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Trombe Walls in Hot and Humid Climates: a Brazilian Case

Fernando Sá Cavalcanti

Abstract— This paper intends to show an analysis of the potential use of Trombe walls to three Brazilian cities (Belém-PA, Maceió-AL and Rio de Janeiro-RJ) with similar climates, investigating the possibility of including this component in the repertoire of local architecture, promoting natural ventilation in interior spaces. In hot and humid climates, the natural ventilation is the main strategy to provide comfortable spaces and reduction of energy consumption in buildings, since it is known that this is a subject little studied for the Brazilian climates. Between the tropics, it is known that there is great potential for utilization of solar radiation. A low energy technique for heat removal from the interior of a building under summer conditions is the employ of natural ventilation. There are several ways to promote this ventilation; the use of this device to obtain this objective is studied in the present work. The Trombe walls can be vented or un-vented. The vented wall allows heated air to circulate directly to the living area and requires night time closing of wall vents, because if not closed the heated air would cycle back to the front of this component from the living area, however, the performance of this device is poorly studied mainly for tropical climates, case of the most of the Brazilian territory. This analysis was performed using computer simulations and same parameters were varied to analyze the effect of the variables in the values of air velocity inside, comparatively in a standard building with dimensions of 4,00x4,00m. The inlet and outlet openings were designed so to optimize the air flow in the channel of the trombe wall. The thickness of wall assume values of 0.15, 0.30 and 0.45m to verify the influence of thermal mass in performance of this component and the glazed area be composed for 3 kinds of materials: glass with 3,0mm, double glass and glass block. The results indicate a possibility of the use of this architectonical component in hot and humid climates to natural ventilation induction and promotion of thermal comfort, this device also promoted increased air flow inside the room at the work level. The computer simulation gives possibility to analyze this passive cooling strategy in buildings located at regions with other typical climates of Brazil.

Index Terms— Trombe Walls, Natural ventilation, Hot and Humid Climates, Brazil.

1 Introduction

The search for adapted buildings to the climate of the region passes for the inquiry of the environmental performance of the various architectural components, between them Trombe Walls, whose potential of application still is little explored in Brazil. Bioclimatic architecture of buildings is increasing in popularity as an intelligent way to design and construct more energy efficient buildings as well as to increase indoor comfort (1).

The Trombe wall is a clever device for collecting and storing heat from the sun during the day and releasing heat into a building space during the night; they are a means for free solar space heating. The wall is typically located on the north face of a building (in the southern hemisphere) to maximize its solar exposure throughout the year. Overhangs are used to shade the wall during the summer to prevent overheating but allow sunlight at lower angles to heat the wall during the winter. Heat is collected and stored in the thick concrete wall. One or more layers of glazing on the exterior and an optional selective surface turn the wall into a one-way heat valve. The glazing forms an air gap between the wall surface and the outside air that helps to insulate the wall from outside convection. The selective surface is adhered to the wall surface and is characterized by a very high absorptivity and very low emissivity, allowing solar radiation to be absorbed but preventing it from being re-emitted as long wave radiation (2).

The vented trombe wall allows heated air to circulate directly to the living area and requires nighttime closing of wall vents, because if not closed the heated air would cycle back to the front of this component from the living area. trombe walls have been used less frequently in recent years because of the difficulty in ensuring the proper opening and closing of vents. Research indicates that trombe walls gain more heat during the night, therefore moveable insulation over the trombe wall will improve its efficiency. The Figure 1 shows the basic operation of a Vented trombe wall for cooling, used in this research.

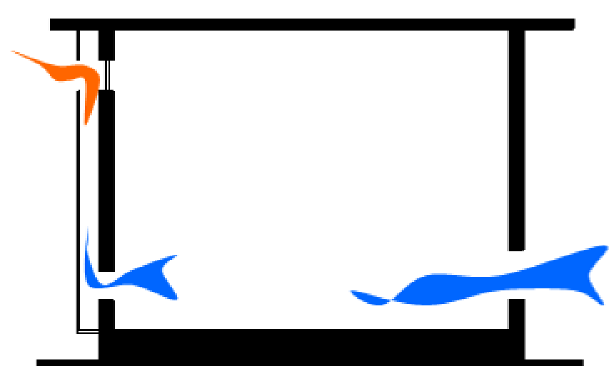

Fig. 1. Operation of a Vented Trombe wall to cooling (natural ventilation).

