22nd International Conference on Renewable Energies and Power Quality (ICREPQ'24)
Bilbao (Spain), 26th to 28th June 2024

ISBN: 978-84-09-60656-6

EVALUATION OF CONSTRUCTIVE PARAMETERS TO MINIMIZE THE EFFECTS OF SOLAR RADIATION IN HOUSEHOLDS WITH TROPICAL CLIMATE

J. Cárdenas[1], G. Osma[1] and J. Jaramillo[2]

[1] Department of Electrical Engineering
[2] Department of Mechanical Engineering
Universidad Industrial de Santander
Bucaramanga, Colombia

Abstract.

In tropical climates, the energy consumption of buildings is strongly influenced by solar radiation. However, more research needs to be done on how specific design parameters can mitigate the effects of solar radiation in tropical homes. This study uses simulations in EnergyPlus to evaluate how orientation, roof solar absorptance, overhang depth, glass type, and wall type affect energy consumption in a typical middle-income home in a tropical climate. The results highlight the benefits of adequate solar absorbance and correct orientation. Incorporating insulation into exterior walls does not offer significant improvements in the energy performance of the building.

Key words. Building energy simulation, Tropical climate, parametric analysis.

1. Introduction

The buildings have high energy consumption. Several studies have determined that solar radiation is a determining factor for the energy consumption of buildings [1], [2], [3]. Most of these studies have focused on non-residential buildings in climates other than tropical ones. On the other hand, only a few research studies have addressed the problem of solar radiation from the perspective of the design parameters of residential buildings. For this reason, this work seeks, through a parametric analysis, to identify which construction parameters influenced by solar radiation have a more significant impact on the energy consumption of a tropical home belonging to the middle-income category.

To develop this research, the authors initially adapted the energy model of a multifamily building in Bucaramanga (section 2. a). Then, they selected a series of construction variables that influence the mitigation of solar radiation (section 2. b). Subsequently, parametric simulations were carried out in the energy simulation tool DesignBuilder and the parametric simulation tool JEPlus to consider different ranges of variation. A correlation analysis of variables influencing energy consumption was also considered (section 2.C). Finally, the analysis of the results of the parametric simulations and the compilation of the study's main findings and conclusions are presented in sections 3 and 4, respectively.

The findings of this study can guide housing designers in warm tropical climates in improving their designs.

2. Methodology

For this research, the authors considered a four-phase methodology: adjustment of the energy model, definition of parameters, parametric simulations, and analysis of results. Figure 1 presents a summary of the applied method.

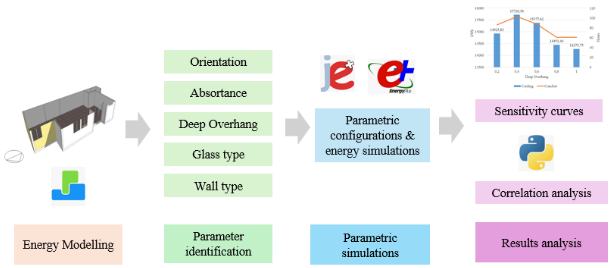

Figure 1. Study methodology.

A. *Energy Modelling*

The selected home is part of a middle-income multifamily building. It is located in the city of Bucaramanga in Colombia. The predominant climate of Bucaramanga is warm tropical. The building to which the home belongs is considered representative of the stock of buildings of its type.

The home's location corresponds to one of the ends of the top floor of the building to guarantee the greatest exposure to solar radiation in its enclosures. Some of the characteristics of the home are presented in Table 1.

Table 1. Housing characteristics.

Characteristic	Value
Area	56 m^2
Number of rooms	3
Number of people	4

Income Category	Medium
Lighting power density	2.6 W/m^2
Plug-in power density	12,8 W/m^2
Exterior walls	Reinforced concrete walls with mortar and plaster finish on both sides.
Roof	Solid concrete with asphalt finish. No reflective paint.
Glass type	4mm clear glass

The house has no artificial air conditioning system; it is naturally ventilated.

The energy model of the building was obtained in a previously carried out energy modelling process [4]. The model was received in the energy simulation tool DesignBuilder V6. The original model was simplified to the household level for this parametric analysis. The other homes and spaces of the building were excluded from the calculations that led to obtaining energy consumption.

The house was modelled as a single thermal zone because there are no artificial air conditioning units, they have similar uses, no temperature control and their interior spaces are thermally connected. The Figure 2 presents the virtual model of the building and the home under study.

Figure 2. Energy model of the home.

The authors decided to integrate a standard air conditioning system into the home model, according to the recommendations of Appendix G of ASHRAE 90.1 [5]. This facilitates quantifying the impact of the construction parameters affected by solar radiation.

