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Thermal performance of light blocks in a Mediterranean climate

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Abstract

The challenge of reducing energy consumption in buildings is fundamental for the near future, considering the impact of buildings in the overall energy demands. Mediterranean regions have a mild heating season and a hot and dry winter. Its climate is characterized by plentiful solar radiation all along the year and large daily range of temperature during the summer. Thermal inertia and insulation material properties can act in a different way along the day and the year, and the better solution for the summer can be the worst solution for the cooling season. Masonry walls that define the boundary between the interior and exterior are one of the most important components of buildings mainly for energy efficiency. Despite being one of the most common and ancient building materials, it is possible to improve its performance working in units, mortars and finishes. This work aims at studying the effect of materials with different thermal insulation and thermal mass on thermal comfort and energy savings of three types of buildings, two single-family houses and one apartment, in a Mediterranean climate. Thermal behavior of traditional and light solutions is compared and it is found that thermal comfort is similar but light solutions present lower energy consumptions for the three studied house topologies. Otherwise, this study shows that housing topology has more influence namely, when comparing energy needs.

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List of symbols

- A_{in}: indoor temperature amplitude (ºC)
- A_{ext}: outdoor temperature amplitude (ºC)
- cp: specific heat capacity (J/Kg.K)
- $Damp$: temperature damping (ºC)
- h: hours
- Q: air volumetric flow (m^3/s)
- R: thermal resistance (m^2·K/W)
- T_{in}: indoor mean temperatures (ºC)
- T_{ext}: outdoor mean temperatures (ºC)
- U: thermal transmittance (W/(m^2·K))
- ρ: density (kg/m^3)
- λ: thermal conductivity (W/(m.K))
- Δt: T_{in} - T_{ext} (ºC)

1. Introduction

Buildings have a great impact on energy use and carbon emissions worldwide and they are important in formulating sustainable development strategies. It has been estimated that the energy used by the building sector is still increasing, because new buildings are constructed faster than old ones are retired. In addition the energy used in the mining, processing, manufacturing and transporting of the all building materials, construction and decommissioning of the buildings, together with the energy used during the life span of a building, accounts for about one third of the global greenhouse gas emissions [1]. Nowadays there is an evident interest in ZEBs (zero energy buildings). The reduction of the energy consumption and efficient use of energy in buildings have become very important. The growing energy demands caused high impact on the building sector since this sector is consuming 40% of the total energy usage in the European Union. In order to reduce this energy consumption the new directive on buildings energy performance established that all buildings constructed after 2020 should be nearly zero energy buildings [2]. ZEBs involves two strategies, minimization of the need for energy use in buildings, especially for heating and cooling, and the adoption of renewable energy methods and other technologies to get all needed energy. The first strategy includes building envelopes and internal conditions. In old cities and historical centers, the best opportunity to improve energy efficiency is during building retrofit actions, and recommendations to improve buildings performance and comfort levels, focus on applying solutions to improve energy efficiency [3,4].

Masonry is yet the most popular and used solution for external/enclosure walls of buildings. Consequently, the reduction of the thermal transmittance (U) of these walls is an important factor to be considered, along with an appropriate combination with the thermal mass, especially in moderate climates and if passive solar design principles are properly used

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like building solar orientation and level of shading, glazing elements surface properties, amongst others [4-6]. The masonry materials industry, including masonry units, mortars, insulation and finishes is very concerned about the building energy consumption problem, which is complex because there are several constraints to be considered simultaneously, such as the wall thickness, unit weight, enough mechanical resistance and a competitive price.

Focusing on the reduction of thermal transmittance of masonry, this can be achieved throughout the use of raw/base materials with lower thermal conductivity and with the use of units whose topology/geometry is conceived to optimize the thermal resistance (*R*-value) [7-13]. For more demanding performance, complementary thermal insulation layers namely thermal renderings and external insulation systems, and the filling of the unit voids with thermal insulation materials can also be used, in particular when the increase of wall thickness is not possible due to practical or economic reasons [9-12].

The impact on the energy consumption of building by reducing the thermal transmittance of enclosure walls has been estimated in some scientific studies. For example, according to a numerical study [9], performed on building with four floors and two exposed facades (masonry walls with vertical hollow units made with thermally enhanced clay), presenting 33 % of glazing area, annual energy savings near 8% were estimated, when decreasing the equivalent thermal transmittance of the enclosure walls by 43%. Currently the *R*-value is considered to be the principal parameter influencing the thermal performance of all walling systems. An 8-year research focusing on the thermal performance of Australian housing [14] showed that under the same weather conditions, similar internal conditions were achieved in housing modules with different wall *R*-values; authors conclude that the *R*-value of the walls is not the only predictor of the thermal performance of a building, in terms of thermal comfort and energy demand. Furthermore the study concludes that the *R*-value parameter can only be used as a predictor for walling systems with no thermal mass.

