Influence of phase change materials on the thermal performance of hollow bricks under cold climate conditions: an experimental study

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Abstract. The escalating energy consumption in buildings and the substantial thermal losses in building envelopes pose formidable challenges to the increasingly strained energy resources. With the building envelope constituting the primary contributor to thermal losses in buildings, there arises an urgent need for structures that can mitigate building energy consumption and thermal losses. This study investigates the infusion of phase change materials into hollow bricks to create phase change material-filled hollow bricks, juxtaposed against unfilled counterparts through experimental analyses. Findings reveal that: 1) Hollow bricks filled with phase change materials exhibit higher inner surface temperatures, with an average temperature disparity of 0.89℃ compared to unfilled counterparts, indicating superior thermal insulation. 2) The internal temperature of phase change material-filled hollow bricks surpasses that of unfilled bricks by an average of 4.14℃, with fluctuations remaining below 1.5℃, affirming the effective heat storage capability of phase change materials with stable thermal performance. 3) The average heat flux on the inner surface of phase change material-filled hollow bricks stands at 7.37W/m2, 7.71W/m2 lower than unfilled bricks, signifying reduced energy dissipation and enhanced thermal insulation. These outcomes furnish a theoretical underpinning and experimental roadmap for the integration of phase change material-filled hollow bricks in building applications.

1 Introduction

With the escalating demand for building energy conservation, the exploration and application of novel wall materials have garnered intensified attention. The depletion of fossil fuels and the concomitant environmental degradation present profound challenges, with building energy consumption exceeding 40% of total energy consumption [1,2]. Urgent measures are thus imperative to augment energy utilization efficiency and optimize energy

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consumption patterns, thereby alleviating the prevailing energy and environmental crises [3,4]. Within the realm of building energy consumption, the lion's share of thermal losses emanates from building envelope structures, where subpar thermal performance substantially curtails energy utilization efficiency, underscoring the imperative of optimizing thermal performance in building envelopes for energy conservation [5]. Phase change material-filled hollow bricks, besides delivering commendable thermal storage and insulation attributes, offer ancillary benefits such as streamlined construction processes, resource conservation, reduced environmental footprint, and synchronous service life with buildings, thereby holding immense promise in the domain of construction [6].

Concurrently, scholars have endeavored to amalgamate phase change materials with hollow bricks to fashion models of phase change material-filled hollow bricks, aimed at enhancing thermal comfort and energy conservation efficacy in buildings. Researchers such as Bachir A [7] and Gao Y [8] have leveraged simulation software to optimize and analyze the thermal performance of phase change material-filled hollow brick models. Their findings underscore the commendable thermal attenuation performance and insulation effects exhibited by hollow bricks infused with phase change materials.

Jia C [9] and others have integrated thermal insulation materials (TIM) and phase change materials (PCM) into hollow sintered bricks, subsequently subjecting them to numerical simulations and validations predicated on experimental data. Their results underscore the differential operational mechanisms in augmenting the thermal performance of bricks, with TIM infusion primarily enhancing thermal resistance and PCM infusion significantly bolstering thermal inertia.

Scholars like Hejin Zhao [10] have proposed an innovative methodology entailing the integration of phase change energy storage materials into building components, aimed at augmenting energy efficiency in buildings and enhancing indoor environmental comfort. Their conceptual framework entails embedding phase change materials (PCMs) into building elements such as ceilings, glass windows, walls, and floors, thereby facilitating heat absorption and dissipation during phase transitions to regulate indoor temperatures. This paradigm enables buildings to effectuate energy storage and transfer between thermal loads, thereby curtailing reliance on external energy supply and fostering self-sustaining energy cycles. This strategy not only underpins reductions in building energy consumption but also amplifies occupant comfort, thus epitomizing the pursuit of authentic green building objectives.

