Case Studies in Thermal Engineering 49 (2023) 103350

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: www.elsevier.com/locate/csite

Experimental performance assessment of a novel insulation plaster as an energy-efficient retrofit solution for external walls: A key building material towards low/zero carbon buildings

Erdem Cuce[a,b,c,*], Pinar Mert Cuce[b,d,e], Emre Alvur[a,b], Yusuf Nadir Yilmaz[a,b], Shaik Saboor[f], Ilker Ustabas[g], Emanoil Linul[h,**], Mohammad Asif[i]

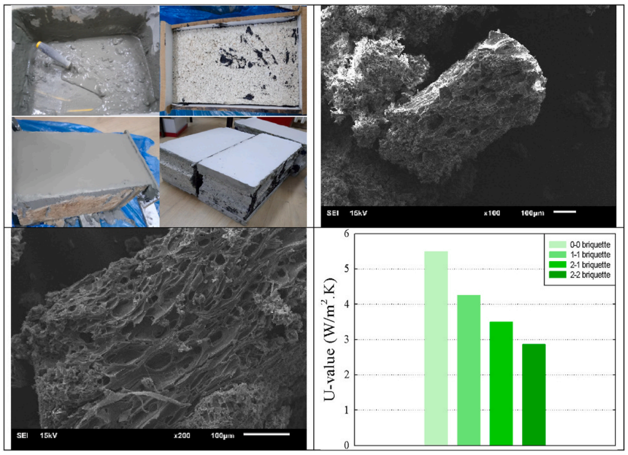
[a] *Department of Mechanical Engineering, Faculty of Engineering and Architecture, Recep Tayyip Erdogan University, Zihni Derin Campus, 53100, Rize, Turkey*
[b] *Low/Zero Carbon Energy Technologies Laboratory, Faculty of Engineering and Architecture, Recep Tayyip Erdogan University, Zihni Derin Campus, 53100, Rize, Turkey*
[c] *School of Engineering and the Built Environment, Birmingham City University, B4 7XG, Birmingham, UK*
[d] *Department of Architecture, Faculty of Engineering and Architecture, Recep Tayyip Erdogan University, Zihni Derin Campus, 53100, Rize, Turkey*
[e] *Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, NG7 2RD, Nottingham, UK*
[f] *Department of Thermal and Energy Engineering, School of Mechanical Engineering, Vellore Institute of Technology, VIT, Vellore, 632 014, Tamilnadu, India*
[g] *Department of Civil Engineering, Faculty of Engineering and Architecture, Recep Tayyip Erdogan University, Zihni Derin Campus, 53100, Rize, Turkey*
[h] *Department of Mechanics and Strength of Materials, Politehnica University Timisoara, 1 Mihai Viteazu Avenue, 300222, Timisoara, Romania*
[i] *Department of Chemical Engineering, King Saud University, P.O. Box 800, Riyadh, 11421, Saudi Arabia*

* Corresponding author. Department of Mechanical Engineering, Faculty of Engineering and Architecture, Recep Tayyip Erdogan University, Zihni Derin Campus, 53100, Rize, Turkey.
** Corresponding author.
E-mail address: erdem.cuce@erdogan.edu.tr (E. Cuce).

https://doi.org/10.1016/j.csite.2023.103350

Available online 28 July 2023

GRAPHICAL ABSTRACT



ARTICLE INFO

Handling Editor: Huihe Qiu

Keywords:
Thermal insulation plaster
External wall insulation
U-value
Energy-efficient retrofit
Co-heating test

ABSTRACT

Thermal insulation plasters have become the focus of attention in the building sector. Among the most important reasons for this is the high thermal energy losses of the buildings. Since conventional briquettes used in buildings allow high heat transfer, the construction industries are looking for alternative insulation ways with low cost and high thermal efficiency. The use of insulation plasters is becoming popular due to the high cost and installation of insulation materials such as Expanded Polystyrene (EPS), which is among the alternative ways. Therefore, in this study, the novel insulation plaster (NIP) developed in contrast to traditional insulation plasters is tested on conventional briquettes in different thicknesses. On considering the total heat transfer coefficient (U-value), it is understood that whilst the conventional briquette has the highest value with approximately 5.5 W/m^{2}K, the briquette with 2-2 NIP thickness has the lowest value with a value of almost 2.86 W/m^{2}K. As a result of the tests, the total heat transfer coefficient of the briquette with 1-1 NIP thickness is observed to have an improvement of nearly 22.5% compared to conventional briquettes, while a progress of approximately 36.4% is seen in briquettes with 2-1 NIP thickness. In addition, it is revealed that the best mitigation in the overall heat transfer coefficient is about 47.9% in briquettes with 2-2 NIP thickness. It is also figured out that NIP has additional thermal durability thanks to the dead air pores and boron minerals in its internal structure.

1. Introduction

Recently, with the emergence of global economic crises and the gradual decrease of non-renewable energy resources, it has gained great importance to use energy sparingly [1]. Looking back forty years ago, energy demand increased by almost 1.8% per year, accounting for practically 58% of total energy by 2050 [2]. The construction sector accounts for approximately 32% of the total energy consumption worldwide [3]. In general, multi-storey buildings lose about 40% of their heat from the exterior wall, about 30% from the windows, approximately 7% from the roof, practically 6% from the basements and finally, the remaining 17% from air leaks [4]. The fact that 40% of the heat losses of the buildings are from the outer wall indicates that the buildings should be strengthened or reconstructed with a building envelope that is more resistant to heat loss. In addition, energy losses can be reduced by using thermal insulation in buildings and thus, energy savings can be achieved. Among the most significant reasons for using insulation are to reduce energy costs visibly and to minimise energy losses and thus to achieve energy efficiency; it is seen that its use has become a necessity rather than a choice [5].

Plaster used in building structures is known as one of the oldest materials. Plaster, discovered about 9000 years ago [6], can be used as thermal insulation by mixing with various components as well as providing a holistic visuality [7], and it is still up to date due to its low cost. Since plaster gives positive results in terms of physical and chemical aspects, it has been used in building construction for many years. Recently, the preference of plasters has been increasing in new buildings, especially in building restoration works [8,9], thanks to LWAs (Light Weight Aggregates) like cork, clay, perlite etc. that grow in their thermal properties and their price performance [10]. Nowadays, various studies are carried out by using different LWAs, such as herbal [11–13], and mineral [14–16], in order to possess a good thermal performance.