Building performance reflects not only the thermal resistance and mass of the building components, but also the dynamic external temperature. The effect of thermal mass varies with insulation properties, climate conditions and occupancy [15].Usually high mass buildings present benefit regarding the heating demand. However in the northern countries low mass buildings with high *R*-value of the walls perform better regarding the heating demand as the increase of the thermal mass of the building enclosure has a negligible influence. Also in well insulated buildings in Nordic European countries, the increase in thermal mass will reduce the cooling demand by approximately 30-50% [16].

The Mediterranean climate is characterized by relatively mild winters and very warm summers. Near the sea, temperatures are generally moderate presenting a small range of temperatures between the winter and summer; however, the daily range of temperature during the summer is large due to dry and clear conditions. Building cooling is the most challenging issue in the Mediterranean zones, due to the plenty solar radiation and to the high ambient temperature [15]. In South Mediterranean, buildings differ with respect to building technology, as they may be ‘massive’, or ‘light’. The reduction of energy needs for heating may be achieved by applying a proper building orientation and an adequate thermal insulation of the building envelope.

This research focuses on indoor comfort and energy demand during winter (January) and summer (August) in residential family houses in a Mediterranean climate with the main goal of reducing the energy for space heating and cooling.

Simple steady-state calculations ignore the dynamic processes apparent in real buildings, not allowing the evaluation of the thermal performance of buildings under real conditions [17]. Non-steady simulation has been performed using the well-known building simulation program EnergyPlus, an open source software, able to simulate the performance of a building using real climate data under dynamic conditions. The analyses includes not only the envelope, walls and roof, but also considers the building as a whole, including heat gains through windows, and heat gains/losses due to life occupancy and ventilation. The paper is organized into two stages. In the first, thermal comfort analysis is carried out considering different types of retrofit solutions for a simplified housing model: heavy and light envelope solutions, insulation of the envelope, glazing with different orientation and different combinations of these strategies. A parametric analysis is presented in order to investigate how the variation in climatic conditions, thermal insulation, glass ratio, ventilation and occupancy internal heat affects the thermal inertia of three constructive solutions. In the second part, the research characterizes the behavior of different wall solutions, traditional and light solutions using Saint-Gobain Weber Portugal products. Dynamic thermal simulations allowed comparing comfort and thermal demands for three types of buildings, two single-family houses and one apartment. All studies take into account the mechanisms involved between various components of the complete building envelope, which jointly respond to external environmental variations.

Reported studies showed benefits due to ventilation and ventilated envelope adoption [15-18]. In the second study, one single-family house presenting a sloped roof is considered, in order to investigate its influence in energy savings and thermal comfort.

2. Thermal analysis

Building internal comfort and energy consumptions were evaluated using dynamic thermal simulations with EnergyPlus software.

EnergyPlus™ is a open access program developed by U.S. Department of Energy to perform energy analysis and thermal load simulations of heating, cooling, ventilation, lighting, plug and process loads and water use in buildings in a dynamic regime. EnergyPlus™ is based on a simulation engine, which allows, amongst others, the simulation of the following main aspects:

- Simulation of transient heat conduction through building elements (e.g. walls, roofs, floors) using conduction transfer functions;
- Simulation of radiant and convective effects in the interior and exterior surfaces for the calculation of heat balance, surface temperatures and absorbed solar energy;
- Simulation of combined heat and mass transfer that accounts for air movement between zones and moisture adsorption/desorption;
- Simulation of thermal loads based on internal conditions (activity, inside dry bulb, humidity) and external thermal zone conditions and response of HVAC systems, including the interactions between thermal zones and HVAC systems.

In a Mediterranean climate, the major design task is the reduction of the energy need for cooling, maintaining good thermal comfort conditions. A building must be designed to perform well both under extreme summer conditions and under mild winter weather with proper building orientation and shape, adequate thermal insulation of the building envelope, airtightness and adequate natural or mechanical ventilation.

The thermal performance of a building depends on its physical properties like the thermal resistance of the building envelope, the heat storing capacity of components, solar heat gain through windows, ventilation rate, etc. The characterization of the dynamic thermal response of walling systems where the complete building envelope jointly responds to external environmental variations is a difficult task. For building simulation it is necessary to consider interior walls, floor, roof and window components described by their physical properties (density) and thermal properties (specific heat capacity and thermal conductivity). Other parameters considered in the heat balance of the building are, for example, air change rate, internal gains due to occupancy and heating/cooling systems.

The heat gains/losses, q_s, due to natural ventilation through each opening is calculated based on the pressure difference, wind velocity and internal and external temperatures [19]:

$$\boldsymbol{q_s = Q\,\rho\,c_p\,\Delta t} \qquad (1)$$

where Q is the air volumetric flow through the opening, ρ and c_p are the air density and specific heat capacity respectively, and Δt is the difference between indoor and outdoor temperatures.

