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Evaluation of thermal storage as latent heat in phase change material wallboard by differential scanning calorimetry and large scale thermal testing

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Abstract

Differential scanning calorimetry and large scale thermal testing were conducted to determine the latent heat storage in a thermal storage wallboard. Thermal storage wallboard was developed at School for Building, Concordia University, by incorporating about 20% by weight of a phase change material in gypsum wallboard. It was determined that differential scanning calorimetry can adequately predict the performance of a full-scale installation of thermal storage wallboard. Consequently, the expensive large scale tests need only be performed when the development of thermal storage wallboard is well advanced. © 1998 Elsevier Science B.V.

Keywords: DSC; Large scale thermal testing; Thermal storage; Thermal storage wallboard; Wallboard

1. Introduction

Amongst the various heat storage techniques of interest, latent heat storage is particularly attractive due to its ability to provide a high energy storage density and its capacity to store heat in a narrow temperature interval corresponding to the phase transition temperature of the heat storage substance. A substance utilized for latent heat storage is known as phase change material (PCM). PCMs absorb heat while melting, which cools the surrounding environment, then the stored heat is returned to surroundings when PCMs freeze. The characteristic of PCMs to store heat in a narrow temperature range is important for most applications concerning the energy conservation in buildings.

The PCMs include both inorganic and organic materials. Most of inorganic materials are salt hydrates and as organic materials fatty acids and their mixtures, fatty acid esters, fatty alcohols and hydrocarbon waxes have been considered as PCMs for several years. The work done in this field was reviewed by several authors [1–3] and the efficacy of PCMs for energy storage has clearly been demonstrated [4–6].

To provide a simple and relatively low cost thermal storage system, an energy storing building material was developed at School for Building (SFB) Concordia University by incorporating a PCM in gypsum wallboard.

The reasons for selecting wallboard for thermal storage with PCM were described elsewhere [6]. The search for suitable PCMs was directed towards the use of organic materials in an effort to avoid some of the problems inherent in inorganic PCMs such as

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corosivity, supercooling and segregation. Special attention was also given to PCMs that are derived from renewable vegetable oils or animal fats, whose availability grow with increasing world food production.

Differential scanning calorimetry (DSC) was one of the important testing methods used in the development of PCM wallboard. It was used for selecting the PCMs, evaluation of PCM wallboard prototypes, investigating the reproducibility of PCM thermal characteristics in wallboard, verifying the spatial uniformity of PCM in wallboard and ascertaining the effect of temperature cycling on the thermal characteristics of PCM wallboard. The initial DSC tests were followed by laboratory tests for thermal conductivity, thermal diffusivity, flexural strength, compatibility with selected materials and, finally, preliminary tests for flame spread and fire resistance. Careful analysis of the results of these tests led to the selection of one PCM material from nine PCM candidates [7]. The PCM thus selected was then tested on a full-size structure consisting of a small building comprising two identical rooms located in a controlled environment at the SFB Concordia University. One room was lined with standard wallboard and the other with wallboard impregnated with about 20% by weight of PCM. Part of the full-scale test results were published elsewhere [9]. This paper covers the tests, carried out at this facility for measuring the thermal storage capacity of PCM wallboard in order to correlate the full-scale test results with the laboratory scale DSC results.

The PCM selected for testing was a commercial mixture of Butyl Stearate-Palmitate (Emerest 2325 produced by Henkel Canada).

2. Experimental

The DSC measurements were performed using a 912 DuPont DSC provided with a DuPont Mechanical Cooling Accessory and connected to a 2100 DuPont Thermal Analyst. DSC runs were carried out in most cases at a heating/cooling rate of 2°C min^{-1}. Then, when the desired characteristics were achieved, a test rate closer to the actual rise and fall of temperature normally experienced in buildings was used, i.e. 0.2°C min^{-1} for final tests. The specimens weight was about 5 mg for PCM alone and about 20 mg for PCM wallboard. Details regarding the DSC analyses of PCM wallboard were described elsewhere [8].

