Impact of Different Radiation Decomposition Models and ERA5 Dataset on Building Energy Simulation Results: A Case Study in Brazil

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Abstract

This study compares three different radiation decomposition models (Erbs, DIRINT, and DISC) for estimating direct normal radiation to the data from the reanalysis dataset ERA5. It also evaluates the impact of considering these different models and datasets on building energy simulation outcomes for three locations in Brazil (Brasília, Salvador, and São Paulo). As the simulation study case, we analyzed a typical residential building in the Brazilian context. This building model was analyzed in three different cases (Brazilian standard building characteristics reference, low solar absorptance values, and considering a 0.80 m overhang). Regarding radiation datasets, the Erbs model exhibited the lowest RMSE for direct and diffuse radiation compared to the monthly values provided by the Brazilian Solar Atlas. By analyzing the RMSE values, we demonstrated that ERA5 overestimated direct normal radiation while significantly underestimating diffuse values compared to the Solar Atlas. Concerning simulation results, we observed differences of up to 14% higher cooling load values when comparing the results using ERA5 data with the DISC model ones. However, maximum operative temperatures did not show such significant differences, with a maximum deviation of 1%. Also, the three cases tested demonstrated the sensitivity of the building simulation to the different radiation datasets. These results are important for advancing the understanding of the impacts of using reanalysis datasets, which is becoming an increasingly common approach.

1. Introduction

The impact of solar resources directly influences the outcomes of building energy simulations (BES). However, measurements are frequently restricted to global radiation, with limited data on its components: direct and diffuse. While global radiation can be readily and cost-effectively measured, obtaining data on the more expensive measurements of direct and diffuse components is less common (Schlager et al., 2023). Henceforth, various models for decomposing direct and diffuse radiation have been developed since the 1960s (Liu et al., 1960). These models may rely on global radiation values, solar elevation, apparent solar time, air temperature, and cloudiness.

In recent years, reanalysis data has been employed to develop weather files for BES. Reanalysis datasets combine historical observations into global estimates using advanced modelling and data assimilation systems (ECMWF, 2024). The ERA5 dataset from the European Center for Medium-Range Weather Forecasts is among the extensively utilized reanalysis datasets.

Researchers have been analyzing the impact of different decomposition models on simulation outcomes. Zweifel and Zelenka (2007) assessed that improvements in radiation data modelling could significantly affect BES results in Switzerland. They found a 34% increase in cooling load values when comparing different datasets with different radiation decomposition models. However, these datasets also exhibited temperature modifications. Lupato et al. (2017) compared 33 different split algorithms with data measured over ten years in Trieste, Italy. In this case, the Perez model (Perez et al., 1992) performed significantly better than the other models. When considering simulation results, errors of up to 4% were found for cooling and heating loads for this model compared with the case considering the ground measurements.

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Pernigotto, G., Ballarini, I., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2025. Building simulation applications BSA 2024. bu,press.
https://doi.org/10.13124/9788860462022

Copper and Sproul (2013) compared various models to estimate both global irradiance and its direct and diffuse components using data collected in Australia. The authors also assessed the impact on BES results. This study suggests that bias and uncertainty in simulation results were minimal when global irradiance was measured, and only diffuse and direct irradiance were estimated. However, when global irradiance was unknown, bias and uncertainty levels notably increased.

Some studies have also examined how ERA5 data compare to measurements. Sianturi et al. (2019) evaluated the ERA5, and MERRA-2 datasets compared to ground observations in Indonesia. The authors reported that ERA5 tends to overestimate monthly solar radiation. Additionally, they noticed that both reanalysis models tend to overestimate values, especially on cloudy days. Cao et al. (2022) conducted a similar study in China, considering ERA5 and MERRA-2, along with two satellite-derived datasets, compared to 98 solar radiation measurement stations. Their findings revealed that the ERA5 data overestimated the direct normal component. Additionally, they observed that daily global radiation data exhibited greater accuracy than direct, diffuse, and hourly global solar radiation products.

