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Impact of phase change wall room on indoor thermal environment in winter

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Abstract

Through combining gypsum boards with phase change materials (PCM), the compound phase change wallboards are formed. The transition temperature and latent heat of these phase change wallboards are tested by differential scanning calorimetry (DSC). The results indicate that these phase change wallboards can be applied in buildings to save energy cost and electric power. Then, the thermal properties of phase change wallboards are analyzed. The phase change wall room and the ordinary wall room are experimented and compared under the climatic conditions in winter in the northeast of China. The impact on the indoor temperature, surface temperature of wallboards and thermal flow through wall are achieved. Finally, it can be got that the phase change wallboards can improve indoor thermal environment.

Keywords: Phase change wallboards; Phase change wall room; Ordinary room; Temperature; Thermal flow

1. Introduction

Some phase change materials (PCM's) strong ability of heat storage and characteristic of constant temperature in the course of absorbing or releasing energy have received the extensive concern and study in recent years. In the HVAC field, because the thermal comfortable demand for the indoor environment has been raised increasingly, building energy consumption correspondingly is increased, which leads energy consumption to be increased continuously and the natural environment to be aggravatingly polluted. Through combining PCM and building materials to form phase change wallboards, we can get an effective way to improve indoor thermal comfort, reduce energy consumption and alleviate the negative effect in the atmospheric environment [1–9].

The enclosure of phase change wall room is constructed by bricks with phase change wallboards. Phase change wallboards usually are put onto the interior surfaces of wall. Because PCM can increase thermal inertia of the enclosure, the phase change wall room can improve the thermal comfort of indoor environment notably. In addition, according to the climatic characteristics of different districts, different PCM whose melting points are close to the domestic indoor comfortable temperature can be chosen to be integrated in phase change wallboards to maintain the interior surface temperature of wall, reduce the fluctuation range of indoor temperature and improve the thermal environment in the room [10–16].

2. Experimental

The experiment was carried in the winter in the northeast of China. The phase change wallboards made up of PCM and gypsum boards were stick on the surface of an ordinary room wall to form the phase change wall room. Under the similar climatic condition of ambient environment temperature, the thermal characteristics of ordinary wall room and phase change wall room were compared and studied. Then, the impact of the application of phase change wallboards on thermal comfort of the room was achieved.

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Table 1
The climatic materials of Shenyang

	November	December	January	February	March
Average of maximum temperature (°C)	5.7	−2.2	−5.2	−1.7	6.4
Average of minimum temperature (°C)	−4.2	−12.5	−16.6	−13.1	−4.4
Average temperature (°C)	0.3	−7.9	−11.5	−7.8	0.7

2.1. Experimental place

The experimental place is Shenyang, in the northeast of China, latitude 41.8°N, longitude 123.4°E, where the four seasons are clearly distinctive and belong to the continental monsoon climate in the northern temperate zone. The experiment was operated in winter (from mid-November to March of next year). Table 1 provides the climatic parameters of winter in Shenyang.

2.2. PCM

The interest on thermal energy storage by using fatty acid as PCM has risen in the recent years since they have desired thermodynamic and kinetic criteria for low temperature latent heat storage. Fatty acids have superior properties over many PCM such as melting congruency, good chemical stability and non-toxicity. More important characteristics are their smaller volume change during phase transition and high latent heat of fusion per unit mass and suitable melting temperature range. In this experiment, capric acid and lauric acid are mixed with the proportion of 82:18% as the PCM applied to the phase change wallboards.

The mixture was tested by DSC in Changchun Institute of Applied Chemistry of Chinese Academy Sciences. The testing instrument is DSC7 series of Thermal Analysis System produce by U.S.A. Perkin-Elmer Company. Fig. 1 shows the test results. The melting and frozen temperatures are 20.394 and 19.138 °C, respectively, which are in the range of indoor comfortable temperature in winter. The

