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A novel hygrothermal control material and its buffering behaviour in buildings

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SUMMARY

High thermal and hygric mass material can suppress temperature and relative humidity variation, which have been widely used for indoor hygrothermal control. Here, A novel of hygrothermal control materials were prepared by simple grinding microencapsulated phase change material (MicroPCM) and metal-organic framework (MOF). Hygrothermal properties of the MOF/MicroPCM composites were measured by differential scanning calorimetry (DSC) and dynamic vapor sorption (DVS) methods. A building model in which the envelope contains MOF/MicroPCM composites was established using WUFI Plus V.3.2. The influence of the MOF/MicroPCM composites on indoor air was studied in a typical summer. Numerical results demonstrate that MOF/MicroPCM composites used as an innovative passive material show great potential for indoor hygrothermal control.

KEYWORDS

Indoor hygrothermal control; Hygrothermal buffering; Building simulation; Energy saving

1 INTRODUCTION

Building energy saving plays an important role in improving indoor comfort and achieving green sustainable development. (Waqas and UD, 2013; Yao et al. 2018). Attempting to regulate indoor environment through passive energy-saving technologies to achieve the purpose of energy conservation has attracted increasing attention.

MicroPCMs and conventional porous materials (diatomite, etc.) has been combined to simultaneously regulate temperature and humidity for energy saving (Chen et al. 2015, 2016). Building energy efficiency using hygrothermal materials in Paris can reach 19.57% (Wu et al. 2018). However, conventional hygroscopic materials are suffering from low moisture absorption capacity and shortcoming that most of the moisture absorption takes place beyond desired comfort level (Feng et al. 2018).

Metal-organic framework (MOF) is a new kind of porous crystalline material with periodic network structure formed by self-assembly of inorganic metal nodes and organic linkers (Férey et al. 2005; Yaghi et al. 2003). MOF is becoming a promising alternative for moisture adsorption due to its high specific surface area, permanent porosity, tunable crystalline structure, and organic functionality (Cohen, 2010; Furukawa et al. 2014). MIL-100(Fe) as one of the major crucial MOF that possesses high water up take capacity, hydrothermal and cycle stability. In addition, the main constituent element iron atom is non-toxic, widely sourced, inexpensive, and environmentally friendly (Horcajada et al. 2007), making MIL-100(Fe) a priority for this work.

In this paper, a novel MOF/MicroPCM composites were prepared and studied for temperature and humidity control. Hygrothermal buffering behaviour of the MOF/MicroPCM composites has been analysed.

2 MATERIALS/METHODS

Preparation of MIL-100(Fe)/MicroPCM composites

MicroPCMs were prepared by encapsulating the core material n-octadecane with polymethyl methacrylate using interfacial polymerization (Shi et al. 2015). MIL-100(Fe) was prepared by hydrothermal reaction method (Seo et al. 2012). MIL-100(Fe)/MicroPCM composites were obtained by hand gridding two ingredients. MicroPCM and MIL-100(Fe) were dried in a vacuum oven at 50 and 70 °C for 24 h, respectively. Then MIL-100 (Fe) and MicroPCM were mixed with a proportion of 1 to 1 and ground in ambient atmosphere at least 5 min until homogeneous.

Characterization of MIL-100(Fe)/MicroPCM composites

Water sorption isotherms of the materials were measured by a dynamic vapor sorption (DVS intrinsic; SMS) instrument from RH=0% to 95% at 25 °C. The relative humidity gradient was set as10% and the last step was 5%. Mass balance criteria was set as $0.001\%\cdot\text{min}^{-1}$. Differential scanning calorimeter (DSC) curves were obtained by TA Q200 from -10 °C to 50 °C with the heating rate of 10 °C/min under N_2 atmosphere.

