Solar Energy
And Sustainable Development
Refereed, biannual scientific journal issued by:
The Libyan Center for Solar Energy Research and Studies

Impact of Ecological Thermal Roof Insulation on the Energy Efficiency of Conventional Buildings in a Semi-Arid Climate

Mohammed Benfars[1*], Abdelmounaim Alioui[2], Youness Azalam[3], Mourad Kaddiri[4], Mustapha Mabrouki[5].

[1,2,3,4,5]Laboratory of Industrial and Surface Engineering, Sultan Moulay Slimane University, Beni Mellal, Morocco.
[2]Polydisciplinary Faculty, Sultan Moulay Slimane University, Beni Mellal, Morocco.

E-*mail:* [1] mohammed.fars@usms.ma ,[2] abdelmounaim.aliouifpb@usms.ac.ma ,[3] youness.azalam@usms.ma .

SPECIAL ISSUE ON:

The 2024 1st International Conference on Materials Sciences and Mechatronics for Sustainable Energy and the Environment
October 1-3, 2024 at Béni-Mellal, Morocco

KEYWORDS

Thermal simulation; Thermal insulation; Energy efficiency; Ecological panels; Sustainable building.

ABSTRACT

The roof is the most exposed element of a building's envelope and significantly contributes to cooling loads in hot climates. Effective thermal insulation of the roof can substantially reduce energy consumption for cooling and help achieve sustainability goals. This theoretical study focuses on the thermal and energy performance of an eco-friendly insulation material, aiming to determine the optimal thickness for the roof of a traditional residential building in the semi-arid climate. The study evaluated the effectiveness of an insulation material composed of 60% cardboard and 40% straw, with varying thicknesses.

TRNSYS software was used to simulate the thermal behavior of the building. The study's results reveal that the optimal thickness is 4 cm, providing the best thermal performance by reducing maximum indoor temperatures by 2.67°C during the hottest months, leading to a 37.93% reduction in annual cooling energy demand. Furthermore, the 4 cm panels represent the best compromise between thermal performance, resource efficiency, and economic feasibility. In conclusion, this study provides valuable insights for the design of more energy-efficient buildings through optimized thermal insulation. Future research should explore additional factors influencing building performance, such as the long-term durability of materials in different climates, as well as the impact of building occupancy and orientation. Although this study has certain limitations in its analysis of specific parameters and alternatives, it makes a significant contribution to understanding the performance of buildings with ecological insulation.

*Corresponding author.

DOI: https://doi.org/10.51646/jsesd.v14iSI_MSMS2E.401

تأثير العزل الحراري الإيكولوجي للسقف على كفاءة استخدام الطاقة في المباني التقليدية في مناخ شبه جاف

محمد بن فارس، عبد المنعم عليوي، يونس ازالم، مراد قاديري، مصطفى مبروكي.

ملخص: السقف هو العنصر الأكثر تعرضًا في غلاف المبنى، وله تأثير كبير على أحمال التبريد في المناخات الحارة. يمكن أن يؤدي العزل الحراري الفعّال للسقف إلى خفض استهلاك الطاقة المستخدمة للتبريد بشكل كبير، مما يسهم في تحقيق أهداف الاستدامة. تركز هذه الدراسة النظرية على الأداء الحراري والطاقي لمادة عزل صديقة للبيئة، وتهدف إلى تحديد السمك الأمثل للعزل في سقف مبنى سكني تقليدي يقع في مناخ شبه جاف. قامت الدراسة بتقييم فعالية مادة عازلة مكونة من 60% من الورق المقوى و40% من القش، مع اختلاف في السماكات. تم استخدام برنامج TRNSYS لمحاكاة السلوك الحراري للمبنى. أظهرت نتائج الدراسة أن السمك الأمثل هو 4 سم، حيث يوفر هذا السمك أفضل أداء حراري من خلال خفض درجات الحرارة الداخلية القصوى بمقدار 2.67 درجة مئوية خلال أشهر الصيف الأكثر حرارة، مما يؤدي إلى تقليل استهلاك الطاقة السنوي للتبريد بنسبة 37.93%. علاوة على ذلك، تمثل ألواح العزل بسماكة 4 سم التوازن الأمثل بين الأداء الحراري وكفاءة استغلال الموارد والجدوى الاقتصادية. في الختام، تقدم هذه الدراسة رؤى قيمة لتصميم مبانٍ أكثر كفاءة في استهلاك الطاقة عبر تحسين العزل الحراري. وينبغي أن تتناول الأبحاث المستقبلية عوامل إضافية تؤثر على أداء المباني، مثل متانة المواد على المدى الطويل في ظروف مناخية مختلفة، بالإضافة إلى تأثير إشغال المباني وتوجهها. وعلى الرغم من وجود بعض القيود في هذه الدراسة فيما يتعلق بتحليل معايير محددة وبدائل أخرى، إلا أنها تُشكل مساهمة مهمة في فهم أداء المباني التي تستخدم العزل البيئي.

