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The utilization of microencapsulated phase change material wallboards for energy saving

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Abstract−Wallboards with micro encapsulated phase changing material (micro PCM) were used to investigate the performance and the energy saving characteristics as building materials in winter and summer climate conditions. The test house consisted of a boiler with under floor heating system, an air conditioner, micro PCM wallboard room and conventional wallboard room. The outer temperature of the rooms could be artificially controlled at the temperature range of −12 to 35 °C. Micro PCM content in wallboards was 0-4 kg/m^2. The melting temperature and latent heat of Micro PCM are 23 °C and 211 J/g. Also, micro PCM shows stable mechanical strength under 500 psi. As micro PCM content increased, the temperature fluctuations decreased. In case of micro PCM wallboard, temperature profiles in the room show stable and comfortable ranges. The optimum amount of micro PCM in wallboard to maximize energy saving efficiency was around 3 kg/m^2.

Key words: PCM, Building Material, Wallboard, Latent Heat

INTRODUCTION

As construction companies try to design modernized style and construct light architecture, the capacity of heat holding capacity is gradually decreased. Especially, thermal energy storage for space heating and cooling of buildings is becoming increasingly important due to the rising cost of fossil fuels and environmental concerns [1]. Phase changing material (PCM) has been utilized for thermal energy storage in various fields since the early 1980's because it has the ability to store and release large amount of heat energy during phase change while maintaining constant temperature. Unlike other insulation materials, PCM on reaching its melting temperature absorbs a large amount of heat and releases its stored latent heat with solidification.

Thermal energy storage techniques for construction materials can play an important role in building energy saving by using stored energy for passive cooling or heating. With the advent of PCM implemented in gypsum board, plaster, concrete for other wall, thermal storage can be increased from latent heat as a part of the building structure [2]. PCM wallboard is flexible for alteration and refurbishment of a conventional building. However, problems such as long-term thermal behavior, durability of PCM-impregnated wallboards, fire problem and heat transfer enhancement, combination with active systems, etc., still need to be focused on in future work [3].

Recently, microencapsulation techniques are most widely used in the development and production of improved drug or food delivery systems. These techniques normally have advantages such as enhancing material stability, reducing adverse or toxic effects and extending material release for different applications in various fields of products [4]. With the merits of microencapsulation, such as no agglomeration of each PCMs due to leakage from melting process, microencapsulated PCM (Micro PCM) can be used for heat transport media and building material applications [5-10]. Micro PCM looks like fine particles apparently from keeping PCM compounds separately inside capsule walls even during the melting process. Therefore, stability as well as energy saving by using PCM can be obtained after the microencapsulation process. It was reported that effective use of micro PCMs in the building and construction sector can significantly eliminate the requirement for traditional generators, heaters and coolers and therefore help in reducing emission of greenhouse gases.

To analyze energy saving effects of micro PCM, temperature profiles of inner and outer rooms with and without Micro PCM wallboard and temperature fluctuations were measured in summer and winter climate conditions. Also, power consumption and difference power consumption to maintain comfortable room temperature were investigated in a test house with a boiler with under floor heating system and an air conditioner.

EXPERIMENTAL

To prepare micro PCM, in-situ microencapsulation process was used. Hexadecane ($C_{14}H_{36}$) was used as a core material having melting temperature of 23 °C and melamine-resin was used as a shell material (7). The composition of micro PCM is shown in Table 1. The photograph of micro PCM particles by SEM is shown in Fig. 1. As shown in Fig. 1, the shape of micro PCM was almost spherical. But the diameters of each micro PCMs are different. The thermal properties measured by DSC (differential scanning calorimeter) show that melting temperature is 23 °C and latent heat 211 J/g. The preparation procedure and operating conditions have been described in previous papers [4,7].

To demonstrate and analyze thermal energy storage for space heating and cooling of building, micro PCM wallboards were produced by mixing inorganic material, organic material, aggregate, anti-

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Table 1. Compositions of Micro PCM

Components	Chemicals	Composition (wt%)	Melting temperature Tm (°C)	Latent heat (J/g)
Core	Hexadecane ($C_{16}H_{34}$)	80-85	23 °C	229
Shell	Melamine	14-19	354 °C	
Additives	Surfactants	~1	-	

