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Experimental Evaluation of Phase Change Material Buffering in Radiant Floor Heating

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Abstract
This study investigated the thermal performance of a radiant floor heating system integrated with a phase change material (PCM) layer compared to a conventional system without PCM. The objective was to assess the PCM's ability to store and release thermal energy after the heat transfer fluid (HTF) flow is stopped. The slab temperature was selected as the primary performance indicator for evaluating both configurations. Results revealed that incorporating PCM significantly enhances the thermal storage capacity of the system, maintaining the slab temperature up to 15% higher than that of the conventional system after the HTF is turned off. These findings highlight the potential of PCM integration to improve energy efficiency and thermal comfort in radiant floor heating applications.

Introduction
Radiant floor heating has been widely studied for its potential to provide comfortable, low-temperature heating with improved energy efficiency compared with convective systems. Zhang et al.[1] combined experiments and numerical modelling to characterize heat-up dynamics and control sensitivity of a lightweight radiant floor, showing that floor structure and material layers strongly affect transient performance and required supply temperatures. Wang et al.[2] experimentally evaluated an enhanced-convection, overhead variant of radiant floor systems and reported improved heat transfer rates and faster response compared with conventional embedded-tube designs, suggesting design options to reduce lag time while keeping low supply temperatures. Pantelic et al.[3] performed full-scale laboratory tests focused on the heating capacity of radiant floor panels; their results highlight the achievable sensible exchange and the operational constraints (e.g., condensation risk, supply temperature windows), which are useful when considering dual heating/cooling functionality of floor systems. On the control side, Shin & Rhe [4]e developed occupancy-inference based start/stop control strategies showing that predictive schedules can significantly reduce energy use of radiant floor systems without compromising comfort — an important point given the high thermal inertia of floors. Finally, several foundational modelling and calculation methods remain important for design and control: Jin et al. [5] proposed a practical calculation method for estimating floor surface temperature and heat transfer behaviour under varying operating conditions, which is often used in design checks and control logic development. The experiment conducted in this study is to compare thermal response of a radiant floor heating with and without PCM layer. In this regard, heat transfer fluid, water, is supplied to radiant floor system for an hour. Then, the flow is shut off, and the thermal response of the floor slab for three hours is recorded for both cases.

Proposed system
The experimental setup for this study is presented in Figure 1. It consists of 260 cm copper pipe in 8 passes embedded inside a layer of paraffin PCM (n-Tetradecane).

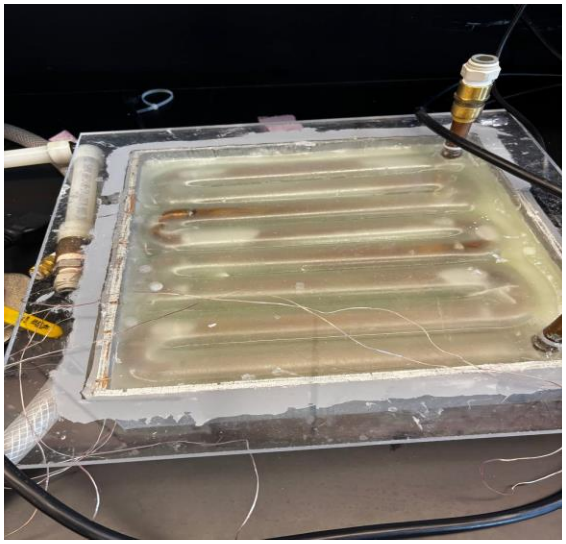

Figure 1. Experimental setup.

Thermal properties of this PCM is presented in Table 1.

Table 1. Thermal properties of the paraffin PCM [6,7] .

Parameter	**Value**
Melting temperature	45 ℃
Solid density	776 kg.m^{-3}
Liquid density	760 kg.m^{-3}
Solid specific heat	1.9 kJ.kg^{-1}.K^{-1}
Liquid specific heat	2.2 kJ.kg^{-1}.K^{-1}
Solid Thermal conductivity	0.33 W.m^{-1}.K^{-1}
Liquid Thermal conductivity	0.15 W.m^{-1}.K^{-1}
Enthalpy of fusion	236 kJ.kg^{-1}

Results

Figure 2 illustrates the transient temperature profiles of the HTF, PCM layer, and floor surface during a complete heating and cooling cycle. The HTF was supplied at approximately 50 °C, initiating heat transfer to the PCM and floor surface. At the start, both PCM and surface temperatures increased rapidly as sensible heating dominated. Around 40–46 °C, the temperature rise of the PCM slowed, forming a distinct plateau region — a clear indication of phase change (melting), during which the PCM absorbed latent heat while maintaining an almost constant temperature. This buffering effect resulted in a delayed and moderated surface temperature rise, demonstrating the thermal storage capability of the PCM. During the cooling phase (after the HTF was switched back to 20 °C), the PCM released stored heat gradually, maintaining the surface temperature significantly higher for a longer period compared to the initial heating. This thermal lag indicates the PCM’s energy retention and heat release capacity, confirming its potential to stabilize floor surface temperatures and enhance thermal comfort in radiant floor heating applications.

