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Comparative Analysis of the Effect of Thermal Insulation on the Energy Requirements of a Tertiary Building in Meknes

A. BOUCHARK[1]*, M.C. EL BOUBAKRAOUI[1], A. EL BAKKALI[1] and M. HADDAD[1]

[1] Laboratoire de Spectrométrie des Matériaux et des Archéomatériaux (LASMAR), URL-CNRST N°7, Faculty of Sciences - Moulay Ismail University of Meknes, Morocco

*Abouchark@gmail.com

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Abstract. Thermal insulation materials are essential for minimizing heat loss in winter and heat gain in summer in buildings, irrespective of the presence or absence of air conditioning systems. The right choice of insulation materials paves the way for considerable savings in buildings' energy requirements, while rationalizing the use of air-conditioning systems. This is all the more important in Morocco, where the building sector is one of the biggest consumers of energy. Consequently, improving the energy efficiency of buildings is an imperative, especially in the current context characterized by the gradual depletion of fossil resources and ever-rising energy costs. Our study focuses on the practical impact of integrating different insulation materials, including phase-change materials (PCMs), hemp concrete and polystyrene, into the structure of a tertiary building in Meknes, Morocco. The results of this research highlight that the incorporation of effective thermal insulation in the building's various construction elements results in substantial reductions in energy requirements, both in terms of heating and cooling. It should be noted that this study was carried out using energy simulations with TRNSYS software.

Introduction

Today, energy efficiency has become a global issue, as energy demand increases exponentially in sectors such as building, transport and industry. Indeed, the majority of energy policies target the building sector first and foremost as an energy-intensive entity in order to achieve energy consumption reduction targets [1].

In Morocco, the building sector is the second largest consumer of energy, prompting the Moroccan government to adopt thermal regulations (RTCM) in 2014 to integrate energy efficiency measures into the Moroccan construction context [2].

The building envelope is one of the fundamental elements on which energy efficiency measures are based, and is considered an effective passive strategy for improving the thermal performance and energy requirements of both tertiary and residential buildings [3-5]. For this purpose, a great deal of research has been carried out, focusing on thermal insulation [6-10].

A numerical simulation study to measure the effect of several insulation materials on the energy demand of an educational building, revealed that extruded polystyrene and polyurethane were the best choices for low energy consumption [11].

Another study evaluates the thermal behavior of six thermal insulants introduced separately into a wall using a simulation with ANSYS/FLUENT16 software, with the results showing that polystyrene is the most suitable insulator [12].

Phase-change materials (PCM) have also been used as insulation elements [13-17]. An experimental and numerical study was carried out to assess the thermal performance of a wall panel incorporating PCMs. According to the study, the use of the PCM layer reduced the thermal load by 15% [18].

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Other research has also focused on the use of bio-sourced materials for thermal insulation [19-21], such as hemp and hemp concrete, were subjected to a dynamic simulation analysis using TRNSYS software to assess their performance in a building in Meknes, Morocco. The results showed a 36.78% reduction in annual heating and cooling requirements when the building's roof and external walls were insulated with hemp [22].

In the present study, we are interested in the choice of a thermal insulation material adapted to the specific climatic conditions in Meknes city, while respecting the recommendations of the Moroccan thermal regulations (RTCM), in order to optimize the energy efficiency of a primary school annex in this region. We carried out a numerical simulation using TRNSYS software to compare the energy performance of three types of insulation: polystyrene, hemp concrete and phase-change materials. These materials were chosen for their distinct thermophysical properties, offering a variety of potential solutions to meet the specific energy requirements of the Meknes region, Morocco's third climate zone [2]. We aim to rigorously validate our results according to RTCM norms, thereby reinforcing the reliability and relevance of our study in the Moroccan regulatory context.

Description of the studied building

Our study focused on an extension being built to a primary school in Meknes, comprising three classrooms. The basic dimensions of the building are 20.45m long, 9.20m wide and 3.20m high. These parameters prioritize the space in which pupils will learn.