Full-scale evaluation of the PCM board was performed in a test facility consisting of two identical insulated adjacent rooms 2.29 m×2.27 m×2.75 m high. The interior of one of the rooms was finished with conventional gypsum board, while that of the other room was finished with wallboard impregnated with about 20% by weight of Emerest 2325 PCM. Air conditioning and heating pump units equipped with computerized controllers serviced each room. The temperatures of back and front surfaces of the wallboards, room air and external environment were recorded through 70 channels of a computer controlled data acquisition system. The computer program was designated to record temperature measurements and heating energy consumption. The measured data were recorded every 5 s and an average value was given every 5 min.

In order to control the environment surrounding the test structure, this was isolated from the rest of the laboratory by constructing a separation wall. Full description of this facility is given elsewhere [9].

Impregnation of the wallboard with PCM was achieved by immersing ordinary wallboard in a 2.5 m×1.2 m×1.2 m×01 m bath which was filled with a constant volume of PCM (90±5L), while the temperature of PCM was maintained at 50±5°C. Prior to immersion the wallboard was kept at 50±3°C for 4 h. The immersion time varied between 1.5 and 4 min and was a function of wallboard dimensions. The content of PCM in each wallboard panel was slightly different varying between 18.8% and 21.3%.

The total weight of gypsum wallboard utilized for covering the PCM-room was 199.8 kg and its weight after impregnation with PCM was 250.21 kg. Therefore, the total weight of PCM in the PCM wallboard was 50.4 kg which represents an average loading of 20.1%.

3. Results and Discussions

3.1. DSC analysis

Figs. 1 and 2 present a typical DSC curve for PCM Emerest 2325 alone and for wallboard impregnated with 20.6% by weight of Emerest 2325 respectively. Both curves were recorded at a scanning rate of 0.2°C min^{-1}.

The thermal characteristics of Emerest 2325 determined by DSC at 0.2°C min^{-1} scanning rate (average of six samples) are: melting freezing-interval 17–20°C, ΔH_m=137.8 J g^{-1} with a standard deviation of 2.2 J g^{-1} or 1.6%, ΔH_f=139.4 J g^{-1} with a standard deviation of 2.1 J g^{-1} or 1.5%.

In the PCM impregnated wallboard samples tested by DSC, it was found that the PCM content was slightly different from sample to sample, varying from 19.5% to 21.5%. These values were obtained by dividing the latent heat of each PCM wallboard sample to the latent heat of PCM alone.

Consequently, the latent heat of each sample was recalculated as the latent heat of PCM. To arrive at that value, the latent heat of each PCM wallboard sample, as determined by DSC, was divided by its PCM content (%) determined gravimetrically.

The thermal characteristics of PCM in wallboard samples determined by DSC at a 0.2°C min^{-1} scanning rate (average of four samples) are: melting freezing-interval 18–21°C, ΔH_m=143.2 J g^{-1} with a standard deviation of 13.7 J g^{-1} or 9.6%, ΔH_f= 146.4 J g^{-1} with a standard deviation of 13.8 J g^{-1} or 9.4%.

These data show that the thermal characteristics of the PCM which is impregnated in wallboard are very close to those of the same PCM which was analyzed alone.

From Figs. 1 and 2 it can be seen that the melting and freezing curves are quite broad due to impurities present in the commercial product. The entire latent

