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AMBIENTE CONSTRUÍDO E USUÁRIO: PERSPECTIVAS LATINO-AMERICANAS

Typical and extreme weather files for building performance assessment in Brazil

Arquivos climáticos típicos e extremos para análise de desempenho de edifícios no Brasil

Archivos climáticos típicos y extremos para la evaluación del desempeño de edificios en Brasil

Energy efficiency / *Eficiência energética* / *Eficiencia energética*

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Abstract

Building performance simulation is highly dependent on the weather conditions provided by the simulator. Usually, typical climate conditions are preferred for building performance simulations, but the current climate scenario show that these conditions may not be sufficient. This study focused on comparing typical and extreme conditions and analyzed their impacts on the operative temperature and energy use of a single-family house. The initial climate assessment shows an increase in cooling degree-hours and direct normal irradiation. The simulation results showed that extreme years had an average operative temperature 1.3 °C higher than typical conditions, in addition to a 20 % increase in energy use.

Keywords: Weather data. Building performance simulation. Residential buildings. Parametric analysis.

Resumo

A simulação do desempenho do edifício é altamente dependente das condições climáticas fornecidas pelo simulador. Normalmente, as condições climáticas típicas são utilizadas para simulações de desempenho de edifícios, mas o cenário climático atual mostra que estas condições podem não ser suficientes. Este estudo concentrou-se na comparação de condições típicas e extremas e analisou seus impactos na temperatura operativa e no uso de energia de uma residência unifamiliar. A avaliação climática mostra um aumento nos graus-hora de resfriamento e na irradiação direta normal. Os resultados da simulação mostraram que anos extremos apresentaram uma temperatura operativa média 1,3 °C maior que condições típicas, além de um aumento de 20 % no uso de energia.

Palavras-chave: Dados climáticos. Simulação de desempenho de edificações. Edifícios residenciais. Análise paramétrica.

Resumen

La simulación del rendimiento de un edificio depende en gran medida de las condiciones climáticas proporcionadas por el simulador. Normalmente, se prefieren las condiciones climáticas típicas para las simulaciones del rendimiento de los edificios, pero el escenario climático actual muestra que estas condiciones pueden no ser suficientes. Este estudio se centró en comparar condiciones típicas y extremas y analizó sus impactos en la temperatura de funcionamiento y el uso de energía de una casa unifamiliar. La evaluación climática inicial muestra un aumento en los grados-hora de enfriamiento y la irradiación normal directa. Los resultados de la simulación mostraron que los años extremos tuvieron una temperatura operativa promedio 1,3 °C más alta que las condiciones típicas, además de un aumento del 20 % en el uso de energía.

Palabras clave: Datos meteorológicos. Simulación del rendimiento del edificio. Edificios residenciales. Análisis paramétrico.

Introduction

Building performance simulation (BPS) relies on several aspects mainly describing the interaction between the indoor and outdoor characteristics of a determined building geometry and its thermal-physical properties. BPS often depends on weather files to emulate the outdoor environment. Therefore, depending on the weather file used to characterize the climatic conditions, the results can significantly change (BRACHT *et al.*, 2024). In the late 90's, questions on whether different weather files could impact BPS results were raised, showing that users of simulation software should be aware of those impacts and carefully select the typical weather file used in their simulations (CRAWLEY; HUANG; BERKELEY, 1997).

Despite widely used, Typical meteorological year (TMY) weather files can only account for the average climatic conditions and fail to portrait extreme events (MACHARD *et al.*, 2024). Typical weather files are generally described by TMY, capable of providing an average climatic profile based on different weather parameters, such as dry bulb temperature, relative humidity, and solar irradiation (HALL *et al.*, 1978; PAPAKYRIAKOU; BIGTASHI; LEE, 2024; PERNIGOTTO *et al.*, 2014). In this context, Pernigotto *et al.* (2014) evaluates both the creation of new typical weather files based on different statistical methods and the application of new weights, indicating improvement on the traditional methods such as the ISO 15927-4 approach (CEN, 2005). Hosseini *et al.* (2020) and Papakyriakou *et al.* (2024) propose the creation of site-specific weather files, aided by a machine learning algorithm to retrieve the weights based on actual meteorological year (AMY) simulation results. Therefore, the different approaches can lead to weather files that affect simulation results.

