Informes de la Construcción
Vol. 65, EXTRA-1, 11-22,
septiembre 2013
ISSN: 0020-0883
eISSN: 1988-3234
doi: 10.3989/ic.11.152

Trombe wall and glazings facades: Energy efficiency for different Portuguese Climates

Fachadas con muro Trombe y doble acristalamiento: Eficiencia energética para diferentes climas Portugueses

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SUMMARY

High performance glass and Trombe walls in the façade was studied in this research. The paper reports results of an ongoing investigation on a new façade system concept, designed as: "Façade Modules for Eco-Efficient Refurbishment of Buildings", especially on energy efficiency of Trombe wall and glazing modules arrangement. Computational simulation was carried out by using the software DesignBuilder. Two double glazing types and Trombe walls were considered for three different climates in Portugal and four solar orientations. Results obtained for heating energy needs were compared to all façade configurations. The use of Trombe wall and the double self-cleaning glass in the façade point towards a significant decrease of heating energy needs. The great majority of the façades combinations presented energy needs lower than the maximum allowed by the Portuguese regulation (RCCTE).

RESUMEN

Esta investigación aborda el estudio de fachadas con cristales de altas prestaciones y muros Trombe. El artículo presenta los resultados de la investigación en curso sobre un nuevo concepto en sistemas de fachada, denominado "Módulos de fachada para el acondicionamiento eco-eficiente de edificios", especialmente enfocado a la eficiencia energética de muros Trombe y módulos con doble acristalamiento. Haciendo uso del software DesignBuilder se realizaron simulaciones de una estancia, analizando distintos conjuntos de fachadas modulares. Para la realización de las simulaciones se consideraron dos tipos de módulos de doble acristalamiento, dos configuraciones de muros Trombe, tres climas diferentes en Portugal y cuatro orientaciones solares. Se compararon los requerimientos de calefacción de cada una de las configuraciones, observándose que tanto los muros Trombe como los módulos de doble acristalamiento presentaron disminuciones significativas en cuanto a requerimientos de calefacción. De las configuraciones analizadas, la mayoría presentó demandas energéticas de calefacción menores a lo especificado en la normativa portuguesa (RCCTE).

113-126

Keywords: Façade; energy efficiency; Trombe wall; double glazing.

Palabras clave: *Fachada; eficiencia energética; muro Trombe; doble acristalamiento.*

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Recibido/Received: 20 dec 2011
Aceptado/Accepted: 19 apr 2012

1. Diagram: Operation of Trombe wall in winter and summer.

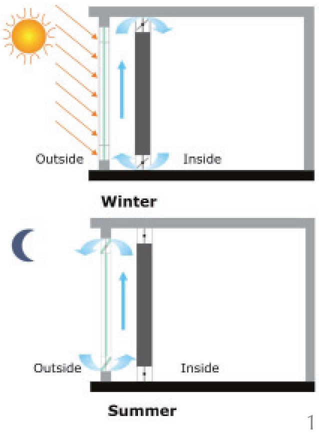
2. Visitor Center Trombe wall. Reference: NREL, 2011 (7).

3. "Casa Termicamente Optimizada" – South Façade, Porto. Reference: GONÇALVES *et al.*, 1997 (8).

1. INTRODUCTION

Passive solar design can greatly increase the energy efficiency of a building. It includes a variety of strategies and technologies that use the free energy received from the sun for the purpose of heating and lighting building spaces. Trombe wall is one example of this kind of technology. An American named Edward Morse was the first to describe the Trombe wall concept in a patent in 1881 (1). This concept was ahead of its time and stayed more or less unknown until 1972, when the idea was repatented and popularized by the French engineer Felix Trombe and the architect Jacques Michel (2). The Trombe wall is also known as a Trombe-Michel wall, solar wall, thermal storage wall, collector storage wall, or simply storage wall.

A typical Trombe wall consists of a 10- to 41-cm-thick, south facing wall with a dark, heat-absorbing material on the exterior surface and faced with a single or double layer of glass. The glass is placed from 2 to 5 cm from the massive wall to create a small airspace. Heat from sunlight passing through the glass is absorbed by the dark surface, stored in the wall, and conducted slowly inward through the wall. High transmission glass maximizes solar gains to the wall. As an architectural detail, patterned glass can limit the exterior visibility of the dark concrete wall without sacrificing transmissivity. For a 20cm-thick Trombe wall, heat will take about 8 to 10 hours to reach the interior of the building. It means that rooms warm slowly, reducing the need for conventional heating considerably (3).



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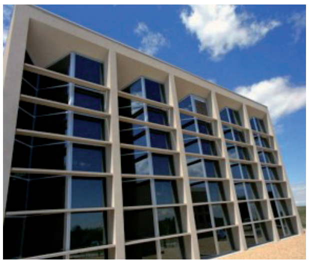

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During the day in winter, vents should only be opened because heating is necessary, in other words, when the temperature of the air space exceeds inside temperature. At night to reduce heat losses, vents on glazing and massive wall should be closed. The vents should be closed in summer and have a shading system should be provided. During the night to facilitate cooling outside vents should be opened (Figure 1).

The performance of Trombe walls is poor if the interior part of the wall is not in contact with the indoor airspace. Based on previous experiences with Trombe walls (4) (5), the heat delivered by a Trombe wall in a residence was reduced by over 40% because kitchen cabinets were placed against the interior surface of the wall. Trombe-wall (TW) has been used in decades as an efficient and durable solar heating method. The TW comprises a massive thermal wall and a clear glazing cover with an air duct in between.

The outer surface of the massive wall is usually painted black to increase its absorptivity of solar radiation (6) Some example of Trombe wall uses can be shown. The Visitor Center Trombe wall is located on the entire length of south-facing walls of the Visitor Center. The wall is 44% of the total south facing wall area (Figure 2).

The Trombe wall is (20 cm) grout-filled concrete masonry units and has a single piece of high transmittance patterned glass installed on a thermally broken storefront system. In the Visitor Center, 20% of the annual heating is supplied by the Trombe wall (3).The huge, undulating Trombe wall has five sections, and each angled in a "V" shape. Windows on the south side of the "V" provide natural daylighting and early morning heat. Horizontal beams in front of the windows prevent direct sunlight from entering during the summer.

On the other side of the "V" there is a thick concrete wall coated with black paint and faced with glass. A small airspace separates the wall from the glass (7). Figure 3 presents another example of Trombe wall use in Portugal. This system is on the first floor and its function is capture, storage and heating distribution. Bezian and Arnaud propose a system similar to the Trombe wall with parallelipipedic spaces filled with water inside the collector wall (9). In the Barra-Constantini system (10) the southern wall can be any conventional wall, e.g. concrete, bricks, stud wall, etc., but it requires a better external insulation. A solar collecting element is placed in front of the wall, (e.g. a number of metal lath layers or a corrugated metal sheet), covered by glazing.