3 RESULTS

Hygroscopic properties

Water sorption isotherms of MIL-100(Fe), MicroPCM and MIL-100(Fe)/MicroPCM composites were shown in Figure 1. As presented in Figure 1, the water adsorption isotherm of MIL-100(Fe) has a steep rise between 20% to 50% with the characteristic of "S" type. While the MicroPCM shows linear shape. The water uptake of MIL-100(Fe) at RH=95% is 0.58 g/g, which indicates that MIL-100 (Fe) as a moisture buffer material shows great potential in building energy-saving applications over traditional materials. The water uptake of MicroPCM is 0.009 g/g, indicating that MicroPCM is hydrophobic. The adsorption curve changed dramatically by adding MicroPCM to MIL-100(Fe) and the maximum water uptake of the composites is 0.24 g/g. Trigger point of steep adsorption and desorption of MIL-100(Fe) moved from 20% and 40% RH to 70% RH, respectively, which means the composites is easier to desorb than the pure MIL-100(Fe).

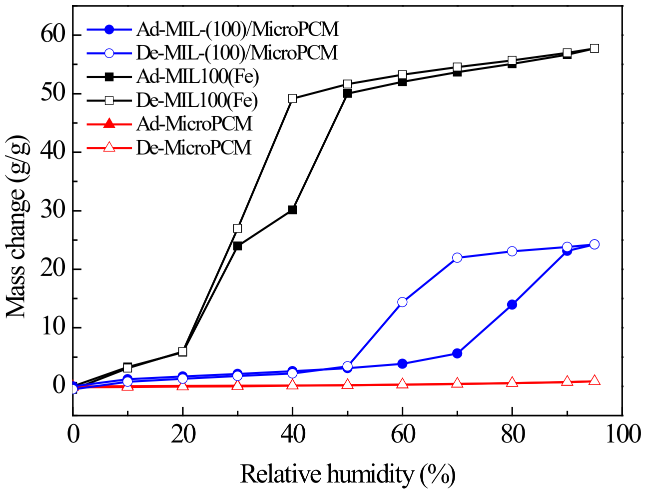


Figure 1. Water adsorption isotherms MIL-100(Fe), MicroPCM and MIL-100(Fe)/MicroPCM composites.

Thermal properties

DSC curves of MIL-100(Fe), MicroPCM and MIL-100(Fe)/MicroPCM composites are presented in Figure 2. MicroPCM and MIL-100(Fe)/MicroPCM showed a single endothermic peak except for pure MIL-100(Fe), indicating that MIL-100 (Fe) has no phase transition during the test temperature range and the addition of MIL-100(Fe) does not change the crystallization form of MicroPCM. Compared with pure MicroPCM, melting temperature (onset temperature) and peak temperature of MIL-100(Fe)/MicroPCM composites were reduced from 24.05 and 28.16 °C to 22.67 and 25.66 °C, respectively. This may be caused by the surface tension, capillary action and intermolecular force between the nanoparticles. Compared with pure MicroPCM, the enthalpy value of composites reduced from 144.2 to 44.8 kJ/kg. This is because that both of MicroPCM and MIL-100(Fe) were dried sufficiently before grinding. MIL-100(Fe)/MicroPCM composites might adsorb moisture during grinding and the period before the DSC testing, which directly increased the weight of MIL-100(Fe) and decreased the relative proportion of MicroPCM.

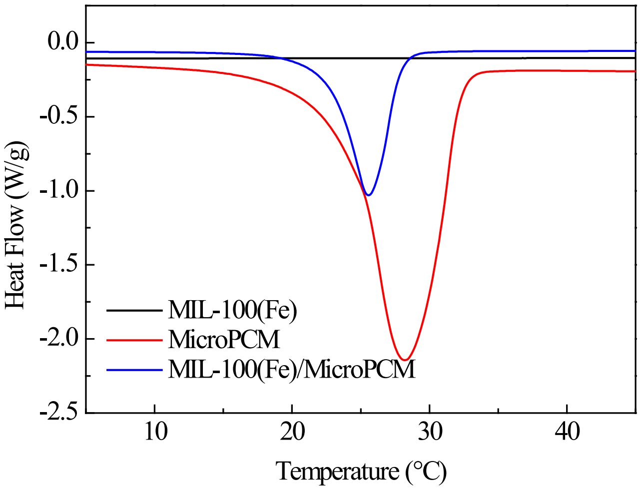


Figure 2. DSC curves of MIL-100(Fe), MicroPCM and MIL-100(Fe)/MicroPCM composites.