The Intergovernmental Panel on Climate Change (IPCC) reports systematically show the increasing occurrence of extreme events, leading to an increase in the global temperature (CALVIN *et al.*, 2023). Therefore, BPS needs to account also for the extreme climatic events. The literature provides many examples of weather file compilation methods based on extreme events (MACHARD *et al.*, 2024; PERNIGOTTO; PRADA; GASPARELLA, 2020). Pernigotto, Prada, and Gasparella (2020) present an approach like the TMY method, but instead of selecting the typical months with the lowest difference of dry bulb temperature and solar irradiation records, the method defined the representative records based on the highest differences. Machard *et al.* (2024) presents an approach that focuses on extreme weather data and weather files based on heatwave events.

Considering the extreme and future climatic conditions, different studies quantified the impact on BPS results in the Brazilian territory (BRACHT *et al.*, 2024; RODRIGUES; PARENTE; FERNANDES, 2024). Bracht *et al.* (2024) quantified the impact of different future weather file projections on the performance of a residential building for all the state capitals in Brazil, showing the significant variations across the territory. Rodrigues *et al.* (2024) proposes a parametric analysis to identify the optimal building envelope thermal properties to face the uncertainties of future climates. However, none of the studies addressed the extreme events from historical records. Given the territorial extension of Brazil and the results from previous studies, it is necessary to provide a vast analysis, accounting for different locations and considering the influence of extreme events. Therefore, this study aims to quantify the impact of using typical and extreme weather files on building performance simulation of Brazilian buildings.

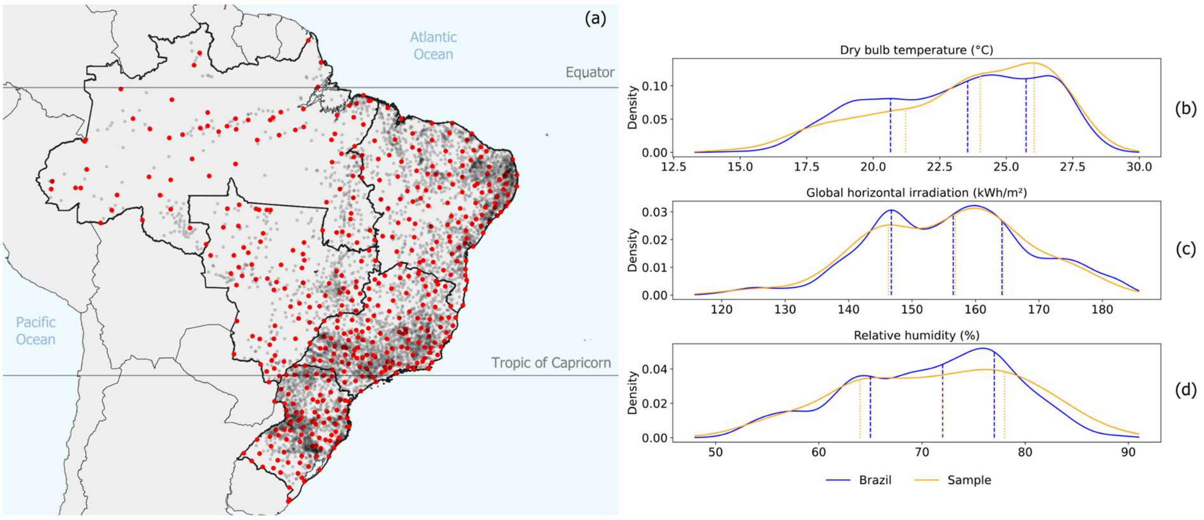
Methods

The following subsections describe the steps to gather and process the weather data used in this study. Then, a methodology to compare the typical and extreme weather files is presented. Finally, the building models and simulation settings are shown along with the methodology adopted to process and analyze the simulation results.