Bianco et al. [8] have investigated the thermal properties of a historical house by adding a new type of heat-insulating plaster added to the maize waste products to the wall layer to reduce the heating load. In situ measurements are made by keeping the house interior temperature constant at 23°C. According to the result, the thermal conductivity of the new insulation plaster is within the limits of 0.08-0.13 W/mK. This result has shown that approximately 20-40% more energy consumption can be observed if conventional plaster is covered instead of trial. Fenoglio et al. [17] have examined the thermal conductivity, by adding perlite at two different percentages to the lime-based thermal insulation plaster. As a result, a surface covered with a 25% perlite has a value of 0.118 W/mK, when applied to a similar surface with 40% perlite, it has a value of 0.059 W/mK. This shows that the increase in perlite ratio has a profound effect on heat conduction up to merely 40%. Selvaranjan et al. [18] have investigated the thermal comfort of the residents of two similarly sized houses by coating the walls of one house with rice husk ash (RHA)-based insulation plaster and the other with conventional plaster, and the result has shown that RHA-based insulation plaster is better. Additionally, with 10% RHA-based mortar to be poured into the plaster, the thermal conductivity value is 0.58 W/mK with a decrease of approximately 28% compared to the conventional mortar. It is also understood that it absorbs greenhouse gas emissions by about 14%. Schuss et al. [19] have calculated the U-value from a building wall with gypsum plaster and brick wall envelope using in situ measurement technique. They are able to find the U-value of 1.25 W/mK by covering 25 cm bricks with 2 cm thick plaster on each side of the surfaces. The thermal conductivity values are shown in Table 1.

Miskinis et al. [20] have compared the effect of sound value and any thermal change by covering a rock wool-filled surface with plaster and Expanded Polystyrene (EPS). It increases the sound insulation from 3 dB to 7 dB even though it does not make any changes in the thermal insulation in both cases. Considering the sound insulation with EPS, a negligible change is observed. Charai et al. [21] have investigated the effectiveness of ordinary plaster by adding hemp fibre in various proportions into the plaster, as well as its effect when used with hemp. Their result are presented in Table 2.

Dylewski et al. [22] investigate whether coating the exterior building mortar with thermal insulation plaster has an advantage over covering it with cement plaster. The result shows that bims granule plaster and EPS plaster have much smaller thermal conductivity values than cement plaster. The thermal conductivity values of the bims granule plaster, cement plaster, and EPS plaster are reported as to be 0.068 W/mK, 0.93 W/mK, and 0.07 W/mK, respectively. Krsti et al. [23] have compared the theoretical and measured U-value of 2 types of the building envelope by using the co-heating test method. The result is illustrated in Table 3.

Rashad et al. [24] have studied whether a thermal insulation plaster can be made from cementitious materials. The bonding process with gypsum or cement without using any LWA and foaming agent is succeeded. In this study, eight different types of plaster are used. Data gathered show that thermal insulation plaster can be obtained without using any foamer and LWAs. Topcu et al. [25] have calculated the thermal conductivity coefficient of a perlite brick with a ratio of 30%. According to the result, whilst the thermal conductivity of a typical brick is 0.47 W/mK, the coefficient of the brick formed by adding perlite is calculated as 0.22 W/mK, and it is concluded that the perlite brick can be a much better insulation material compared to the standard brick. Al-Naghi et al. [26] attempt to examine the thermal performance comparison by using a combination of autoclaved aerated concrete block (ACC), thermal insulating plaster, reflective coating and standard hollow concrete block (HCB). The materials and thicknesses used in the test sample of the envelope are given in Table 4.

The study is carried out in two test chambers with similar characteristics, and data is collected with thermal sensors in the summer months. As a result, it is recorded that standard hollow concrete block and ACC wall samples are 2.03 and 0.38 W/m^{2}K, respectively. Fantucci et al. [27] have applied on three different samples of thermal insulation plaster such as vegetal-based plaster (VBP), perlite-based plaster (PBP), and aerogel-based plaster (ABP) aggregates. VBP, PBP, and ABP are tested for 19 days, four days, and more than 30 days, respectively. While the calculated U-value of VBP and PBP are 0.56 W/m^{2}K and 0.80 W/m^{2}K separately, the measured U-value of ABP is 0.42 W/m^{2}K.

Today, thermal insulating plasters are becoming necessary in buildings thanks to their low cost and significantly effective insulation. In this experimental research, four briquettes with the relatively the same properties are used, and thermal insulation plasters with different thicknesses are coated on the inner and outer surfaces of these briquettes by mixing them with the mortar method. The briquettes are coated with thermal insulating plaster with inner-outer thicknesses of 0-0, 1-1, 2-1 and 2-2, respectively. After these preparations are completed, they are placed in the hot box so that there is no leakage. An electrical heater is located inside the box in order to create a temperature difference between indoor and outdoor environments. T-type thermocouples are used to measure the inner and outer surface temperatures of the briquettes, and a highly sensitive sensor is used to determine the heat flux. Co-heating testing procedure is applied to the test rig. The aim of the experimental work is to examine the effect of insulation plasters with different thicknesses on the thermal insulation properties of conventional briquettes and to find the comparative U-values after enhancement.

Table 1
Thermal conductivity values of the samples in the test field [19].

Material	**k** (W/m^{2}K)	Thickness (mm)
Gypsum plaster	0.2	15
Brick wall	0.4	250
Lime cement plaster	0.8	20

Table 2
Thermal properties of hemp-plaster composites [21].

Fibre Content (%)	Thermal Conductivity (W/mK)
0	0.531 ± 0.001
2	0.485 ± 0.001
4	0.441 ± 0.003
6	0.364 ± 0.001

Table 3
Theoretical and Co-heating test results [23].

Wall material	Theoretical U-value (W/m^2K)	Measured U-value (W/m^2K)
Plaster (2 cm) + Concrete block with recycled brick aggregate (12 cm)	1.96	1.96
Plaster (2 cm) + Hollow brick with integrated rock wool insulation (25 cm)	0.28	0.40

Table 4
Material properties used for the test [26].

Materials	Thickness (mm)	k (W/mK)
HCB	200	0.52
ACC	200	0.16
Cement mortar and plaster	10	0.72
Thermal insulating plaster	15	0.06
Acrylic paint	0.15	0.20
Reflective coating	3	0.03

2. Material and method

2.1. *Thermophysical and material properties of novel insulation plaster*

The Novel Insulation Plaster (NIP) is produced according to TSE EN 13501-1 standards and has A-1 class certificate. It is prepared according to international standards in heat, water and sound insulation as well as extremely vital fire insulation. It can withstand up to about 1000 °C for 3 h. It does not contain carcinogenic substances and has an entirely natural structure. It also has the ability to breathe. It has a structure that can prevent formations such as moisture, mold, and fungus that may occur in buildings. In this research, NIP, which has the patent for the first use of the boron mine in Turkey, is used. The technical specifications of the novel insulation plaster used are given in Table 5.

Fig. 1 indicates that the NIP is produced before hydration from expanded perlite, boron mineral colemanite in a small amount, polymer fibre, and binder. Perlite layers widened in the form of plates are observed, and also products expanding in the form of burgeons on these plates. The structure has many cavities and amorphous forms with polymer fibres in the voids.