الكلمات المفتاحية – المحاكاة الحرارية؛ العزل الحراري؛ النجاعة الطاقية؛ الألواح البيئية؛ البناء المستدام.

1. INTRODUCTION

In recent years, humanity has faced two major challenges: the energy crisis and environmental issues [1]. Currently, the building sector is the largest energy consumer, accounting for over 36% of total global energy consumption [2] and responsible for more than 30% of global carbon dioxide (CO2) emissions [3,4]. The building envelope consists of the elements that provide thermal separation between the interior and exterior. The thermal performance of this envelope is crucial, as over 60% of heat loss occurs through walls and roofs [5], the latter is the most exposed to climatic conditions [6]. It plays a fundamental role in regulating the internal temperature, significantly contributing to the thermal load from outside [7]. In hot climates, the roof can account for up to 50% of a building's total thermal load. Therefore, improving the thermal characteristics of the roof can notably reduce the energy consumption required for cooling buildings [8]. On the other hand, inadequate insulation can lead to significant energy loss, increasing the demand for heating or cooling, and consequently, energy consumption. In this regard, the use of insulating materials in the building envelope helps reduce energy losses throughout the year by optimizing the efficiency of heating and cooling systems [9][10].

In this context, experimental research conducted by Alvardo and his collaborators on laboratory prototypes revealed that a hybrid system combining an insulating material and a reflector installed on the roof reduced thermal conduction by 65% to 88% compared to a control prototype [11]. A study conducted in Japan showed that installing lawns on roofs reduced the maximum air temperature by 3 to 4°C during the summer season [12]. Charai et al. [13] examined the thermal efficiency of hemp-gypsum biocomposites and their role in reducing the energy consumption of a model building adapted to semi-arid climates, whether cold or hot, based on the climatic conditions of the cities of Oujda and Marrakech. The study was carried out using the EnergyPlus software. The findings of this research reveal that roof insulation with a 5 cm thick hemp-gypsum board reduces overall energy demand (heating and cooling) by 4.7% in Oujda and 5.4% in Marrakech. Additionally, a simulation study conducted with Transys indicates that using 8 cm of hemp wool for roof insulation can achieve significant energy savings, with reductions of up to 36.7% for cooling and 35.2% for heating [14]. These studies clearly demonstrate that building envelope insulation contributes to substantial energy savings, with a particular focus, in most cases, on reducing heat gains at the roof level.

Despite the variety of existing studies, the effect of roofing insulation using a mixture of cardboard and straw has not yet been explored. Therefore, this work aims to provide a comprehensive understanding of the impact of an insulation composed of 60% cardboard and 40% straw, applied in various thicknesses ranging from 4 to 12 cm, on the energy performance of a typical residential building. Additionally, a detailed parametric study is presented, analyzing the influence of this insulation on the building's energy efficiency through simulations conducted using TRNSYS software. The primary objective is to determine the optimal thickness of the insulation suited to the semi-arid climate conditions of the city of Beni Mellal and assess its effect on indoor temperature as well as energy demand for cooling.

2. METHODOLOGY

The approach adopted in this study consists of analyzing the energy efficiency and thermal comfort of a traditional house located in the city of Beni Mellal. The first step aimed to identify the deficiencies of the house to formulate recommendations for reducing energy consumption and improving indoor environmental quality through passive strategies. The methodology then involves conducting simulations for an ecological insulation with varying thicknesses to assess the performance of the insulation material. These simulations were conducted using Trnsys software, a reliable tool for modeling the thermal behavior of buildings. To determine the optimal thickness, the simulation results were analyzed for each thickness to examine their effect on the internal surface temperature of the roof. We then evaluated the impact of this optimal thickness on indoor thermal comfort and on reducing energy consumption for cooling. To clarify the methodology, a flowchart was presented in Figure 1, illustrating the research process. This approach allowed for the determination of the most effective insulation thickness, applicable to the design and construction of energy-efficient buildings in semi-arid regions.

