THERMAL COMFORT ANALYSIS BASED ON COMPUTER SIMULATIONS OF BUILDING ENVELOPE IN AN AUDITORIUM: A CASE STUDY IN BRASILIA – BRAZIL

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ABSTRACT

This article focuses on the architectural design of Auditorium Dois Candangos, with the capacity for 120 users, which was built in 1962 by the architect Alcides da Rocha Miranda. This building is important due to its history and its modern architecture style. In 2015 it was reported by the users that this building had problems regarding thermal comfort and obsolete electric equipment. According to International Energy Agency and its guidelines towards a more efficient building envelope in hot climates, this study aimed at making thermal simulations in order to quantify the percentage of discomfort hours in this auditorium. To reach this goal, the software Design Builder was used to evaluate this historical auditorium with its original design and with modifications applying different insulated roofs and walls with distinct thermal and physical properties. Moreover, the lighting system and ventilations were also considered during simulations. These materials are being chosen according to the recommendations for the climate of Brasilia, Brazil. Solar radiation, wind, humidity and sky conditions are being taken into account. In conclusion, thermal simulations helped to determine the correct choice of the roof materials and its relation to the thermal comfort of this space. Therefore, it will be possible to create design guidelines for the optimization of the thermal comfort in such an important historical building situated in the University of Brasilia.

KEYWORDS

Computer simulation, auditorium, thermal comfort, roof, neutral adaptive temperature

INTRODUCTION

The Auditorium Dois Candangos is part of the Faculty of Education, first erected building of the University of Brasilia – UnB. Projected by the modernist architect Alcides da Rocha Miranda, the space was inaugurated in 1962 and composes the group of Modern Architecture of Brasilia. Since 1987 the city is considered Cultural Heritage of Humanity by UNESCO. In 2015, Oscar Niemeyer Planning Center (CEPLAN – Centro de Planejamento Oscar Niemeyer) – local Architecture planning center of the campus, pointed out the necessity of renovation of the auditorium due to thermal

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discomfort and its obsolete electric equipment. The Auditorium was never renovated and is not currently in use.

According to Puhl (2015, p.15), Alcides Miranda believed that "historical sites should be used in order to be alive and preserved" and that "adaptations of historical cities and buildings should be faced as necessary, regarding user demands". Tiwari, Lugani, Singh (1993) proved in a case study in a cinema hall at Chopansai Lane, in India, that passive strategies are more effective in a hot dry climate when evaporative cooling and natural ventilation are used.

In this regard, the main purpose of this paper is to evaluate building envelope materials in order to obtain a better thermal comfort in such an important historical building located in the climatic conditions of Brasilia. The specific purpose is to indicate the more adequate materials towards a better thermal performance of the indoor space.

CLIMATIC CONDITIONS OF BRASILIA AND OVERALL RECOMMENDATIONS

According to data by the National Institute of Meteorology (INMET 2015), the climate of Brasilia presents to distinct seasons:

1) Hot and humid season: rainy summer from October to April
2) Hot and dry season: dry winter from May to September.

The daily temperature variations occur as a result of climatic factors such as altitude and continentality, which are intensified during the dry season. The air relative humidity is normally below 30% in the afternoon. The temperature ranges from 18°C to 30°C during summer and from 15°C to 29°C during dry season (winter). Reports of the International Energy Agency show some recommendations towards a more efficient building envelope following economical, constructive and technological conditions of the countries (IEA 2013). The most important recommendations for a hot and dry climate includes external shading, the constructions of coated insulated and reflective walls and roofs and windows with low solar heat gain coefficient (SHGC).

CASE STUDIES REGARDING THERMAL COMFORT

Regarding case studies of thermal comfort utilizing computer simulations, a case study was made in Gilman Building located at Tel Aviv University campus (ALEKSANDROWICZ and MAHDAVI 2015). The results showed that solar shading devices offered excellent protection against overheating, but these devices were not optimized for winter. The roof was not properly insulated and is a weak point because the air temperature is higher in the second floor than in first floor.

Ochoa e Capeluto (2008) made some studies at Zim-Opher-House in Haifa, Israel, and they concluded that modifications of the building envelope could reduce energy demand in 40% and increase thermal comfort among workers. Ricciardi, Ziletti and Buratti (2016) applied a methodology based on neutral comfort temperature (Tn) to assess conditions of thermal comfort in an Italian theater from the 17th century. Around 400 questionnaires were answered and the authors made some studies to determine values of neutral temperature that could please the diversity of users regarding age and gender. The most preferable temperatures were between 20°C and 23°C (RICCIARDI and BURATTI 2015). Leavy et al (2015) highlight the importance of monitoring user behavior, air quality (concentration of gases) and temperature distribution and that these factors could reduce energy consumption up to 79% of lighting and air-conditioning systems.