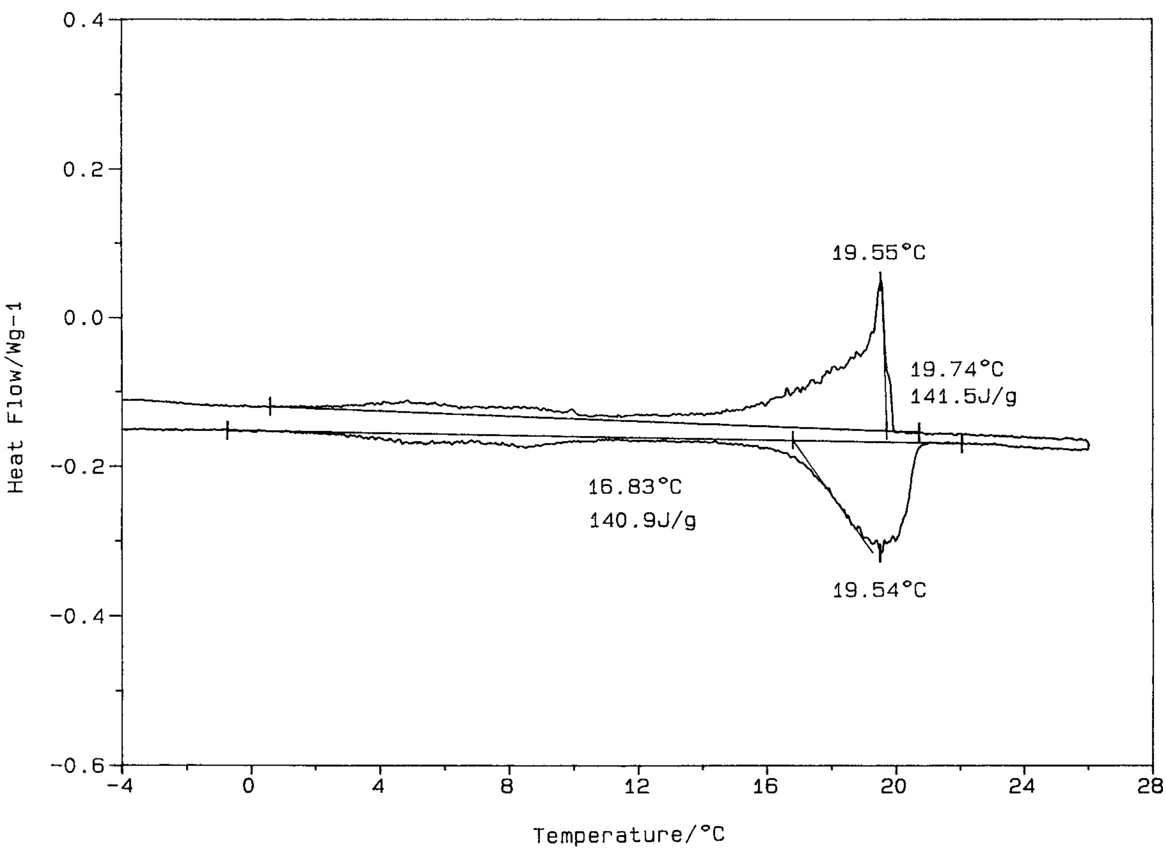


Fig. 1. DSC curve of Emerest 2325 recorded at a 0.2°C min^{-1} scanning rate.