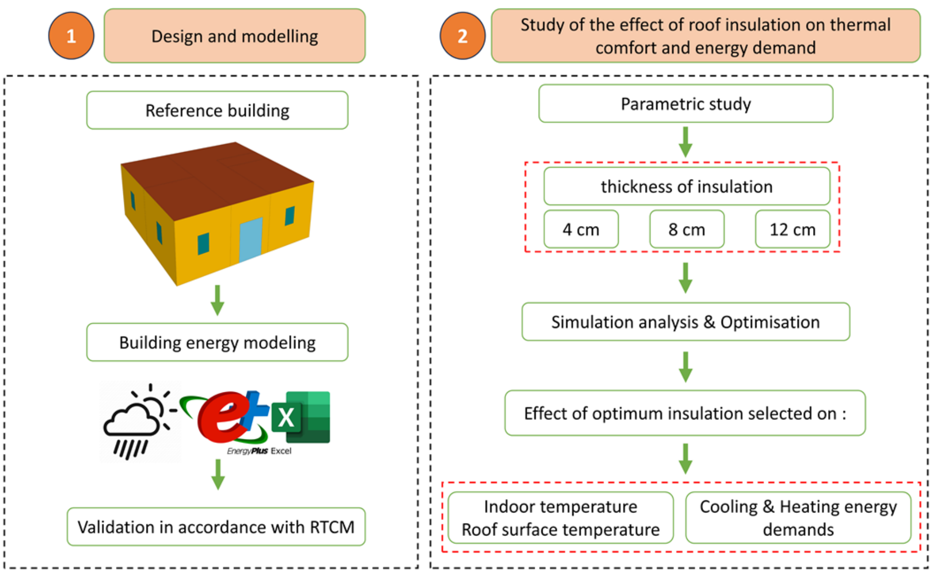

Figure 1. Organisation chart of the work.

2.1. Simulating building energy transfer: mathematical and physical models

The aim of our study, carried out using TRNSYS simulation software, is to assess the energy efficiency of a building. The model simulates the building structure in the SketchUp environment and uses the TRNSYS type 56 module (TRNBUILD) to detail the structure as a function of building materials (thicknesses, thermophysical properties), air infiltration levels, occupancy planning, lighting, and other parameters.

The three modes of heat transfer in the building are as follows:

a- Conductive heat transfer:

The walls of the building are modelled using the conductive transfer function method (based on the approach of Stephenson and Mitalas), which allows the transfer of heat by conduction through the various surfaces of the building to be represented.

$$\dot{q}_{so} = \sum_{k=0}^{n_a} a^k T_{s,o}^k - \sum_{k=0}^{n_b} b^k T_{s,o}^k - \sum_{k=1}^{n_d} d^k \dot{q}_{s,o}^k \quad (1)$$

$$\dot{q}_{si} = \sum_{k=0}^{n_b} b^k T_{s,o}^k - \sum_{k=0}^{n_c} c^k T_{s,o}^k - \sum_{k=1}^{n_d} d^k \dot{q}_{s,i}^k \quad (2)$$

Where $\dot{q}_{so}$ and $\dot{q}_{si}$ represent the heat fluxes exiting and entering the wall, respectively. The temperatures of the external and internal surfaces of the wall are denoted as $T_{s,0}$ and $T_{s,i}$ (see Figure 2). The equations (1) and (2) describe time series of heat fluxes and surface temperatures, where the exponent k denotes the time step *k=0* corresponds to the current hour, and *k=0* to the previous hour). The coefficients *a,b,c*, and *d* define these time series.

b- Convection heat transfer:

The equations for the heat flows exchanged by convection near the inner and outer surfaces of the wall are as follows:

$$\dot{q}_{c,s,o} = h_{outside}(T_{a,s} - T_{s,o}) \quad (3)$$

$$\dot{q}_{c,s,i} = h_{inside}(T_i - T_{s,i}) \quad (4)$$

h_{inside} and $h_{outside}$ represent the convective heat transfer coefficients for the interior and exterior surfaces, respectively. $T_{(a,s)}$ and $T_{(i)}$, on the other hand, denote the ambient air temperatures outside and inside the thermal zone, respectively.

c- Radiative Heat Transfer:

The formula for the heat flux exchanged through radiation is:

$$\dot{q}_{r,s,o} = \sigma \varepsilon_{s,o}(T_{s,o}^4 - T_{fsky}^4) \quad (5)$$

where :

σ : the Stefan-Boltzmann constant.

$\varepsilon_{s,o}$: the long-wave emissivity of the outer wall surface.

T_{fsky} : the fictitious temperature of the sky with respect to the longwave radiation exchange.

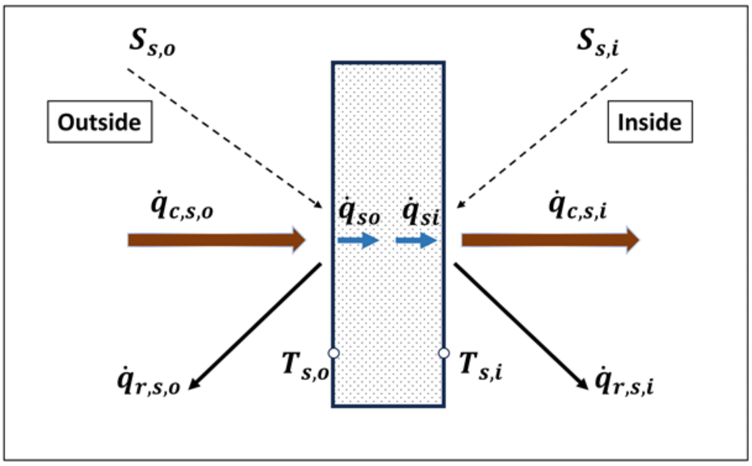

Figure 2. Heat fluxes and temperatures near the wall.