In the Brazilian context, a widely used data source for solar resources is the Brazilian Solar Atlas (Pereira et al., 2017). The atlas has a horizontal spatial resolution of 0.09° x 0.09° (approximately 10 x 10 km at the satellite's zenith axis). The Solar Atlas was developed based on the satellite radiation model BRASIL-SR (Martins et al., 2007), derived from the GKSS model (Stuhlmann et al., 1990) and adapted to the typical Brazilian climate and seasonal atmospheric conditions. As a validation step for the development of the atlas, a statistical comparison was made with 503 surface meteorological stations from INMET (National Institute of Meteorology) and INPE (Brazilian Institute for Space Research), considering the period from 2005 to 2015.

This study aims to compare different radiation decomposition models for estimating direct normal radiation (DNI) with data from the ERA5 and evaluate the impact of these different datasets on BES results.

2. Method

The method of this study consists of the development and analysis of different weather files, considering three DNI estimation models compared to radiation data obtained from ERA5 reanalysis. Afterwards, these files were used as inputs for the BES of a reference building, and the resulting cooling load and internal operative temperature values obtained were compared among themselves.

In this way, we structured the method section into two primary components: (1) the development and analysis of the weather files and (2) the Building Energy Simulation method by itself.

2.1 Development and Analysis of the Weather Files

We employed the TMYx.2007-2021 weather files developed by Dru Crawley and Linda Lawrie as a basis for comparison (Climate OneBuilding, 2024). The solar resource in these files is derived from ERA5 reanalysis data; thus, global horizontal (GHI), direct normal, and horizontal diffuse radiation (DIF) all come from the same source.

We employed three distinct DNI estimation models, using the GHI data from these weather files for calculation. The DNI estimation models utilized in this study were Erbs (Erbs et al., 1982), DISC (Maxwell, 1987), and DIRINT (Perez et al., 1992). The Erbs model estimates diffuse horizontal radiation (DIF) from GHI using an empirical relationship between DIF and the ratio of GHI to extraterrestrial irradiation. The DISC algorithm derives DNI from GHI through empirical relationships between global and direct clearness indices, accounting for absolute (pressure-corrected) airmass. The DIRINT model enhances the DISC model by incorporating time-series GHI data and dew point temperature information. To implement these models, we used the pvlib python v0.10.3 library (Anderson et al., 2023). It is important to note that various estimation models are available, such as the Boland–Ridley–Laurent (BRL) model used in certain radiation studies in Brazil (Lemos et al., 2017). However, for this study, we chose to limit the comparison to these three traditional models, with future research aiming to expand the comparisons to include additional models and ground-based data.

Using the estimates of DNI and DIF fractions obtained from each method employed, we modified the TMYx.2007-2021 EPW files for the following Brazilian locations: São Paulo (latitude: 23.56° S), Salvador (latitude: 12.97° S), and Brasília (latitude: 15.79° S). Table 1 summarizes the sites, including their Köppen-Geiger climate classification (with the corresponding ASHRAE 169/2006 climate zone in parentheses).

Table 1 – Characterization of the considered locations

Location	Lat., Long.	Altitude (m)	Climate
Brasília	-15.8°, -47.9°	1060	Aw (2A)
Salvador	-12.9°, -38.3°	19	Af (0A)
São Paulo	-23.4°, -46.4°	749	Cfa (2A)

Lastly, the obtained results were calculated for monthly and annual resolutions and compared to the values provided by the Brazilian Solar Atlas (Pereira et al., 2017), which presents monthly weather data for DNI, DIF and GHI. We used the root-mean-square error (RMSE) indicator for this comparison, considering the Brazilian Solar Atlas monthly data as the reference.

2.2 Building Energy Simulation

For the BES part, we used a single-family reference building based on the Brazilian building characterization conducted by Triana et al. (2015). The model represents an affordable one-story house with two bedrooms, a living room integrated with the kitchen, and one bathroom, totaling approximately 40 m^2. The model was simulated using EnergyPlus (version 23.2) with the basic thermal properties for walls, ceilings, floors, and windows in accordance with the reference values of the Brazilian Residential Building Performance Standard (NBR 15575:2021) (ABNT, 2021). Table 2 presents these thermal properties for each type of building component.

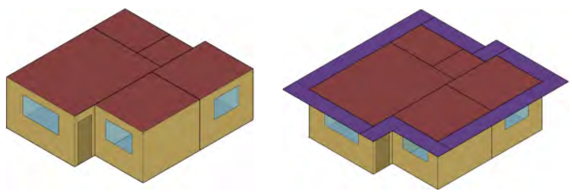
The transparent elements have a solar heat gain coefficient of 0.87 and a thermal transmittance of 5.70 W/(m^2·K). The GroundDomain:Slab object was employed to simulate the ground contact with the floor properties according to the NBR 15575 standard. This floor properties compare to a 10 cm concrete slab featuring a thermal conductivity of 1.75 W/(m·K), a specific heat of 1000 J/(kg·K), a solar absorptance of 0.65, and a 2,200 kg/m^3 density.

