Comparison of future weather files for Brazilian cities

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Abstract. There is an increasing interest from academia, government, and private companies in future weather generation to predict new climate realities and prepare our assets for resilience and adaptability. In the built environment, practitioners have evolved by building simulation weather files with new tools to implement updated climate change predictions. Thus, this paper focuses on testing and understanding Brazilian climate change using the tool Future Weather Generator. Simulations under different Shared Socioeconomic Pathways were carried out, and future climate variables were discussed. This paper is part of an ongoing effort to understand how future climates may impact buildings, including comfort and energy consumption. In conclusion, the climate in Brazil is expected to become warmer in all cities, although there is a higher dry bulb temperature increase in the centre-west and northern regions. As for wind speed, relative humidity and radiation, different trends were observed in each climate. Brazil must adapt to each new climate reality and focus on efforts to provide adaptability and resilience.

1 Introduction

Climate change is a consensus among scientists worldwide, with modifications in temperature patterns, water cycle and other natural phenomena. Recently, the International Panel on Climate Change (IPCC) released the sixth Assessment Report (IPCC, 2023), the first international set of documents indicating that human activity is the primary driver of the change. The main contribution of humans to climate change is through greenhouse gas emissions (GHG), which derive from fossil fuel use, changes in land use, lifestyles and other specific production processes [1]. Thus, changing the conventional supply chains has been studied and proposed, mainly focusing on individual and global efforts to decrease GHG and diminish the expected climate catastrophe.

However, despite the implementation of many efforts, there is also a consensus on the necessity to research adaptability and resilience towards a much more probable future climate. Cities, buildings, and the built environment must adapt to future climates and be ready to provide comfort and security to citizens. Such adaptations start with correctly predicting future climates and proposing interventions that may improve local conditions. Thus, there is a need for a clear connection between climate scientists, engineers, and local public authorities to optimise the existing structures [2].

In the built environment, designers try to improve comfort by correctly predicting the thermal conditions of buildings and proposing interventions. Usually, such a process starts with using climate files, which aim to gather information on the main characteristics of a locality. One example is using Energy Plus software to predict thermal processes within a building, which considers the Energy Plus Weather files (EPWs) as inputs [3]. The correct handling of EPWs is essential to understanding the local climate reality and, thus, correctly predicting the thermal processes involving a building.

Ever since climate change has formed consensus among researchers and designers, there has been a goal to update EPWs to future climates, thus understanding the future reality of buildings. The effort has significantly improved with the release of CCWeatherGen [4], the first application that used international climate change models to modify the parameters of EPWs according to the user's set of future alternatives. The tool has been widely used to understand the modifications on local built environment parameters that may require more focus by designers and public policies [5–7].

However, with the advances in the Coupled Model Intercomparison Project (CMIP), there has been an interest in improving the tools for EPW future weather modifications. One recent paper has provided a new tool for designers and engineers [8]. The Future Weather Generator tool [8] has emerged as an open-source initiative that simplifies using CMIP 6 models to upgrade current EPW files to future weather. The ease of understanding climate impact in local parameters may help enhance resilience and adaptability and help decision-makers visualise the changes. New studies have also focused on applying this tool to understand climate realities better [9,10].

Thus, through the use of the Future Weather Generator, this work provides an overview of future

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DBT stands for mean Dry Bulb Temperature, RH stands for mean Relative Humidity, WS stands for mean Wind Speed, and GHR stands for mean daily Global Horizontal Radiation.

Table 1. Summary of climate data for the twelve cities [12].

City	Bioclimatic zone	Latitude	Longitude	DBT (°C)	RH (%)	WS (m/s)	GHR (Wh/m².day)
Fortaleza	6A	-3.73	-38.53	27.08	72.85	5.26	5791
Recife	5A	-8.05	-34.88	26.68	76.04	4.21	5340
Palmas	6B	-10.19	-48.33	27.10	66.84	2.25	5481
Vitória da Conquista	3A	-14.87	-40.84	21.50	74.84	3.44	5168
Cuiaba	5B	-15.60	-56.10	26.65	70.83	2.53	5323
Brasília	3B	-15.79	-47.88	22.05	65.79	2.55	5447
Goiania	4B	-16.68	-49.26	24.34	63.48	2.51	5513
Rio de Janeiro	4A	-22.91	-43.21	24.24	75.17	3.04	4706
São Paulo	2M	-23.55	-46.63	20.44	73.40	3.32	4632
Curitiba	1M	-25.43	-49.27	17.62	83.49	3.20	4147
Canela	1R	-29.37	-50.82	16.25	81.46	2.86	4556
Porto Alegre	2R	-30.03	-51.23	20.01	78.88	3.41	4595

Climates in a cooling-dominated country. The goal is to understand the existing predictions and discuss the results regarding climate files for the thermal performance of buildings. One aims to show the potential of such tools for policy making and spreading the applicability of future climate modelling.