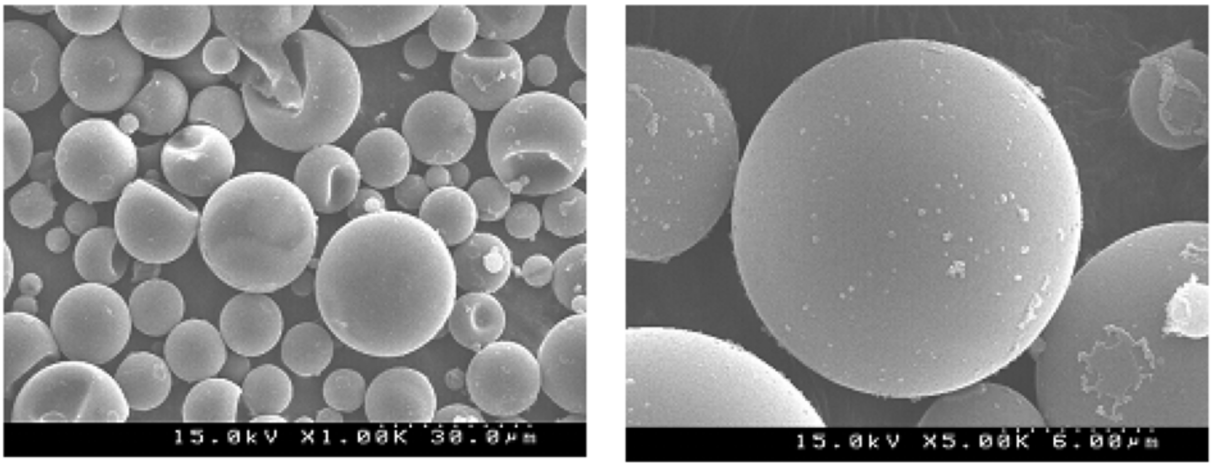
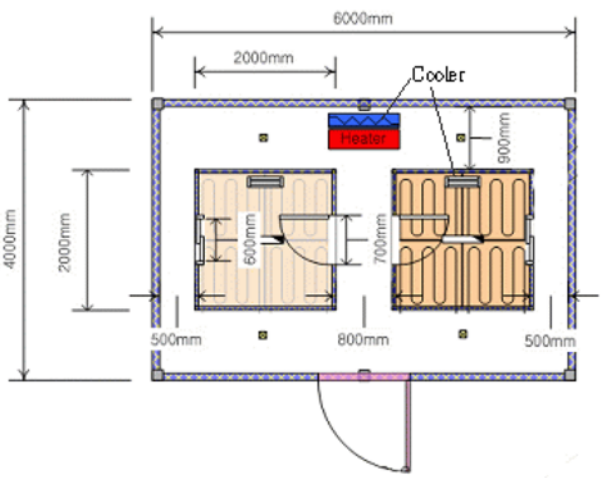


Fig. 1. Photographs of Micro PCM.

(a) Test house



(b) Test room layout and dimensions

Fig. 2. Picture and plane figure of test house.

crack material, and micro PCM particles, of which weight fractions were 1, 2, 3, and 4 kg/m^2, respectively, as shown in Table 1. Micro PCM wallboards were made in a mold (0.3 m×0.3 m×0.015 m) by mixing various components with water and micro PCMs.

The test house (2 m×2 m×1.8 m) consisted of one room (2 m ×2 m×1.8 m) with micro PCM wallboard and the other room with conventional wallboard as shown in Fig. 2. Fig. 2(a) is the picture of the test house and (b) is the floor plan with layout and dimension of the test house. As shown in Fig. 2(b), it was equipped with a boiler with under floor heating system and an air conditioner to make the room comfortable. The experiments were carried out by heating or cooling the test house to maintain room temperature at 22 °C during winter season and 26 °C during summer season, and each test took over 60 hours. T-type thermocouples were used for measuring the room temperature of the test house.

RESULTS AND DISCUSSION

A highly effective micro PCM was designed and made by in-situ polymerization process. In the in-situ polymerization process, the emulsification speed, mixing ratio, surfactants, polymerization time, and temperature affected the particle size distribution of micro PCM [7]. Fig. 3 shows the particle size distribution of micro PCM. Lee et al. [7] said the mean particle size of micro PCM decreased with increasing emulsification time, and peak temperature of the core material increased because the shell thickness of might affect the heat transfer. The mean particle size of micro PCM was 7.44 µm, calculated by using data in Fig. 3.