Table 2 – Thermal properties of the building components

Component	U* (W/m^2K)	TC** (kJ/m^2K)	Solar absorptance (-)
Internal walls	3.37	220	-
External walls	4.84	220	0.58
Roof	2.42	220	0.65

*U = Thermal Transmittance (U-Factor with Film from EnergyPlus' outputs)
**TC = Thermal capacity

To better understand the effects of decomposition models on simulation results, we considered three cases for the selected typology: (1) case 0 - reference, (2) case 1 - low absorptance, and (3) case 2 - shading. Case 0 considers absorptance values required by NBR15575 for walls (0.58) and roof (0.65). Case 1 modifies these values to 0.30 for both walls and roof. Finally, case 2 adds a 0.80-meter overhang around the perimeter of the building. Fig. 1 shows the model of the considered cases.



(a) Cases 0 (reference) and 1 (low solar absorptance)

(b) Case 2 (0.8m overhang)

Fig. 1 – Building energy model of the considered cases

The simulation was carried out in two stages. In the first scenario, the living room and bedrooms were conditioned, while in the second scenario, all rooms were naturally ventilated. For the conditioned scenario, the air-conditioning model was configured as an Ideal Loads system, with a heating setpoint of 21 °C and a cooling setpoint of 24 °C. The outputs included the heating and cooling thermal loads, measured in kWh. In the naturally ventilated scenario, the Air Flow Network system was employed, considering a slider window with a maximum opening factor of 0.45 operated according to the inside and outside temperatures. The windows are always opened when the space is occupied, and the indoor temperature is 19 °C or higher and exceeds the external temperature. The output consisted of the operative temperature for each room, which was then utilized to calculate the thermal autonomy (percentage of occupied hours within a specific temperature range). The method considers different maximum operative temperature limits based on the weather file of each location for thermal autonomy calculation and thermal load consideration, with thresholds set at 26 °C for São Paulo and Brasília and 28 °C for Salvador. To simplify the presentation of results, we will analyze the indicators of cooling thermal loads and inside maximum operative temperature in this work.

3. Results

We noticed a consistent trend in our results: the annual DNI values obtained from ERA5 were consistently higher than those from the Solar Atlas. At the same time, the other models showed lower values except for the Erbs model in São Paulo, as shown in Table 3. On the other hand, the DIF consistently shows lower values in ERA5 compared to the Solar Atlas. Meanwhile, the decomposition models consistently yielded higher values than those in the Atlas.

Table 3 – Annual DNI and DIF values (kWh/m² per day) for each location and model

Model	Brasília		Salvador		São Paulo	
	DNI	DIF	DNI	DIF	DNI	DIF
ERA5	**5.577**	*1.554*	**5.783**	*1.518*	**4.381**	*1.640*
DIRINT	*3.954*	2.791	4.149	2.732	*2.765*	**2.772**
DISC	3.968	**2.831**	*3.947*	**2.935**	3.096	2.744
Ersb	4.301	2.424	4.189	2.573	3.926	2.340
Solar Atlas	4.895	2.088	4.666	2.099	3.657	2.002

* The highest values for each location are highlighted in red bold and the lowest in blue italic.

Fig. 2 summarizes each method's DIN and DIF monthly values for each city. Upon analyzing the distribution of monthly values for each location, we observe that the ERA5 values and decomposition models follow the trend of the Solar Atlas. All three locations show a reduction in diffuse values during the Southern Hemisphere winter. Regarding DNI, Brasília exhibits peak values between August and September, the dry season in the region, while Salvador shows higher values during the summer months (December to February), and São Paulo presents more constant values during the year. Overall, there is a tendency for higher DNI values considering ERA5 data in all cases except for Brasília from May to August. The Solar Atlas values exceeded those of other datasets, possibly due to variations during the measurement period, which did not coincide with the other values. For DIF, the ERA5 values are consistently lower across all periods and locations.