2 Method

The method was divided into two parts. First, the objects of study were presented, including the cities and current climate parameters. Second, a description of future weather parameters was explored.

2.1 Objects of study

Twelve Brazilian cities were selected based on the country's bioclimatic zoning standard. The standard was updated in 2024, including twelve zones divided into six major groups and two intensity levels of the climate extremes. A representative city of each bioclimatic zone was selected, focusing on selecting cities with a high number of inhabitants and located in different parts of the country. Table 1 shows the data available for each city selected. The EPW file presents a set of 29 climatic parameters; however, only four are shown in Table 1, as these parameters are the most assessed in building simulation.

Data were obtained via ClimateOneBuilding [11] with the TMYx 2007-2021 version, the recommended climate file in NBR 15220 [12]. The cities are very different, as Brazil is an extensive territory. Latitudes range from -3.73 to -30.03 degrees and vary considerably across all climatic variables. For instance, temperature and relative humidity influence the thermal perception of the inhabitants, ranging from cold in Canela to hot climates, such as in Fortaleza. In most bioclimatic zones, natural ventilation enhances thermal environmental conditions. Thus, wind speed and direction are influential factors in naturally ventilated buildings. Global Horizontal Radiation (GHR) also varies in the country, but it is usually high, with a potential for photovoltaic systems to produce energy. The cities in the northern region show a higher potential, with higher GHR.

2.2 Future weather parameters

The Future Weather Generator default parameters were used to convert the Brazilian EPWs. The programme presents a bilinear interpolation between the closest grid points as the default method, considering the selected models for future weather. Models from CMIP 6 are available for selection, including the Model for Interdisciplinary Research on Climate (MIROC), Centre National de Recherches Météorologiques (CNRM), Chinese Academy of Sciences (CAS), and others. The default selection is based on models with at least 25,000 grid points worldwide. The programme then provides an EPW for each weather model and an ensemble file, which is the resumed results file analysed in this research.

Scenarios for carbon emissions define the future expected in terms of carbon concentration in the atmosphere. There are eight scenarios available, including the years of 2050 and 2080 and four different Shared Socio Pathways (SSPs). SSPs are pathways predicted by the IPCC that show how emissions are expected according to social and narrative decisions worldwide. These scenarios are usually coupled with the corresponding radiative forcing (W/m²) to show how much more energy is expected to be balanced by Earth in future hotter configurations.

SSP1 is the green road, where a gradual transition to sustainable practices occurs, and there are low challenges to adaptation and mitigation. SSP2 is the middle-term scenario, with a medium challenge in adaptation and mitigation and a more conventional transition. SSP3 shows the regional rivalry, where national protectionism is predominant. This scenario presents high challenges to both mitigation and adaptation. SSP4 shows the inequality scenario, in which there is a balance between green initiatives in high-income countries and carbon-intense alternatives elsewhere. This scenario shows the problem of not tackling climate change together, in which there are low challenges to mitigation but high challenges to adaptation. Lastly, SSP5 shows the ecomodernist scenario, where fossil fuel use continues, and there is a push towards global development. Although it shows a low challenge to adaptation, as solutions are expected to be obtained under a high energy evolution, the scenario shows a high mitigation challenge, as a higher global warming index is expected.

In this work, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5 were used. SSP1-2.6 is the best possible practice, in which the global climate will change slightly (less than 2°C). SSP5-8.5 predicts the worst possible climate under the status of evolution, with a radiative forcing of 8.5 and the consequent increase in global average air temperature of over 4°C. Both other SSPs show a middle ground, with an intermediary effect over the globe. Figure 1 shows a flowchart of all the outcomes. In total, 108 files were assessed in this work.