In recent decades façade technologies have undergone to substantial innovations both in quality of materials/components and the overall design concept of the façade system by integrating specific elements to adapt the mediation of the outside conditions to user requirements. These improvements include passive technologies, such as multi layered glazing, sun protections, ventilation, Trombe walls, etc. (11) as shown previously.

The ideal goal for new façade system would be the development of a dynamic and flexible system in way to adapt to the climatic changes, to the occupants requirements and, on the other hand, to adapt to the building. An improvement would be the development of a suitable system that facilitates the assembly of the façade, containing passive elements, glazing and reception of solar energy. Improve the comfort conditions in agreement with the climatic needs and be mounted in agreement with the solar orientations and wanted functions.

 Informes de la Construcción, Vol. 65, Nº EXTRA-1, 11-22, septiembre 2013. ISSN: 0020-0883. eISSN: 1988-3234. doi: 10.3989/ic.11.152

This paper presents partial results of an investigation about glazing and Trombe wall modules of a new façade system, designed as: "Façade Modules for Eco-efficient Refurbishment of Buildings" on the development (12) (13), especially on thermal performance of some modules arrangement. Solar shading and ventilation modules also were added to a façade arrangement that presented one of the largest cooling energy needs among other solutions.

2. METHODOLOGY

Computational simulation was carried out applying the DesignBuilder (graphical interface for EnergyPlus) software. A room (25 m²) with different arrangements of façade modules was considered as a case study. Simulations were made considering the following parameters:

1. Two different double glazing types (composed by green solar control glass and low-e glass; self-cleaning glass and float clear glass);
2. Four solar orientations (north, south, east and west);
3. Three Portuguese climates;
4. Two envelopes: a Portuguese conventional system (double masonry) and a light gauge steel framing system (LGSF).

For validation purposes, the heating and cooling energy needs values obtained by thermal simulations were compared with the ones calculated in accordance with the Portuguese energy building performance regulation, “Regulamento das Características do Comportamento Térmico dos Edifícios - RCCTE” (14). The use of a façade with one and two Trombe walls modules arrangement was studied.

To assist the minimizing energy consumption for cooling in summer, solar shading and ventilation modules have been inserted also in a façade arrangement that presented one of the largest cooling energy needs.

For thermal performance simulation, three Portuguese climates were analyzed, in this case, Bragança, Coimbra and Faro. Simulations were carried out for four solar orientations (north, south, east and west), considering the annual period, and the energy heating and cooling energy needs calculated according to RCCTE were used in the analysis (Table 1).

2.1 Design Builder

In order to test passive solutions and foresee their performance in a more economical and less time-consuming way than with practical experiments, computer simulation offer a variety of tools that can be used. Ellis (15) did a validation of EnergyPlus use for unvented Trombe wall model and it performs well compared to experimental data. According to the author, users should not hesitate to use the model for the simulation of passive solar buildings.

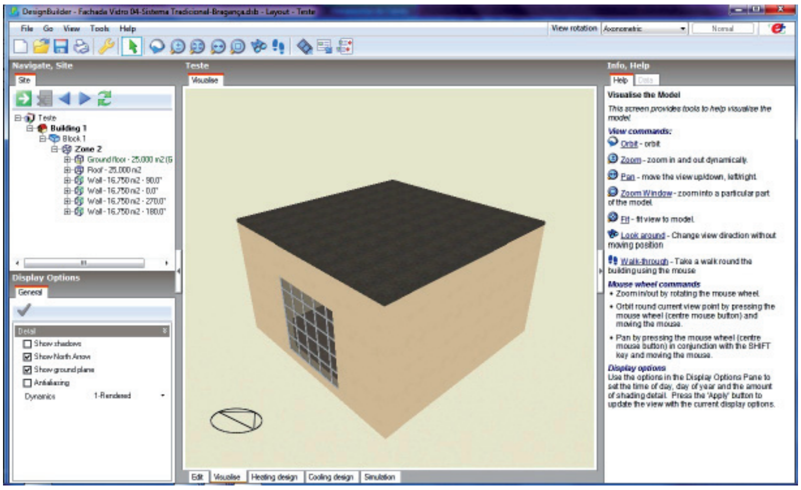
In this research, the software used was DesignBuilder v. 1.8. DesignBuilder software is a friendly graphic interface for the program EnergyPlus simulation engine, to the family of software tools for modeling building façades and fenestration systems. Developed for use at all stages of building design, DesignBuilder combines state-of-the-art thermal simulation software with an easy-to-use interface. This software allows calculating building energy use; evaluating façade options for overheating and visual appearance; visualization of site layouts and solar shading; thermal simulation of naturally ventilated buildings; lighting control systems model savings in electric lighting from daylight; calculating heating and cooling equipment sizes, etc.

The results of “Standard Method of Test for the evaluation of Building Energy Analysis Computer Programs” for DesignBuilder agree with the equivalent results for the EnergyPlus simulation engine. It shows that DesignBuilder is generating correct input data for EnergyPlus, as well as adding to confidence in the absolute accuracy of the results generated by DesignBuilder/ EnergyPlus (16).

The majority of results for DesignBuilder were found to be identical to the results extracted from the Gard Analytics report for EnergyPlus run in standalone mode; the remainders were showed as minimal differences (17). This kind of tool can be used for the development of new façades system, incorporating passive solutions, as in this case (Figure 4).

Table 1. Climates for Computational Simulation.

Climates	Climatic Zone		Energy Needs		Duration of Winter (months)	Degree Days (ºC DD)
	Winter	Summer	Heating (kWh/m².year)	Cooling (kWh/m².year)		
Bragança	I3	V3	128.70	26.00	8.0	2850
Coimbra	I1	V2	68.13	16.00	6.0	1460
Faro	I1	V2	50.69	32.00	4.3	1060



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4. DesignBuilder software main screen.

5. Model: One Trombe wall.

6. Model: Two Trombe wall.

Trombe wall systems can be simulated in DesignBulder software using an option of inside convection algorithm called "cavity". In this option, the zone is a cavity such as the glazed cavity within Trombe wall or a double façade.