When assessing the RMSE results at the monthly resolution, the Erbs model consistently demonstrated the lowest values for both DNI and DIF across all studied locations, except for DIF in São Paulo, where ERA5 exhibited the smallest RMSE value (Table 4). Notably, for DNI, ERA5 yielded the highest RMSE values in Brasília (32.79 kWh/m²) and Salvador (36.07 kWh/m²), while in São Paulo, it ranked as the second highest, falling below the DISC model (26.06 kWh/m²).

Table 4 – RMSE of the monthly DNI and DIF values (kWh/m² per month) for each location and model

Model	Brasília		Salvador		São Paulo	
	DNI	DIF	DNI	DIF	DNI	DIF
ERA5	**32.79**	16.65	**36.07**	17.79	25.86	*11.71*
DIRINT	31.30	23.58	19.42	19.47	25.80	20.71
DISC	30.61	**24.85**	24.81	**25.85**	**26.06**	**21.83**
Ersb	*24.27*	*11.51*	*17.96*	*14.64*	*20.03*	12.29

* The highest values for each location are highlighted in red bold and the lowest in blue italic.

Simulation results revealed variations in cooling loads, with those derived from ERA5 data showing the lowest values, while the DISC model exhibited the highest values for all locations (Table 5).

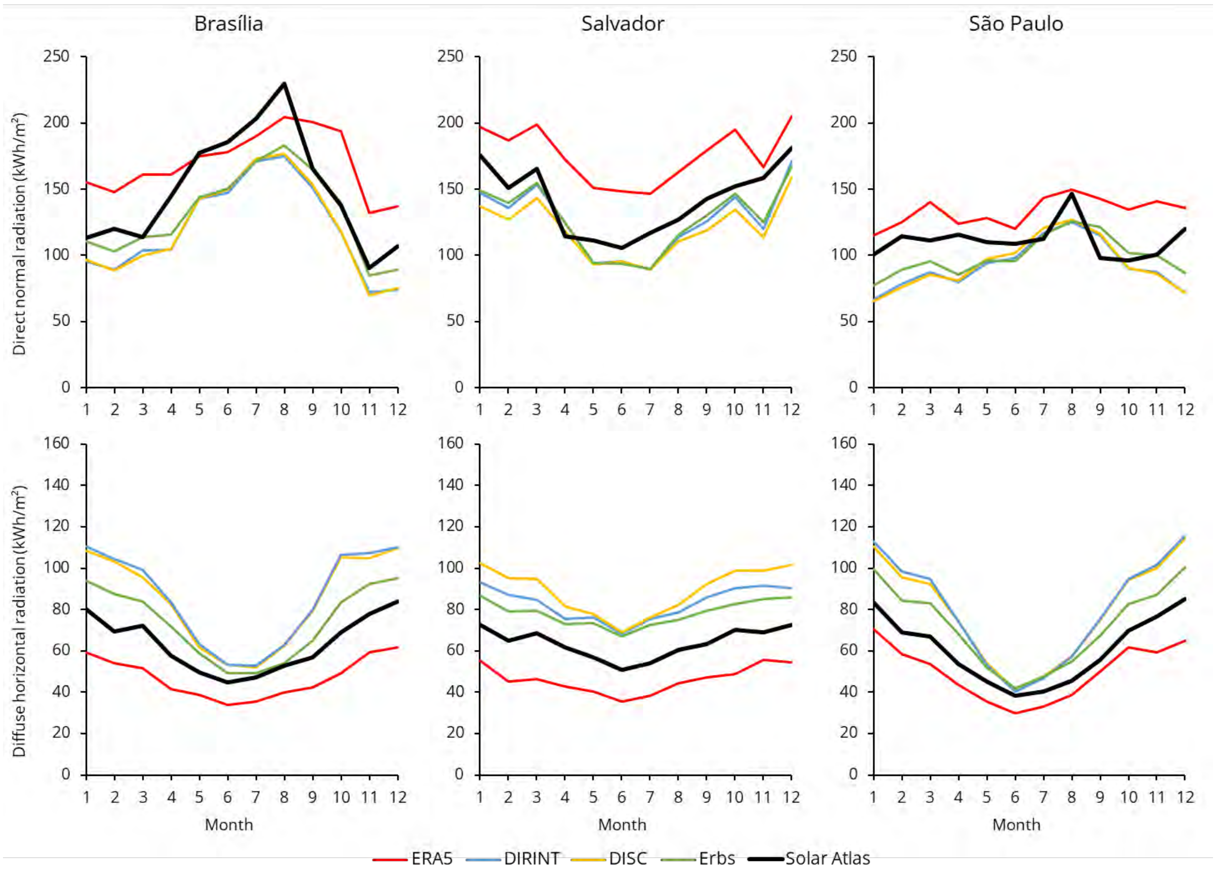


Fig. 2 – Monthly irradiation (DNI and DIF) values for each location

Table 5 – Cooling load values (kWh) with the percentage difference from ERA5 case in parentheses

Location	Model	Case 0 (ref.)	Case 1 (low abs.)	Case 2 (overhang)
Brasília	ERA5	4,825 (-)	1,589 (-)	3,683 (-)
	DIRINT	5,201 (8%)	1,768 (11%)	4,025 (9%)
	DISC	5,240 (9%)	1,784 (12%)	4,062 (10%)
	Ersb	5,054 (5%)	1,688 (6%)	3,889 (6%)
Salvador	ERA5	10,327 (-)	5,445 (-)	8,867 (-)
	DIRINT	10,691 (4%)	5,694 (5%)	9,215 (4%)
	DISC	10,777 (4%)	5,769 (6%)	9,291 (5%)
	Ersb	10,558 (2%)	5,616 (3%)	9,102 (3%)
São Paulo	ERA5	2,630 (-)	804 (-)	1,908 (-)
	DIRINT	2,845 (8%)	904 (12%)	2,100 (10%)
	DISC	2,878 (9%)	914 (14%)	2,122 (11%)
	Ersb	2,749 (5%)	855 (6%)	2,017 (6%)

The largest relative differences in cooling load results occurred in case 1 (lower absorptance), reaching values of up to 14%. This case also exhibited the lowest absolute thermal load values. When comparing these results with those obtained using the Erbs model (which demonstrated the lowest RMSE values compared to the Solar Atlas), relative differences with ERA5 ranged from 5 to 6% for Brasília and São Paulo and from 2 to 3% for Salvador. This variation can be attributed to the greater influence of the temperature on cooling load estimation in Salvador due to its warmer climate.

