Energy usage in buildings for future climate: a case study of Concordia University Buildings in Montreal

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1. Abstract

. In light of escalating extreme events and climate change, this research focuses on understanding energy consumption in buildings, specifically under varied weather scenarios including past (2019-2022) and future projections (2061, 2099). Traditional building simulations stemming from representative, using typical year's weather data, doesn't capture the intricacies of long-term climate shifts especially for the future. To address this, this study incorporates detailed future climate data from combination of RCMs & GCMs. This data is used in combination with open-geospatial data to create a building geometry. Initial results highlight a shift to warmer temperatures in 2061 and 2099. When contrasted with a typical mean weather scenario (1960-1986), there's a noticeable increase in cooling energy and a decrease in heating energy consumption from 2019-2022. By 2099, overall energy use is predicted to decrease by 10%-30%, which when broken down constitutes to reduction in heating energy and increase in cooling energy. The research underscores the impending shift towards increased cooling demands and reduced heating needs. The findings emphasize the urgency for future building designs to be energy-efficient and resilient in the face of evolving climate conditions.

Keywords - Future energy use, extreme climate, extreme weather, future weather

2. Introduction

Climate change has amplified extreme weather events with catastrophic global impacts. Although there is growing global evidence of climate change consequences, a body of literature highlights mitigation measures across various sectors. [1], [2]. In the realm of infrastructure, buildings play a pivotal role, accounting for significant global energy consumption and emissions amounting to almost 1/3rd [3]. Buildings are also identified as susceptible to climate change impacts [4], [5], and for the province of Quebec in Canada [6], [7] but also as pivotal in mitigation efforts against such changes [8].

Incorporating insights from short-term weather and long-term climate data is crucial in building design and operations. The same has been widely used in building design regarding climate zones in buildings to incorporate predefined climatic strategies anchored on metrics like Heating/Cooling Degree Days (HDD/CDD). Additionally, modern building design frequently employs updated weather files [9], [10] for example, the CWEEDs dataset in Canada [11]. With increasing & updated data being available, numerous studies compare building energy performance using typical vs. historical/projected weather[12], [13]. The projected or future weather often relies on commonly employed General Circulation Models (GCMs). While these models incorporate multiple parameters and offer refined grids, they often need to be used in tandem with higher-resolution Regional Climate Models (RCMs). It's essential to account for biases in GCM/RCMs by aligning them with actual historical climate data, using statistical or dynamic downscaling methods. Gaur et al. [11] derived such weather data for 564 Canadian locations. But when the future scenarios are considered, very few studies integrate both future weather and its impact on building energy consumption [5], [14]. In one such study for Canada, Williams et al., [13] outline how an archetype-based building model for a multi-unit residential unit was used to modelled in future climate scenarios for typical mean weather conditions for 2040s, and interestingly, it was observed that the energy usage of buildings decreases in future climate. There is also an ongoing discussion about whether the typical meteorological year (TMY) is enough for building design or should the industry shift to XMY (extreme meteorological year) [15], [16], but only a few studies have been seen implementing the same. Thus, there is a lack of literature that uses such weather files for understanding the building energy consumption in future.

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Understanding building energy consumption thus is pivotal, especially with the anticipated doubling of the global building floor area by 2060 [17]. Canada similarly foresees growth in its sectors and thus faces intensifying energy demands. To address this, a vast array of tools certified by the Canadian LEED body [18], codes [19], and certifications [20] are applied. A growing trend in urban energy modelling targets broader [21], [22] scales, like districts. The rise in open geospatial aids this cause [23], especially for the City of Montreal [24], and when such geospatial data is lacking, methods like UAV and photogrammetry offer precise city modelling solutions [25].

Given the intricate dynamics between urban buildings and the evident impacts of climate change, there's an urgency to study future building energy performance. Amidst mounting evidence of climate effects, this research introduces a Geospatial data driven approach, encompassing historical and projected climates. The adaptable downscaling method aligns with current workflows. Utilizing open-source data and energy simulation tools, the study's findings will guide future building policies, ensuring structures can endure long-term challenges.