This algorithm correctly calculates the convection coefficients for a narrow sealed vertical cavity based on the ISO 15099 standard . The algorithm analyzes the Trombe wall zone to figure out which are the two major surfaces and then sets the coefficients on those surfaces. The other minor surfaces receive negligible convection (18). As previously mentioned (15), EnergyPlus modeling approach for the sealed passive Trombe wall has been validated with experimental data.

For a naturally ventilated Trombe wall, there is no built-in algorithm for calculating the correct convection coefficients on the inside of the cavity walls. One option is to use the "Detailed" inside convection algorithm. This algorithm takes into account some natural convection effects but is intended for a normal sized room. It is possible to define holes and vents through the Trombe wall by drawing them on at surface level. Vent openings can be scheduled and controlled by internal temperature (18).

In this research "cavity" and "detailed" inside convection algorithms was tested in DesignBuilder, but as the heating energy needs values were similar for a small ventilation ($0.10x0.20m^2$) and Trombe wall area of $0.50x2.50m^2$. Based on these initial tests, the zone inside convection algorithm was set to "cavity" for Trombe wall study.

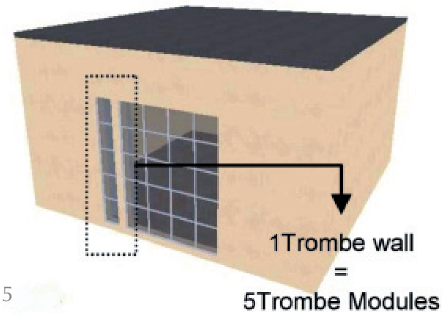
Solar shading devices also can be simulated in DesignBuilder software using two types for external windows: window shading (blinds, curtains etc walls and roofs) and local shading (overhangs, louvres, sidefins on external walls only). These types of shading can be used individually or combined. The window solar shading devices can be positioned in one of four ways: inside (the window shading devices is positioned inside the zone); mid-pane (the window shading device is positioned between the inner pane and the second pane); outside (the shading devices positioned outside) and switchable (select this option for electrochromic glazing in which case the outer pane is switched based on the shading control). However, according to types of solar shading there are different possibilities (18).

2.2 Standard Model Definition

2.2.1. Trombe wall

The "standard model" was defined considering a one-storey isolated room, with regular geometry 5.0 x 5.0 (25 m^2), a ceiling height of 2.80 m, and a total dimension of 2.5 x 2.5 (6.25 m^2) for the façade glazing modules composition (Figure 4).

These dimensions followed the recommendations of the Portuguese Urban Building Regulation *"Regulamento Geral das Edificações Urbanas"* (19). This isolated room was simulated considering the implementation of one or two Trombe walls. A set of five Trombe modules makes a complete "Trombe wall" (Figures 5 and 6).



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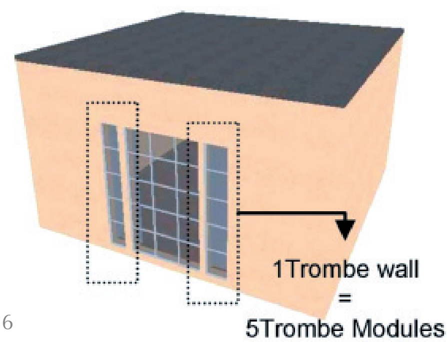

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For Trombe wall module, in this facade system, was considered the use of a double glazing with high shading coefficient. The double glazing has two panes composed by diamant glass 4 mm (Saint-Gobain Glass) and 12 mm air space, thus allowing maximum solar radiation penetration. The area of a complete Trombe wall composed of five modules is 0.50 x 2.50m (1.25m²). Higher and lower modules have ventilation openings on the massive wall, whose area is 0.02m² (0.10x0.20m²), as previously mentioned. The operating time was considered for such openings from 9:00 to 18:00 for the winter. During the summer the openinings remained closed during the day and opened at night.

2.2.2. Solar shading and ventilation modules

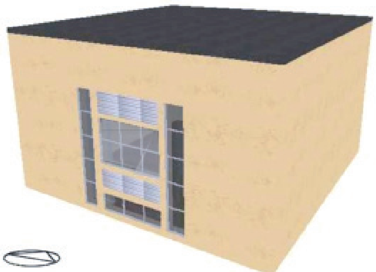
The ideal objective for glazed façades is to maximize the solar radiation through the glazing in winter and to minimize it in summer and solar shading devices can assist in this process. To propose the use of shading devices becomes necessary to know the sun apparent path to be possible a proper and effective design of such elements. In summer, ventilation devices also can offer an important cooling energy consumption decrease.

Thereafter, solar shading and ventilation modules were added to façade composed by glazing 07 and one Trombe wall studied, because this solution presented one of the largest cooling energy needs among other solutions (glazing 07 and two Trombe walls showed similar results). The simulated configuration consists of a small horizontal louvers set positioned on the main part of the glazing outside (because in the software is not possible to choose different types of solar shading for the same wall to shading different façade elements). To help minimizing energy consumption for cooling, ventilation modules have been inserted also in the façade system (Figures 7 and 8).

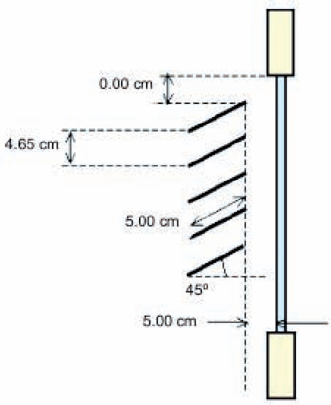
Solar protection devices were composed by horizontal aluminum profiles. The activation profile of this modules considered was the same necessary for the period in which cooling is required (summer).

2.3. Envelopes

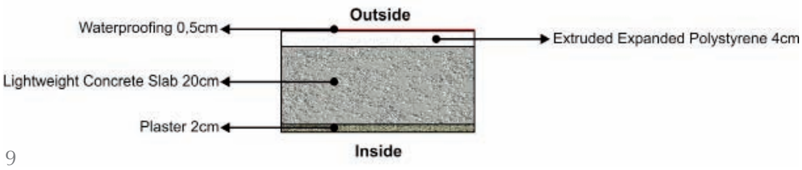
A Portuguese conventional construction system (double-wall masonry) and a light gauge steel framing system (LGSF) were considered in the model for the opaque envelope. The conventional system is composed by lightweight concrete slabs and insulation (Extruded Expanded polystyrene - EPS), plaster and waterproofing. External walls are double masonry with interior insulation, air space and cement mortar plaster (Figure 9 and 10). The LGSF envelope composition was based on the work of Santos *et al.* (20). Lightweight concrete, rock wool, gipson board, OSB, ceramic and air space compose the light gauge steel framing system slab. EIFS (External Insulation and Finish System), OSB boards, stone wool and gypsum plasterboard was used in the walls (Figure 11 and 12).