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Much of Brazil's territory is classified as having a hot humid climate. In such regions, natural ventilation combined with solar protection are the most effective building bioclimatic design strategy in order to improve thermal comfort by passive means. For the residential sector the "Thermal performance in buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Houses" (3) is the main reference. The requirements were related to thermal envelope, lighting and acoustics, along with minimum requirements for ventilation and opening areas. One important contribution of this document was the definition of bioclimatic zones and Figure 2 shows their definitions. Eight zones were defined according to its climate characteristics from 330 cities across Brazil. Based upon this division, a set of specific bioclimatic design strategies was indicated focusing its application during the early design stage.

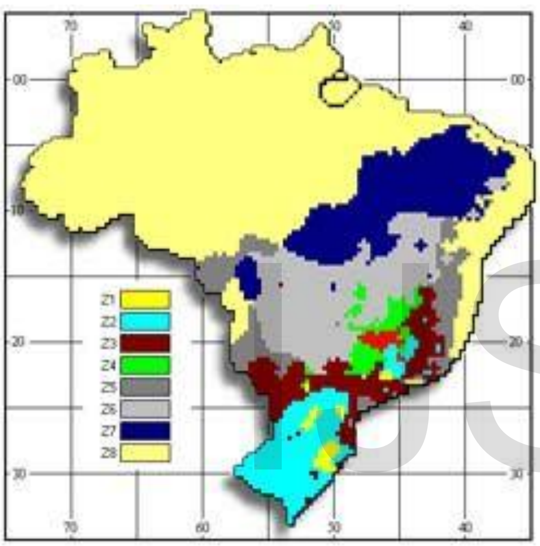

Fig. 2. Bioclimatic zones in Brazil. Font: (ABNT, 2005)

(4) conducted a numerical study based on parameters that can influence the performance of this device, such as width and height of the channel, level of insulation and heat gains. For the width of the openings defined that if it is equal to the width of the channel Trombe wall, its performance is optimized.

Based on the studies of (4;5), analyzed the use of Trombe walls for various climates in Spain, producing proposals for the design of this element, from three combinations (always closed in the summer with flow only the outside air and air flow from inside to outside promoting natural ventilation).

Several studies were performed on thermal storage walls (Trombe-walls). (6) has studied the effects on the heating and cooling loads, resulting from the use of building thermal mass in Cyprus, by modeling and simulation with TRNSYS program. The results of the simulation have shown that there is approximately 47% reduction in heating load requirement in case of using a 25-cm thick Trombe wall in a south-oriented room. In summer, an overhang of 1 to 1.5 m is required for shading the Trombe-wall. (7) studied the thermal performances of a classical Trombe wall and a composite Trombe-Michel wall. It was found that the composite wall has better energetic performances than classical wall in cold and/or cloudy weather. An experimental approach to the thermal response of passive systems was performed by (8) in Turkey. A full-scale model of a single zone with a thermal wall was constructed. It was found that any change in solar intensity could cause fluctuation in the temperature of the thermal wall.

For Brazil, few studies were found in the literature on the topic, as the work of (9) where measurements were made in loco to evaluate the performance of a Trombe wall for the climate of the south. This system had bottles filled with water to aid in the heat storage. They observed a thermal lag 4-5 hours between the peak of radiation and the peak heat accumulated in Trombe wall.

Trombe walls have been studied mainly to promote winter heating, nevertheless, in summer, the non wished effect of excessive heat gain can be presented through this element. This situation could be critic in those climates where summer is hot. In consequence, the Trombe wall utility must be carefully evaluated. To increase the possibility of use of Trombe walls in hot climates, this element can be operated in different modes in order to minimize conduction heat gains through the storage wall and to maximize heat removal from the interior by the natural ventilation.