This study operates under the assumption of limited data for future climate projections. Given the tie between building energy and weather variables, the unavailability of specific data from 2019-2022, such as direct and indirect solar radiation, necessitates the use of standard weather data. The research predominantly focuses on LOD1 blocks, widely used urban building energy modelling scenarios. Due to data constraints, the study only downscales the 'tas' or near-surface air temperature for future climate scenarios. The methodology encompasses workflows for generating weather files, energy modelling, and climate forecasts, as explained in section 2 of the paper. It utilizes data from past observations to future projections for 2099, including reference weather reference files from the Natural Resource Council of Canada. Based on diverse scenarios, results from climate data analysis and energy modelling are elaborated in section 4. Section 5 provides an outlook on the discussion, and section 6 highlights the conclusion, limitations, and prospective directions.

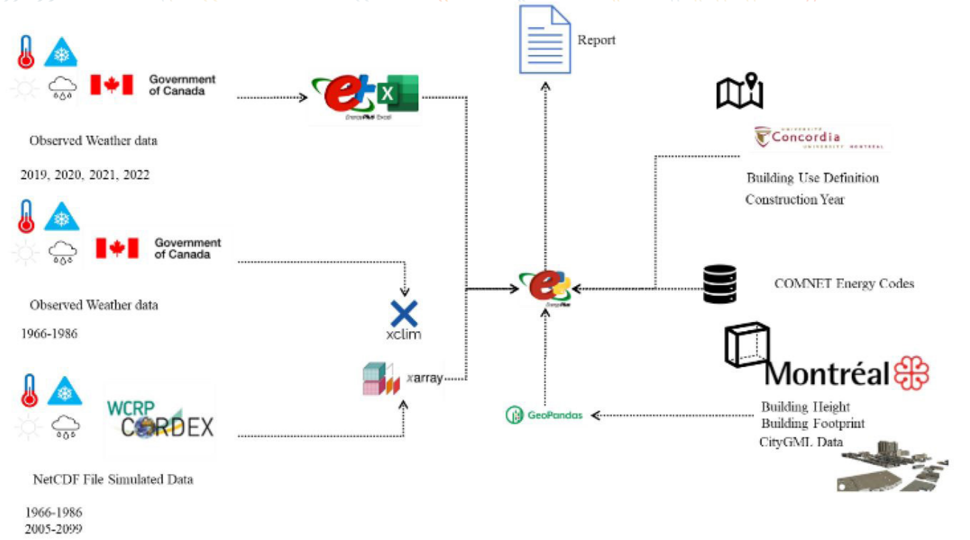

Figure 1: Methodology adopted for the study.

A LOD1 simplified building energy model for the EV and GM building at the Concordia Campus was developed, simplifying the roof to be flat. The geometry, refined using the GeoPandas[26] python module, was converted to the EnergyPlus format and detailed using the Geomeppy[27] module. After setting up the building, additional attributes like construction properties, window-wall ratio, and ideal air-load HVAC systems were incorporated. This ideal system ensures optimal heating/cooling for building comfort suitable for simplified scenarios, which was assigned to the model.
To analyze the impact of weather data on energy consumption patterns from 2019 to 2022, 2061 and 2099, we obtained weather data in the EnergyPlus format. Data was sourced from the hourly climate data extraction tool, capturing parameters like temperature, humidity, and wind speed. The other parameters, including solar radiation and winds-peed, were not included in the study. Missing

values were replaced with data from the nearest station. The collected data was processed using the EnergyPlus weather converter, converting Typical Meteorological Year (TMY) data into a CSV format. After integrating observed data from 2019-2022, the CSV data was converted back to EPW format. For accuracy, the EPW files underwent validation against the original datasets, ensuring error correction before further analysis.

For modeling future climate scenarios, the study followed a multi-step process. Initially, available GCM models focusing on 'tas' (surface air temperature) were identified. The 3Dimensional NetCDF files containing the climate data were parsed and extracted using Python modules, specifically X-arrays [28] and NetCDF4. By determining the nearest x and y grid for Montreal's location, specific data was sliced from these 3D files. Once extracted, the data was organized into a Pandas Dataframe formatted with date-time. The X-clim[29] Python library, particularly its quantile mapping module, was employed to downscale and bias-correct the obtained climate data. To ensure compatibility, the data was converted into X-arrays format. With the future data arranged, the study aimed to downscale it using a typical climate reference file. However, due to X-Clim's limitations, downscaling was performed for 2061-2080 and 2081-2099 using 1966-1986 as a reference.