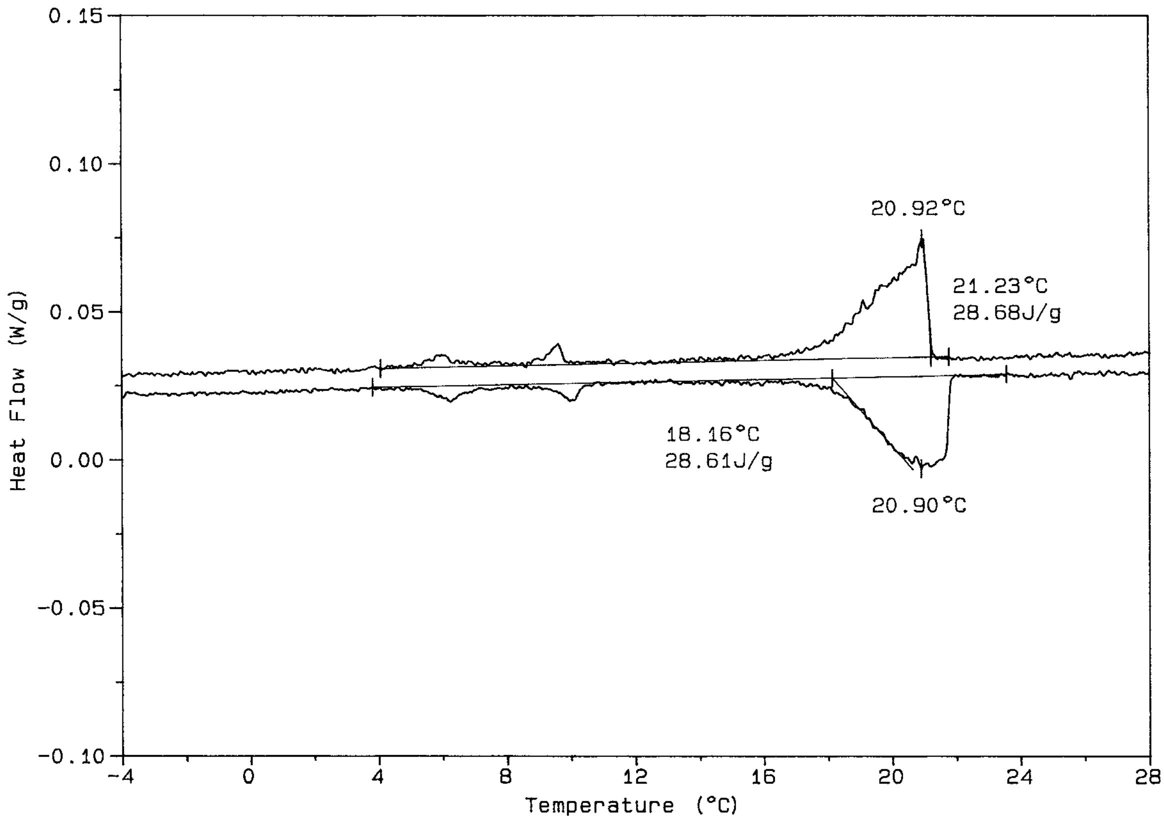


Fig. 2. DSC curve of PCM wallboard recorded at a 0.2°C min^{-1} scanning rate; PCM Emerest 2325, PCM content in Wallboard 20.6% by weight.

heats are evolved over a rather large temperature interval. However, for a smaller temperature interval, i.e. 5°C, which is of greater interest for thermal storage in buildings, the evolved latent heats are about 85% of total latent heats which is quite satisfactory for the intended applications.