In this study only internal gains due to occupancy were considered and no heating or cooling systems were taken into account. The analysis requires also parameters that depend on climatic conditions. Daily and hourly ambient mean temperatures, humidity, wind velocity, direction and warming and cooling factors, and solar radiation were considered.

The thermal performance of a building can be expressed by various quantitative ways. The temperature on the outside surface of a wall fluctuates widely, from a high temperature during the sunny midday to a low temperature in the middle of the night. This can be thought of as a temperature "wave". The indoor temperature is clearly affected by external weather conditions, presenting the same behavior than the outdoor temperature with smaller amplitude and a delay between occurrence of peak (maximum and minimum) indoor temperatures and peak outdoor temperatures [20,21].This phenomenon due to the thermal mass is known as the time lag and is particularly important in the design of buildings in environments with a high diurnal range. The wall "damps" or reduces, the amplitude of the temperature wave. The narrower temperature fluctuation on the interior means that the cooling and heating loads are lower, and the inside of the building is more comfortable. The damping depends on both the insulation and the heat capacity of the construction. The thermal inertia of the envelope depends on the thermo-physical properties of the materials and on the thickness of the construction assembly envelope [20]. For two walls with the same insulation, the more massive wall will display greater temperature damping characteristics. Figure 1 shows the time lag that appears when mass and insulation are reasonably applied in a building structure. The other parameter adopted in this study, temperature damping, is a characteristic of mass construction that describes the way exterior temperatures and heat flows affect the interior of a building. Temperature damping, can be measured as the difference between indoor to outdoor temperatures amplitudes as shown in the right side of Figure 1.

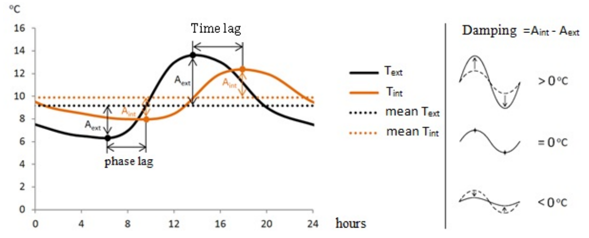

Figure 1. Comfort characterization using indoor and outdoor temperatures

In the first study of this work, thermal comfort analysis, a simple metric that encapsulates the contribution of all physical parameters influencing the thermal performance is adopted: monthly mean indoor temperatures, average of amplitude of indoor to outdoor peak temperatures (mean temperature damping) and the time lag between indoor and outdoor maxima and minima temperatures. In the second analysis, the comparison of the thermal performance between traditional and light solutions, in terms of the energy consumption is also performed.

2.1. Preliminary analytic study

A simplified model was adopted for evaluating the thermal behavior of three different scenarios. First it is modeled a single room considering that all the elements, ground floor slab, roof and walls, have the same composition (Figure 2). Then several changes were performed introducing a thicker insulation layer, glazing, occupancy gains and ventilation.

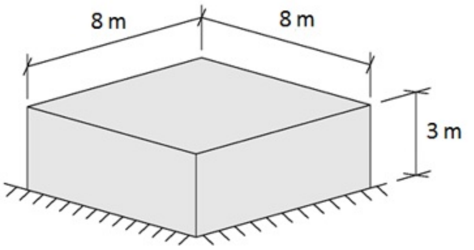

Figure 2. Compartment model

Table 1 shows the properties of the three scenarios, two heavy models and one light, all with exterior render coating and internal plaster coating finishes (scheme 1).

Table 1. Thermal properties of the three studied scenarios

		Thickness (cm)	**Density ρ (kg/m^2)**	**Specific heat capacity (*) c_p (J/(kg.K))**	**Thermal conductivity λ (W/(m.K))**	**Thermal transmittance U (W/(m^2.K))**
External rendering		2.5	1858	837	0.6918	0.98
Internal plastering		1.3	785	830	0.1600	
Heavy model_1	Current concrete	20.3	2243	837	1.7296	
	External insulation layer (Mineral wool)	3.4	91	837	0.0432	
Heavy model_2	Current concrete	20.3	2243	837	1.7296	
	Internal insulation layer (Mineral wool)	3.4	91	837	0.0432	
Light model	Thermal insulation	3.9	91	837	0.0432	

*For typical building materials other than metals, plastics and wood, specific heat values vary between 800 and 1000 J / kg.K.

