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Future Weather Files to Support Climate Resilient Building Design in Vancouver

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Future weather files to support climate resilient building design in Vancouver

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Abstract:
Since local weather and climate greatly affect the construction and performance of buildings, reliable meteorological data is essential when simulating building performance. It is well understood that climate change will affect future weather and there is a growing interest in generating future weather files to support climate resilient building design. Weather files that account for climate change have not been widely used for the lower mainland region of British Columbia. In this study, hourly weather files for future climate conditions in Vancouver are created for three time periods using a "morphing" methodology. Morphing uses results from global climate models to adjust observed weather data at a specific location. In this study, daily data from climate simulations for the RCP8.5 emission scenario have been used. The weather variables that have been adjusted are dry-bulb temperature, relative humidity, solar radiation, cloud cover, wind speed and atmospheric pressure. The impact of climate change on the energy performance of a multi-unit residential building located on the University of BC campus is analyzed using the energy modelling software EnergyPlus. The simulation results indicate that the changing climate in Vancouver, following RCP8.5, would have a considerable effect on building energy performance and energy demand due to decrease in space heating and increase in cooling requirements.

Keywords:
Weather File, Climate Change, Energy Modelling, Building Simulation, Downscaling

1. Introduction

Dynamic building simulation is an important tool in analyzing the energy performance of building design options. The performance of building envelopes as well as heating and cooling systems are greatly affected by local climate. Therefore, reliable meteorological data is essential when simulating building performance to achieve energy efficient and comfortable buildings. It is well understood that climate change will affect future weather [1]. Since typical building lifetimes can be around 60 years or more, weather files need to cover projected future changes [2]. This has been acknowledged globally and there is a growing interest in using weather files that account for climate change [2-6].

The impact of climate change on energy use patterns in the building sector is poorly understood in the lower mainland region of British Columbia. In this study, hourly weather files for future climate conditions are produced to investigate potential implications for building energy performance in Vancouver.

This project was initiated by the University of British Columbia (UBC) Sustainability and Engineering and was carried out in conjunction with two main project partners: Pacific Climate Impact Consortium (PCIC) and RDH Building Science.

2. Methodology

Several methods can be used to construct weather files for building simulation [1,2]. As a first step, the methodology in this study is based on the work by Belcher et al. [3], referred to as morphing. The concept behind morphing is to generate weather files that account for future climate changes by adjusting historical observations with results from simulations made with global and/or regional climate models.

The morphing methodology has been widely used to predict the impact of climate change on building performance [7-11]. Morphing is particularly attractive for this purpose because it allows for spatial and temporal downscaling by using site-specific weather data. This way weather files for future climate conditions can be generated while preserving the characteristics of the weather for the specific station.

The scope of this preliminary investigation was to apply morphing techniques that have been used elsewhere, with only one modification (using daily rather than monthly climate projections). It was beyond the scope of this first step to evaluate the morphing operations used for each parameter and the implications that different choices would have. However, this is an important aspect to evaluate. Several recommendations for further research are provided in the conclusions.

2.1 Climate Change Correction

The first step in the morphing procedure is to create baselines that represent current and future climate. Baselines consist of climate data for each day of the year and are defined by taking the average of climate simulations over a 30-year period [12].

Daily simulations for the parameters (see Table 2) were available from eight global climate models (GCMs). These GCMs are listed in Table 1.

Table 1: The global climate models used to simulate present-day and future climate baselines.

Global Climate Model
CNRM-CM5
CanESM2
ACCESS1-0
Inmcm4
MIROC5
GFDL-ESM3g
MRI-CGCM3
GFDL-ESM3G

Daily climate projections for the simulation period 1950-2100 were provided by Pacific Climate Impact Consortium (PCIC). For temperature and precipitation PCIC offers statistically downscaled climate data for Canada. Data from GCMs were downscaled to a gridded resolution of roughly 10 km by using Bias-Correction/Constructed Analogues with Quantile mapping reordering (BCCAQ) [13]. For the rest of the weather variables (see Table 2) climate data were provided by PCIC with a gridded resolution of roughly 100 km.