Weather file compilation and climatic assessment

This study uses a sample of 480 municipalities in Brazil providing a good representation of the 5570 municipalities within the Brazilian territory for the 2008-2022 timeframe (Figure 1). The sample was previously adopted by da Silva *et al.* (2025) to create typical weather files from ERA5-Land records (MUÑOZ-SABATER *et al.*, 2021). The ISO methodology (CEN, 2005) was adopted as the typical meteorological year (TMY_{ISO}) approach in this study.

Figure 1: The 480 locations (red dots) overlaying the remaining 5090 municipalities (black-shaded dots), and the distribution of annual records of dry-bult temperature, solar radiation, and relative humidity.



The TMY_{ISO} method first requires the calculation of the daily average dry-bulb temperature, solar radiation, and relative humidity, for each individual year and the long-term records. Then, the probabilistic difference between each year and the long-term is calculated using the Finkelstein-Schafer (FS) statistic. After this process, the ISO method ranks the years for each weather quantity, sums the individual ranks, identifies the three lowest sums, and uses the wind speed deviation between the individual years and long-term to select the representative months. The process is repeated for each calendar month and the reference years are combined in the end to create a single file with 8760 hourly records, representing a TMY.

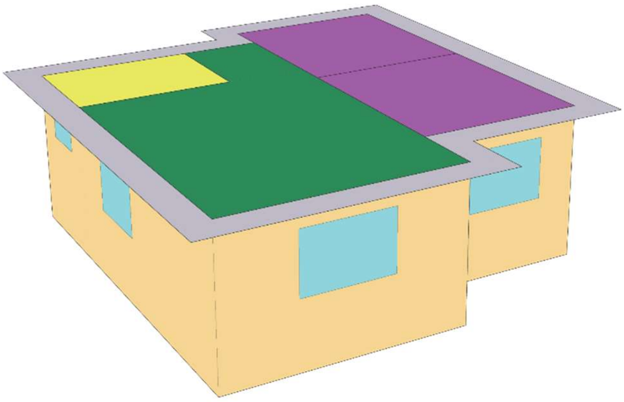
The process of creating the extreme reference years (*ERY*) follows the methodology proposed by Pernigotto, Prada, and Gasparella (2020). The authors proposed an extreme cold (ERY_{COLD}) and an extreme hot (ERY_{HOT}), but our study only employs the ERY_{HOT}, since the studies show a heating trend for Brazil. As done for the ISO method, the daily averages of dry-bulb temperature and solar radiation are calculated, for each calendar year and the long-term records. Then, the *FS* statistics are calculated, and ranks are assigned giving the same weight to the variables. In this point, the method differentiates from the previous TMY approaches, because it seeks the years with high differences, instead of the ones closer to the long-term. After defining the most different years, a predefined constraint selects the months with average dry-bulb temperature and solar radiation higher than the long-term average. Finally, the calendar year with the highest difference is used as reference.

Following the *ERY* compilation, a climatic assessment compared the typical and extreme years. The procedure follows the assessment of annual summaries of heating degree hours for cooling (*CDH*) and heating (*HDH*), direct (*DNI*) and diffuse radiation (*DHI*), and relative humidity (*RH*), as proposed by Bracht *et al.* (2024). The *HDH* and *CDH* indicators follow the base temperatures of 16 °C (HDH_{16}) and 26 °C (CDH_{26}), respectively. For the radiation parameters, this study used the annual integral from hourly records.

Building performance simulation models and settings

A simulation approach quantified the impact of typical and extreme weather files on the performance of a single-family house geometry (Figure 2) representing one of the most common typologies in the Brazilian social housing building stock (TRIANA; LAMBERTS; SASSI, 2015). EnergyPlus 23.2 was used for the building performance simulations, considering nine building envelope configurations (Table 1), the four cardinal orientations, and two conditioning models: naturally ventilated and ideal HVAC system. The gains, loads, schedules, and windows constructions followed the NBR 15575 (ABNT, 2021).

