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CONSTRUCTION WITH SOIL-CEMENT BLOCKS AS A SUSTAINABLE ALTERNATIVE FOR BUILDING ENVELOPES[1]

CONSTRUCCIÓN CON BLOQUES DE SUELO CEMENTO COMO ALTERNATIVA SOSTENIBLE PARA ENVOLVENTE EDILICIA

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RESUMEN

Los materiales alternativos, como los bloques de suelo estabilizado con cemento (BSEC), brindan nuevas oportunidades para realizar envolventes amigables con el medio ambiente. Los materiales de construcción realizados con suelo son fáciles de obtener y abundantes en la naturaleza, además de que su uso minimiza los impactos ambientales y mejora el comportamiento térmico de las edificaciones. En este trabajo se analizan las propiedades térmicas de los BSEC con el objeto de evaluar la eficiencia de los bloques para la construcción de envolventes. Se determina, mediante ensayos experimentales, que los porcentajes de cemento deberían ubicarse entre 3% y 9% para la fabricación de BSEC adecuados para mamposterías no portantes. El contenido de humedad debería ser inferior al 20%, a fin de evitar aumentos significativos en la conductividad térmica. A través de termografía pasiva se define también la resistencia térmica de los muros y las resistencias superficial interior y exterior mediante. Las distintas composiciones de muros con BSEC de una vivienda experimental en condiciones reales de uso se monitorearon durante época invernal y, a partir de ello, se establecieron transmitancias térmicas para los muros desde 1,219 W/m2K a 1,599 W/m2K. Los resultados obtenidos permitieron determinar la eficiencia relativa de los distintos tipos de envolventes para evitar pérdidas de calor.

Palabras clave
ladrillos sustentables, termografía pasiva en viviendas, reducción de pérdidas de calor, conductividad térmica, resistencia térmica superficial.

ABSTRACT

Alternative materials, such as cement-stabilized earth blocks (CSEB), provide new opportunities to make environmentally friendly envelopes. Earth-based construction materials are easy to obtain, abundant in nature, and their use minimizes environmental impacts and improves the thermal performance of bricks. In this work, the thermal properties of CSEB are analyzed, to evaluate their efficiency for building envelopes. It is experimentally determined that cement percentages are between 3% and 9% for the manufacturing of CSEB for non-bearing masonry. The moisture content should be less than 20%, to avoid significant increases in thermal conductivity. Wall thermal resistivity and inner and outer thermal resistance are also determined by means of passive building thermography measurements. The different CSEB wall compositions of experimental dwellings under real use conditions were monitored during the winter, and from this, thermal transmittances were established for the walls of 1,219 W/m2K to 1.599 W/m2K The results obtained allow determining the relative efficiency of each building envelope type in avoiding heat losses.

Keywords
sustainable bricks, passive thermography in buildings, reduction of heat losses, thermal conductivity, surface thermal resistance.

INTRODUCTION

Buildings are currently responsible for a large percentage of global energy consumption. The United Nations Environmental Program indicates that buildings, in fact, represent more than 40% (United Nations Environment Program [UNEP], 2009) of this. This energy expense generates between 25% and 30% of the annual CO_2 emissions and, therefore, constitutes between 10% and 12% of human contribution to climate change through the heat retained in the atmosphere. Facing this scenario, all technological improvements and the use of alternative construction materials that can reduce heat losses and gains in buildings have a very high potential impact on the reduction of greenhouse gas emissions, and the resulting global warming.

According to the Argentine National Institute of Industrial Technology, it could be said that approximately one-third of the energy generated in that country is consumed by buildings, and just under half of this energy is lost through thermal air-conditioning demand (INTI, 2005). From this amount, almost half is used to satisfy cooling and heating demand, and more than 30% of the rest is lost through roofs with poor quality thermal insulation, which leads to heat escaping in winter, and overheating in summer.

