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Thermal Performance evaluation of Hempcrete as Infill-wall in a Building: A Case Study of Janakpur, Nepal

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Abstract
This study investigates the thermal performance implications of Hempcrete, an eco-friendly construction material, in the hot region of Janakpur, Nepal. Hempcrete, a bio-aggregate building material comprising hemp fibers, lime, and water, is a sustainable, low-conductivity, low-carbon material, with humidity-regulating properties The objective of this study is to investigate the thermal performance of Hempcrete when used as an infill wall material under actual climatic conditions in Nepal, while also simulating and validating our findings through field measurements to provide a comparative assessment of Hempcrete versus traditional brick walls. This research adopts the post-positivist paradigm. The objective set lead towards quantitative research as well as qualitative research method.The thermal performance of Hempcrete infill- wall was experimentally measured by using Hobo data logger and the results showed a significant 2.5℃ temperature difference between interior and outdoor spaces as well as a sizeable 12.65% relative humidity differential. Additionally, computer-based simulation using Ecotect demonstrated a remarkable 26% decrease in conduction loss when compared to traditional brick wall construction, further demonstrating Hempcrete's excellent thermal efficiency. This study contributes to sustainable building practices by demonstrating Hempcrete's capacity to enhance energy efficiency, thermal performance, and occupant well-being. It highlights the material's potential in creating more comfortable, energy-efficient, and environmentally conscious living and working spaces. Moreover, it encourages further exploration in diverse global contexts.

Keywords
Hempcrete,thermal performance , simulation, sustainable material,low-carbon footprint

1. Introduction

The building sector is a major contributor to global energy consumption, carbon emissions, and resource utilization, accounting for 36%, 40%, and 40% of each, respectively [1]. As the global population grows and living standards improve, a corresponding increase in these statistics is anticipated. Consequently, it is imperative to prioritize mitigating the environmental impact of the building sector to facilitate a transition towards sustainability. This necessitates reducing CO2 emissions and energy consumption, both of which are critical. Achieving a reduced environmental impact relies on advancing sustainable building materials [2].

In alignment with global sustainability goals, Nepal's Climate Change Policy (2011) vigorously promotes low-carbon development and adaptation initiatives. The Nepalese government is increasingly recognizing the significance of green construction to foster sustainable development. As a result,it is actively encouraging the use of eco-friendly building materials and practices [3].In this context, Hempcrete could emerge as an attractive alternative building technology (ABT) in Nepal, offering economic potential, sustainability, and favorable structural properties [4]. One such emerging and notable eco-friendly construction material is Hempcrete, celebrated for its significant sustainability advantages [2]. Hempcrete is a composite material composed with mineral binder and plant-based aggregates ground to 5–40 mm long from hemp's shiv or woody core. Using hemp in construction has proven to be a promising strategy for substantially decreasing the carbon footprint of buildings [5]. It's lightweight properties make hempcrete advantageous for construction in earthquake-prone areas.Various hempcrete construction methods exist, with the "cast in-situ" or a “cast-in-place” approach being a cost-effective option. Mixed hempcrete is placed into wall forms by hand and then tamped down [4] .Properly encasing the frame within the hempcrete wall provides structural stability and protection against moisture and insect damage [6].

Shah Hemp Inno-Ventures (SHIV), a local Nepali social enterprise, has been instrumental in promoting and implementing hempcrete construction in Nepal since 2015.Most of the materials needed for hempcrete construction are locally available throughout the country. However, it's important to note that the legal status of the cannabis plant has limited its use in most parts of Nepal.

Despite substantial global study on Hempcrete, a significant gap in understanding its thermal efficiency in specific regions, such as Nepal's, remains. Existing studies frequently include a wide range of climates, emphasising the need for research that is suited to regional differences. The climate diversity of Nepal, with locations like Janakpur experiencing high temperatures, poses both obstacles and potential for the use of Hempcrete. This study sets out to solve a critical knowledge gap by thoroughly examining the thermal performance of Hempcrete as an infill wall material in Nepal's diverse climatic conditions. Our primary goal is to evaluate how Hempcrete performs under real climatic conditions, with particular focus on hot climate places like Janakpur. Furthermore, our secondary objective is to simulate and validate our field based findings and also providing a comparative assessment of Hempcrete versus traditional brick walls. This comparative analysis not only enhances our understanding of Hempcrete's thermal behavior but also establishes a practical foundation for evaluating its potential as a sustainable building material in Nepal.