2.2. Building and Materials Description

The studied building is a single-family, one-story construction with a total area of 74 m² and an interior height of 3 meters. It is organized into four distinct thermal zones: two bedrooms, a living room, and a bathroom, as detailed in Figure 3 which gives an overview of the building, highlighting its architectural and functional specifics. The thermophysical properties of the construction materials, including their thermal conductivity, density, and specific heat capacity, are detailed in Table. 1.

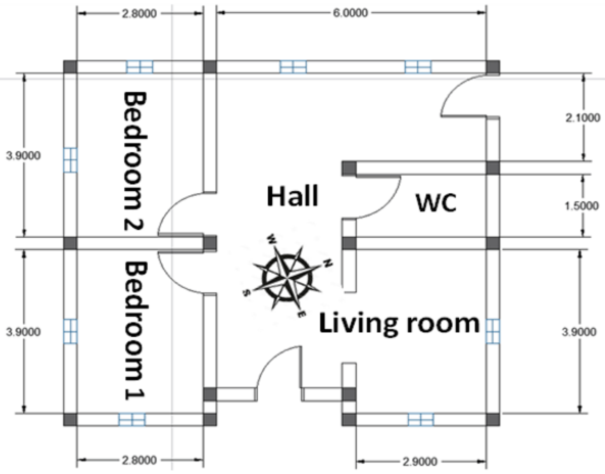

Figure 3. Layout of the building modelled for this study.

Figure 3. Layout of the building modelled for this study.

Materials	Thermal conductivity (W/m K)	Specific Heat capacity (J/kg*K)	Density (kg/m3)
Concrete [15]	1.7	880	2240
Cement mortar[16]	0.93	1050	1800
Concrete masonry [17]	1.1	1000	2076
insulation panel [18]	0.080	1626.4	281.1

2.3. Climatic conditions

The city of Beni Mellal (latitude: 32.367°, longitude: -6.4°, altitude: 472 m) is located in a region characterized by a Mediterranean climate heavily influenced by semi-arid conditions. This climate is marked by high temperatures during the dry season, which extends from May to October.

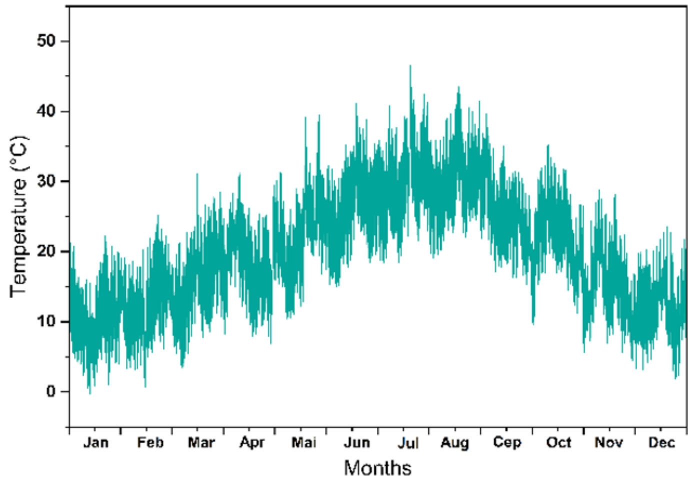

Figure 4. Outdoor air temperature of Beni Mellal city.

During this period, daytime temperatures frequently range between 38 and 40 °C, with warm nights as well, as shown in Figure 4. For this research, climate data was generated using version 8 of Meteonorm, ensuring accuracy in the climatic conditions specific to this region for thermal simulations.

3. RESULTS AND DISCUSSIONS

3.1. Effect of Insulation on Roof Surface Temperatures

Figure 5. shows the variation in temperatures on the exterior and interior surfaces of the roof, with and without insulation, over a 24-hour period during the hottest month. The results reveal that the maximum temperature of the upper surface of the roof reaches 57.19°C regardless of the configuration type, due to the homogeneous concrete composition. However, data from Figure 5. and Table. 2. clearly demonstrate the significant impact of insulation panel thickness on several critical thermal parameters, such as the soffit temperature, time lag, and decrement factor.
Without insulation, the maximum soffit temperature of the roof is 43.45°C, leading to thermal discomfort for occupants due to harmful infrared radiation. Thermal insulation panels significantly reduce this temperature: 35.53°C for a 4 cm thickness, 33.73°C for 8 cm, and 32.79°C for 12 cm, thus improving the thermal insulation properties.

