THERMAL PERFORMANCE OF TROMBE WALLS IN THE SOUTH OF BRAZIL

Clarissa Sartori Ziebell[1] and José Luis Farinatti Aymone[2]
[1]Department of Design and Graphic Expression, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
clarissa.ziebell@ufrgs.br
[2] Department of Design and Graphic Expression, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
aymone@ufrgs.br

ABSTRACT

In this paper an analysis of the thermal performance of a Trombe wall through a simulation model is presented. The climate context is Bento Gonçalves, a city in 'Serra Gaúcha' (a region in Rio Grande do Sul, Brazil, characterized for the low temperatures during winter). The model consists in a prototype with 25 m². The Trombe wall, when inserted in the models, is oriented towards the North façade. The thermal performance of this model is measured through the percentage of time in thermal comfort during one year. Three solutions are compared: a traditional Trombe wall, a curtain inside the Trombe wall for the cold periods, and a standard wall. As a result, the Trombe wall system was found to be a suitable alternative for Serra Gaúcha, since the percentage of time in thermal comfort is greater when this system is adopted. However, the use of such system alone is not enough to guarantee thermal comfort all year round, which may require the simultaneous adoption of other strategies. In addition, the use of curtain did not improve the thermal comfort.

KEYWORDS: *Trombe Wall, Computer Simulation, Thermal Performance.*

I. INTRODUCTION

In recent years much has been said about energy saving in buildings. It is known that a great part of the energy consumed in residential buildings comes from artificial air conditioning (20% of the consumption by end use in residences). For this reason, passive heating and cooling alternatives have been studied. One of these alternatives is the Trombe wall, also known as accumulating wall, which allows indirect heat gain [1].

The Trombe wall is composed of a layer of high thermal inertia material and a glass positioned in front of the first layer. The glass has the function of avoiding the loss of heat by convection and by radiation to the outside. The Trombe wall should be facing the orientation of greater solar insolation [1]. In the case of the Southern Hemisphere, this orientation is to the North. The system can work through a manner that combines effects of radiation and convection originating from the insertion of openings in the lower and upper part [2], as shown in Figure 1.

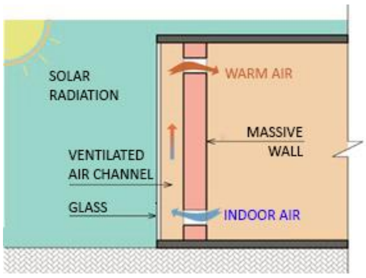


Figure 1. Ventilated Trombe wall. Adapted from Abbassi et al. [3]

According to Mendonça [2], the Trombe wall may take the following configurations:

a) Accumulating wall (non-ventilated Trombe wall), which consists of a thermal storage wall without thermo-circulation openings;

b) Dynamic wall, where a ventilation system is combined with the greenhouse effect. The openings are closed during winter nights or in overcast weather without thermal gains;

c) Wall of water-filled containers, where water is the element of thermal storage.

Other configurations can also be found such as: the zigzag wall, the use of phase exchange materials to increase efficiency, and the photovoltaic Trombe wall, where photovoltaic panels are placed in front of the glass [4].

Several studies are dedicated to the improvement of the thermal performance of the Trombe wall. Chen et al. [5] analysed the thermal performance of a Trombe wall with the insertion of a curtain with low emissivity in the internal channel during the night time of winter in Dalian, a city located in China. The author states that the use of insulation can minimize the heat loss in the channel between 20% to 40% during winter nights, in addition to increasing the external surface temperature of the Trombe wall.

Hong et al.[6] investigated, through a CFD (Computer Fluid Dynamics) model, the flows and thermal transports in a Trombe wall with venetian blinds, with one of its side covered with high absorption coating and the other side covered with high reflectivity coating. In such way that the venetian blinds could absorb or reflect solar radiation as needed. Through these studies the authors noticed that the position of the venetian blinds, the width of the air channel and the area of entrance and exit of the openings, exert an influence on the thermal performance of the system. The adoption of the venetian blinds was also studied by He et al. [7] and by Hu et al. [8].

Rabani and Kalantar [9] compared the heating performance of a normal Trombe wall with a newly designed one through numerical simulation, considering the coldest sunny day of the winter of Yazd (Iran). The new design consisted in a Trombe wall in which the sides were glazed in order to receive solar radiation from three directions. Also, its width was equivalent to 50% of the width of the storage wall to reduce costs. Duan et al. [10] compared the thermal performance of two Trombe walls, one with an absorber plate pasted on the thermal storage wall and another with the absorber plate positioned between the glass and the thermal storage wall which formed an air channel between the glass and the plate. Sameti [11] investigated a new design of a storage water wall. In this new design, the gap between the glass and the wall is filled with aerogel and the water storage is placed between two walls. Long et al. [12] studied the performance of a Trombe wall which consisted in a collector plate, a thermal radiation reflection layer and an indoor radiation panel in hot summer and cold winter zone. The system also makes it possible to heat water. Yu et al. [13] studied a novel Trombe wall system that can perform both functions of space heating and air purification through a photocatalytic layer which is coated on the internal surface of the glazing cover in a conventional Trombe wall system.

The studies above demonstrate the wide variety of forms that a Trombe wall can assume. For this reason, it is important to study the best alternative for the climate in question. In Brazil, for example, studies such as Suzuki [14], Cavalcanti [15] and Bianco [16] show that the use of a ventilated Trombe Wall can increase the thermal comfort of environments, especially in the South and Southeast regions of the country.

