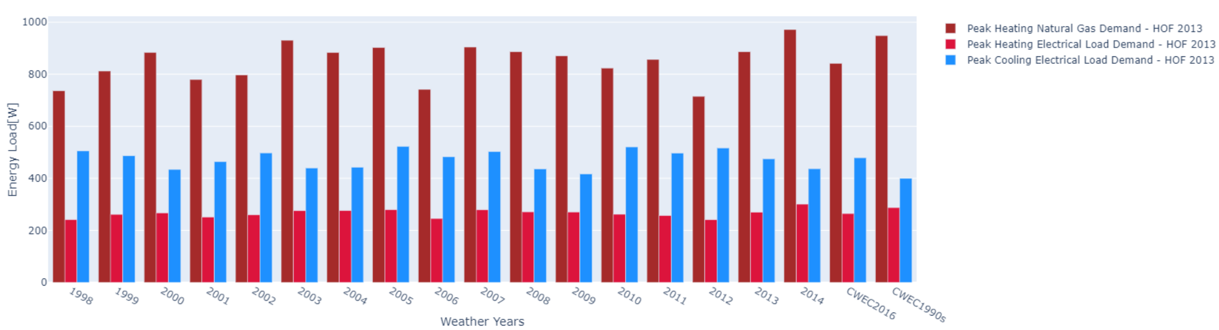
Peak Energy Loads - Historical vs Typical(OfficeSmall)



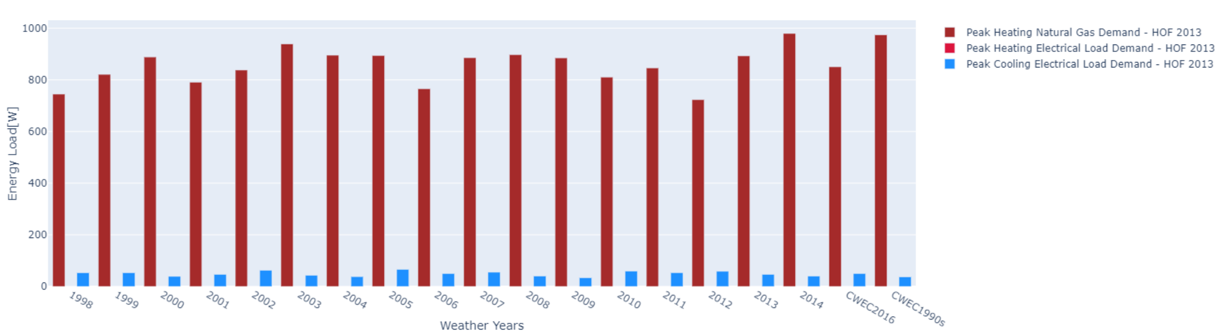
Peak Energy Loads - Historical vs Typical(RestaurantFastFood)

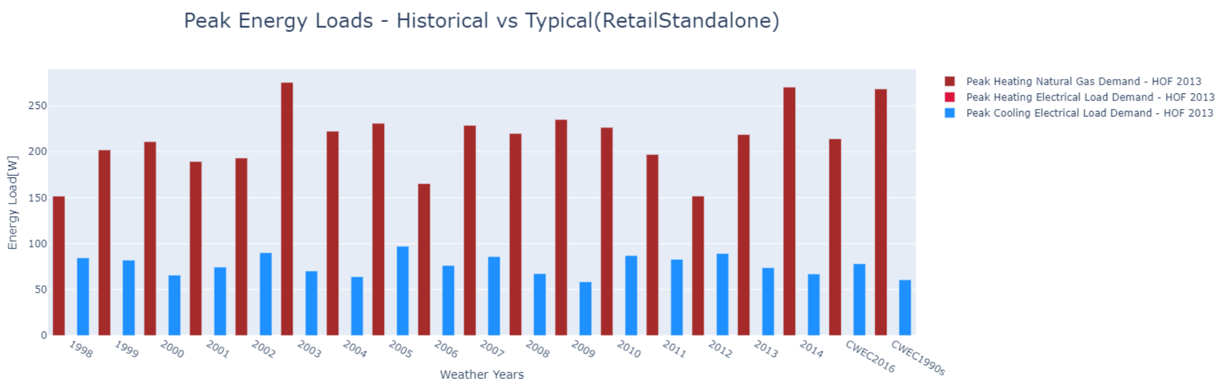


Peak Energy Loads - Historical vs Typical(OutPatientHealthCare)