In Argentina, several standards define the thermal conditioning guidelines for buildings (IRAM N° 11549, 11601, 11603, 11604, 11605, 11507-4, 11900, 11659-1, and 11659-2). These guidelines establish the thermal values, among other design parameters, for the most commonly used construction materials. Among these parameters, density ρ (kg/m^3), thermal conductivity λ (W/mK), specific heat *cp* (J/kgK), and the water vapor diffusion resistance factor, μ (non-dimensional), stand out among the most important for heat flow. From these, it is possible to characterize construction materials to obtain the thermal transmittance K (W/m^{2}K), or the opposite, the thermal resistance R (m^2.K/W). It is important to consider that the thermal determinations are made under a stationary system, for which the most relevant parameter is the thermal conductivity λ of the material (Damfeu, Meukam & Jannot, 2016; Ouedraogo, Aubert, Tribout & Escadeillas, 2020).

The heat transfer mechanisms are conduction, convection, and radiation. The traditional envelopes of buildings are made, mainly, with solid materials with medium or low porosity, which are subjected to environmental temperature changes. The standards that regulate housing enclosures are mainly based on controlling heat transmission in the enclosures. As such, they consider the definition of the envelope’s material and mass as priority (Dao, Ouedraogo, Millogo, Aubert & Gomina, 2018).

In recent decades, there has been a significant rise in the interest to get new materials for envelopes to make buildings more efficient from an energy point of view. Compressed stabilized cement-earth blocks (CSEB) are one of the alternatives explored, on being low-cost materials, whose manufacture is environmentally friendly as their use minimizes the carbon dioxide emissions generated by the traditional construction industry. CSEBs are manufactured with local earth and the addition of an aggregate (generally, cement and/or limestone), and water, which provides cohesion to the mixture and mechanical resistance to the masonry. This mixture is subjected to elevated pressure by mechanical compression, and unlike other masonries, it does not have any type of cooking process Nagaraj, Sravan, Arun & Jagadish, 2014; Costantini, Francisca & Giomi, 2021; Allen, 2012; Sekhar & Nayak 2018). Then, curing is done for at least 28 days. These blocks are a green economic and efficient alternative for buildings (Dahmen & Muñoz 2014; William, Goodhew, Griffiths & Watson, 2010).

The industrialization and construction with CSEB are limited by the lack of standards on the matter. There is a Standard that addresses the appropriate selection of earth and the construction with CSEB, with guidelines of principles and ways to build in countries such as Spain, France, New Zealand, and the United States, and in several regions of Africa. All these Standards are recommendations and directives of the CSEB production process (AENOR, 2008). Despite the advantages of using local earth and the lack of regulations in many countries, the use of CSEB for envelope construction has been noticeably increasing in recent times (Costantini, Carro Pérez, & Francisca, 2016). Recent studies showed that CSEBs with different soil types and a suitable stabilizing aggregate content exceed the mechanical resistance required by the traditional construction standards for seismic-resistant masonry (AENOR, 2008; Balaji, Mani & Venkatarama Reddy, 2016; Sitton, Zeinali, Heidarian & Story, 2018).

The heat flow through CSEB is considered, in general, as pure conduction, but heat transfer is also produced by radiation and convection. In porous mediums, such as compressed earth, the main form of heat transfer is conduction through solid particles (Yagi & Kunii 1957; Yun & Santamarina, 2008; Borbón, Cabanillas & Pérez, 2010; Mozejko & Francisca, 2020), given that the thermal conductivity of minerals is higher than that of the water and air found in the pores between particles. It is because of this that, among the factors that control the thermal conductivity of a material formed by particles, contact between said particles, density (or porosity), and the degree of humidification (or moisture content) are found (Costantini *et al.*,2021). Likewise, other secondary factors have an impact, to a lesser extent, in the heat transfers between porous mediums, such as the mineralogy of the particles, the particle size, and the pressure applied (Revuelta, García-Calvo, Carballosa & Pedrosa, 2021).

In the case of cemented earths, it is necessary to also consider the thermophysical properties of the stabilizing material incorporated, the curing time, and its thermal conductivity and calorific capacity (Costantin *et al.*, 2021). In CSEBs, heat flow is generally generated through solids (earth and cement particles), since the heat is transmitted more easily by conduction than through the air within the pores. As porosity increases (for example, in CSEBs with less density or holes), the thermal conductivity decreases, but the convection and radiation phenomena begin to gain relevance (Muñoz, Thomas y Marino, 2015; Balaji & Mani, 2019).