Monteiro and Alucci (2008) analyzed thermal comfort of semi-open spaces in São Paulo, Brazil and determined that the neutral adaptive operative temperature (OTn) was the most appropriate parameter to study user satisfaction. With many combinations of commercial building typologies, Melo et al. (2015) simulated the energy efficiency in three Brazilian cities of hot climate and the results showed that depending on building geometry, thermal insulation could increase the annual gain of thermal loads and could retain heat dissipation to the exterior.

HISTORICAL AND ARCHITECTURAL BACKGROUND

The Faculty of Education consists of five blocks. With capacity for 120 people and occupying an area of 250.00m², the space was part of the cultural life of Brasilia during 1960's and 1970's. The block of the auditorium is comprised of only one floor high, its plan is regular and embraces two courtyards. The main accesses are made from east and west façades (**Figure 1**). The building structure is of concrete and external walls are white and made of bricks and mortar. The elevations are mostly horizontal in this kind of composition (**Figure 2**). The auditorium has no external windows.

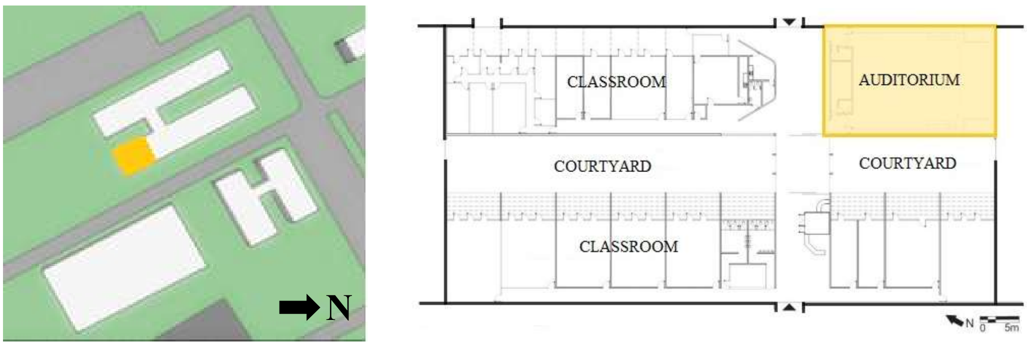

Figure 1. *Aerial view of the Faculty of Education (the Auditorium Dois Candangos is highlighted). Source: CEPLAN (2015).*

Figure 2. *East façade and view of the Auditorium. Source: authors and Faculty of Education (2015).*

The roofing is made of corrugated fiber cement over steel beams and the water is collected through steel gutters. The entire roof is hidden by a concrete frame. Internally the acoustic isolation is made of perforated wood panels and wool fiber in the walls.

SIMULATION

The building was simulated in the software Energy Plus (U.S. Department of Energy 2013), recommended by Brazilian standards and the modelling was made in Design Builder v.3.4. The first simulated model was made according with the building original features (1962) as shown in **Figure 3**. The simulated model has four main thermal zones: the auditorium, aisles and one technical room.

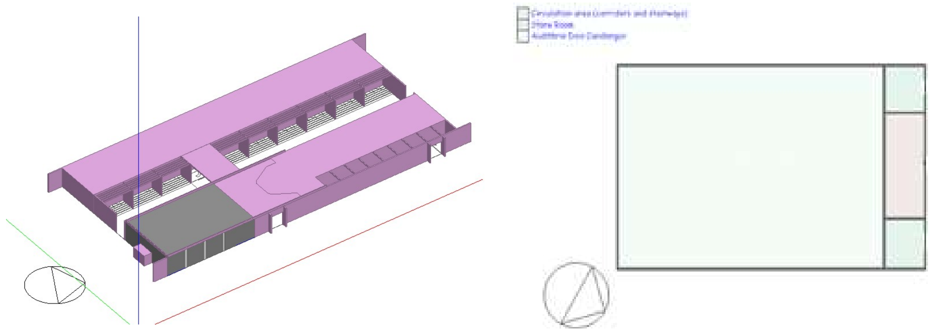

Figure 3. *Simulated model in Design Builder v.3.4 and thermal zones of the model*

The thermal properties (specific heat, density and solar absorptance) were taken from Brazilian standard ABNT NBR 15.220 and from existent literature. The weather file was developed by Laboratory of Energy Efficiency in Buildings (LABEEE) of University of Santa Catarina based on monitored weather data (from the years 2000 - 2010). It was updated by Roriz (2012) in order to improve its accuracy.