2. Literature Review

Hemp-lime mix found its modern application in France during the late 1980s, notably in the renovation of the Maison de la Turquie, a historic wattle and daub structure [7]. An even earlier example can be traced to Miasa village, Nagano, Japan, where a hemp-based home dating back to 1698 still stands, recognized as a Japanese national historical site. More recently, the United Kingdom has witnessed a surge in the use of hempcrete for various commercial and residential constructions, partly driven by government support through programs like the Renewable House Programme between 2007 and 2010 [6].

Research on Hempcrete has evolved with advancements in research methodologies, particularly focusing on its thermal performance assessment. Hempcrete offers a multitude of advantages, including breathability, mold resistance, acoustic performance, moisture buffering, durability, pest resistance, and fire resistance [8]. Notably, it demonstrates remarkable environmental benefits, such as the ability to be recycled into new projects or naturally decompose, enriching the soil with lime and organic matter at the end of its lifecycle [9].A key contributor to its sustainability is the choice of calcium hydroxide (hydrated lime) as a binder, which exhibits lower embodied energy and reduced carbon emissions compared to Portland cement [10].The carbon stored by photosynthesis and recarbonation (68 kg CO2e) is greater than the carbon emitted by the lifecycle (33 kg CO2e), resulting in a net balance of 35 kg CO2e (14 kg CO2e for economic allocation over 100 years per m2 [11] so it is renowned for being carbon-negative or carbon-neutral and outstanding insulation properties [12].The density, thermal conductivity, and compressive strength of hemp–lime primarily depend on the relative proportions of shiv and binder [13] with lower hemp-to-lime ratios resulting in reduced thermal conductivity[2] .Hempcrete samples with higher dry density and hemp-to-binder ratios in specific ranges have shown varying thermal conductivities [8].

Extensive research has been conducted to understand the thermal performance of Hempcrete. Researchers have employed various measurement methods, including transient heat flow analysis using heat flow meters [14].Advanced numerical modeling and simulation tools, such as finite element analysis (FEA), have allowed for comprehensive assessments of heat transfer within Hempcrete walls under diverse climatic conditions [15].

While some studies provide specific values for thermal conductivity, such as 0.115 W/mK for a density of 440 kg/m3 [16] and a k-value of 0.103 W/mK for a density of 387.8 kg/m3 [9], others report ranges, such as a k-value of 0.09-0.115 W/mK and a density range of 330-440 kg/m3 [17] .These variations highlight the impact of factors like density and binder proportions on Hempcrete's thermal properties. Furthermore, a review of 18 articles revealed dry thermal conductivity values ranging from 0.06 to 0.12 W/mK for dry density of 300-500 kg/m3 [11].

The outstanding insulating properties of Hempcrete, characterized by its low thermal conductivity, play a pivotal role in sustainable construction. This attribute enhances energy efficiency by minimizing heat transfer, enabling buildings to maintain comfortable indoor temperatures with reduced reliance on heating or cooling systems.In addition to promoting eco-friendly building practices, it contributes to lower energy costs and a reduced carbon footprint, establishing Hempcrete as an appealing choice for contemporary,environmentally conscious construction projects.

3. Methodology

The mixed-method technique used in this study is based on the post-positivist paradigm. A quantitative study into Hempcrete's thermal performance was carried out in Janakpur, Nepal. Different literature was also researched to better comprehend different study indicators such as air temperature measurement, building orientation, thermal conductivity, thermal transmittance (U-value) of materials used, and opening size. Hobo data loggers were used for primary data collection which include temperature and relative humidity data.The field measurements were conducted from August 20 to September 2, 2023. Concurrently, a systematic survey questionnaire survey was used to collect qualitative information about occupant thermal comfort. The secondary data was obtained from the Department of Hydrology and Meteorology (DHM) of Nepal.The collected field data, especially the quantitative data, underwent thorough validation through modeling and simulation using the Ecotect software. Additionally, a base case scenario was executed, involving simulations that replaced the Hempcrete with conventional brick wall constructions.