Post-downscaling, the data was processed into the EnergyPlus weather file format, replicating the methodology from earlier steps. With the EnergyPlus weather files ready, simulations were executed using the EnergyPlus batch simulation option. No advanced building parameter modifications were needed. After simulation completion, various metrics like EPI, peak loads, and monthly consumptions were analyzed and visualized.

4. Case-study and Data

A Wide range of multi-disciplinary datasets are used for the different parts of the study. Table 1 summarises all the weatherrelated datasets used for the research.

Table 1: Overview of Climatic data used in the study.

Period	Source				
1966-86	https://energyplus.net/weather-location/north_and_central_america_wmo_region_4/CAN/PQ/CAN_PQ_Montreal.Intl.AP.716270_CWEC				
1966-86 2019-22	https://climate-change.canada.ca/climate-data/#/hourly-climate-data				
1966-86 2005-99	https://www.earthsystemgrid.org/search/cordexsearch.html	Model 1: GFDL-ESM2M.WRF RCP85	Model 2: HadGEM2-ES.WRF RCP85	Model 3: MPI-ESM-LR.RegCM4 RCP85	Model 4: MPI-ESM-LR.WRF RCP85

Using advanced climate data tools from Environment Canada, historical climate data for Montreal was extracted from the St Hubert A weather station (Station ID: 716270), with its comprehensive data for 1966-1986 and 2019-2022. A typical meteorological year weather file was also obtained, representing 30-year typical scenarios. The study also incorporated reference extreme weather files for Canada [11] for the extreme temperature RCP8.5 scenarios. Four GCM scenarios with hourly temperature variables were selected from the NA-CORDEX dataset for the NAM domain, with the RCP 8.5 scenario indicating the peak future greenhouse gas concentration. The building energy model utilized 2D building footprint data from the City of Montreal [24], extracted from a high-fidelity LoD3 model derived from oblique imagery and LiDAR. Natural Resources Canada offers similar 2D datasets [30] for other Canadian provinces.

The building's function, primarily an office/education mix, was predetermined. Construction material data, vital for thermophysical interactions, was obtained from Concordia University's management team. Key values include wall R-value at 11.9 (ft2·°F·h/BTU), roof at 17.2 (ft2·°F·h/BTU), glazing at 2.7 (ft2·°F·h/BTU), a 0.44 shading coefficient, and a 33% window/wall ratio.

5. Results

This section discusses the results obtained for downscaling to obtain the future weather files and subsequently used for building energy modelling scenarios.

5.1 Downscaling Results

The results of downscaling the future weather data are plotted in the QQ and CDF plots for all four scenarios in Figure 2 for 20 years for hourly values, along with ridge plots showing the monthly distribution of hourly scenarios for the selected scenarios. From the results it is observed that after the downscaling the values are shifted towards the right side, which means the climate is shifting more towards a warmer side. For the M1 and M2 model, the shift intensity is greater than the M3 and M4 models. Similarly, the QQ plots show that that data is left-skewed, i.e., negatively skewed.