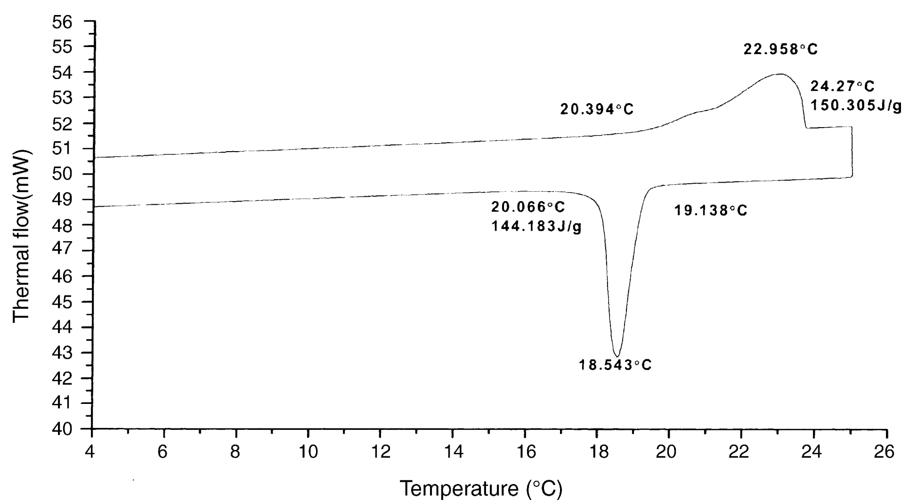

Fig. 1. DSC curve of the mixture 82–18% capric–lauric acids scanned at 0.2 °C/min.

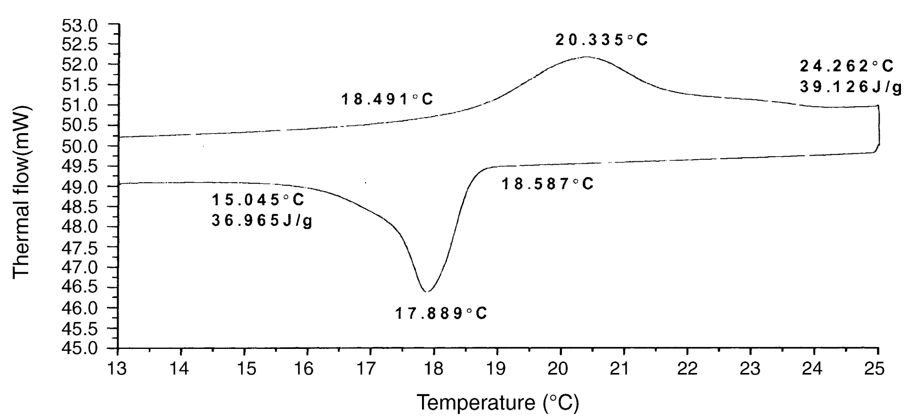

Fig. 2. DSC curve of the phase change wallboard scanned at 0.2 °C/min.

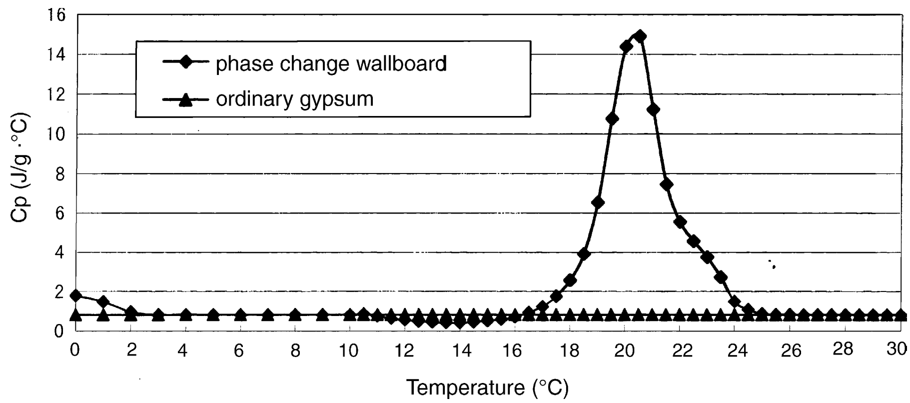

Fig. 3. The curves of specific heat and temperature.

melting and frozen latent heat are 150.305 and 144.183 J/g, which approves that this kind of phase change wallboards have suitable transition temperature and big latent heat and are adapt to being applied to phase change wall room.