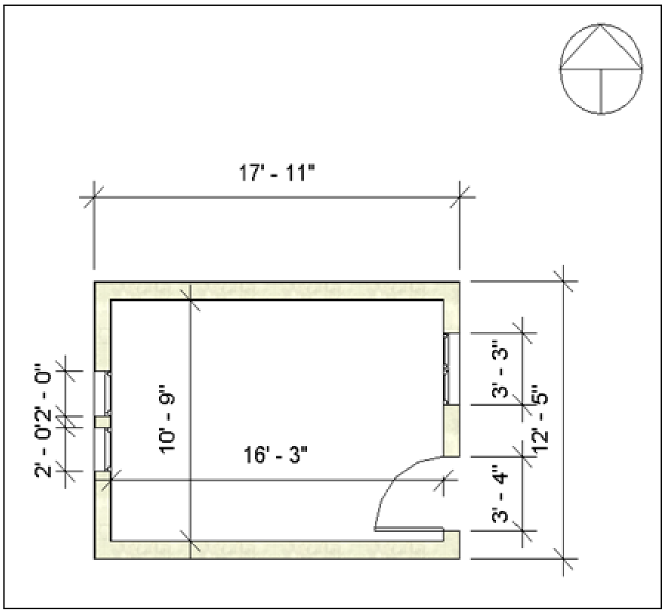

Figure 1: Layout of building

Figure 2: Outdoor Sensor

Figure 3: Indoor Sensor

4. Study Area

The coordinates for the research site in Janakpur, Nepal, are approximately 26°43’ 43” North latitude and 85°55’30” East longitude which is 75 meters above sea level, features a one-story building entirely made of hempcrete, demonstrating the adaptability of this sustainable material. The structure has a 2-inch hempcrete insulation in roof with CGI sheeting, providing an environmentally aware and energy-efficient roofing alternative. The walls of the building are likewise made of hempcrete, demonstrating its versatility for use in a variety of climates. The four corners are provided with metal truss foundation covered by 9” brick. The application of 2-inch roof insulation and 9" hempcrete walls in these distinct research settings enhances our comprehension of eco-conscious construction methods, offering valuable perspectives on the utilization of hempcrete and sustainable building materials in practical situations. Lime rendering was administered to both the external and internal surfaces of the hempcrete wall, further contributing to its performance.

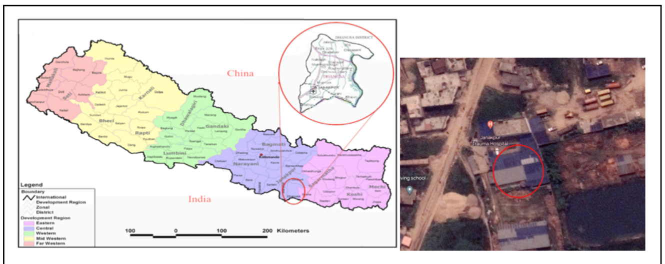

Figure 4: Study Area

Figure 5: Hempcrete Building

5. Modelling and Simulation

Hempcrete building was modeled and simulated as the base case.In an alternative scenario, it was substituted with conventional bricks for comparative analysis.The building was modelled by using 10 years data obtained from Department of hydrology and meteorology (DHM).