The structure of this paper is given as follows: in Section II the main goals are explained; in Section III the method of this research is detailed; Section IV is dedicated to present and discuss the results; the conclusion is developed in Section V and the future work is presented in Section VI.

II. OBJECTIVES

The objective of this article is to study the thermal performance of a Trombe wall through a simulation model. The climate context is Bento Gonçalves, a city in 'Serra Gaúcha'. The thermal performance is measured through the number of hours in thermal comfort.

III. METHOD

The method of this work consists in comparing three different solutions: a model with a Trombe wall, a model with a curtain inside the Trombe wall for the cold periods and a model with a standard wall. Below is a description of the simulated models.

3.1. Main characteristics of the simulated models

The selected city for this study was Bento Gonçalves (latitude -29.27; longitude -51.52). This city is located in the State of Rio Grande do Sul (Figure 2). According to the Municipality of Bento Gonçalves [17], the city has an altitude subtropical climate. The months with lower temperatures are June and July, while the months with higher temperatures are January and February. The high altitude of the city (640 m), contributes to the low winter temperatures. The graph shown in Figure 3 shows the average temperature variation over a year. The choice of the city is due to the easy availability of the weather file [18]. Besides that, the city presents cold winters, so the use of Trombe walls may be suitable. The weather file adopted in this work is called 'BRA_RS_Bento.Goncalves.869790_INMET.epw.' [18].

Figure 2. Bento Gonçalves location. Source: Google Maps

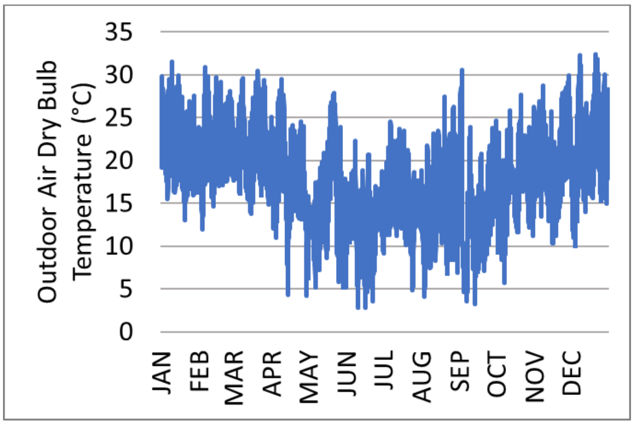


Figure 3. Temperature variation over a year. Source: data from Labeee [18]

In order to verify the thermal performance of a Trombe wall, a prototype of 5 m x 5 m x 3 m was modelled. The Trombe wall, when inserted in the models, is oriented towards the North façade. Figure 4 shows the reference model (without the Trombe wall) with a view to the North façade, while in Figure 5 the model with a view to the South façade is presented.

In the South side there is a sliding window with dimensions 3 x 2 m, while in the North side there is a hopper window (hinged at the bottom and opening outward) with dimensions 4,80 x 0,40 m. Through this configuration, on hot days, cross ventilation can be generated to renew ambient air and remove heat.

The software selected for computational simulations was EnergyPlus, made available by the United States Department of Energy [19]. The choice of this software is due to its reliability. The software allows you to simulate a building through data entry with respect to geometry, materials and various systems which compose it. In this way, several parameters of the model can be easily changed. In addition, the algorithm used by the EnergyPlus to model the convection of the air within the zone of a Trombe wall was validated through an experimental work by Ellis [20]. This algorithm can be selected in the field "Zone Inside Convection Algorithm" in the window "Zone object" in the EnergyPlus software (Figure 6).

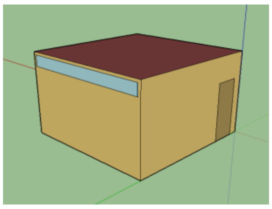


Figure 4. View of the north façade of the standard model. The green line indicates the direction of the North

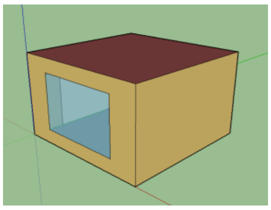
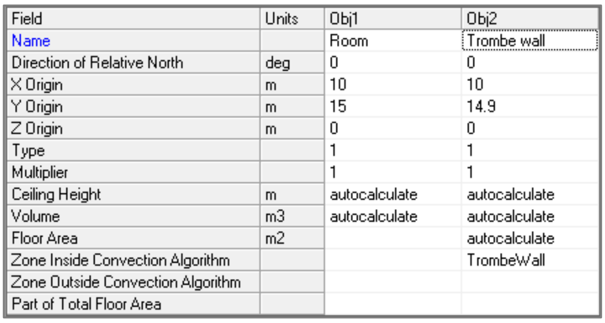


Figure 5. View to the southern façade of the standard model. The south window has double glazing



Field	Units	Obj1	Obj2
Name		Room	Trombe wall
Direction of Relative North	deg	0	0
X Origin	m	10	10
Y Origin	m	15	14.9
Z Origin	m	0	0
Type		1	1
Multiplier		1	1
Ceiling Height	m	autocalculate	autocalculate
Volume	m3	autocalculate	autocalculate
Floor Area	m2		autocalculate
Zone Inside Convection Algorithm			TrombeWall
Zone Outside Convection Algorithm			
Part of Total Floor Area			

Figure 6. Insertion of the algorithm for the Trombe wall

The walls are made of a solid heading brick (10 cm x 6 cm x 20 cm) plastered on both sides and painted white. The floor consists of a 10 cm concrete slab set on a 40 cm soil layer. The roof consists of a concrete slab and fiber cement tiles. The Trombe wall is formed by a double layer of 20 cm thick bricks, joined by 1 cm of mortar. Both faces are plastered with 2 cm of mortar. The inner face is painted white and the outer face black. The details of the materials are shown in Table 1. The data of thermal conductivity, density and specific heat were obtained from NBR 15220-2 [21], which is a Brazilian standard from the Brazilian Association of Technical Standards (ABNT). The only exception was the soil data, which was based in Costa [22]. Table 2 shows the composition of each surfaces which are part of the model.

