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Improving energy efficiency in Moroccan homes: Thermal performance of gypsum plaster and expanded clay

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Abstract: Thermophysical properties of construction materials, such as thermal conductivity and thermal diffusivity, play a crucial role in evaluating the thermal performance of buildings. This study investigates these properties in gypsum plaster mixed with expanded clay granules and assesses its impact on residential building energy demand. Gypsum plaster samples were prepared with varying mass proportions of expanded clay while maintaining a constant water-to-plaster ratio. Thermal conductivity and diffusivity were measured using the heated plate and flash methods, respectively. Additionally, a Trnsys-based simulation was conducted to evaluate the effect of these mixtures on energy consumption. The results indicate that adding expanded clay granules reduces the thermal properties of gypsum plaster, likely due to water absorption during mixing. However, using gypsum plaster with 6% expanded clay led to an 18.16% energy gain. Moreover, insulation of exterior walls and roofs improved energy performance by 21.83% and 33.21%, respectively, while floor insulation negatively affected efficiency. These findings emphasize the importance of material selection in optimizing energy consumption. The study highlights the potential of integrating expanded clay in gypsum plaster to enhance building energy efficiency, offering valuable insights into sustainable construction practices.

Keywords: *Construction, Energy efficiency, Energy simulation, Expanded clay, Gypsum plaster, Thermal.*

1. Introduction

In contemporary construction, evaluating the thermophysical properties of materials is crucial for achieving both technical efficiency and economic sustainability. Among the most effective strategies for reducing construction costs and minimizing energy consumption, optimizing thermal insulation has become a fundamental objective in sustainable building design. Studies have shown that proper insulation can reduce heating and cooling energy demands by up to 30%, underscoring the importance of selecting materials that not only meet high-performance standards but also contribute to energy efficiency.

Conventional insulation systems typically consist of multiple layers of various insulating materials. While these systems are effective, they often result in increased costs, excessive bulk, and sometimes suboptimal energy performance. In contrast, lightweight aggregates (LWAs) represent a promising alternative due to their favorable thermal properties, porous structure, and mechanical resilience. Empirical studies have demonstrated that LWAs can achieve up to a 50% reduction in density while maintaining thermal conductivity values below 0.15 W/m·K. This ensures high thermal efficiency with minimal structural load, offering significant advantages in modern construction, where material optimization is a primary concern.

The environmental impact of construction materials is another critical factor in modern building practices. The production of gypsum plaster, widely used in the industry, is a notable source of CO_2

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emissions, particularly due to the calcination process involved in producing one ton of plaster. To mitigate these emissions, a key strategy is to reduce the amount of natural gypsum used by substituting it with alternative materials. These substitutes, which may be either natural or synthetic, interact chemically with the plaster matrix in some cases, while others remain inert. The aggregates in the mixture are typically thermally stable up to temperatures of 300–350°C, with their physical properties, chemical characteristics, and thermal stability becoming essential when the plaster is exposed to high temperatures.

Expanded clay is produced on a global scale, with annual production reaching approximately 4 to 6 million cubic meters, primarily in Europe and Asia. In Morocco, however, specific data on the production of expanded clay is unavailable, as the focus is primarily on bricks and terracotta materials. Lightweight expanded clay aggregate (LECA) is produced by heating clay in a rotary kiln at temperatures between 1100 and 1200°C, which causes internal gases to expand the clay, forming a lightweight and porous structure. The clays used typically contain minerals such as illite, montmorillonite, and kaolinite, along with impurities like quartz and carbonates. LECA is highly valued in construction for its low weight and excellent insulating properties. Moreover, dust generated during the production of LECA has potential applications in the manufacturing of paints or heat-resistant concrete. The cellular internal structure of LECA, composed of thousands of air-filled voids, contributes significantly to its thermal and acoustic insulation capabilities.

When used in its unsaturated state, lightweight aggregate (LWA) exhibits superior strength compared to its saturated counterpart. However, in certain situations, especially at higher temperatures, the pre-saturated nature of LWA—widely used in practice—can cause spalling in lightweight matrices. LWA is often produced as a byproduct of volcanic eruptions or combustion, resulting in materials such as pumice, ceramiste, and expanded clay. These aggregates are known for their high heat resistance and low thermal conductivity, making concrete made with them more durable at elevated temperatures compared to conventional concrete made with standard aggregates.

Ongoing research continues to enhance the thermophysical properties of composite materials, such as cement, clay, and plaster. Clay, with its high thermal mass and ability to regulate moisture, is particularly effective in moderating indoor temperature fluctuations, especially in hot climates, where it can reduce indoor temperature variations by 5 to 7°C. Similarly, plaster, known for its fire resistance and low density, exhibits considerable thermal insulation potential when integrated into advanced composites. Studies have shown that such composites can reduce wall thermal conductivity by as much as 40% compared to conventional configurations.

The exploration of these innovative materials is essential to meet the growing demand for energy-efficient and sustainable construction. By optimizing the thermophysical properties of materials used in building envelopes, it is possible to reduce energy consumption, enhance durability, and improve overall structural efficiency. These advancements align with global efforts to reduce carbon emissions and promote sustainable development within the construction sector.

Development and characterization of new lightweight waste-based plaster composites for building applications Benzal-Zaragoza, et al. [1]. Thermal Performance Analysis of Plaster Reinforced with Raffia Vinifera Particles for Use as Insulating Materials in Building [2]. The effect of fly ash and pine tree resin on thermo-mechanical properties of concretes with expanded clay aggregates [3]. The mechanical properties of lightweight (volcanic pumice) concrete containing fibers with exposure to high temperatures [4]. Improving nonlinear behavior and tensile and compressive strengths of sustainable lightweight concrete using waste glass powder, nanosilica, and recycled polypropylene fiber [5]. Improving building energy efficiency and thermal comfort with natural fibre insulation [6]. Assessment of the Thermal Properties of Gypsum Plaster with Plastic Waste Aggregates [7]. Mechanical and thermophysical characterization of gypsum composites reinforced by different wastes for green building applications [8]. Expanded Clay Production Waste as Supplementary Cementitious Material [9]. Effect of jute fiber reinforcement on the mechanical properties of expanded perlite particles-filled gypsum composites [10].

