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Experimental investigation of latent heat thermal energy storage for highly glazed apartments in a continental climate.

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ABSTRACT

The high solar heat gains in highly glazed buildings are a major thermal discomfort factor leading to higher energy consumption for space cooling. Higher window to wall ratios (WWR) also entail large temperature fluctuations due to heat loss and temperature extremes in buildings. Passive latent heat thermal energy storage (LHTES) is a potential solution to regulate the indoor thermal environment in buildings through mitigating the indoor surface temperatures. In this study, the effectiveness of phase change materials (PCMs) in the context of a highly glazed apartment unit with 80% WWR is investigated for internal wall and ceiling applications. To provide thermal energy storage across the year, a composite PCM system with two melting temperatures is proposed, comprised of two PCM products, one with a melting temperature of 21.7 °C and the other with a melting temperature of 25 °C. To test the performance of this PCM, experimental tests were performed using test cells placed under climate conditions of Toronto to monitor changes in the phase change cycles of the PCMs and their impact on indoor air and surface temperatures. The results indicate improved thermal performance of the test cell containing the PCM system compared to a baseline cell in lowering peak indoor air and surface temperatures up to 6 °C. A relation was observed between the peak solar gain periods and the PCM behavior during the melting and solidification processes. This paper shows the potential of using PCMs as retrofit applications in highly glazed buildings by targeting specifically annual LHTES with two melting temperatures in one zone in a continental climate.

KEYWORDS

Thermal energy storage, phase change materials, thermal comfort, test cell, building retrofit.

INTRODUCTION

The thermal discomfort in buildings implies higher reliance on mechanical systems to provide a comfortable thermal environment. This is a critical issue considering the highest share of energy use in buildings is for space conditioning (Berardi, 2017). This effect is specifically important in buildings with high window to wall ratios (WWR) as they experience overheating in the cooling season and extreme heat loss in the heating one. Meanwhile, newer high-rise apartments in Canada often adopt transparent facades that are faced with high energy consumption and thermal discomfort levels (Touchie et al., 2014; Bennet and O'Brien, 2017).

To improve the thermal environment of highly glazed apartments, passive latent heat thermal energy storage (LHTES) has been considered through the incorporation of phase change materials (PCMs) as a retrofit measure for interior surfaces of apartment units. PCMs stabilize surface and indoor temperatures by undergoing a phase change at specific melting temperatures. It is argued by Heim (2010) and Navarro et al. (2016) that the isothermal behavior of PCMs allows for better surface temperature stabilization compared to traditionally high mass building structures with sensible storage. The high thermal storage capacity of PCMs in small volumes represents a main advantage of LHTES systems (Saffari et al., 2017).

Thermophysical properties of PCMs such as melting temperature, latent heat, and specific heat direct how PCMs affect the surface and indoor air temperatures. In particular, the melting temperature of PCMs is the most influential parameter of a PCM, and must be compatible with the environment and the climatic conditions the PCM is applied to (Cabeza et al., 2011, Kosny et al., 2012). The integration of PCMs in the Canadian climate has been investigated by Chen et al. (2014), Delcroix et al. (2017), Guarino et al. (2017) and Berardi and Soudian (2018) showing good potential in both heating and cooling seasons. Nevertheless, optimizing PCMs to operate for an entire year is difficult as PCMs with a melting point close to summer boundary conditions do not operate in other seasons. Consequently, recent studies have suggested optimizing PCMs for annual performance by using two or more melting temperatures in a hybrid PCM system (Hoes and Hensen, 2015, Kheradmand et al., 2016).

The aim of this paper is to evaluate the benefits of integrating thin layers of PCMs as unobtrusive retrofit measures to regulate indoor temperature swings. Considering the case specific design and performance of PCMs in relation to climate, this research focuses on the Canadian climate and looks at the annual thermal energy storage using a PCM system with two melting points to address both heating and cooling seasons with different boundary conditions.

METHODS

The composite PCM system investigated in this study is comprised of two commercially available PCM products with different melting temperatures as shown in Figure 1. The first layer in the composite PCM system has a melting temperature of 25 °C and the second layer in the system has a melting temperature of 21.7 °C, closer to winter boundary conditions. As shown in Fig. 1, the high latent heat storage capacity of this composite PCM system in a small thickness suggests a good potential for temperature stabilization in buildings. Both PCM products used in the composite PCM system are individual boards attached to each other.