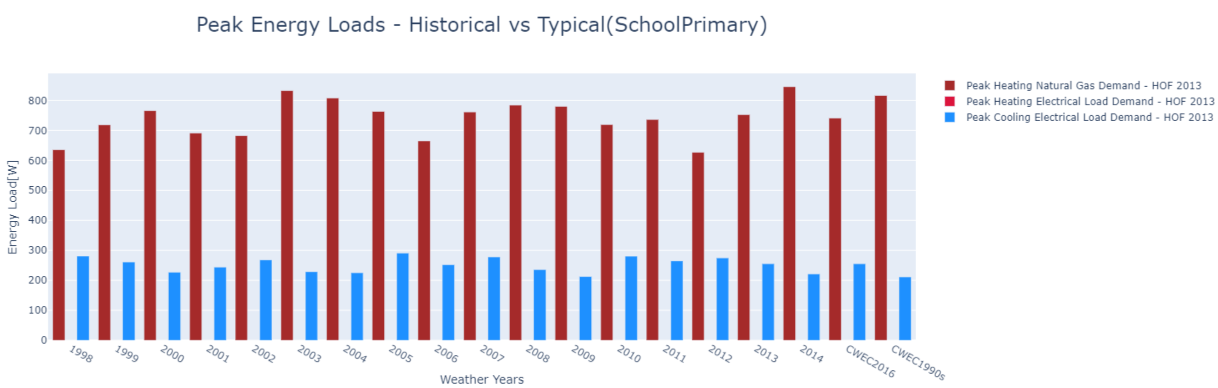


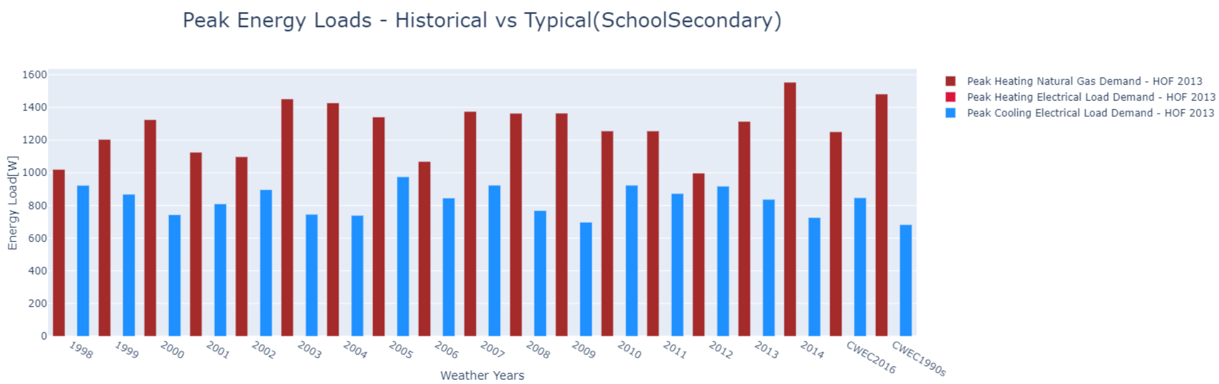
Peak Energy Loads - Historical vs Typical(RestaurantSitDown)

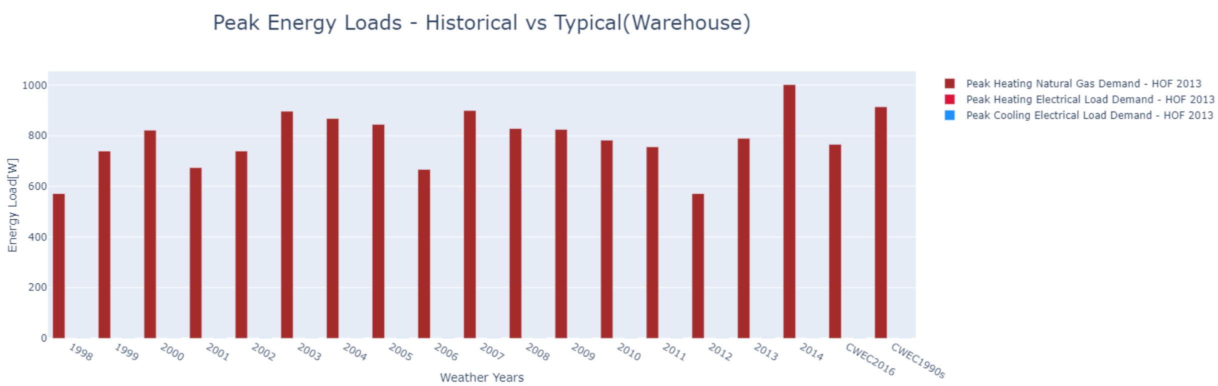



Peak Energy Loads - Historical vs Typical(RetailStandalone)
Energy Load[W]
Weather Years
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013


Peak Energy Loads - Historical vs Typical(RetailStripmall)
Energy Load[W]
Weather Years
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013


Peak Energy Loads - Historical vs Typical(SchoolPrimary)
Energy Load[W]
Weather Years
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013


Peak Energy Loads - Historical vs Typical(SchoolSecondary)
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013
Energy Load[W]
Weather Years
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s


Peak Energy Loads - Historical vs Typical(Warehouse)
Peak Heating Natural Gas Demand - HOF 2013
Peak Heating Electrical Load Demand - HOF 2013
Peak Cooling Electrical Load Demand - HOF 2013
Energy Load[W]
Weather Years
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CWEC2016
CWEC1990s