Table 1. Characteristics of materials used in computational simulation.

Material	**Thermal Conductivity [W/m.K]**	**Density [kg/m³]**	**Specific Heat [J/kg.K]**	**Absorptance**
Solid ceramic brick	0.90	1600	920	Not defined
Mortar / plaster	1.15	2000	1000	0.30
Trombe wall plaster	1.15	2000	1000	0.97
Fiber cement tile	0.95	1900	840	0.7
Concrete slab	1.75	2200	100	Not defined
Concrete subfloor	1.75	2200	100	Not defined
Soil	1.00	1200	1200	Not defined
Wood	0.15	600	1340	0.5
Aluminum	230	2700	880	0.2

Table 2. Composition of Trombe wall surfaces with the thickness of each material.

Walls	**Trombe wall**	**Roof**	**Floor**	**Door**	**Window - simple glass**	**Window - double glass**	**Trombe wall window frame**
Mortar 2 cm	Mortar 2 cm	Fiber cement tile 6 cm	Concrete subfloor 10 cm	Wood 2.5 cm	Clear glass 3 mm	Clear glass 3 mm	Aluminum
Solid brick 20 cm	Solid brick 20 cm	Ceiling air space	Soil 40 cm			Air 13 mm	
Mortar 2 cm	Plaster 1 cm	Concrete slab 10 cm				Clear glass 3 mm	
	Solid brick 20 cm						
	Trombe wall plaster 2 cm						

The simulation model consists of one thermal zone in the case of the standard model (with a common wall) and of two thermal zones when is inserted a Trombe wall. In this second case, zone 1 corresponds to the internal environment and zone 2 corresponds to the Trombe wall (Figure 7), where a window that covers almost all the wall area was included. This window was simulated with double clear glass, following the recommendations described in Cavalcanti [15]. The channel is 10 cm deep. As the model with the standard wall, in this case there is also a hopper window (hinged at the bottom and opening outward) with the same size at the top of the wall. Inside the Trombe wall, at the bottom, there is another window with the same size. In this way, on hot days, the air can cross the interior of the prototype and be released through the channel (Figure 8).

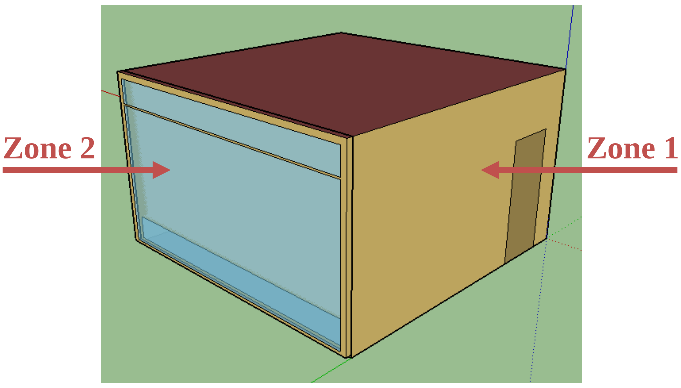


Figure 7. Simulation model elaborated in SketchUp software

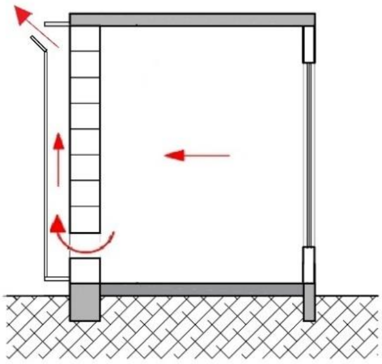


Figure 8. Airflow during hot periods

In addition to the influence of the Trombe wall on the thermal performance of the model, the influence of the internal insulation is also evaluated. As mentioned in the introduction, Chen et al. [5] found that inserting a curtain with low emissivity into the interior of the channel during winter nights in China can keep the heat inside the channel, avoiding loss. Thus, a curtain which is activated only during autumn and winter nights (between 7 p.m. and 6 a.m. of the following day) was added to the model. The internal insulation was inserted into the EnergyPlus through the "Window Property: Shading Control" object. Shading can reduce solar gain and heat loss, and it can minimize daylighting glare [23]. As in this work the internal shading is only activated at night, it will only function to reduce heat loss. The inserted shading is a fabric curtain whose thermal properties were obtained with the company Mermet [24] (Table 3).

Table 3. Data on the curtain with low emissivity, corresponding to the product called GreenScreen® Reflect™, in the color bronze, from the company Mermet [24].