The use of techniques like thermography allows rating the energy efficiency of constructions, detecting construction issues, thermal bridges, lack of water tightness, and heat losses, through thermal contrasts where specific defects and pathologies can be differentiated (Sharlon, 2008; Fox, Coley, Goodhew & de Wilde, 2014). The experiences reported in specialized literature have shown the suitability of thermographic analysis to quantify the efficiency of insulation systems, detecting preference heat flow paths, air losses, and mapping moisture content (Grinzato, Vavilov & Kauppinen, 1998). One of the main advantages of thermography in housing is that it allows measuring surface temperatures non-invasively. Starting from these measurements, it is possible to perform qualitative analysis, differentiating building areas and different materials (Revillas, 2011). This also facilitates quantifying heat losses through an envelope and defining the thermal transmittance coefficient of each one of the walls a building is made up of (Sekhar & Nayak, 2018; Muñoz *et al.*, 2015).

In particular, the purpose of this work is to evaluate the thermal behavior of compressed cement-earth blocks used to build envelopes in an experimental dwelling. In this sense, different wall types are analyzed in the dwelling to determine the thermal transmittance of each composition with CSEB and the surface thermal resistances (interior and exterior), to determine the efficiency of each envelope.

METHODOLOGY

Initially, the thermal conductivity of the cement-earth blocks is characterized in the laboratory, and the thermal properties of the construction materials, used for the analysis of the results, are defined. Then, a building is monitored using HOBOs and a thermographic camera, determining temperature variations and thermal bridges with a qualitative and quantitative analysis of the surface temperatures of the envelopes. After this, an analysis of the Argentine IRAM Standards, and of the requirements of suitable comfort for building envelopes, is made. From this, the admissible surface resistance and wall thermal transmittance values are analyzed, determining the minimum values to reach thermal comfort considering the bio-environmental zone. In this way, the surface thermal resistances are calculated to define the heat losses of each envelope typology configured with cement-earth blocks, in real use conditions and in winter.

THERMAL CONDUCTIVITY MEASUREMENT

The thermal conductivity of the cement-earth masonry of the envelope is made using an East 30 Sensor. The experimental procedure, and the methodological details of this technique, fall under the ASTM D-5334 Standard. Before testing the bricks, the measurement needle is calibrated, and the values measured with the thermal conductivity of materials with known properties are compared. Distilled water and liquid glycerin are used for the calibration. This process results, in the case of the first material, in a value of 0.595 W/(m K), for a theoretical value of 0.607 +/- 0.03, and of the second one, a value of 0.293 W/(m K), for a theoretical value of 0.292 +/-0.003. It is worth highlighting that the percentage errors are less than +/- 3%:

The CSEBs are 25 cm long, 12.5 cm wide, and 7 cm tongue-and-groove prisms. They have two 7 cm diameter holes on the side that are used for their installation inside the wall. To measure the thermal conductivity of the CSEBs, the 1 mm diameter, 60 mm long stainless-steel needle sensor is introduced into a hole drilled in the blocks. The hole is made of a diameter that is slightly larger than that of the sensor, so that the needle can enter. The position of the hole is chosen carefully to avoid that the presence of air chambers produces border effects that could affect the measured results.

Once water is inserted, a direct current is applied using an Agilent E3645A voltage generator, which produces heating since a conductor thread is lodged inside the needle. The heat generated dissipates through the medium in contact with the needle, through a thermocouple of 0.01°C accuracy at the heart of the needle, which detects the temperature changes over time. This measurement is made with an Agilent 34410A multi-meter. Starting from the temperature changes over time, an inverse analysis is made to calibrate the solution of the axisymmetric heat flow equation, and thus determine the thermal conductivity of the material around the needle. Figure 1 presents a standard result where the temperature increase caused by the heating the needle over time can be seen, as well as the curve sector used to approximate the theoretical solution to the experimental results, following the guidelines suggested in the ASTMD-5334 Standard.