Appendix C - Script 1 -Weather File Convertor WYEC3 to EPW

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%B-1
Inputs%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%B-1-I)Mode
%%Mode 1 - Standard-All Years , Mode 2 - Custom Time Range(fill in B-1-II)
Mode=1;

%B-1-II)Mode 2 Configurations --> Ignore if using Mode 1
%%Time Input for custom weather file
CustomStart_Year=1999;
CustomStart_Month=1;
CustomStart_Day=1;
CustomStart_Hour=13;

CustomEnd_Year=2008;
CustomEnd_Month=12;
CustomEnd_Day=8;
CustomEnd_Hour=24;

%%Custom file name tag
CustomTag='custom'

%B-1-III) Header Lines for
%%Taken from CWEC file
line1='LOCATION,TORONTO INTL A,ON,CAN,CWEC2011,716240,43.68,-79.63,-
5.0,173.4';
line2='DESIGN CONDITIONS,1,Climate Design Data 2013 ASHRAE
Handbook,,Heating,1,-18.1,-15.6,-23.3,0.5,-17.6,-20.4,0.6,-15.2,14.2,-
4.7,12.7,-
4.1,4.8,0,Cooling,7,9.9,31.4,22.4,29.6,21.4,27.9,20.6,23.7,29.1,22.7,27.8,21.
7,26.3,5.8,270,22.1,17.1,26.7,21,16,25.6,20.1,15.1,24.6,71.9,29.2,68,28.1,64.
2,26.2,692,Extremes,12.1,10.5,9.3,28.5,-21.6,33.9,3.3,1.9,-24,35.3,-
25.9,36.4,-27.7,37.5,-30.1,38.9';
line3='TYPICAL/EXTREME PERIODS,6,Summer - Week Nearest Max Temperature For
Period,Extreme,7/17,7/23,Summer - Week Nearest Average Temperature For
Period,Typical,7/24,7/30,Winter - Week Nearest Min Temperature For
Period,Extreme,1/ 4,1/10,Winter - Week Nearest Average Temperature For
Period,Typical,12/ 6,12/12,Autumn - Week Nearest Average Temperature For
Period,Typical,9/19,9/25,Spring - Week Nearest Average Temperature For
Period,Typical,3/22,3/28';
line4='GROUND TEMPERATURES,3,.5,,,,-2.55,-3.69,-
1.66,1.51,9.82,16.22,20.55,21.86,19.62,14.65,8.00,1.83,2,,,,1.66,-
0.38,0.04,1.73,7.28,12.31,16.32,18.48,18.02,15.20,10.62,5.76,4,,,,5.15,3.06,2
.60,3.23,6.38,9.76,12.86,15.02,15.53,14.30,11.61,8.33';
line5='HOLIDAYS/DAYLIGHT SAVINGS,No,0,0,0';
line6='COMMENTS 1,Custom/User Format -- WMO#716240; Custom DEF format for
CWEC2011 formatted files.;';
line7='COMMENTS 2, -- Ground temps produced with a standard soil diffusivity
of 2.3225760E-03 {m**2/day}';
line8='DATA PERIODS,1,1,Data,Sunday,1/ 1,12/31';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Script%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
fprintf('Process Begins\n')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% B-2 Extract File Names
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('Extract File Names\n')
datedir = dir('*.WY3');
filenames = {datedir.name};
filenames = filenames';

z=1;
d=1;
chr=string(filenames);

%Splitting file name so parts of it can be used in exported files
filenames=chr;
[u,y]=size(filenames);
filnamediv=split(filenames,'_');
filenamediv=string(filnamediv);
filenamediv=filenamediv';



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% B-3 Extract Data from Files
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Iterates through the list of file in folder
fprintf('Extract Data From Files\n')

for z=1:u
EPW = cell2table(cell(0,5)) ;
RelHum=zeros(1,1);



q=0;
filename=filenames(z,1);
%convert wy3 to txt
file1=filenames(z,1);
file2=strrep(file1,'.WY3','.txt');

file1=char(file1);
file2=char(file2);

copyfile(file1,file2);

%extract variables from fixed width txt
DataStartLine = 2;
NumVariables = 47;
VariableNames  =
{'Station','SourceCode','Year','Month','Day','Hour','ExtIr','GlobHorIr','Glob
HorIrFlag','DirNormIr','DirNormIrFlag','DifHorIr','DifHorIrFlag','GloHorIllum
','GloHorIllumFlag','DirNormIllum','DirNormIllumFlag','DifHorIllum','DifHorIl
lumFlag','ZenIll','ZenIllFlag','MinSun','MinSunFlag','CeilHeight','CeilHeight
Flag','SkyCondition','SkyConditionFlag','Visibility','VisibilityFlag','Presen
tWeather','PresentWeatherFlag','StationPressure','StationPressureFlag','DryBu
lbTemp','DryBulbTempFlag','DewPointTemp','DewPointTempFlag','WindDir','WindDi
rFlag','WindSpeed','WindSpeedFlag','TotSkyCov','TotSkyCovFlag','OpSkyCov','Op
SkyCovFlag','SnowCov','SnowCovFlag'};
```