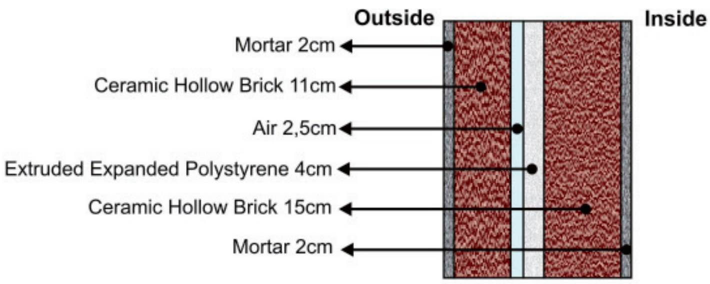
7. Model: One Trombe wall with solar shading area and ventilation modules.



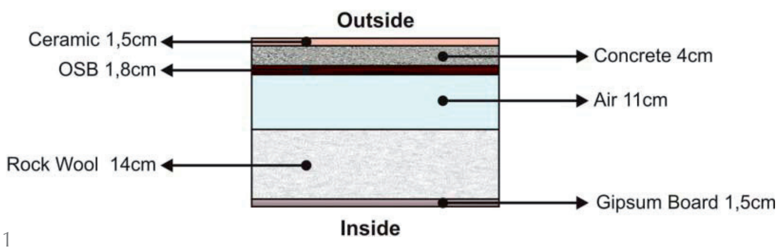
8. Louvers details.



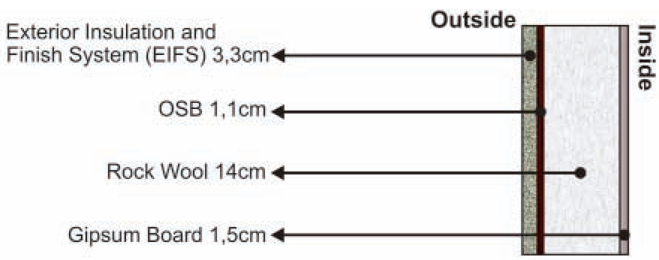
9. Portuguese Conventional System: Roof Slab.



10. Portuguese Conventional System: Wall.



11. Light Gauge Steel Framing System: Roof Slab.



12. Light Gauge Steel Framing System: Wall.

In this case, it was not considered a real roof, only an insulated slab in order to take advantage of façade solutions and focus on thermal performance of those modules.

Table 2 presents the overall heat transfer coefficient values - U-factor (W/m² ºC) for Portuguese conventional construction system and light gauge steel framing system.

Table 2. Overall Heat Transfer Coefficient (W/m² ºC).

Heat Transfer Coefficient (W/m² ºC)		
Element-Envelope	Portuguese Conventional System	
	Total Thickness (cm)	U (W/m²ºC)
External Walls	0.365	0.46
Roof Slab	0.280	0.55
Element-Envelope	Light Gauge Steel Framing System	
	Total Thickness (cm)	U (W/m²ºC)
External Walls	0.200	0.14
Roof Slab	0.333	0.22

Table 3. Glass types for standard module.

Glass Types						
Properties	Cool Lite KNT 155 Green	Bioclean	Planilux	Planitherm Total	Planitherm Futur Ultra N	Diamant
Thickness (mm)	4 mm	4 mm	4 mm	4 mm	4 mm	4 mm
Solar Factor	0.45	0.84	0.85	0.66	0.63	0.90
Shading Coefficient	0.52	0.97	0.98	0.78	0.72	1.04
Visible Transmittance	0.47	0.87	0.90	0.85	0.88	0.91
U (W/m²K)	5.75	5.87	5.80	5.74	5.73	5.80

Table 4. Glass Samples.

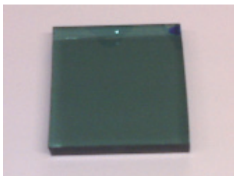
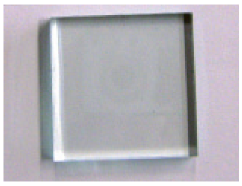
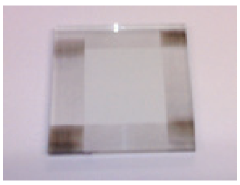
Glass Samples		
Cool Lite KNT 155 Green	Bioclean	Planilux
		
Planitherm Total	Planitherm Futur Ultra N	Diamant
		

Table 5. Glazing Properties.

Properties	Glazing		
	Glazing 04	Glazing 07	Trombe Glazing
Outermost Pane	Cool Lite KNT 155 Green 4mm	Bioclean 4mm	Diamant 4mm
Inner Pane	Planitherm Futur Ultra N 4mm	Planilux 4mm	Diamant 4mm
U (W/m²K)	1.66	2.69	2.72
Solar Factor	0.28	0.40	0.83
Shading Coefficient	0.33	0.46	0.95
Visible Transmittance (%)	0.42	0.71	0.84
Relative Heat Gain (W/m²)	217.72	311.28	622.90

Table 6. Internal Gains (W/m²).

Internal Gains	Values (W/m²)	Details
Occupation	5.6 W/m² (2 people)	70W per person
Lighting	9.4 W/m²	Illuminance (incidence): 300 lux; Fluorescent lamp (40 W); Efficiency 80 lm/W (40 % delivery efficiency).
Equipments	8 W/m²	Equipment potency: 200 W.

2.4 Glazing Types

Important factors must be observed in the glazing choice, such as: solar factor (or g-value), solar heat gain coefficient, shading coefficient, and visible transmittance, furthermore U-factor resultant of glazing composition. The glasses selected for the standard façade module simulations are from Saint-Gobain Glass.

Table 3 presents the main properties of simple glasses and Table 4 glass samples.

These glasses were used in the computational simulations in DesignBuilder software to obtain heating energy needs for climates. Furthermore, a 12mm air layer between outermost and inner panes was considered. It should be noted that these values were obtained from Window 6.2.33.0 software (21).

Table 5 presents the glazing compositions based on the glasses types presented in Table 3. In addition, cool Lite KNT 155 green is a temperable solar control glass; planitherm futur ultra N is a glass with emissivity extremely low; Bioclean is a self-cleaning glass; Planilux is a multi-purpose clear float glass, and Diamant is a clear float glass.

2.5. Internal Gains and Reference Temperatures

The Portuguese standard RCCTE (14) presents 4W/m² as an average value for the total internal gains (occupation, lighting and equipments). However, due to possibilities and simulation options offered by the software DesignBuilder, the internal gains were separated for the occupation, lighting and equipments (Table 6).