Technological advances allowed for thermal analysis of buildings in a more fast and low cost since the development of passive solar technology in the United States in 70 years. The computer simulation programs can play a key role as an instrument for evaluating projects for passive solar green buildings. These programs allow the user to enter some variable parameters, thereby optimizing projects. The EnergyPlus program is a useful tool to perform analysis of thermal performance of buildings (2).

2. Objective

The objective of this paper is to investigate the influence of the use of Trombe wall in natural ventilation and thermal performance of buildings, thus contributing to the establishment of bases for the design of buildings in the Bioclimatical Zone 8 of Brazil, based on the results for three typical cities: Belém, Maceió and Rio de Janeiro.

3. Method

This methodology was based on parametric studies obtained from computer simulations using software EnergyPlus, regarded internationally as one of the best software today, so get the best configuration of a Trombe wall, making it possible to use this device architecture in buildings built in climates similar to those analyzed. From these simulations it was possible to evaluate the performance of the buildings analyzed for thermal comfort, checking the impact that the use of this device can provide in buildings in hot and humid climate.

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3,1 Description of the digital model

The analysis of this paper will be given from several computer simulations using EnergyPlus. The standard building will have dimensions of 4.00 x 4.00 m with ceiling height of 3.00 m and possess a Trombe wall on the north façade (Figure 3) with all walls painted white (absorptivity = 0.27), this environment will be simulated between two other similar volumes (Figure 4) in order to check the thermal exchanges between the facade and the external environment only by the facades where the openings are located. The north façade is fully exposed to solar radiation, while the south facade presents an overhang of 3.00 m wide, creating a transitional space between inside and outside and preventing direct radiation influence way too much for heating zone simulated.

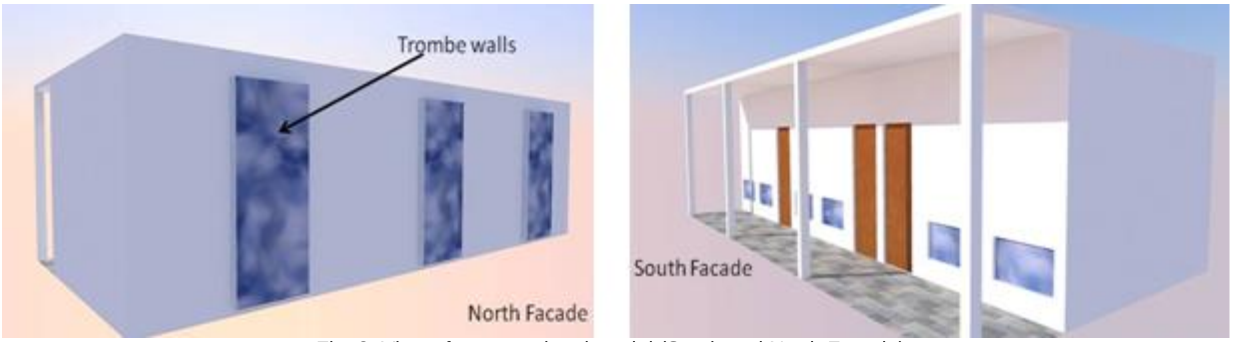

Fig. 3. View of computational model (South and North Façade).