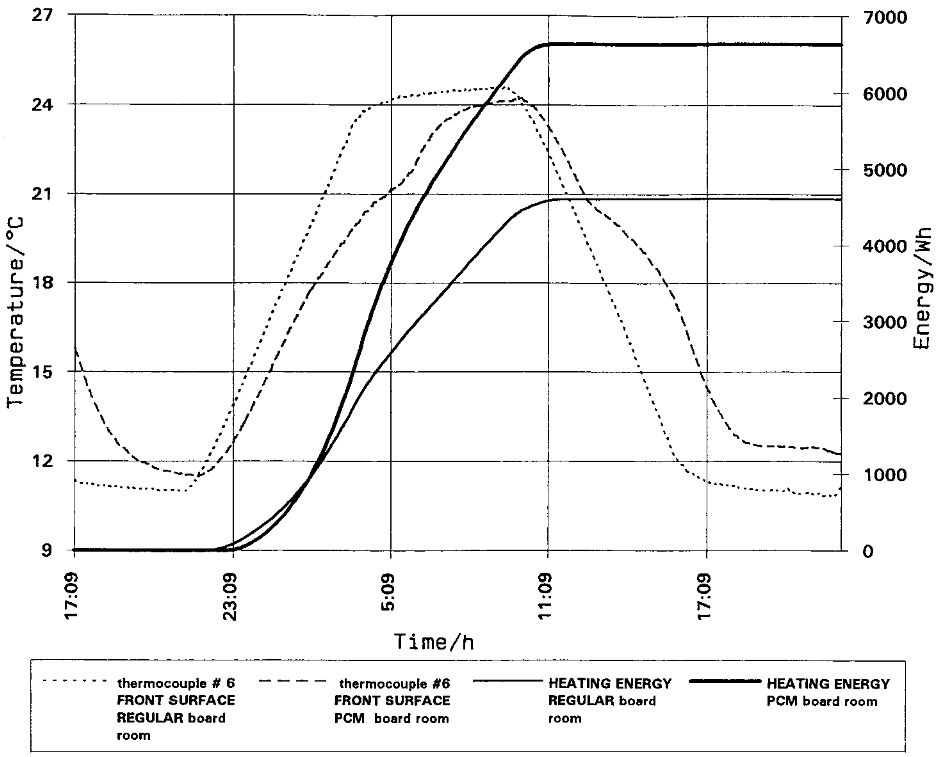
3.2. Large scale test

The room scale tests were conducted in the facility described earlier. Several room scale tests were conducted with the following objectives: to determine the feasibility of latent heat storage in full-scale models, charging and discharging times, thermal performance of PCM wallboard vs. that of ordinary wallboard, the effect of PCM on indoor air quality. The results of these tests were described elsewhere [9].

The tests discussed here were conducted to obtain a direct measurement of energy stored in PCM wallboard relative to standard wallboard. For this purpose, the controllers were programmed so that the temperature in both rooms would cycle between the same limits with various heating and cooling rates, mostly between 11–25°C at a 0.03°C min^{-1} heating or cooling rate. This temperature range included the zone of indoor comfort conditions and also an extension below and above it. Our experiments were programmed so that the full-scale results could be compared with those obtained by DSC.

The energy consumed during the heating cycle was used to calculate the energy stored in PCM wallboard. Two assumptions were taken into consideration for this calculation:

1. The difference in heating energy required to heat



High set point = 26 °C, Low set point = 11 °C
Heating rate = 0.03 °C min^{-1}, Cooling rate = 0.03 °C min^{-1}
Dwell time = 6 hours
Environmental temperature = 14 °C
Heating energy consumption regular board room = 4618 W h
Heating energy consumption PCM board room = 6622 W h
A 30 hour test from 17:09 to 23:09

Fig. 3. Temperature profiles and heating energy consumption during a large scale temperature cycling test.

and keep both rooms at the same temperature is equal to the difference in thermal storage between PCM wallboard and ordinary wallboard.

2. Infiltration loads and conduction loads through walls, ceiling, doors, floors and windows are identical in both rooms. This assumption was based on the fact that, both rooms are constructed alike and subjected to the same environmental conditions during the test. In addition, the overall coefficients of heat transmission, as determined for the enclosure of each room are very close, i.e. 0.710 and 0.713 W m^{-2} °C^{-1} for the enclosure in the room lined with standard wallboard and for the enclosure in the room lined with PCM wallboard, respectively.

Fig. 3 is an example of the temperature profiles of a PCM and regular board during a temperature cycling test, as well as the heating energy consumed by each room during the heating cycle. Data presented in Fig. 3 were collected in a 30 h test. In this test, temperature in both rooms was cycled between 11°C and 26°C. The heating/cooling rate was 0.03°C min^{-1} and the environmental temperature was maintained at 14°C.