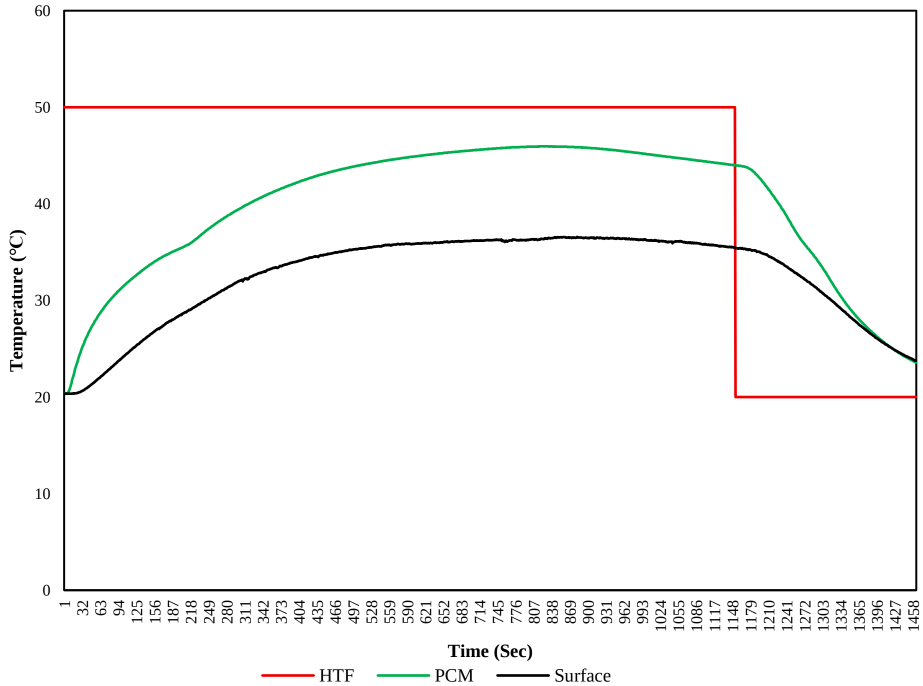

Figure 2. Thermal response of the system with PCM.

Figure 3 presents the temperature evolution of the system without PCM under identical boundary conditions. When the HTF temperature increased to 50 °C, the floor surface temperature rose quickly and reached a steady state without any phase change buffering. Once the HTF temperature dropped back to 20 °C, the surface temperature decreased sharply, with no extended heat release period observed. This response highlights the lack of latent heat storage and the direct thermal coupling between the HTF and the floor surface. Compared to Figure 2, the absence of PCM led to larger temperature fluctuations, demonstrating that the PCM layer effectively dampens thermal oscillations and improves the dynamic thermal stability of the floor system.

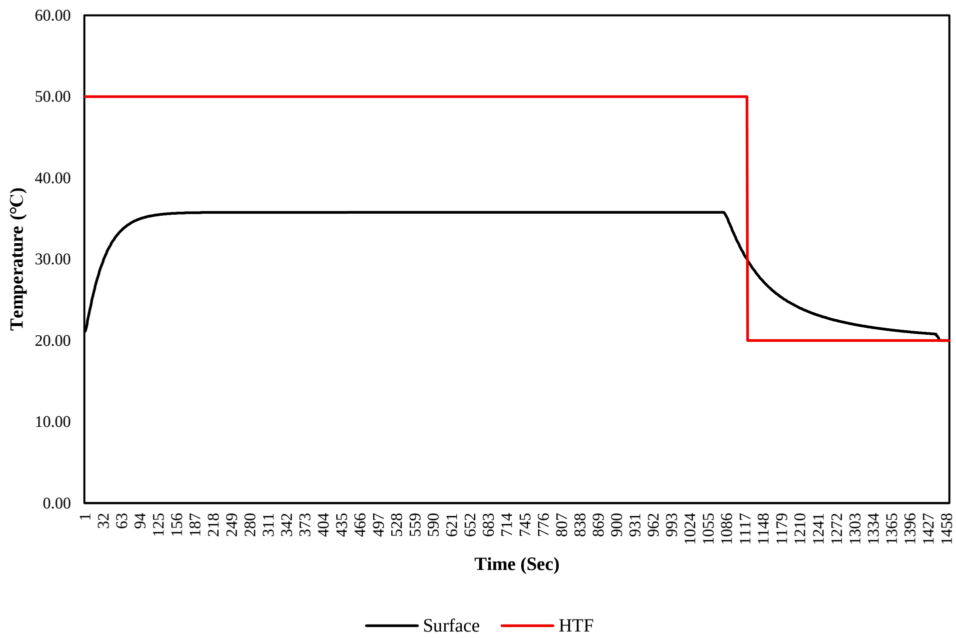

Figure 3. Thermal response of the system without PCM.

Conclusion

The comparative analysis of the radiant floor system with and without PCM demonstrated the significant influence of phase change materials on thermal performance. The integration of PCM effectively moderated surface temperature fluctuations by absorbing excess heat during the charging phase and releasing it gradually during cooling. This behavior resulted in a noticeable delay in both heating and cooling responses, indicating enhanced energy storage capacity and thermal inertia which was equivalent to 15% higher temperature after shut off. In contrast, the system without PCM exhibited rapid temperature changes and lacked thermal buffering. Overall, incorporating PCM into radiant floor heating systems improves thermal comfort, energy efficiency, and stability under dynamic operating conditions.

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