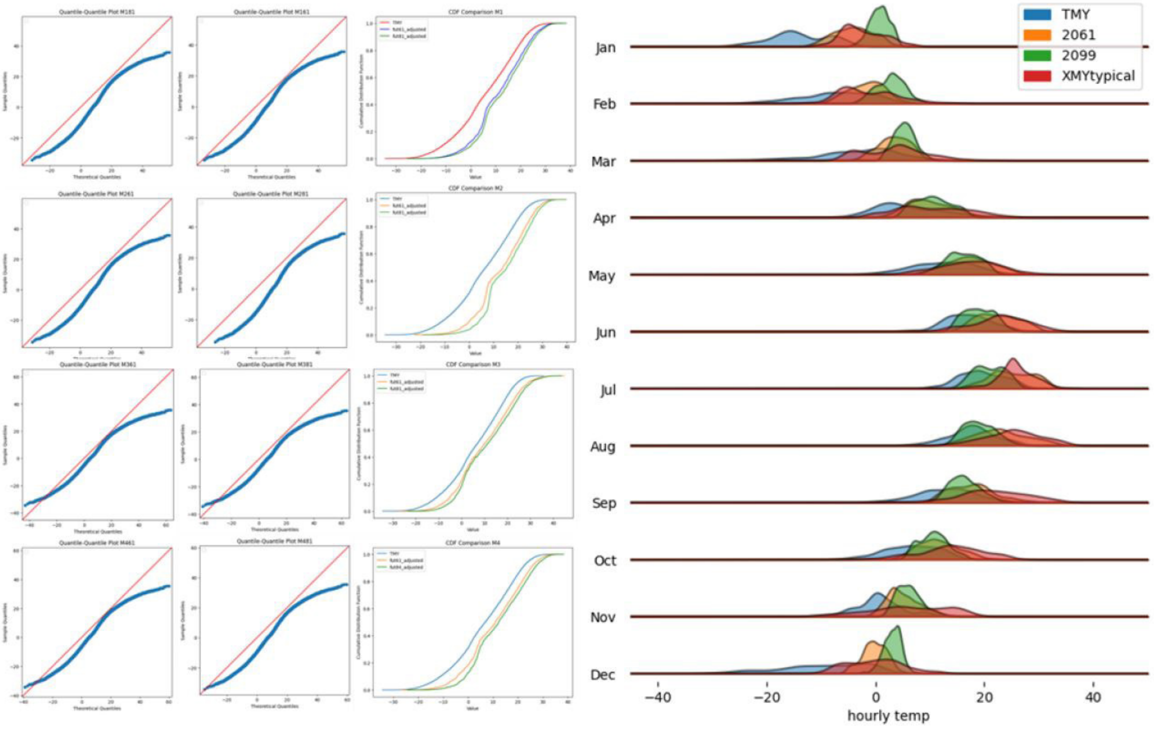

Figure 2: QQ plots and CDF plots for downscaled weather (Left) and Joy plots for extracted weather scenarios (Right)

To better understand the overarching comparison of the extracted weather data for the future, a ridge plot was plotted for different weather scenarios considered in the studies. From the ridge plots, it was observed that there is a noticeable shift in climate in all months towards warmer scenarios. Colder months also see a considerable shift towards warmer temperatures for all scenarios, especially for the 2099 scenario year. The Heating/cooling degree days extracted for each scenario are tabulated in Table 2.

Scenario	TMY	2019	2020	2021	2022	2061	2099	XMY Max	XMY Min	XMY typical	XMY Fstat
HDD	4949	4384	3900	3774	4050	3199	2807	1996	4485	3217	3286
CDD	26	102	145	131	105	201	18	886	82	260	279

Table 2: HDD/CDD for all scenarios

The figure 3 presents the annual heating/cooling consumption in kWh for a base case, three different years (2019-2022), and two extreme weather years (2061 and 2099), as well as for four different climate scenarios (Extreme Warm, Extreme Cold, Typical downscaled year, and TMY FSTAT).

The energy consumption is broken down by end-use: Room electricity, lighting, heating (gas), cooling (electricity), and domestic hot water (electricity). Since the room electricity and lighting scenarios will remain the same and are not affected by weather-related scenarios, they are not considered in the plot. The base case (i.e., Typical mean year) shows that heating is the largest end-use, accounting for 42% of the total energy consumption (57 kWh/m^2). Whereas heating accounts for almost 20% (26 kWh/m^2). Between 2019 and 2022, there's a notable trend in energy consumption. Heating energy consumption decreased from 57 kWh/m^2 in 2019 to 51 kWh/m2 in 2022. However, cooling energy consumption increased from 26 kWh/m^2 in 2019 to 31 kWh/m2 by 2021, before slightly decreasing in 2022. For the year of 2061, a 33% decrease is observed. At the same time, cooling energy consumption remains similar. For 2099, a 60% drop in heating observation and a 26% decrease in cooling energy consumption are observed.