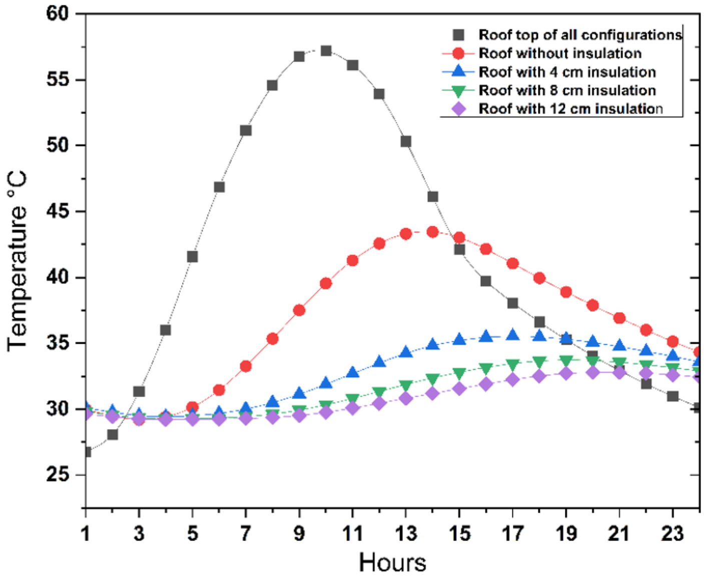

Figure 5. Top and bottom surface temperatures of the slab without insulation, and with 4 cm, 8 cm, and 12 cm thick insulation over a period of 24 hours during the hottest month, July.

Table.2. Decrement factors of the evaluated models.

Type of roof	Roof top maximum temperature (°C)	Roof soffit maximum temperature (°C)	Time lag (hours)	Decrement factor
Roof without insulation	57.19	43.45	4	0.46
Roof with 4cm insulation	57.19	35.53	7	0.20
Roof with 8cm insulation	57.19	33.73	9	0.14
Roof with 12cm insulation	57.19	32.79	11	0.11

Insulation panels also improve the time lag. For a non-insulated roof, the thermal lag is 4 hours, whereas it increases to 7, 9, and 11 hours for 4 cm, 8 cm, and 12 cm thick panels, respectively. In contrast, similar results were obtained in another study, where a 25 mm thick bamboo insulation layer provided a 3-hour delay [19]. This suggests that the insulation investigated in this study has greater potential to effectively modulate thermal variations.

The decrement factor, which quantifies the reduction in thermal amplitude, shows a similar trend. It is 0.46 for the non-insulated roof, compared to 0.20, 0.14, and 0.11 for 4 cm, 8 cm, and 12 cm thick panels, respectively. This improvement indicates that the panel thickness contributes to the increased ability of the roof to attenuate thermal fluctuations.

However, the difference in thermal performance between 8 cm and 12 cm thick panels is relatively small. Indeed, the temperature difference is only 0.94°C and the decrement factor shows a minimal difference of 0.03. Increasing the thickness to 12 cm results in higher material consumption, which may compromise economic feasibility. On the other hand, although 8 cm panels are twice as thick as 4 cm panels, the comparison between them reveals only a 1.8°C difference in soffit temperature and a variation of 0.06 in decrement factors. These differences are also minor; therefore, 4 cm panels represent the best balance between thermal performance and resource efficiency.

3.2. Effect of Insulation on Indoor air Temperature

Figure 6. Shows the variations in air temperature over the three months of the hot season, from June to August. The results reveal that for an uninsulated roof, the indoor temperature ranges from 25.12 °C to 36.80 °C. In contrast, the addition of 4 cm thermal insulation panels reduces this range to 24.79 °C - 34.13 °C. This reduction of 2.67 °C in maximum temperatures is particularly significant in terms of thermal performance, as it reduces the need for air conditioning systems, thereby decreasing energy consumption and operational costs.

The effectiveness of the insulation panels is also highlighted by the comparative analysis of the reduction in indoor temperature relative to the outside temperature. Without insulation, the indoor temperature is 11.68 °C lower than the outside temperature. However, with the integration of the panels, this difference increases to 13.94 °C, marking an improvement of 2.26 °C. This improvement underscores the contribution of the insulation panels to enhancing the thermal comfort of indoor spaces.