As part of our analysis of this school annex, we took detailed measurements to assess the building's thermal performance. Specific features include the presence of 12 single-glazed windows measuring 1.6 x 1.2 m^2, as well as three wooden doors measuring 2.1 x 1 m^2. Our analysis took these details into account to assess the significant impact of these components on our school's energy consumption. At the same time, we also noted the presence of 18 light bulbs of 40W each, which added a further dimension to our determination of the building's energy load. In addition, we identified a permanent occupancy of 93 people for 10 hours a day from 8h00 to 18h00, as this school works in groups, the first group in the morning from 8h00 to 13h00 and the second group in the afternoon from 13h00 to 18h00, an essential parameter for assessing heating and cooling requirements, and defining precise strategies for optimizing the energy efficiency of this school annex currently under construction.

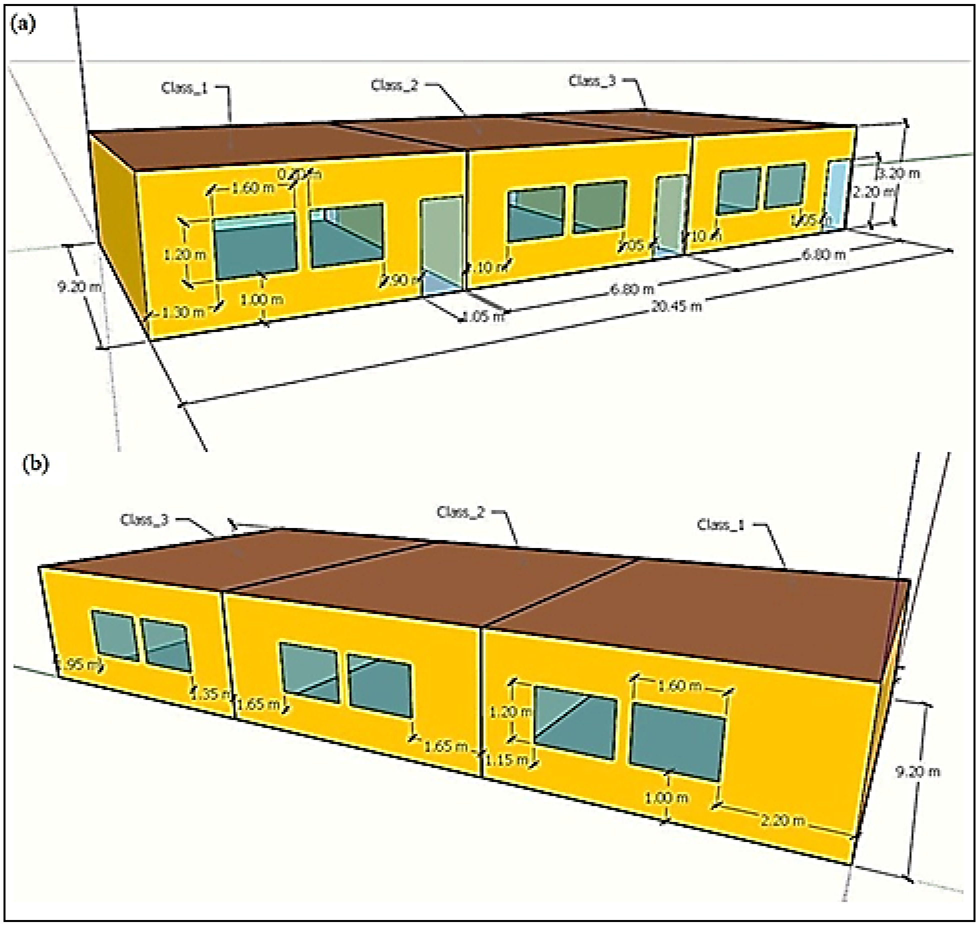

Fig. 1: 3D school plan: (a) Front facade, (b) Rear facade

The thermophysical characteristics of walls, roofs and low floors are of crucial importance in the thermal design of buildings. The essential data relating to these properties are detailed in the tables below:

Table 1: Exterior wall compositions

Materials	Mortar	Brick (8holes)	Air gap	Brick (8holes)	Mortar
Thickness (cm)	1	10	10	10	1
Thermal conductivity (W/m K)	1.4	1.15	0.556	1.15	1.4
Density (kg/m^3)	2000	743	1	743	2000

Table 2: Interior wall compositions

Materials	Mortar	Brick (8holes)	Mortar
Thickness (cm)	1	10	1
Thermal conductivity (W/m K)	1.4	1.15	1.4
Density (kg/m^3)	2000	743	2000