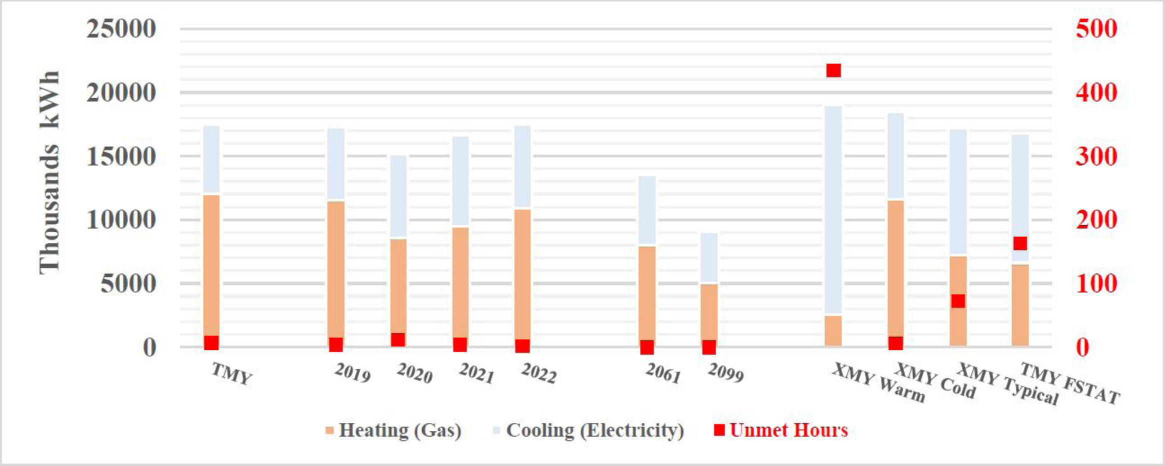

Figure 3: Heating and cooling energy consumption for all scenarios (Unmet hours are highlighted on the secondary axis)

When contrasted with the reference weather file obtained from Climate Canada for the four different climate scenarios, it shows that the energy consumption for heating and cooling varies greatly depending on the scenario. XMY Warm has the highest energy consumption for cooling, i.e., 78 kWh/m2, compared to 26 kWh/m2 in the TMY scenario. XMY Cold has the higher energy consumption amongst the four reference scenarios (i.e., 55 kWh/m2), but it is still lower than the base TMY scenario. Finally, both XMY typical and XMY F-stat (i.e., meteorological) observe a decrease in heating energy and an increase in cooling energy.

6. Discussion

The downscaling results and energy consumption analysis highlight the effects of climate change on future building performance. Both the NRC study [18] and a study on Canadian prairies [31] show a trend towards warmer temperatures. While different attributes and scenarios were used in these studies, the consistent shift to warmer temperatures across models used in the relevant studies highlights the need for mitigation strategies. Even though RCP85, the highest forcing scenario, was selected, the combined insights from all four models present a comprehensive view of potential future scenarios.

While the overall energy consumption saw an increase of 8.5% in 2020 compared to TMY, the observed weather data indicates that when the building's hourly values exceeded those of the Typical Meteorological Year (TMY), the energy consumption was higher. Similar observations are observed for 2021 and 2022. However, in 2022, it is observed that while the heating energy consumption increases, the decrease in cooling energy negates the overall increase. Thus, results remain like the Typical year. A study in Catania [32] and Canada [12] highlighted the uncertainties when using TMYs in energy modelling, noting significant discrepancies in some years. Additionally, while the current study considered parameters like Temp, RH, and Dewpoint temperatures for the 2019-2022 files, the relationship with solar irradiation remains, and other parameters remain unexplored. Solar irradiation is pivotal in energy consumption, especially in regions experiencing significant climate variations. While many studies use statistics-based methods to create custom weather files based on combinations of extreme climatic events, this study took a unique approach by considering the actual weather year, reflecting real-world conditions buildings encounter. Energy efficiency initiatives can influence a decline in heating energy consumption over time. Still, it depends highly on evolving weather trends, notably the observed reduction in cooling degree days, as seen in Table 2. Research indicates that fewer Heating Degree Days (HDD) correlate with reduced energy consumption [33], [34]. For instance, a study on Toronto's climate forecasted decreased energy consumption in 2040 due to fewer HDDs [13]. Although this study hasn't explicitly calculated HDDs, the linear relationship between HDD and heating energy consumption suggests that the decrease in HDDs likely results in reduced heating energy consumption. This challenges the notion that climate change will invariably lead to increased building energy consumption. While this analysis focuses on Montreal's cold and humid climate (ASHRAE classification 5A), the impact of HDD variations might differ in other Canadian cities with distinct climatic classifications. Moreover, the implications of these shifts could be significant for cities in predominantly climates, where changes in heating and cooling degree days have profound future implications [35], [36].