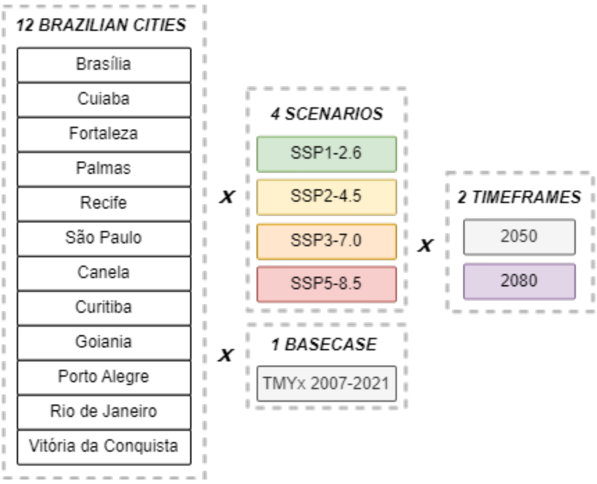

Fig. 1. Flowchart of scenarios analysed.

2.3 Scripts, data management and statistics

Two pieces of software were considered to simplify the processes needed to assess the climate data. First, *EnergyPlus Weather Statistics and Conversion* converted the EPW to Comma Separated Values (CSV), as this file type is easier to manage and extract data. All 108 files were converted to CSV. The data were then managed in Python, considering all necessary packages. The results were then plotted under an automatic script, which may be replicated in other locations. Heating and cooling degree hours were used to assess the differences that future climate may impose on buildings.

3 Results and discussion

First, the direct changes in climate data were observed via the modified EPW files. After converting to CSV and managing the data via Python, nine files were obtained for each city, considering the different timeframes and carbon concentration scenarios. Figure 2 shows a scatterplot of the four climatic parameters, with values ranging from nine scenarios to twelve cities. One observes a warming trend in all cities, although Figure 3 shows that Palmas, for example, warmed more than Recife.

Wind speed, relative humidity and global horizontal radiation followed a different trend. Except for Curitiba, all cities presented a slight increase in wind speed. Curitiba, although, presented a higher variation, with an increase of 0.5 to 2.0 m/s depending on the SSP considered. As for relative humidity, changes to drier or wetter climates appeared in the results, with the centre-west, north and northeast cities presenting a drying pattern and the south and southeast a wetter pattern. As for radiation, trends followed the inverse pattern, with drier cities presenting higher radiation in the future. Figures 4, 5 and 6 show the variation trends in future climate. The hatched areas show the variation due to the SSP scenarios. For example, in São Paulo (Figure 3), one can see that the temperature delta ranges from 1.4 to 2.8°C. In the best-case scenario (SSP1-2.6), the temperature increase is 1.4°C, while in the worst-case scenario (SSP5-8.5), it is 2.8°C.

One understands that drier places may have presented more days without clouds, possibly related to increased global radiation over the cities. Such an increase is vital to be assessed, as the radiation is directly related to the heat gain over windows, photovoltaic production and water heating. In a future where solar energy is increasingly demanded, understanding changes in global radiation is important. For example, cities in the northeast are known to be photovoltaic power plant sites and may be increasingly productive in this field, at least considering the radiation parameter.

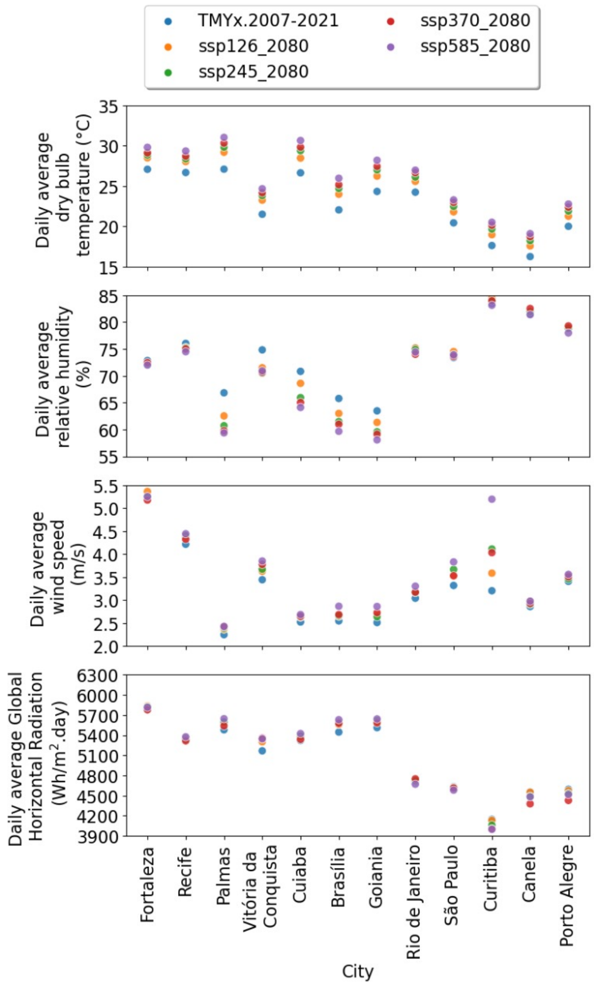

Fig. 2. Range of climate variables in baseline years (2021) and future year (2080) scenarios.