Table 1: *Thermal properties of simulated materials*

Material	*Thermal Conductivity (W/m·K)*	*Density (kg/m³)*	*Specific heat (J/kg·K)*
Concrete	1.75	2300	1000
Brick (ceramic)	0.55	661.3	604.8
Mortar	1.15	1800	1000
Perforated wood panel	0.15	400	2300
Common glass	1	2500	840
Polystyrene	0.035	30	1420
Rockwool	0.045	50	750
Ceramic	0.90	1600	920
Air	Thermal resistance		0.21 m²K/W

Table 2: *Solar absorptance of external material*

Material	*Solar Absorptance*
PVA White painting	0.20
Fiber cement	0.60
Dark green venetian blinds	0.70

The simulations were made during work hours (between 8h and 18h) covering daylight hours when problems regarding overheating occurred. The activity was configured as lecture hall (auditorium) with the capacity for 100 people with an area of 250.00m² (density of 0.40persons/m²). The lighting power density was 12W/m² (original lighting system with fluorescent light bulbs). The comfortable temperatures configured were between 20°C and 23°C and the air renovation rate was of 0.35l/s per person and 0.40l/s per m² (NBR 16.401-3 2008). For a better evaluation of thermal comfort in an auditorium, the neutral temperature (Tn) formula was adapted by Ricciardi and Buratti (2015). With adaptations for the climate of Brasilia, the neutral temperature is defined as follows:

$$Tn = A + B.Tamb \qquad (1)$$

Where A=17.6 and B=0.314, "Tamb" is outdoor dry-bulb air temperature for a naturally ventilated indoor environment. Firstly, four materials were chosen for the roof in order to evaluate the influence on thermal comfort. The neutral and indoor air temperatures were analyzed. Secondly, the percentage of thermal comfort hours (TCH) was obtained and was related to neutral temperatures. For summer evaluation, if operative temperature is lower than neutral temperature, the simulated hour is considered as comfort hour. For winter conditions, the electric equipment, lighting systems and the metabolism of users were sufficient to heat the auditorium during heating hours, especially in July.

Table 3. *Simulated roofs*

Scenarios	Material	Transmittance values (W/m2²K)
1	Original – fiber cement	1.44 (α=0.60)
2	Zinc roof	1.485 (α=0.30)
3	Metallic roof (zinc) with polystyrene insulation	0.46 (α=0.30)
4	Metallic roof (zinc) with mineral wool insulation	0.581 (α=0.30)
5	Metallic roof (zinc) with polystyrene insulation with ventilated air gap	External shading 1.027 (α=0.30)

Table 4. *Thermal properties of simulated walls*

Scenarios	Materials	Transmittance values (W/m2²K)
1	Original – ceramic brick walls with mortar (white painting)	1.26 (α=0.30)
2	Modified – as original with thermal insulation (mineral wool)	0.97 (α=0.30)
3	Modified – as original with thermal insulation (mineral wool) with ceramic layer with 5 cm of ventilated air gap	0.97 (α=0.30)

RESULTS

Comparing the percentage of thermal comfort hours (TCH) with neutral temperature, results show in **Figure 4** that the simulated roof materials without lighting system contributed to the increase of comfort hours, reaching values greater than 90% (Tn+2°C) following the concept of adaptive temperature. The auditorium did not have problems regarding cold (Tn-8°C). Comparing the results modifying the building envelope and the lighting system, it is observed that the TCH was increased when thermal insulation and ventilation of the façade strategies were combined. The results also showed the influence of lighting system on TCH results (**Figure 5**).