B. *Identification of parameters*

The parameters object of this study were determined from a literature review that considered energy analysis studies of buildings in a tropical climate, as well as the expertise of experts from the local construction sector. The parameters identified the orientation of the main facade of the building, solar shading on exterior windows, roof solar absorptance, type of glass of the windows and type of exterior wall. Table 2 lists the identified parameters along with their variation ranges.

Table 2. Selected parameters and variation ranges.

Parameter	Variation range	
Orientation [Degrees with respect to north]	{45, 90, 135, 180, 225, 270, 315, 360}	
Roof solar absorptance [Adimensional]	{0.3, 0.5, 0.7, 0.9}	
Depth of sun protection overhang [Meters]	{0.2, 0.4, 0.6, 0.8, 1.0}	
Glass type	Double	Conductivity: 1.0 W/(m·K) SHGC: 0.6
	Floated	Conductivity: 0.9 W/(m·K) SHGC: 0.8
	Laminate	Conductivity: 0.8 W/(m·K) SHGC: 0.7
	LowE	Conductivity: 0.5 W/(m·K) SHGC: 0.2
Wall type	Conventional	Gypsum platering Concrete reinforced Mortar Plaster
	Wall insulated with expanded polystyrene.	Gypsum platering Plasterboard EPS Expanded Polystyrene Concrete reinforced Mortar Plaster
	Fiberglass insulated wall	Gypsum platering Plasterboard MW Glass Wool. Concrete reinforced Mortar Plaster

Regarding the orientation of the main facade of the building, the authors selected a wide range of variations that covered all possible orientations every 45°. In this way, the building's sensitivity analysis considers the effect of radiation on the entire envelope.

Some researchers have revealed the importance of the roof in the energy performance of buildings [6]. In the present study, the authors decided to consider roof solar absorptance. This parameter determines the amount of solar radiation that the roof absorbs about the total amount of solar radiation that falls on it. The roof solar absorptance depends on other parameters such as the colour and finish of the surface, the thickness and the thermal transmittance value.

Solar shading on exterior windows was studied through the depth of the overhang. The authors considered depths ranging from twenty centimeters to one meter.

Another parameter considered was the type of glass in exterior windows. To define the range of variation of this parameter, the authors considered the commercial supply of glass in some of the most relevant companies in the sector at the national level. In this way, four types of glass were established to be included in the analysis: double glass, float glass, laminated glass and Low-E glass. In particular, the variation in thermal conductivity and the Solar Heat Gain Coefficient – SHGC of each type of glass considered was considered.

Finally, the authors included the exterior walls in the analysis. The definition of the variation range considered the configuration of layers that make up the exterior wall. The case studies included conventional walls and two other configurations with thermal insulation.

C. *Parametric simulations*

Parametric simulations in this study used the EnergyPlus calculation engine. The parameters' configuration and range of variation were carried out through the JEPlus application [7].

Parameters such as orientation and solar absorbance were modelled only with the location of their respective search tags within the IDF of the home. Another, such as the depth of the exterior overhang, required the addition of new objects. At the same time, modelling the type of glass and the type of wall took into account the use of programming with EP Macro.

Table 3 presents the plan of simulations carried out in this research.

Table 3. Simulations plan.

Parameter	Number of simulations	Results of interest
Orientation	8	Cooling energy consumption. Annual hours of discomfort.
Thermal absorption of the roof	4	
Depth of sun protection overhang	5	
Glass type	4	
Wall type	3	
All parameters	100	

3. Parametric analysis

This section presents the analysis and discussion of the results of the parametric simulations.

The orientation variation results show lower consumption for the orientations of the actual case (0° or 360°). Under this guidance, cooling consumption is approximately 13978 kWh/year. The 90° orientation represents the highest energy consumption, approximately 15270 kWh/year. This is due to a greater incidence of solar radiation on the home's glazing. Regarding comfort, the best results occur under 180° and 225°. The home only presents 61 hours of discomfort per year in these cases. Figure 3 presents the results of the orientation variation.

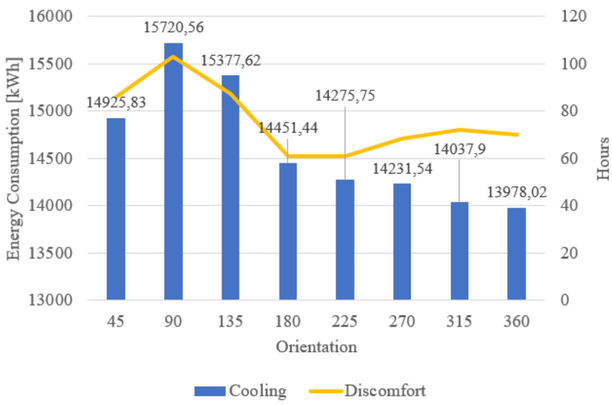

Figure 3. Orientation Variation.