The energy consumption breakdown emphasizes the dominance of heating and cooling systems in total energy use, while lighting and room electricity play a lesser role. Given that buildings are designed with a lifespan of 80-100 years, or even longer, evaluating their performance in future climate scenarios is crucial. In extreme weather conditions, such as intense warmth or cold, heating and cooling energy demands can vary by 58% to 70%. For instance, during exceptionally warm periods, cooling energy requirements may double beyond the building's designed capacity, stressing the comfort systems. Conversely, in reduced cooling energy needs scenarios, high-capacity systems designed today might become redundant, leading to underutilized resources and capital losses as equipment deteriorates without reaching its full potential.

The rising cooling energy consumption underscores the necessity for research into efficient cooling systems and passive strategies. Although passive cooling methods offer limited potential in extreme conditions, they often need pairing with active systems to achieve thermal comfort and reduce energy usage. This variation in energy demands across climate scenarios highlights the importance of customized building designs and energy management. Even with an ideal air load system, the notable unmet heating and cooling hours suggest that these systems may fall short in providing the desired comfort. While there's no global standard for acceptable unmet hours, their frequency impacts equipment sizing, making it a critical factor for future climate resilience and cost-efficiency.

7. Conclusion and further remarks

The study offered a data-driven approach for cities to gauge climate change's effect on building energy use. Key findings indicated an increased cooling energy need and decreased heating consumption from 2019-2022 compared to typical weather. Up to 2099, a decrease of up to 30% was anticipated in the long term. Extreme weather, especially in NRC study scenarios, highlighted potential unmet heating and cooling demands. The study underscored the need to factor in climate change when designing HVAC systems, with peak load variations between winter and summer weeks as a significant indicator. Given the rise in extreme weather, integrating climate insights into HVAC design is crucial.

The study employed statistical climatic downscaling for future climate projections, a method scalable for other cities. With advancements in machine learning, transitioning to dynamic downscaling could yield more precise future climate representations.A primary limitation was the study's focus on only temperature, relative humidity, and dewpoint, excluding variables like wind speed and solar radiation. Future research should broaden the scope to include these for a fuller understanding. Additionally, weather files for 2061 and 2099 lacked relative humidity and dewpoint considerations, restricting insights to near-surface air temperature impacts only.

Finally, the study highlighted the importance of considering the impact of climate change on building energy consumption in the context of sustainable building design and energy management practices. With the increase in extreme weather events, it is imperative to incorporate climate change considerations in building design and operation. Sustainable building design and energy management practices can help reduce the impact of climate change on building energy consumption and contribute to a more sustainable built environment.

In conclusion, the study provided a data-driven method for cities to inform climate adaptation decisions by understanding the impact of climate change on building energy consumption. The study found that climate change has the potential to significantly impact building energy use and performance, emphasizing the need for adaptive and sustainable building design and energy management practices. While the study had limitations, including the need to consider variables other than temperature, relative humidity, and dewpoint in future studies, it demonstrated the importance of incorporating climate change considerations in building design and operation. With the increase in extreme weather events, sustainable building design and energy management practices can help reduce the impact of climate change on building energy consumption and contribute to a more sustainable built environment.

An immediate future scope of study that can be endeavoured are the implementation of climate files developed in the NRC, for all 564 locations. With the NRC data available for all these locations and the availability of urban building modelling tools, this is a very required study that can be undertaken. This study can help inform the building industry and the federal government in identifying which cities are the greatest target for climate change in terms of energy consumption in buildings.

8. References

[1] IPCC, "Climate Change 2021—The Physical Science Basis," Chemistry International, vol. 43, no. 4, pp. 22–23, Oct. 2021, doi: 10.1515/ci-2021-0407.

[2] "Climate-resilient Infrastructure," 2018. Accessed: Aug. 06, 2023. [Online]. Available: https://www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf

[3] IEA, "Buildings," 2022. Accessed: Apr. 26, 2023. [Online]. Available: https://www.iea.org/reports/buildings

[4] Evelyn Long, "The Impact of Climate Change on Building Design," 2021. https://www.construction21.org/articles/h/the-impact-of-climate-change-on-building-design.html (accessed Apr. 26, 2023).