The Heavy model_1 presents concrete wall with mineral wool insulation layer on external face and the Heavy model_2 has a concrete wall with mineral wool insulation layer on internal face; the Light model is an element composed exclusively of thermal insulating material coated with interior and exterior plastering/rendering. The thermal transmittance for the three solutions becomes equal to 0.98W/m2.K

Climatic input files containing the outdoor winter (January) and summer (August) climatic conditions, in three Portuguese cities, Porto, Bragança and Évora, were obtained from EnergyPlus weather data [22,23]. Porto features a warm-summer Mediterranean climate, with influences of an Oceanic climate. Bragança city with a temperate Mediterranean climate is open to both continental and maritime influences as it is not far away from Atlantic Ocean. In Évora region the climate is typically Mediterranean, although it also has some atlantic influence. Scheme1, scheme1_B and scheme1_E concerns scheme1 in Porto, Bragança and Évora cities respectively. Scheme 1_J and Scheme 1_A concern sheme1 considering January and August. For each scenario and Porto city, several schemes were performed:

- Scheme 2: A thicker insulation layer of 10.1 and 10.6cm thickness for the massive and light models respectively is considered, and the obtained thermal transmittance for the solutions becomes equal to 0.39w/m^2.K;
- Scheme 3: the previous scenario, Scheme 1, is completed by introducing two types of glazing orientation, one with north facing windows (scheme 3_N) and the other with south facing windows (scheme 3_S). Glazing elements are composed by a single glazed window glass with aluminum frames, glass panels with 3 mm thickness, thermal conductivity equal to 2.5W/m.k, emissivity equal of 0.84 and transmittance equal to 0.85.
- Scheme 4: starting from Scheme 1 occupancy gains are introduced considering five occupants and internal gains due to each occupant were set equal to 75 W/individual;
- Scheme 5: Natural ventilation during all the day: two values for ventilation rate are set: 0.4 air change rate per hour (ach) corresponding to scheme 5_4, and 0.6 ach for scheme 5_6;
- Scheme 6.1: The combination of previous variables, is performed considering north and south facing windows, occupancy gains and natural ventilation (0.6 ach);
- Scheme 6.2: Starting from Scheme 6.1 the increase of the insulation layer is introduced.

2.2. Case study: energy and comfort analysis

The previous analysis considers one single room but buildings are more complex as they present different rooms with different temperatures and envelopes. Thermal comfort of two single-family houses and one apartment has been examined during January and August. In addition, energy consumptions were calculated in order to compare the energy demand provided by each scenario considering different envelope solutions, traditional walls and light solutions. Two locations, Bragança and Évora cities were analyzed in this single-floor family houses study. Figure 3 shows building geometric characteristics of the three considered scenarios.

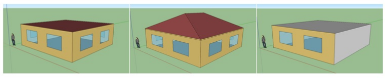

Figure 3. Single-floor family house with flat roof, single-floor family house with a ventilated sloped roof and an apartment with a glazed south façade

All the models have a square area equal to 100m^2, a storey height of 3 meters and a glazing area of 25% by façade corresponding to two windows. Two single-floor family houses with one stage and glazed windows in the four facades, one presenting a flat roof and the other a ventilated sloped roof with 6 hourly renovations, were considered. The apartment has a south-facing facade with glazed windows and the other envelope elements were considered adiabatic. The conditions of occupation were as follows: Full-time occupants (120 W per person), full-time interior space ventilation with a ventilation rate equal to 0.6 air changes per hour and comfort temperatures between 18 and 25ºC.

Table 2 shows the properties of the roof, ground slabs and compartment pavement solutions, thickness, thermal conductivity and thermal transmittance ($\mathbf{U}$).

Two types of walls were considered, traditional clay masonry walls and a lightweight concrete masonry walls (Figure 4). All the walls have mortar plastering of 0.015m thick on internal side with thermal conductivity equal to 0.61W/m.K.

Table 2. Roofs and pavements solutions

Construction elements	Layers	Thickness (m)	Conductivity λ (W/(m.K))	$\mathbf{U}$ (W/(m^2.K))
Flat roof: Concrete slab (beam and block system), with thermal insulation layer and traditional plastering	Bitumen sheet (water proofing)			
	EPS 100 insulation	0.06	0.036	0.50
	Form layer (slab)	0.04	1.3	
	Compression layer (slab)	0.05	1.65	
	Ceramic blocks (slab)	0.15	0.65	
	Plastering mortar	0.015	0.61	
Sloped roof Roof with a ventilated attic, made with a slop layer of ceramic tiles and a horizontal reinforced concrete slab (beam and block system) coated thermal insulation and traditional plastering	Ceramic tile	0.04	0.77	19.25
	EPS 100 Insulation	0.06	0.036	0.50
	Form layer (slab)	0.04	1.3	
	Compression layer (slab)	0.05	1.65	
	Ceramic blocks (slab)	0.15	0.65	
	Plastering mortar	0.015	0.61	
Ground floor (family house): Concrete floor without thermal insulation, coated with ceramic tiles.	Ceramic tile	0.01	1.3	7.73
	Form layer	0.04	1.3	
	Concrete floor	0.15	1.65	
Current floor (apartment): Reinforced concrete slab (beam and block system), coated with ceramic tiles and traditional plastering.	Ceramic tile	0.01	1.3	3.09
	Form layer (slab)	0.04	1.3	
	Compression layer (slab)	0.05	1.65	
	Ceramic blocks (slab)	0.15	0.65	
	Plastering mortar	0.015	0.61	

