THERMAL-ENERGY SIMULATION OF SHAPED PAVILION BUILDING IN BRASILIA: THE ROLE OF ENVELOPE IN THERMAL COMFORT

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ABSTRACT

The correct choice of building components that are appropriate to the climate context is fundamental to reduce the energy consumption demand of a building. Characteristics such as width, capacity and thermal transmittance of walls and roofs of the building, can significantly change the internal conditions of comfort and consequently the demand for cooling and mechanical heating. In this context, this article aims to evaluate the influence of types of roofs and walls with different thermal properties in the thermal-energy performance in a building shaped like a horizontal rectangular block (pavilion shaped building). This shape pattern is very common in institutional buildings of Brasilia as it is a characteristic of modern architecture. The building chosen as a model for analysis was the Headquarters of the Teaching Staff Association of the University of Brasilia (ADUnB), in Brasilia, Brazil. The building contains an auditorium with a foyer, a multipurpose room and lavatories. The building model was simulated in DesignBuilder version v4.7.0.027 software. Six scenarios were evaluated comparing two types of roof (thermoacoustic tile and green roof) and three types of wall (concrete, ceramic block masonry and a composition of plasterboard, mineral fibre/ wool and gypsum plasterboard). In order to conduct the analysis, data from the energy consumption of the building have been raised and the data of the executive project relating to envelope components were considered. From the results obtained, it was possible to identify the types of roofs and walls that contributed most to the reduction of energy consumption of the building within the climate context of Brasilia (tropical savanna) and analyzed architectural shape. It was also possible to observe the influence of roof and walls in thermal-energy performance in a pavilion shaped building, demonstrating the materials that most influence its thermal comfort. For this climate context, solutions and components with higher thermal mass showed superior results, even in buildings without openings.

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KEYWORDS
Thermal-energy simulation, Thermal comfort, Envelope, Pavilion shaped building, Brasilia

INTRODUCTION

The increase in energy consumption in the world over the years is notorious and the buildings represent a significant portion of this. The need to detain this growing energy demand stimulated the establishment of strategies both to energy production and reducing energy consumption in several countries. The International Energy Agency (IEA 2015) data show that from 1971 to 2014 world energy consumption increased 92%. In Brazil, according to the Brazilian Energy Balance (Brazil 2015), in the year 2014 the final electricity consumption had an increase of 2.9% compared with 2013, that corresponded to a total electricity consumption of 45.655 (10^3. TOE). From this amount 24,9% corresponded to the residential sector; 17,1% to the commercial sector; and 8% to the public sector (Brazil 2015, p 34). Therefore, these sectors represented 50% of electricity consumption in the country.

In this context of increased energy consumption, the Brazilian government stipulated in the National Energy Efficiency Plan (Brazil 2011) the goal of 10% reduction in final energy consumption in 2030, having as a priority the establishment of energy conservation mechanism and management of energy use, in addition to improving technologies efficiency. It also emphasized the importance of usage in construction processes of passive solutions to promote user´s comfort and reduce the need to use artificial mechanisms for air conditioning and lighting of the building.