The temperature monitoring time ranges between 60 and 120 seconds, during which care is taken that the temperature increase of the sensor does not exceed 3°C. All the tests are made under controlled temperature and humidity conditions of 24°C and 50°, respectively. Each test was repeated at least 6 times, to then adopt the average of the measurements as a representative value.

THERMOGRAPHIC ANALYSIS

Images were taken using a TESTO 871 thermographic camera, with an IR resolution of 240 x 180 pixels, field of vision of 35° x 26° / 0.5m, spatial resolution 1.6 mrad, thermal sensitivity 90 mK, measurement frequency 9Hz, temperature range of -30°C to 650°C, and precision of 2°C ±2 % of the value measured.

During the measurements, an emissivity equal to 0.95 and a background reflected temperature compensation of 20°C, were adopted as the setup of the camera, following the recommendations of the infrared thermographic guide (Revillas, 2011). The thermographic images were taken at 4 different moments of the day, with overcast weather to avoid direct solar radiation on the external images of the dwelling. Using these images, a daily average surface temperature of each wall type was determined. This procedure allowed obtaining indoor images in a minimum time difference and thus knowing the indoor-outdoor temperature difference within short periods (not more than 1-minute differences). After the analysis and processing of the thermograms, the surface resistance of the walls was determined, using their thermal resistance and heat flow calculations.

To calculate the surface thermal resistance, the properties of the surface, emissivity, airspeed along the surface, and the surface, ambient air, and surrounding surface temperatures were used. In this way, the RS surface thermal resistance on flat surfaces resulted in (AENOR, 2008)

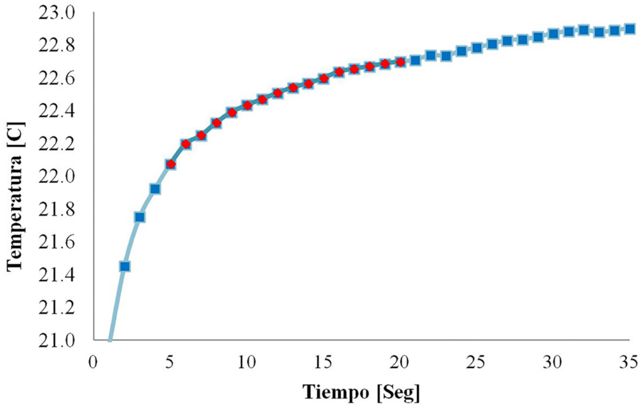


Figure 1. Standard temperature change response of the needle over time, during the thermal conductivity measurement. Source: Prepared by Francisca and Costantini Romero.

$$Rs = 1/(hc+hr) \quad \text{......................(1)}$$

Where *hc* is the convection coefficient and *hr* is the radiation coefficient. The convection coefficient, in the case of horizontal heat flow, was 2.5 W/(m^2K) on the indoor surface, and 20 W W/(m^2K) on the outdoor one, as per the IRAM Standard (1996). On the other hand, the convection coefficient was determined as follows:

$$hr = \varepsilon\, hr_0 \quad \text{......................(2)}$$

Where ε is the emissivity coefficient and *hr0* is the radiation coefficient for a black body, as follows:

$$hr_0 = 4\ \sigma\ Tm^3 \quad \text{......................(3)}$$

Where σ = 5.67 x 10^{-8} W/m^2K^4 is the Stefan-Boltzmann Constant, and *Tm* is the thermodynamic mean temperature of the surface and its surroundings. Following equations (1) to (3), *Rs* was:

$$Rs = 1/(hc + \varepsilon\ 4\ \sigma\ Tm^3) \quad \text{.............(4)}$$

EXPERIMENTAL DWELLING

The proposed methodology was applied to the study of the facades of the second floor of an experimental dwelling located in the city of Alta Gracia, in the Province of Cordoba, Argentina, which is shown in Figure 2. The dwelling has two floors and only the top floor is built with compressed cement-earth blocks (CSEB). The particularity of this dwelling is that, on the entire top floor, built with a traditional or wet system, different types of coatings were used on the envelope walls. This dwelling is residential.

Figure 2. Experimental dwelling: a) East façade; b) West façade. Source: Preparation by Costantini Romero.