Hygrothermal buffering behaviour

MIL-100(Fe)/MicroPCM composites can be used as interior wall coating material for indoor hygrothermal control. In order to evaluate the effect of MIL-100(Fe)/MicroPCM composites on the indoor air. A single-room model was built based on the case 600 from International Energy Agency (IEA) ECBCS Annex 21 (Judkoff and Neymark, 1995). Except the internal wall was coated by hygrothermal control material or plasterboard, the materials of the building component are same to lightweight case 600. Detail dimensions of the building are shown in Figure 3. The light weight building was assumed in Shanghai with a subtropical monsoon climate. The mechanical ventilation rate is 0.5 ACH for the whole day.

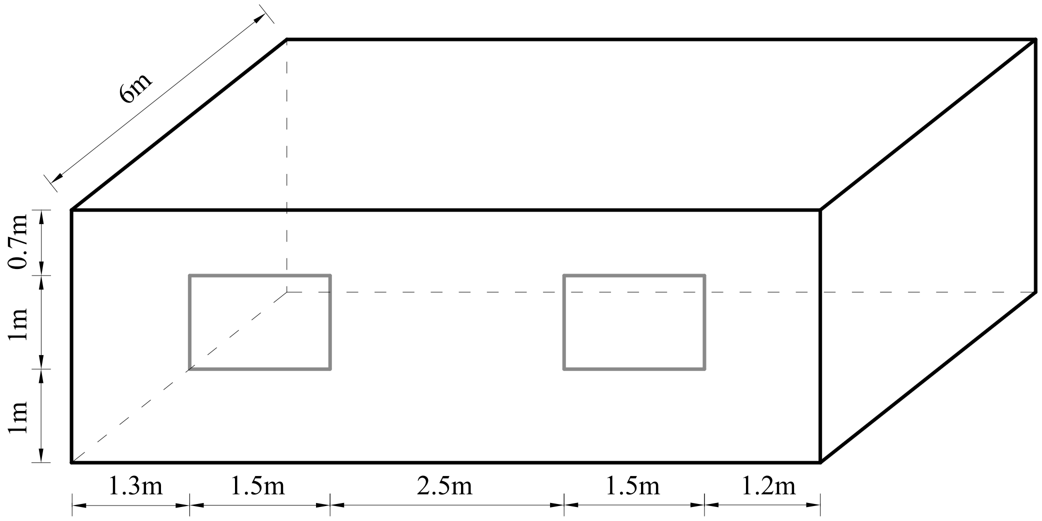
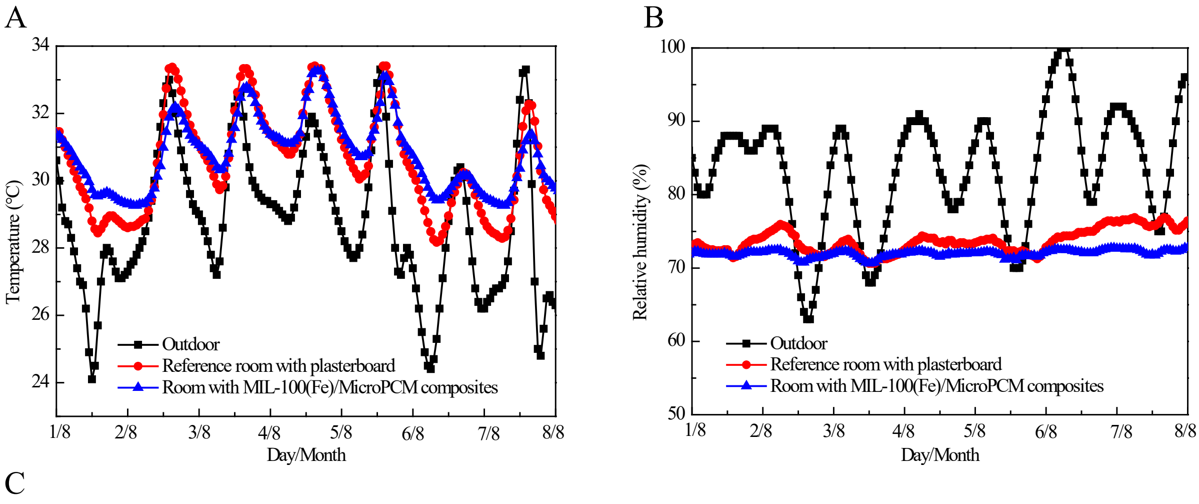