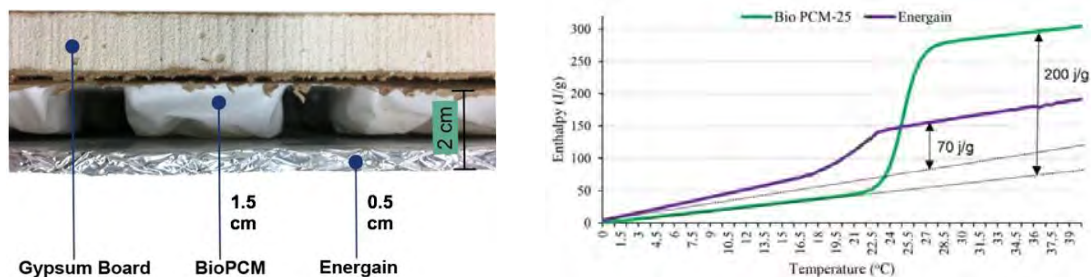


Figure 1. The composite PCM system (left) and temperature-enthalpy curves for the PCM boards (right).

Quantifying the performance of PCMs is more accurate using experimental test methods considering the simplifications of simulation modeling in calculating PCM behavior on a material scale (Cabeza et al., 2015). Therefore, in this study, two small scale test cells were constructed, one reference cell as a baseline and one cell with PCM-enhanced walls and ceiling. Test cells were constructed to represent typical highly glazed apartment units on a scale of 1:10 with one glazed wall covering 80% of one wall with an overhang shading (Fig. 2). The construction characteristics of the test cells are shown in Fig. 3.

The performance of the composite PCM system was assessed on a surface and room level through a comparative analysis between the reference test cell and the PCM integrated test cell. The main parameters of analysis were the rate of change in surfaces and room temperatures of

the composite PCM test cell compared to the reference cell in relation to ambient weather and solar gain variations. The experimental tests were conducted in Toronto under free floating conditions from July to October (2016) to assess the effects of different weather variations on the composite PCM's performance.



Figure 2. Experimental test cells: the test cell on the right contains the investigated PCM system.

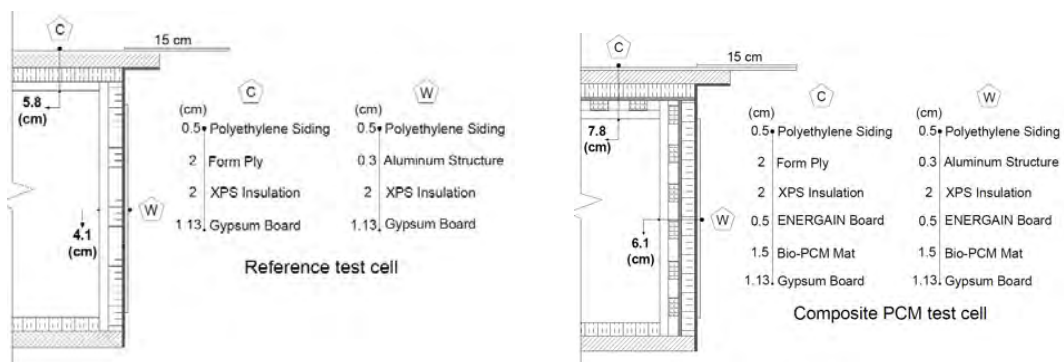


Figure 3. Construction characteristics of the experimental test cells.

RESULTS

Influence of solar gain on PCM performance

Figure 4a shows the indoor cell temperature variations in three days in July when the cells were facing south. The temperature changes are attenuated in the composite PCM test cell and overall, the air temperature swings are reduced by 6.8 °C. In particular, the effectiveness of the composite system at night is significant in maintaining indoor temperatures. An apparent peak temperature shifting of one hour happens in the composite PCM test cell. The maximum air temperature is shifted to later afternoon due to thermal lag in the composite PCM test cell. By rotating the test cells towards west, significant changes are observed as demonstrated in Fig. 4b. Unlike the south facing orientation, the highest temperatures in the test cells occur close to the sunset period from 5 to 7 pm when the benefits of PCM system also become more evident.

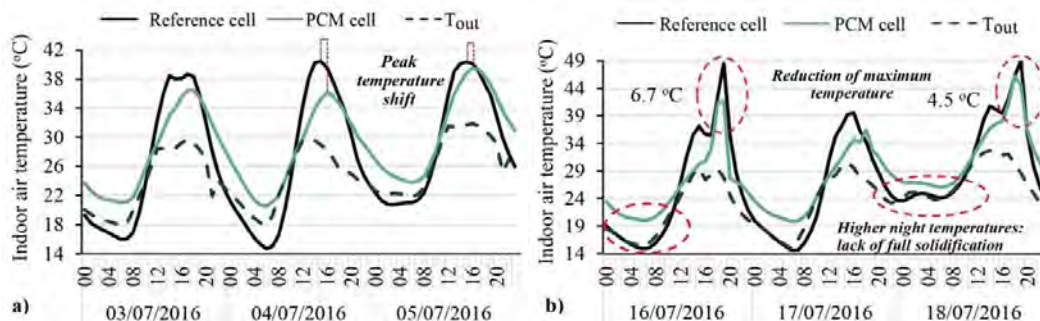


Figure 4. Hourly indoor room temperatures; a) South orientation – b) West orientation.