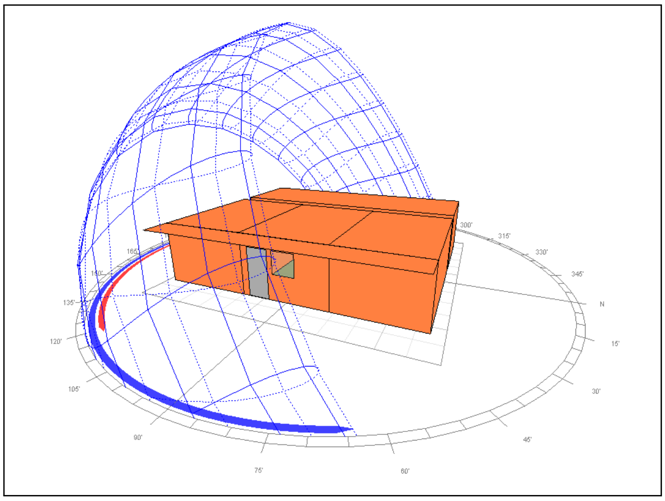

Figure 6: Modelling in Ecotect

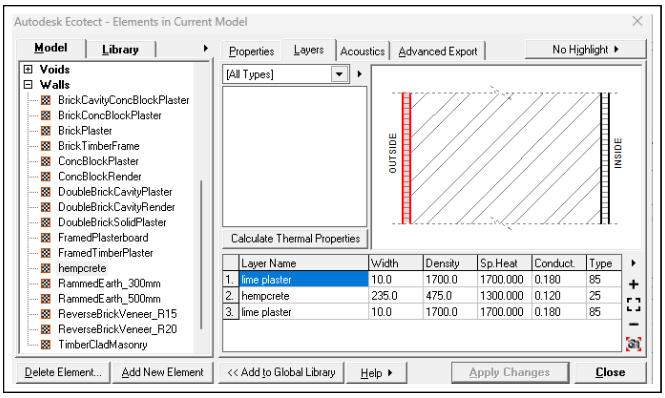

Figure 7: Hempcrete wall detail

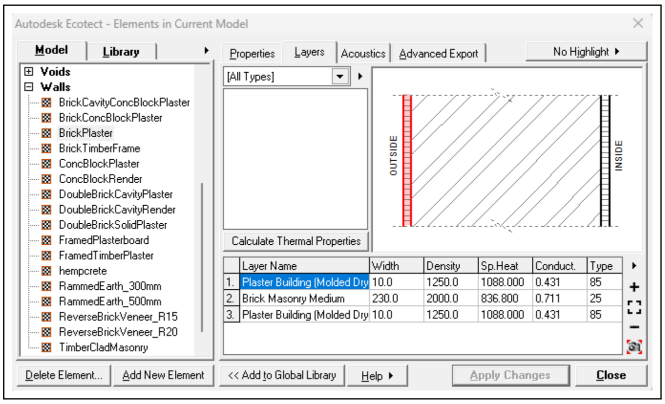

Figure 8: Brick wall detail

6. Result and Analysis

A similar temperature difference of approximately 2.5°C was found between indoor and outdoor spaces in Janakpur, where the climate offers its own distinctive features. This temperature variance was critical in improving the thermal comfort of inhabitants in hempcrete constructions. For validation simulation was done and despite accepting the limits of our simulation software (Ecotect), the results generally confirmed our observations in the field.

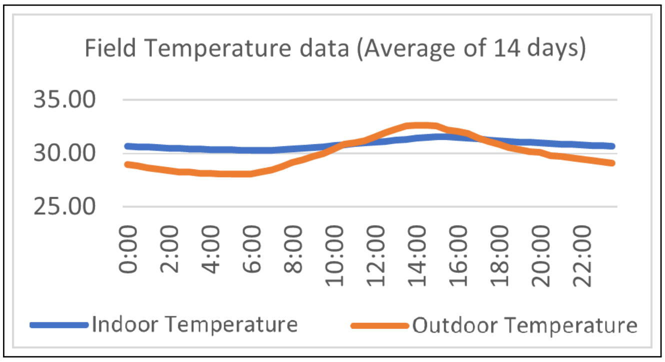

Figure 9: Field Temperature data

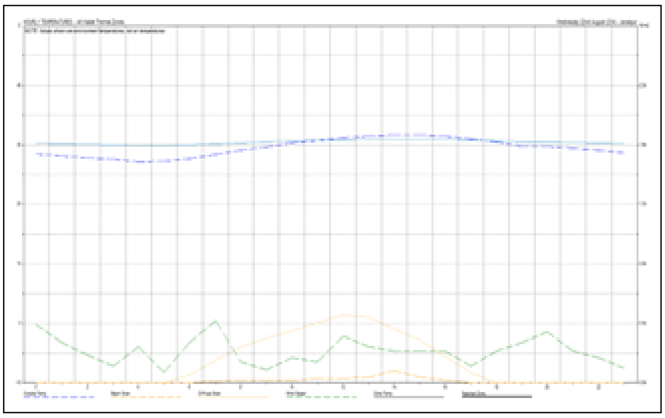

Figure 10: Simulated temperature data

A significant relative humidity differential of approximately 12.65% between indoor and outdoor conditions within hempcrete buildings. This large difference in humidity promotes a more comfortable, healthy, and pleasant interior environment.

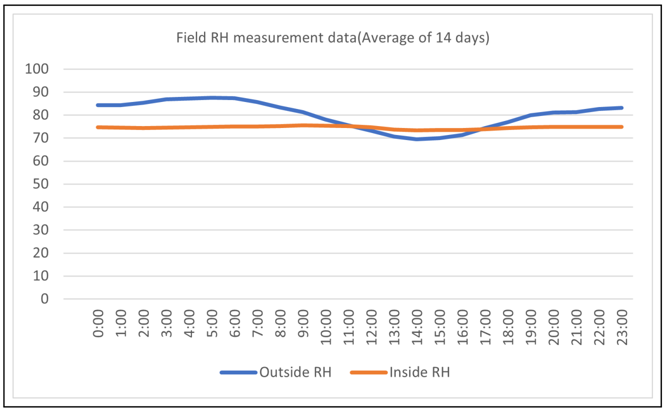

Figure 11: Field Relative Humidity data

A simulation result also discovered an impressive 26% reduction in conduction loss for hempcrete buildings in crucial simulations comparing hempcrete to conventional brick wall construction.