Huang Kepeng [11] and his colleagues developed an innovative solution for efficient thermal energy storage in agricultural greenhouses by synthesizing a novel composite phase change material, Na2SO4·10H2O-Al2O3 (NAPCM), and incorporating it into paints and hollow bricks. The study revealed the homogeneous dispersion of porous Al2O3 particles in SSD, effectively preventing phase separation in NAPCM and ensuring its durable shape stability. Through optimization, phase change paint with uniform particle size distribution and exceptional resistance to various environmental factors was achieved. Thermal testing demonstrated the superior thermal insulation performance of phase change bricks compared to traditional bricks. While the phase change greenhouse showed improved insulation effects relative to the ordinary greenhouse, further optimization is needed to enhance the performance and stability of phase change materials.

In summation, the collective research endeavors of domestic and international scholars underscore the efficacy of infusing phase change materials into cavities to enhance the thermal attenuation performance and insulation effects of hollow bricks. However, in practical engineering applications, discernible disparities in thermal performance requirements exist vis-à-vis phase change material-filled hollow bricks across diverse climatic conditions and energy conservation imperatives. Hence, to reconcile these variances, this study undertakes a comparative analysis of hollow bricks with and without phase change materials under cold climate conditions, envisaging the derivation of a phase change hollow brick model tailored to cold climate exigencies, thereby furnishing technical insights and reference points for the design and fabrication of phase change material-filled hollow brick models.

2 Methodology

2.1 Experimental materials

Paraffin wax was selected as the phase change material (PCM) in this study to explore its efficacy in energy storage and temperature modulation. Its performance parameters are outlined in **Table 1**.

Table 1. Performance parameters of experimental materials.

Names of materials	**Densities（kg/m³）**	**specific heat capacity（KJ/(kg·K)）**	**Thermal conductivity(W/(m•K))**
Paraffin wax	760	2.14	0.21
Hollow brick	1654.00	0.75	0.970
Atmosphere	1.23	1.006	0.242

2.2 Experimental model

Hollow brick blocks, measuring 240mm×100mm×30mm and featuring eight holes, were chosen as the experimental materials. These blocks were filled with varying proportions of paraffin wax. The experimental design employed a comparative approach, with filling rates of 0% (control group) and 100% (experimental group).

Fig. 1. Schematic diagram of the hollow brick model.

2.3 Thermal performance analysis

Steady-state conditions indoors were simulated using a thermal chamber, with the chamber's air temperature set higher than the ambient air temperature. Heat transfer occurred through the wall thickness of the chamber towards the exterior, resulting in temperature gradients: air temperature of hot box (T_{in}) > inner surface temperature of the brick (T_{is}) > temperature of the phase change material within the brick (T_{PCM}) > outer surface temperature of the brick (T_{os}) > ambient air temperature (T_{out}). The heat transfer process across the wall was divided into three stages. In this experiment, the thermal performance of the hollow brick was assessed using temperature and heat flux measurements at the inner surface of the wall.

As the temperature inside the hot box exceeded the inner surface temperature of the brick ($T_{in} > T_{is}$), heat flowed from the chamber to the inner surface of the brick. This heat transfer process involved both convective heat transfer with the surrounding air and radiative heat transfer between the inner surface and the surfaces within the chamber. The heat flux at the inner surface of the hollow brick **Formula (1)** is represented as:

$$q_i = \alpha_i (T_{in} - T_{is}) \tag{1}$$

α_i- heat transfer coefficient of the inner surface of the wall, measured in W/(m^2·K).
T_{in}- temperature of the air inside the chamber, measured in °C.
T_{is} - inner surface temperature of the brick, measured in °C.

2.4 Experimental platform instrumentation arrangement

The experiment aimed to replicate the thermal environment of brick blocks in real-world applications, leveraging the cold outdoor climate to establish a testing system suitable for wall experiments. A temperature gradient was established between the thermal chamber and the cold outdoor air on either side of the wall, and heat flux temperatures were subsequently calculated. Conducted within a university laboratory setting, the experiment involved the setup depicted in **Figure 2**. Plastic film was applied to the holes of the hollow brick, with the phase change material positioned inside. Brick blocks filled with different proportions of phase change materials were then positioned centrally between the thermal chamber and the cold outdoor environment. Temperature probes were strategically placed at various locations, including within the thermal chamber, on the inner surface of the brick, within the brick, on the outer surface of the brick, and outside the chamber. Furthermore, **Table 2** provided an overview of the experimental instrument parameters. At the onset of the experiment, the thermal chamber was heated to approximately 26°C, after which the heating power was reduced to simulate temperature fluctuations within a room containing brick blocks filled with different phase change materials under energy-saving conditions.