Figure 3. The BESTEST lightweight case building

Figure 4 shows the fluctuation in temperature and humidity of the indoor air for a typical summer week in August of Shanghai in China. Compared with reference room, the room with MIL-100(Fe)/MicroPCM composites has a significant reduction of periodic fluctuations in temperature. This phenomenon is more obvious particularly for the case with large temperature difference between day and night (such as August 1 to August 3). This is because that PCM can make full use of the temperature difference for thermal storage and release to play the role of peak cutting and valley filling, thereby reducing the peak electrical load of the building.



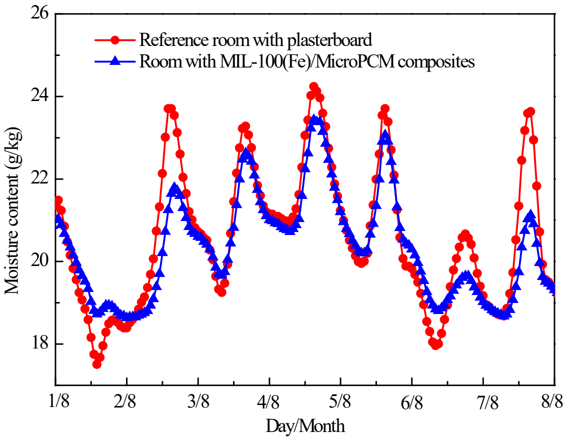


Figure 4. Impact of hygrothermal material on indoor climate. a) Temperature, b) Relative humidity, c) Absolute humidity.

Figure 4 b) shows the relative humidity change of the indoor air. Although both groups are humid, the relative humidity of hygrothermal control group is more stable and lower than the reference group. Relative humidity is affected by both of temperature and moisture content. For a clearer comparison of the humidity differences in the two groups, the changes in the moisture content of the indoor air are also shown in Figure 4 c). The fluctuation of the moisture content in the room with hygrothermal material is lower than reference room. Further analysis found that the temperature and moisture content of hygrothermal control group is lower than reference room by 2.2 °C and 1.9 g/kg at the best of times. The time corresponding to the peak value is delayed by one hour.

Figure 5 shows the heat and moisture flux between internal wall surface and indoor air. It can be found that when the external environment changes, the fluctuation of heat and moisture flux for hygrothermal control group is more drastic. This indicates that hygrothermal control material has faster response speed and stronger heat and humidity control ability than ordinary plasterboard.

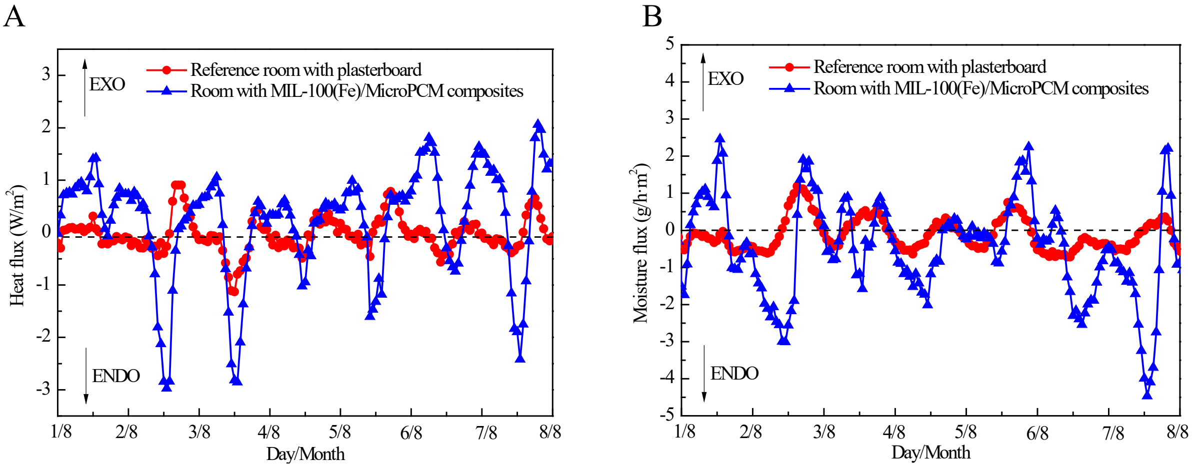


Figure 5. Heat and moisture flux between internal wall surface and indoor air. a) Heat flux, b) Moisture flux