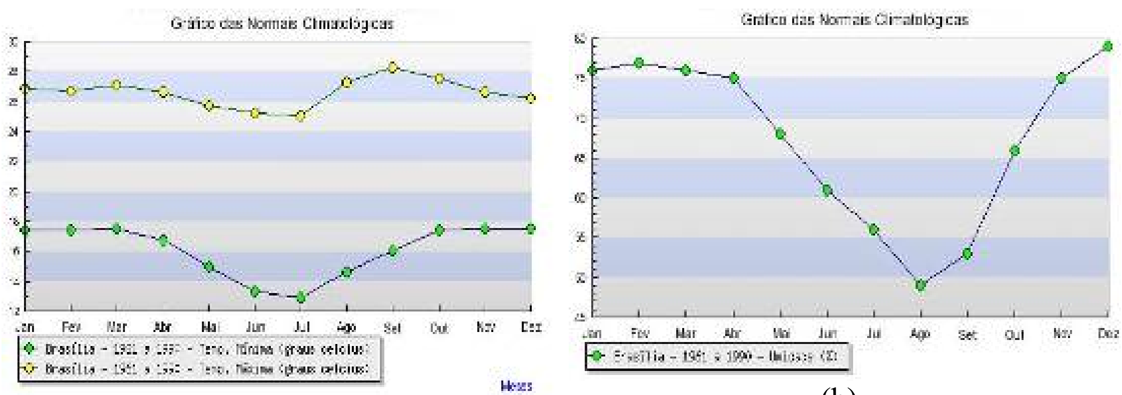
The building envelope directly influences the environmental comfort and energy consumption. It happens because "the building envelope acts as a filter between the interior and the exterior, and it is a regulator of energy flow. An accurate assessment of envelope thermal performance will aid optimal sizing of systems for comfort and efficiency" (Srinivasan et al. 2011, p 358). "It has been long understood that thermally massive building elements reduces the instantaneous heat transmission under transient conditions and that this in turn can lead to reduced overall energy consumption for heating and cooling a building." (Williamson 2011, p 1655). Thus, the correct choice of the construction components of the envelope appropriate to the climate context is fundamental to producing an architecture that is energetically efficient and comfortable to the building user.

In the case of Brasilia, Brazil, the prismatic shape is common in institutional buildings, which is a characteristic of its modern architecture. However, few studies were made relating the influence of constructive elements in this envelope type and the climatic context. Therefore, this study intends to evaluate the influence of types of roofs and walls with different thermal properties in thermal-energy performance in a pavilion-type building in Brasilia.

BACKGROUND

The climate in Brasilia is characterized by the tropical savanna type. The brazilian capital has two distinct seasons: the dry winter and the rainy summer. During the year, it can present cold weather at night and hot weather in the afternoon (Ferreira et al. 2014), which causes daily wide temperature ranges. According to weather data provided by INMET (2016), from 1960 to 1991 in Brasilia, the highest temperatures occurred between August and September, while the lowest occurred between May and July. The relative humidity presented lower rates between July and August (Figure 1).

The procedures for thermal conditioning according to the climate are described in brazilian technical standard NBR 15220 - Thermal performance in buildings (ABNT 2005), which classifies Brazil in eight bioclimatic zones. According to NBR 15220 (ABNT 2005), Brasilia is classified under Bioclimatic Zone #4 (ZB4, in portuguese), that recommends the shading of the windows; medium-sized windows (between 15% and 25% of aperture in relation to floor area); heavy external walls ($U \leqslant 2{,}2$ W/m^2.K; $\phi \geqslant 6{,}5$ h; $FS \leqslant 3{,}5\%$); and light insulated roofs ($U \leqslant 2{,}0$ W/m^2.K; $\phi \geqslant 3{,}3$ h; $FS \leqslant 6{,}5\%$). Moreover, the recommended strategies to passive thermal conditioning in winter are solar heating of the envelope and internal thermal inertia, whereas in summer the recommendations are evaporative cooling, thermal mass and passive ventilation (ABNT 2005).



(a) (b)

***Figure 1**. (a) Average minima and maxima temperatures and (b) Brasilia´s relative humidity throughout the year. (INMET 2016)*

CASE STUDY

The case study is a building located inside the Campus of the University of Brasilia, in the north wing of the Pilot Project of Brasilia, near Lake Paranoa. (Figure 2). The building selected for the thermal-energetic simulation was the headquarters of the Teaching Staff Association of the University of Brasilia (ADUnB in portuguese), which was designed by the brazilian architect Raimundo Nonato Veloso Filho and was constructed in 2016 (Figure 3).