The objective of this research is to analyze the impact of incorporating expanded clay beads on the thermal conductivity and diffusivity of gypsum plaster. An energy simulation will be conducted to evaluate the effects of this material on wall insulation and the building's annual energy consumption. This study seeks to optimize thermal efficiency and reduce energy losses. The findings are expected to provide valuable insights into the potential benefits of using expanded clay to enhance the energy performance of modern buildings.

2. Materials and Samples Preparation

2.1. Description

Plaster is a construction material known for its insulating and fire-resistant properties, derived from gypsum, a natural mineral. It exists in three forms: dry powder (industrial plaster), a paste (activated with water), or as hardened boards and coatings. The dry powder consists mainly of calcium sulfate hemihydrate ($CaSO_4 \cdot ½H_2O$) and anhydrite ($CaSO_4$), produced by the thermal dehydration of gypsum. When mixed with water, it rehydrates into gypsum ($CaSO_4 \cdot 2H_2O$), forming a durable and moldable material.

Plaster's thermal conductivity ranges from 0.17 to 0.35 W/m·K, making it an efficient insulator in buildings. Additives such as fillers, pigments, and lightweight materials can enhance its properties, reducing density and improving thermal performance. Additionally, plaster's fire resistance stems from its crystalline water, which helps cool surfaces during heating. These characteristics, combined with its versatility and ease of application, make plaster a key material in modern, energy-efficient construction.

Many additives, including fillers, pigments, and colorants, can also be incorporated into the composition of plaster.

Expanded clay is a lightweight and insulating material obtained by heating natural clay at high temperatures, resulting in porous beads. Its thermal and acoustic insulation properties make it a popular aggregate in construction, especially in lightweight concrete and insulation systems, with a thermal conductivity generally ranging between 0.097 W/m·K and 0.123 W/m·K. This material also offers good mechanical strength and durability, which are essential for various applications. Additionally, its ability to regulate humidity makes it particularly suitable for sustainable construction projects. This study aims to explore the impact of expanded clay on the thermophysical properties of plaster-based composites.

The production of plaster releases approximately 0.24 kg of CO_2 per kilogram due to the high-temperature calcination of gypsum, making it energy-intensive. In comparison, expanded clay emits around 0.15 kg of CO_2 per kilogram, although it requires firing at temperatures close to 1,200°C. Both materials have notable environmental constraints, primarily due to their CO_2 emissions and resource extraction impacts. However, expanded clay generally has a slightly lower carbon footprint, making it a somewhat greener alternative in construction.

In this study, dust captured in the electronic filter during the combustion gas cleaning process in expanded clay production (ECD) and standard gypsum plaster used in construction were utilized. The chemical composition of both the dust and the gypsum plaster (GP) is presented in the following section, Table 1.

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Table 1.
Chemical composition of raw materials (wt.%).

Component (wt%.)	GP	ECD
$CaSO_4.2H_2O$	90	-
$CaCO_3$	1.5	-
SiO_2	3	44.9
Al_2O_3	0.95	25.3
Fe_2O_3	0.72	9.79
CaO	-	4.83
MgO	-	1.33
K_2O	-	1.46
Na_2O	-	0.27
SO_3	-	0.67
P_2O_5	-	0.35
TiO_2	-	1.03
Eau libre	1.36	-
Other	0.5	0.10
Loss on Ignition	16	9.84
Specific surface area (m2/kg)	477	360

2.2. Preparation

Before formulating the various mixtures, we characterized the physical properties of the aggregates by examining the particle size distribution, bulk densities, and water absorption. The values selected for these characteristics are based on the average of three measurements, ensuring the reliability and representativeness of the results.

After sorting the expanded clay beads, we defined three particle size classes: (8-10 mm), (10-12.5 mm), and (12.5-16 mm). The aggregates from the (12.5-16 mm) class were chosen for sample preparation and were dried at 70°C until their mass became constant, defined as a variation of less than 0.1% after one hour of drying. The mixing was done with a fixed quantity of 0.625 g, resulting in four cylindrical samples: one control sample made of pure plaster (0% aggregates) and three others containing 2%, 6%, and 10% expanded clay beads, respectively, Figure 1.

To assess the impact of these beads on the thermal properties of the plaster, the samples were first air-dried for 24 hours, followed by further drying in an oven at 65°C for one week to minimize moisture content in the pores.

Figure 1.
Expanded Clay and the Four Samples Studied.

3. Method of Measurement

3.1. Transient Hot Plate Method

The guarded hot plate apparatus measures thermal conductivity and resistance by generating a heat flux at its center via the Joule effect Figure 2. An electric resistance surrounds the heating zone, maintaining a zero-temperature difference. By measuring temperatures on both faces of identical samples, thermal conductivity (λ) and thermal resistance (R) can be calculated using R = e/λ, where e is the sample thickness. This method provides an absolute measurement of thermal conductivity.

This method involves measuring the temperature at the center of a circular heating element (100 x 100 x 0.1 mm^3) placed between two samples. The principle consists of applying a voltage of U = 12.08 V across the heating element, which is positioned between the sample and the polyethylene foam. A thermocouple is securely attached to the inner surface of the heating element. The sample, heating element, and insulating foam are arranged between two aluminum blocks with high thermal conductivity, ensuring a rapid transition to a steady state.

$$\lambda_1 = \frac{e_1}{((T_0 - T_1)} = [\frac{U^2}{R.S} - \frac{\lambda_2}{e_2}(T_0 - T_2)] \qquad (1)$$

The equation allows us to determine the thermal conductivity of the sample once the system reaches the equilibrium state. Withe e^1 is the sample's thickness, e^2=10 mm is the heating element thickness, λ_2=0,047 W.m^{-1}. K^{-1} is the thermal conductivity of the heating element S corresponds to its section.