In this study, simulations under the assumption of the RCP8.5 emission scenario are used. In 2014 the IPCC finalized the fifth Assessment Report (AR5) which includes four greenhouse gas concentration pathways, the so called Representative Concentration Pathways (RCPs). These scenarios describe possible climate futures depending on how much greenhouse gases that are emitted in the years to come. The RCP8.5 scenario roughly reflects a 'business as usual' scenario [14].

To define the present-day climate baseline, simulations for the time period 1971-2000 are used. Three future time periods are studied: centred on 2020s, 2050s and 2080s (i.e., 2011-2040, 2041-2070, 2071-2100).

When the present-day and future climate baselines are defined the climate 'correction factors' can be determined. The 'correction factors' represent the change in the daily mean value for each variable.

The remaining section is following the convention of Belcher et al [3]:

The absolute change between the future and present-day baseline for day *d* is called 'shift factor', Δx_d, and is calculated by equation 1.

$$\Delta x_d = \langle x_{future} \rangle_d - \langle x_{present} \rangle_d \quad (1)$$

The fractional change between the future and present-day baseline for day *d* is called 'stretch factor', α_d, and is calculated by equation 2.

$$\alpha_d = \frac{\langle x_{future} \rangle_d}{\langle x_{present} \rangle_d} \quad (2)$$

Unlike the previously mentioned studies [7-11] in which monthly climate projections were used to create future weather files, the climate projections used in this study are daily time series.

2.2 Morphing operation

After the climate correction factors are generated, the next step is to adjust observed data. This is achieved by creating algorithms where a function of the difference between the climate baselines is applied to the existing data. These algorithms are based on three different operations, following Belcher et al., equation 3-5 demonstrate the operations. Note that these methods include an estimation of change in diurnal cycle because they were designed for use with monthly climate projections. The next step in this work is to re-evaluate which variables are shifted, stretched, or both – and if some variables should not be adjusted at all (see conclusions). The choice of which changes were applied to which variables in this initial investigation follows the conventions of Belcher et al. (see section 2.3 and Table 2).

Shift

$$x = x_0 + \Delta x_d \quad (3)$$

x : future hourly weather variable
x_0 : hourly observed weather variable
Δx_d : shift factor, predicted absolute change in the daily mean value of the variable for day *d*

The shift operation adds the projected absolute change obtained from climate model simulations and as a result the observed weather data for a given day is shifted by Δx_d. The daily variance of the variable remains unchanged. The new daily mean value of the variable is $\langle x\rangle_d = \langle x_0\rangle_d + \Delta x_d$, where $\langle x_0\rangle_d$ is the observed present-day daily mean value of the variable, x_0, for day *d.*

Stretch

$$x = \alpha_d x_0 \quad (4)$$

α_d : stretch factor, predicted fractional change in the daily value of the variable for day *d*

The stretch operation multiplies the observed weather data by the predicted fractional change obtained from climate model simulations. As a result, the observed weather data is scaled with α_d. This operation changes the daily mean and variance of the future weather variable. The daily mean value becomes $\langle x\rangle_d = \alpha_d\langle x_0\rangle_d$ and the daily variance becomes $\langle \sigma^2\rangle_d = {\alpha_d}^2\langle {\sigma_0}^2\rangle_d$, where $\langle {\sigma_0}^2\rangle_d$ is the daily variance of the observed weather data for day *d*.

Combination of shift and stretch

$$x = x_0 + \Delta x_d + \alpha_d \times (x_0 - \langle x_0\rangle_d) \quad (5)$$

The third operation is a combination of a shift and a stretch. The current hourly weather data is shifted by adding the predicted absolute change and stretched by a predicted diurnal ratio of the variable. This approach is applied when both the mean and variance of the variable is changed. This operation results in a change in the daily mean value and variance of the future weather variable. The new mean value is $\langle x\rangle_d = \langle x_0\rangle_d + \Delta x_d$ and the new daily variance is $\langle \sigma^2\rangle_d = {\alpha_d}^2\langle {\sigma_0}^2\rangle_d$.

2.3 Current and future weather files for Vancouver

In North America, the most commonly used weather file for building energy performance simulations is called Typical Meteorological Year (TMY) [15]. A TMY file represents the typical long-term weather pattern and is created by analyzing 15-30 years of historical hourly data for the specific site [16].