In Fig. 2(a), the EDS image of the NIP is seen, whille in Fig. 2(b), there is an image of the elements in the NIP, which can be understood by spectral analysis. Abundant expanded perlite microplates are observed. SiO_2 covers a significant part of its content in the NIP of the chemical composition. The chemical composition of the NIP also includes Al_2O_3, CaO, and Fe_2O_3. Although the boron mineral is present in the NIP, it is not visible in the spectral analysis because it is in tiny amounts.

When the internal structure of the NIP used in the experiment is examined, it is understood that there are many expanded perlite structures, as shown in Fig. 3(a). When this expanded perlite is examined more closely, it is thought that the dead air pores formed, as shown in Fig. 3(b) can be associated with thermal insulation.

2.2. *Preparation of the test sample*

Round-shaped concrete blocks made of sand, gravel, cement, and water and used as building and concrete wall materials, are called briquettes. The briquettes are a construction material commonly used in the Anatolian lands of Turkey. The U-value is high due to the relative conductivity rate when the briquette is not covered with any insulation. Therefore, its widespread use especially in Anatolian building stock does not indicate that it has good thermal properties. The high U-value of the briquette brings about unwanted heat

Table 5
Technical characteristics of the NIP.

Density	**950 ± 50 kg/m^3**
Thermal Conductivity	0.13 W/mK
Compressive Strength	CSII 2.448 N/mm^2
Bond Strength	0.50 N/mm^2
Water Absorption	W2 0.188 $kg/m^2min^{0.5}$
Fire Resistance	A-1
Sound Absorption	15 dB

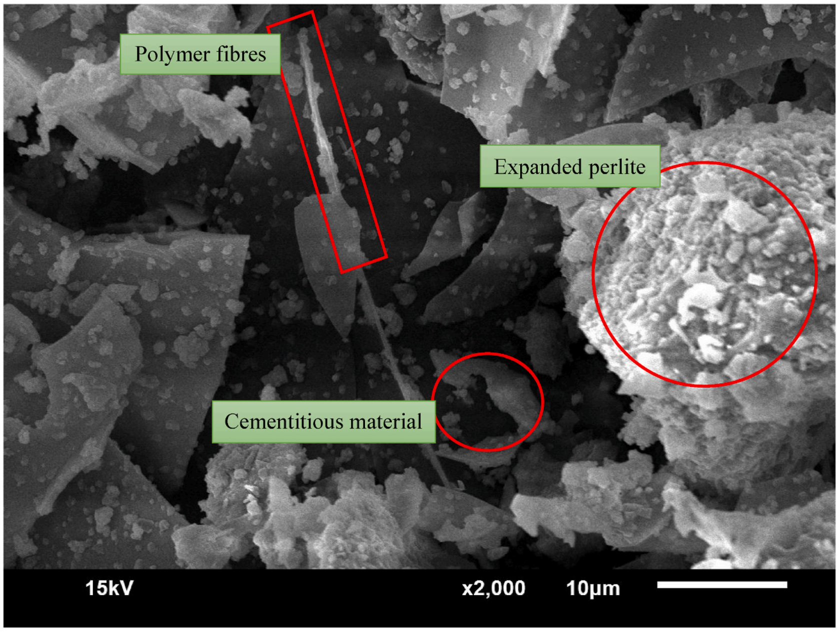


Fig. 1. The image of the NIP before hydrated.

losses due to the aggregates used, which means more energy consumption and higher costs. Hence, existing briquettes need to be reinforced with environmentally friendly, non-toxic, and sustainable insulation. In addition to these, coating with NIP, which is light and has good insulating properties, will provide both a more attractive appearance and better thermal resistance, and this will add potential to different areas of use.

The preparation is started by adding 20 L of water to NIP weighing 20 kg and mixing it for about 5 min until a homogeneous structure is obtained. After the mortar process is completed, it is checked whether there is a problem affecting the insulation on the surface. Then the inner and outer surfaces of the briquettes are covered with 1-1, 2-1 and 2-2 thicknesses with the help of molds and left them to dry for a sufficient time. The images in Fig. 4 show the application phase of the NIP, respectively.

2.3. Co-heating test

A co-heating test is a trustworthy method to assess heat loss with a unit of W/K (both fabric and background ventilation) applied to an unused building [28]. Even though countries have been researching the co-heating test method since 1970 [29], it still needs an international standard [30]. In a standardized co-heating test, the indoor environment should be kept up to 25 °C with a temperature-controlled electrical heater until thermal equilibrium is reached, and the test takes about 2-4 weeks. In addition, the inside and outside temperature differences should be at least 10 °C [31]. Co-heating test is used not only for external walls but also for thermal performance analysis of windows and airtightness assessment [32–37]. Another essential part of information about the co-heating test is that when uses in conjunction with other techniques, such as thermal imaging and heat flux measurement, it makes its accuracy seem more comfortable. The co-heating test can be reduced to smaller sizes for use in a laboratory setting, creating a basically artificial building environment as shown in Fig. 5(a, b) prepared by virtually. The analyses of the laboratory-based experimental co-heating test are performed in a zone consisting of an adiabatic hot box and an environmental chamber, as shown in Fig. 5(c). Frankly, such a co-heating test which is carried out in a laboratory medium, aims to be a pioneer study in verifying the suitable NIP for the construction industry. In such an experiment, the inside of the hot box is increased up to 25 °C with an electrical heater and the temperature control unit is used to keep the inner at constant whilst the outdoor temperature is adjusted with the air conditioner in accordance with the temperature difference specified in the standards. T-type thermocouples used in experimental research are connected to a data logger, and temperature values are calculated. On the other hand, the heat fluxes are related to the highly vulnerable data logger, which receives data every 5 s. The test is supported by a thermal imaging camera in order to reach a more reliable consensus, as shown in Fig. 5(d).

Thermal imaging testing is one method/analyse that advocates co-heating testing. It is associated with the extent of the improvement in the thermal behaviour of the building before and after retrofitting. For example, sometimes, after reinforcement, undesirable situations such as cold spots and hot spots may occur on facades, corners, and joints, where columns and beams meet. Therefore, the thermal imaging test is of vital importance of having information about such undesirable events.