Characteristics	Data entered
Solar Transmittance	0.04
Solar reflectance	0.75
Visible Transmittance	0.04
Visible reflectance	0.72
Infrared Hemispherical Emissivity	0.27
Infrared Transmitance	0.06
Conductivity (W/mK)	0.15
Thickness (m)	0.021
Airflow permeability	0.05

3.2. Site ground temperatures

To calculate the soil temperature, the EnergyPlus pre-processor called "Slab" was used. Slab can be run individually before the simulation in EnergyPlus or simultaneously with the EnergyPlus simulation [22]. In this work the first option was adopted, and the Slab output data was later inserted into the EnergyPlus object called "Site: Building Surface Ground Temperature". The data entered in Slab was based in Costa [22] and is shown in Table 4.

Table 4. Data entered in Slab. The data was defined based on Costa [22].

Field	Data entered
Number of materials	2
Surface albedo (with and without snow)	0.26
Surface emissivity (with and without snow)	0.95
Surface roughness with snow	4
Surface roughness without snow	0.05
Coefficient of heat transfer by convection and by radiation with vertical flow (descending) (W/m².K)	6.13
Coefficient of heat transfer by convection and by radiation with vertical flow (ascending) (W/m².K)	9.26
Slab material density (kg/m³)	2400
Soil density (kg/m³)	1200
Slab specific heat (J/kg.K)	1000
Soil specific heat (J/kg.K)	1200
Slab thermal conductivity (W/m.K)	1.75
Soil thermal conductivity (W/m.K)	1
Area to perimeter ratio (m)	1.5 (minimum)
Slab thickness (m)	0.10
Dimension of the horizontal and vertical domain of the model (m)	15

Also, evaporation simulations were considered, the model was not allowed to use a fixed temperature or zero heat flow condition for the lower limit of the vertical domain, and no heat transfer coefficient was established for the soil surface (in this case, according to Costa [22], the program calculates the heat transfer coefficient based on the available meteorological conditions). The value of 10 years was defined to obtain the results through iterative processes.

3.3. Airflow parameters

The simulations were carried out for the whole year. In order to calculate the impact of natural ventilation, the "Airflow Network" object was used to simulate wind directed airflow [25]. The model consists of a series of nodes connected through linkages to airflow components [26]. Therefore, it is assumed that the air flows from one node to another, which simplifies airflow in paths [25].

The effects of ventilation are simulated through the "Airflow Network" by following three steps: the calculation of pressures and airflow, the calculation of temperature and humidity of nodes, and the calculation of sensible and latent heat loads [26]. In the case of the present model, the zones represent the nodes, whereas the windows are the airflow linkages.

With respect to the input data, it was established that the pressure coefficients are calculated by the program. This is possible due to the rectangular shape of the building [23]. Control of ventilation occurs through temperature. For the windows to be opened, the temperature inside the zone must be higher than the external temperature and equal to or higher than the setpoint temperature. In the work of Martins et al. [27], it was found that when the internal temperature was around 25° C, the PMV (Predicted Mean Vote) calculated by the Energy Plus tended to zero. As this work is analysing thermal comfort, the setpoint temperature has been set to 25° C. Finally, the airflow coefficients and the airflow through the gaps established for the doors and windows can be defined according to INMETRO [28], being 0.65 and 0.001 kg/s.m, respectively.

3.4. Thermal comfort definition

To measure the thermal comfort a model of thermal comfort for environments naturally vented called "adaptive model" was used. In this model the comfort temperature for naturally ventilated buildings is calculated according to Equation 1 [29].

$$T_{comf} = (0.31 \text{ x } T_{a,out}) + 17.8 \quad \text{Eq. [1]}$$

where,

T_{comf} = comfort temperature (°C);

$T_{a,out}$ = mean outdoor dry bulb temperature (°C).

To find acceptable temperature ranges for 80% overall acceptability, it is necessary to add or subtract 3.5°C from the comfort temperature for naturally ventilated buildings. If the aim is to reach the 90% overall acceptability range, it is necessary to add or subtract 2.5°C.

In this article the thermal performance of the analyzed building is measured by the level of thermal comfort provided by the building to its occupants. The level of comfort is defined according to the methodology described by Dear and Brager [29], considering 90% of general acceptability. Therefore, in EnergyPlus the operative temperature and the external temperature can be generated as output data, both in hourly data. Later, the external temperatures are inserted in Equation 1. The comfort temperatures obtained with the equation are then compared with the hourly operative temperatures in order to verify in how many hours these temperatures are within the thermal comfort range defined by Equation 1.

IV. ANALYSIS OF RESULTS

The results obtained in this research are presented below. Figure 9 shows the result for the thermal comfort. In the first case (standard wall) the model achieves temperature in comfort during 35% of the year (considering 90% of satisfaction). The use of the Trombe wall increased this period by almost 10%, despite the slight increase in the heat discomfort. When the use of a curtain was analyzed, it was found that its influence in the cold discomfort is almost insignificant. In all cases studied the heat discomfort was low, which makes the adoption of alternative strategies to avoid the heat gain during the winter unnecessary.