In this study, the open-source software EnergyPlus is used as the simulation tool. EnergyPlus provides weather files in the TMY format for cities around the world, commonly referred to as 'EnergyPlus/ESP-r Weather' (EPW). The EPW file currently used in EnergyPlus for Vancouver is based on observed data from YVR for the time period 1960-1985 [17]. It was decided that the most suitable approach was to develop climate change adapted TMY files and to provide them as EPW files.

In this study, the EPW file for Vancouver is morphed. Table 2 summarizes the weather variables that are adjusted, together with the required projected climate variables and the algorithm used to generate future data. For each variable, an algorithm has been designed in Matlab to suit the format of the climate data. The choice of morphing algorithm for each variable is presented below, following the work by Belcher et al. [3].

Dry Bulb Temperature (°C)

The methodology proposes to change the mean and the variance of the existing dry bulb temperature (daily mean surface temperature). This is achieved by the third morphing operation, a combination of a shift and a stretch.

Relative humidity (%)

Following Belcher et al. a stretch operation is applied to calculate the morphed relative humidity. The change between the climate baselines is therefore calculated as a fractional change.

Atmospheric Pressure (Pa)

The climate models provide daily values for sea level pressure. The change in the atmospheric pressure is assumed to be the same as the change in sea level pressure. A shift factor calculated based on the change in sea level pressure is applied to the observed atmospheric pressure to compute the future atmospheric pressure.

Global horizontal radiation (Wh/m²)

The global horizontal radiation is the total amount of direct and diffuse solar radiation received on a horizontal surface. For the global horizontal radiation, it is recommended to stretch the observed data. The stretch operation had to be adopted to avoid the operation resulting in irradiance at night.

Direct normal radiation (Wh/m²)

The direct normal radiation is the amount of solar radiation received directly from the solar disk on a surface perpendicular to the sun's rays. Climate model simulations for direct normal radiation are not readily available. Therefore, an indirect method is applied. It is assumed that the distribution between direct and diffuse radiation is unchanged. The direct normal radiation can be calculated using the generated future data for global and diffuse horizontal radiation.

Table 2 : Morphed EPW weather variables along with climate projection parameters and an overview of the methodology used to generate future weather data

EPW node	EPW weather variable (unit)	Climate projection parameter (unit)	Methodology for future weather data generation
N6	Dry bulb temperature (ºC)	tasmin: minimum air temperature tasmax: maximum air temperature (all ºC)	Combined shift and stretch using tasmin, tasmax and calculated predicted mean temperature (ºC)
N8	Relative humidity (%)	rhs: relative humidity	Stretch of EPW data using rhs
N9	Atmospheric pressure (Pa)	psl: air pressure at sea level (Pa)	Shift of EPW data using psl
N13	Global horizontal radiation (Wh/m^2)	rsds: surface downwelling shortwave (W/m^2)	Stretch of EPW data using rsds
N14	Direct normal radiation (Wh/m^2)	-	Calculated by assuming that the relationship between N13, N14 and N15 remains the same
N15	Diffuse horizontal radiation (Wh/m^2)	-	Stretch of EPW data using the same stretch factor as for N13
N21	Wind speed (m/s)	uas: eastward wind (m/s) vas: northward wind (m/s)	Stretch of EPW data using the magnitude of the two vectors
N22	Total sky cover (tenths of sky)	clt: cloud area fraction (%)	Shift of EPW data using clt

Diffuse horizontal radiation (Wh/m^2)

As with direct normal radiation, climate data is not available for diffuse horizontal radiation. It is assumed that the change in diffuse horizontal radiation is proportional to the change in global horizontal radiation. The observed data for diffuse horizontal radiation is morphed using the calculated scaling factor for global horizontal radiation.

Wind speed (m/s)

The wind speed data series is calculated by applying a shift operation to the observed data,

Total cloud cover (tenths of sky)

Following Belcher et al. a stretch operation is applied to calculate the morphed cloud cover. The change between the baselines is therefore calculated as a fractional change.

2.4 Impact of climate change on building energy performance in Vancouver

The future hourly weather data for each scenario is compiled and formatted into EPW files using the software tool Elements [18]. To understand the potential impact of climate change on building energy use in Vancouver, the generated weather files are used to carry out an initial energy analysis.