When micro PCM wallboard is used in a building system, the durability of microcapsules is a very important factor. As mentioned by Zalba et al. [11], poor stability of inorganic PCMs involves two aspects: poor stability of material properties during repeated ther-

Table 2. Contents in Micro-PCM wallboards (unit: kg/m^2)

Sample	Inorganic	Organic	PCM	Aggregate	Anti-crack	Total
PCM 0	0.71	0.17	0	0.08	0.04	1
PCM 1	1.43	0.5	1	0.17	0.06	3.16
PCM 2	2.87	1	2	0.33	0.14	6.34
PCM 3	4.3	1.5	3	0.5	0.2	9.5

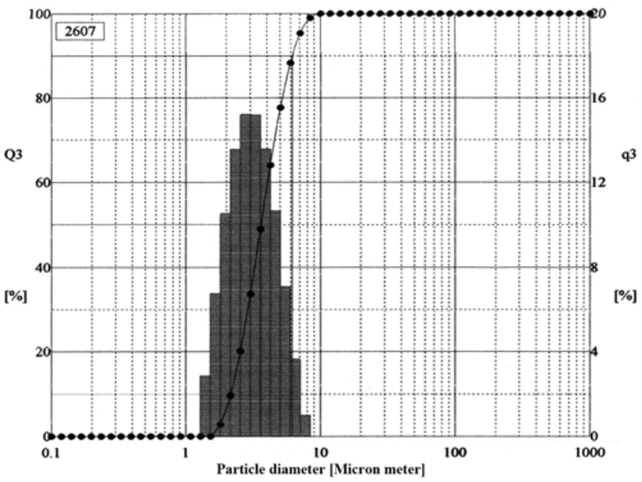


Fig. 3. Particle size distribution of Micro PCM.

mal cyclings, and corrosion between the PCM and its surrounding containers. Organic PCM mixtures have been verified to have excellent thermal stability [12,13]. Oil soluble dye (Oil-N-Red) was used to test the strength of micro PCM shell. Oil soluble dye was mixed with paraffinic oil as core material before microencapsulation. Micro PCM was compressed under high pressure during 24 hrs to investigate microcapsule strength. The fraction of shell breakage was measured from the color detection in aqueous phase. From the

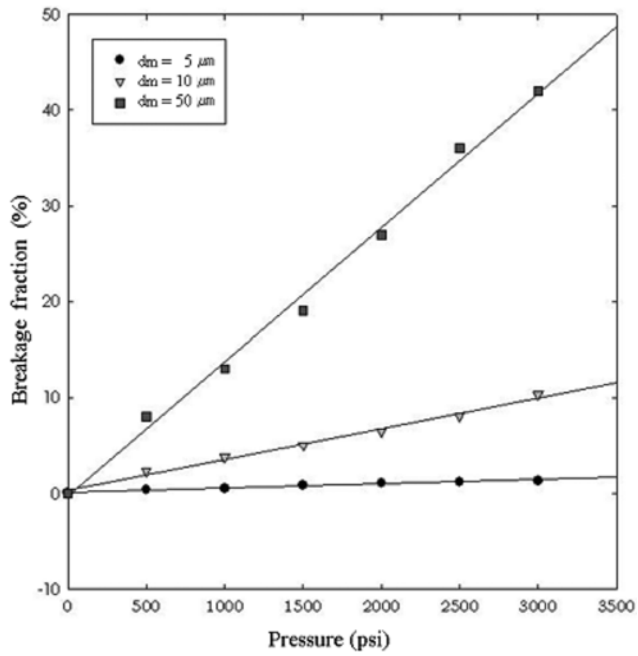


Fig. 4. Breakage fraction of microcapsule with particle diameters.

experimental results, breakage fractions with various micro PCMs were calculated and shown in Fig. 4. As can be seen, the breakage