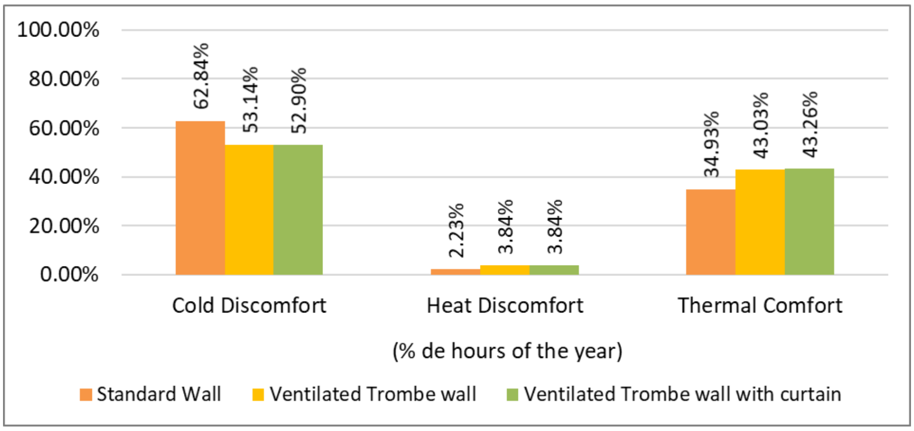


Figure 9. Thermal comfort, cold discomfort and heat discomfort for the three simulated models

For better understanding of those results, it is possible to observe Figure 10, where the heat conduction through the opaque surfaces, including walls, floor and roof for the Winter Solstice is shown. Since the only change between the three models occurs in the north wall, the graph in Figure 10 can help to understand the benefits of the Trombe wall for thermal comfort. It is possible to observe that all the three models present the same behavior, receiving heat from the beginning of the day until 9 a.m., losing heat between 9 a.m. and 5 p.m., and receiving heat again between 5 p.m. and midnight. However, it is clear that in the model without the Trombe wall the heat exchanges are greater, resulting in lower temperatures.

When the model with the curtain is compared with the model without it, the results are almost the same, with a small advantage for the first one. It is important to highlight that during this day the windows were closed all day long, since the internal temperature was always under 25°C (Figure 11). Therefore, there was almost no influence from the external air entrance, besides the air that entered through the gaps around the window.

Furthermore, as it can be seen in Figure 11, in all simulated models the internal operative temperatures are below the thermal comfort zone during the whole day, which means that other strategies to increase internal temperature are required. The minimum temperature should be 19°C, but not even the best model achieved 15°C.

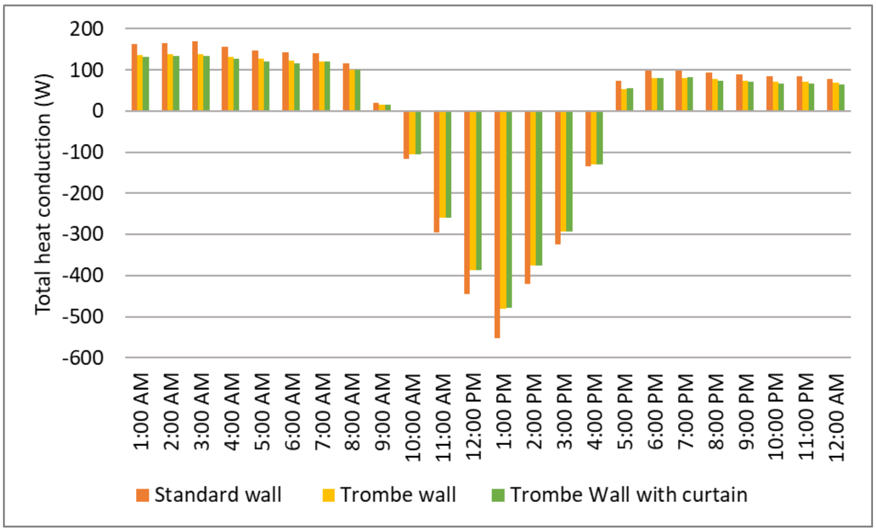


Figure 10. Total heat conduction for the three simulated models during the Winter Solstice

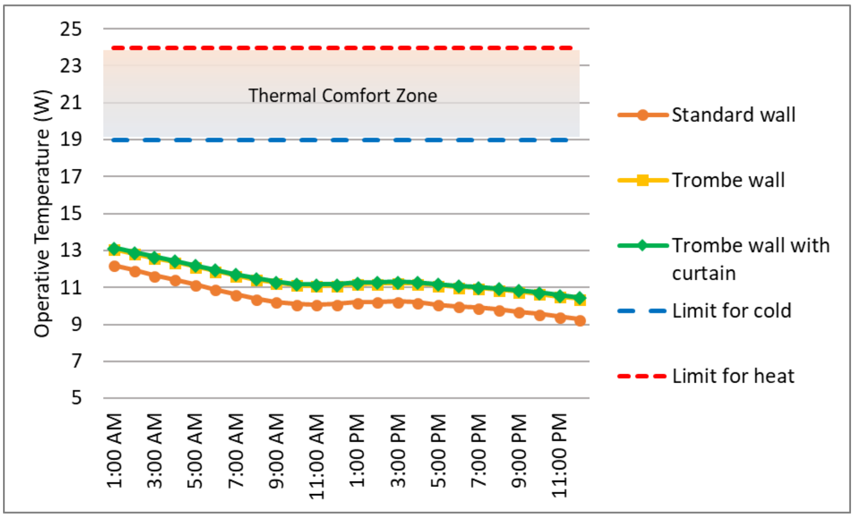


Figure 11. Operative temperature for the three simulated models during the Winter Solstice

During the Summer solstice (Figure 12), the total amount of heat conduction through the opaque surface is also greater for the model with the standard wall, as expected. The model receives less heat during most part of the night and loses more heat during the day, which leads to lower temperatures. However, in a greater part of the day, the temperatures are higher than the heat limit for all simulated models. In those cases, the internal shade is not used during this day, so the results are the same as those from the Trombe wall model without it. In addition, the windows are open almost all the time, because of the high temperature (Figure 13).