Fig. 2. Layout of the experimental site.

Table 2. Parametric chart of the experimental apparatus.

Instrument Name	**model number**	**Precision**	**Measurement range**
Multi-Channel Temperature Tester	JK4000	±0.5%	-200~1800℃

3 Results and discussion

3.1 Indoor and outdoor temperature comparison and analysis

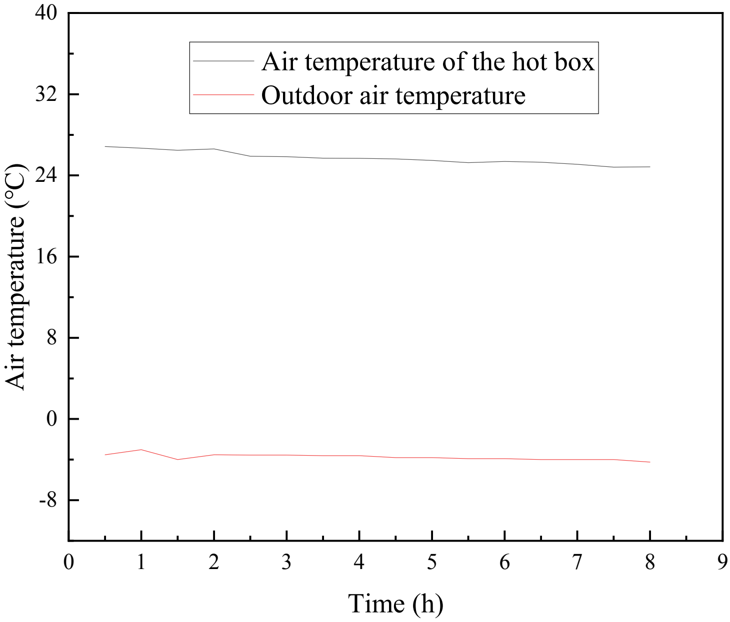

Fig. 3. Indoor and outdoor temperature curve.

The temperature curves for indoor and outdoor environments illustrate a stable trend observed throughout the observation period. Within the thermal chamber, the average temperature was 25.72°C, exhibiting minimal fluctuations. Conversely, the average outdoor temperature during the observation period was recorded at -3.76°C, resulting in an average temperature differential of 29.48°C between indoor and outdoor settings. This consistent temperature pattern indoors and outdoors indicates predictable fluctuations. By methodically regulating indoor and outdoor temperatures, a conducive experimental environment can be maintained.

3.2 Comparison and analysis of inner surface temperatures of hollow bricks

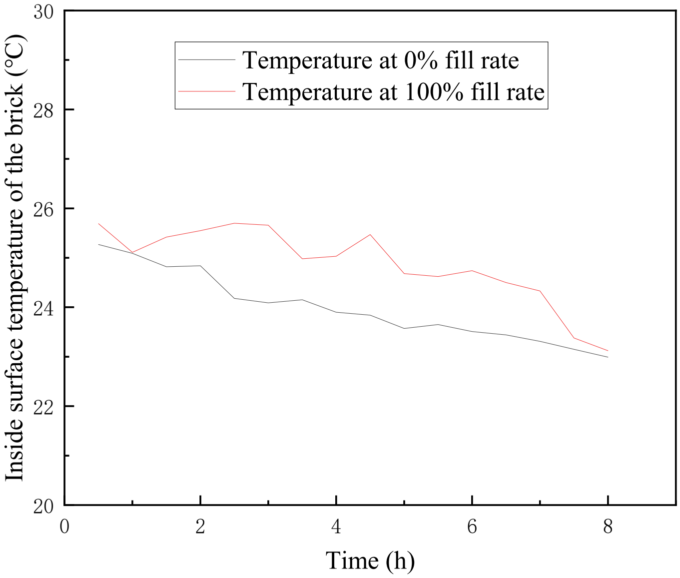

Fig. 4. Inner surface temperature comparison of hollow bricks.