As RCCTE standard does not contemplate schedules (days of the week, hour and time) of occupation, lighting and equipments use for housing buildings, the values was obtained from Souza (22) and ventilation schedules were estimated (Figure 13 to 16).

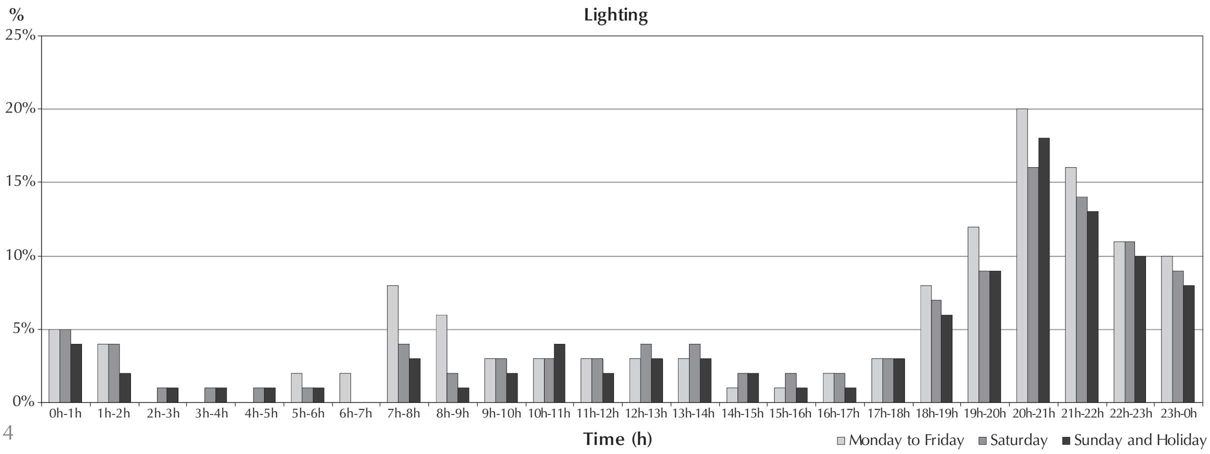
The value 20°C was considered as reference of heating indoor temperature (winter) and 25°C for cooling indoor temperature (summer), in agreement with RCCTE.

The heating and cooling energy needs for four solar orientations (north, south, east and west), considering the annual period, are presented.

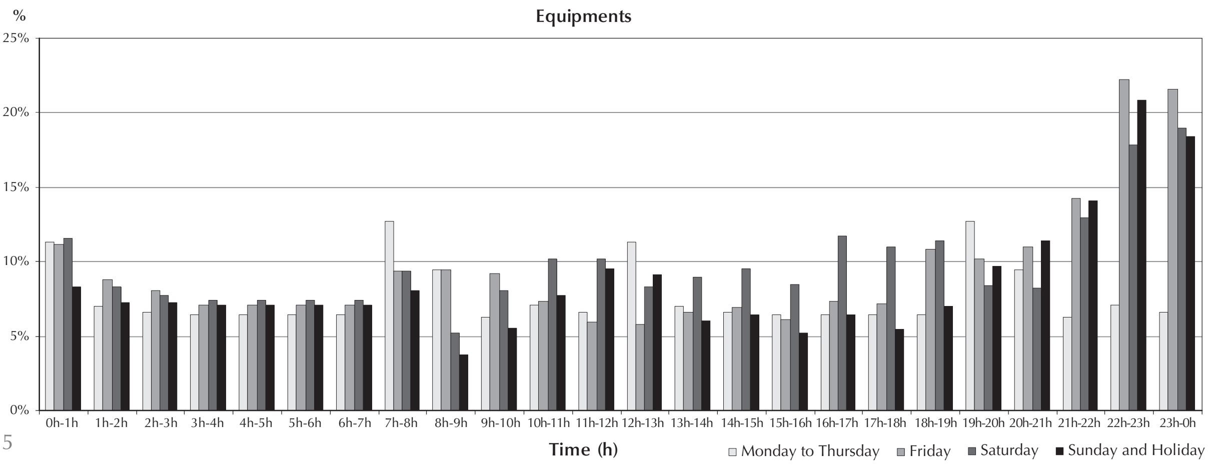
The analysis of the results was based on the heating and cooling energy needs estimation for Bragança, Coimbra, and Faro performed according the RCCTE energy calculation method.


Occupation
%
Time (h)
Monday to Friday
Saturday
Sunday and Holiday

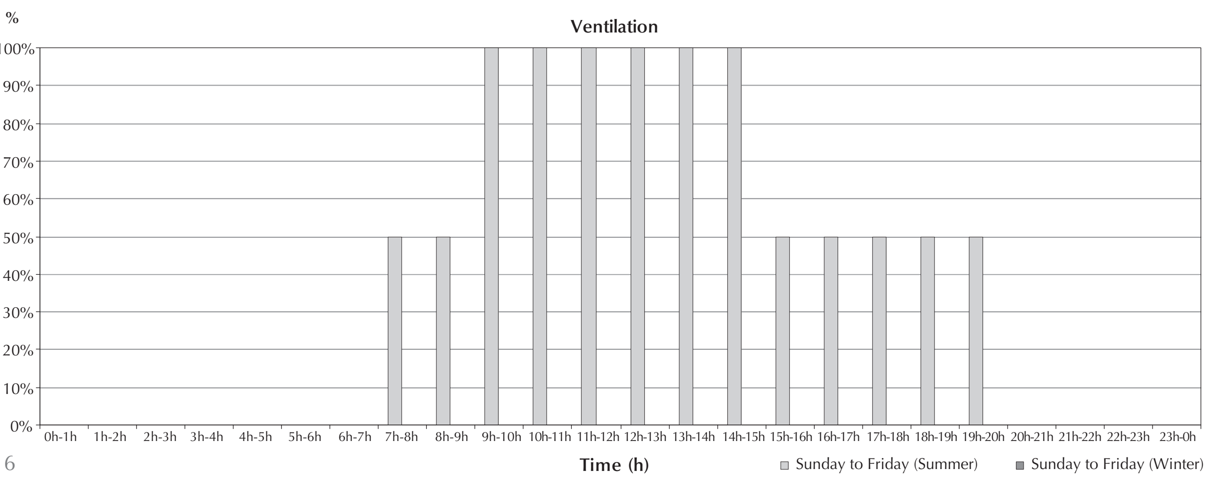
13


Lighting
%
Time (h)
Monday to Friday
Saturday
Sunday and Holiday

14


Equipments
%
Time (h)
Monday to Thursday
Friday
Saturday
Sunday and Holiday

15


Ventilation
%
Time (h)
Sunday to Friday (Summer)
Sunday to Friday (Winter)

16

13. Occupation Schedule.
14. Lighting Schedule.
15. Equipment Schedule
16. Ventilation Schedule.
(Figures in previous page)

2.6. Heating and Cooling Energy Needs

Computer simulations results for each façade configuration were compared, considering the delivered or maximum nominal energy for heating (*Ni*). According to Article 15° of the RCCTE (14), the limits of *Ni* of a building unit in kWh/m². years, depend on the values of the form factor (*FF*) of the built unit and degree-days (*DD*) of the local climate. In the case of the "standard model" (5 x 5m² area; ceiling height of 2.80 m) the form factor (*FF*) will be [1] [2].