2.3. Phase change wallboards

There are some building materials such as gypsum, plaster board, cements board which can be combined with PCM. After analyzing and comparing, it is found that gypsum is porous, in which the 40% volume is the air vent and has good absorbing ability to make PCM absorbed easily. Additionally, gypsum is light, cheap, conveniently and simply constructed and can insulate against sound and heat. Thus, Mount Tai gypsum with 9.5 mm thick is chosen in this experiment.

It costs 6–10 min to integrate PCM into the gypsum by soaking. The amount of absorption can be controlled to the proportion in demand. The PCM absorbed in the gypsum is about the 26% of total weight. Then, phase change wallboards were tested by DSC. Fig. 2 shows the test results. The melting and frozen temperatures are 18.491 and 18.587 °C, respectively, which are both in the indoor design temperature range of the winter. The melting and frozen latent heat are 39.126 and 36.965 J/g, which proves that this kind of phase change wallboards have bigger latent heat and are adapt to being applied to phase change wall room.

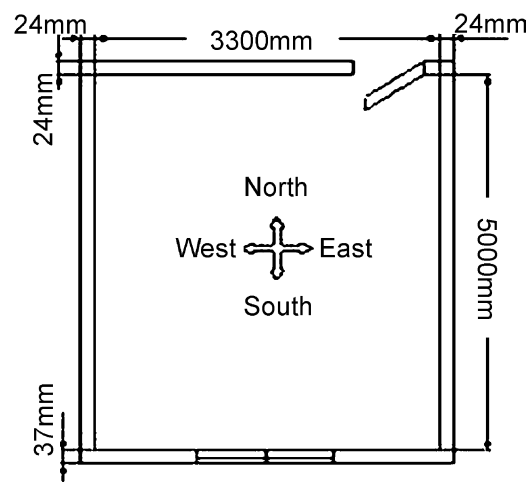

Fig. 5. Vertical view of room.

After comparing specific heat capacity, density and heat-transfer coefficient of phase change wallboards with them of ordinary gypsum, the peculiar thermal characteristics of phase change wallboards can be got.

The specific heat values of phase change wallboards and gypsum were tested by DSC. Fig. 3 shows the variation of specific heat in the course of solid–liquid phase change. Compared with specific heat value of gypsum samples, phase change wallboards have higher heat storage ability.

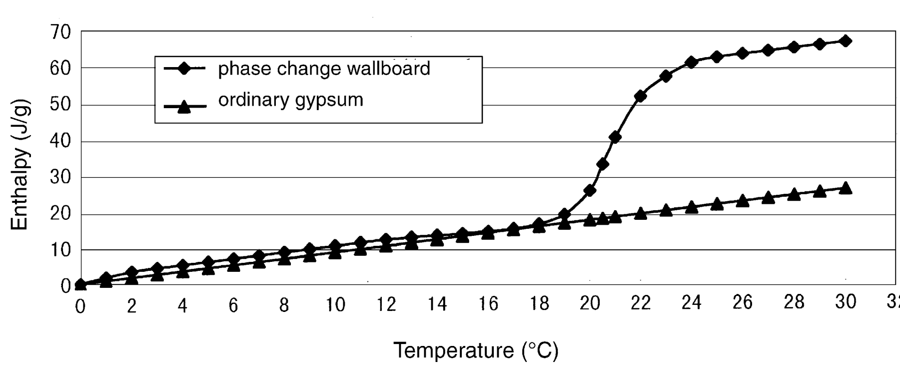

Fig. 4. The curves of enthalpy variation with temperature.

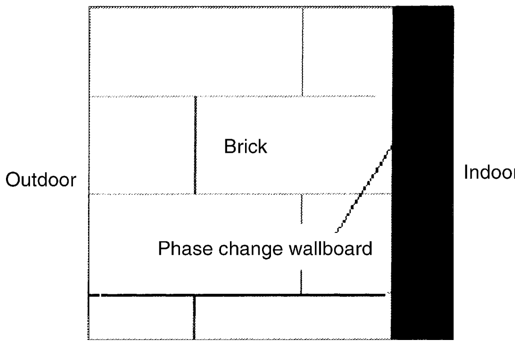

Fig. 6. Structure of phase change wall.