```
VariableWidths =
[7,1,4,2,2,2,4,4,2,4,2,4,2,4,1,4,1,4,1,4,1,2,1,4,1,4,1,4,1,8,1,5,1,4,1,4,1,3,
1,4,1,2,1,2,1,1,1] ;

opts=fixedWidthImportOptions('NumVariables',NumVariables,'DataLines',DataStar
tLine,'VariableNames',VariableNames,'VariableWidths',VariableWidths);

T =zeros(1,1);
T = readtable(filename,opts);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% C-1 Assign Variables to Weather
Elements + Data Processing%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('Process Data\n')
%Date
YEAR=T.Year;
DAY=T.Day;
MONTH=T.Month;

%Time
minute=zeros(size(T.Hour));
MINUTE=string(minute);
HOUR=T.Hour;


%DataSource
Datasource=zeros(size(T.Hour));
Datasource=string(Datasource);
Datasource(:,1)={'?9?9?9?9E0?9?9?9?9?9?9?9*9?9?9?9?9?9*9*_?9*9'};

%DryBulb
DryBulb=string(T.DryBulbTemp);
DryBulb=str2double(DryBulb);
DryBulb=(0.1)*DryBulb;
DryBulb=round(DryBulb,1);


%DewPoint
DewPoint=string(T.DewPointTemp);
DewPoint=str2double(DewPoint);
DewPoint=(0.1)*DewPoint;
DewPoint=round(DewPoint,1);

%RelativeHumidity
%refer to http://www.bom.gov.au/climate/averages/climatology/relhum/calc-
rh.pdf
i=0;
for i=1:size(DryBulb)
v(i,1)=100*exp(1.8096+((17.2694*DewPoint(i,1)/(237.3+DewPoint(i,1)))));
r(i,1)=exp(1.8096+((17.2694*DryBulb(i,1))/(237.3+DryBulb(i,1))));
RelHum(i,1)=v(i,1)/r(i,1);
RelHum=round(RelHum);
i=i+1;
end
```

```
%AtmosPressure
AtmosPressure=string(T.StationPressure);
AtmosPressure=str2double(AtmosPressure);
AtmosPressure=(10)*AtmosPressure;


%ExtHorzRad
ExtHorzRad=string(T.ExtIr);
ExtHorzRad=str2double(ExtHorzRad);
ExtHorzRad=ExtHorzRad/(3.6);
ExtHorzRad=round(ExtHorzRad);


%ExtDirRad
ExtDirRad=zeros(size(T.Hour));
ExtDirRad=string(ExtDirRad);
ExtDirRad(:,1)={'9999'};


OpaqSkyCvr=T.OpSkyCov;
OpaqSkyCvr=str2double(OpaqSkyCvr);

%HorzIRSky
HorzIRSky=zeros(size(T.Hour));
HorzIRSky=string(HorzIRSky);
HorzIRSky(:,1)={'9999'};

%GloHorzRad
GloHorzRad=T.GlobHorIr;
GloHorzRad=str2double(GloHorzRad);
GloHorzRad=GloHorzRad/(3.6);
GloHorzRad=round(GloHorzRad);

%DirNormRad
DirNormRad=T.DirNormIr;
DirNormRad=str2double(DirNormRad);
DirNormRad=DirNormRad/(3.6);
DirNormRad=round(DirNormRad);

%DifHorzRad
DifHorzRad=T.DifHorIr;
DifHorzRad=str2double(DifHorzRad);
DifHorzRad=DifHorzRad/(3.6);
DifHorzRad=round(DifHorzRad);

%GloHorzIllum
GloHorzIllum=T.GloHorIllum;
GloHorzIllum=str2double(GloHorzIllum);
GloHorzIllum=GloHorzIllum*(100);
GloHorzIllum=round(GloHorzIllum);

%DirNormIllum
DirNormIllum=T.DirNormIllum;
```

```
DirNormIllum=str2double(DirNormIllum);
DirNormIllum=DirNormIllum*(100);
DirNormIllum=round(DirNormIllum);

%DifHorzIllum
DifHorzIllum=T.DifHorIllum;
DifHorzIllum=str2double(DifHorzIllum);
DifHorzIllum=DifHorzIllum*(100);
DifHorzIllum=round(DifHorzIllum);

%ZenLum
ZenLum=T.ZenIll;
ZenLum=str2double(ZenLum);
ZenLum=ZenLum*(100);
ZenLum=round(ZenLum);

%WindDir
WindDir=T.WindDir;

%WindSpd
WindSpd=T.WindSpeed;
WindSpd=str2double(WindSpd);
WindSpd=WindSpd/(10);
WindSpd=round(WindSpd,1);

%TotSkyCvr
TotSkyCvr=T.TotSkyCov;

%OpaqSkyCvr
OpaqSkyCvr=T.OpSkyCov;