Table 3: Roof compositions

Materials	Plaster	Concrete slabs	Slab	Mortar	Tiles
Thickness (cm)	1	16	7	10	5
Thermal conductivity (W/m K)	0.351	1.23	1.65	1	1
Density (kg/m^3)	1500	1300	2150	1700	2500

Table 4: Floor on ground compositions

Materials	Exposed aggregate concrete	Form	Slab	Sand	Gravel
Thickness (cm)	2	6	12	3	20
Thermal conductivity (W/m K)	1	0.39	1.7	0.39	0.47
Density (kg/m^3)	2000	600	2400	750	570

Building orientation is of crucial importance in determining energy loads. The way our building is positioned in relation to the sun directly influences its energy requirements. For the orientation of our school's facades (Fig. 1), we have:

Table 5: Orientation of the school facades

Façade	Orientation
Front façade	South
Rear façade	North
Left lateral	West
Right lateral	East

Description of the studied climate

The city of Meknes, located in northern Morocco at an altitude of 531m, has a subtropical climate with hot, sunny summers and mild winters. Although it is slightly cooler (on average, it's around two degrees cooler in winter and even three quarters cooler in summer). It is also rainier, due to its more northerly location [23].

- In winter, temperature variations between day and night are significant: the average daytime temperature is 14°C, while the minimum night-time temperature is 5°C.
- In summer, the average daytime temperature is 35°C, with little difference from the night-time temperature. Similar to many regions of Morocco.

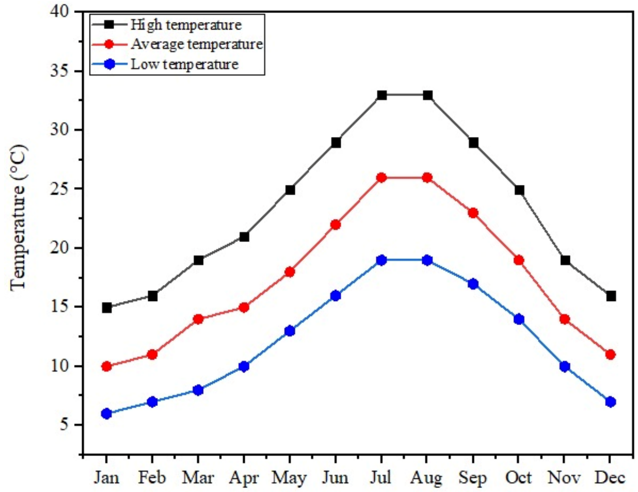

Fig. 2: Temperature chart of Meknes city.

Building simulation

In this stage of our study to evaluate and optimize the energy efficiency of the annex of our primary school in Meknes, we resorted to advanced energy simulations. These simulations were carried out using TRNSYS software. This energy simulation methodology offers an in-depth and accurate perspective on the building's thermal performance, enabling a detailed assessment of the impact of the various architectural elements and energy systems considered. The three-dimensional representation of the structure was created using SketchUp software. Simulation of the school's thermal behavior is carried out using multi-zone transient modeling with a time interval of one hour. The TRNBuild tool is used to input the data required for the multi-zone building simulation, describing the specific characteristics of the envelope (building materials, thickness of each layer and thermophysical parameters), window details and the school's occupancy schedule.

Our study is based on the annual working calendar, with the exception of the period from mid-July to August, when schools are closed for the school vacations. These months were not included in our analysis to ensure an accurate and relevant representation of working conditions throughout the year, avoiding variations linked to school closures during the summer. In addition, we took into consideration the thermal comfort set-point temperatures established by the RTCM, i.e. 26°C in summer and 20°C in winter. These values were incorporated into our model to ensure a realistic assessment of energy requirements. In addition, we also took into account the high occupancy rate, which is a crucial element for a comprehensive analysis of energy loads. It is important to note that we carried out the simulation with the single glazing for the windows, with a transmission coefficient of 5.5 W/m^2 K and a solar factor of 0.871.

Results and discussion

Firstly, a fundamental step in our analysis is to calculate the energy requirements of our school under baseline conditions, using conventional parameters. This initial assessment will then be compared with the recommendations of the RTCM to validate the consistency of our study. Once this validation has been carried out, we plan to introduce insulating materials to improve the energy performance of the building. The results obtained by calculating the energy requirements of our building and comparing them with RTCM standards are clearly presented in Fig 3.