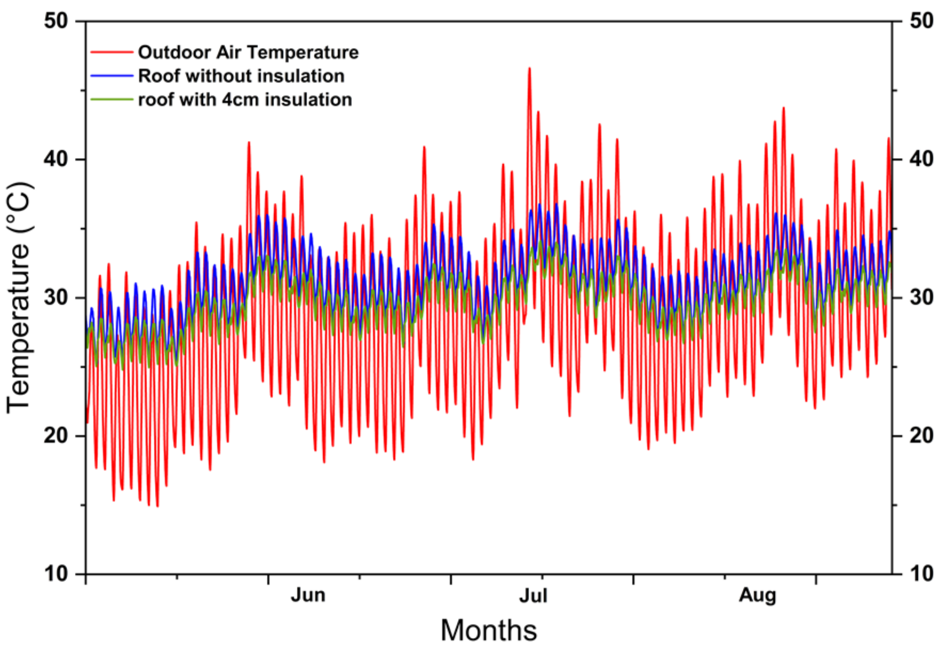

Figure 6. Indoor air temperature of the slab without insulation and with 4 cm insulation during the hot period from June to August.

Furthermore, the analysis of thermal fluctuations reveals a notable improvement in thermal stability. For the uninsulated roof, the amplitude of indoor temperature fluctuation ranges between 2.69 °C and 5.07 °C, indicating a significant thermal response to external climatic variations that could compromise indoor comfort. In contrast, with the insulation panels, this fluctuation range is reduced to between 1.24 °C and 2.72 °C, indicating increased thermal stability. This reduction in thermal fluctuation demonstrates the panels' ability to better manage temperature variations, contributing to a more stable indoor environment. In conclusion, the integration of 4 cm thermal insulation panels under roof significantly enhances the thermal performance of the envelope. The results highlight not only an effective reduction in indoor temperatures but also a decrease in thermal fluctuations.

3.3. Effect of Insulation on Cooling Energy Loads

Figure 7. shows the annual and monthly cooling loads. A detailed analysis of the monthly results from the thermal simulation reveals that the integration of 4 cm thick heat insulation panels significantly reduces energy requirements for air conditioning, especially during the hottest months. In June, energy demand decreased by 40.8%, while in July and August, it reached reductions of 33.9% and 31.5% respectively. These results highlight the exceptional efficiency of insulation panels during periods of high temperature. Over an annual period, the data show that the air conditioning energy demand for an uninsulated roof is 103.44 kWh/m² per year. In contrast, applying the insulation panels reduces this demand to 64.2 kWh/m² per year, representing an overall decrease of 37.93%. In comparison, a similar study using hemp insulation with a thickness of 8 cm showed a 36.7% reduction in cooling load [20]. Although the materials and thicknesses differ, our study demonstrates that the application of ecological panels results in a slightly higher energy savings, especially with a thickness of 4 cm, offering greater flexibility and efficiency in reducing energy consumption. These results suggest that our approach is not only comparable but potentially more advantageous in terms of energy efficiency, while using a bio-based material that could also provide benefits in terms of sustainability and environmental impact.

