

Trombe Wall Revisited for Southern Hemisphere. Experimental Analysis of Energy Supply For Room Heating by Vented Trombe Wall

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ABSTRACT: This paper analyzes the energy supply by a Trombe wall for room heating operated by thermo-circulation vents.

Calculation procedures for design applications have been developed by Douglas Balcomb et Al at Los Alamos Scientific Laboratory.

When considering the performance of a Trombe wall system one of the major problems is the evaluation of the ratio between the heat contribution to the room and the solar radiation received by the wall.

For the current study the energy supply by vented Trombe wall was experimentally obtained and related to the radiation received by glassed area. To test and analyze the performance of the wall, a prototype of it has been designed and built to scale on the site of the Solar Energy Laboratory of Universidad Tecnica Federico Santa Maria (UTFSM), Viña del Mar, Chile.

Obtained results are presented graphically for the daily energy input/output relationship.

Keywords: Trombe wall, energy supply, energy balance.

NOMENCLATURE

ti	Interior daily mean temperature [°C], measured at 1,5m from floor.	qa	Heat gain through ventilation or infiltration [W/°C]
text	Exterior daily mean temperature [°C], measured outdoor.	U	Coefficient of heat transmission (U-value) of heat flow through test cell envelope [W/m ² °C]
Rad	Radiation measured vertically on North oriented wall [W/m ²]	A	Perpendicular area [m ²] to heat flow through conduction
Rad m	Daily mean radiation [W/m ²]	V	Introduced air through ventilation or infiltration [m ³ /s]
Atrombe	Trombe wall area [m ²]	C	Air specific heat, 1003 [J/Kg.°C]
EE	Trombe wall entering energy from radiation measured vertically on North oriented wall [MJ/ m ² day]	d	Air density, 1,29 [Kg./m ³]
OE	Trombe wall output energy [MJ/m ² day]		
qr	Total heat required [W/°C]		
qp	Heat loss to exterior [W/°C]		

1. INTRODUCTION

Calculation procedures for design applications have been developed by Douglas Balcomb et Al at Los Alamos

Scientific Laboratory, USA. When considering the performance of a Trombe wall system one of the major problems is the evaluation of the ratio between the heat contribution to the room and the solar radiation received by the wall.

The purpose of this study is to set terms for the aforementioned relation.

2. TEST CELL

This study was pursued at the Solar Energy Laboratory of the UTFSM, on inland Viña del Mar City (Latitude 33°2' S. and Longitude 70°). As described on NCh 1079, Architecture and Construction - Climatic Zones and Recommendations for Architectural Design for Residential Use in Chile, the climate for this location is denominated as "Central Inland" characterized by moderate temperatures, short winter, clouds and humidity dissipate at noon, important rains, predominantly western winds, salty and relative humid environment.

The test cell for the current study was built within the aforementioned climatic zone (Fig. 1), therefore the Trombe wall of the test cell was facing North and it has four vents, two located on the upper section and two on the lower section of the wall (Fig. 2).

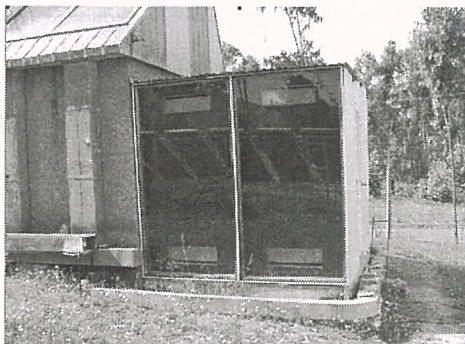


Figure 1: Trombe Wall Front View

2.1 Design Features

The design of the Trombe wall in regard the gap between the glass and wall and the specific locations of vents were specified on previous publication of the author (Sarmiento 1999).