In this study, the energy performance of a typical high-rise under current building code in Vancouver, located on the UBC campus, is simulated. The archetype was designed by RDH Building Science, as part of a project where building designs were explored to support development of UBC's green building strategy. The archetype consists of a 22-storey multi-unit residential building and sixteen 2-storey townhouses. The archetype includes a mechanical cooling system and is connected to UBC's district heating system. The total floor area of the building is approximately 26 600 m^2 [19].

The model was run with the EPW currently provided in EnergyPlus, and with the weather files created using the morphing process. The future building energy performance was simulated under the assumption that no technological advances are going to take place.

3. Results and discussions

Table 3 shows the annual mean value of each morphed weather variable. The results indicate that dry-bulb temperature and relative humidity are the variables that will experience the most change.

Table 3: Annual mean value of the morphed weather data

Weather Variable	Present-day	2020s	2050s	2080s
Dry-bulb temperature (□C)	9.7	11.1	12.4	14.1
Relative humidity (%)	60.3	79.5	79.2	79.1
Atmospheric pressure (kPa)	101.6	101.6	101.6	101.6
Global horizontal radiation (Wh/m^2)	140.4	140.8	141.7	142.9
Direct normal radiation (Wh/m^2)	147.1	155.4	155.3	154.0
Diffuse horizontal radiation (Wh/m^2)	59.6	59.8	60.2	60.9
Wind speed (m/s)	3.35	3.39	3.46	3.47
Total sky cover (tenths of sky)	6.75	6.75	6.74	6.72

Figure 1 and 2 below demonstrate the morphing process on dry-bulb temperature. Figure 1 shows the simulated shift factors for dry-bulb temperature for each time scenario.

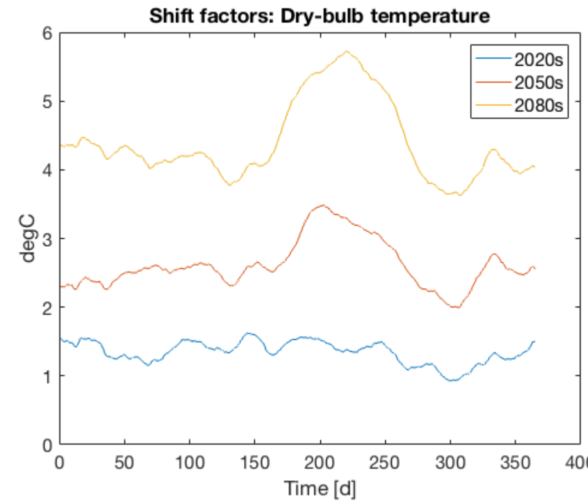

Figure 1: Shift factors for dry-bulb temperature for each time scenario from 8 BCCAQ downscaled GCMs

Figure 2 shows the final climate change adjusted hourly data for dry-bulb temperature under four days in May, together with data from the EPW file for the same time period.

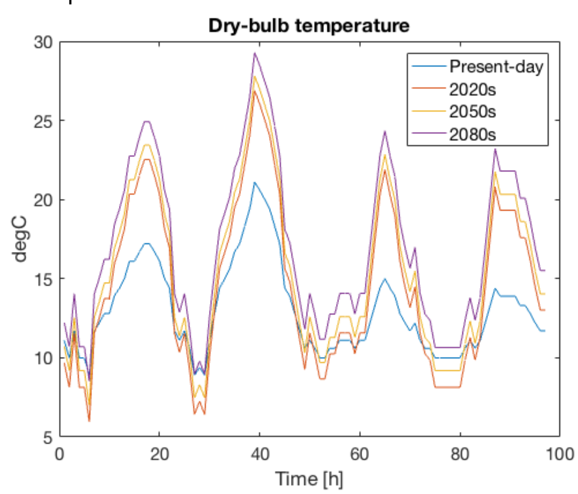

Figure 2: Climate change adjusted hourly data for dry-bulb temperature together with EPW data for four selected days

Figure 3 shows the mean monthly dry-bulb temperature for each weather file.