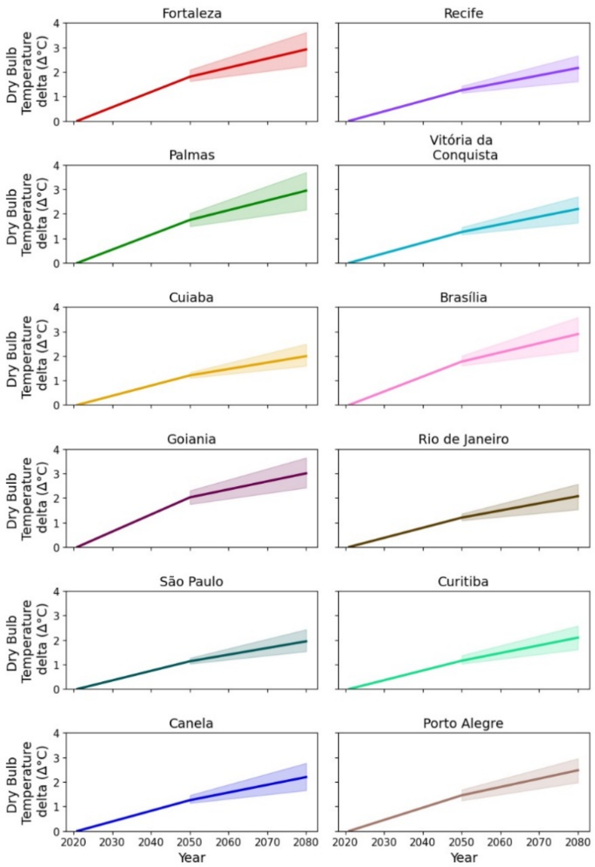

Fig. 3. Variation of future (2050 and 2080) to current (2021) dry bulb temperature.

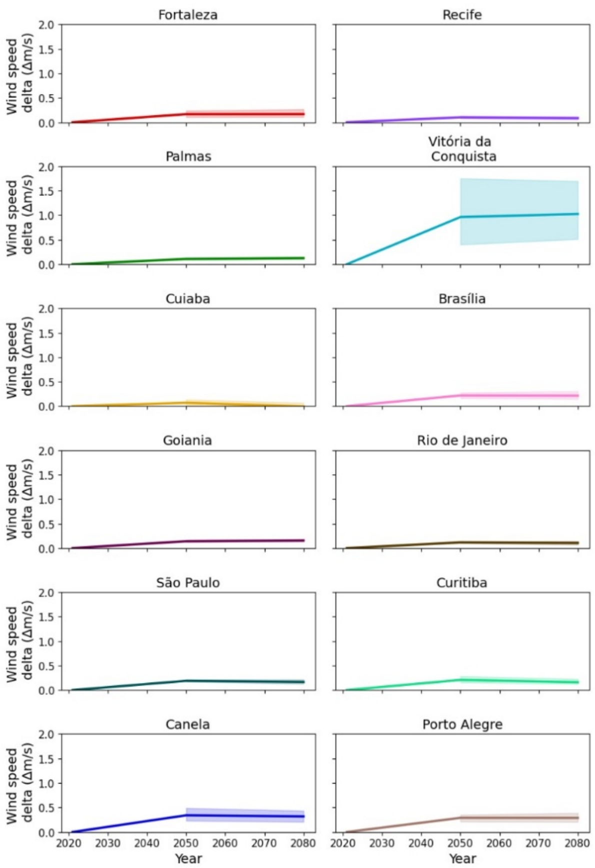

Fig. 4. Variation of future (2050 and 2080) to current (2021) wind speed.