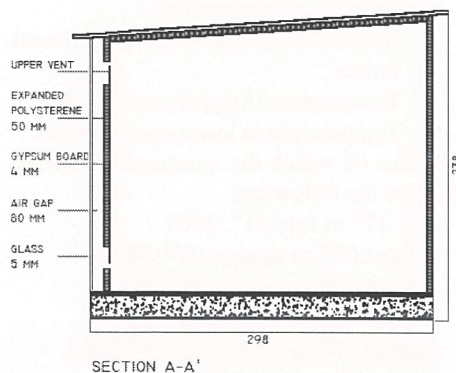
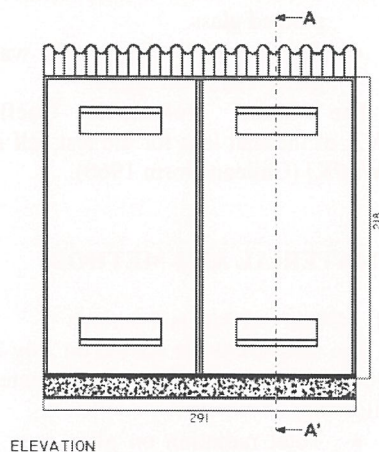


Figure 2: Elevation and Section of Test Cell

2.2 Building Specifications

The test cell was built under the following specifications:

- Exterior walls, light wood structure of 2x2" pine studs veneered with 4mm "Permanit" fibrocement panel.
- Roof, "Pizarreño" fibrocement 10cm wave roof panel.

- Wall insulation, 50mm expanded polystyrene.
- Floor, cement.
- Trombe Wall Paint, black opaque paint to facilitate solar radiation absorption.
- Trombe Wall Glass, 5mm single panned glass.
- Trombe Wall Gap within wall and glass, 80mm air space.

The Global Volumetric Coefficient, GV2, of thermal loss for the test cell is 1,64 [W/m³K] (Chilean Norm 1960).

3. MATERIAL AND METHOD

3.1 Observed data and periods

The measurements started on July 27th of 2004, being the registered parameters the following:

- Total radiation on glass area of the wall obtained by pyranograph
- Exterior air temperature
- Interior air temperature at different levels
- Temperature in upper section vents
- Temperature in lower section vents

The dates on which the measurements were made are the following:

- July 27th to July 31st, 2004
- August 03rd to August 09th, 2004
- August 09th to August 12th, 2004
- August 16th to August 21st, 2004
- August 27th to September 11th, 2004
- April 05th to April 20th, 2005
- July 21st to July 23rd, 2005
- July 25th to August 05th, 2005
- August 11th to August 26th, 2005

3.2 Instruments

- Piranograph Kipp&Zonen
- Voltage datalogger Gemini
- Temperature datalogger Gemini

3.3 Determination of entering energy (EE) and Trombe wall output energy (OE).

Data registered by the pyranograph (Fig. 3) was use to determine EE.

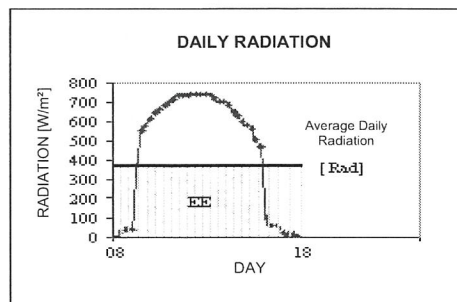


Figure 3: Daily Mean Radiation and EE

$$EE = \text{Rad m} \cdot T \cdot 10^{-6} [\text{MJ/m}^2 \text{ día}] \quad (1)$$

To obtain the value of Trombe wall output energy (OE) the following equation was applied

$$EA = \frac{[(qr) (ti - text) \times 24 \times 3600 \times 10^{-6}]}{A_{\text{Trombe}} [\text{MJ/m}^2 \text{ day}]} \quad (2)$$

This expresses the required heating energy per Trombe wall area unit during one day, based on heat loss to exterior and through ventilation or infiltrations generated by the system.

At the same time equation (2) is dependant on equations (3), (4) and (5), on figure 4 is possible to visualize an energy flow scheme:

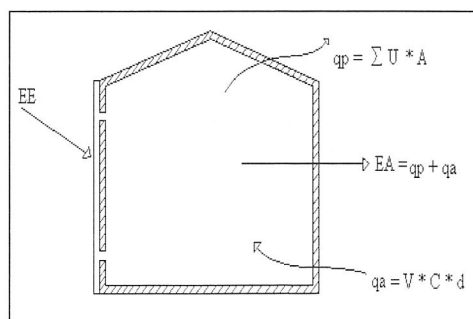


Figure 4: Energy Flow Scheme of EE and OE

$$q_r = q_p + q_a \quad [\text{W}/^\circ\text{C}] \quad (3)$$

$$q_p = \Sigma U^* A \quad [\text{W}/^\circ\text{C}] \quad (4)$$

$$q_a = V * c * d \quad [\text{W}/^\circ\text{C}] \quad (5)$$

3.4 Daily cycle to take into consideration

The cycle of solar energy intake by the Trombe wall started at sunrise and ended at sunset. It was also important to consider that the entering energy to indoor, obtained through the Trombe wall, was not restricted only to sun hours.