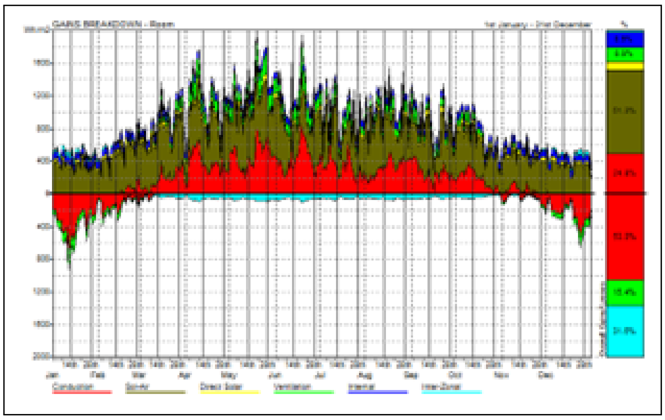

Figure 12: Passive Gain Breakdown of Hempcrete

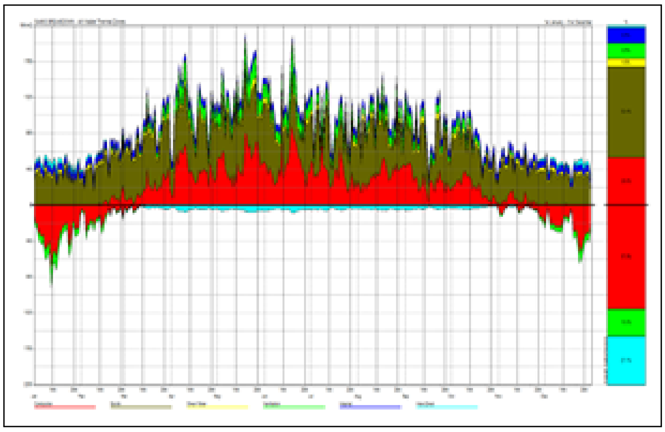

Figure 13: Passive Gain Breakdown of Brick

A significant majority of respondents observed a noticeable humidity differential between the interior and outside surroundings in the context of a questionnaire survey delivered to a sample of five respondents. In terms of the thermal conditions within the room, it was established that 60% of the participants were satisfied with the current conditions, while the other 40% were dissatisfied.

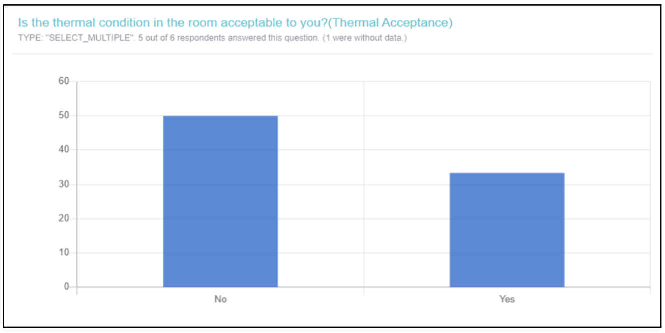

Figure 14: Thermal Acceptance

7. Conclusion

The study conducted in the hot climate of Janakpur, Nepal, to explore Hempcrete's thermal performance as an infill wall material, yielded significant results. Initially, Hempcrete displayed remarkable thermal efficiency, manifesting a temperature difference of approximately 2.5°C between indoor and outdoor spaces, suggesting its potential to create more comfortable indoor environments. Moreover, simulations demonstrated a noteworthy reduction in conduction loss, underscoring Hempcrete's capacity to contribute to energy conservation and enhance sustainability.A substantial relative humidity disparity of 12.6% between the exterior and interior spaces further enhances occupant comfort. These findings not only address the research inquiry but also carry practical implications. Hempcrete emerges as a viable and sustainable solution for construction in regions with drastic temperature fluctuations, offering energy-efficient and comfortable living and working conditions. Embracing this environmentally friendly material signifies a stride toward a greener and more sustainable future in the construction industry, where Hempcrete stands as a cornerstone of innovation and sustainability.