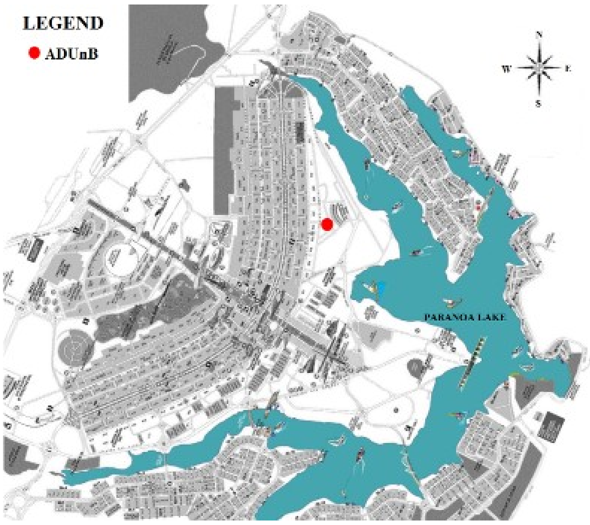


Figure 2. Localization of building of the ADUnB in the Pilot Project of Brasilia.

The building of ADUnB has a total rough area of 1412,65 m² and it's composed by an auditorium (capacity of 555 seats and total area of 533,78 m²) with a foyer, a multipurpose room and lavatories (Figure 3). Nearby, there is a building composed by a restaurant, bathrooms and administrative rooms. Its construction predates the building of ADUnB and also is characterized by its pavilion shape.