%Visibility
Visibility=T.Visibility;
Visibility=str2double(Visibility);
Visibility=Visibility/(10);
Visibility=round(Visibility);

%CeilingHgt
CeilingHgt=T.CeilHeight;
CeilingHgt=str2double(CeilingHgt);
CeilingHgt=CeilingHgt*(10);


%PresWeathObs
PresWeathObs=zeros(size(T.Hour));
PresWeathObs=string(PresWeathObs);
PresWeathObs(:,1)={'9'};

%PresWeathCodes
PresWeathCodes=T.PresentWeather;


%PrecipWtr
PrecipWtr=zeros(size(T.Hour));
```

```
PrecipWtr=string(PrecipWtr);
PrecipWtr(:,1)={'999'};


%AerosolOptDepth
AerosolOptDepth=zeros(size(T.Hour));
AerosolOptDepth=string(AerosolOptDepth);
AerosolOptDepth(:,1)={'999'};

%SnowDepth should be in cm but kept to be consistent with CWEC
SnowDepth=T.SnowCov;

%DaysLastSnow

DaysLastSnow=zeros(size(T.Hour));
DaysLastSnow=string(DaysLastSnow);
DaysLastSnow(:,1)={'88'};

%Albedo

Albedo=zeros(size(T.Hour));
Albedo=string(Albedo);
Albedo(:,1)={'999'};

%Rain

Rain=zeros(size(T.Hour));
Rain=string(Rain);
Rain(:,1)={'999'};

%RainQuantity

RainQuantity=zeros(size(T.Hour));
RainQuantity=string(RainQuantity);
RainQuantity(:,1)={'99'};

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%C-2 Organize all data into a
table%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
EPW=table(YEAR,MONTH,DAY,HOUR,MINUTE,Datasource,DryBulb,DewPoint,RelHum,Atmos
Pressure,ExtHorzRad,ExtDirRad,HorzIRSky,GloHorzRad,DirNormRad,DifHorzRad,GloH
orzIllum,DirNormIllum,DifHorzIllum,ZenLum,WindDir,WindSpd,TotSkyCvr,OpaqSkyCv
r,Visibility,CeilingHgt,PresWeathObs,PresWeathCodes,PrecipWtr,AerosolOptDepth
,SnowDepth,DaysLastSnow,Albedo,Rain,RainQuantity);



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% D-I Mode 1
script%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Mode==1

%separate data into years
[sizeTm,sizeTn]=size(T.Year);
```

```
endyear=str2double(T{sizeTm,'Year'});
startyear=str2double(T{1,'Year'});

range=endyear-startyear+1;



v=1;
w=1;
q=1;
leapyears=[1976 1980 1984 1988 1992 1996 2000 2004 2008 2012 2016];


houradd=0;
u=1;

for v=1:range


year=str2double(T{q,'Year'});

  if ismember(year,leapyears)==1

    n=366;

  else
    n=365;

  end

hourstart=u;

houradd=n*24;

hourend=(u+houradd)-1;

EPWYEAR=EPW(hourstart:hourend,:);

u=u+(n*24);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%% E-1 export table to txt, remove headerline with
variable names%%%%%%%%%%%%%%%%%%%%%
epwyeartoyear=sprintf('%s_%s_%s_%s_%d.txt',filenamediv(z,1),filenamediv(z,2),
filenamediv(z,3),filenamediv(z,4),year)
writetable(EPWYEAR,epwyeartoyear,'WriteVariableNames',0);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%% E-2 read txt file and store as
string%%%%%%%%%%%%%%%%%%%%%%%%%%%
tempfile = fopen(epwyeartoyear,'r');
tabstr = textscan(tempfile,'%s','Delimiter','\n');
fclose(tempfile);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% E-3 combine header lines with
string%%%%%%%%%%%%%%%%%%%%%%%%%%%%
header = [line1;line2;line3;line4;line5;line6;line7;line8;tabstr{1}];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% F-1 Export to txt
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tempfile2 = fopen(epwyeartoyear,'w');
fprintf(tempfile2,'%s\n', header{:});
fclose(tempfile2);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%% F-2 Convert txt to epw
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
file1=epwyeartoyear;
file2=strrep(file1,'.txt','.epw');

file1=char(file1);
file2=char(file2);

copyfile(file1,file2);

q=q+(24*n);

end

else

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% D-II Mode 2
script%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Custom Time Range
YEARstr=str2double(string(YEAR));
MONTHstr=str2double(string(MONTH));
DAYstr=str2double(string(DAY));
HOURstr=str2double(HOUR);


%create datetime coloumn
t1=datetime(YEARstr,MONTHstr,DAYstr,HOURstr,minute,minute);

%insert datetime coloumn and create time table
EPWs=timetable(t1,YEAR,MONTH,DAY,HOUR,MINUTE,Datasource,DryBulb,DewPoint,RelH
um,AtmosPressure,ExtHorzRad,ExtDirRad,HorzIRSky,GloHorzRad,DirNormRad,DifHorz
Rad,GloHorzIllum,DirNormIllum,DifHorzIllum,ZenLum,WindDir,WindSpd,TotSkyCvr,O
paqSkyCvr,Visibility,CeilingHgt,PresWeathObs,PresWeathCodes,PrecipWtr,Aerosol
OptDepth,SnowDepth,DaysLastSnow,Albedo,Rain,RainQuantity);