[5] H. Bazazzadeh, A. Nadolny, and S. S. H. Safaei, "Climate Change and Building Energy Consumption: A Review of the Impact of Weather Parameters Influenced by Climate Change on Household Heating and Cooling Demands of Buildings," European Journal of Sustainable Development, vol. 10, no. 2, pp. 1– 12, Jun. 2021, doi: 10.14207/EJSD.2021.V10N2P1.

[6] Montreal, "CLIMATE CHANGE ADAPTATION PLAN FOR THE MONTRÉAL URBAN AGGLOMERATION 2015-2020," 2017.

[7] "Climate change impacts | Gouvernement du Québec." https://www.quebec.ca/en/government/policiesorientations/plan-green-economy/initiatives-fight-climate-change/understand-climate-change/impacts (accessed Apr. 26, 2023).

[8] M. de lEnvironnement, de la Lutte contre les changements climatiques, and D. générale de la transition
climatique, "A WIN-WIN FOR QUÉBEC AND THE PLANET. FRAMEWORK POLICY ON ELECTRIFICATION AND THE FIGHT AGAINST CLIMATE CHANGE," 2030, Accessed: Apr. 26, 2023. [Online]. Available: http://www.environnement.gouv.qc.ca/formulaires/renseignements-en.asp

[9] D. B. Crawley, "Which Weather Data Should You Use for Energy Simulations of Commercial Buildings?".

[10] "Improving Availability, Access and Use of Climate Information | World Meteorological Organization." https://public.wmo.int/en/bulletin/improving-availability-access-and-use-climate-information (accessed Apr. 27, 2023).

[11] A. Gaur and M. Lacasse, "Climate Data to Support the Adaptation of Buildings to Climate Change in Canada," Data (Basel), vol. 7, no. 4, p. 42, Apr. 2022, doi: 10.3390/data7040042.

[12] C. Y. Siu and Z. Liao, "Is building energy simulation based on TMY representative: A comparative simulation study on doe reference buildings in Toronto with typical year and historical year type weather files," Energy Build, vol. 211, p. 109760, Mar. 2020, doi: 10.1016/J.ENBUILD.2020.109760.

[13] M. Williams, "MODELLING WEATHER FUTURES," 2016.

[14] Z. J. Zhai and J. M. Helman, "Climate change: Projections and implications to building energy use," Build Simul, vol. 12, no. 4, pp. 585–596, Aug. 2019, doi: 10.1007/S12273-019-0509-5/METRICS.

[15] D. Crawley and L. Lawrie, "Rethinking the TMY: is the 'Typical' Meteorological Year Best for Building Performance Simulation?," Dec. 2015. doi: 10.26868/25222708.2015.2707.

[16] D. B. Crawley and L. K. Lawrie, "Our climate conditions are already changing – Should we care?,"
Building Services Engineering Research and Technology, vol. 42, no. 5, pp. 507–516, Sep. 2021, doi: 10.1177/01436244211004279/ASSET/IMAGES/LARGE/10.1177_01436244211004279-FIG7.JPEG.

[17] D. Ness, G. Liu, F. Pomponi, E. Napier, and J. Arehart, "Growth in floor area: the blind spot in cutting carbon," Emerald Open Research 2020 2:2, vol. 2, p. 2, Apr. 2020, doi: 10.35241/emeraldopenres.13420.3.

[18] "Approved Energy Simulation Software for LEED Canada The following document outlines the energy simulation software currently accepted for projects pursuing LEED Canada for New Construction and
Major Renovations (NC) and LEED Canada Core and Shell (CS) certification", Accessed: Apr. 26, 2023. [Online]. Available: http://www1.eere.energy.gov/buildings/qualified_software.html.

[19] Nrc-cnrc, "ENERGY National Energy Code of Canada for Buildings 2020 CANADIAN COMMISSION ON BUILDING AND FIRE CODES," 2020.

[20] "REAL ESTATE'S CLIMATE LEADERSHIP IN ACTION 2 Full Disclosure Real Estate's Climate Leadership in Action".

[21] M. Ferrando, F. Causone, T. Hong, and Y. Chen, "Urban building energy modeling (UBEM) tools: A state-of-the-art review of bottom-up physics-based approaches," Sustain Cities Soc, vol. 62, Nov. 2020, doi: 10.1016/J.SCS.2020.102408.