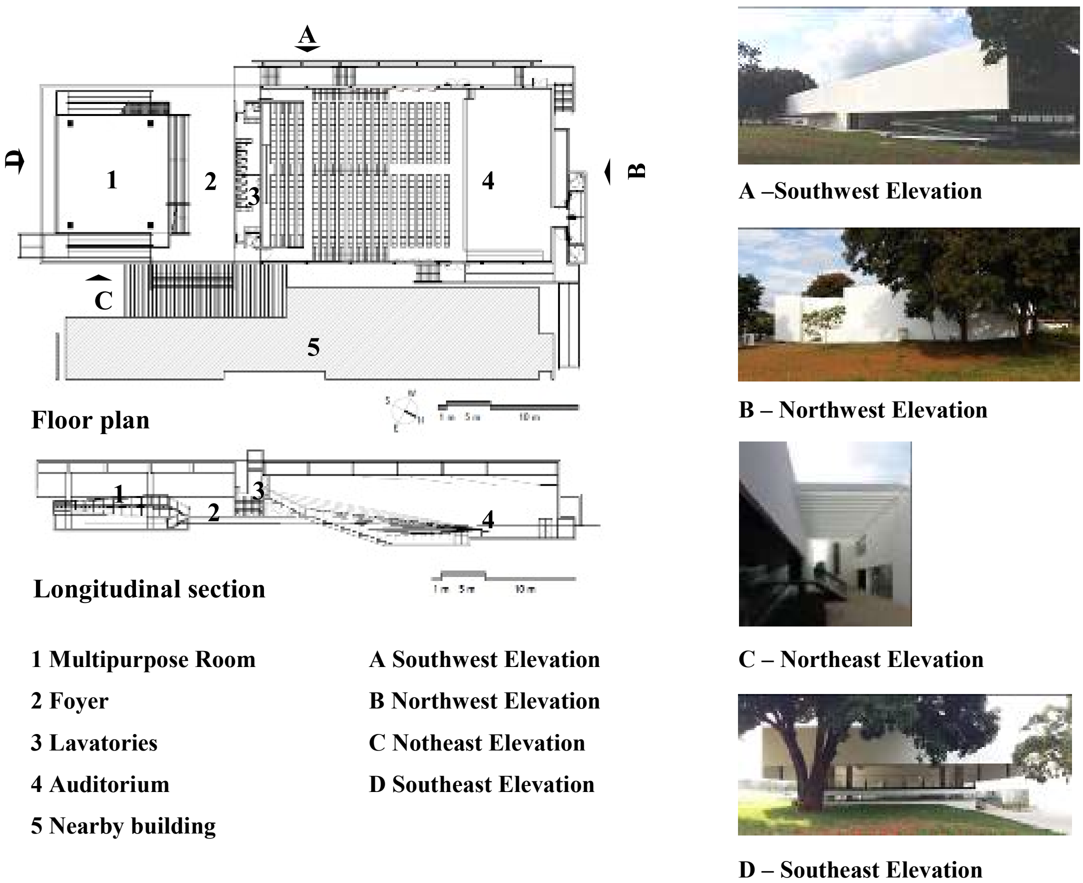


Figure 3. Plan, section and elevations of building of the ADUnB

SIMULATION METHOD

Thermal-energy simulation was conducted using the popular building energy simulation software DesignBuilder, in version 4.7.0.027. It analyzes energy consumption and project performance.

The simulation in the building intended to evaluate the environment of the auditorium, which is 5.75 m high and does not have openings for ventilation. The volume of lavatories (near the auditorium) and the nearby building (5.75 m high) were included in the analysis, however, the foyer and the multipurpose room were not included for being open spaces.

The parameter used in the model configuration of the thermal loads is presented in Table 1. Been considered in the model configuration the northern location of 235° and simulation weather data of BRA_BRASILIA_IWEC.

Table 1. *Parameter of use, activity, lighting, cooling system and equipament used in the model configuration*

Parameters of use and activity:	*Parameters of lighting:*	*Parameters of cooling system:*	*Parameters of equipament:*
Activity: Auditoria Occupied floor area (m²): 701,3 Occupied Volume (m3): 4032, 3 Density (people/ m²):0,3412 Metabolic Activitcy: Bedroon, factor 0,9 (considerate men, women and childreen) Clothing (clo) winter: 1,0 Clothing (clo) summer: 0,5	General lighting normalised power density (W/m²-100 lux): 5 Luminaire type: suspended Radiante fraction: 0,42 Visible fraction: 0,18	Type fan coil unit (4-pipe), air cooled chiller Fuel electricity fron grid Cop: 1,80 Outside air definition method: min fresh air	Equipament (W/m²): 1,78 Radiante fraction: 0,2

For thermal energy performance evaluation of the envelope six scenarios were simulated and two types of roofs and three types of walls were analyzed, as shown in Figure 4. The characteristics of these building components, as well as their thermal resistance and thermal transmittance are shown in the Table 2. The thermal properties of the building materials were calculated using the same software (version 4.7.0.027 of the DesignBuilder).

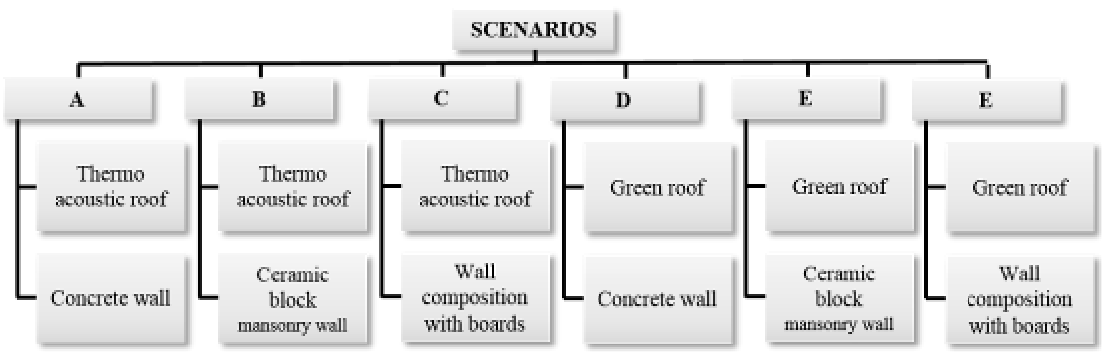


Figure 4*. Simulated scenarios to evaluate thermal-energy performance*

Table 2. Characteristics and thermal properties of the simulated building components