2.4. Uncertainty analysis

In accordance with Coleman and Steele [38], the total uncertainty is calculated by:

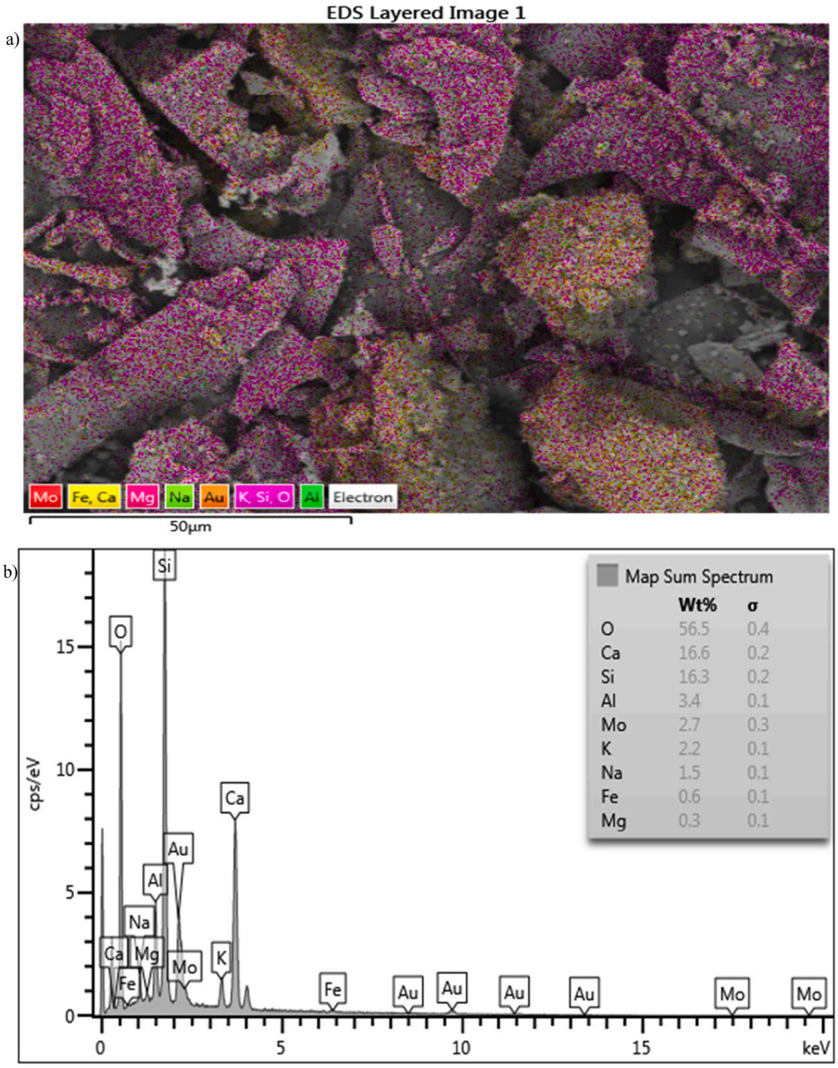


Fig. 2. a) Energy-dispersive spectroscopy (EDS) layered image of the NIP b) Spectral analysis of the NIP.

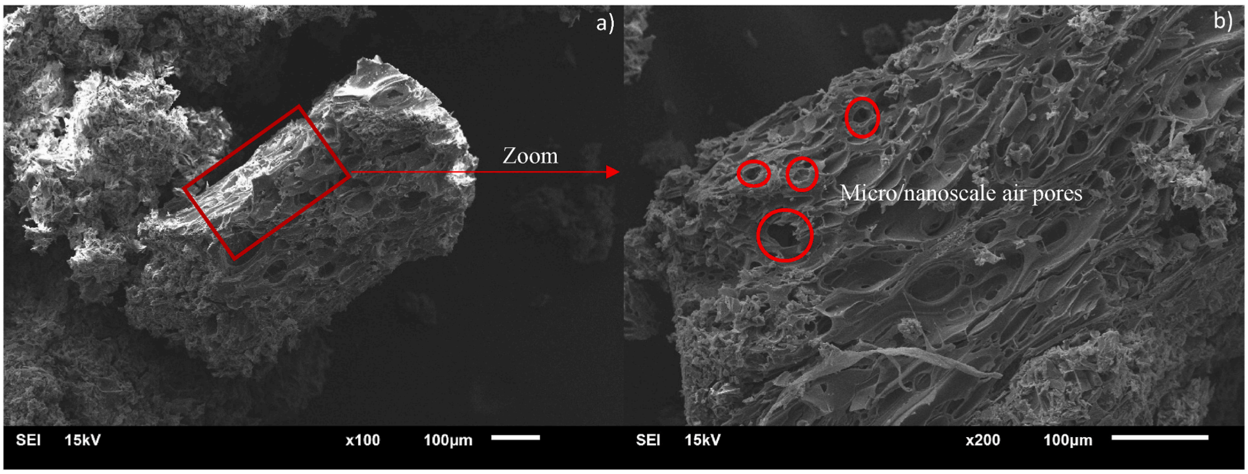


Fig. 3. a) SEM image of the NIP at 100X, b) Representation of micro-nano air pores.

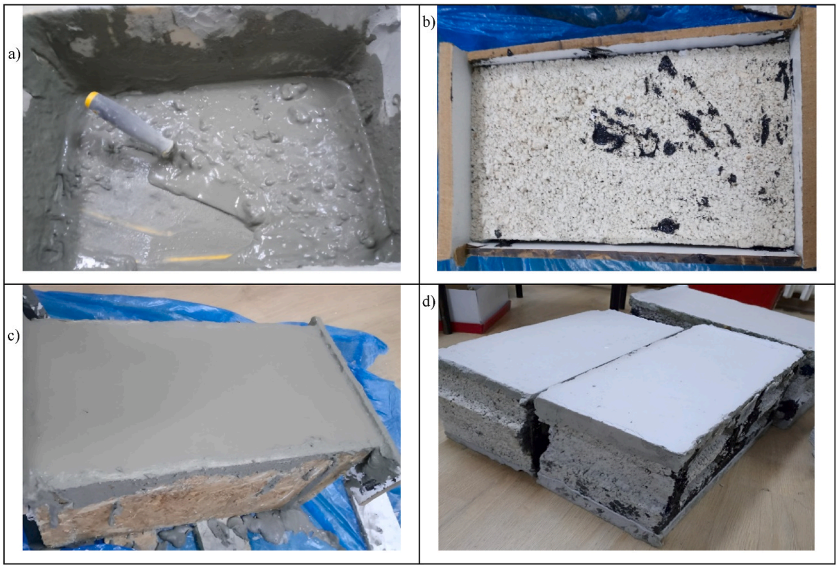


Fig. 4. a) Image of the mortar preparation stage, b) Image of the test sample placed in the mold, c) Image of the step of coating the test sample with NIP, d) The final image of the test samples after waiting for sufficient time.

$$W_Q = \left[\left(\frac{\partial Q}{\partial X_1} \times W_1\right)^2 + \left(\frac{\partial Q}{\partial X_2} \times W_2\right)^2 + ..\right]^{\frac{1}{2}} \tag{1}$$

where;

Q: Size to measure
X: Variable affecting measurement
W: Uncertainty of the independent variable
Data needed in uncertainty analysis:
$T_{in} = 25$ °C, $T_{ex} = 11.5$ °C, $\Delta T = (25 - 11.5)^\circ C = 13.5\,^\circ C$, Uncertainty of thermocouples: 0.25
Uncertainty of heat flux: 0.03

$$Q = U \times A \times \Delta T = 240\ W \tag{2}$$

$$H_{losses} = \frac{Q}{\Delta T}\ (\mathrm{W / K}) \tag{3}$$

$$\frac{\partial H_{losses}}{\partial Q} = \frac{1}{\Delta T} = \frac{1}{13.5} = 0.074 \tag{4}$$

$$\frac{\partial H_{losses}}{\partial T} = -\frac{Q}{\Delta T^2} = \frac{240}{13.5^2} = -1.317 \tag{5}$$

Uncertainty of thermocouples: 0.25.
Uncertainty of heat flux = 0.03

$$H = \frac{Q}{\Delta T} = \frac{240}{13.5} = 17.777 \tag{6}$$

$$\frac{W_H}{H} = \frac{0.329}{17.777} \times 100 = 1.85\% \tag{7}$$

The overall uncertainty was calculated as 1.85%.