Traditional walls have the same exterior finish except the single leaf clay masonry wall which, like light solution, is rendered on

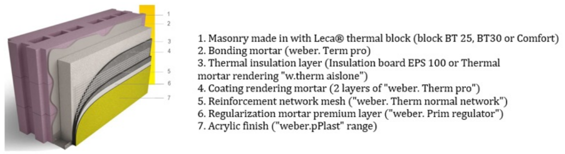

Figure 4. Scheme of the light external wall

external side by an acrylic finish/ topcoat (ETICS) of 0.0015m thick and a thermal conductivity equal to 0.82W/m.K. The composition of the adopted solutions and corresponding thermal properties are presented in Tables 3 and 4. Two types of insulating materials are used, expanded polystyree (EPS) and extruded polystyrene (XPS). Glazing elements/windows (2.5 × 1.5 m^2) with a thermal transmittance of 3.0 W/m^2.K, are made with aluminum frames and single glass panels of green color.

Table 3. Traditional walls solutions

Traditional solutions	**Layers**	**Thickness (m)**	**Conductivity λ (W/(m.K))**	**U (W/(m^2.K))**
Exterior wall for single-family house and apartment building Clay masonry cavity wall, with thermal insulation in the air layer, coated with traditional mortar rendering on both sides of the wall. (Ref. CW)	Clay block (11cm)	0.11	0.41	0.51
	XPS Insulation board	0.04	0.037	
	Air	0.06	5.56	
	Clay block (15cm)	0.15	0.38	
Exterior wall for single-family house and apartment building Single leaf clay masonry wall coated with external thermal insulation system (ETICS) and internal traditional rendering. (Ref. SL)	Clay block (22cm)	0.22	0.42	0.45
	EPS 100 Insulation board (ETICS)	0.06	0.036	
	Reinforced rendering mortar (ETICS)	0.006	0.42	
	Acrylic Finish (ETICS)	0.0015	0.82	
Interior wall between two apartments Clay masonry cavity wall, without thermal insulation in the air layer, coated with traditional rendering on both sides of the wall.	Clay block (11cm)	0.11	0.41	1.31
	Air	0.06	5.56	
	Clay block (11cm)	0.11	0.41	

Table 4. Light wall solutions

Light solutions	**Layers**	**Thickness (m)**	**Conductivity λ (W/(m.K))**	**U (W/(m^2.K))**
Exterior wall for single-family houses and apartment building Single leaf wall made with thermal blocks (BT 25), coated with external thermal insulation system (ETICS) and internal traditional rendering. (Ref. TB 25)	Leca® thermal block (BT25)	0.25	0.40	0.43
	Insulation board EPS 100 (ETICS)	0.06	0.036	
	Reinforced rendering mortar (ETICS)	0.006	0.42	
Exterior wall for single-family houses and apartment building Single leaf wall made with thermal blocks (BT 25), coated with external thermal rendering (w.therm aislone), and internal traditional rendering. (Ref. TB 30)	Leca® thermal block (BT30)	0.3	0.43	0.46
	Thermal mortar (w.therm aislone)	0.06	0.042	
	Reinforced rendering mortar (ETICS)	0.006	0.42	
Exterior wall for single-family houses and apartment building Single leaf wall made with thermal blocks (Comfort), coated with external thermal insulation system (ETICS), and internal traditional rendering. (Ref. TB Comfort)	Leca® thermal block (Comfort)	0.35	0.19	0.29
	Insulation board EPS 100 (ETICS)	0.06	0.036	
	Reinforced rendering mortar (ETICS)	0.006	0.42	

2.3. Numerical simulation

The energy performance of buildings is important due to economic, political and ecological reasons. Numerical simulations allow testing different solutions taking into account building properties. The progress of computer power allowed performing dynamic building energy simulation. Instead of measuring the energy demand of a building in operation, energy simulation allows to estimate the energy consumption during the design phase of a new building and optimize building retrofit strategies when integrated in the architectural design process [24]. The building energy simulation program EnergyPlus, as referred, is an open-source software tool that simulates models for building heating, cooling, lighting, ventilating, and other energy flows [25]. It is an accurate and powerful simulation software tool that can support designers to optimize and take decisions about the best measures to apply for a building.