Figure 4 presents the variation of the absorbance. The results show a decrease in cooling consumption as this parameter decreases. The lowest consumption achieved is approximately 14925 kWh/year. The lowest values of annual discomfort hours also occur for the lowest values of solar absorbance of the roof.

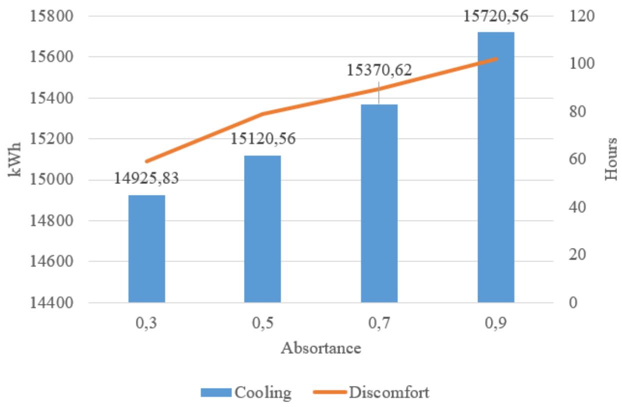

Figure 4. Variation of the solar absorbance of the roof.

The variation in the depth of the shading overhang on the exterior windows suggests lower consumption for longer overhang lengths. In this case, a minimum cooling consumption of approximately 14275 kWh/year is achieved. The hours of discomfort present similar behaviour. The details of the previous results are shown in Figure 5.

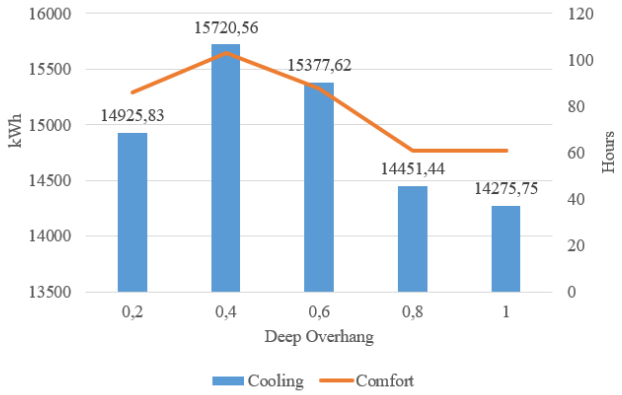

Figure 5. Variation of the depth of the overhang.

The examination of glass type variation confirms, as anticipated, that LowE glass, distinguished by superior conductivity and SHGC traits, stands out as the most energy-efficient choice, resulting in fewer hours of discomfort. Conversely, the alternative glass options demonstrate marginal energy savings. Detailed results of these simulations are depicted in Figure 6.

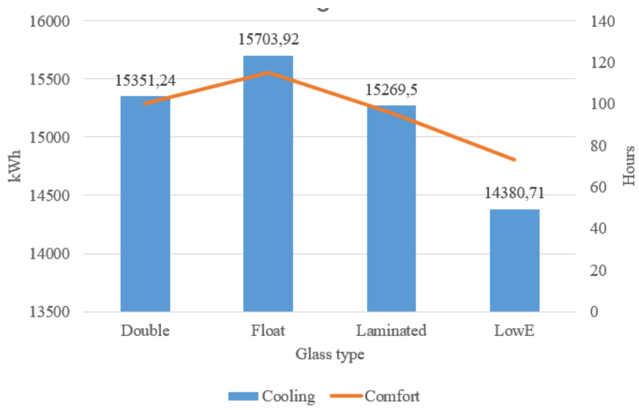

Figure 6. Variation in glass type.

The wall type variation shown in Figure 7 shows a reduction in cooling consumption for walls with insulation systems. However, the consumption reduction is less than 1% compared to the base case.

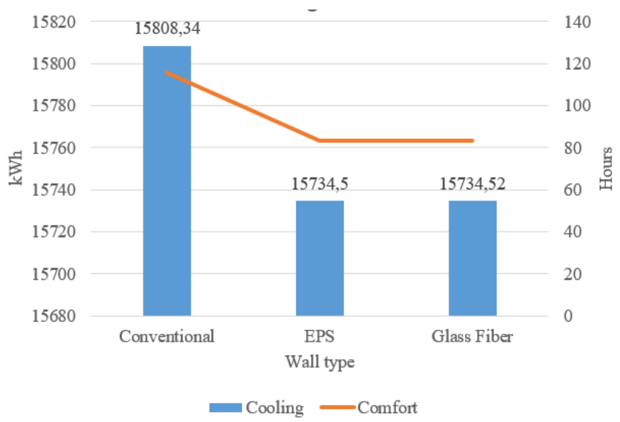

Figure 7. Variation of the type of Wall.