[1] $FF = [A_{out} + \Sigma\ (\tau\ A_{ins})i]\ /\ V$

A_{out}= 81m² (Outside envelope areas summation)
A_{ins}= 0 (Inside envelope areas summation) (There is not inside walls)
V= 5 x 5 x 2.8= 70m³ (Inside Volume)

Then FF = 1.16

For form factor between $1 < FF \leq 1.5$

[2] $Ni = [4.5 + (0.021+0.037FF)\ DD]\ (1.2\text{-}0.2\ FF)$

Maximum annual nominal cooling energy needs (*Nv*) of a building unit depend on the climatic zone of the city and these values were listed in Article 15. of the RCCTE. Maximum nominal energy for heating (*Ni*) and maximum annual nominal cooling energy needs (*Nv*) for each climate was presented previously in the Table 1.

3. RESULTS

Results present heating energy needs for each climate, for conventional envelope and light gauge steel framing and four passive solutions. After that, solar shading and ventilation modules were added to a passive composed by glazing 07 and one Trombe wall, because this solution presented one of the largest cooling energy needs among other solutions. To better understand the results, it should be noted that:

- 1TW= Five Trombe wall modules, making one entire Trombe wall;
- 2TW= Two sets of five Trombe wall modules, making two Trombe walls;
- SI= Six ventilation modules, 3 positioned at the bottom of the façade and 3 at the top.
- Shade= 6 solar shading modules positioned outside of the main façade glazing area.

3.1. Bragança

All facade types presented for Bragança climate, heating energy needs were lower than value calculated according to RCCTE (128.70 kWh/m².year). The facade solutions with glazing 07 and one or two Trombe walls presented better results in comparison with the other façades types (Figure 17 and Figure 18).

It was observed that the heating energy needs presented approximate values for the both analyzed envelopes. For north solar orientation, the solutions variation did not show any significant differences between results. For south solar orientation was observed the minimum energy consumption with the passive solutions incorporation.

For Bragança climate, the use of solar shading and ventilation modules help to decrease energy consumption for cooling. For conventional envelope, cooling energy needs value were lower than the one calculated according to RCCTE, only with the addition of the solar shading and ventilation modules (Figure 19). Studied façades presented cooling energy needs lower than value calculated according to RCCTE for light gauge steel framing envelope (26 kWh/ m².year) (Figure 20).

Solar shading modules and ventilation modules use resulted in a maximum decrease of energy consumption of 55.97% for LGSF envelope and 56.73% for conventional envelope, based on energy consumption for the same façade without this type of modules (Table 7).

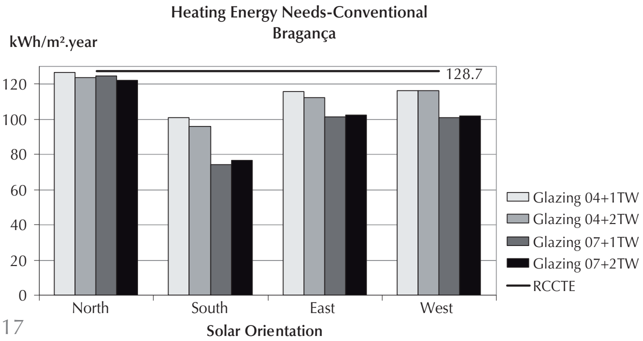
3.2. Coimbra

Taking into account the charts illustrated in Figures 21 and 22, for Coimbra climate, all analyzed façade types presented heating energy needs lower than the one calculated according to RCCTE (68.13 kWh/ m².year). Façades with glazing 07 and one or two Trombe walls presented better results in comparison with the other façades types.

For south solar orientation, it was observed minimum energy consumption with the passive solutions incorporation. Heating energy needs presented approximate values for both analyzed envelopes.

For Coimbra climate conventional envelope model presented cooling energy needs value lower than the one calculated according to RCCTE, only with the addition of the solar shading and ventilation modules (Figure 23).

Cooling energy needs were lower than value calculated according to RCCTE for light gauge steel framing envelope (16 kWh/ m².year) (Figure 24).



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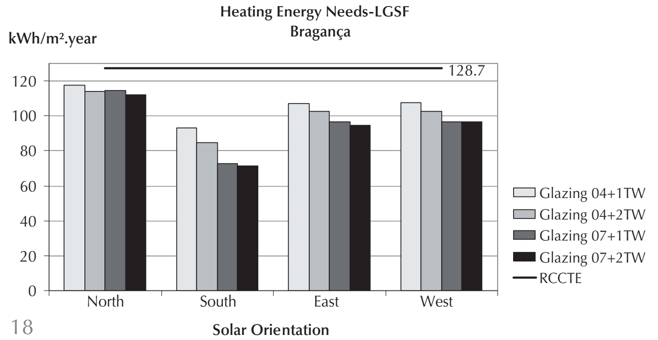

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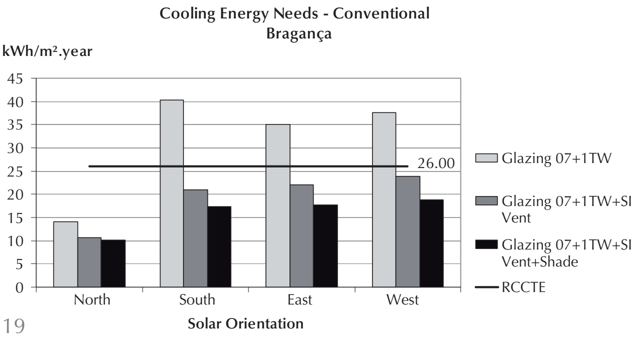