Data from four temperature cycling tests are presented in Table 1, where the following are indicated: heating range, heating rate, environmental temperature and energy used by each room during the heating cycle. The difference between the energy

Table 1
Experimental data utilized to calculate the thermal storage, as latent heat of PCM-wallboard

Temperature (°C)		Heating rate (2°C min^{-1})	Energy used for heating (Wh)		Energy difference		Latent heat (kJ kg^{-1})	
Environmental	Heating range		PCM wlbd.room	Standard wlbd. room	(W h)	(kJ)	PCM wlbd.	PCM
23	26–09	0.04	2443	528	1915	6894	27.6	136.8
23	25–12	0.03	2490	543	1947	7009	28.0	139.1
14	26–11	0.03	6622	4618	2004	7214	28.8	143.1
14	24–11	0.03	6222	4272	1950	7020	28.1	139.3
Average							28.1	139.6

consumed in the PCM wallboard room and the standard room is indicated in W h as well as kJ (1 W h=3.6 kJ).

As shown earlier, we assume that the difference in heating energy required to heat the PCM wallboard room and that required for standard wallboard room is due entirely to the latent heat energy stored in the incorporated PCM.

When this difference is divided by the total weight of PCM wallboard, i.e. 250.2 kg, then the thermal storage or the latent heat of PCM wallboard is obtained. The average latent heat of PCM wallboard derived from the data presented in Table 1 is 28.1 kJ kg^{-1}. When the same difference is divided by the total weight of PCM, i.e. 50.4 kg, then the latent heat of PCM is obtained. The average ΔH_m of Emerest 2325 as resulted from the data presented in Table 1 is 139.6 kJ kg^{-1}. This result varied by only 2.5% compared to the ΔH_m of 143.2 kJ kg^{-1} recorded by DSC.

It is interesting to note that the temperature vs. time curve of PCM wallboard from Fig. 3 shows that the transition process of the PCM takes place in the expected temperature range. In the respective curve, a first inflection appears at around 18°C, which corresponds to the initial m_p in the DSC curve in Fig. 2, followed by a more visible one at around 21°C, which corresponds to the final m_p in the DSC curve in the same figure.

A good correlation between the results of DSC analysis and large scale thermal testing was found also by Rudd [4], who tested the thermal storage of a wallboard impregnated with 25% PCM, 625 coconut fatty acid, by DSC and large scale tests (test room 3.35 m×3.35 m×2.44 m). His PCM wallboard was designed for a cooling-dominated climate.

In our work for development of PCM wallboard prototypes [7,8], DSC was a very useful method for selecting PCMs, for verifying the PCMs distribution in wallboard and for determining the effects of temperature cycling on the thermal characteristics of PCM wallboard. In addition, it has proven to be a very useful method in evaluation of PCM prototypes due to its accuracy in measuring temperatures and latent heats of transition.

4. Conclusion

DSC tests can be used successfully during the development of a particular PCM wallboard, so that expensive large scale tests need only be performed when the development of the PCM wallboard product is well advanced.

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References

[1] G.A. Lane, Phase-Change Storage Materials, in: E.C. Guyer (Ed.), The Handbook of Applied Thermal Design, Mc Graw Hill, New York, 1987.
[2] A. Ahbat, Solar Energy 30 (1983) 313.

[3] M. Shapiro, D. Feldman, D. Hawes, D. Banu, Passive Solar J. 4 (1987) 419.
[4] A.F. Rudd, ASHRAE Transcation, 99 Part 2 (1993) 339.
[5] T.K. Stoval, J.J. Tomlinson, J. Solar Energy Eng. 117 (1995) 318.
[6] D. Hawes, D. Feldman, D. Banu, Energy and Buildings 20 (1993) 77.
[7] D. Feldman, M.M. Shapiro, P. Fazio, D.W. Hawes, D. Banu, Energy Storing Wallboard (Phase I), Report on Contract File No. 23216-6-6090/01-St, Renewable Energy Branch, Energy Mines and Resources Canada, Ottawa, 1987.
[8] D. Feldman, D. Banu, Thermochim. Acta 272 (1996) 243.
[9] S. Scalat, D. Banu, D. Hawes, J. Paris, F. Haghighat, D. Feldman, Solar Energy Mater. and Solar Cells, 44, (1996) 49.