%assigning start time and end time based on custom time range input
ts=datetime(CustomStart_Year,CustomStart_Month,CustomStart_Day,CustomStart_Ho
ur,0,0);
te=datetime(CustomEnd_Year,CustomEnd_Month,CustomEnd_Day,CustomEnd_Hour,0,0);

%calcuate time range
TR = timerange(ts,te,'closed');
```

```
%extract data from custom time range
EPWEX = EPWs(TR,:);

%convert timetable back to table
EPWEX=timetable2table(EPWEX);

%remove datetime coloumn
EPWEX.t1=[];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%% E-1 export table to txt, remove headerline with
variable names%%%%%%%%%%%%%%%%%%%%%%
epwcustomyear=sprintf('%s_%s_%s_%s_%s.txt',filenamediv(z,1),filenamediv(z,2),
filenamediv(z,3),filenamediv(z,4),CustomTag)
writetable(EPWEX,epwcustomyear,'WriteVariableNames',0);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%% E-2 read txt file and store as
string%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tempfile = fopen(epwcustomyear,'r');
tabstr = textscan(tempfile,'%s','Delimiter','\n');
fclose(tempfile);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% E-3 combine header lines with
string%%%%%%%%%%%%%%%%%%%%%%%%%%%%
header = [line1;line2;line3;line4;line5;line6;line7;line8;tabstr{1}];



%%%%%%%%%%%%%%%%%%%%%%%%%%%%% F-1 Export to txt
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tempfile2 = fopen(epwcustomyear,'w');
fprintf(tempfile2,'%s\n', header{:});
fclose(tempfile2);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% F-2 Convert txt to epw
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
file1=epwcustomyear;
file2=strrep(file1,'.txt','.epw');

file1=char(file1);
file2=char(file2);

copyfile(file1,file2);


end

z=z+1;
fprintf('Next File\n')
end

fprintf('Processing Ends\n')
```

Appendix D - Script 2 -Graphing Script

```python
import os
import numpy as np
import matplotlib as plot
import pandas as pd
import glob
from pathlib import Path
import shutil
import plotly.express as px
import plotly.graph_objects as go
import json


#Extract all filenames with .epw extension in folder
maindir='/Users/siu_a\Desktop\Python - Weather Analysis\WeatherFiles\Historical'
combined='combined_csv.csv'
pathway= Path(maindir)
os.chdir(pathway)
extension = 'epw'

os.remove("combined_csv.csv")
all_filenames = [i for i in glob.glob('*.{}'.format(extension))]
print(all_filenames)


new_extension='.csv'
for f in all_filenames:
    pre, ext = os.path.splitext(f)
    shutil.copyfile(f,pre + new_extension)

all_filenames_csv = [i for i in glob.glob('*.{}'.format('csv'))]
print(all_filenames_csv)

#Create combined data frame
combined_csv =[]
combined_csv = pd.concat([pd.read_csv(f,sep=",",skiprows=8,names=['Year','Month','Day','Hour','Minute','Datasource','DryBulb','DewPoint','RelHum','AtmosPressure','ExtHorzRad','ExtDirRad','HorzIRSky','GloHorzRad','DirNormRad','DifHorzRad','GloHorzIllum','DirNormIllum','DifHorzIllum','ZenLum','WindDir','WindSpd','TotSkyCvr','OpaqSkyCvr','Visibility','CeilingHgt','PresWeathObs','PresWeathCodes','PrecipWtr','AerosolOptDepth','SnowDepth','DaysLastSnow','Albedo','LiquidPrecipitationDepth','LiquidPrecipitationQuantity']) for f in all_filenames_csv ])

y=len(combined_csv)
print(y)

#print(combined_csv)
times=pd.date_range('1998-01-01 01:00:00', '2015-01-01 01:00:00', freq='1H', closed='left')

combined_csv['times']=times
combined_csv.to_csv( "combined_csv.csv", index=False, encoding='utf-8-sig')


################################################Division into Seasons#########################################################
combined_csv_new_month=combined_csv
Historical_Winter=combined_csv_new_month.loc[(combined_csv_new_month['Month']==1) | (combined_csv_new_month['Month']==2) | (combined_csv_new_month['Month']==12)]
```

```python
Historical_Summer=combined_csv_new_month.loc[(combined_csv_new_month['Month']==6) | (combined_csv_new_month['Month']==7) | (combined_csv_new_month['Month']==8)]
Historical_Spring=combined_csv_new_month.loc[(combined_csv_new_month['Month']==3) | (combined_csv_new_month['Month']==4) | (combined_csv_new_month['Month']==5)]
Historical_Fall=combined_csv_new_month.loc[(combined_csv_new_month['Month']==9) | (combined_csv_new_month['Month']==10) | (combined_csv_new_month['Month']==11)]