Analysis of the inner surface temperatures of hollow bricks reveals a gradual decrease in temperature. For unfilled hollow bricks, temperatures ranged from a high of 25.27°C to a low of 22.99°C, with an average of 23.99°C. In contrast, hollow bricks filled with phase change material exhibited temperatures ranging from a high of 25.7°C to a low of 23.12°C, with an average of 24.87°C. The average temperature difference between the two groups was 0.89°C. These findings demonstrate that hollow bricks filled with 100% phase change material attain higher surface temperatures than unfilled bricks, showcasing the superior thermal insulation capabilities of phase change material-filled bricks, particularly in mitigating heat loss in cold climates.

3.3 Comparison and analysis of internal temperatures of hollow bricks

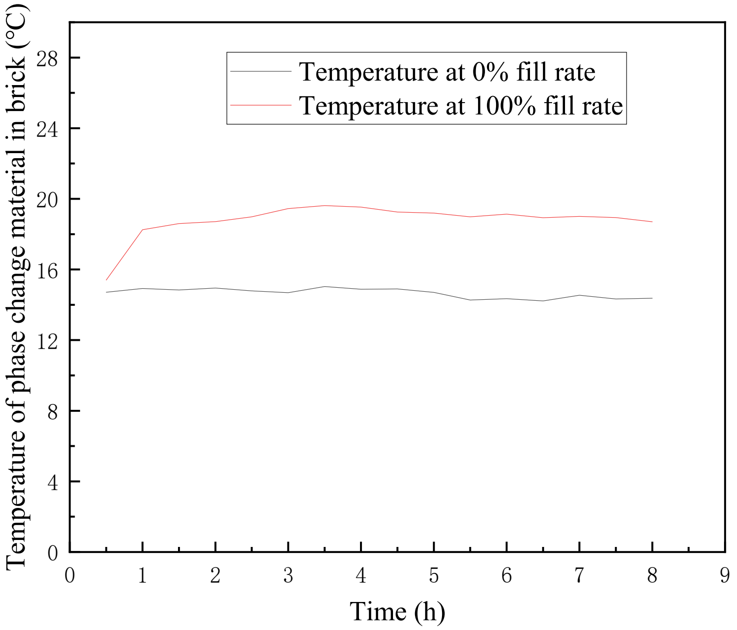

Fig. 5. Internal temperature comparison of hollow bricks.

Analysis of internal temperatures within hollow bricks reveals a relatively stable trend, with bricks filled with phase change material initially experiencing temperature increases followed by stabilization. Throughout the experiment, temperatures within bricks filled with phase change material consistently exceeded those of unfilled bricks. Temperatures within bricks filled with phase change material ranged from 15.4°C to 19.62°C, with an average of 18.79°C, while unfilled bricks ranged from 14.22°C to 15.03°C, with an average of 14.66°C. The average temperature difference between the two groups was 4.14°C. These observations underscore the effective heat storage capacity of phase change material, ensuring temperature stability during the experiment.