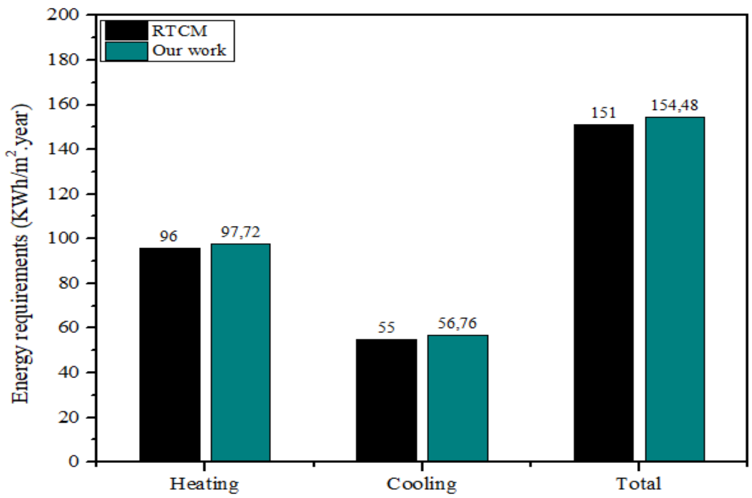

Fig. 3: Validation of our work to RTCM.

A comparative analysis of the annual energy requirements of our building, as calculated in our work compared with the references set out in the RTCM, reveals significant results. For cooling requirements, our simulation produced a figure of 56.76 kWh/m^2 year, slightly higher than the 55 kWh/m^2 year defined by the RTCM. On the other hand, for heating, our assessment indicated a requirement of 97.72 kWh/m^2 year, compared with the RTCM reference of 96 kWh/m^2 year. The sum total of our calculations is 154.48 kWh/m^2 year, slightly exceeding the RTCM figure of 151 kWh/m^2 year. These results indicate a remarkable concordance between our analysis and the regulatory standards, validating the reliability of our approach in determining the energy requirements of our building.

Having validated our results in accordance with the RTCM, we are now committed to the next phase, which focuses on the introduction of insulation materials to improve the energy efficiency of our building. We have chosen to compare three types of insulation: polystyrene, hemp concrete and phase change materials, to determine which best meets our requirements in our conditions, particularly in Meknes, located as Morocco's third climatic zone. The focus will be on energy efficiency, assessing the ability of each insulation to meet the specific cooling and heating needs in the city's distinct climatic context. This targeted approach aims to optimize the energy performance of our building by selecting the insulation best suited to our particular climatic environment.

Before comparing the insulation, materials selected, it is essential to know the thermophysical characteristics of each material. This preliminary step will enable us to rigorously assess the performance of each insulation material, whether polymeric, biobased or phase change materials. The data are shown in Table 6.

Table 6: insulation characteristics

Materials	Expended Polystyrene	Hemp Concrete	PCM (BioPCM M27/Q23)
insulation thickness in exterior walls and Roof (cm)	4	4	4
insulation thickness in Floor on ground (cm)	2	2	2
Thermal conductivity (W/m K)	0.037	0.082	0.2
Density (kg/m^3)	30	317	860

After a detailed study of the thermophysical characteristics of each insulating material, we will proceed to the numerical simulation of our building by introducing 4 cm of each insulating material in the external walls and the roof, while 2 cm of insulating material will be added to the floor on ground. The aim of this simulation is to assess the relative performance of each insulating material in our specific context. The detailed results of this numerical analysis, illustrated in Fig 4.