Figure 2: Single-family building model. The roof color represents the different building zones (yellow indicates the bathroom, green indicates the shared space for the kitchen and the living room, and purple indicates the bedrooms).



The operative temperature (T_o) and the energy use with cooling and heating system, expressed in kWh/m², were used to analyze the simulation results. The analysis considered the average of the four orientations but discretized the parametric envelope results and discussed its impact on the employed performance metrics.

Table 1: Building envelope configuration.

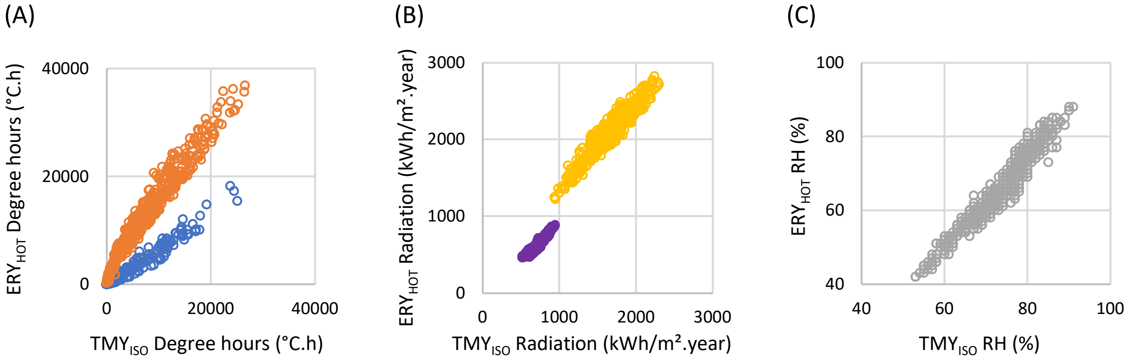
Construction set	Surface	U-value (W/m².K)	Thermal capacity (kJ/m².K)	Solar absorptance
CS1	Walls	0.41	125	0.3, 0.5, and 0.7
	Roof	0.56	230	0.6
CS2	Walls	2.51	150	0.3, 0.5, and 0.7
	Roof	2.01	21	0.6
CS3	Walls	4.84	220	0.3, 0.5, and 0.7
	Roof	2.41	233	0.6

Results and discussion

Weather data analysis

The ERY_{HOT} weather files are designed to select the hottest years in the multi-year series while the TMY_{ISO} method selects values close to the average. Therefore, the climatic assessment results clearly depict the lower HDH_{16}, RH, and DHI, while the CDH_{26} and DNI are higher for the extreme weather file (Figure 3).

Figure 3: Climatic assessment results' distribution. Figure A shows the degree hours results (HDH_{16} in blue and CDH_{26} in orange), figure B shows the *DNI* results in yellow and the *DHI* results in purple, and figure C shows the relative humidity results.



In general, the HDH_{16} results showed an average reduction of 10 % when using the ERY_{HOT}, with some locations showing a 100 % reduction, reaching a point of no heating needs considering the 16 °C setpoint. As for the CDH_{26}, the results showed an average increase of 117 %, with locations in the South region presenting an increase above 1000 % for locations that shown zero of extremely low CDH_{26} when considering the TMY_{ISO} records, such as Urubici-SC (1790 %) and São Joaquim-SC (1552 %). The locations which had considerably higher cooling needs, as the ones mentioned, are in the coldest regions of Brazil. Therefore, they have a low CDH_{26} when considering the TMY_{ISO} and the use of ERY_{HOT} records increases the cooling requirements, but they still present a low value, considering the Brazilian context (Figure 4).

Figure 4: Distribution of the HDH_{16} and CDH_{26} records for the TMY_{ISO} (green) and the ERY_{HOT} (pink) weather files.