The authors also carried out an analysis considering the variation of all parameters in the simulation. One hundred uniformly distributed simulations were run using the Latin Hypercube Statistical Sampling (LHS) method. According to the results, achieving a minimum cooling consumption of 5982.2 kWh/year under an orientation of 270°, absorptivity of 0.3, depth of the overhang of 0.8 cm, LowE glass and walls with expanded polystyrene insulation is possible.

Finally, a variable correlation analysis reveals that the solar absorbance of the roof is the variable with the most significant influence on cooling energy consumption. This variable presents a correlation with energy consumption of 0.96. Figure 8 presents the results of this last analysis.

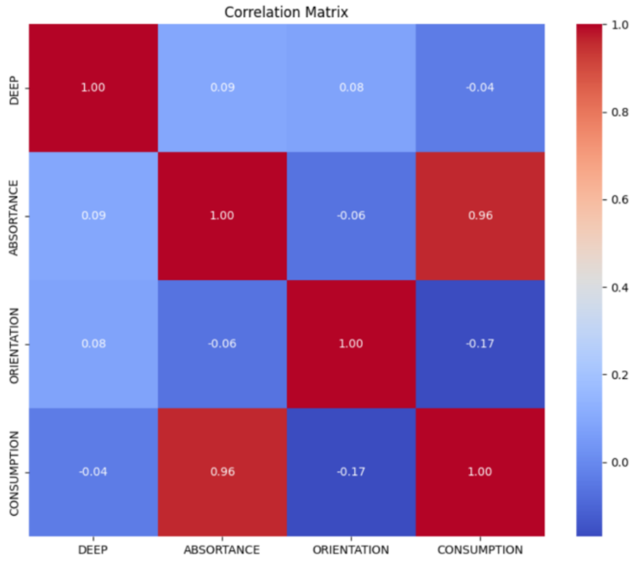

Figure 8. Correlation analysis of parameters with cooling energy consumption.

4. Conclusions

The results of this study highlight the importance of parameters such as the orientation and solar absorbance of the roof on the energy consumption of a home in a tropical climate. This last parameter presents a correlation of 0.96, much higher than other parameters.

Unlike other studies carried out in temperate climates, the composition of the exterior wall has little impact on a home's energy performance in tropical climates. Although choosing a LowE type glass can offer savings close to 10% in cooling consumption, there may be other economical options to implement in the type of housing studied.

The JEPlus application represents a versatile tool that is very useful for carrying out parametric analyses with energy simulation of buildings.

The results obtained in this research can be considered by the local regulatory entity, designers or other tropical climate researchers seeking to improve the energy efficiency of residential buildings.

Acknowledgement

The authors wish to thank the Vice-Rectorate for Research and Extension (Vicerrectoría de Investigación y Extensión) from the Universidad Industrial de Santander (Project 3945).

References

[1] A. Verma, V. Gupta, K. Nihar, A. Jana, R. K. Jain, and C. Deb, “Tropical climates and the interplay between IEQ and energy consumption in buildings: A review,” Building and Environment, vol. 242, no. June, 2023, doi: 10.1016/j.buildenv.2023.110551.
[2] J. Cárdenas-Rangel, G. Osma-Pinto, and J. Jaramillo-Ibarra, “Energy characterization of residential and office

buildings in a tropical location," Heliyon, vol. 9, no. 5, 2023, doi: 10.1016/j.heliyon.2023.e16048.
[3] A. Kamal et al., "Detailed profiling of high-rise building energy consumption in extremely hot and humid climate," Cleaner Energy Systems, vol. 4, no. February, p. 100060, 2023, doi: 10.1016/j.cles.2023.100060.
[4] J. Cárdenas-Rangel, G. Osma-Pinto, and J. Jaramillo-Ibarra, "Energy characterization of residential and office buildings in a tropical location," Heliyon, vol. 9, no. 5, 2023, doi: 10.1016/j.heliyon.2023.e16048.
[5] I. E. S. Standard, "Energy standard for buildings except low-rise residential buildings," ASHRAE Standard, vol. 2019, no. 90.1-2013 (I-P), pp. 404–636, 2013.
[6] J. Yu, W. S. Chang, and Y. Dong, "Building Energy Prediction Models and Related Uncertainties: A Review," Buildings, vol. 12, no. 8. MDPI, Aug. 01, 2022. doi: 10.3390/buildings12081284.
[7] I. Korolija, L. Marjanovic-Halburd, Y. Zhang, and V. I. Hanby, "UK office buildings archetypal model as methodological approach in development of regression models for predicting building energy consumption from heating and cooling demands," Energy and Buildings, vol. 60, pp. 152–162, 2013, doi: 10.1016/j.enbuild.2012.12.032.