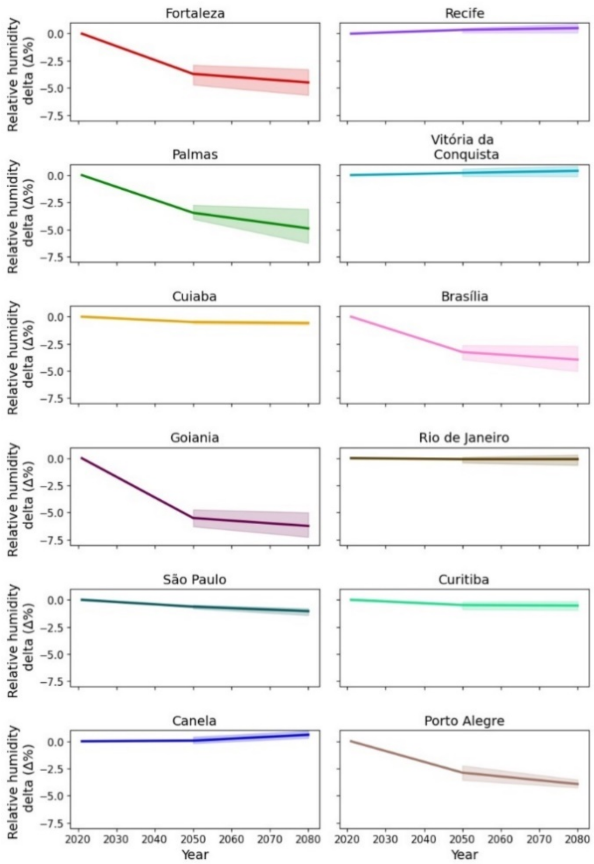

Fig. 5. Variation of future (2050 and 2080) to current (2021) relative humidity.

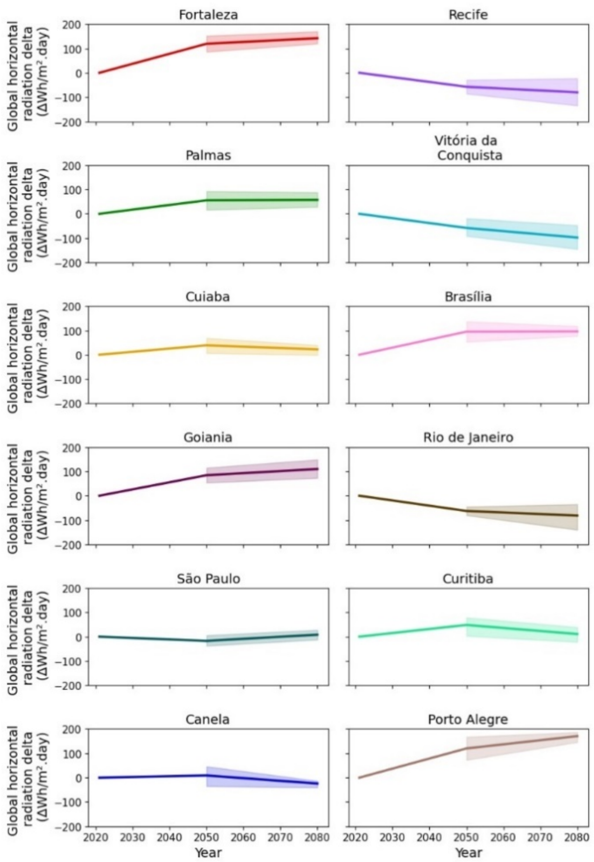

Fig. 6. Variation of future (2050 and 2080) to current (2021) global horizontal radiation.

All three other variables (temperature, wind speed and relative humidity) are closely related to the thermal comfort experienced by inhabitants. Therefore, it is also interesting to understand how drier future conditions may relate to a difference in comfort perception. In future studies, such climates should be assessed under building scopes to understand the increase in air-conditioning or ventilation and how people will be affected. Thermal analysis of buildings should be coupled with future weather simulations and modifications according to the urban arrangements [13]. As new tools have emerged, research must be done to improve the resilience and adaptability of the built environments.

4 Conclusions

In this paper, we assessed twelve different Brazilian cities using the new tool of Future Weather Generator. The changes in dry bulb temperature, wind speed, relative humidity and global horizontal radiation show that cities will not uniformly change, and local adaptations according to the new reality must be provided. Using a programming language coupled with thermal simulation weather files has also proven easy, providing much workability and possibilities. One hopes that this paper and the tools used help other practitioners understand and simulate future climates, helping to design for adaptability and resilience in built environments.

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