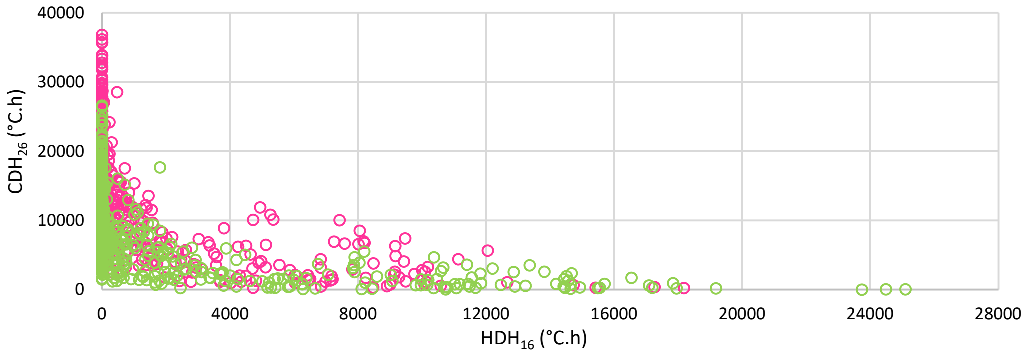
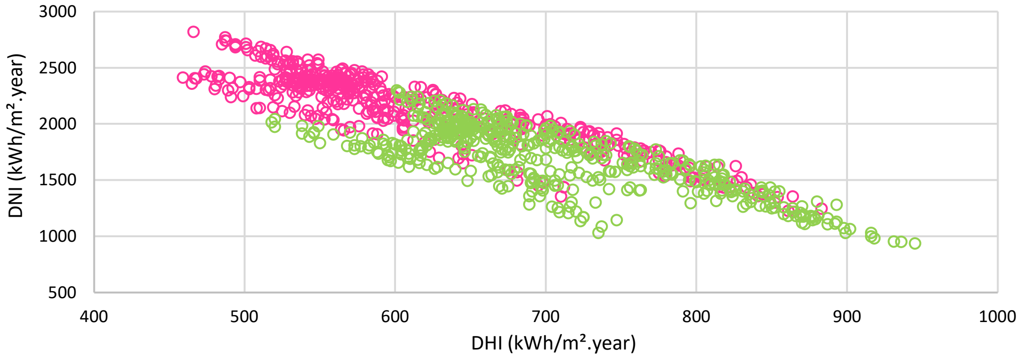


Figure 5: Distribution of the DNI and DHI records for the TMY_{ISO} (green) and the ERY_{HOT} (pink) weather files.

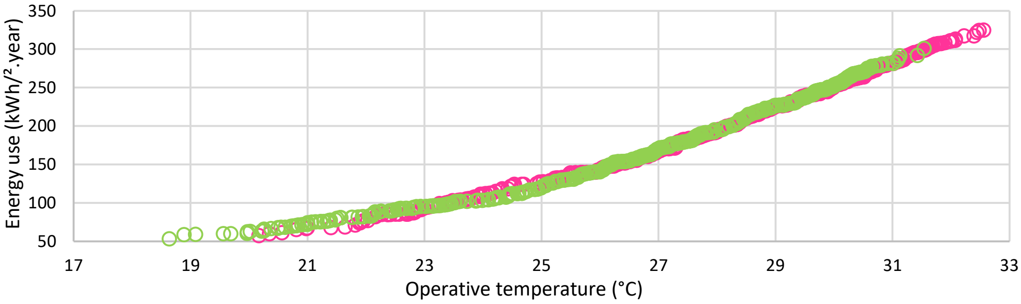


The RH results showed an average reduction of 10 % when comparing the ERY_{HOT} and TMY_{ISO} climatic data. Florianópolis-SC was the only location with a slight increase in the humidity levels (1 %). The remaining locations varied from no reduction to a 23 % lower annual RH based on hourly records. The climatic assessment also allowed correlating the humidity and the solar radiation summary. The DNI increased while the DHI decreased for ERY_{HOT} records (Figure 5), given the humidity reduction that directly reduces nebulosity. The direct radiation increased, in average, 26 %, varying from 12 % in Conde-BA to 49 % in Paritins-AM. On the other hand, the diffuse component reduced 13 % in average, from 2 % in Itajaí-SC to 24 % in Guanambi-BA.