To further assess the influence of solar gain on the PCM performance, the shading part of the cells were removed to allow more solar radiation to get into the cells for one week in October. The reference test cell showed high dependence on outdoor weather conditions ultimately leading to average colder indoor air temperatures. Whereas, in the composite PCM test cell, indoor air temperatures were constantly above the outdoor temperatures. Removing the shading negatively affected PCMs performance in reducing excessive heat gain in the spaces. Figure 5 shows that by removing the shading, indoor air temperatures in the composite PCM test cell increased by 11 °C in the peak solar period in the south facing orientation. This sharp increase in the indoor air of the test cell is due to the sensible heat gain after the PCMs are melted.

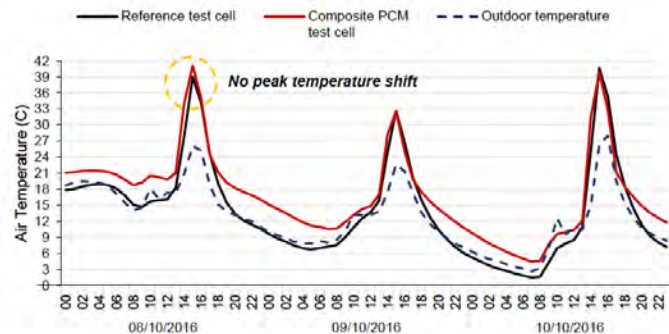


Figure 5. Hourly indoor room temperature variations from October 8th -10th.

Performance of PCM integrated surfaces

One side wall and the ceiling in the two test cells were simultaneously monitored. The primary parameter of analysis was the difference between the wall and ceiling surface temperature changes in relation to the room temperature. The hourly surface temperatures in the composite PCM wall show a faster response to ambient and indoor room temperature variations compared to the ceiling surface temperature changes. During the day, the wall heats up more rapidly, and at night, it loses heat faster as temperatures decrease compared to the composite PCM ceiling.

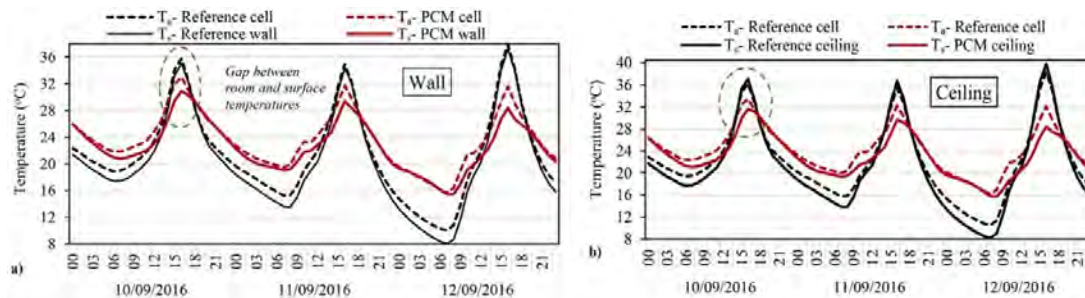


Figure 6. Hourly indoor air and surface temperature variations on wall (a) and ceiling (b)

Figure 6 shows hourly room (T_a) and surface temperature (T_s) variations in three consecutive days in September. Without PCMs, the indoor room temperatures of the reference cell show a close proximity to the reference wall and the ceiling's surface temperatures particularly in maximum peak periods in the day. Conversely, a gap is observed between the indoor air in the composite PCM cell and the composite PCM surface temperatures.

DISCUSSION

The focus in this study was to assess the impact of solar gain and ambient weather variations on PCM performance. The experimental results demonstrated that the impact of ambient weather is more significant as temperature variations control the entire transition of the composite PCM system during the day. Nevertheless, the exposure to solar radiation enhance the melting process periodically, specifically at times of highest solar intensity.

To better explain the impact of ambient weather on PCM performance, average data in the testing period are compared in Table 4. The trend of outdoor temperature variations and PCM activation points to the highest percentage of PCM being activated in July. Correspondingly in July, the composite PCM system reduced the indoor temperature swings and high peak temperatures significantly compared to other months. The benefit of a hybrid PCM system is evident as during the summer the Energain PCM is mostly in liquid form where in contrast, the BioPCM is often in the solid state during the fall.

Table 1. Summary of the impact of the composite PCM on indoor air temperatures.