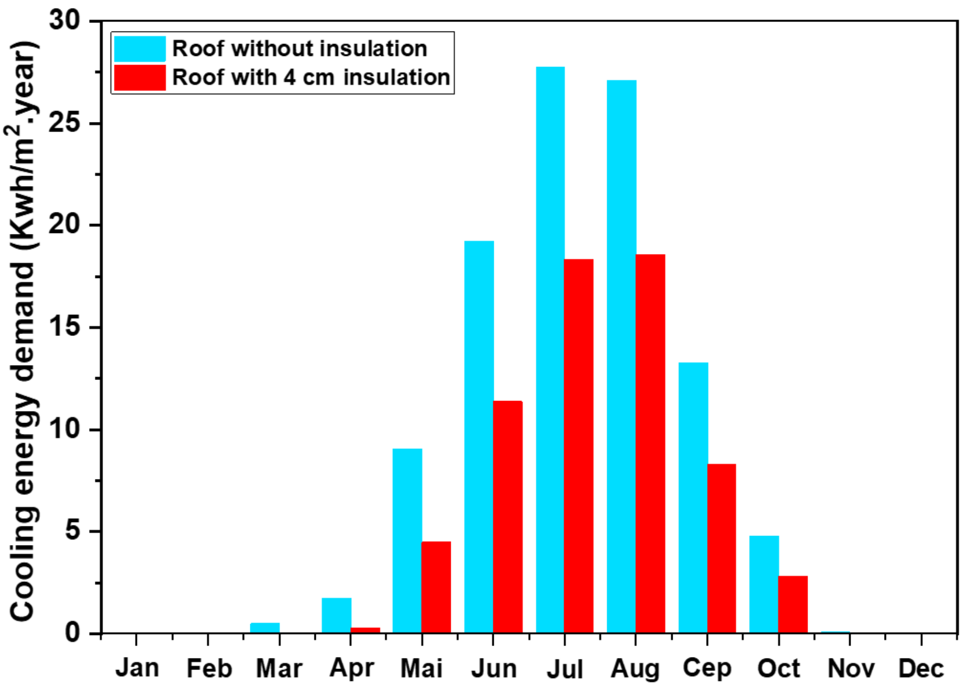

Figure 7. Monthly cooling for the slab without and slab with 4cm thick insulation.

4. CONCLUSION

In summary, this study examined the effectiveness of an eco-friendly thermal insulation material composed of 60% cardboard and 40% straw, with varying thicknesses, for traditional buildings in semi-arid climates, specifically in the city of Beni Mellal, Morocco. The objective was to investigate the impact of this insulation on indoor thermal comfort, energy efficiency, and the reduction of greenhouse gas emissions.

The simulation results obtained using TRNSYS software highlight the importance of this insulation in enhancing indoor comfort and reducing cooling energy consumption in hot regions. An optimal thickness of 4 cm was identified, which reduced maximum indoor temperatures by 2.67°C while maintaining thermal comfort, demonstrating the effectiveness of insulation even at minimal thickness. The energy impact is also significant, with a 37.93% reduction in annual cooling demand.

For future research, it is recommended to focus on the long-term performance and durability of cardboard and straw thermal insulation panels in various climatic contexts. It would also be relevant to explore additional bio-based or innovative materials that could further enhance thermal efficiency and durability of the panels. Such investigations will provide valuable insights for the development of more effective insulation solutions tailored to the specific requirements of buildings in semi-arid climates like that of Beni Mellal.

Authors contribution: M.B. : conceptualization, methodology, data curation, writingoriginal draft, formal analysis, visualization, supervision, writingreview and editing. A.A. : investigation, conceptualization, methodology, supervision, writingoriginal draft, writingreview and editing. Y.A. : conceptualization, methodology, supervision, writingoriginal draft, writingreview and editing. M.k. : conceptualization, data curation, supervision. M.M. : conceptualization, data curation, supervision.

Funding: The authors have not disclosed any funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare that they have no known conflicts of interest.

Acknowledgements: This work was supported by the industrial and surface engineering laboratory of the Faculty of Science and Technology of Béni Mellal, Morocco.

REFERENCES

[1] A. Bachir and N. Taieb, "Numerical analysis for energy performance optimization of hollow bricks for roofing. Case study: Hot climate of Algeria," Constr Build Mater, vol. 367, p. 130336, Feb. 2023, doi: 10.1016/J.CONBUILDMAT.2023.130336.

[2] A. Alioui, S. Idrissi Kaitouni, Y. Azalam, N. Al armouzi, E. M. Bendada, and M. Mabrouki, "Effect of straw fibers addition on hygrothermal and mechanical properties of carbon-free adobe bricks: From material to building scale in a semi-arid climate," Build Environ, vol. 255, p. 111380, May 2024, doi: 10.1016/J.BUILDENV.2024.111380.

[3] I. Bouchefra, F. Z. EL Bichri, H. Chehouani, and B. Benhamou, "Mechanical and thermophysical properties of compressed earth brick rienforced by raw and treated doum fibers," Constr Build Mater, vol. 318, p. 126031, Feb. 2022, doi: 10.1016/J.CONBUILDMAT.2021.126031.

[4] Y. Azalam, A. Alioui, N. Al Armouzi, M. Benfars, M. Mabrouki, and E. M. Bendada, "Physical and mechanical properties of adobe bricks reinforced by natural additives, a case study of alfalfa fibers," EUREKA: Physics and Engineering, vol. 2024-July, no. 4, pp. 144–159, Jul. 2024, doi: 10.21303/2461-4262.2024.003426.

[5] C. Jia, X. Geng, F. Liu, and Y. Gao, "Thermal behavior improvement of hollow sintered bricks

integrated with both thermal insulation material (TIM) and Phase-Change Material (PCM)," Case Studies in Thermal Engineering, vol. 25, p. 100938, Jun. 2021, doi: 10.1016/J.CSITE.2021.100938.