Building component	*Building component layers*	*Thermal resistance – R (m².K)/W*	*Thermal transmittance - U (W/m².K)*
Green roof 0,50 m	Cast concrete 0,10 + cultivated peat soil 366% D.W. Moisture 0,41 m + vegetation	1,048	0,954
Thermoacoustic tile 0,07 m	Aluminium 0,0005 m + Polyuretane 0,0615 m + Aluminium 0,0005 m	0,388	2,58
Concrete wall 0,30 m	Cast concrete 0,30 m	0,435	2,296
Ceramic block masonry wall 0,19 m	Cement/plaster/mortar- cement plaster 0,025 m + brick aerated 0,09 m+ Cement/plaster/mortar - cement plaster 0,025 m	0,539	1,854
Wall composition with boards 0,11 m	Plasterboard 0,01 m + mineral fibre/ wool 0,09 m+ gypsum plasterboard 0,0125 m	2,628	0,38

RESULTS AND DISCUSSION

Monthly and annual energy consumption of the six analyzed scenarios are presented on Figure 5. It is possible to observe that in the case using concrete walls and green roof (D) presented the lowest annual energy consumption of 56.48 kWh/m². On the other hand, in the case using a wall composition with boards and thermo-acoustic roof (C) presented the highest annual energy consumption of 77,89 kWh/m². The difference between these two results was 21,41 kWh/m².

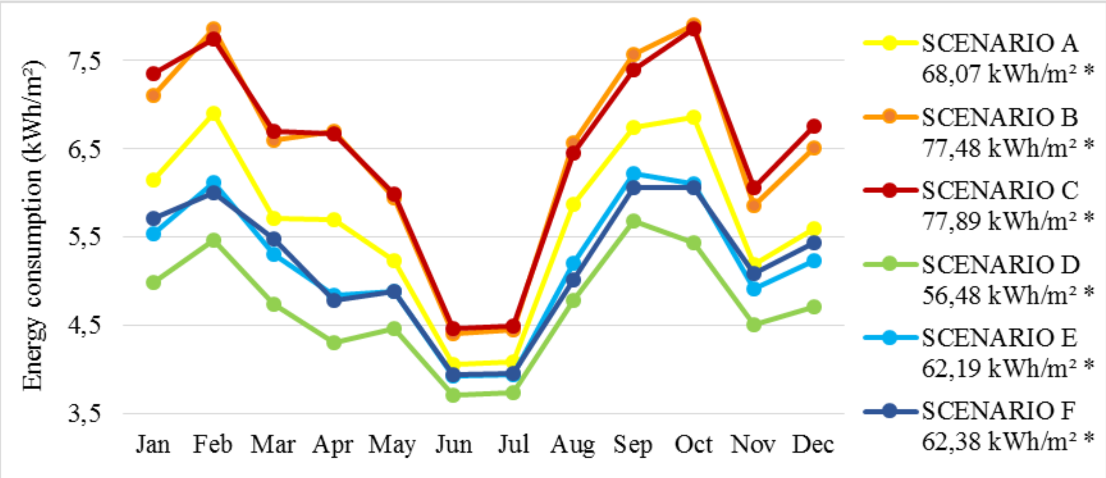


***Figure 5**. Monthly energy consumption in kWh / m² by scenario. * Total annual consumption*

Regarding the monthly energy consumption to scenarios with green roof (D, E, F), it is perceptible the lower energy consumption in D scenario, with concrete wall; whereas in scenarios with thermo-acoustic roofing (A, B, C), the A scenario with concrete wall presented lower energy consumption. Therefore, it is noticeable that the concrete wall presented lower energy consumption towards the other types of wall, either in scenarios with green roof or with thermo-acoustic roofing. Both ceramic block masonry walls and wall composition with boards presented similar energy consumption values throughout the year for both types of roof.