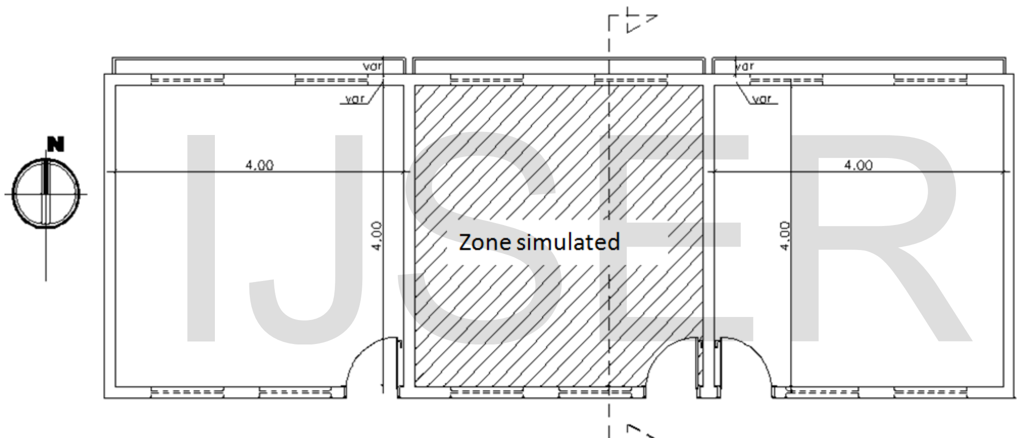

Fig. 4. Floor plan of the model simulated

The width of the Trombe wall was considered 2.00 m and height of the Trombe wall was composed of 3.00 m. The height of the openings, assuming that the openings is 3% of the total area Trombe wall, was composed of 0.18 m² and the thickness of the channel, however, was set to 0.10 m.

The constructive systems adopted for the simulations of this work are depicted in Table 1, where it is possible to observe the thermophysical properties of materials used as inputs for EnergyPlus. This software is considered to be one of the best software engines for energy simulations of buildings.

TABLE 1

LIST OF COMPONENTS AND THEIR PROPERTIES.

Walls				Floor				Ceiling			
Component	λ (W/m °C)	ρ (Kg/m³)	c (J/Kg °C)	Component	λ (W/m °C)	ρ (Kg/m³)	c (J/Kg °C)	Component	λ (W/m °C)	ρ (Kg/m³)	c (J/Kg °C)
Ceramic block 08 holes 19x19x09cm	0,4	1200	960	Concrete	1,75	2400	1005	Concrete	1,75	2400	1005
Plaster	0,85	2000	1005	Ceramic floor	1,1	2000	1005	Insulating	0,04	18	1675

Where:

λ – Thermal Conductivity;

ρ – Density;

c – Specific Heat.

The parameters which were varied in the simulations were the wall thickness with high thermal inertia and the type of glass soletor solar vertical. The walls are shaped as shown in Figure 5 and were considered as single glass (3.0 mm), with argon double glass (6.0 mm) and the glass block. For this paper were simulated buildings containing Trombe walls in three Brazilian cities as noted in table 2.

The computer simulation assists in decision-making by enabling analyzes in virtual environment, the thermal comfort of the users. The choice of the program as a tool EnergyPlus is justified by the resources it offered, compared with other simulation programs for energy efficiency in buildings, such as BLAST, DOE-2, 1E, TRACE,TRNSYS, ESP-r and TAS (10).

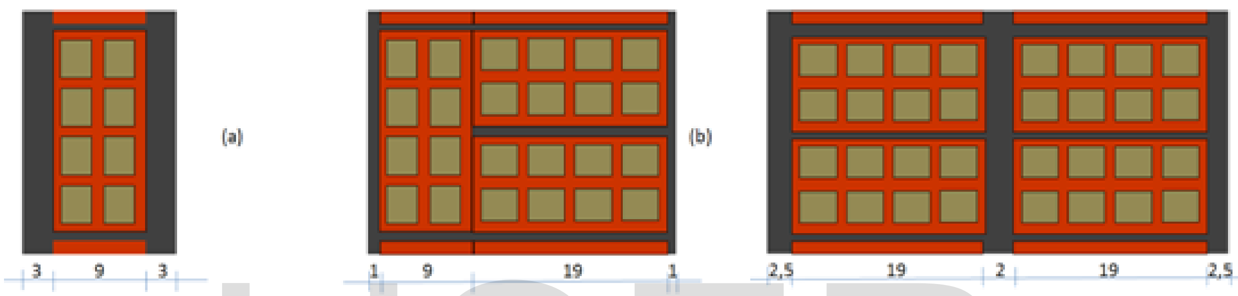

Fig 5 Details of walls used in this paper: (a) 0,15m (b) 0,30m and (c) 0,45m.