During solar gain hours, part of the energy output went to the interior air and also it was absorbed by the floor. The absorbed energy is released to the interior air past sunset hours until the cycle of solar energy started again.

Therefore, the daily cycle to be taken into consideration was not from 0 to 24 hours, it was 24 hours from dawn on instead.

3.5 System Performance

It is possible to obtain the daily system performance for each day, due to EE and OE data, where performance η is define on equation (6) as:

$$\eta = EA / EE * 100 \quad [\%] \quad (6)$$

3.6 Collected Data

Figure 5 shows interior air temperature of test cell, measured at three different heights for the studied period. The results depicted from clear sky, cloudy sky to overcast days. During clear sky interior air reached maximum temperatures, over 35°C .

Also, the most representative interior air temperatures of the test cell were those taken at 1,5m height from floor, which are the typical one taken in this type of studies, therefore it is the one considered for the current paper.

Nevertheless, it is interesting to find that important differences for a given day between temperatures are observed mainly during clear sky, when overcast temperatures tend to mix.

AIR TEMPERATURE COMPARISON AT DIFFERENT HEIGHTS
(03 - 09 August 2002)

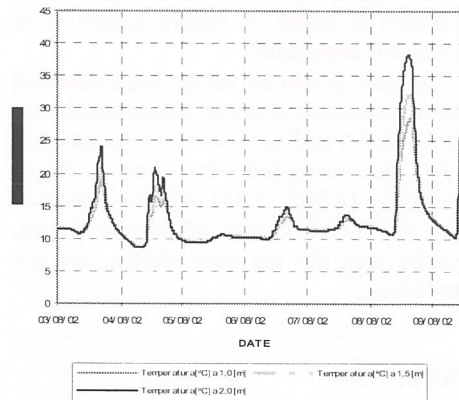


Figure 5: Comparison of interior air temperatures of test cell, at three different heights.

INTERIOR AIR TEMPERATURE AT 1.5[m] & EXTERIOR AIR TEMPERATURE (03 TO 09 AUGUST 2002)

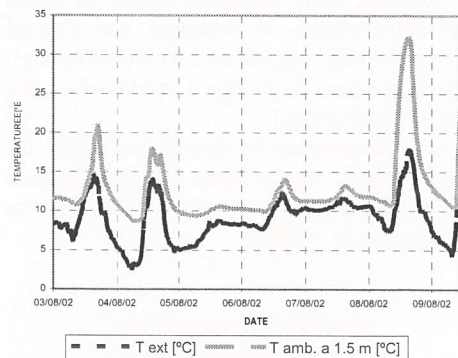


Figure 6: shows interior and exterior air temperature for the studied period, it is possible to distinguish clear sky from overcast days.

The analysis of this graph (Fig. 6) allow us to confirm the consideration of Trombe wall energy output as the energy equivalent to the heat loss of test cell to exterior. It is clear too that interior air temperature is always above exterior air temperature during the studied period. Therefore, heat flow can be calculated from equations (2), (3), (4) and (5).

3.7 Calculation of results

To make desired calculations was necessary to count on shown equations as well as collected data.

Test cell q_r and q_a values were obtained from construction features, which results are 24,71 (W/°C) and 5,39 (W/°C) respectively.

As recommended by Los Alamos Laboratory (ASES, 1983), it is convenient to point out that heat loss of passive device, Trombe wall for the case shown, are not considered.

4. RESULTS

Results are presented on graph of Trombe wall energy output (fig. 7), where OE, Trombe wall output energy versus EE, Trombe wall entering energy from radiation are the axis respectively.

Average daily radiation values on North vertical surfaces, in Santiago and Central areas of Chile, vary from 6 to 8 [MJ/m²day], reaching a maximum for a winter clear sky day 16 [MJ/m²day].

It is interesting to demonstrate that for Trombe wall works better a single panned glass instead of double panned glass, where cost saving is evident.