CWEC2016_Winter=CWEC2016.loc[(CWEC2016['Month']==1) | (CWEC2016['Month']==2) | (CWEC2016['Month']==12)]
CWEC2016_Summer=CWEC2016.loc[(CWEC2016['Month']==6) | (CWEC2016['Month']==7) | (CWEC2016['Month']==8)]
CWEC2016_Spring=CWEC2016.loc[(CWEC2016['Month']==3) | (CWEC2016['Month']==4) | (CWEC2016['Month']==5)]
CWEC2016_Fall=CWEC2016.loc[(CWEC2016['Month']==9) | (CWEC2016['Month']==10)| (CWEC2016['Month']==11)]

CWEC1990s_Winter=CWEC1990s.loc[(CWEC1990s['Month']==1) | (CWEC1990s['Month']==2) | (CWEC1990s['Month']==12)]
CWEC1990s_Summer=CWEC1990s.loc[(CWEC1990s['Month']==6) | (CWEC1990s['Month']==7) | (CWEC1990s['Month']==8)]
CWEC1990s_Spring=CWEC1990s.loc[(CWEC1990s['Month']==3) | (CWEC1990s['Month']==4) | (CWEC1990s['Month']==5)]
CWEC1990s_Fall=CWEC1990s.loc[(CWEC1990s['Month']==9) | (CWEC1990s['Month']==10) | (CWEC1990s['Month']==11)]

################################################Division into Seasons##################################################################

Season='Winter'


t_Hist_Winter=Historical_Winter['Hour']
t_Typ_Winter=CWEC2016_Winter['Hour']
DB_Hist_Winter=Historical_Winter['DryBulb']
DB_CWEC2016_Winter=CWEC2016_Winter['DryBulb']
DB_CWEC1990s_Winter=CWEC1990s_Winter['DryBulb']

fig = go.Figure()


fig.add_trace(go.Scatter(x=t_Hist_Winter, y=DB_Hist_Winter,name='Historical',mode='markers',marker_color='blue'))
fig.add_trace(go.Scatter(x=t_Typ_Winter, y=DB_CWEC2016_Winter,name='CWEC2016',mode='markers',marker_color='green'))
fig.add_trace(go.Scatter(x=t_Typ_Winter, y=DB_CWEC1990s_Winter,name='CWEC1990s',mode='markers',marker_color='orange'))


#fig.add_trace(go.Box(y=DB_Hist_Winter, name='Historical',marker_color = 'blue'))
#fig.add_trace(go.Box(y=DB_CWEC1990s_Winter, name = 'CWEC1990s',marker_color = 'orange'))
#fig.add_trace(go.Box(y=DB_CWEC2016_Winter, name = 'CWEC2016',marker_color = 'green'))

fig.update_layout(title = go.layout.Title(
        text="DryBulb Temperature(Winter) - Typical Vs Historical",font=dict(size=24),xref="paper",x=0.5),
        xaxis_title="Hours", yaxis_title="Temperature [C]",width=1000,height=650,)


fig.show()
```

Appendix E - Script 3 - Report Data Extraction

```
from eppy.results import readhtml
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import os
import plotly.express as px
import plotly.graph_objects as go
import pprint
import glob
from pathlib import Path

ddcompare=pd.DataFrame(columns=['Building Type','90.1 Standard','ASHRAE Design Day','Weather file - Year','Heating Energy - Natural Gas [GJ]',
                                'Heating Energy - Electricity [GJ]', 'Heating Energy - Total', 'Cooling Energy - Electricity [GJ]',
                                'Unmet Heating Hours - Facility', 'Unmet Cooling Hours - Facility',
                                'Peak Heating Load - Natural Gas [W]','Peak Heating Load - Electricity [W]','Peak Cooling Load - Electricity [W]'])


extension = 'html'
filenames = [i for i in glob.glob('*.{}'.format(extension))]



for i in filenames:

    filename=i
    print(i)
    filehandle = open(filename, 'r').read() # get a file handle to the html file
    htables = readhtml.titletable(filehandle) # reads the tables with their titles
    ltables = readhtml.lines_table(filehandle)

    ########################Extract End Use Table################################
    line1 = 'End Uses'

    endusetabs=[htable for htable in htables
        if htable[0]==line1]

    #print(endusetabs[0])

    endusetab=endusetabs[0]
    endusetab=endusetab[1]
    #print(endusetab)

    endusetabarr=np.asarray(endusetab)



    df=pd.DataFrame(data=endusetabarr[1:,1:],index=endusetabarr[1:,0],columns=endusetabarr[0,1:])



    Heating_Elec=float(df.loc['Heating','Electricity [GJ]'])
    Heating_Gas=float(df.loc['Heating','Natural Gas [GJ]'])
    Heating_Total=Heating_Elec + Heating_Gas
```

```

    Cooling_Elec=df.loc['Heating','Electricity [GJ]']

    ###############################Extract Unmet Hours Table###########################