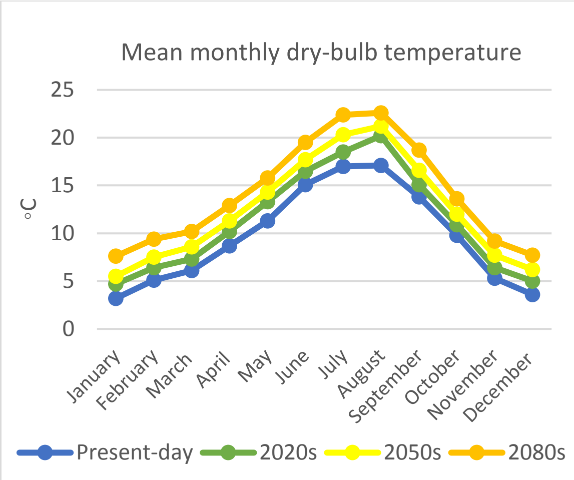

Figure 3: Mean monthly dry-bulb temperature for each weather file

Figure 4 shows the daily standard deviation for dry-bulb temperature, for all four weather files. Note that all sub-daily variability comes from the historical hourly data in the weather files. The standard deviation for dry-bulb temperature is higher for the generated weather files than for the observed weather file. This is due to the use of shift and stretch and indicates that for the predicted future dry-bulb temperature there is a larger variance from the daily mean value. This suggests that application of both a shift and stretch to temperature when using daily climate simulations amplifies the change in diurnal cycle. The effect on the present results is likely an underestimation of the reduction in heating (note in Figure 2 how the stretch causes colder days than present to occur in the coldest hours of the day), and likely an overestimation of the increase in cooling.

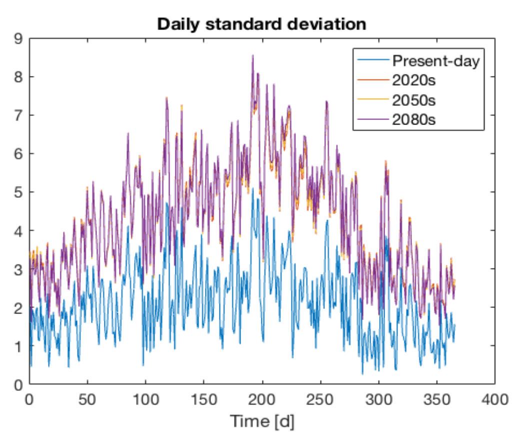

Figure 4: Daily standard deviation for temperature from each weather file

Findings from the building energy analysis are presented below. Figure 5 shows the monthly space heating load for each time scenario.

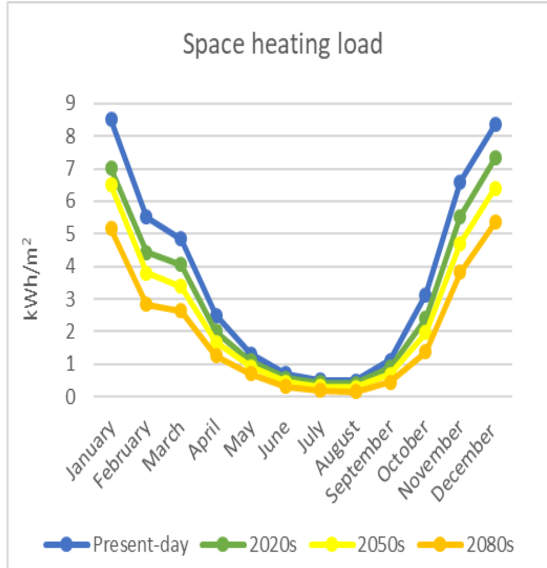

Figure 5: Monthly space heating load for each time scenario

Figure 6 shows the cooling load for each time scenario.

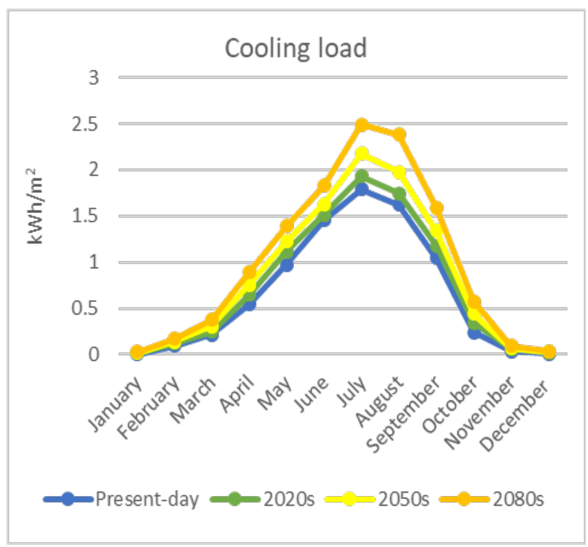

Figure 6: Monthly cooling load for each time scenario

Table 4 shows the percent change in electricity and district heating demand for each time scenario, compared to the results given when using the present-day EPW file.