From DSC test results above, it can be known that absorption and release of energy in the course of phase transition lead to the variation of specific heat according, as the formula (1) describes. So, enthalpy's variation with temperature difference is non-linear in the course of raising temperature. But, the specific heat of ordinary wallboards does not vary with the absorption and release of energy. The heat obtained in the course of raising temperature keeps the linear relation with temperature difference generally. Fig. 4 shows the curves of enthalpy–temperature in the course of raising temperature of two kinds of wallboards.

$$\Delta H = C_p \times \Delta T \quad (1)$$

2.4. Experimental room

Limited to various kinds of conditions as the place, etc., the experiment of phase change wall room was operated after the test of the ordinary wall room. The experimental room is 5 m × 3.3 m × 2.8 m with a 1.5 m × 1.5 m window in the south wall and a 1 m × 2 m wooden door in the north wall. Outside the east wall is outdoor space, but not sunned in the whole year. The south wall is sunned directly. The west and north wall are the interior partition wall. Fig. 5 describes vertical view of the room. The structure of phase change wall is showed in Fig. 6. Figs. 7 and 8 are the photographs of phase change wall room.

The room was heated by 2040 W electric heat membrane in the ceiling, above which was the ultra slight glass wool with 40 mm thick as a heat-insulating layer. Another layer of glass wool with 150 mm thick was put on the room to make the room and ceiling insulate heat. The room was equipped with an air fan to mix indoor air.

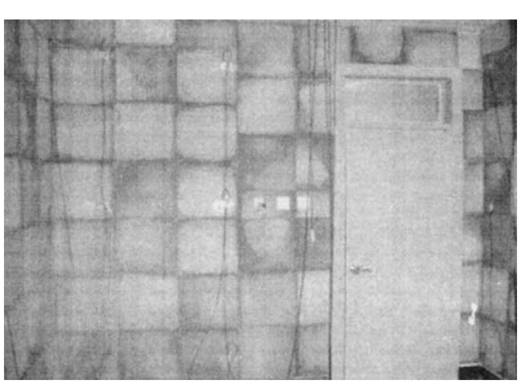

Fig. 7. Phase change wall room (1).

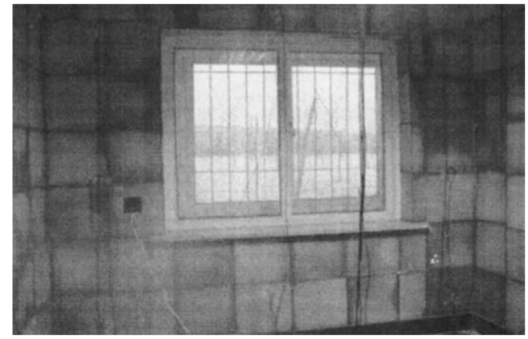

Fig. 8. Phase change wall room (2).

2.5. Distribution of thermal flow boards and thermocouples

Thermocouple probes were distributed at the middle of the room and wallboards and at 300 mm height above the floor, below the ceiling and the same height on the interior and exterior surfaces of wall both in the ordinary wall room and phase change wall room. All data were gathered every 10 min by the temperature patrolling instrument automatically linked with a computer through a 232 interchanger to record and export the data. Thermal flow boards which can measure thermal flow through wallboards were separately stick on the interior surfaces of the east, south and west wall of the room both in the ordinary wall room and phase change wall room, too. All the data of temperature and thermal flow were continually record for several days. The distribution of thermocouples is showed in Figs. 9 and 10.

3. Results and discussions

Firstly, the ordinary wall room was tested for three continuous days. Next, under the almost similar outdoor climatic condition, the thermal characteristics of this room

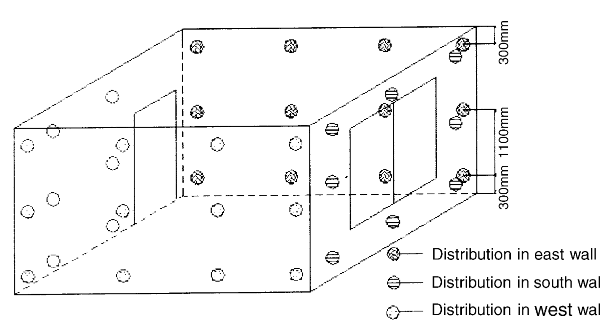

Fig. 9. Distribution of thermocouples in the interior surfaces of wall.