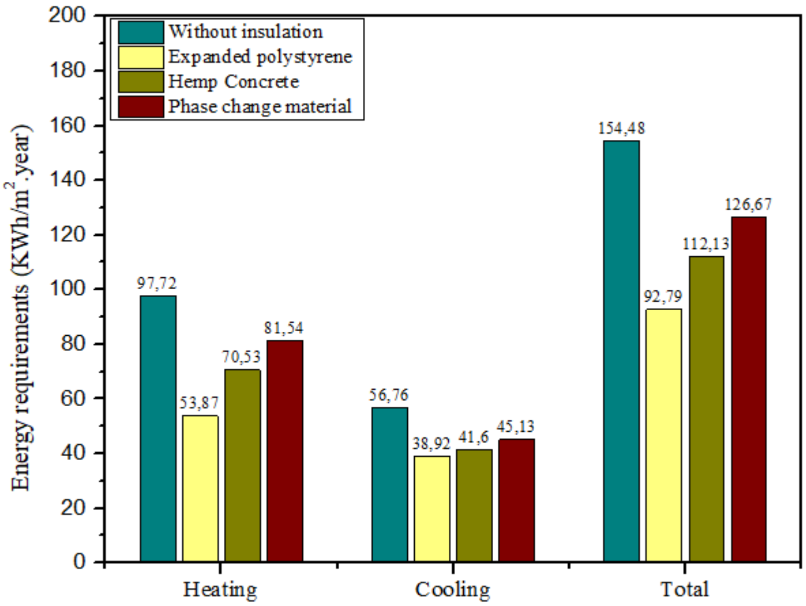

Fig. 4: energy loads with and without the three insulators.

The results presented in Figure 4 provide an in-depth analysis of the impact of different insulation methods on the annual energy requirements of our building in Meknes. Without insulation, the total energy requirement is 154.48 kWh/m² year, with a heating component of 97.72 kWh/m² year and a cooling component of 56.76 kWh/m² year. The introduction of polystyrene results in a significant reduction, bringing total energy requirements down to 92.79 kWh/m² year, an impressive reduction of almost 40.13%. Heating showed a substantial reduction of 45.02%, from 97.72 to 53.87 kWh/m² year, while cooling fell by 31.42%, from 56.76 to 38.92 kWh/m² year. For hemp concrete, a total reduction of 27.43% was observed, with significant reductions of 28.01% for heating (70.53 kWh/m² year) and 26.67% for cooling (41.60 kWh/m² year). Finally, the introduction of the PCM results in a total reduction of 18.03%, with decreases of 16.57% for heating (81.54 kWh/m² year) and 20.42% for cooling (45.13 kWh/m² year).

To ensure performance equivalent to that achieved with polystyrene, we undertook a series of simulations varying insulation thicknesses in different parts of the building, including external walls, the floor on ground, and roof (Table 7). This approach enabled us to explore various scenarios for each insulation material, seeking to identify the optimum thicknesses for achieving performance levels comparable to those of polystyrene. The results obtained from these simulations were carefully analyzed to inform our final choice of insulation material for our school in Meknes. The thicknesses selected for each material were adjusted to ensure optimum thermal performance, enabling us to make an informed decision in favor of the insulation that best met our specific energy and climatic criteria.

Table 7: various insulation thicknesses

Materials	Expended polystyrene	Hemp Concrete	PCM (BioPCM M27/Q23)
insulation thickness in exterior walls (cm)	4	8	12
insulation thickness in roof (cm)	4	8	18
insulation thickness in Floor on ground (cm)	2	2	10

The results obtained by varying the thicknesses of insulating materials such as hemp concrete and PCM are illustrated in detail in Fig 5.

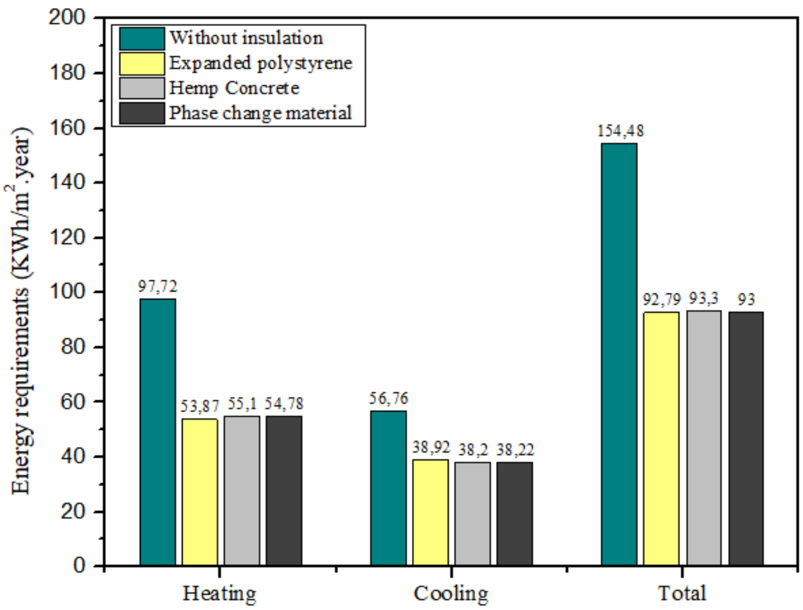

Fig. 5: energy load with and without the three insulators (with different thicknesses)