3. Results and discussion

3.1 Comfort analysis using a simplified model

A set of dynamic simulations were performed considering two months, January and August, in order to compare the comfort level for the different constructive solutions of the envelope of a simplified model with a single room. Three locations with similar climatic conditions were considered, Porto, Bragança and Évora cities. In Table 5 thermal comfort of different scenarios is analyzed using indoor mean temperatures (T_{in}), average amplitude of indoor to outdoor peak temperatures (temperature damping - Damp) and time lag or delay (Delay) parameters. Regarding scheme 1 and the comparison between the three climate zones it can be seen that in Porto city, the average amplitude of indoor to outdoor peak temperatures is slightly higher in winter and lower in summer, and time delay is about an hour higher.

Table 5. Thermal comfort of different scenarios

	T_{ext}	**Heavy model_1**			**Heavy model_2**			**Light model**		
	Average (^{o}C)	T_{in} (^{o}C)	Damp (^{o}C)	Delay (h)	T_{in} (^{o}C)	Damp (^{o}C)	Delay (h)	T_{in} (^{o}C)	Damp (^{o}C)	Delay (h)
Scheme1_J	**9.4**	**13.2**	**-3.4**	**5 - 7**	**13.7**	**-2.4**	**5 - 8**	**13.3**	**3.0**	**1 - 2**
Scheme1_A	**19.4**	**25.2**	**-3.1**	**6 - 7**	**26.5**	**-1.1**	**7**	**25.1**	**7.7**	**2**
Scheme1_BJ	4.3	10.2	-2.3	4 - 6	10.3	-1.5	4 - 6	10.0	2.9	0 - 1
Scheme1_BA	21.0	26.9	-5.7	5 - 6	27.6	-3.6	6	26.5	5.9	1
Scheme1_EJ	8.8	14.2	-2.0	5 - 10	14.0	-1.0	6 - 7	13.7	3.8	2
Scheme1_BA	22.9	27.8	-5.6	6	28.1	-3.3	7	27.8	5.6	1
Scheme2_J	9.4	13.8	-3.5	6 - 11	13.6	-3.0	7 - 12	13.3	-0.3	3 - 4
scheme2_A	19.4	25.2	-3.4	7 - 8	26.5	-2.4	9	25.3	2.3	4
Scheme3_NJ	9.4	13.2	-3.4	1 - 6	13.6	-2.5	1 - 6	13.2	3.4	1 - 2
Scheme3_NA	19.4	25.5	-3.1	2 - 4	26.6	-1.1	3 - 4	25.3	8.2	2
Scheme3_SJ	9.4	15.0	-2.8	1 - 0	15.3	0	1 - 0	14.8	5.9	1
Scheme3_SA	19.4	26.8	-2.8	2 - 0	28.0	0.3	3 e 1	26.7	10.3	2 - 1
Scheme4_J	9.4	15.9	-3.3	5 - 7	16.4	-2.3	5 - 7	15.8	3.0	1 - 2
Scheme4_A	19.4	27.2	-3.1	6 - 7	28.3	-1.4	7	26.8	6.7	2
Scheme5_4J	9.4	12.1	-2.9	1 - 0	12.4	-1.6	1	12.1	2.9	1
Scheme5_4A	19.4	23.5	-2.8	2 - 1	24.3	-1.2	3	23.3	6.4	2 - 1
Scheme5_6J	9.4	11.9	-2.8	1 - 0	12.2	-1.6	1	11.9	2.8	1
Scheme5_6A	19.4	23.2	-2.7	1	24.0	-1.2	2	23.1	6.1	2 - 1

Regarding the comparison between the different envelope solutions of scheme 1, heavy solutions guarantee a better stabilization of the interior temperature showing high damping, slightly lower when the insulation layer is on the internal surface; furthermore the light model with the same thermal transmittance coefficient, promotes overheating of the interior space (from +3 to +8ºC). High time delay is found for heavy solutions (between 4 and 10 hours) while low values are found for the light model, between 0 and 2 hours.

The comparison between scheme 1 and each of the different retrofit interventions allows concluding that:

- The increase of thermal insulation thickness effect on temperature damping depends on the type of construction, being null for heavy construction with insulation layer on the external surface and showing a significant reduction on the peak temperatures for the light solution (3 to 5 ºC comparing with Sheme1);
- With the increment of thermal insulation thickness, time lag increases for all construction solutions but no mean temperatures changes are found;
- North-facing windows had little influence on all the studied parameters for the three constructive solutions and in both seasons;
- Considering south facing windows the heavy model with insulation layer on the internal side of the wall, shows not to be able to avoid temperature fluctuations in the same way as the envelope solution with insulation on the external side of the wall; furthermore the reduction of the temperature damping also promotes a slight indoor heating for heavy construction with insulation layer on the external surface and a greater one, for the light solution (2.6 to 2.9ºC); It can also be noticed that for all the construction solutions the time lag becomes very small;
- The occupancy of the spaces promotes the increase of the indoor temperature in all the analyzed cases, without affecting the other parameters;
- Natural ventilation promotes reduction of indoor mean temperatures and temperature damping is also influenced presenting a slightly decrease in the heavy solution with insulation layer on the external surface and a minor increase in the light one;
- Ventilation effect on time lag varies according construction solution: heavy solution with insulation layer on the external surface lost time lag while light model presents the same time lag of Scheme 1.