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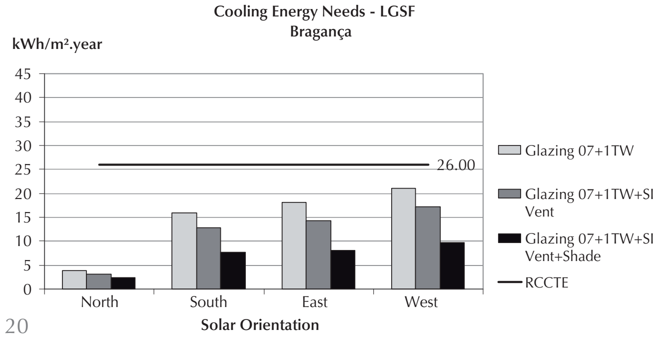

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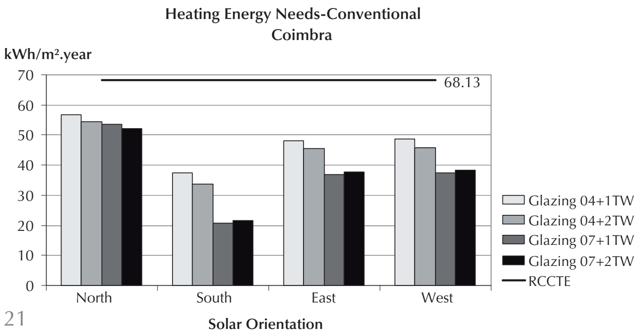

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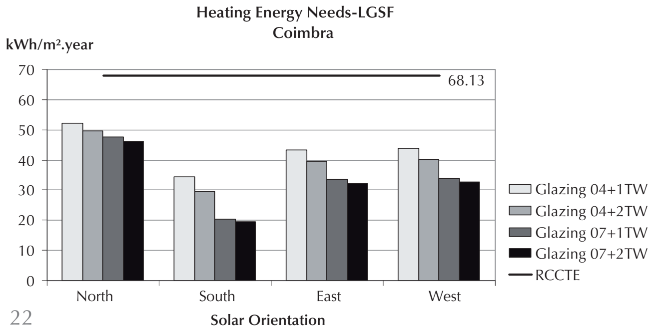

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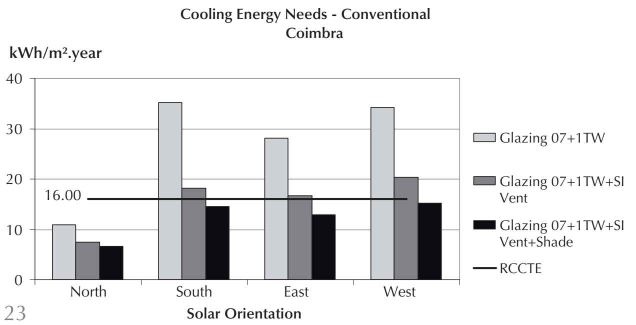

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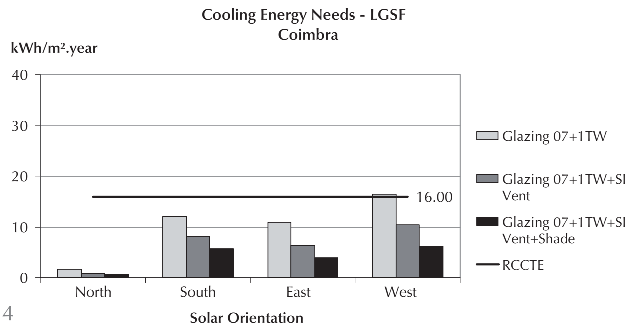

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Table 7. Bragança: Cooling energy consumption decrease with the use of horizontal solar shading and ventilation modules.

Solutions	**Solar Orientation**							
LGSF	North		South		East		West	
	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i
07+1TW	3.81	-	15.93	-	18.12	-	21.12	-
07+1TW+SI	2.68	-29.66	10.76	-32.45	11.63	-35.82	14.32	-32.20
07+1TW+SI +Shade	2.34	**-38.51**	7.64	**-52.05**	7.98	**-55.97**	9.70	**-54.06**
Solutions	**Solar Orientation**							
Conventional	North		South		East		West	
	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i
07+1TW	14.12	-	40.27	-	35.05	-	37.63	-
07+1TW+SI	10.64	-24.66	21.02	-47.79	22.01	-37.19	23.83	-36.67
07+1TW+SI +Shade	10.17	**-28.00**	17.43	**-56.73**	17.77	**-49.31**	18.84	**-49.93**

17. Bragança: Heating Energy Needs for Conventional System.

18. Bragança: Heating Energy Needs for LGSF System.

19. Bragança: Cooling Energy Needs for Conventional System.

20. Bragança: Cooling Energy Needs for LGSF System.

21. Coimbra: Heating Energy Needs for Conventional System.

22. Coimbra: Heating Energy Needs for LGSF System.

23. Coimbra: Cooling Energy Needs for Conventional System.

24. Coimbra: Cooling Energy Needs for LGSF System.

Table 8. Coimbra: Cooling energy consumption decrease with the use of horizontal solar shading and ventilation modules.

Solutions	**Solar Orientation**							
LGSF	North		South		East		West	
	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i
07+1TW	1.56	-	12.02	-	10.95	-	16.47	-
07+1TW+SI	0.89	-42.86	8.18	-31.91	6.36	-41.94	10.35	-37.17
07+1TW+SI +Shade	0.70	**-55.44**	5.62	**-53.22**	3.93	**-64.09**	6.18	**-62.48**
Solutions	**Solar Orientation**							
Conventional	North		South		East		West	
	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i	kWh/m².year	% i
07+1TW	10.83	-	35.24	-	28.09	-	34.24	-
07+1TW+SI	7.38	-31.92	18.17	-48.45	16.64	-40.77	20.35	-40.57
07+1TW+SI +Shade	6.64	**-38.71**	14.57	**-58.66**	12.88	**-54.14**	15.20	**-55.60**

Table 9. Faro: Cooling energy consumption decrease with the use of horizontal solar shading and ventilation modules.