3. Results and discussion

As a result of the studies on conventional briquettes, the average thermal conductivity value is calculated as 0.8 W/mK [39]. According to the experimental test result, the traditional briquette k-value is 0.82 W/mK. It is understood that the difference among the values is due to factors such as density and weight between the briquettes used. Fig. 6 graphically illustrates the check of reference and experimental data.

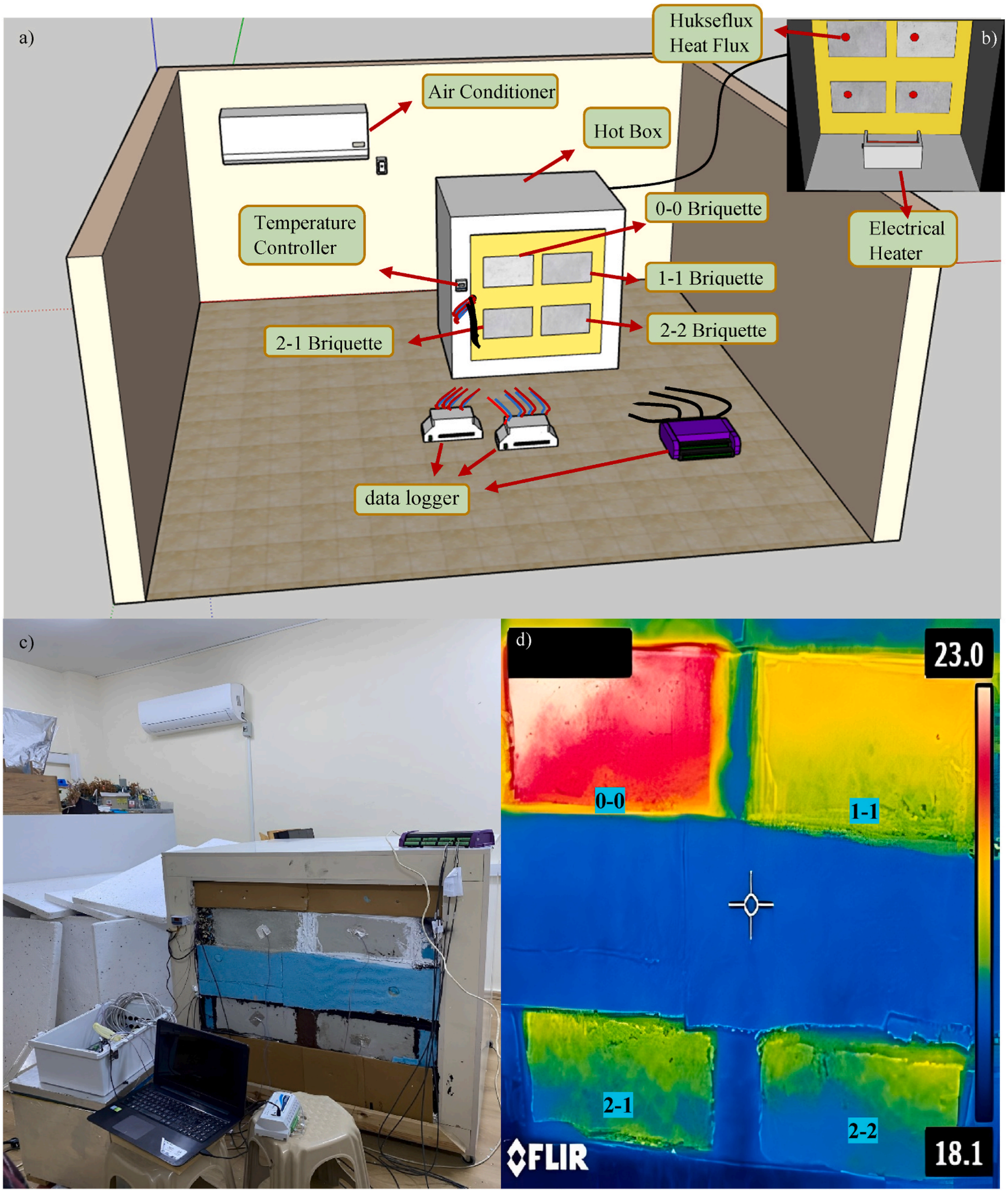


Fig. 5. a) Representative view of the test room from the outside environment, b) Cross-sectional view of the inside of the hot box, c) Real view of the test room from the outside, d) Thermal imaging representation.

According to the experimental analysis results, it is observed that the indoor and outdoor temperatures of 0-0 changed between 21.95 °C and 24.72 °C, and 16.94 °C and 18.58 °C, individually, while the internal and external temperatures for 1-1 are between 24.04 °C and 25.4 °C, and 18.4 °C and 18.83 °C, respectively. On the other hand, it is seen that the inlet and outlet temperatures of 2-1 alter between 24.77 °C and 26.1 °C, and 18.23 °C and 18.79 °C, separately, whilst the interior and exterior temperatures for 2-2 are between 24.92 °C and 26.04 °C, and 18.04 °C and 18.39 °C, severally. According to the results, the briquette with a thickness of 2-2 has the highest internal temperature because the heat transfer is lower than the others due to the NIP thickness. Additionally, the briquette structure with the highest temperature difference is calculated as 2-2. As for the heat flux values, it is obtained that they vary between 0.04 W/m^2 × 10^{-2} and 1.19 W/m^2 × 10^{-2} for 0-0, between 0.0024 W/m^2 × 10^{-2} and 1.13 W/m^2 × 10^{-2} for 1-1, between 0.00764 W/m^2 × 10^{-2} and 1.49 W/m^2 × 10^{-2} for 2-1, and finally between 0.019 W/m^2 × 10^{-2} and 1.38 W/m^2 × 10^{-2} for 2-2 one by one. Also, average heat flux values are recorded as 0.32 W/m^2 × 10^{-2}, 0.26 W/m^2 × 10^{-2}, 0.24 W/m^2 × 10^{-2}, and 0.21 W/m^2 × 10^{-2} for 0-0, 1-1, 2-1, and 2-2, respectively. According to the experimental test results, the heat flux has the highest value of 0-0 in contrast to the temperature because the heat transfer is higher than the others. Graphical drawings of all these values are shown in Fig. 7.