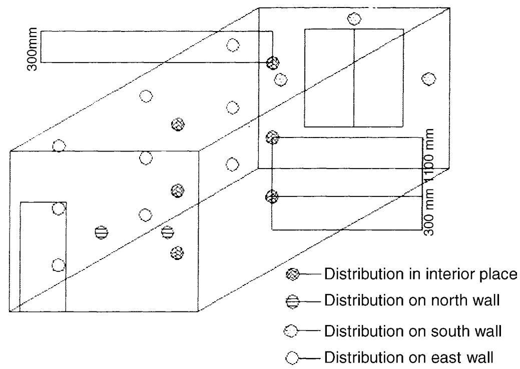

Fig. 10. Distribution of thermocouples on the exterior surfaces of wall and in the room.

with phase change wallboards were tested for three continuous days, too. In both periods of tests, the electric heat membrane was run at full capacity. Because the transition temperature of phase change wallboards is in the range of design temperature of indoor air in winter, when the indoor temperature is higher than transition temperature, PCM in the phase change wallboards transits from solid to liquid, phase change wallboards can absorb surplus heat in the room and become a regenerative equipment. But, yet, when indoor temperature drops lower than transition temperature, they will release heat and raise the indoor temperature. Through analyzing two groups of test data of different rooms mentioned above, the impact of phase change wallboards on indoor air temperature, surface temperature of wall can be achieved.

3.1. Premise

In order to get the impact of phase change room on temperature and thermal flow, outdoor climatic conditions must be similar. In fact, it was both fine, calm and of similar temperature fluctuation in two rooms' experiments. So, the test results of the ordinary wall room and phase change wall room are comparable-Fig. 11 shows the curves of ambient temperature in three continuous days' experiments of ordinary wall room and phase change wall room. Ambient temperature both fluctuated from −1 to 9 °C and rose day after day. Whether in the test period of ordinary wall room or phase change wall room, the maximums of temperature come in the third day and up to 8.04 and 8.09 °C, the minimums of temperature in the first day and low to −0.19 and −0.23 °C separately. Thus, the outdoor climatic environment in two types of tests was similar. So, the experimental results of ordinary wall room and phase change wall room can be applied to analyze and compare to achieve the impact of phase change wallboards on indoor thermal parameters.

3.2. Impact on temperature

Fig. 12 shows the curves of indoor temperature in three continuous days' experiments of ordinary wall room and phase change wall room. It can be known that the indoor temperature in ordinary wall room fluctuated from 19 to 24 °C, phase change wall room from 18.5 to 22 °C. The average accumulation temperatures were 21.03 °C in the test

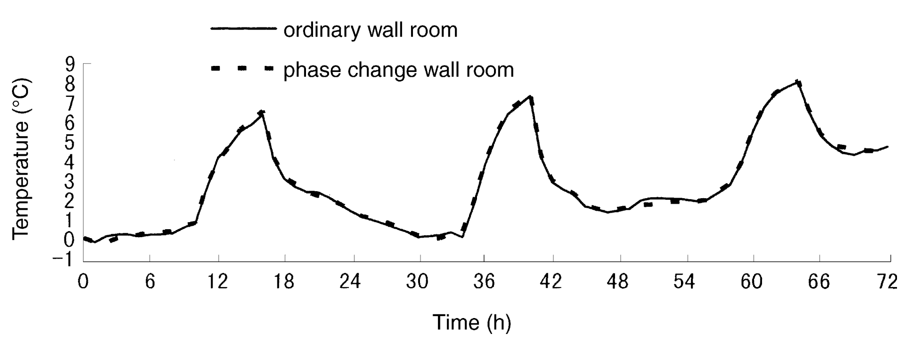

Fig. 11. The curves of ambient temperature.