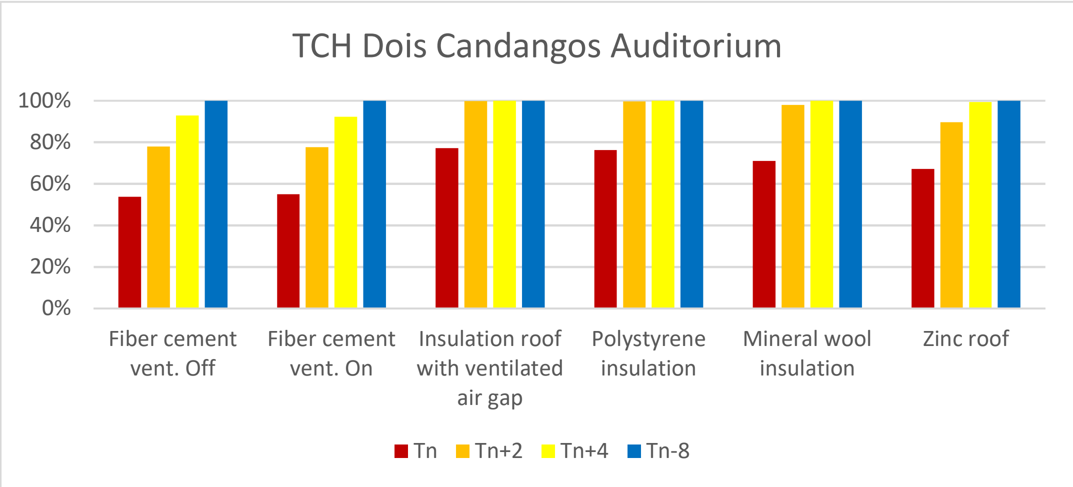

Figure 4. *TCH analysis of roof material without influence of lighting system*

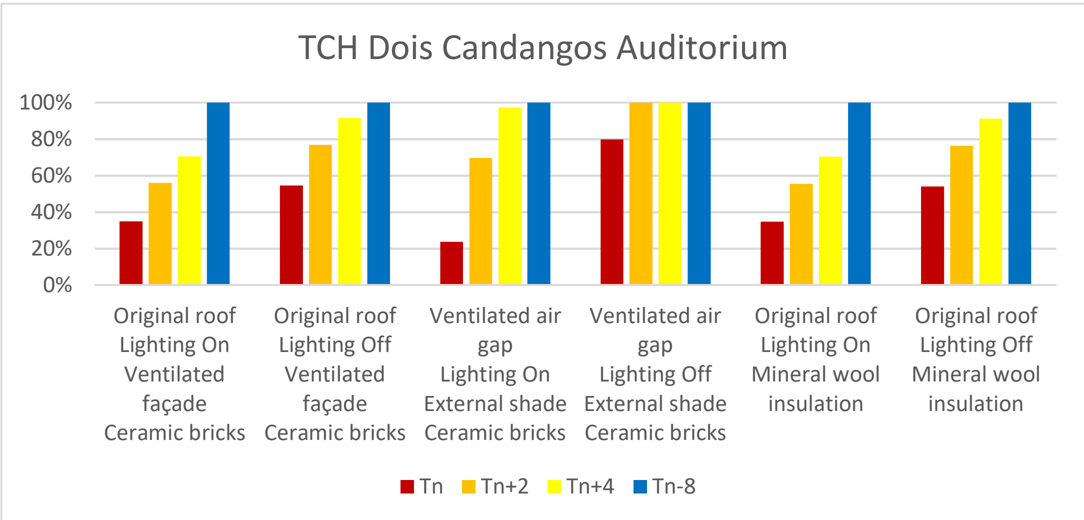

Figure 5. *TCH analysis of building envelope (roof and walls) with lighting system*

At last, the indoor temperature variations for the hottest day of the year (September 25th) was taken into account according with the weather file