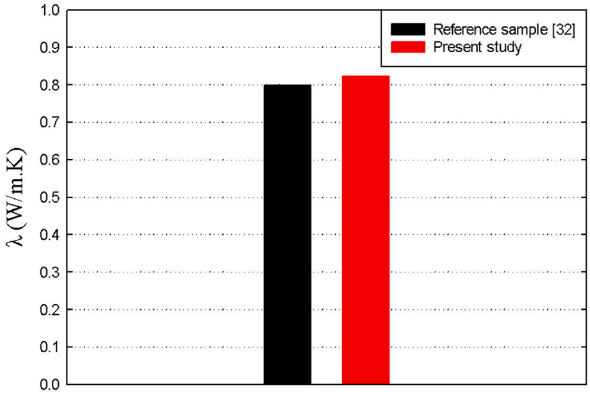


Fig. 6. Verification of the test result through thermal conductivity of conventional briquette.

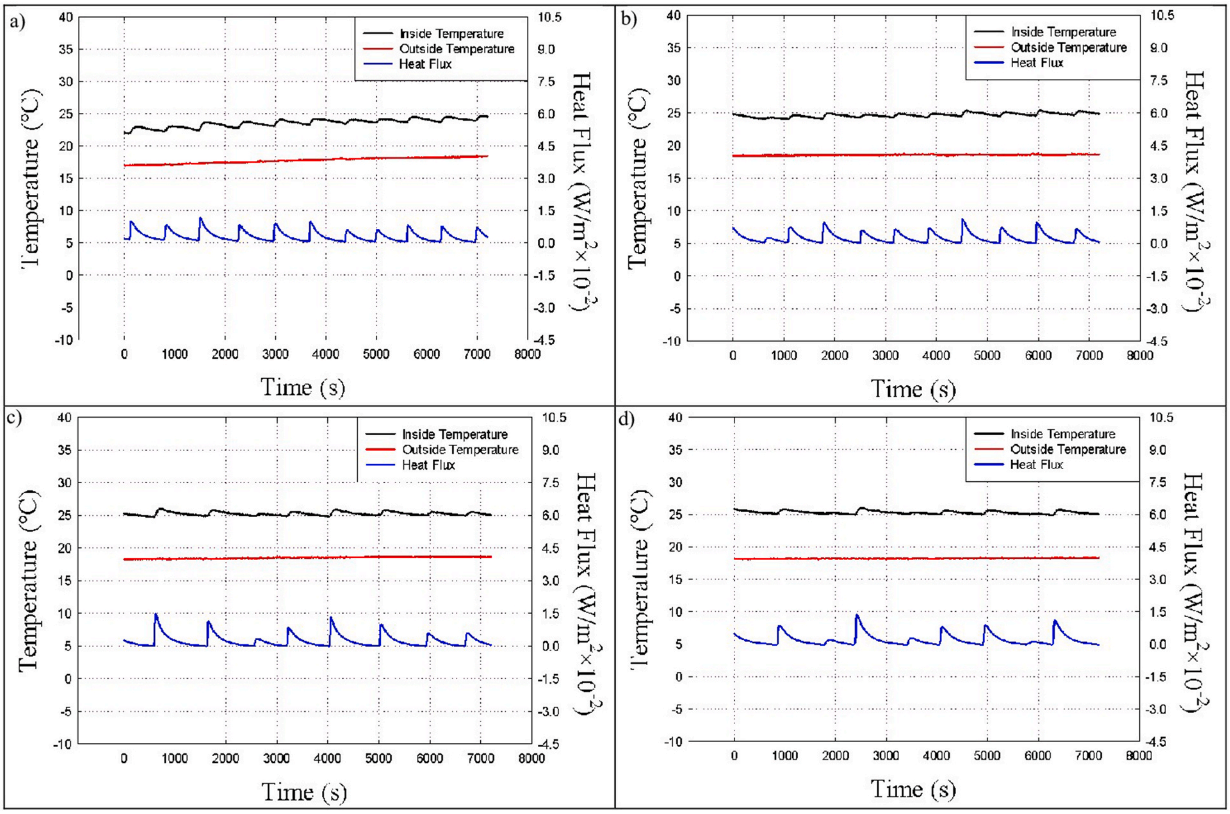


Fig. 7. a) Inside temperature, outside temperature, and heat flux values of briquette 0–0, b) Briquette 1-1, c) Briquette 2-1, d) Briquette 2-2.

According to the test results, the total heat transfer coefficient values alter between 0.75 W/m^{2}K and 21.71 W/m^{2}K for 0-0, 0.04 W/m^{2}K and 18.42 W/m^{2}K for 1-1, 0.12 W/m^{2}K and 22.24 W/m^{2}K for 2-1, and 0.28 W/m^{2}K and 19.35 W/m^{2}K for 2-2. As a result of the experiments, the average heat transfer coefficient values for 0-0, 1-1, 2-1, and 2-2 are calculated as 5.49 W/m^{2}K, 4.26 W/m^{2}K, 3.5 W/m^{2}K, and 2.86 W/m^{2}K, respectively. As a result of the conventional briquette and NIP material being brought to a thickness of 2-2 with the mortar method, the overall heat transfer coefficient of 2-2 is observed to be almost two times lower than the conventional briquette. These values are obtained from high-precision heat flux. Values are acquired by connecting this heat flux sensor placed on the inner surface of the briquette to the data logger and by transferring the data from the data logger to the computer. The individual U-values of the test specimens are presented in Fig. 8.

In Fig. 9 above, it can be clearly observed that the average heat transfer coefficients of the test samples decrease proportionally depending on the NIP thickness in the column chart. According to these results, a diminishment of about 22.53% is observed between 0-0 and 1-1. While there is a decrease of approximately 18.14% between 2-1 and 2-2, there is a reduction of nearly 17.85% between 1-1