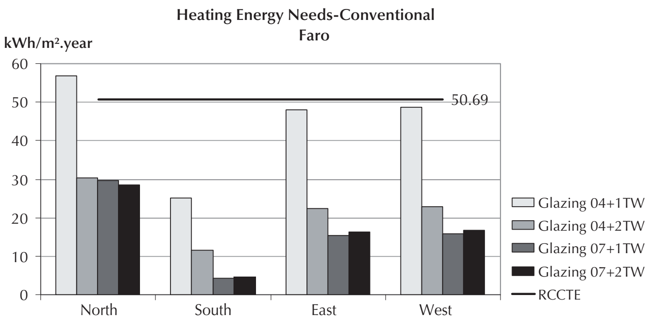
Solutions	**Solar Orientation**							
LGSF	North		South		East		West	
	kWh/m².year	% i	kWh/m². year	% i	kWh/m². year	% i	kWh/m². year	% i
07+1TW	9.69	-	24.46	-	33.72	-	36.43	-
07+1TW+SI	6.87	-29.09	18.54	-24.21	24.52	-27.29	26.70	-26.70
07+1TW+SI +Shade	6.18	**-36.24**	15.25	**-37.67**	18.45	**-45.28**	20.03	**-45.02**
Solutions	**Solar Orientation**							
Conventional	North		South		East		West	
	kWh/m².year	% i	kWh/m². year	% i	kWh/m². year	% i	kWh/m². year	% i
07+1TW	27.35	-	55.56	-	56.67	-	59.77	-
07+1TW+SI	20.33	-25.67	33.61	-39.51	39.30	-30.65	41.16	-31.13
07+1TW+SI +Shade	13.73	**-49.79**	23.43	**-57.83**	26.02	**-54.08**	27.26	**-54.39**

25. Faro: Heating Energy Needs for Conventional System.

26. Faro: Heating Energy Needs for LGSF System.

27. Faro: Cooling Energy Needs for Conventional System.

28. Faro: Cooling Energy Needs for LGSF System.



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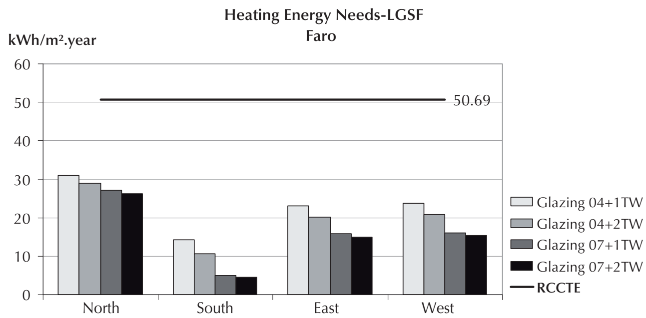

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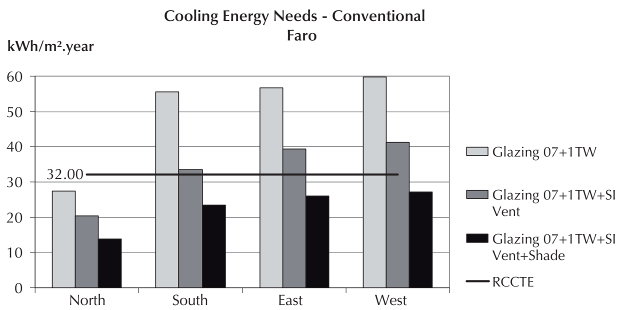

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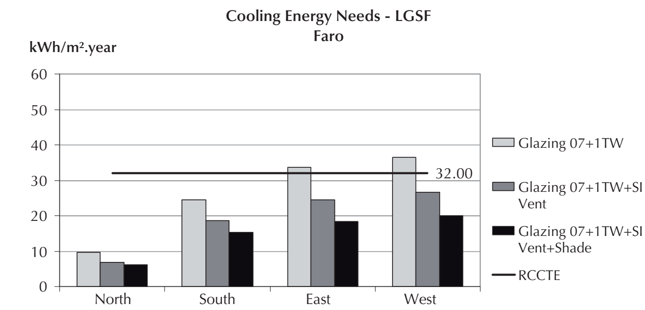

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As expected, the use of solar shading devices and ventilation modules are very much important to decrease energy consumption for cooling.

Solar shading devices implied in a maximum decrease of energy consumption of 64.09% for LGSF envelope and 58.66% for conventional envelope, based on energy consumption for the same façade without this type of modules (Table 8).

3.3. Faro

For Faro climate, all analyzed façade types presented heating energy needs lower than the one calculated according to RCCTE (50.69 kWh/ m².year) (Figures 25 and 26). Glazing 07 arranged with one or two Trombe walls presented better results in comparison with the other façades types. Heating energy needs for Glazing 04 and one Trombe wall presented some high values for the conventional envelope (Figure 25). It happened for north, east and west solar orientation. In general, the results were identical for the use of one or two Trombe walls.

Cooling energy needs were lower than value calculated according to RCCTE (32 kWh/ m².year) due to the use of solar shading devices and ventilation modules. Best results, in terms of decreasing the energy consumption, were found with solar shading and ventilation modules use simultaneously.

For Faro, solar shading modules and ventilation modules use resulted in a maximum decrease of energy consumption of 45.28% for LGSF envelope and 57.83% for conventional envelope, based on energy consumption for the same façade without this type of modules (Table 9).

4. CONCLUSIONS

The energy simulations for two glazing types and Trombe walls were evaluated for three Portuguese climates in this research work. The results showed that all façade types presented heating energy needs lower than the maximum limits according to the Portuguese energy building performance regulation RCCTE.

Façades with Glazing 07 (Bioclean 4 mm - Planilux 4 mm) with one or two Trombe walls stood out due to the smallest heating energy need when compared with others. Both analyzed envelopes presented heating energy needs similar. Practically, the results were identical for the use of one or two Trombe walls arranged with glazing 07.

According to RCCTE, the period in months of heating season for the analyzed climates are: Bragança 8 months; Coimbra 6 months and Faro 4,3 months. It means that during these months per year, heating is necessary to maintain comfortable conditions. Based on this period, the use of heating passive solutions and glazing 07 in the façade modules can be suggested, due to the good performance to decrease the heating energy needs. However, to Faro, it is more important to be cautious with the cooling energy needs because, for this climate, the winter period is shorter and milder than the other Portuguese climates. In this case, passive solutions with glazing 04 have a better performance.

Therefore, solar shading and ventilation modules were added to the façade composed by glazing 07 and one Trombe wall studied, because this solution presented one of the largest cooling needs among other solutions. Comparing all analyzed climates, the use of these modules resulted in a maximum decrease of energy consumption of 64.09% for LGSF envelope and 58.66% for conventional envelope, based on energy consumption for the façade composed by glazing 07 and one Trombe wall.

The results showed that Trombe walls can present a very good performance to decrease heating energy needs and ventilation and solar shading modules to decrease cooling energy needs. As expected, preliminary results show a reduction of energy consumption with the application of these modules façade, which represents an advantage of passive solar systems.

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