Table 6 shows obtained results considering the combination of the all analyzed parameters.

Table 6. Results for the combination of the all analyzed parameters

	T_{ext}	**Heavy model_1**			**Heavy model_2**			**Light model**		
	Average (^{o}C)	T_{in} (^{o}C)	Damp (^{o}C)	Delay (h)	T_{in} (^{o}C)	Damp (^{o}C)	Delay (h)	T_{in} (^{o}C)	Damp (^{o}C)	Delay (h)
Scheme1_J	**9.4**	**13.2**	**-3.4**	**5 - 7**	**13.7**	**-2.4**	**5 - 8**	**13.3**	**3.0**	**1 - 2**
Scheme1_A	**19.4**	**25.2**	**-3.1**	**6 - 7**	**26.5**	**-1.1**	**7**	**25.1**	**7.7**	**2**
Scheme6_1J	9.4	15.2	-2.3	0	15.4	0.6	1 - 0	15.1	4.9	0 - 1
Scheme 6_1A	19.4	26.6	-2.2	1 - 0	27.3	0.7	2 - 0	26.3	8.0	1
Scheme6_2J	9.4	16.7	-2.2	0	16.6	1.8	1	16.4	3.7	1
Scheme6_2A	19.4	27.7	-2.3	1 - 0	28.2	2.0	2 - 1	27.7	5.6	1 - 2

If the thinner insulation layer (3.4cm) is adopted, the combination of the analyzed parameters (Scheme 6.1) causes clear increase in mean indoor temperature (between 1 and 2^{o}C) and in peak temperatures, in all constructive solutions, mainly in the solution with interior insulation layer in which the temperature damping becomes zero. Furthermore, the time lag becomes almost null for the three constructive solutions. In scheme 6.2 the previous scenarios are improved with a thicker insulation layer. The results demonstrate that there is a clear increase in the average indoor temperature between 2ºC and 3^{o} C regarding scheme 1, greater than in scheme 6.1. In heavy construction with internal insulation the increase in peak (1ºC) temperatures is verified when comparing with the previous scheme 6.1, while in heavy construction with insulation on the external surface temperature damping did not change significantly. It is also verified that the light constructive solution, unlike the others, presents a reduction of the temperature peaks when comparing with scheme 6.1. Like in previous scheme the time lag becomes almost null.

Various authors highlighted the overheating due to super-insulated envelopes usually introduced by the energy saving standards [26-28]. In this study, the increase in insulation layer thickness promotes a decrease in temperature damping and affects indoor temperatures, promoting mean temperature increase, if there are thermal gains due to occupation, solar radiation and ventilation. Regarding the combination of all parameters it can be concluded that the heavy construction with insulation on the external surface has importance in the stabilization of the indoor environment as it still guarantees high temperature damping. It is also verified that the time lag between the interior and exterior temperature peaks becomes zero, which may be of little importance if there is a little indoor temperature fluctuating throughout the day. Otherwise the light solution presents an increase of temperature damping and time delay with the increase of the insulation thickness.

3.2 Energy demand

Energy performance of buildings assessment has become an important concerning in the last decade due to political, economic and ecological motives. Besides the thermal comfort analysis, the determination of the energy demand of three family houses, two single-family houses and one apartment is also performed for two Portuguese cities with Mediterranean climate, Bragança and Évora. Figure 5 reports the comfort parameters and Figure 6 the total energy demand for two months, January and August, in Bragança city. Figures 7 and 8 show the results obtained for Évora City.

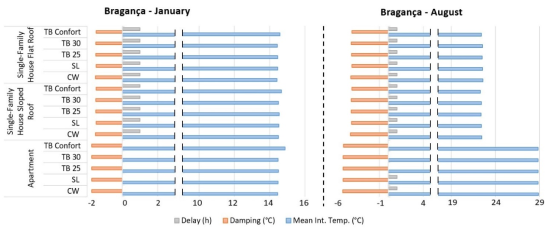

Figure 5. Average temperatures, damping and time lag: Bragança in January (left) and in August (right)

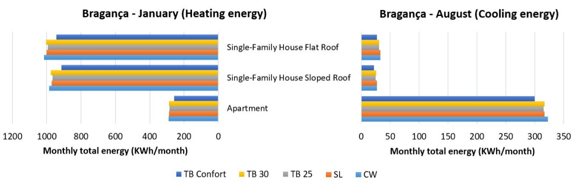

Figure 6. Energy needs: Bragança - January (heating energy) and August (cooling energy)