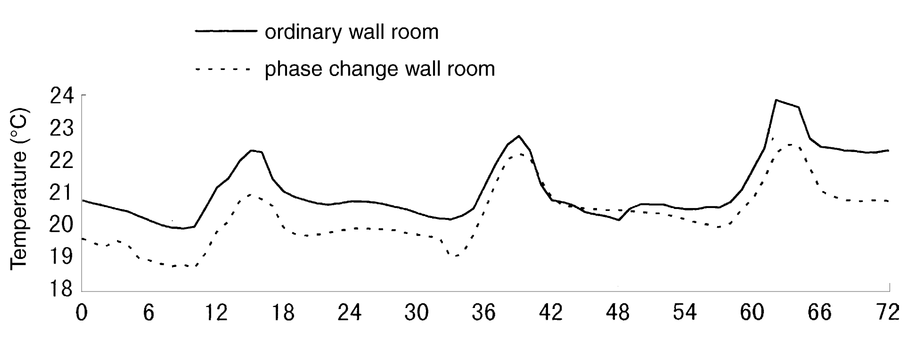

Fig. 12. The curves of indoor temperature.

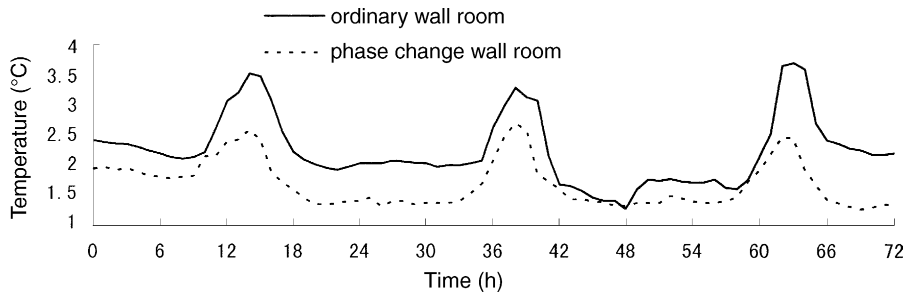

Fig. 13. The curves of temperature difference between indoor air and interior surface of outdoor wall.

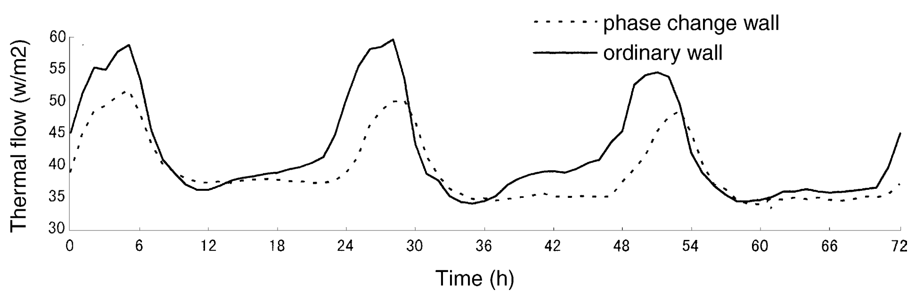

Fig. 14. The curves of thermal flow through wall.

period of ordinary wall room and 20.18 °C of phase change wall room. In the experiment of ordinary wall room, the maximum of indoor temperature fluctuation was 3.74 °C in the third day, the hottest day, but the maximum in the phase change wall room was only 2.59 °C which is 1.15 °C less than ordinary room's. Therefore, it proves that phase change wall room can alleviate indoor temperature fluctuation. Besides, in Fig. 12, it also can be found that indoor temperature of phase change wall room was lower than that of ordinary wall room in that PCM in phase change wallboards absorbed some heat while the heat source is heating the indoor air.

Fig. 13 shows the curves of temperature difference between indoor air and the interior surface of outdoor wall in two types of rooms' experiments. The average accumulation and maximum of temperature difference of ordinary room were 2.21 and 3.7 °C, respectively. In phase change wall room, for the latent heat storage ability of phase change wallboards, the temperature difference between indoor air and the surface of phase change wallboards was less than ordinary wall. As shown in Fig. 13, the average accumulation and maximum of temperature differences of phase change wall room were 1.63 and 2.68 °C, respectively.

3.3. Impact on thermal flow

Thermal flow boards were distributed on the interior surfaces of east, south, and west wall to measure the thermal flow, as the heat-transfer value through the wait in different time.