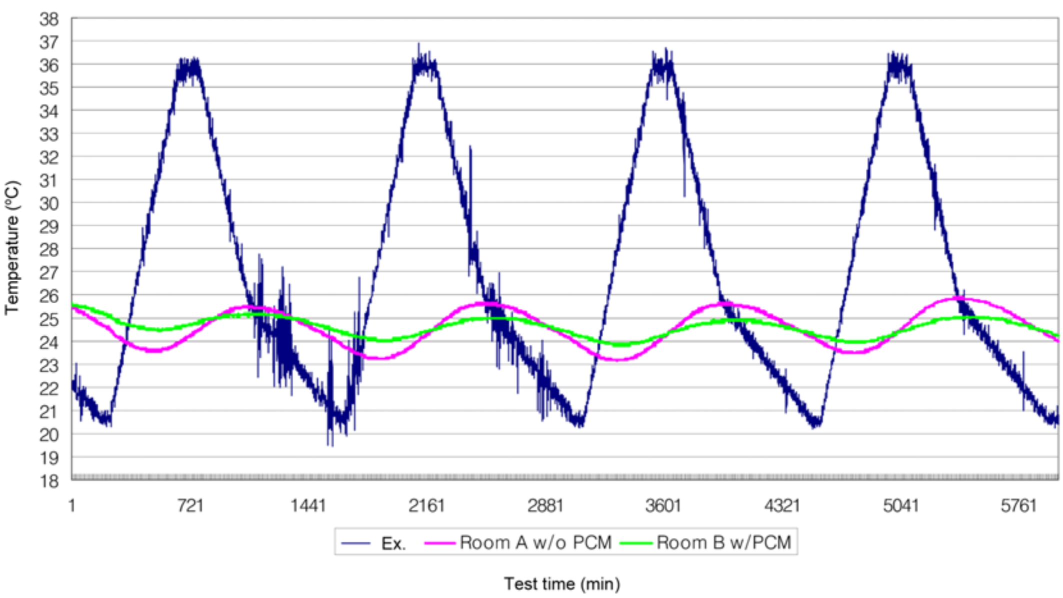


Fig. 5. Temperature profiles during summer season without air conditioning.

fractions decrease with decreasing micro PCM diameter. At the condition of 500 psi, breakage fraction under 50 mm was under 10%. So, micro PCM wallboards might be very stable because not easily broken under 500 psi.

PCM has been successfully incorporated into wall materials such as gypsum wallboard and concrete to enhance the thermal energy storage capacity of buildings with particular interest in passive solar applications, peak loading shifting etc [1]. The typical temperature profile of test rooms without air conditioning at the conditions of external temperatures 20-36 °C is presented in Fig. 5. Conventional wallboard without micro PCM was installed in the reference room to compare the effects of micro PCM. As can be seen, the temperature profiles in the room with micro PCM wallboard showed more stability than that in the reference room, and so it can be seen that the micro PCM might help room temperature to remain in the range of comfortable living environment. In the PCM wall experiments for short-term heat storage, direct energy savings of 5-20% were expected [14].

The temperature profiles and electrical consumption during test times at the conditions of simulated winter and summer season are presented in Fig. 6. The temperature difference between floor and room in the test room was smaller than that in the reference room. As a result, on/off time periods of heater or air conditioner to control the room temperature were longer than in the reference room. In the room with micro PCM wallboard, the room temperature was closer to the set temperature of the boiler, so it can be seen that the micro PCM might help room temperature to remain in the range of comfortable living environment. Thus, power consumption of the PCM room for heating or cooling was required to be smaller than that of the reference room. The utilization of PCM gypsum board may reduce the maximum room temperature by about 4 °C during the day and can reduce the heating load at night significantly [15]. Also, solar energy stored in the PCM gypsum panels can reduce the heating energy demand by up to 90% at times during the heating season [16].

To compare the effects of PCM, the power consumption with various wallboards was measured and the power ratios calculated. The power ratio means the value of the power consumption with PCM wallboard divided into the power consumption without PCM.

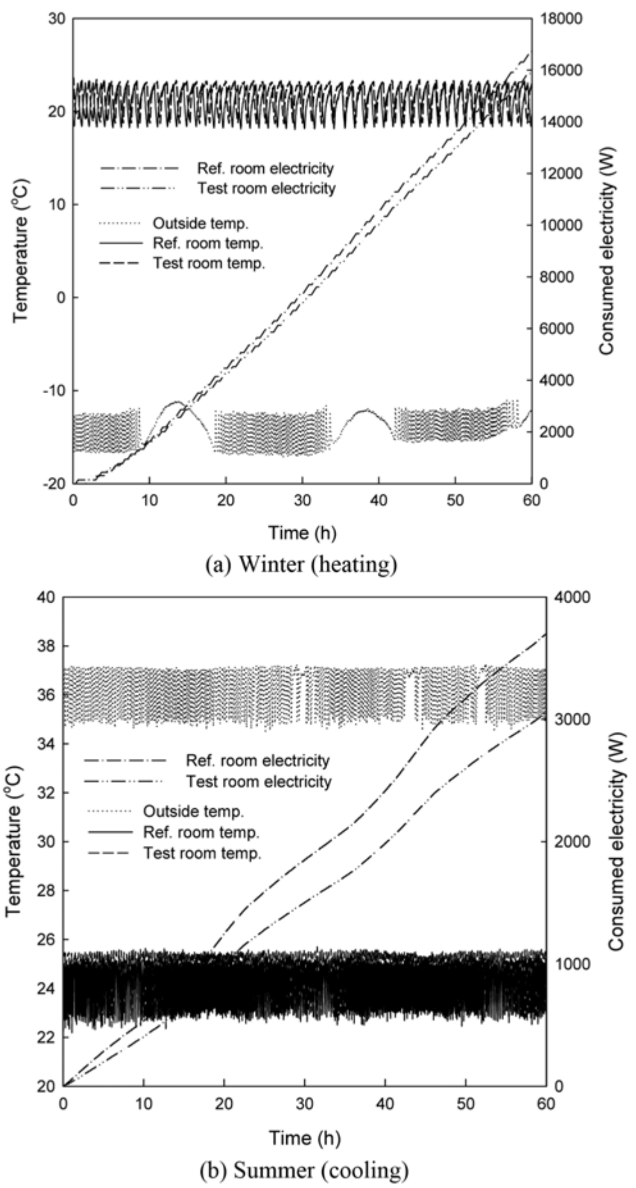


Fig. 6. Typical temperature profiles in a test house.