Table 4: Percent change for electricity and district heating demand for each time scenario

	2020s	**2050s**	**2080s**
Electricity			
Cooling	16%	31%	54%
Pumps	5%	10%	17%
Heat Rejection	8%	15%	25%
Total Electricity Demand	2%	4%	6%
District Heating			
Heating	-15%	-27%	-43%
Total District Heating Demand	-10%	-18%	-28%
Total Energy Demand	-3%	-6%	-9%

The findings in this research project indicate that the total energy demand for the studied archetype will slightly decrease with time. The demand for space heating is expected to decline with time and the cooling load to increase with time. For UBC, this means a reduced dependency on district heating (natural gas) and a higher electrical demand. This would have a positive effect on UBC's greenhouse gas (GHG) emissions. However, an increase in electricity load during cooling season is going to exert a greater pressure on the electricity grid. This may result in failure in the power grid and in turn lead to a need to purchase electricity, which may not be GHG neutral.

4. Conclusions and outlook

In this study, weather data in the EPW file currently used in EnergyPlus is adjusted for climate change. The EPW file is in the TMY format, which captures typical weather conditions at a specific site. However, TMY files by design represent "typical" (median) conditions and thus will not include extreme weather events. It is likely that extreme weather events will become more common in the future as a result of climate change. Designing buildings for typical conditions could lead to future vulnerability. To allow designers and engineers to stress test building performance and adapt building design for atypical conditions further research is recommended to focus on creating weather files that represent hotter than average conditions, including extreme events.

Further, a set of raw data for a specific weather station, where each year is different from the previous one could be morphed. This would offer an alternative to the traditionally used TMY file which would allow to assess the impact of climate change on building design options while introducing year-to-year variability.

Alternatively to morphing the weather file, past and future simulated weather could be constructed from a GCM simulation directly with station data only used for hourly information and variables not present in the GCMs.

A simplified method to predict future solar radiation has been used in this study. It is assumed that the distribution between diffuse and direct solar radiation in unchanged. The diffuse solar radiation is affected by cloud cover. In this initial study, the solar radiation and cloud cover are computed independently and the results are not consistent with each other. Since solar radiation has a considerable effect on the energy performance of buildings, these parameters need further work.

In this study, the impact of climate change on a MURB located on UBC campus is analyzed. The building energy simulation is conducted using the software EnergyPlus. The simulation results show that the cooling load can be expected to increase with time, and the heating load to decrease with time. Moreover, the demand for cooling is expected to increase during cooling season. With a warmer climate, there is an increased risk for overheating in buildings. Thermal comfort and risk analysis are not in the scope of this project. To enhance the understanding of overheating risk in the future, further simulations could focus on analysing thermal comfort on zone level under high temperature events. Understanding of overheating during near-extreme weather events is of specific importance.

Further analysis is recommended to understand the impact of climate change on thermal and energy performance of archetypes with different design options such as size and orientation, as well as building design features including window-to-wall ratio, glazing, shadings, thermal insulation, natural ventilation strategies etc. There is a growing interest in energy-efficient building design with strong envelopes, such as passive-houses and net zero buildings. It is important to understand how these envelopes will perform under a changing climate and if today's targets will be met also in the future.

Buildings that are built today, as well as existing buildings, will experience future climate conditions. The results from this study indicate that analyzing future performance of buildings can be expected to become increasingly important. It is crucial that we consider future vulnerability and understand future design options as well as retrofit pathways to achieve climate resilient buildings.

Weather files that account for climate change are important tools to evaluate future building performance. However, it is important that users are aware of the limitations and the uncertainties when conducting building performance simulations.

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