The total heat gain through the air infiltration can be analyzed in Figure 14. It is possible to see that the model with the Trombe wall lost more heat than the model with the standard wall. However, the airflow is not enough to remove the extra heat gain through conduction by the opaque surfaces in the model with the Trombe wall.

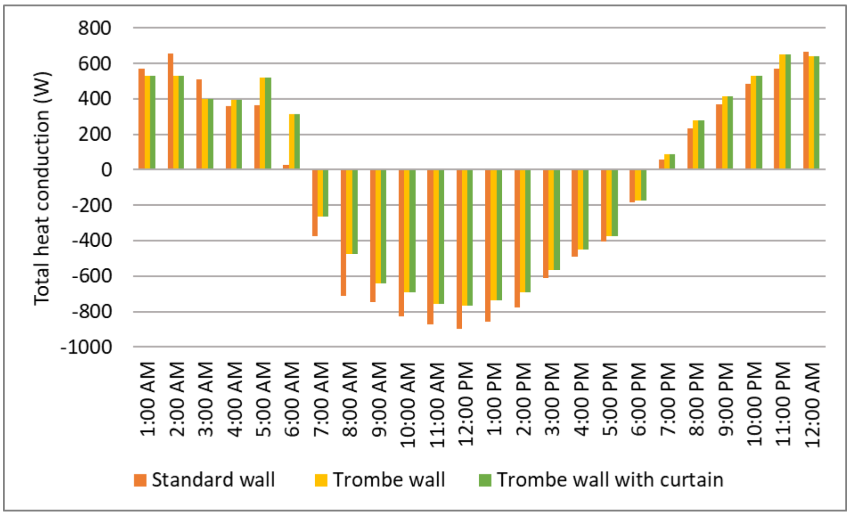


Figure 12. Total heat conduction for the three simulated models during the Summer Solstice

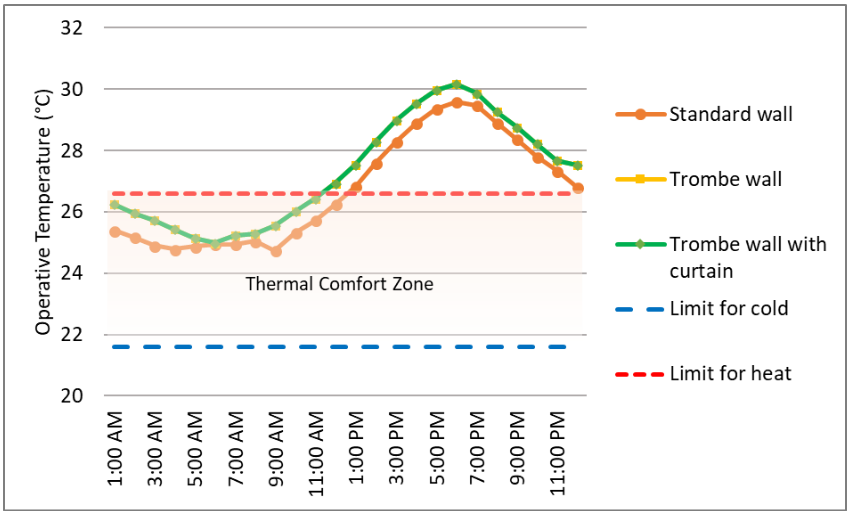


Figure 13. Operative temperature for the three simulated models during the Summer Solstice

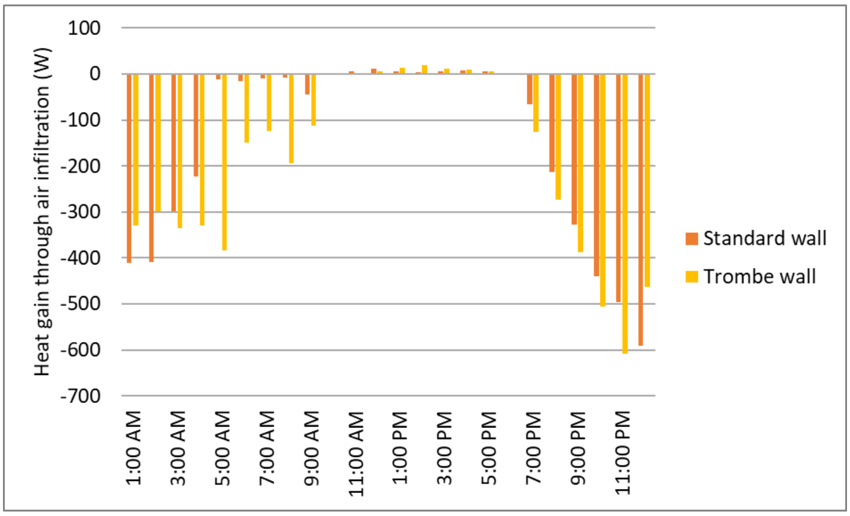


Figure 14. Heat transfer through air infiltration during the Summer Solstice

With regard to air mass flow, it can be observed that in the model with the standard wall the airflow is almost inexpressive during the day. Between 1 a.m. and 4 a.m., the flow rate occurs in the opposite way from the expected, while between 7 p.m. and 11 p.m. it flows from the south window to the north window. In the model with the Trombe wall, the ventilation is functioning as desired between 7 p.m. and 11 p.m., which is important, since the air that was heated during the day can be released. During the rest of the day, however, the direction to which the air flows oscillates (Figure 15).