Building performance simulation assessment

Considering the average annual indoor T_o from hourly simulation outputs of each city, the TMY_{ISO} showed an average of 26.7 °C, varying from 18.6 °C in São Joaquim-SC to 31.5 °C in Teresina-PI. The ERY_{HOT} showed an average of 27.9 °C, varying from 20.2 °C in São Joaquim-SC to 32.5 °C in Teresina-PI and Piripiri-PI. Using the typical and extreme weather files clearly influences the analysis of the operative temperature, since the extremes belong to the same locations and differ at least 1 °C when using an extreme weather file. The extreme weather temperatures presented an average deviation of 1.3 °C, varying from 0.4 °C in João Pessoa-PB and Aracaju-SE to 2.4 °C in Marechal Cândido Rondon-PR. The average energy use of TMY_{ISO} files was 173 kWh/m^2, varying from 53 kWh/m^2 in Campos do Jordão-SP to 301 kWh/m^2 in Parnaíba-PI. In contrast, the average energy use of extreme weather files was 202 kWh/m^2, varying from 58 kWh/m^2 in São José dos Ausentes-RS to 325 kWh/m^2 in Parnaíba-PI and Santarém-PA. Again, the use of ERY_{HOT} restates the influence of extreme conditions on building performance, given the increase in energy use in the average and extremes. The relative deviation increase of the energy use was of 20 %, varying from 2 % in Votuporanga-SP to 36 % in Rio de Janeiro-RJ. Figure 6 depicts the correlation between T_o and the energy use for the TMY_{ISO} and the ERY_{HOT} outputs.

Figure 6: Distribution of the operative temperature and energy use for the TMY_{ISO} (green) and the ERY_{HOT} (pink) weather files.