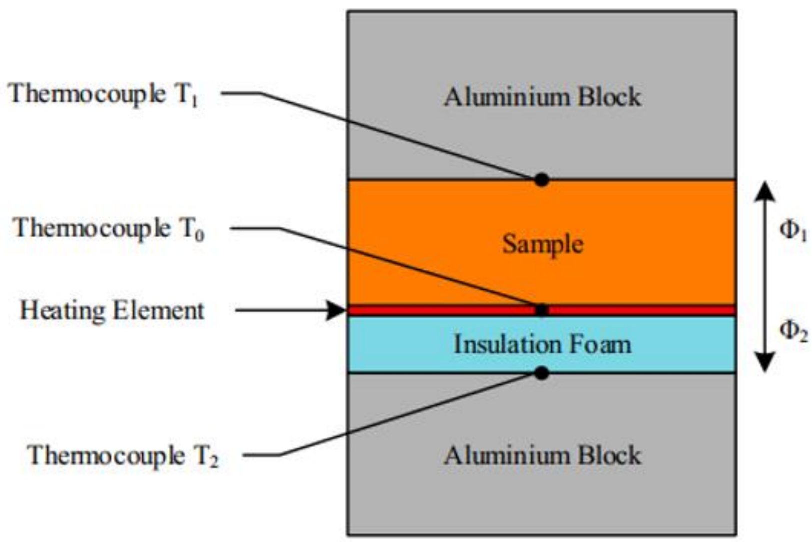

Figure 2.
Experimental Setup of the Steady-State Hot Plate Method.

3.2. Flash Method

The principle of this method relies on analyzing the short-term thermal response of a sample subjected to an almost instantaneous heat flux Figure 3. Initially, the sample is in thermal equilibrium with its surrounding environment and stabilized at a baseline temperature T_0. The front face of the sample is then exposed to a high-intensity light flux ϕ_0 for a brief duration (τ=4 s). A thermocouple positioned at the center of the back face records the temperature increase when the front face is subjected to the heat pulse. A heat transfer model is applied within the sample to estimate thermal diffusivity based on the resulting experimental thermogram. The quadrupole method is used to formulate:

$$\Theta(p) = \frac{\frac{q}{p}(1-e^{-\tau p})}{h^2\frac{Sonh(ke)}{\lambda k}+2hcosh(ke)+\lambda k.\sinh(ke)} \quad (2)$$

τ is the elapsed time from the flash pulse heating and p stands for the Laplace parameter and, a, and e are respectively, the thermal diffusivity, the thermal conductivity and thickness of the sample.

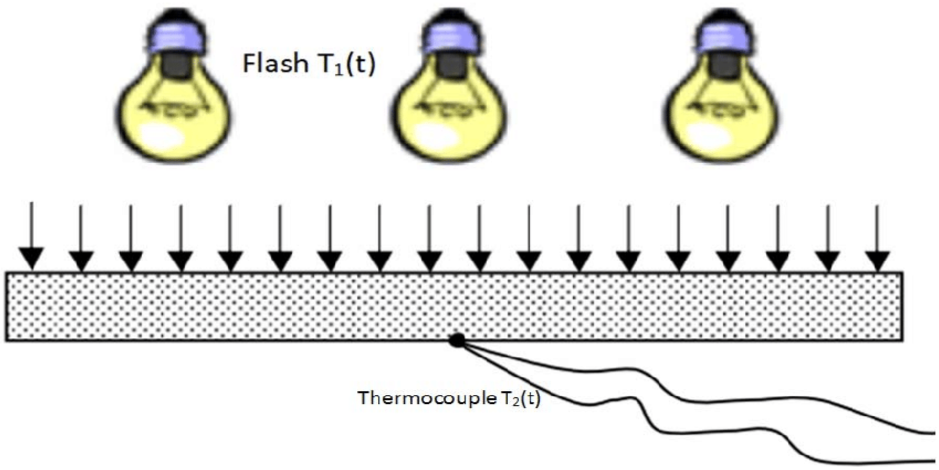

Figure 3.
Flash Method for Thermal diffusivity Measurement

4. Simulation Software

Trnsys (Transient System Simulation) is a widely used software tool for simulating the transient performance of complex energy systems. Developed primarily for building energy analysis, Trnsys allows users to model the interactions between various components such as heating, cooling, ventilation, and renewable energy systems. Its modular architecture enables the integration of diverse physical models, making it adaptable for a variety of applications, including solar energy systems, HVAC systems, and energy storage solutions. Users can create detailed simulations of thermal and electrical behavior over time, analyzing the effects of different design choices and operating conditions. Trnsys also features a user-friendly graphical interface, facilitating model setup and visualization. The software supports a range of input parameters and can produce comprehensive output data for performance assessment. Its versatility makes TRNSYS a valuable tool for researchers, engineers, and architects aiming to optimize energy efficiency and sustainability in building designs.

4.1. Case Study

A design plan for a simple residential building in Salé will be developed. applying the specific climatic conditions of the region as defined in the RTCM (Moroccan Climate Reference). This building will be modeled using TRNSYS software Figure 4, which is essential for conducting detailed energy simulations. Through this simulation, TRNSYS enables the analysis of the thermal performance of the building, with a focus on the influence of incorporating new composite materials into the wall structures.to evaluate how these modifications impact both the energy efficiency and indoor comfort levels within the building. The construction model in the software includes materials specified in the accompanying Table 2.