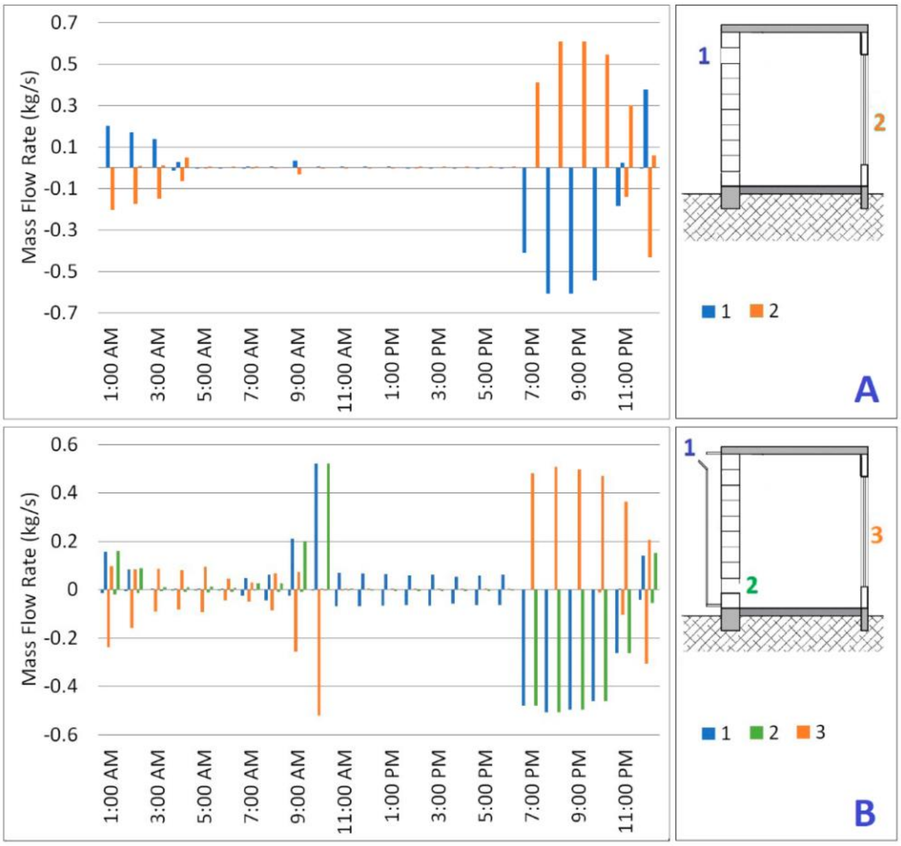


Figure 15. Mass flow rate during the Summer Solstice for the model with the common wall (A) and for the model with the Trombe wall (B). Negative values mean that the air is leaving the internal zone

V. CONCLUSIONS

From the analyses presented hereby, it can be observed that the Trombe wall system is a suitable alternative for Serra Gaúcha. Despite the slight increase of internal temperatures during the summer, the percentage of time in thermal comfort is greater when the Trombe wall is adopted.

However, the use of such system alone is not enough to guarantee thermal comfort the entire year. Although the Trombe wall can elevate the internal temperatures during the winter season, this increase is not enough to provide the indoor thermal comfort all year round. In the same way, during summer season, the air which flows through the openings of the Trombe wall intensifies the heat loss, but it cannot remove entirely the heat received during the day. Both situations may require the simultaneous adoption of other strategies. In addition, the use of curtain in winter and autumn nights did not improve thermal comfort in a significant way, which would not justify such investment.

VI. FUTURE SCOPE

The study of different materials to the storage wall and the adoption of the ventilated Trombe wall through the insertion of a window at the top of the storage wall to increase the heat gain are suggested as future work.