These results highlight the significant impact of thickness variation on the reduction in energy requirements, underlining the outstanding performance of both hemp concrete and PCM. For hemp concrete, judicious thickness adjustment resulted in considerable reductions, with total energy requirements falling to 93.3 kWh/m² year, reflecting a significant reduction of 39.59%. The reduction in heating requirements is 43.65%, from 97.72 to 55.1 kWh/m² year, while the reduction in cooling requirements is 32.70%, from 56.76 to 38.2 kWh/m² year. For the PCM, thickness adjustments have also led to significant improvements, with total energy requirements reduced to 93 kWh/m² year, representing a significant reduction of 39.84%. The reduction in heating requirements is 43.93%, from 97.72 to 54.78 kWh/m² year, and the reduction in cooling requirements is 32.52%, from 56.76 to 38.22 kWh/m² year.

These results show that, despite the significant increase in insulation thickness, hemp concrete and PCM achieve energy performances almost equivalent to those of polystyrene in its initial configuration. In this case, polystyrene stands out as the optimum insulator, maintaining equivalent or even superior energy performance despite variations in the thickness of the other insulators chosen.

According to our study carried out in the climatic context of Meknes, polystyrene stands out as the best performing insulation for our specific application. Simulation results using TRNSYS software highlight its remarkable efficiency, largely attributed to its low thermal conductivity. However, it's essential to note that this doesn't mean that other insulants, such as hemp concrete and PCM, don't meet our requirements. On the contrary, these insulants demonstrate a significant capacity to reduce energy requirements. In particular, hemp concrete offers outstanding performance, with a reduction of almost 27.43% in cooling requirements and 18.3% in heating requirements compared to the situation without insulation. As for PCM, although its performance is slightly lower, it offers a distinct advantage thanks to its high energy storage capacity. This unique feature could be a key element in specific applications where thermal storage is an important consideration. Thus, although polystyrene emerges as the optimal choice in our current context, it would be interesting to consider further studies to improve other materials, particularly phase-change materials. The latter could benefit from further investigation in order to fully exploit their potential as innovative solutions for energy efficiency, while taking into account the specific characteristics of the Meknes climate.

Application: Real case

Following this study, polystyrene appears to be the optimal insulation choice for our building, representing an effective passive strategy for significantly improving its thermal performance and reducing its energy requirements. The simulation results clearly demonstrate the considerable advantages offered by polystyrene in our specific Meknes context.

Based on these conclusions, we decided to adopt polystyrene in our specific case, namely in our school building. This decision was based on concrete data and simulation results, guaranteeing a significant improvement in the thermal performance of our building. Here are a few images of the installation of polystyrene insulation in our school building envelope (fig 6):

Fig. 6: Installing polystyrene as insulation in the building envelope: (a) external wall, (b) floor on ground, (c) roof.

Conclusion

In conclusion, our study involved a comparative analysis of the effect of thermal insulation on the energy requirements of a primary school annex in Meknes. We carefully compared energy requirements without insulation with those resulting from the integration of three different insulating materials: polymers, bio-sourced materials and phase change materials. The results, obtained from a numerical simulation using TRNSYS software, offer significant insight into the efficiency of each insulator in the specific climatic context of Meknes.

The overall percentage reduction in energy requirements is encouraging, with polystyrene leading the way with a substantial reduction of around 40.13 %, followed by hemp concrete with 27.43 % and PCM with 18.03 %. These results guided our strategic choice to adopt polystyrene as the insulation in our real case, particularly in our school building. This decision was based on polystyrene's ability to offer the most significant reductions in energy costs, reinforcing its status as the preferred choice for improving the energy efficiency of our building in Meknes.

It is important to note that other scenarios aimed at further reducing these energy requirements form part of the objectives of future studies, with the aim of continually optimizing the energy performance of the building. A concrete example of such scenarios could be the integration of solutions such as more efficient glazing to minimize thermal losses, thus contributing to a further reduction in the building energy requirements.

However, this conclusion does not close the debate. It opens the door to future studies, inviting further exploration of the possibilities offered by other insulating materials. The constant evolution of technologies and knowledge in the field of energy efficiency suggests that further innovations could be envisaged to further optimize the thermal performance of buildings in similar climates.

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