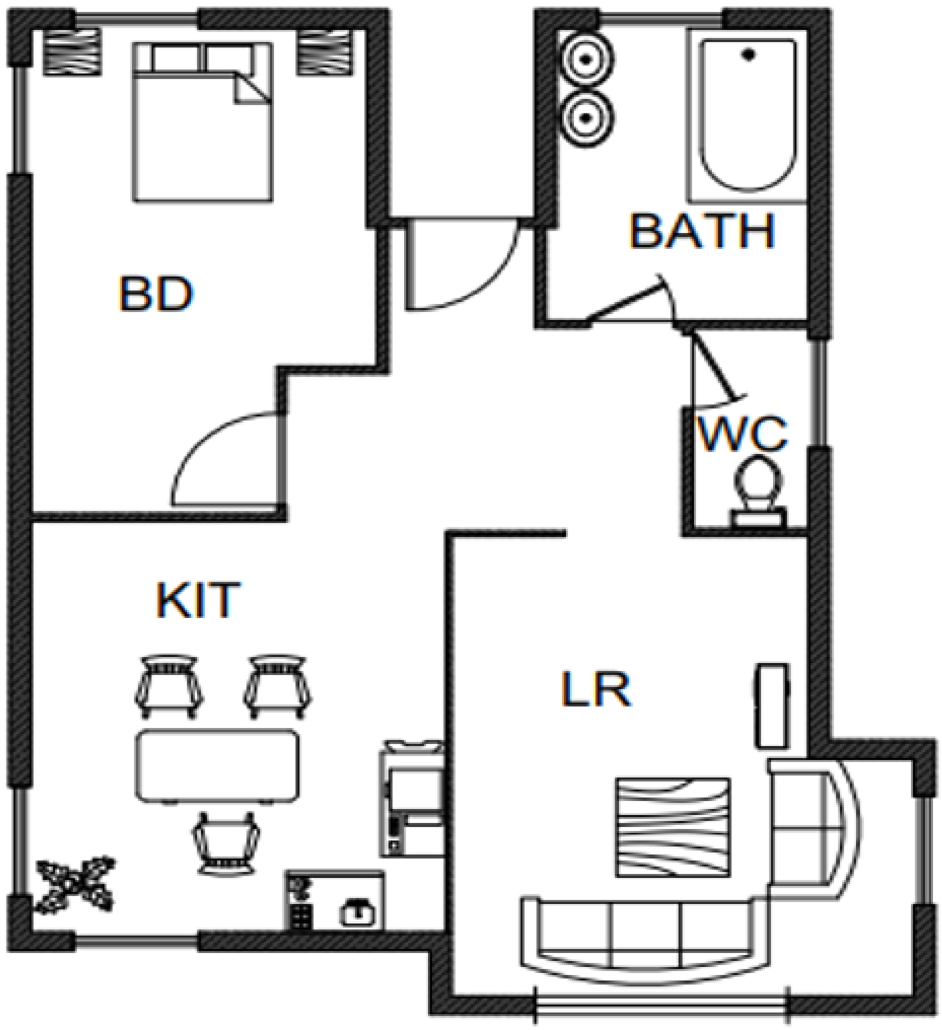

Figure 4.
General Building Layout, Base Case.

This building is built on an area of 88 m^2, a volume of 264 m^3 and is made up of five distinct zones as follows:

- WC: Domestic Toilet
- BATH: Domestic Bathroom
- BD: Cozy Domestic Bedroom
- KIT: Domestic Kitchen
- LR: Domestic Living Room

Table 2.
Characteristics of Construction Materials.

Material	λ (w/m.K)	c (kJ/kg.K)	d (kg/m³)	e (m)
Hollow brick	0.80	0.79	720	0.15
Hollow Concrete brick	4.0	0.65	1300	0.1
Concrete	1.7	0.8	2400	0.1
Plaster coating	0.1847	0.5	965	0.02
Plaste /expanded clay	0.2386	0.3	933	0.03
Air blade	0.025	1.22	1	0.05
Stone	3.0	1.0	2000	0.45

The glazed area constitutes 10% of the total floor area, corresponding to approximately 6.67% of the glazed surface per façade. The windows are single-glazed, with a thermal transmittance coefficient (U-value) of 5.74 W/(m²·K) and a solar heat gain coefficient (g-value) of 0.87.

The exterior walls are constructed from 15 cm thick hollow bricks, finished with an exterior cement mortar coating and an interior plaster layer. An additional 3 cm layer of the new insulating mixture is applied to the inner surface of the exterior walls. Internal partitions are made of 10 cm thick hollow bricks, coated with plaster on both sides.

The ground floor slab comprises a 20 cm layer of stone, followed by a 10 cm concrete layer, and is finished with ceramic tiles. The screed layer consists of a 2 cm thick cement mortar.

The roof is constructed with a 20 cm thick hollow-core concrete slab, topped with a cement mortar screed. The interior is finished with a plaster coating, which includes an additional 3 cm layer of insulating material (plaster/expanded clay mixture).

4.2. The Simulation Method

The Rabat-Salé region of Morocco enjoys a Mediterranean climate, tempered by Atlantic influences. Seasonal temperature variations range from 12–14°C in winter (January–February) to 24–26°C in summer (July–August). Winters are mild with moderate rainfall, while summers are hot and dry, alleviated by coastal breezes. Spring and autumn provide pleasant, temperate conditions with average temperatures between 18 and 22°C. The region's coastal proximity contributes to elevated humidity levels, enhancing air moisture and maintaining a cooling effect throughout the year.

In general, and according to the figure below, temperatures in the Rabat-Salé region are moderate and lack significant extremes, placing the area among those with a mild climate. As illustrated in the chart above, the lowest average temperature recorded in 2023 was 13°C in January, with a maximum of approximately 19°C and a minimum of 7°C. Conversely, the highest average temperature occurred in August, reaching 25°C, with peak temperatures around 30°C and lows of 19°C. This consistent mildness underscores the region's temperate climate, moderated by Atlantic influences, which keeps seasonal variations relatively gentle, Figure 5.