The evaluation of the thermal behavior of the building was carried out with the continuous record of temperature and humidity for 7 days in August, from Friday, August 9th, to Friday, August 16th, 2019. In this period, the trends of the results obtained were similar.

Figure 3 shows the top floor of the dwelling under study, with the position of the sensors installed, and the description and location of walls being studied. As can be seen, the temperature and humidity sensors are in the living room, in one of the bedrooms, and outside the dwelling. The monitoring of the environmental conditions was made using the installation of a HOBOtemp and the storage and recording of the data with an RH logger. 2 HOBOs were placed inside the dwelling at a height of 1.50 m from the floor, and one on the outside. This allowed obtaining the real temperature of the environment with values recorded every 60 minutes.

The temperatures recorded oscillated between 2°C and 32°C, while the outdoor relative humidity was between 15% and 75°. Table 1 presents the outline and a description of the setup of each one of the walls analyzed in the experimental dwelling.

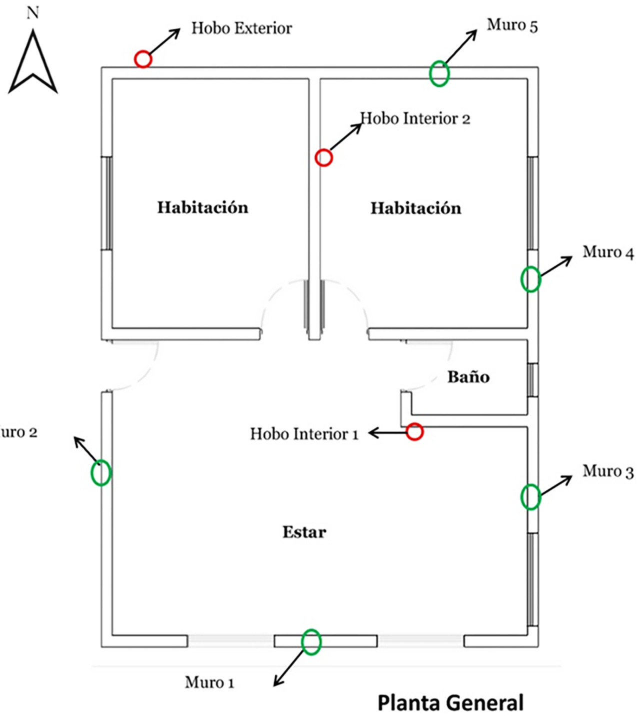


Figure 3. General floorplan of the dwelling with the HOBO layout and wall designation. Source: Preparation by Costantini Romero.

THERMAL RESISTANCE AND HEAT FLOW

The heat flow by area unit [W/m²] through the building envelope can be calculated as:

$$q= K\,(Te-Ti) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where *K [W/(m² K)]* is the thermal transmittance of the masonry, and *Te* and *Ti [K]* are the outdoor and indoor temperature, respectively. As these are exterior envelopes, the *K* value is obtained by the resistance of heat *R* passing through, bearing in mind that this is a heat flow problem perpendicular to the wall layers, resulting in:

$$R=1/K = Rsi+\sum_i e_i/\lambda_i+Rse \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

With e_i *[m]* is the thickness of each wall component layer; λ_i *[W/(m K)]*is the thermal conductivity of the material of each wall layer; *Rsi [m² K/ W]* is the internal surface thermal resistance; and, *Rse [m² K/ W]* is the external surface thermal resistance.

In equation [6], the thermal conductivity of each layer was obtained from the current Argentinian Standard, IRAM 11601. In the case of the CSEBs, this was calculated using the measurements of the material's λ, the geometry (12.5 cm x 25 cm x 7 cm), and the 2, 7cm diameter air chambers located symmetrically and equidistant from the block's walls. For the case of the air, *λair* = 0.165 W/m K was considered, a value obtained from the IRAM Standard [4].