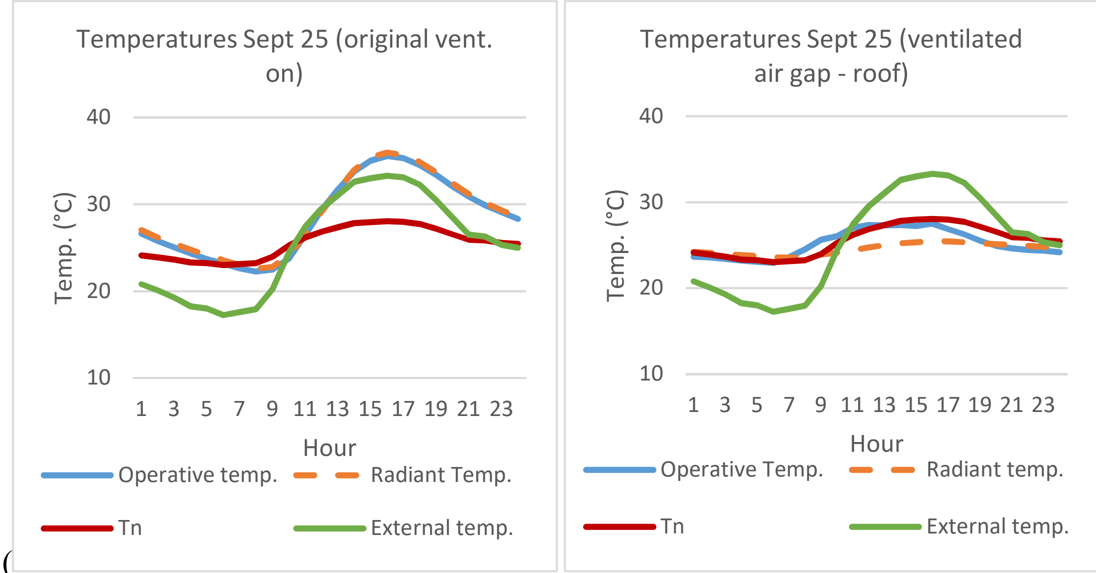

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Figure 6). It is observed that in the building of the original features, the indoor temperatures were higher than the outdoor temperatures. The strategy of ventilated air gap of the roof with polystyrene and zinc presented the most similar curve to the neutral temperature and the radiant temperature values were lower during the hottest hours.

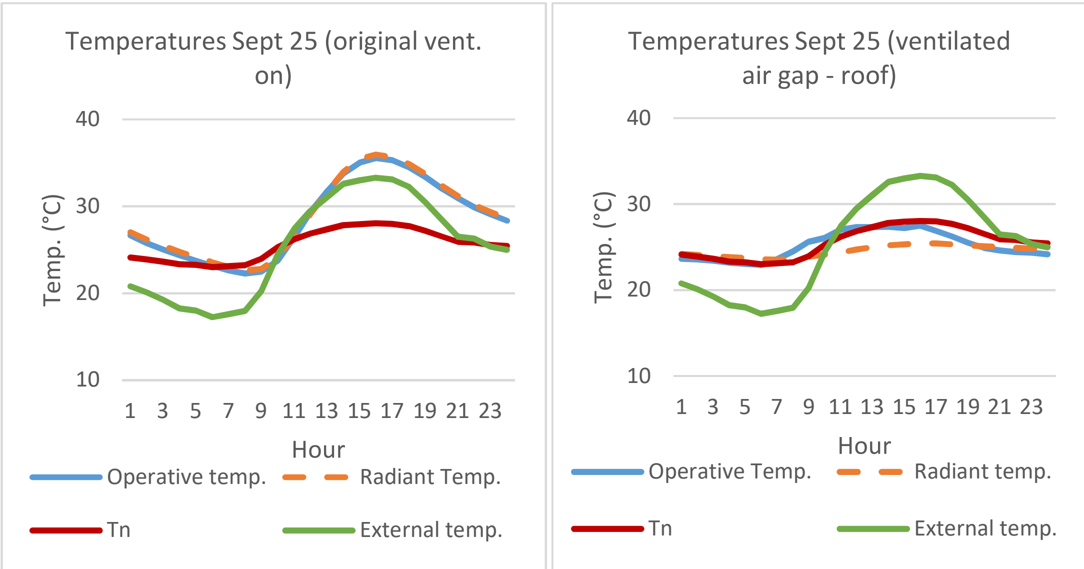

Figure 6. *Variations of temperature on September 25th (hottest day of the year)*

DISCUSSION

In general, the original building (fibrocement) presented the lowest values of TCH, followed by the zinc roof without insulation layer. Comparing the simulations, it is observed that the thermal insulation applied on the roof of this one-story building increased the values of TCH, especially when the ventilated air gap was considered. The passive strategy of ventilated air gap showed some importance demonstrating reduction of indoor air operative and radiant temperatures on the hottest day of the year during working hours. Regarding thermal insulation of the building envelope, results showed more efficiency when passive strategies of air ventilation gap and external shading were combined. This ventilation strategy is useful for shading and to remove hot air during hottest hours on afternoon. The lighting system was decisive to reduce TCH in more than 15% on simulated scenarios.

CONCLUSION AND IMPLICATIONS

Thermal insulation of roof was meaningful to increase TCH, confirming as an important variable in diminishing indoor air temperature. Although, as pointed by Melo et al. (2015), the efficiency of the insulating layer is perceptible in predominantly cold climates. In this case study of Auditorium Dois Candangos, thermal insulation of the walls decreased the TCH (from 60% to 53%) without lighting system. This prevented heat dissipation through the building envelope to the exterior. Despite the impossibility of external openings for natural ventilation due to acoustic and luminic characteristics, the combination of thermal insulation of roof with ventilated air gap showed a reduction of the indoor air temperature from 30°C to 28°C between 15h and 17h on the hottest day of September. Therefore, thermal insulation of the roof and the ventilated air gap of the envelope were considered the best passive strategies for this auditorium.

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