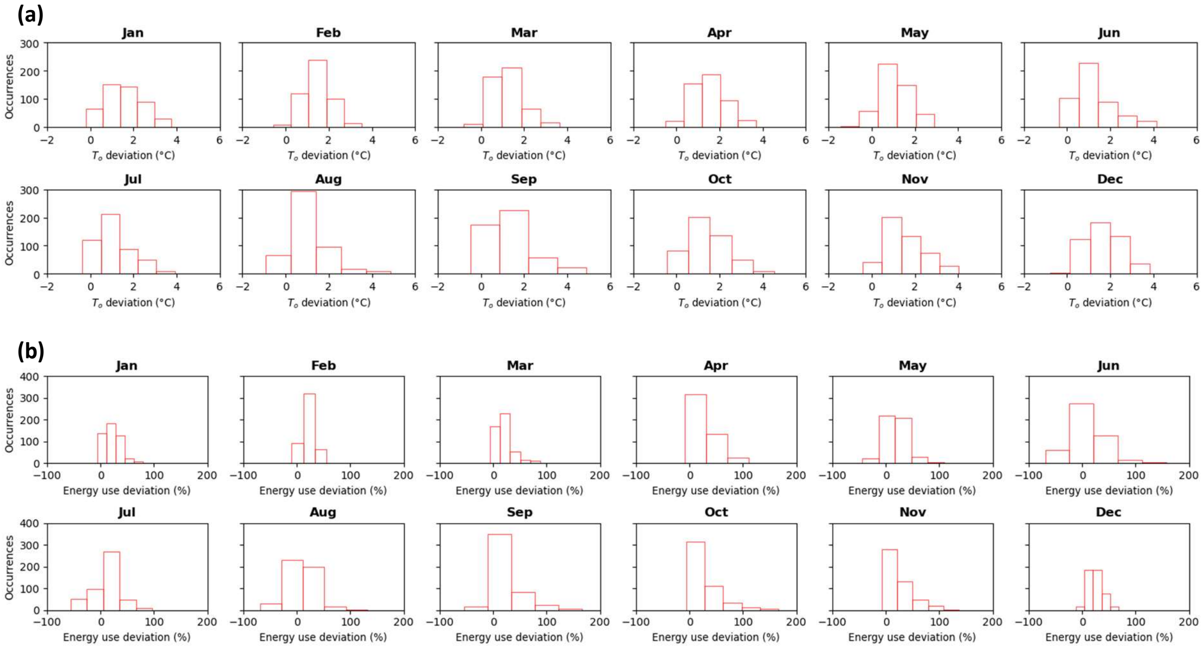


The results also showed that parametric envelope influenced the average operative temperature. Considering the average solar absorptance, the lowest value presented the best T_o results, while the highest presented the worst. However, the constructive components analysis pointed that the three configurations achieved a similar operative temperature with an average maximum difference of 0.2 °C. Therefore, the solar absorptance impacted more than the combination of *U-value* and thermal capacity for the exterior walls and roof. While T_o was mostly influenced by solar absorptance, the energy use results showed that the highly insulated construction component (*CS1*) presented the best average performance with an energy use 29 % lower than the worst configuration (*CS3*). Likewise, the lowest solar absorptance and average best performance had an energy use 13 % lower than the worst external walls solar absorptance (0.7). These results allowed stating that the construction components were more influent on the energy use, since the independent analysis of the constructions sets showed a higher variation in the energy use than the solar absorptance.

The performance results based on monthly summaries pointed that, during summer, the average T_o and the energy needs presented a higher variation between TMY_{ISO} and ERY_{HOT} results. January and December had the highest T_o and energy use results, while July had the lowest operative temperature and energy use. The average T_o for the summer averaged 28.9 °C for the TMY_{ISO} while the ERY_{HOT} reached 30.5 °C. The operative temperature also increased in July, from 24.4 °C in the typical weather file to 25.5 °C in the extreme records. The amplitude of T_o also had significant variation, with an average increase of 1.2 °C for the maximum and 1.4 °C for the minimum.

The energy needs for January also showed the highest values and the highest increase, from 22.2 kWh/m² (TMY_{ISO}) to 26.9 kWh/m² (ERY_{HOT}). June had the lowest, varying from 14 kWh/m² in the typical conditions to 12.9 kWh/m² with extreme records. As for the maximum and minimum energy use, the results followed the same pattern as the operative temperature. These results restated the influence of the extreme weather file methodology in selecting the hottest months to represent the multi-year series. The deviation results shown in Figure 7 depict the overall behavior of the To and the energy use throughout the months, highlighting the months in which the use of typical and extreme data influenced the most the simulation outcomes.

Figure 7: Distribution of the operative temperature (a) and energy use (b) deviations for each month.



Conclusions

The results found in this study clearly demonstrated the influence of using typical and extreme weather conditions to create weather files and, consequently, their effect on building performance simulation analysis. In the Brazilian context, standards and policies are drawn based on typical conditions. However, they can be insufficient to describe the current environmental context of Brazil by underestimating the extreme events that are becoming more frequent and tend to increase in the coming years. This study can be used as an initial assessment of the consequences of relying solemnly on average climatic conditions. Given the current climatic conditions and the results found in this study, extreme conditions should also be part of the analysis process.

Even though the operative temperature showed a more smoothly variation between the TMY_{ISO} and ERY_{HOT} simulation results for some locations, for many others the difference was equal or higher than 1 °C. Moreover, the energy use results showed a more concerning pattern. The use of typical or extreme conditions significantly changed the simulation outputs. Since the approach used in this study addressed the energy by area, the difference between the weather files resulted in a considerable higher energy use for the single-family model. Considering the typology context, i.e., social housing, and the economic environment within this context, this variation in the energy use associated with the energy cost could compromise the annual budget of a family.

The average climatic conditions are limited and can bias building performance simulation results, given the current climatic conditions of the present days. As an overall recommendation, extreme weather conditions should be included in the analysis always as possible, since climate change is a reality that tends to increase in future years. In this way, future policies and standards should include analysis that consider also the extreme events. Future studies should include the comparison of future weather files as well as quantify their correlation with extreme weather files, providing insights on the impact of climate change over historical records. Regarding the limitations of this study, the authors highlight the building typology, since different uses and geometries could lead to different energy use results, despite an expected increasing trend as observed with residential buildings.