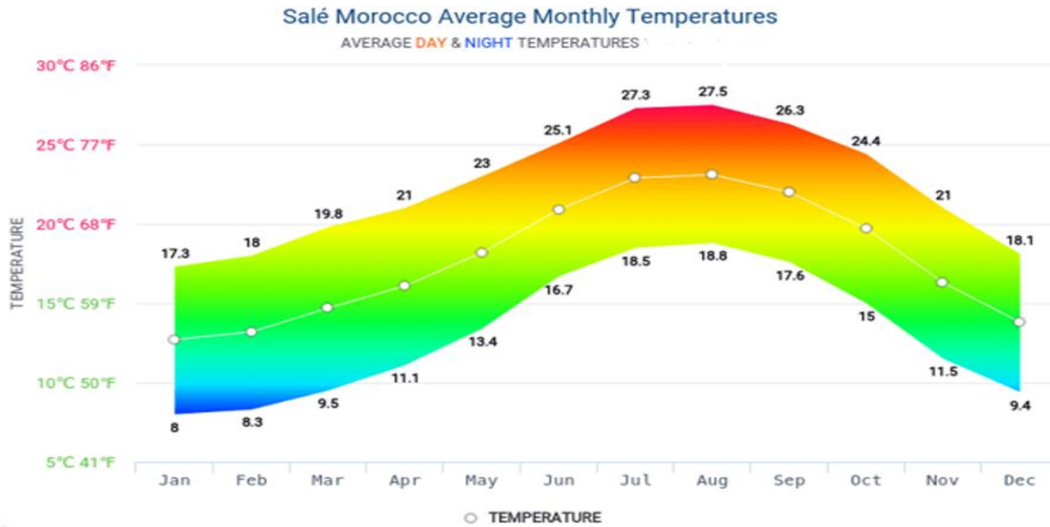

Figure 5.
Temperature Diagram of the Rabat-Salé Region.

The impact of insulation will be assessed by applying it to the core of the ceiling and the exterior walls of the building. Specifically, we have chosen an innovative composite material comprising a mixture of gypsum plaster with 6% expanded clay as an insulating component. The thermal properties of this material are: λ=0.286 W/mK, Cp=0.3 kJ/kg K et ρ=933kg/m^3.

This mixture was selected based on its promising thermal stability, applicability, and enhanced physical properties, which contribute to both the thermal insulation and structural reinforcement of the construction. These qualities make it a strong candidate for optimizing building performance, pending final validation through simulation. As the material is still in the experimental phase, this study aims to further confirm its effectiveness in achieving our thermal and physical objectives.

The insulation will be applied at a uniform thickness of 3 cm on the exterior facades and the roof. This approach aims to identify the areas that should be prioritized for insulation and to determine the optimal insulation thickness needed to achieve minimal energy demand.

In this study, all zones are air-conditioned as a single zone, except for the WC and bathroom. The HVAC system is a standard heating and cooling setup, operating for 10 hours during the day and shutting down at night. This approach allows the walls to absorb heat, utilizing their thermal capacity to stabilize indoor temperatures, minimize heat loss and energy consumption, and ensure thermal comfort for occupants.

5. Results and Discussion

5.1. Density

The results of the bulk density measurements of the four samples are compiled in **Table 3**, based on their volume and mass after drying.

Table 3.
Sample dimensions and density.

Samples	Thickness (cm)	Length (cm)	Mass (kg)	Density (kg/m^3)
PA10	2.205	10.37	168.17	928
PA6	2.145	10.05	163.21	933
PA2	1.998	10.10	152.9	955
PA0	1.855	10.05	141.33	965

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The experiment investigated the effect of adding expanded clay granules to plaster, with mass fractions of 10%, 6%, 2%, and 0% (designated as PA10, PA6, PA2, and PA0, respectively). As the mass fraction of expanded clay increased, the density of the samples decreased. The pure plaster sample, PA0, exhibited the highest density at 965 kg/m³, while the addition of expanded clay resulted in progressively lower densities for the other samples: PA2 showed a density of 955 kg/m³, PA6 had 933 kg/m³, and PA10 displayed the lowest density at 928 kg/m³.

This reduction in density is attributed to the increase in porosity caused by the expanded clay granules. Expanded clay, being a lightweight material with a porous structure, displaces a portion of the denser plaster, thereby reducing the overall mass of the composite. The decrease in density is a direct result of the clay's contribution, which lowers the mass without significantly increasing the material's volume.

These results demonstrate that incorporating expanded clay into plaster can effectively reduce its density, making it a viable option for applications where lightweight materials are essential, such as in energy-efficient and insulating construction. Further research is required to evaluate the mechanical strength and thermal properties of these composites to determine their suitability for real-world applications.

4.2. Thermal Conductivity

The thermal conductivity of gypsum plaster embedded with expanded clay granules was measured using the steady-state hot plate method. The average values and the measurement deviation are shown in this Figure 6.