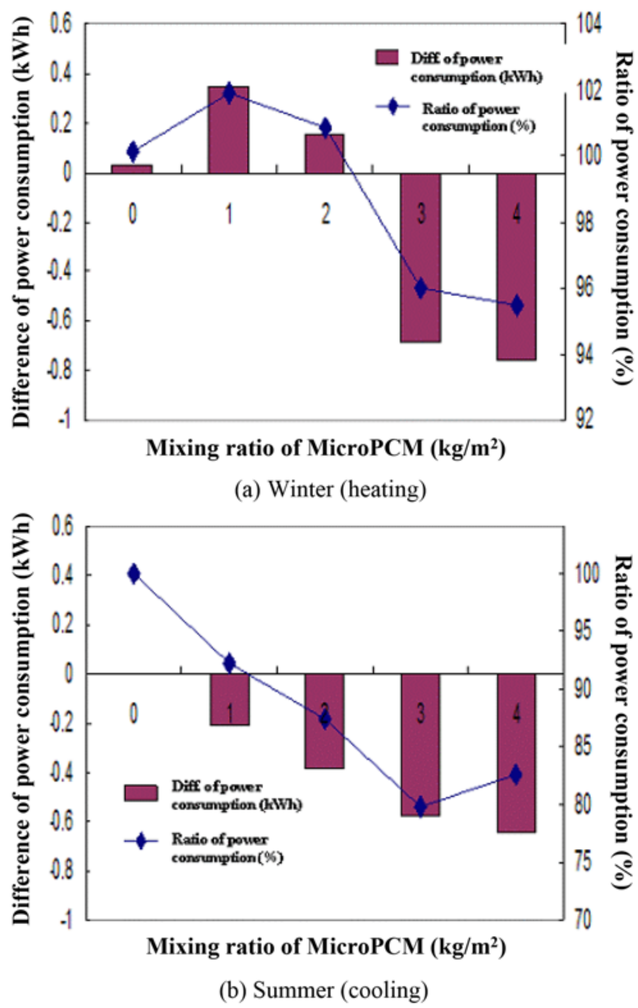


Fig. 7. Power consumption and power ratio in a test house.

During heating and cooling conditions power consumption and power ratio are shown in Fig. 7. The power differences and power ratio during heating conditions decreased after slight increase with increasing the amount of micro PCM. However, when we increased the amount of micro PCM up to 4 kg/m^2 the forming of molding state became more difficult. And so the optimum content of micro PCM in wallboard was 3 kg/m^2 in this experiment.

In the summer season during cooling condition, the power differences increased with the amount of PCM. PCM with melting temperature 23 °C was used in this study and the set point for room temperature is different for summer and winter season. And the effects of power ratio during cooling condition at summer season showed higher values than that during winter season. In this study the power ratio in summer season was 0.8-0.92 and in winter season 0.95-1.

In the previous work, the amount of thermal storage should increase with increasing the PCM materials [6]. Alawadhi [17] reported that total heat flux at the indoor space can be reduced by 17.55% when PCM cylinders are introduced into the bricks. As a result, energy cooling load decreased and the same amount of energy could be saved. In this study, it was shown that the energy consumption to keep comfortable room temperatures was decreased up to 20% depending upon PCM properties and outside temperatures. Stoval and Tomlinson [18] have examined the shifting of heating and cooling loads to off peak times of the electrical utility and found it saved energy with payback of PCM investment in 3-5 years.

CONCLUSIONS

The energy saving building materials by using micro PCM wallboard, which might be very stable because it is not easily broken under 500 psi, were characterized in a test house at the artificial climate control system. The outer temperatures were from −12 to 35 °C and the set points for room temperature were 22 °C (winter season) and 26 °C (summer season). In summer season without air conditioning, the temperature profiles in the test room with micro PCM wallboard showed more stable and comfortable ranges than that with conventional wallboard. As the PCM content increased, the temperature fluctuations decreased and the optimum amount was around 3 kg/m^2. By using micro PCM wallboard, the energy consumption to maintain comfortable temperatures decreased up to 20%.

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