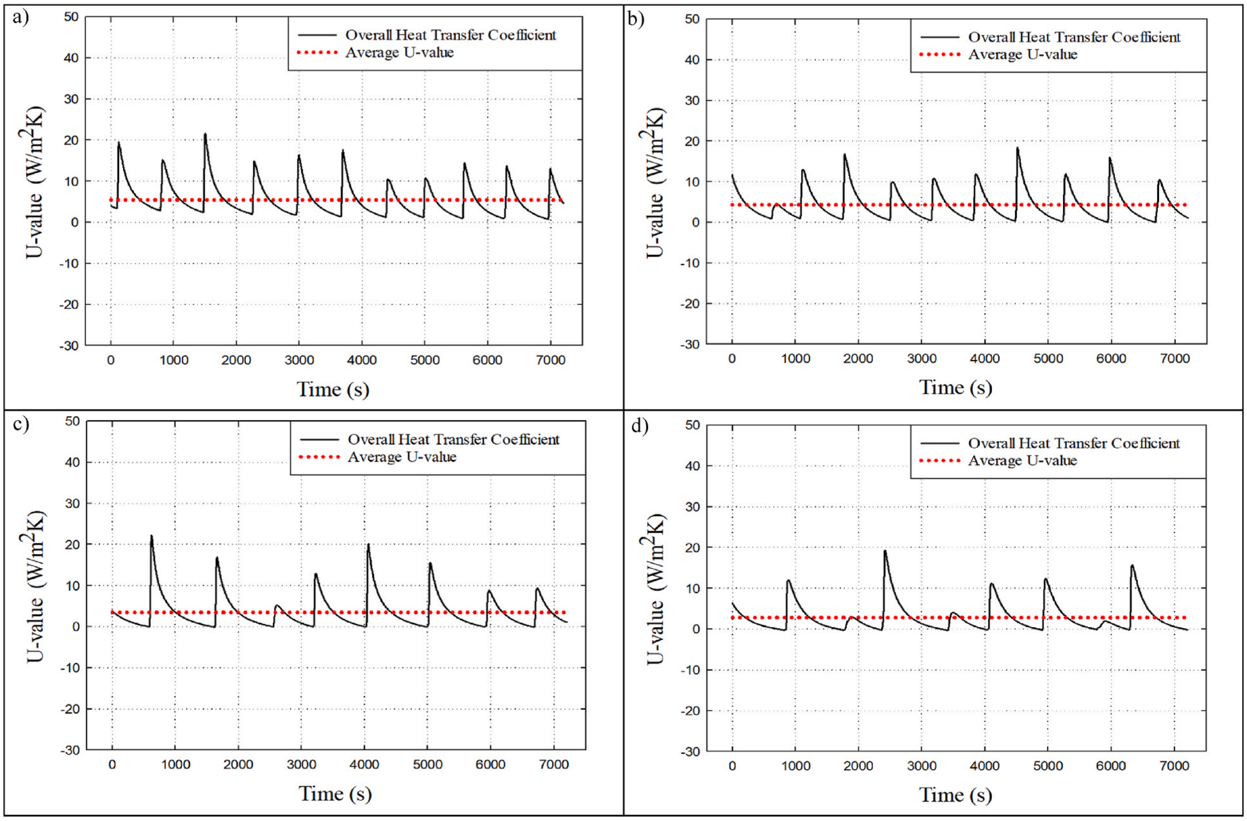


Fig. 8. a) U-value of briquette 0–0, b) Briquette 1-1, c) Briquette 2-1, d) Briquette 2-2.

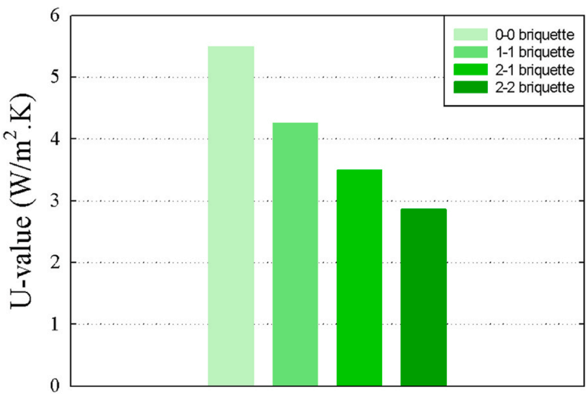


Fig. 9. Improvements in thermal insulation features of briquette through NIP.

and 2-1. On the other hand, the most striking mitigation ratio is around 47.9%, between 0-0 and 2-2. Thanks to this drastic reduction, floor occupants are faced with lower costs. At the same time, it is anticipated that NIP, which is expected to develop in terms of trade, will attract the attention of the building sector since it has positive features such as low cost, eco-friendly, and high energy efficiency.

4. Conclusion

This experimental research is carried out to observe the heat transfer effect of Novel Insulation Plaster (NIP) on the briquette, which varies according to the 0-0, 1-1, 2-1 and 2-2 thicknesses. The proposed NIP has been tested under certain operating conditions by means of temperature difference, and its parameters have been determined. The following bullet points can be obtained from the experiment:

- When looking inside the expanded perlite in its inner structure, it is observed that there are dead air pores, and it is understood that the NIP has extra thermal resistance thanks to these pores.
- Whilst 0-0 is the lowest with a temperature difference of 5.82 °C, it is concluded that it is 2-2 with the highest temperature difference at 7.1 °C.
- According to the studies, the briquette with a thickness of 2-2 has the best overall heat transfer coefficient (U-value) with 2.86 W/m^2K.
- The NIP with a thickness of 2-2 has shown an improvement of nearly 49% compared to the conventional briquette.
- In further studies, a comprehensive theoretical and experimental study will be made on thermal efficiency improvements, acoustic behaviour, and radiation effects with the combination of different building elements.

Authors contributions

Erdem Cuce: Formal analysis, Writing - original draft, Writing - review & editing, Conceptualization, methodology.
Pinar Mert Cuce: Investigation, Methodology, Writing - review & editing.
Emre Alvur: Formal analysis, Writing - review & editing.
Yusuf Nadir Yilmaz: Formal analysis, Writing - review & editing.
Shaik Saboor: Conceptualization, Formal analysis.
Ilker Ustabas: Conceptualization, Supervision.
Emanoil Linul: Resources, Funding acquisition.
Mohammad Asif: Resources, Funding acquisition.

Declaration of competing interest

The authors confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Data availability

No data was used for the research described in the article.

Acknowledgment

The financial support from the Researchers Supporting Project (RSP2023R42), King Saud University, Riyadh, Saudi Arabia is appreciated.