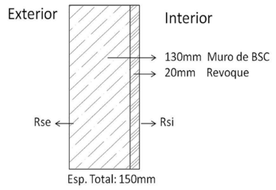
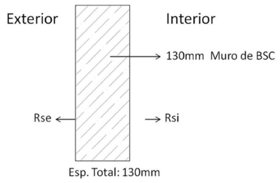
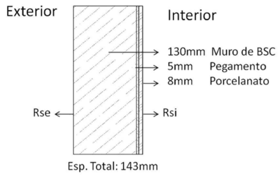
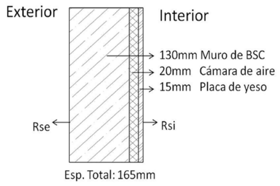
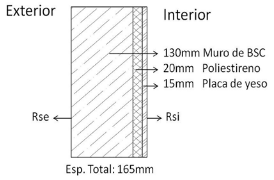
Wall	Wall Type	Layout and Description
Wall 1	Coated cement earth	
Walls 2	Cement earth	
Wall 3	Cement earth with porcelain tile	
Wall 4	Cement earth with plasterboard	
Wall 5	Cement earth with plasterboard and polystyrene	

Table 1. Main characteristics of the tested walls. Source: Preparation by Costantini Romero

RESULTS AND DISCUSSION

THERMAL CONDUCTIVITY OF CSEBS

The conductivity values were obtained through tests in 10 CSEBs. These measurements allowed defining the thermal conductivity of the solid fraction of the CSEBs, that is to say, of the compressed cement-earth. Using these measurements, an average and a standard deviation were calculated for the compressed cement earth: $\lambda = 0.347 \pm 0.021$ W/mK. Then, the equivalent thermal conductivity of the CSEB was analytically determined, considering the geometry of the block and the presence of air chambers shown. In this way, a thermal conductivity of $\lambda_{CSEB} = 0{,}283$ W/m K was obtained for the CSEB.

The difference between the thermal conductivity of the block material (compressed cement earth) and the block itself ($\lambda = 0.347$ W/mK in the former and $\lambda_{CSEB} = 0.283$ W/mK in the latter) reflects the importance of the holes and the thermal bridges, as practically the entire heat flow in the CSEB would be passing through the nerves, despite 46% of the transversal section being interrupted by the air chambers.

INDOOR AND OUTDOOR SURFACE RESISTANCES

The surface resistances are calculated using the indoor and outdoor temperatures of the surface of each wall selected. Figure 4 presents thermograms of the outside walls of the experimental dwelling. The thermograms show the temperature differences of the different construction materials, differentiating the thermal bridges and highlighting the thermal gains and losses through the envelope. The emissivity of the different materials (mainly inside), shows that the *Rse* should be different to calculate the thermal conductivity of each wall typology.

The indoor and outdoor surface thermal resistances were obtained using equation [4], considering the surface mean