TABLE 2
SIMULATED CITIES.

Simulated Cities	State	Bioclimatic Zone	Latitude	Longitude	Altitude (m)
Belém	PA	8	-1,38	-48,48	10
Maceió	AL	8	-9,47	-35,51	16
Rio de Janeiro	RJ	8	-22,53	-43,17	18

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4 RESULTS AND DISCUSSIONS

From computer simulations it is observed that the building wall that has a thickness of 15 cm has an internal temperature higher than the other environments analyzed providing greater thermal discomfort to users and temperatures reaching above the tolerable comfort zone established by ASHRAE-55 (11) especially in summer.

There is an increasing function of the natural ventilation in lowering the temperature of air inside the standard environment due to the increase of the greenhouse effect inside the Trombe wall, providing a higher temperature difference between the air in Trombe wall and the outside air.

The figure 6 shows the average behavior for the three cities analyzed in each case determined for this paper.

The type of glass has little influence on the performance of Trombe wall investigated in this case. Since the wall thickness among the main variable analyzed, providing a thermal lag and damping of indoor temperature in relation to outdoor temperature which promotes a greater sense of comfort to users and allows for the cases of walls 30 and 45 inches use throughout the year to enhance natural ventilation in indoor spaces.

The absorptance of 0.27 in the Trombe wall influenced so that the glass was not essential in thermal performance of buildings analyzed, as you can see in Figure 6 the behavior of the surface temperature of the collector which is directly linked to the transmittance, reflectance and absorptance thermal. Much less the temperature of the glass, it allows more radiation to pass through, but as the surface showed low absorptance this radiation was not well used and yet the Trombe wall showed a good performance.