8. Recommendations and Future Works

While the conclusions drawn from this study specifically pertain to the use of Hempcrete as an infill wall material in the hot climate of Janakpur, Nepal, they offer valuable insights with broader applicability for similar regions. The recommendations provided here aim to guide the effective construction of Hempcrete infill walls, ultimately contributing to the creation of thermally comfortable indoor environments in hot climates.

- Conducting multiple case studies across buildings with varying designs and occupancy patterns to assess the generalizability of the findings.
- Extending the data collection period to capture seasonal variations and the long-term performance of Hempcrete.
- Using modern simulation tools and extensive material characterization to improve the technical accuracy of the analysis.
- Performing a comprehensive life cycle assessment to evaluate the environmental impact of Hempcrete compared to traditional materials.
- Exploring the cost-benefit analysis and long-term durability of Hempcrete, as well as opportunities for policy and regulatory support to promote its adoption.

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References

[1] A Feehan, H Nagpal, A Marvuglia, and J Gallagher. Adopting an integrated building energy simulation and life cycle assessment framework for the optimisation of facades and fenestration in building envelopes. *Journal of Building Engineering*, 43:103138, 2021.

[2] R Haik, A Peled, and IA Meir. Thermal performance of alternative binders lime hemp concrete (lhc) building: comparison with conventional building materials. *Building Research & Information*, 49(7):763–776, 2021.

[3] Bibek Bhattarai and Bikram Singh Bhattarai. Green building approach towards achieving sustainability in nepal. *American Journal of Modern Energy*, 9(2):27–35, 2023.

[4] David J Eaton and Niraj Prakash Josh. Post-earthquake home reconstruction in the surrounding hills of kathmandu valley, nepal, prp 200. Technical report, LBJ School of Public Affairs, 2018.

[5] Bassam Moujalled, Yacine Ait Oumeziane, Sophie Moissette, Marjorie Bart, Christophe Lanos, and Driss Samri. Experimental and numerical evaluation of the hygrothermal performance of a hemp lime concrete building: A long term case study. *Building and Environment*, 136:11–27, 2018.

[6] William Stanwix and Alex Sparrow. *The Hempcrete Book: Designing and building with hemp-lime*. Bloomsbury Publishing, 2014.

[7] Michał Gołębiewski. Hemp-lime composites in architectural design. *Kwartalnik Naukowy Uczelni Vistula*, (4 (54):162–171, 2017.

[8] Yaser Abdellatef, Mohammad Amil Khan, Asif Khan, Mehdi Iftekharul Alam, and Miroslava Kavgic. Mechanical, thermal, and moisture buffering properties of novel insulating hemp-lime composite building materials. *Materials*, 13(21):5000, 2020.

[9] Ujwal Dhakal, Umberto Berardi, Mark Gorgolewski, and Russell Richman. Hygrothermal performance of hempcrete for ontario (canada) buildings. *Journal of cleaner production*, 142:3655–3664, 2017.

[10] Mohammad Amil Khan. Physical and microstructural properties of insulating hempcrete mixes and their impact as infill system on the foundations due to increase in dead load. 2020.

[11] Ujwal Dhakal. The effect of different mix proportions on the hygrothermal performance of hempcrete in the canadian context. *Ryerson University, Canada*, 2016.

[12] P Aversa, A Marzo, C Tripepi, S Sabbadini, G Dotelli, P Lauriola, C Moletti, and VAM Luprano. Hemp-lime buildings: thermo-hygrometric behaviour of two case studies in north and south italy. *Energy and Buildings*, 247:111147, 2021.

[13] Andy Shea, Mike Lawrence, and Pete Walker. Hygrothermal performance of an experimental hemp–lime building. *Construction and building materials*, 36:270–275, 2012.

[14] Aidan Reilly and Oliver Kinnane. The thermal behaviour and embodied energy of hemplime construction. In *Proceedings of the International Conference for Sustainable Design of the Built Environment (SDBE), London, UK*, pages 20–21, 2017.

[15] Przemysław Brzyski, Magdalena Grudzińska, and Dariusz Majerek. Analysis of the occurrence of thermal bridges in several variants of connections of the wall and the ground floor in construction technology with the use of a hemp–lime composite. *Materials*, 12(15):2392, 2019.

[16] Mike Lawrence, Enrico Fodde, Kevin Paine, and Pete Walker. Hygrothermal performance of an experimental hemp-lime building. *Key Engineering Materials*, 517:413–421, 2012.

[17] Francesca Contrada, A Kindinis, and A Dony. Hemp-lime in construction: applications, comfort qualities and critical analysis. In *International Conference Inovations in construction, Paris*, 2015.