	Average ambient conditions (°C)	Decrease of T _{max} (%)	Increase of T _{min} (%)	Decrease in temperature swings (%)	Frequency of PCM activation			
					PCM Layer	Solid	Phase change	Liquid
July	19.2 - 31.1	6%	18%	46%	BioPCM	29%	28%	43%
					Energain	6%	30%	64%
August	19.9 - 35.7	4%	16%	37%	BioPCM	7%	18%	74%
					Energain	0%	9%	91%
September	15.2 - 31.1	6%	19%	35%	BioPCM	57%	18%	25%
					Energain	41%	21%	38%
October	11.2 - 25.6	1%	24%	18%	BioPCM	86%	7%	6%

The relation of solar gain to PCM performance on surfaces and their influence on indoor air temperatures showed that in addition to peak temperature reductions, peak temperature shifting is another benefit of applying PCMs to highly glazed rooms. Similar observations were made by Kosny et al. (2012), showing that low peak temperatures were shifted to early morning and high peak temperatures in some instances were shifted to later evenings. However, in this study, it was discussed that the latter observations are relative to the orientation. Further testing on the factor of shading showed that due to lower temperatures, the availability of solar radiation was more important in the fall to ensure the activation of the PCMs, whereas in summer, the shading would be beneficial.

CONCLUSIONS

The performance of a composite PCM system proposed for annual thermal energy storage for retrofit applications in high-rise residential buildings in the climate of Toronto was investigated using experimental test cells for four months. The capability of the composite PCM system was clearly displayed as each PCM targeted the fall and summer months as expected. In conclusion, PCM systems constituted by two or more PCM products with different melting points offered potential in becoming a more prominent approach for PCM application in buildings, particularly in continental climates such as Toronto which undergo different weather patterns during the year. This research has shown that with an addition of layer only 2 cm thick of PCMs to interior surfaces, the temperature extremes could be significantly reduced.

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REFERENCES

- Bennet, I. E., O'Brien, W. (2017). Field study of thermal comfort and occupant satisfaction in Canadian condominiums. *Architectural Science Review*, 60(1), 27–39.
- Berardi, U. (2017). A cross-country comparison of the building energy consumptions and their trends. *Resources, Conservation and Recycling*, 123, 230–241.
- Berardi, U., Soudian, S. (2018). Benefits of latent thermal energy storage in the retrofit of Canadian high-rise residential buildings, *Building Simulation*, 11, 709–723.
- Cabeza, L. F., Castell, A., Barreneche, C., De Gracia, A., Fernández, A. I. (2011). Materials used as PCM in thermal energy storage in buildings: A review. *Renewable and Sustainable Energy Reviews*, 15(3), 1675–1695.
- Chen, Y., Athienitis, A., Galal, K. (2014). A charging control strategy for active building-integrated thermal energy storage systems using frequency domain modeling, *Energy and Buildings*, 84, 651–661
- Delcroix, B., Kummert, M., Daoud, A. (2017). Building-scale experimental validation of a new model for walls with phase change materials. *Science and Technology for the Built Environment*, 23(6), 1049–1062.
- Guarino, F., Athienitis, A., Cellura, M., Bastien, D. (2017). PCM thermal storage design in buildings: Experimental studies and applications to solarium in cold climates. *Applied Energy*, 185, 95–106.
- Heim, D. (2010). Isothermal storage of solar energy in building construction. *Renewable Energy*, 35(4), 788–796.
- Hoes, P., Hensen, J. L. M. (2016). The potential of lightweight low-energy houses with hybrid adaptable thermal storage: Comparing the performance of promising concepts. *Energy and Buildings*, 110, 79–93.
- Kheradmand, M., Azenha, M., de Aguiar, J. L. B., Castro-Gomes, J. (2016). Experimental and numerical studies of hybrid PCM embedded in plastering mortar for enhanced thermal behavior of buildings. *Energy*, 94, 250–261.
- Kosny, J., Kossecka, E., Brzezinski, A., Tleoubaev, A., Yarbrough, D. (2012). Dynamic thermal performance analysis of fiber insulations containing bio-based phase change materials (PCMs). *Energy and Buildings*, 52, 122–131.
- Navarro, L., de Gracia, A., Niall, D., Castell, A., Browne, M., McCormack, S.J., Cabeza, L.F. (2016). Thermal energy storage in building integrated thermal systems: A review. Part 2. Integration as passive system. *Renewable Energy*, 85, 1334–1356.
- Saffari, M., de Gracia, A., Ushak, S., Cabeza, L.F. (2017). Passive cooling of buildings with phase change materials using whole-building energy simulation tools: A review. *Renewable and Sustainable Energy Reviews*, 80, 1239–1255.
- Touchie, M. F., Pressnail, K. D., Tzekova, E. S. (2014). Energy Savings by Retrofitting Multi-Unit Residential Buildings: Case Studies. Proceedings of the 3rd Building Enclosure Science and Technology (BEST3) Conference. Atlanta, Georgia, USA.