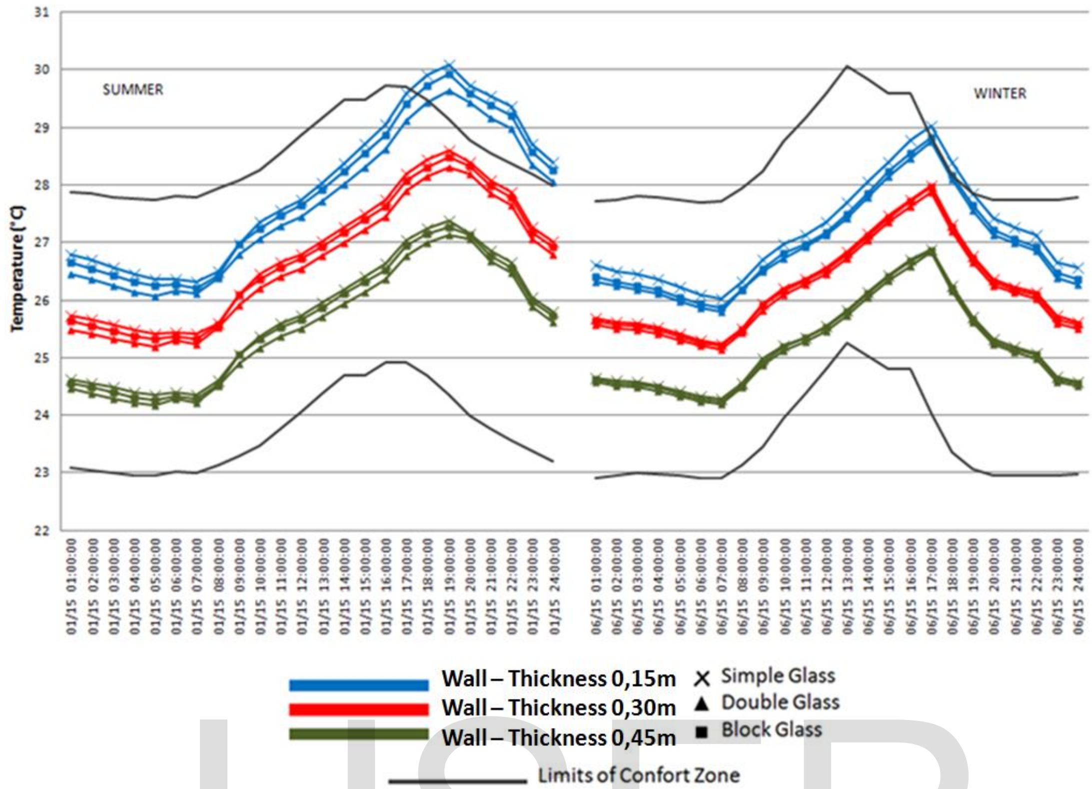

Fig 6 Behavior of the internal temperature in winter and summer for each case analyzed.

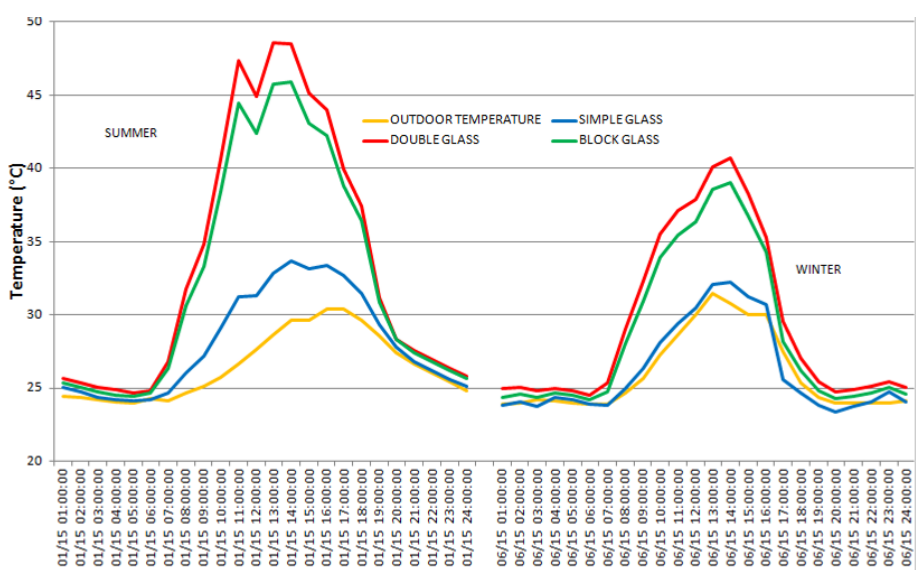

Fig 7 Surface temperature of the collector during the day in winter and summer.

In Figure 7 you can see this variation of the surface temperature of the collector for winter and summer, where the glazing is more demperatura simple glass surface and the lower temperature, allowing greater passage of solar radiation, as well as studies show (12).

5 Conclusion

This study examined the influence of the use of Trombe walls in increasing the natural ventilation to internal spaces in three Brazilian cities, located in hot and humid climate and in all cases, this device showed satisfactory results falling the temperature in 25% approximately.

The use of computer simulations proved to be a satisfactory tool and enabled the achievement of desired ratings. The software used, and provide reliable data, is able to simulate the buildings analyzed in this paper for the day project for winter and summer in a short period of time, each model being simulated in approximately 3 seconds.

The integration of these elements in a building alters the distribution of temperature, influencing positively in the displacement of the air flow even in winter.

This design strategy was effective for the hot and humid climate can be used in areas with high density urban areas where natural ventilation is impaired at the time of the work plan.

The buildings in general, should be carefully planned to minimize overspending with lighting and ventilation by mechanical means. Architectural devices such as trombe walls, they should have investigated its potential to support the construction of buildings more suited to the regional climate, always seeking the highest degree of efficiency.

From these observations, it is intended to enhance awareness of the local architecture should be conducted so that professionals incorporate appropriate language and characteristics, creating a regional typology, giving an identity to architecture that is being imported or poorly copied and loses sight of the most important: the comfort of users. Faced with the energy crisis, and needs to be designed to reduce energy consumption and take into account the climatic conditions of the medium, applying the bioclimatic techniques.

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