References

[1] U. Berardi, A cross country comparison of building energy consumption and their trends, Resour. Conserv. Recycl. 123 (2017) 230–241.
[2] P. Nejat, F. Jomehzadeh, M.M. Taheri, M. Gohari, M.Z.A. Majid, A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries), Renew. Sustain. Energy Rev. 43 (2015) 843–862.
[3] T. Liu, Z. Tan, C. Xu, H. Chen, Z. Li, Study on deep reinforcement learning techniques for building energy consumption forecasting, Energy Build. 208 (2020), 109675.
[4] T. Uygunoglu, S. Ozguven, M. Calıs, Effect of plaster thickness on the performance of external thermal insulation cladding systems (ETICS) in buildings, Construct. Build. Mater. 122 (2016) 496–504.
[5] A.C. Bojan, A.G. Popa, A. Puskas, Alternative solution for thermal rehabilitation of buildings with polystyrene panels, Procedia Eng. 181 (2017) 712–717.
[6] C. Martias, Synthèse et caractérisation de matériaux composites à base de sulfate de calcium destinés à la protection incendie, in: PhD Thesis, Université de Toulon, 2011.
[7] M. Türkmen, Bina Kabuğunda Isı Yalıtımı Uygulamalarının Yapısal Performansı Ve Etkinliğinin İstanbul'da Bir Alan Çalışması İle İncelenmesi, in: PhD Thesis, Istanbul Technical University, 2016.
[8] L. Bianco, V. Serra, S. Fantucci, M. Dutto, M. Massolino, Thermal insulating plaster as a solution for refurbishing historic building envelopes: first experimental results, Energy Build. 95 (2015) 86–91.
[9] A. Formia, C.L. Serra, M. Zerbinatti, J.M. Tulliani, The plasters of the Sacro Monte of Varallo Sesia. From the characterisation to the proposition of a restorative mix, Case Stud. Constr. Mater. 1 (2014) 46–52.
[10] N. Belayachi, D. Hoxha, M. Slaimia, Impact of accelerated climatic aging on the behavior of gypsum plaster-straw material for building thermal insulation, Construct. Build. Mater. 125 (2016) 912–918.
[11] A.B. Cherki, B. Remy, A. Khabbazi, Y. Jannot, D. Baillis, Experimental thermal properties characterization of insulating cork–gypsum composite, Construct. Build. Mater. 54 (2014) 202–209.
[12] B. Mazhoud, F. Collet, S. Pretot, J. Chamoin, Hygric and thermal properties of hemp-lime plasters, Build. Environ. 96 (2016) 206–216.
[13] A. Brás, F. Gonçalves, P. Faustino, Cork-based mortars for thermal bridges correction in a dwelling: thermal performance and cost evaluation, Energy Build. 72 (2014) 296–308.
[14] M.M. Barbero-Barrera, A. García-Santos, F.J. Neila-González, Thermal conductivity of lime mortars and calcined diatoms. Parameters influencing their performance and comparison with the traditional lime and mortars containing crushed marble used as renders, Energy Build. 76 (2014) 422–428.
[15] O. Gencel, J.J. del Coz Diaz, M. Sutcu, F. Koksal, Rabanal Fpá, G. Martinez-Barrera, A novel lightweight gypsum composite with diatomite and polypropylene fibers, Construct. Build. Mater. 113 (2016) 732–740.
[16] D. Koňáková, M. Čáchová, E. Vejmelkova, M. Keppert, M. Jerman, P. Bayer, R. Černý, Lime-based plasters with combined expanded clay-silica aggregate: microstructure, texture and engineering properties, Cement Concr. Compos. 83 (2017) 374–383.
[17] E. Fenoglio, S. Fantucci, V. Serra, C. Carbonaro, R. Pollo, Hygrothermal and environmental performance of a perlite-based insulating plaster for the energy retrofit of buildings, Energy Build. 179 (2018) 26–38.
[18] K. Selvaranjan, S. Navaratnam, J.C.P.H. Gamage, J. Thamboo, R. Siddique, J. Zhang, G. Zhang, Thermal and environmental impact analysis of rice husk ash-based mortar as insulating wall plaster, Construct. Build. Mater. 283 (2021), 122744.

[19] M. Schuss, U. Pont, A. Mahdavi, Long-term experimental performance evaluation of aerogel insulation plaster, Energy Proc. 132 (2017) 508–513.
[20] K. Miskinis, V. Dikavicius, A. Buska, K. Banionis, Influence of EPS, mineral wool and plaster layers on sound and thermal insulation of a wall: a case study, Appl. Acoust. 137 (2018) 62–68.
[21] M. Charai, H. Sghiouri, A. Mezrhab, M. Karkri, Thermal insulation potential of non-industrial hemp (Moroccan cannabis sativa L.) fibers for green plaster-based building materials, J. Clean. Prod. 292 (2021), 126064.
[22] R. Dylewski, J. Adamczyk, The comparison of thermal insulation types of plaster with cement plaster, J. Clean. Prod. 83 (2014) 256–262.
[23] H.R. Krsti, M.I. Domazetovi, Co-heating test as a tool for reduction of energy performance gap in buildings, Int. J. Energy. Prod.Manag. 5 (4) (2020) 328–341, 5 (4).
[24] A.M. Rashad, Possibility of producing thermal insulation materials from cementitious materials without foaming agent or lightweight aggregate, Environ. Sci. Pollut. Control Ser. 29 (3) (2022) 3784–3793.
[25] I.B. Topcu, B. Isıkdag, Manufacture of high heat conductivity resistant clay bricks containing perlite, Build. Environ. 42 (10) (2007) 3540–3546.
[26] A.A.A. Al-Naghi, M.K. Rahman, O.S.B. Al-Amoudi, S.U. Al-Dulaijan, Thermal performance evaluation of walls with AAC blocks, insulating plaster, and reflective coating, J. Energy Eng. 146 (2) (2020), 04019040.
[27] S. Fantucci, E. Fenoglio, V. Serra, Laboratory Vs field performance of innovative thermal insulating plasters, in: XV International Conference on Durability of Building Materials and Components, DBMC), 2020.
[28] D. Johnston, D. Miles-Shenton, D. Farmer, J. Wingfield, Whole House Heat Loss Test Method (Co-heating), Leeds Metropolitan University, Leeds, UK, 2013.
[29] D. Farmer, D. Johnston, D. Miles-Shenton, Obtaining the heat loss coefficient of a dwelling using its heating system (integrated co-heating), Energy Build. 117 (2016) 1–10.
[30] A.S. Kalagasidis, P.E. Emma Brycke, J.P.E. Nilssen, P. Johansson, Evaluation of a modified co-heating test for in-situ measurements of thermal transmittance of single family houses, Thermal Performance of the Exterior Envelopes of Whole Buildings 2016 (2016) 598–608.
[31] D. Johnston, J. Wingfield, D. Miles-Shenton, Measuring the fabric performance of UK dwellings, in: Proceedings of the Association of Researchers in Construction Management (ARCOM) Twenty-Sixth Annual Conference, vol. 2, 2010, pp. 1371–1380.
[32] E. Cuce, Accurate and reliable U-value assessment of argon-filled double glazed windows: a numerical and experimental investigation, Energy Build. 171 (2018) 100–106.
[33] E. Cuce, S.B. Riffat, Vacuum tube window technology for highly insulating building fabric: an experimental and numerical investigation, Vacuum 111 (2015) 83–91.
[34] E. Cuce, S.B. Riffat, Aerogel-assisted support pillars for thermal performance enhancement of vacuum glazing: a CFD research for a commercial product, Arabian J. Sci. Eng. 40 (8) (2015) 2233–2238.
[35] E. Cuce, P.M. Cuce, Solar pond window technology for energy-efficient retrofitting of buildings: an experimental and numerical investigation, Arabian J. Sci. Eng. 42 (2017) 1909–1916.
[36] E. Cuce, P.M. Cuce, S.B. Riffat, Novel glazing technologies to mitigate energy consumption in low-carbon buildings: a comparative experimental investigation, Int. J. Energy Res. 40 (2016) 537–549.
[37] E. Cuce, Role of airtightness in energy loss from windows: experimental results from in-situ tests, Energy Build. 139 (2017) 449–455.
[38] H.W. Coleman, W.G. Steele, Experimentation, Validation, and Uncertainty Analysis for Engineers, John Wiley & Sons, 2018.
[39] B. Cuhadaroglu, Thermal conductivity analysis of a briquette with additive hazelnut shells, Build. Environ. 40 (7) (2005) 942–948.