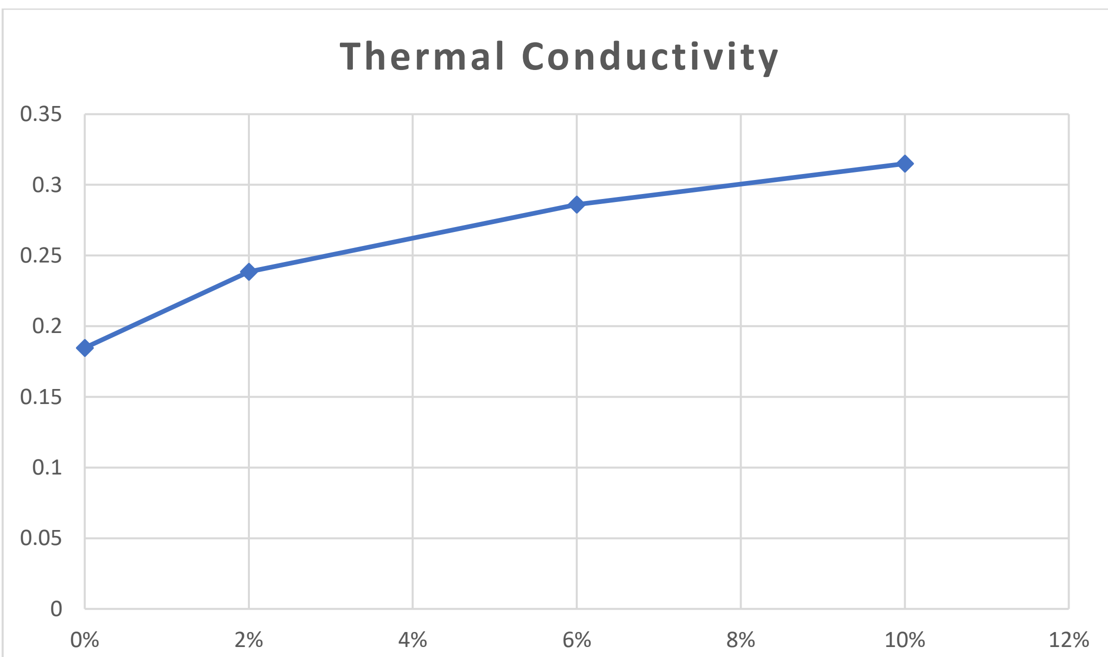

Figure 6.
The variation of thermal conductivity of materials.

The data presented in the figure indicate a significant increase in thermal conductivity with the addition of expanded clay granules to plaster. The thermal conductivity rises from 0.1847 W/m·K for PA0 (pure plaster) to 0.315 W/m·K for PA10 (plaster with 10% expanded clay), representing a 41% increase. This increase is due to the absorption of water and plaster by the expanded clay granules

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during sample preparation, which initially elevates thermal conductivity since water has a higher conductivity than dry plaster.

As the proportion of expanded clay increases, the thermal conductivity rise tends to stabilize. This is likely due to the retention of some water and plaster within the granules even after drying, which facilitates heat transfer. The retained moisture and enhanced porosity of the material contribute to this trend.

These results suggest that by adjusting the percentage of expanded clay, the thermal conductivity of plaster composites can be controlled. Such optimization is essential for applications requiring specific thermal properties, particularly in energy-efficient building materials. Further studies are necessary to explore the long-term stability and performance of these composites.

4.3. Thermal Diffusivity

After using the classical flash method to measure the thermal diffusivity of these four samples, the results obtained are presented in this diagram, Figure 7.

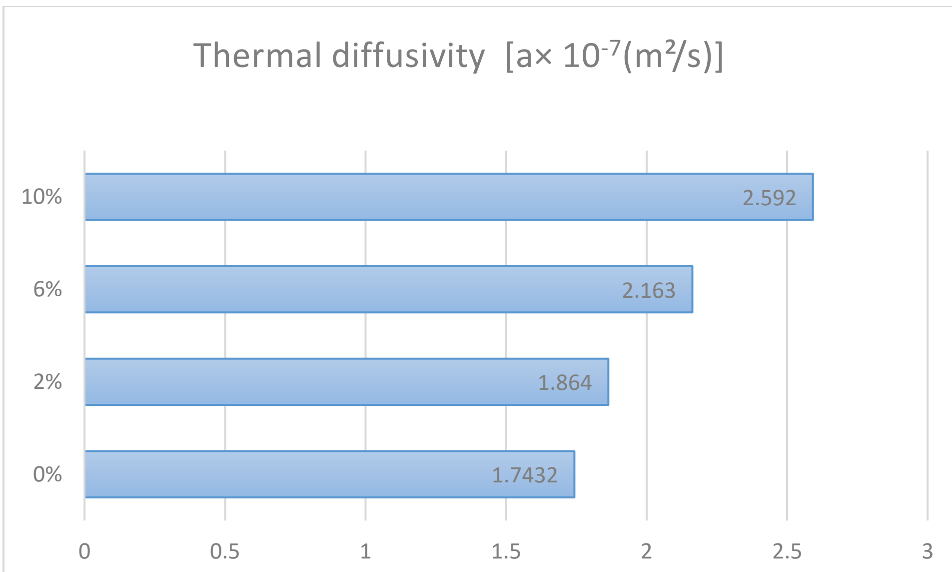

Figure 7.
The thermal diffusivity of materials.

The results show that the thermal diffusivity, measured by the flash method for the four studied samples, varies significantly. For the same class of granules, the thermal diffusivity increases from 1.7432×10^{-7} m²/s for PA0 (pure plaster) to 2.592×10^{-7} m²/s as the proportion of expanded clay granules in the mixtures increases.

This evolution of thermal diffusivity as a function of the mass fraction of expanded clay beads is comparable to that of thermal conductivity, which increases by 32%. These results indicate that the addition of expanded clay granules affects both thermal conductivity and diffusivity, which is essential for applications requiring effective thermal management.

4.4. Simulation

The first step of the simulation focused on controlling the indoor temperatures of our building using the Trnsys software to assess the influence of adding our composite material (gypsum plaster with 6% expanded clay), Figure 8.

We began by analyzing the indoor temperature results provided by the software for the building.

Table 4.
Trnsys Simulation of Indoor Temperature control before thermal insulation.