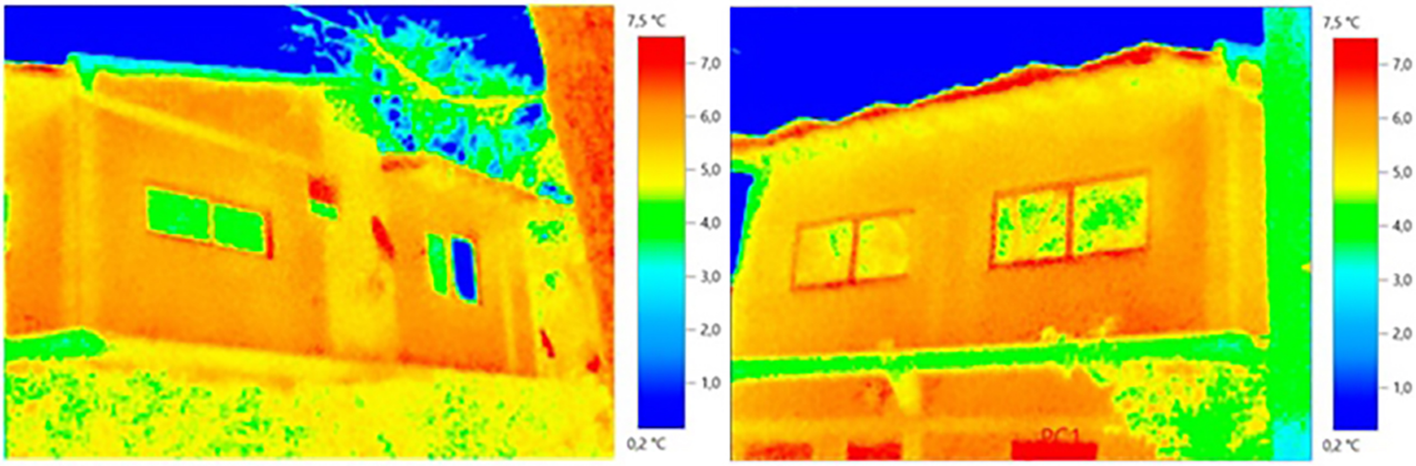


Figure 4. Outdoor thermographic images. Source: Preparation by Costantini Romero.

temperatures *Tm* determined by the thermograms and the emissivity coefficients, ε, established in the AENOR (2008) Standard for the different surface types. The results attained for each wall type are presented in Tables 2 and 3.

The values obtained are very close to those recommended in the Argentinian Standard, which establishes the following values for internal and external surface thermal resistance: *Rsi* = 0.13 m^2K/W and *Rse* = 0.04 m^2K/W, respectively. In both cases, these values correspond to the vertical walls with a horizontal heat flow. It is also seen that the variation throughout the day is negligible for all purposes. It is important to underline the importance of determining experimentally the *Rsi* and *Rse* values, to have more information about the energy efficiency of the enclosures and, therefore, of the buildings. The adoption of standardized values would not be advisable and could lead to significant deviations in the heat losses estimated for the dwellings.

HEAT FLOW

The heat flow is defined considering the composition and typology of each of the 5 walls of the envelope of the dwelling under study, the average *Rsi* and *Rse* calculated in Tables 2 and 3, and the thermal conductivity of the CSEB determined experimentally. The results, in this sense, are presented in Table 4. It is seen that, in these, the thermal transmittance of the walls decreases as insulating elements such as air chambers, polystyrene, or plaster are included, adding to or increasing the thermal resistance of the set. Walls 4 and 5, with transmittance *K* = 1.219W/m^2K and 1.251 W/m^2K, are not only the most thermally resistant, but also reach the values that the

Wall	Wall Surface	Time of the Day				Rsi (m^2K/W)
		00:00	06:00	12:00	18:00	Average
Wall 1	Varnished (ε=0,85)	0,147	0,148	0,146	0,142	0,146
Wall 2	Varnished (ε=0,90)	0,142	0,143	0,141	0,136	0,141
Wall 3	Varnished (ε=0,95)	0,137	0,138	0,136	0,132	0,136
Wall 4	Varnished (ε=0,80)	0,153	0,154	0,152	0,147	0,152
Wall 5	Varnished (ε=0,93)	0,139	0,140	0,138	0,133	0,138

Table 2. Indoor surface thermal resistance (Rsi) for each wall type. Source: Preparation by Costantin Romero

Wall	Wall Surface	Time of the Day				Rsi (m^2K/W)
		00:00	06:00	12:00	18:00	Average
Wall 1	Varnished (ε=0,85)	0,041	0,041	0,040	0,040	0,041
Wall 2	Varnished (ε=0,85)	0,042	0,041	0,041	0,041	0,041

Table 3. Outdoor surface resistance values (Rse) for each wall type. Source: Preparation by Costantini Romero.