    #line1 = 'Time Setpoint Not Met'
    line1 = 'Comfort and Setpoint Not Met Summary'

    #
    #unmettab=[htable for htable in htables
    #if line1 in htable[0]]

    unmettab=[htable for htable in htables
    if htable[0]==line1]

    unmettab=unmettab[1]
    unmettab=unmettab[1]

    arr=np.asarray(unmettab)

    unmettab_df=pd.DataFrame(data=arr[1:,1:],index=arr[1:,0],columns=arr[0,1:])

    #print(unmettab_df)
    unmettab_df=unmettab_df.astype('float')

     ###############################Extract Peak Loads Tables#########################
#

    #Electricity
    line1 = 'Report: COMPONENTS OF PEAK ELECTRICAL DEMAND'
    line2 = 'Report: PEAK ELECTRICAL DEMAND'


    #
    #unmettab=[htable for htable in htables
    #if line1 in htable[0]]

    peakElectab=[ltable for ltable in ltables
    if line1 in ltable[0] or line2 in ltable[0]]

    #print(peakElectab)

    peakElectab=peakElectab[0]
    peakElectab=peakElectab[1]

    arr=np.asarray(peakElectab)

        peakElectab_df=pd.DataFrame(data=arr[1:,1:],index=arr[1:,0],columns=arr[0,1:
])

        #print(peaktab_df)
        #peaktab_df=peaktab_df.astype('float')

        ###################################################
        #Natural Gas
        line1 = 'Report: COMPONENTS OF PEAK GAS DEMAND'
        line2 = 'Report: PEAK GAS DEMAND'
        #line2 = 'For: Meter'

        #
```

```
            #unmettab=[htable for htable in htables
            #if line1 in htable[0]]
            #print (line1)
            peakgastab=[ltable for ltable in ltables
            if line1 in ltable[0] or line2 in ltable[0]]

            #print(peakgastab)

            peakgastab=peakgastab[0]
            peakgastab=peakgastab[1]

            arr=np.asarray(peakgastab)

            peakgastab_df=pd.DataFrame(data=arr[1:,1:],index=arr[1:,0],columns=arr[0,1:])

            ###########################################################################################


            NameSplit=filename.split("_")

            DesignDay=NameSplit[5]
            Year=NameSplit[8]+'-'+NameSplit[9]+'-'+NameSplit[-1]
            BuildingType=NameSplit[1]
            StdYear=NameSplit[2]

            HeatElec=float(df.loc['Heating','Electricity [GJ]'])
            HeatNG=float(df.loc['Heating','Natural Gas [GJ]'])
            HeatingTot=Heating_Elec + Heating_Gas

            CoolElec=df.loc['Cooling','Electricity [GJ]']

            UnmetHeating=unmettab_df.loc['Time Setpoint Not Met During Occupied Heating','Facility [Hours]']
            UnmetCooling=unmettab_df.loc['Time Setpoint Not Met During Occupied Cooling','Facility [Hours]']


            if 'HEATING:GAS {AT MAX/MIN} [W]' in list(peakgastab_df.columns):
                PHeatNG=float(peakgastab_df.loc['Maximum of Months','HEATING:GAS {AT MAX/MIN} [W]'])
                PHeatElec=float(peakElectab_df.loc['Maximum of Months','HEATING:ELECTRICITY {AT MAX/MIN} [W]'])
                PCoolElec=float(peakElectab_df.loc['Maximum of Months','COOLING:ELECTRICITY {AT MAX/MIN} [W]'])
            else :
                PHeatNG=float(peakgastab_df.loc['Maximum of Months','HEATING:GAS {AT MAX/MIN} [kW]'])/1000
                PHeatElec=float(peakElectab_df.loc['Maximum of Months','HEATING:ELECTRICITY {AT MAX/MIN} [kW]'])/1000
                PCoolElec=float(peakElectab_df.loc['Maximum of Months','COOLING:ELECTRICITY {AT MAX/MIN} [kW]'])/1000

            ddadd=pd.DataFrame(columns=['Building Type','90.1 Standard','ASHRAE Design Day','Weather file - Year','Heating Energy - Natural Gas [GJ]',
                                        'Heating Energy - Electricity [GJ]', 'Heating Energy - Total', 'Cooling Energy - Electricity [GJ]',
                                        'Unmet Heating Hours - Facility', 'Unmet Cooling Hours - Facility',
```

```
                                         'Peak Heating Load - Natural Gas [W]','Peak Heating Load - Electricity [W]','Peak Cooling Load - Electricity [W]'])

            ddadd.loc[0]=[BuildingType, StdYear, DesignDay, Year, HeatNG, HeatElec, HeatingTot, CoolElec, UnmetHeating, UnmetCooling, PHeatNG, PHeatElec, PCoolElec]


            ddcompare=ddcompare.append(ddadd)




        #print(ddcompare)
        ddcompare.to_csv(path_or_buf='C:/Users/siu_a/Desktop/Python-HOF2005energyplus/ddcompare.csv',index=False)
```

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