Jaunary	February	March	April	May	June	July	August	Septembre	October	November	Décember
19	21	23	25	25	26	26	28	26	26	23	19

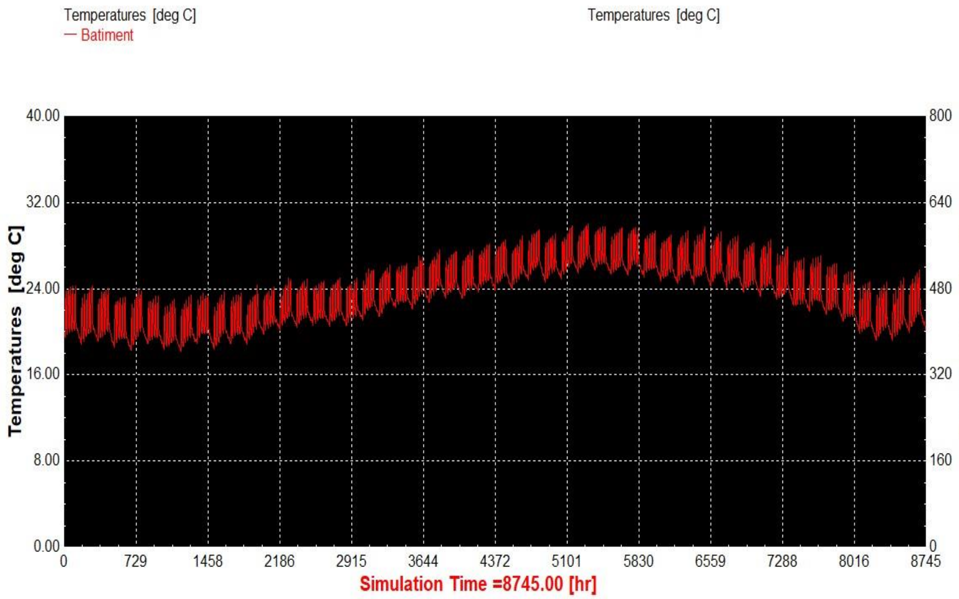

Figure 8.
Excerpt of the Indoor Temperature Diagram of Our Building Without Insulation Using Trnsys Software.

An initial analysis shows that the indoor temperatures, without heating or cooling systems and without the addition of our insulating material, are relatively comfortable for the occupants of our building, table 4. However, during the summer months, particularly in August, temperatures rise significantly, reaching a peak of 28°C.

A second analysis focuses on evaluating the influence of the heating and cooling systems on the indoor temperatures of the building, Table 5.

Table 5.
Trnsys Simulation of Indoor Temperature Control before Thermal Insulation, with HVAC system

Heating											
Jaunary	February	March	April	May	June	July	August	Septembre	October	November	Décember
20	23	23	27	27	29	30	30	29	27	24	20
Cooling											
Jaunary	February	March	April	May	June	July	August	Septembre	October	November	Décember
17	18	21	22	22	24	24	25	24	24	20	17

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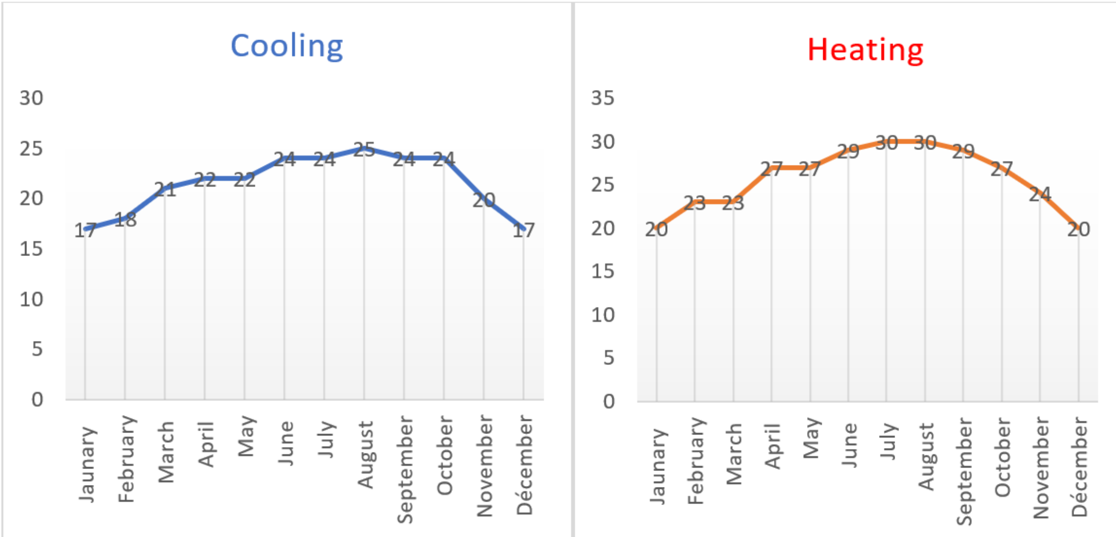

Figure 9.
Evaluation of temperature stability in insulated building with HVAC solutions.

A Third analysis aims to evaluate the differences after adding our insulating material to the exterior walls and roof of the building. This involves assessing its impact on indoor temperatures within the building envelope while the heating and cooling systems operate throughout the year, Table 6. The study focuses on how insulation improves thermal comfort, reduces temperature fluctuations and improves energy efficiency.

Table 6.
Trnsys Simulation of Indoor Temperature control after thermal insulation, with HVAC system.

Heating											
Jaunary	February	March	April	May	June	July	August	September	October	November	Décember
22	24	25	29	29	31	33	33	31	29	25	22
Cooling											
Jaunary	February	March	April	May	June	July	August	September	October	November	Décember
15	17	19	20	21	23	23	23	22	21	20	18

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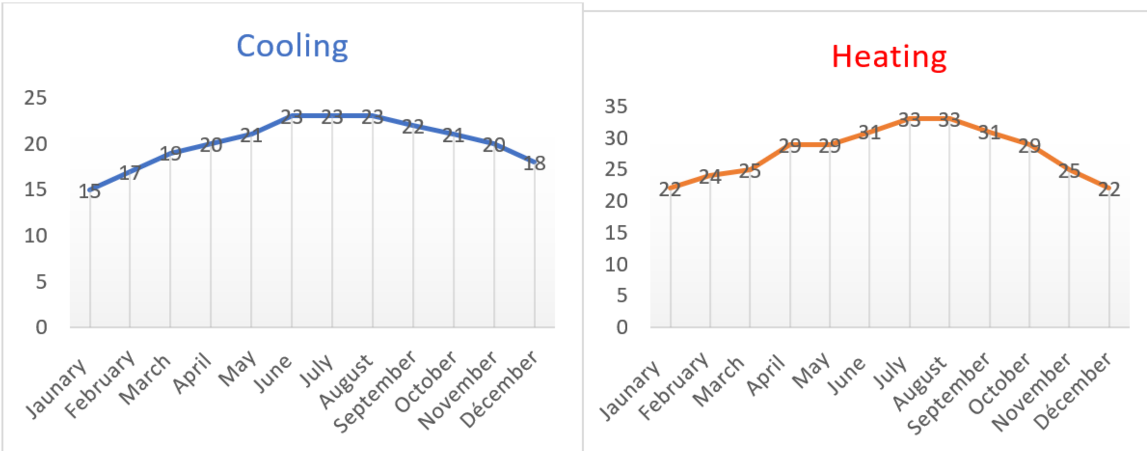