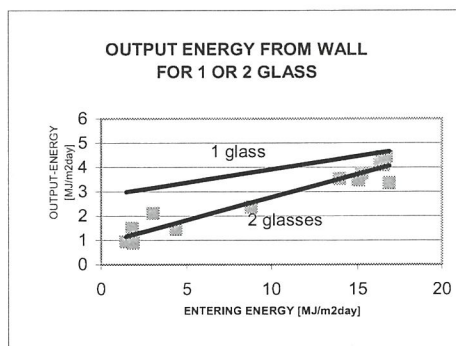


Figure 7: Trombe wall output energy (OE) in function of entering energy (EE).

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Then, why Los Alamos Lab (ASES 1977) and Lunde (1980) recommended double panned glass for all passive applications?

Reasons can be explained by understanding a benign climate, as in the studied case, heat losses to exterior are not very important. The latest depend on the U-value of glass veneer, single or double glass, the external surface of wall and the exterior air temperature. Temperature differences are little for our climate compared to climates where investigations were carried out, because of that, the use of double glass is not necessary for our case, regardless the lower U-value.

Also, one glass has a better transmissivity of solar radiation than two glasses, as a consequence it implies a better solar intake by the exterior wall surface.

Trombe wall performance and output energy can be analyzed through values observed on figure 8.

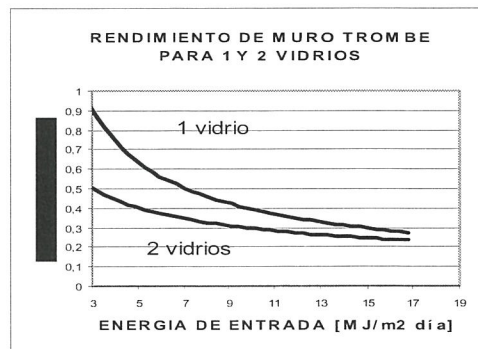


Figure 8: Trombe wall performance for one and two glasses.

As a reference we are including values presented by Mazria (1999), the author has registered annual performance values for the following localities:

Madison, Wisconsin: 24%.

Boston, Massachusetts: 44%.

Fresno, California: 78%.

Albuquerque, New Mexico: 84,4%.

Observed daily performance value for the case study considering one glass is 55% to 28% within a range of interest of 6 to 16 [MJ/m²day] respectively.

It can be demonstrated that performance can reach 90% for 3 [MJ/m²day]. This corresponds to a value for a fully overcast day; however it does not have much practical interest for application.

As solar radiation intake of Trombe wall increases the tendency is to decrease the efficiency of the wall, which can be explained on the increasing heat losses due to exterior surface of the wall.

Nevertheless, it is important to consider that if radiation increases so does the EE, entering energy and OE, output energy, as can be observed in figure 7.

5. CONCLUSIONS

As a very important consequence of this study it was possible to corroborate that for Central Chile climatic conditions characterized by high solar radiation and moderated climate, it is convenient to use one glass for Trombe wall instead of two glasses, recommended on former revised research.

Included graphs will allow others to design a Trombe wall with vents determined by the energy output; therefore it will also be possible to calculate the energy and cost saving on heating involved in a particular design, which will depend on the entering solar energy of the specific site.

Strictly speaking, above conclusions are valid for test conditions only, that is to say, for identical climate and construction material features of Trombe wall.

It is important to highlight that climatic conditions in our country, regardless the ten climatic zones, are not extreme. Also, received solar radiation variations and air temperature oscillations are exiguous, quite comparable to the test cell conditions.

In relation to the construction material features of the test cell, a GV2 value of 1,64 [W/m³K] is not far from GV2 value of 2,7 [W/m³K], average value found for social housing (Sarmiento, Hormazábal, 2002) and it is even closer to the GV2 value for future housing requirements, which will be included promptly on the addendums to the building code by the Chilean housing authority, where thermal standards are to be adjusted to new norms. This is part of the second stage of the thermal regulations for housing to be included in the Chilean Building Code – OGUC, Minister of Housing and Urban Planning – MINVU, which is currently in the Congress for approval.

In relation to performance values, as it was mentioned before, their range of variation is similar to Marzria's work, although we do not count on much comparative antecedents.

Without further available information on the exposed topics, the information currently included in this research is available to anyone interested on heating application through a passive and low energy system, the Trombe wall with vents, especially for people in this region.

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