[22] U. Ali, M. H. Shamsi, C. Hoare, E. Mangina, and J. O'Donnell, "Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis," Energy Build, vol. 246, Sep. 2021, doi: 10.1016/J.ENBUILD.2021.111073/REVIEW_OF_URBAN_BUILDING_ENERGY_MODELING_UBEM_APPROACHES_METHODS_AND_TOOLS_USING_QUALITATIVE_AND_QUANTITATIVE_ANALYSIS.PDF.

[23] A. Mobasheri, F. Pirotti, and G. Agugiaro, "Open-source geospatial tools and technologies for urban and environmental studies," Open Geospatial Data, Software and Standards 2020 5:1, vol. 5, no. 1, pp. 1–4, Dec. 2020, doi: 10.1186/S40965-020-00078-2.

[24] "Open data: A window onto the municipal arena | Ville de Montréal." https://montreal.ca/en/articles/open-data-window-municipal-arena-32256 (accessed Aug. 26, 2023).

[25] K. Sharma et al., "Developing a 3D geometry for urban energy modelling of Indian cities," vol. 2, pp. 44–51, Nov. 2020, Accessed: Aug. 26, 2023. [Online]. Available: https://publications.ibpsa.org/conference/paper/?id=usim2020_A2_2_Sharma

[26] K. Jordahl et al., "geopandas/geopandas: v0.8.1," Jul. 2020, doi: https://doi.org/10.5281/zenodo.8009629.

[27] Bull Jamie, "Geomeppy," 2016. Bull J, et al. GeomEppy, 2016-, https://github.com/jamiebull1/geomeppy [Online; accessed 2019-09-21]. (accessed Aug. 31, 2023).

[28] S. Hoyer and J. Hamman, "xarray: N-D labeled Arrays and Datasets in Python," J Open Res Softw, vol. 5, no. 1, p. 10, Apr. 2017, doi: 10.5334/jors.148.

[29] P. Bourgault et al., "xclim: xarray-based climate data analytics," J Open Source Softw, vol. 8, no. 85, p. 5415, May 2023, doi: 10.21105/JOSS.05415.

[30] "The ODB - an experimental Open Database of Buildings Metadata document: concepts, methodology and data quality." https://www.statcan.gc.ca/en/lode/databases/odb/metadata (accessed Apr. 26, 2023).

[31] X. Zhou, G. Huang, Y. Li, Q. Lin, D. Yan, and X. He, "Dynamical Downscaling of Temperature Variations over the Canadian Prairie Provinces under Climate Change," Remote Sensing 2021, Vol. 13, Page 4350, vol. 13, no. 21, p. 4350, Oct. 2021, doi: 10.3390/RS13214350.

[32] G. Evola, V. Costanzo, M. Infantone, and L. Marletta, "Typical-year and multi-year building energy simulation approaches: A critical comparison," Energy, vol. 219, p. 119591, Mar. 2021, doi: 10.1016/j.energy.2020.119591.

[33] L. M. Campagna and F. Fiorito, "On the Impact of Climate Change on Building Energy Consumptions:
A Meta-Analysis," Energies 2022, Vol. 15, Page 354, vol. 15, no. 1, p. 354, Jan. 2022, doi: 10.3390/EN15010354.

[34] S. E. Chidiac, L. Yao, and P. Liu, "Climate Change Effects on Heating and Cooling Demands of Buildings in Canada," CivilEng 2022, Vol. 3, Pages 277-295, vol. 3, no. 2, pp. 277–295, Apr. 2022, doi: 10.3390/CIVILENG3020017.

[35] S. K. Manapragada Naga, "EVALUATING THE POTENTIAL IMPACT OF CLIMATE CHANGE ON INDIAN RESIDENTIAL BUILDING ENERGY-USE BY USING ENERGY SIMULATION AND DOWNSCALED HOURLY FUTURE WEATHER DATA," International Institute of Information Technology, Hyderabad, 2020. doi: http://dx.doi.org/10.13140/RG.2.2.17277.38885.

[36] S. S. Vishwanathan and A. Garg, "Energy system transformation to meet NDC, 2 °C, and well below 2 °C targets for India," Clim Change, vol. 162, no. 4, pp. 1877–1891, Oct. 2020, doi: 10.1007/S10584019-02616-1/FIGURES/5.