4 DISCUSSION

For passive building, properties of the hygrothermal control materials have an important influence on thermal and humidity environment. Such as the thermal and humidity storage capacity, melting temperature range and the relative humidity range for moisture sorption and desorption. Improvements can be achieved by employing materials with greater thermal and moisture storage capacity. Besides, it is more comfortable for indoor climate if the water step uptake isotherms of the materials have a steep rise around 65% RH and have a steep decrease around 40% RH. The application of hygrothermal control materials should also be based on local climate characteristics. The proportion of desiccant material and PCM should be adjusted according to local environmental hygrothermal loads. To achieve the coordinated adjustment of hygrothermal environment and the maximum utilization of the material.

5 CONCLUSIONS

In this paper, a novel of hygrothermal control materials were prepared and its thermal and humidity buffering behaviour in buildings was analysed by simulation method. Numerical results show that the composites show excellent thermal and moisture buffering performance. Compared with same thickness of the plasterboard, the MIL-100(Fe)/MicroPCM composites can significantly moderate the temperature and humidity fluctuations and reduce peak values. This means that the application of MIL-100(Fe)/MicroPCM as hygrothermal materials has great potential to save energy and improve thermal comfort.

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7 REFERENCES

Chen Z, Qin M, Yang J. 2015. Synthesis and characteristics of hygroscopic phase change material: Composite microencapsulated phase change material (MPCM) and diatomite. *Energy and Buildings*, 106: 175-182.

Chen Z, Qin M. 2016. Preparation and hygrothermal properties of composite phase change humidity control materials. *Applied Thermal Engineering*, 98: 1150-1157.

Cohen S M. 2010. Modifying MOFs: new chemistry, new materials. *Chemical Science*, 1(1): 32-36.

Feng X, Qin M, Cui S, et al. 2018. Metal-organic framework MIL-100 (Fe) as a novel moisture buffer material for energy-efficient indoor humidity control. *Building and Environment*, 145: 234-242.

Férey G, Mellot-Draznieks C, Serre C, et al. 2005. A chromium terephthalate-based solid with unusually large pore volumes and surface area. *Science*, 309(5743): 2040-2042.

Furukawa H, Gándara F, Zhang Y B, et al. 2014. Water adsorption in porous metal–organic frameworks and related materials. *Journal of the American Chemical Society*, 136(11): 4369-4381.

Horcajada P, Surblé S, Serre C, et al. 2007. Synthesis and catalytic properties of MIL-100 (Fe), an iron (III) carboxylate with large pores. *Chemical Communications*, 27: 2820-2822.

Judkoff R, Neymark J. 1995. International Energy Agency building energy simulation test (BESTEST) and diagnostic method. *National Renewable Energy Lab*.

Seo Y K, Yoon J W, Lee J S, et al. 2012. Large scale fluorine-free synthesis of hierarchically porous iron (III) trimesate MIL-100 (Fe) with a zeolite MTN topology. *Microporous and Mesoporous Materials*, 157: 137-145.

Shi J, Wu X, Fu X, et al. 2015. Synthesis and thermal properties of a novel nanoencapsulated phase change material with PMMA and SiO2 as hybrid shell materials. Thermochimica acta, 617: 90-94.

Waqas A , Ud Din Z. 2013. Phase change material (PCM) storage for free cooling of buildings-A review. *Renewable and Sustainable Energy Reviews*, 18: 607-625.

Wu Z, Qin M, Zhang M. 2018. Phase change humidity control material and its impact on building energy consumption. *Energy and Buildings*, 174: 254-261.

Yaghi O M, O'Keeffe M, Ockwig N W, et al. 2003. Reticular synthesis and the design of new materials. *Nature*, 423(6941): 705.

Yao R, Costanzo V, Li X, et al. 2018. The effect of passive measures on thermal comfort and energy conservation. A case study of the hot summer and cold winter climate in the Yangtze River region[J]. *Journal of Building Engineering*, 15: 298-310.