[6] Y. Chihab, L. Essaleh, R. Bouferra, and A. Bouchehma, "Numerical study for energy performance optimization of hollow concrete blocks for roofing in a hot climate of Morocco," Energy Conversion and Management: X, vol. 12, p. 100113, Dec. 2021, doi: 10.1016/J.ECMX.2021.100113.

[7] Y. Chihab, L. Essaleh, R. Bouferra, and A. Bouchehma, "Numerical study for energy performance optimization of hollow concrete blocks for roofing in a hot climate of Morocco," Energy Conversion and Management: X, vol. 12, p. 100113, Dec. 2021, doi: 10.1016/J.ECMX.2021.100113.

[8] P. Principi and R. Fioretti, "Thermal analysis of the application of pcm and low emissivity coating in hollow bricks," Energy Build, vol. 51, pp. 131–142, Aug. 2012, doi: 10.1016/J.ENBUILD.2012.04.022.

[9] A. Bachir and N. Taieb, "Numerical analysis for energy performance optimization of hollow bricks for roofing. Case study: Hot climate of Algeria," Constr Build Mater, vol. 367, p. 130336, Feb. 2023, doi: 10.1016/J.CONBUILDMAT.2023.130336.

[10] J. Xamán, J. Cisneros-Carreño, I. Hernández-Pérez, I. Hernández-López, K. M. Aguilar-Castro, and E. V. Macias-Melo, "Thermal performance of a hollow block with/without insulating and reflective materials for roofing in Mexico," Appl Therm Eng, vol. 123, pp. 243–255, Aug. 2017, doi: 10.1016/J.APPLTHERMALENG.2017.04.163.

[11] K. Nandapala and R. Halwatura, "Operational feasibility of a hybrid roof insulation system with bamboo and vegetation: An experimental study in tropical climatic conditions," Case Studies in Construction Materials, vol. 15, p. e00616, Dec. 2021, doi: 10.1016/J.CSCM.2021.E00616.

[12] N. Zhou, W. Gao, M. Nishida, H. Kitayama, and T. Ojima, "Field study on the thermal environment of passive cooling system in RC building," Energy Build, vol. 36, no. 12, pp. 1265–1272, Dec. 2004, doi: 10.1016/J.ENBUILD.2003.09.012.

[13] M. Charai, H. Sghiouri, A. Mezrhab, and M. Karkri, "Thermal insulation potential of non-industrial hemp (Moroccan cannabis sativa L.) fibers for green plaster-based building materials," J Clean Prod, vol. 292, p. 126064, Apr. 2021, doi: 10.1016/J.JCLEPRO.2021.126064.

[14] "View of Impact of Insulation using Bio-sourced Materials on the Thermal and Energy Performance of a Typical Residential Building in Morocco." Accessed: Aug. 29, 2024. [Online]. Available: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/article/view/6862/4800

[15] Y. Chihab, L. Essaleh, R. Bouferra, and A. Bouchehma, "Numerical study for energy performance optimization of hollow concrete blocks for roofing in a hot climate of Morocco," Energy Conversion and Management: X, vol. 12, p. 100113, Dec. 2021, doi: 10.1016/J.ECMX.2021.100113.

[16] Y. Zhang et al., "Study on the influence of thermo-physical parameters of phase change material panel on the indoor thermal environment of passive solar buildings in Tibet," J Energy Storage, vol. 52, p. 105019, Aug. 2022, doi: 10.1016/J.EST.2022.105019.

[17] P. K. S. Rathore, N. K. Gupta, D. Yadav, S. K. Shukla, and S. Kaul, "Thermal performance of the building envelope integrated with phase change material for thermal energy storage: an updated review.," Sustain Cities Soc, vol. 79, p. 103690, Apr. 2022, doi: 10.1016/J.SCS.2022.103690.

[18] M. Ouakarrouch, S. Bousshine, A. Bybi, N. Laaroussi, and M. Garoum, "Acoustic and thermal performances assessment of sustainable insulation panels made from cardboard waste and natural fibers," Applied Acoustics, vol. 199, p. 109007, Oct. 2022, doi: 10.1016/J.APACOUST.2022.109007.

[19] M. S. Chandra, K. Nandapala, G. Priyadarshana, and R. U. Halwatura, "Developing a durable thermally insulated roof slab system using bamboo insulation panels," International Journal of Energy and Environmental Engineering, vol. 10, no. 4, pp. 511–522, Dec. 2019, doi: 10.1007/S40095-019-0308-X/FIGURES/17.

[20] Hicham Kaddouri, Abderrahim Abidouche, Mohamed Saidi Hassani Alaoui, Ismael Driouch, and Said Hamdaoui, "Impact of Insulation using Bio-sourced Materials on the Thermal and Energy Performance of a Typical Residential Building in Morocco," Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 117, no. 1, pp. 43–59, May 2024, doi: 10.37934/arfmts.117.1.4359.