REFERENCES

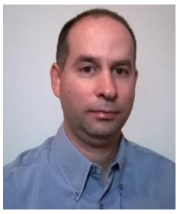
[1]. R. Lamberts, L. Dutra, F. O. R. Pereira. *Eficiência Energética na Arquitetura*. Rio de Janeiro, PROCEL / Eletrobrás, 2014.
[2]. P. J. F. de A. U. de Medonça, "Habitar sob uma segunda pele: Estratégias para a Redução do Impacto Ambiental de Construções Solares Passivas em Climas Temperados", Doctoral thesis, Universidade do Minho, Guimarães, 2005.
[3]. F. Abbassi, N. Dimassi, and L. Dehmani, "Energetic study of a Trombe wall system under different Tunisian building configurations", *Energy And Buildings,* v. 80, [s.l.], Sep., pp. 302-308, 2014.
[4]. O. Saadatian, K. Sopian, C. H. LIM, and M.Y. Sulaiman,"Trombe walls: a review of opportunities and challenge in research and development", *Renewable and Sustainable Energy Reviews*, v. 16, pp. 6340 – 6351, 2012.
[5]. B. Chen, X. Chen, Y.H. Ding, and X. Jia, "Shading effects on the winter thermal performance of the Trombe wall air gap: an experimental study in Dalian", *Renewable Energy*, no 31, pp. 1961-1971, 2006.
[6]. X. Hong et al., "Three-dimensional simulation on the thermal performance of a novel Trombe wall with venetian blind structure", *Energy And Buildings*, v. 89, [s.l.], Feb, pp. 32-38, 2015.
[7]. W. He, et al., "Thermal and hydraulic analysis on a novel Trombe wall with venetian blind structure", *Energy And Buildings*, v. 123, [s.l.], Jul., pp.50-58, 2016.
[8]. Z. Hu, et al., "Numerical analysis on the cooling performance of a ventilated Trombe wall combined with venetian blinds in an office building", *Energy And Buildings*, v. 126, [s.l.], Aug., pp.14-27, 2016.
[9]. M. Rabani and V. Kalantar; KALANTAR, "Numerical investigation of the heating performance of normal and new designed Trombe wall", *Heat And Mass Transfer*, v. 52, [s.l.], n. 6, pp.1139-1151, 2015.
[10]. S. Duan, C. J. and Z. Zhao, "Energy and exergy analysis of different Trombe walls", *Energy And Buildings*, v.126, [s.l.], pp.517-523, 2016.
[11]. M. Sameti, "A new design of a solar water storage wall: a system-level model and simulation", *Energy Syst*, n. 9, pp. 361-383, 2018.
[12]. J. Long, Y.A. and H. Sun, "Thermal insulation performance of a Trombe wall combined with collector and reflection layer in hot summer and cold winter zone", *Energy & Buildings*, n. 171, pp. 144-154, 2018.
[13]. B. Yu, et al., "Study on a high-performance photocatalytic-Trombe wall system for space heating and air purification", *Applied Energy*, n. 226, pp. 365-380, 2018.
[14]. E. V. Suzuki, "Avaliação do Potencial de Aquecimento / Resfriamento de um Sistema de Climatização Passiva". Masters dissertation, Universidade Tecnológica Federal do Paraná, Curitiba, 2012.
[15]. F. A. de M. S. Cavalcanti, "Paredes Trombe no Brasil: análise do potencial de utilização para aquecimento e refrigeração". Doctoral thesis, Universidade de São Paulo, São Carlos, 2013.
[16]. C. F. BIANCO, "Parede Trombe: estudo experimental comparativo de desempenho térmico para aquecimento e arrefecimento na cidade de São Paulo", Masters dissertation, Universidade de São Paulo, São Paulo, 2016.
[17]. Municipality of Bento Gonçalves, "Conheça a Cidade: Bento Gonçalves – RS", *Municipality of Bento Gonçalves*, 2017. [Online]. Available: http://www.bentogoncalves.rs.gov.br/a-cidade/conheca-a-cidade. [Accessed March. 24, 2017].
[18]. LabEEE, "Arquivos climáticos INMET 2016", *LabEEE*, 2017. [Online]. Available: http://www.labeee.ufsc.br/downloads/arquivos-climaticos/inmet2016. [Accessed March. 24, 2017].
[19]. EnergyPlus, "EnergyPlus", *EnergyPlus*, 2017. [Online]. Available: https://energyplus.net/. [Accessed March. 24, 2017].
[20]. P. E. ELLIS, "Development and Validation of the Unvented Trombe Wall Model in EnergyPlus", Masters dissertation, University of Illinois, Urbana-Champaign, 2003.
[21]. ABNT – Associação Brasileira de Normas Técnicas, *NBR 15220. Desempenho Térmico de Edificações – Parte 2: Métodos de cálculo da transmitância térmica, da capacidade térmica, do atraso térmico e do fator solar de elementos e componentes de edificações*, Rio de Janeiro, 2005.
[22]. V. A. C. da Costa, V. F. Roriz and. K. M. S. Chvatal, "Modeling of slab-on-grade heat transfer in EnergyPlus simulation program", Ambiente Construído, v. 17, no. 3, pp. 117-135, 2017.
[23]. EnergyPlus, *Input and Output Reference – The Encyclopedic Reference to EnergyPlus Input and Output*, Version 8.7., Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, USA, 2016.
[24]. Mermet. GreenScreen® Reflect™. "Product Specifications Sheet". Cowpens, USA, 2018.
[25]. L. Gu, "Airflow Network Modeling in EnergyPlus". In. Proc. 10th International Building Performance Simulation Association Conference and Exhibition, 2007, pp. 964-971.
[26]. EnergyPlus, *EngineeringVersion*, Version 8.7, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, USA, 2016.

[27]. A. C. MARTINS, "Contribuição da Parede de Trombe na Redução dos Consumos Energéticos dos Edifícios", Masters dissertation, Universidade de Trás-os-Montes e Alto Douro, Vila Real, 2010.
[28]. INMETRO - Instituto Nacional de Metrologia, Normalização e Qualidade Industrial, Portaria n°18, de 16 de janeiro de 2012, *Regulamento Técnico da Qualidade do Nível de Eficiência Energética Edificações Residenciais*, Brasília, DF, 2012.
[29]. R. de Dear and G. Brager, "Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55", *Energy And Buildings*, v. 34, pp. 549-561, 2002.

AUTHORS

ZIEBELL, Clarissa Sartori Ziebell

Graduated in Architecture and Urbanism from Federal University of Rio Grande do Sul (UFRGS). Master degree in Architecture from UFRGS. Doctorate student in the postgraduate Program in Design from UFRGS, under the guidance of Dr. José Luis Farinatti Aymone.



AYMONE, José Luis Farinatti

Graduated in Civil Engineering from Federal University of Rio Grande do Sul (UFRGS). Master degree in Civil Engineering from UFRGS. Doctor degree in Civil Engineering from UFRGS.