3.4 Comparison and analysis of inner surface heat flux of hollow bricks

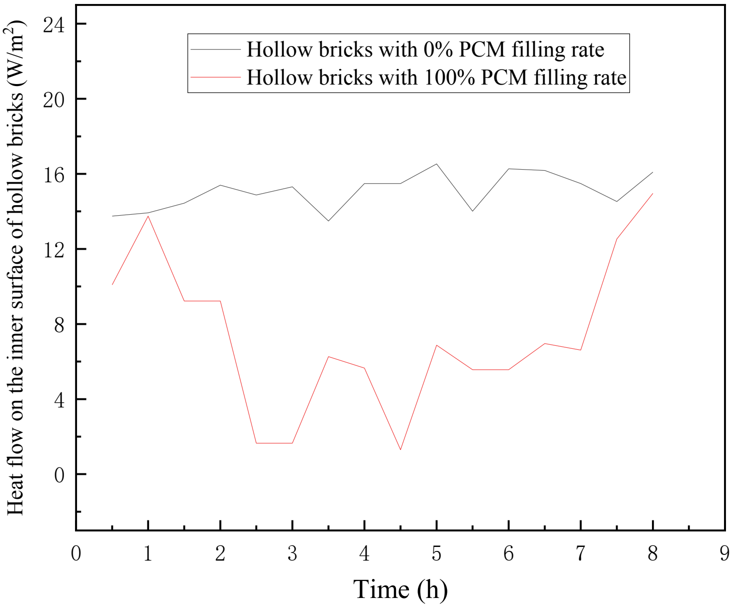

Fig. 6. Inner surface heat flux comparison of hollow bricks.

Utilizing **Formula 1**, the surface heat flux of bricks filled with varying proportions of phase change material was calculated, and a comparison of inner surface heat flux was plotted. As inner surface heat flux inversely correlates with thermal insulation performance, higher flux indicates poorer insulation and vice versa. Flux curves for bricks filled with phase change material ranged from 1.31W/m2 to 17.92W/m2, with an average of 7.37W/m2, while unfilled bricks ranged from 13.49W/m2 to 16.53W/m2, with an average of 15.08W/m2. The average difference between the two groups was 7.71W/m2. Higher flux observed in bricks filled with phase change material signifies superior thermal insulation compared to unfilled bricks.

4 Conclusion

This experiment involved the introduction of phase change material into hollow bricks, thereby creating phase change material-filled hollow bricks. A comparative analysis was conducted between hollow bricks filled with phase change material and those left unfilled. The key conclusions drawn from the study are outlined as follows:

1) Hollow bricks filled with phase change material exhibit higher inner surface temperatures compared to their unfilled counterparts, with an average temperature differential of 0.89°C. This observation underscores the superior insulation properties of hollow bricks filled with phase change material.

2) The internal temperatures of hollow bricks filled with phase change material surpass those of unfilled bricks, with an average temperature difference of 4.14°C and minimal

numerical fluctuations below 1.5°C. This indicates the effective heat storage capabilities of phase change material, ensuring temperature stability.

3) The average inner surface heat flux of hollow bricks filled with phase change material measures 7.37W/m2, representing a reduction of 7.71W/m2 compared to unfilled bricks. This signifies diminished energy dissipation and enhanced insulation performance.

These findings collectively emphasize the potential of incorporating phase change material into hollow bricks to optimize thermal performance and mitigate energy loss, thereby contributing to sustainable building practices.

References

1. W. Hu, A. V. Nickolaev, Y. Huang et al., Applied Energy **344**, 121268 (2023)
2. W. Hu, Y. Huang, M. Yuan et al., Case Studies in Thermal Engineering **35**, 102148 (2022)
3. S. Yang et al., Applied Energy **271**, 115147 (2020)
4. L. Zhu et al., Building and Environment **176**, 106841 (2020)
5. G. Ma, J. Lin, N. Li et al., Energy and Buildings **134**, 329-338 (2017)
6. W. Hu, Y. Xia, F. Li et al., Case Studies in Thermal Engineering **26**, 101023 (2021)
7. Allam Bachir, Nehari Taieb, Construction and Building Materials 367, 130336 (2023)
8. Y. Gao, F. He, X. Meng et al., Journal of Building Engineering **31**, 101447 (2020)
9. C. Jia, X. Geng, F. Liu, Y. Gao, Case Studies in Thermal Engineering **25**, 100938 (2021)
10. Hejin Zhao, Xian Wan, Jiahui Lu, Hongyu Zhang, Baohua Guo, China Plastics **37(11)**, 46 (2023)
11. Kepeng Huang et al., Journal of Energy Storage **89**, 111734 (2024)