References

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - ABNT. **NBR 15575: Edificações habitacionais - Desempenho**. Rio de Janeiro, 2021.

BRACHT, M. K. et al. **Multiple regional climate model projections to assess building thermal performance in Brazil: Understanding the uncertainty**. *Journal of Building Engineering*, v. 88, p. 109248, 2024. ISSN: 2352-7102, DOI: https://doi.org/10.1016/j.jobe.2024.109248.

CALVIN, K. et al. **IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)].** IPCC, Geneva, Switzerland, 2023. DOI: 10.59327/IPCC/AR6-9789291691647.

CRAWLEY, D. B.; HUANG, Y. J.; BERKELEY, L. **Does It Matter Which Weather Data You Use in Energy Simulations?** *Building Energy Simulation User News*, v. 18, nº 1, p. 25–31, 1997.

DA SILVA, M. A. et al. **Impact of the Type of Weather Files on the Outcome of a Weather-Based Climate Classification: The Case of Brazil**. Em: BERARDI, U. (Org.). *Multiphysics and Multiscale Building Physics. IABP 2024. Lecture Notes in Civil Engineering*. Singapore: Springer, 2025. v. 553, p. 258–263. DOI: 10.1007/978-981-97-8309-0_34.

HALL, I. J. et al. **Generation of a typical meteorological year**. United States, 1978. Disponível em: <https://www.osti.gov/biblio/7013202>.

HOSSEINI, M.; BIGTASHI, A.; LEE, B. **A systematic approach in constructing typical meteorological year weather files using machine learning**. *Energy and Buildings*, v. 226, 2020. ISSN: 03787788, DOI: 10.1016/j.enbuild.2020.110375.

MACHARD, A. et al. **Typical and extreme weather datasets for studying the resilience of buildings to climate change and heatwaves**. *Scientific Data*, v. 11, nº 1, p. 531, 2024. ISSN: 2052-4463, DOI: 10.1038/s41597-024-03319-8.

MUÑOZ-SABATER, J. et al. **ERA5-Land: a state-of-the-art global reanalysis dataset for land applications**. *Earth System Science Data*, v. 13, nº 9, p. 4349–4383, 2021. DOI: 10.5194/essd-13-4349-2021.

PAPAKYRIAKOU, A.; BIGTASHI, A.; LEE, B. **Evaluating the applicability of a machine learning methodology to improve TMY weather file generation for different Canadian climate zones**. *Journal of Building Engineering*, v. 95, p. 110096, 2024. ISSN: 2352-7102, DOI: 10.1016/J.JOBE.2024.110096.

PERNIGOTTO, G. et al. **Analysis and improvement of the representativeness of EN ISO 15927-4 reference years for building energy simulation**. *Journal of Building Performance Simulation*, v. 7, nº 6, p. 391–410, 2014. ISSN: 19401493, DOI: 10.1080/19401493.2013.853840.

PERNIGOTTO, G.; PRADA, A.; GASPARELLA, A. **Extreme reference years for building energy performance simulation**. *Journal of Building Performance Simulation*, v. 13, nº 2, p. 152–166, 2020. ISSN: 19401507, DOI: 10.1080/19401493.2019.1585477.

RODRIGUES, E.; PARENTE, J.; FERNANDES, M. S. **Building for tomorrow: Analyzing ideal thermal transmittances in the face of climate change in Brazil**. *Applied Energy*, v. 355, p. 122360, 2024. ISSN: 0306-2619, DOI: https://doi.org/10.1016/j.apenergy.2023.122360.

TRIANA, M. A.; LAMBERTS, R.; SASSI, P. **Characterisation of representative building typologies for social housing projects in Brazil and its energy performance**. *Energy Policy*, v. 87, p. 524–541, 2015. ISSN: 0301-4215, DOI: https://doi.org/10.1016/j.enpol.2015.08.041.

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