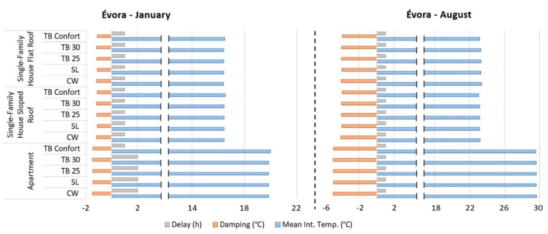

Figure 7. Average temperatures, damping and time lag: Évora in January (left) and in August (right)

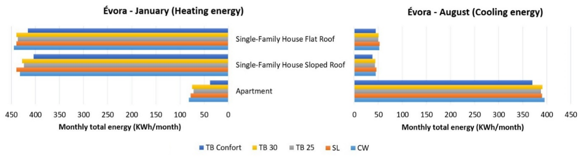

Figure 8. Energy needs: Évora - January (Heating energy) and August (cooling energy)

Considering Bragança city in January, and comparing the obtained results for the three housing typologies, it can be seen that the mean indoor temperatures are approximately equal; however in August the single-family houses mean temperature is 30% lower than the corresponding to the apartment. The temperature damping is equal for the two single houses, but lower than the corresponding value of the apartment, 15% in January and 22% in August. The time lag is similar for the three housing typologies, although in January it can be almost zero for the apartment. The energy demand is similar for the two single-family houses, lower in the dwelling with a sloped roof (3% in January and 12% in August); it is observed that the energy needs of the apartment are very different from the single-family houses, about 3.5 times smaller during January and 11 times greater in August. The introduction of the ventilated sloped roof in the single-family house promotes a slightly reduction in the energy demand, 3% and 12% for January and August respectively.

Considering Évora city the mean indoor temperatures are approximately equal for the single-family houses, lower than for the apartment (20% in January and 27% in August). The temperature damping is almost equal for the two single houses, but lower than the corresponding value of the apartment, 28% in January and 22% in August. During winter the time lag is one hour greater in the apartment while in summer the three housing topologies present the same value, 1 hour. The heating demand, like in Bragança city, is similar for the two single-family houses, slightly lower in the dwelling with a sloped roof (2% in January and 4% in August); the apartment energy needs, are about 10 times smaller during winter and 8 times greater in summer. Obtained results also show that the introduction of the ventilated sloped roof allows a slightly reduction in the energy demand, ranging from 2% for January to 12% in August respectively.

The quantification of the benefices on comfort, consumptions and global cost, by introduction of a ventilated layer are analyzed by some authors [15,18,28]. In this study the introduction of a ventilated sloped roof allows a slightly reduction in the energy demand mainly in summer.

Regarding the comparison of the behavior of different exterior wall solutions, traditional and light, it can be concluded that the three parameters chosen to characterize thermal comfort, mean indoor temperatures, temperature damping and time lag, are similar for the two considered cities during January and also in August. Furthermore, the present study shows that when a ventilated sloped roof is considered, heavy masonry walls are not more effective in delaying heat flow. On the other hand, it was found that the energy demand is lower for Weber solutions, namely the masonry wall with block Comfort where the reduction is between 6% for January in Évora city and 22% for August in Bragança city.

4. Conclusions

Simulation of energy performance for three types of family houses in Portugal was carried out, considering different envelope solutions, traditional and light, these based on WEBER improved masonry systems. Simulation for the two limit months, January and August, in two Mediterranean cities, showed that the thermal comfort parameters (mean indoor temperature, temperature damping and time delay) are not significantly influenced by the constructive solution. In the comparison between heavy solutions and light WEBER solutions, the first are not more efficient in retarding heat flow; they present similar time delay as WEBER masonry systems. Otherwise, WEBER solutions present lower energy consumptions for the three housing topologies, namely masonry walls made with block Comfort.

Housing topology showed to have more influence than expected, when compared with energy needs, since substantial differences were noticed. Single-family houses present between 3.5 and 10 times higher energy consumption in the month of January and 8 to 11 times lower energy consumption in the month of August, probably due to a greater overheating of the apartment in summer. The consideration of ventilated sloped roof in single-floor family houses shows a slight reduction in energy demand for all considered walls.

Analyzing thermal parameters, there are some differences: single-floor family houses present lower indoor mean temperatures (20 to 30%) and temperature damping (15 to 28%). Besides, the analysis of thermal comfort in two Mediterranean cities shows that when considering ventilated sloped roof, heavy masonry walls are not more effective in delaying heat flow.

Further research is needed to assess how thermal inertia can be improved, and how a lower level of thermal inertia can be compensated by building solar orientation, glazing elements surface properties, external shading devices, and other building operation strategies.

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