Wall	Element layer	Thickness (m)	λ(W/mK)	R (m²K/W)	K (W/m²K)
Wall 1	Rsi	-	-	0.1460	1.499
	2- Brick	0.1300	0.283	0.3662	
	3- Interior coating	0.0200	0.960	0.0208	
	Rse	-	-	0.0410	
	Total thickness	0.15	Total Resistance	0.6672	
Wall 2	Rsi	-	-	0.1410	1.599
	2- Brick	0.1300	0.283	0.3662	
	Rse	-	-	0.0410	
	Total thickness	0.13	Total Resistance	0.6414	
Wall 3	Rsi	-	-	0.136	1.473
	2- Brick	0.13	0.283	0.3662	
	3- Mortar	0.005	0.160	0.031	
	4- Porcelain Tiles	0.008	0.700	0.011	
	Rse	-	-	0.041	
	Total thickness	0.143	Total Resistance	0.679	
Wall 4	Rsi	-	-	0.152	1.219
	2- Brick	0.13	0.283	0.3662	
	3- Air Chamber	0.02	0.165	0.125	
	4- Plasterboard	0.015	0.347	0.043	
	Rse	-	-	0.041	
	Total thickness	0.165	Total Resistance	0.821	
Wall 5	Rsi	-	-	0.138	1.251
	2- Brick	0.13	0.283	0.3662	
	3- Polystyrene	0.02	0.170	0.118	
	4- Plasterboard	0.015	0.347	0.043	
	Rse	-	-	0.041	
	Total thickness	0.165	Total Resistance	0.799	

Table 4. Thermal transmittance values for each masonry typology. Source: Preparation by Francisca and Costantini Romero.

IRAM Standard establishes to be recommended in the efficient construction under summer conditions, where the Standard sets a maximum value of 1.80 W/m^{2}K. However, for winter, none of the envelopes should exceed the minimum value required, of 1.00 W/m^{2}K, since the requirements are more rigorous.

The air chambers incorporated in the masonry, materialized through the plasterboards, improve the thermal behavior of the walls, reducing the heat flow by almost 25%. The drop in K is significant compared to that of a simple masonry wall with CSEB. In the walls with air chamber and plastic, and with a polystyrene and plaster aggregate, considerable efficiency improvements were observed. The results of this research present, as can be seen, an experimental database to validate heat transfer models in walls. These results show the advantages of using earth as a sustainable building material.

CONCLUSION

In the work outlined here, the thermal properties of compressive cement-earth bricks were evaluated as a sustainable alternative for the construction of building envelopes. In this framework, the main thermal properties of bricks and their application in an experimental dwelling were examined, where the top floor was built with compressed cement-earth walls with different construction technologies for the enclosures. The heat losses were analyzed for each alternative and, finally, the advantages of adopting this type of bricks for the construction of high thermal efficiency facades were determined. The main conclusions of the study are summarized as follows:

- The analysis of the thermal transmittance of five types of structured walls of different built forms, using compressed cement-earth blocks, allows confirming that the bricks used are an excellent alternative to materialize constructions with a low environmental impact, since their use minimizes the indoor heat gains and losses during summer and winter, respectively.
- The passive thermography was a non-invasive and low-cost method by which it is possible to detect the surface temperatures of each wall. Thus, the indoor and outdoor surface resistances of an envelope wall are obtained directly, which opens the option to develop a suitable design for the thermal conditioning of a building. Having a direct measurement of the surface thermal resistances allows increasing the accuracy in the determination of heat losses in buildings, experimentally determining the thermal conductivity of the masonry material and the *Rsi* and *Rse* surface resistances of the envelope's coating.
- The thermal transmittance of each wall typology varies depending on the resistance to heat passing through that each masonry offers. For the different walls evaluated, values between 1.219 and 1.599 W/m^{2}K were obtained, which are within a suitable range for summer, considering the Argentinian Standard. The analysis method followed in this work can be applied to dwellings built with other construction techniques and in different locations, but always making sure to compare the thermal transmittances obtained with the local regulations.
- The surface resistances vary with each type of material and throughout the day, as such their direct determination is recommended instead of just adopting standardized values. Regarding the walls tested, the values obtained range between 0.138 and 0.152 m^{2}K/W, for internal resistance, and 0.041 m^{2}K/W for the external one. The adoption of values that are suitable for the reality, allows adapting envelope designs and material use to save energy in the thermal conditioning of dwellings. Likewise, it is worth stating that the procedure proposed and carried out in this research is applicable to any construction typology, and to buildings in any bioclimatic region in any country. It is recommended to adopt the procedure proposed here and to compare the results obtained with the local regulation of each country.
- The results analyzed, show the importance of having quantitative heat flow determinations after building a dwelling. This allows considering, directly and concretely, the location in the energy consumption calculation for thermal conditions, and also designs that match the real conditioning needs, to achieve thermal comfort in the buildings.

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