Fig. 14 shows the curves of thermal flow in two types of rooms' experiments. Test time was from 10:00 a.m. to 10:00 a.m. on the third day. In the experiment of ordinary wall room, thermal flow through south wall varied from 34 to 60 W/m^2. The maximum was 59.5 W/m^2. But, in the experiment of phase change wall room, thermal flow through south wall fluctuated from 33 to 52 W/m^2. The maximum was 51.57 W/m^2. Therefore, under the same outdoor environment, thermal flow through phase change wall room was lower than ordinary wall room. That is to say that the heat-transfer through phase change wall was lower than the ordinary wall. It proves that phase change wallboards can keep warmth.

4. Conclusion

Through contrasting the impact on indoor thermal environment between the phase change wall room and ordinary wall room by the experiment in winter, it can be proved that phase change wallboards can weaken indoor air fluctuation and reduce the heat-transfer to outdoor air and have the function of keeping warmth to improve indoor thermal comfortableness. Furthermore, the phase change wall room can reduce the scales of heating equipment and related investment cost, which will be of function of "moving the peak and filling out the valley" to electric power. Therefore, the application of phase change wall room will surely bring more benefits to the building energy-conservation field.

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References

[1] A.K. Athienitis, C. Liu, D. Hawes, D. Banu, D. Feldman, Investigation of the thermal performance of a passive solar test-room with wall latent heat storage, Building and Environment 32 (1997) 405–410.

[2] D. Banu, D. Feldman, D.W. Hawes, Evaluation of thermal storage as latent heat in phase change material wallboard by differential scanning calorimetry and large scale thermal testing, Thermachimica Acta 317 (1998) 39–45.

[3] A.F. Rudd, Phase-change material wallboard for distributed thermal storage in buildings, ASHRAE Transactions 99 (2) (1993) 339–346.

[4] A. Sary, K. Kaygusuz, Thermal energy storage system using some fatty acids as latent heat storage materials, Energy Sources 23 (2) (2001) 75–85.

[5] D. Feldman, D. Banu, D. Hawes, E. Ghanbari, Obtaining an energy storing building material by direct incorporation of an organic phase change material in gypsum wallboard, Solar Energy Materials 22 (1991) 231–242.

[6] M.N.R. Dimaano, A. Escoto, Preliminary assessment of a mixture of capric acid and lauric acid for low-temperature thermal energy storage, Energy 23 (1998) 421–427.

[7] D. Feldman, D. Band, D.W. Hawes, Development and application of organic phase change mixtures in thermal storage gypsum wallboard, Solar Energy Materials and Solar Cells 36 (1995) 147–157.

[8] D. Feldman, M.M. Shapiro, D. Banu, C.J. Fuks, Fatty acids and their mixtures as phase change materials for thermal energy storage, Solar Energy Materials 18 (1989) 201–216.

[9] S. Ahmet, Thermal characteristics of a eutectic mixture of myristic and palmitic acids as phase change material for heating applications, Applied Thermal Engineering 23 (2003) 1005–1017.

[10] T.K. Stovall, J.J. Tomlinson, What are the potential benefits of including latent storage in common wallboard, Transactions ASME 117 (1995) 318–325.

[11] H.E. Feustel, C. Stetiu, Thermal Performance of Phase Change Wallboard for Residential Cooling Applications. Lawrence Berkeley Laboratory Report LBL-38320, UC1600, 1997.

[12] J. Paris, M. Falardeau, C. Villeneuve, Thermal storage by latent heat: a viable option for energy conservation in buildings, Energy Sources 15 (1993) 85–93.

[13] D.A. Neeper, Potential benefits of distributed PCM thermal storage, in: Proceedings of 14th National Passive Solar Conference, Denver, Colorado, American Solar Energy Society, 1989, pp. 283–288.

[14] D. Feldman, D. Banu, D. Hawes, Low chain esters of stearic acid as phase change materials for thermal energy storage in buildings, Solar Energy Materials and Solar Cells 36 (3) (1995) 311–322.

[15] D. Neeper, Thermal dynamics of wallboard with latent heat storage, Solar Energy 68 (5) (2000) 303–393.

[16] F.O. Cedeno, M.M. Prieto, A. Espina, G.R. Garcia, Measurements of temperature and melting heat of some pure fatty acids and their binary and ternary mixtures by scanning calorimetry, Thermochimica Acta 369 (2001) 39–50.