Figure 10.
Evaluation of temperature stability in insulated building with HVAC solutions.

The thermal analysis, performed using simulation software, demonstrates the significant impact of incorporating a thermal insulation material, specifically a plaster/expanded clay composite, on the energy performance of building envelopes. The results indicate a temperature increase of +2 °C during heating and a decrease of -2 °C during cooling, demonstrating the material's effectiveness in stabilizing indoor temperatures and minimizing fluctuations (Figures 9 and 10).

The primary factor driving this performance is the high thermal resistance of the plaster/expanded clay mixture, which significantly reduces heat transfer through the building envelope. This material limits both conductive and convective heat loss by minimizing thermal exchanges between the interior and exterior environments. The composite's thermal mass allows it to absorb heat during warm periods and release it during cooler periods, thereby enhancing thermal efficiency and reducing the demand for temperature regulation.

As a result, integrating this material leads to a marked reduction in the energy consumption of HVAC systems. Without sufficient insulation, HVAC systems must compensate for greater temperature fluctuations, resulting in higher energy expenditure. However, with the plaster/expanded clay composite, the need for active heating and cooling is significantly reduced, optimizing HVAC performance and lowering energy demand.

This insulation not only reduces energy consumption but also ensures thermal comfort for occupants, maintaining a consistent indoor temperature throughout the day and night. Consequently, the building's overall environmental footprint is minimized, aligning with modern sustainability goals and enhancing the building's energy efficiency.

Table 7.
Impact of Construction Material Selection on Building Energy Demand.

	Energy requirement in KWh			Energy performance KWh/m2.year	Energy saving %
	Heating	Air conditioning	Total		
Hollow brick (15 cm)	9200	11000	20200	250,00	-10,75
Hollow brick (10 cm)	10860	11590	22450	282,00	-11,2
Hollow Concrete brick (20cm)	10300	11585	21885	280,40	-20,12
Concrete	12250	10550	22800	284,00	-12,9
Plaster /expanded clay	5260	11640	16900	290,56	18,16
Stone	8100	9740	17840	221,46	11,52

The choice of construction materials and insulation plays a crucial role in determining a building's energy performance, Table 7. Simulation results show that using a gypsum plaster mixed with 6% expanded clay can reduce energy demand by up to 18.16%. In contrast, 20 cm Hollow Concrete Bricks significantly decrease energy efficiency, with a loss of around 20.12%. Concrete blocks, commonly used in construction, exhibit poor energy performance, whereas double hollow brick walls demonstrate impressive energy savings of 21.95%. This indicates that material selection can impact energy needs by up to 50%, highlighting its importance in optimizing building energy efficiency.

The analysis further reveals varying effects of insulation. Floor insulation negatively affects energy savings, while roof and exterior wall insulation have a considerable positive impact, though to different extents. This emphasizes the need for a tailored insulation strategy for each building component. Roof insulation, in particular, is shown to be highly effective, reducing energy demand for both heating and cooling by maintaining a stable internal temperature. The thickness of insulation also plays a significant role: for exterior walls, energy demand increases after 3 cm of insulation, whereas for roofs, energy efficiency continues to improve as insulation thickness increases.

The effectiveness of insulation is proportional to the area being insulated, with roof insulation proving to be the most efficient solution in this study. Additionally, the choice of insulation thickness should be determined through case-specific analysis to ensure optimal energy performance.

Optimizing insulation strategies, particularly for exterior walls and roofs, can significantly reduce energy consumption by up to 21.83% and 33.21%, respectively. However, insulation of the floor may have a negative impact on energy performance. Furthermore, these strategies contribute to a reduction in CO_2 emissions by 30% to 50%. The incorporation of recycled or eco-friendly materials further diminishes the building's carbon footprint. Enhanced energy efficiency also reduces dependence on fossil fuels, supporting the transition to more sustainable energy systems. These measures not only promote a longer building lifespan but also minimize the need for frequent renovations and reduce waste. In the long term, they lead to substantial energy savings and bolster sustainable building practices.

7. Conclusion

This study analyzed the impact of adding expanded clay granules to the thermophysical properties of a plaster-based composite material. The results showed an increase in thermal conductivity and diffusivity, while still maintaining acceptable insulating performance compared to other materials, such as plaster with 5% chicken feathers (λ = 0.309 W/m.K) or plaster combined with hemp (thermal conductivity reduced from 0.531 W/m.K to 0.364 W/m.K, with a 31.5% increase in thermal resistance). Additionally, a decrease in density was observed due to the water absorption by the granules.

Thermal insulation plays a crucial role in reducing the energy demand of buildings. A well-insulated roof, even with conventional materials, can reduce energy consumption by more than one-third.

However, the use of natural, sustainable materials, such as optimized expanded clay granules, offers the potential to further enhance energy-saving performance while being environmentally friendly.

Finally, to maximize the benefits of insulation, it is essential to adopt a thoughtful approach right from the design stage. Future research should focus on treating the expanded clay granules to limit water absorption and optimize their insulating properties, thereby contributing to the durability and energy efficiency of modern buildings.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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