Thermo-acoustic roofing scenarios (A, B, C) showed higher energy consumption than green roof scenarios (D, E, F), reaching 7.91 kWh/m² as a maximum value in October to B scenario and 3.70 kWh/m² as a minimum value in June to D scenario. There is a major influence of the roof in thermal energy performance of the envelope in the analyzed building type in relation to walls in the climate context of Brasilia.

Finally, the highest energy consumption rates in all scenarios are those regarding the months of September, October, January and February. The highest energy consumption rates in these periods coincide with the rise of external temperatures, which daily averages vary from 22,8 to 22,5°C, nearly 3,8ºC higher than the temperatures registered in cooler days, as shown in Figure 6.

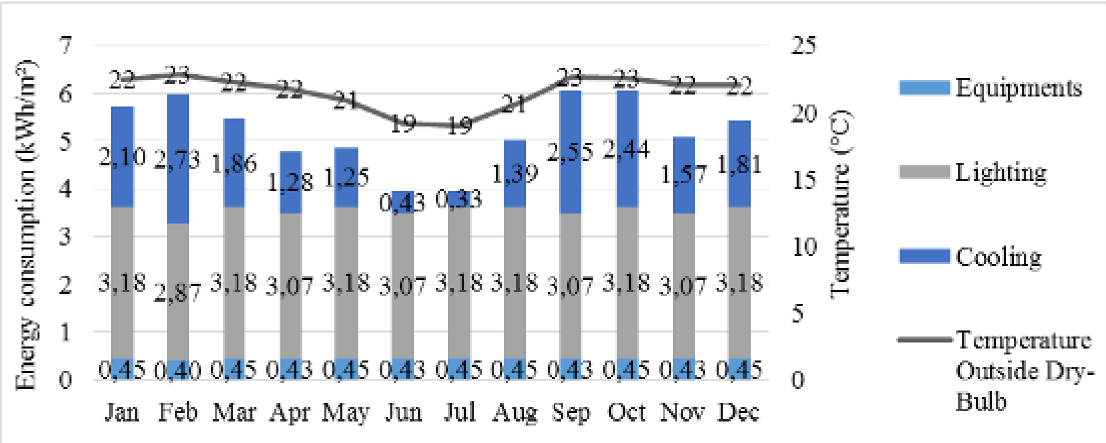


***Figure 6**. Distribution of monthly energy consumption of the D scenario and temperature outside dry-bulb*

The little variation in energy consumption from lighting and equipment is related to the specific characteristics of the routine of occupation, volumetry and envelope composed only by opaque components. Cooling presents much energy consumption variation, along with external temperaure variation throughout the year.

CONCLUSION AND IMPLICATIONS

To this climate context, even in buildings without openings, that need constant air conditioning and usage of solutions with large thermal inertia, components with higher thermal mass presented superior results. It is important to say that in this region, with a hot dry weather and wide temperature ranges, the effect of thermal inertia delays the minima and maxima temperatures, which mainly decreases the need of spending energy in cooling spaces in the warmest hours. In this case, concrete walls and green roof compose the most suitable scenario.

In the analyzed typology, the major influence of the roof rather than the walls is related to the wider area exposed to the sun, in hours of high rates of solar radiation, in other words, when it is positioned perpendicularly. In this situation, the roof with lower thermal transmittance and higher thermal mass presented the best thermal and energetic performance.

It is necessary to say that this study analyzed strictly a confined isolated area, with no possible natural ventilation, with high internal ceiling height and with specific use. In this case, the energy consumption for lighting and equipment presents the same independently of scenario analyzed. On the other hand presents significant variations regarding the energy consumption for cooling between the scenarios and even between different periods of the year in the same scenario.

The evaluation of spaces with natural ventilation, lower ceiling heights and other components and materials could be possibilities to future works.

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