Regarding maximum operative temperature, the results mirrored the trend observed in cooling thermal load values; however, differences remained within 1% compared to the ERA5 results. The Erbs model and ERA5 results were very close to each other (with differences below 0.1%), whereas the largest disparities were noted when compared to the DISC model (approximately 1.0%).

4. Conclusion

This work aimed to assess the impact of different radiation decomposition models and datasets on estimating DNI in BES results. Three decomposition models were compared to data obtained from ERA5 for DNI and DIF. As previously reported in the literature, our results also showed that when comparing ERA5 data with the Brazilian Solar Atlas data, there is a tendency to overestimate DNI values. Furthermore, we found that DIF values are notably underestimated compared to other decomposition models and monthly data from the Brazilian Solar Atlas.

The more traditional radiation decomposition models returned similar values, consistently lower than those from the Brazilian Solar Atlas. Compared to the Atlas, the Erbs model showed the lowest RMSE values for all locations and radiation components, except for DIF in São Paulo. Regarding simulation results, they exhibited differences of up to 14% higher cooling load values when compared to results using ERA5 data with the DISC model. However, maximum operative temperatures did not show such significant differences, with a maximum deviation of 1%. The influence of thermal properties on the sensitivity of building simulations to differences in DIN and DIF decomposition was also demonstrated, as illustrated by the three cases analyzed.

These results are important to advance the understanding of the impacts of using reanalysis model data, which is becoming an increasingly common alternative. Additionally, it highlights the importance of developing and validating estimation models to reduce the uncertainties inherent in building simulations.

Further comparisons with ground measured DNI and DIF data, as well as other estimation models, are necessary to enhance the analyses. Nevertheless, the study already indicates that when using ERA5 data directly, cooling loads tend to be underestimated compared to traditional radiation decomposition models. Furthermore, a limitation of the study is that the period of measured data for the development of the solar atlas differs from that considered for weather file generation.

Acknowledgement

This work has been supported by the following Brazilian research agencies: CAPES and CNPq. The authors would also like to thank Saint-Gobain Research Brasil for the financial resources applied to this research development.

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