Natural Airconditioning System in Buildings Using Phase Change Material (PCM) And Gypsum Wallboard

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ABSTRACT

Research interest into the application of phase change materials (PCM) as energy storage materials in buildings has gathered momentum over recent years. PCMs utilizing latent heat produced during phase change transformation processes do attain higher energy density with small temperature difference than other storage media using sensible heat. One potential concept being pursued for minimizing cooling and heating loads is the integrated PCM wallboard system. This system is based on randomly mixing PCMs into wallboards. This study evaluates the concept of laminated-PCMs as integral part of wallboard system in building fabric. This novel approach of integrating PCMs promotes rapid transfer of latent heat, sharp response to indoor temperature, and minimizes multidimensional mode of heat transfer. It also facilitates production and recycling methods of wallboards. The investigation into the thermal performance of the laminated wallboard system was done numerically and experimentally. Through series of heat transfer simulations and under different sets of properties and conditions, the surface temperature variations were obtained. The temperature variations were then used to calculate the heat flux and the total amount of heat transferred in and out of the wallboard. For the purpose of comparison, simulations will be carried out for randomly mixed PCMs during heat storage and discharge processes

Keywords : Phase Change Materials, Recyclable

I. INTRODUCTION

Rapid development has lead to huge demand on energy. In an attempt to conserve energy and reduce dependency on fossil fuels and also to reduce the greenhouse gas emission, it is essential to seek effective means of reducing peaks in power consumption and to shift portions of the load from periods of maximum demand. Storage of thermal energy, hence, becomes an important aspect in engineering application, especially in energy conservation in buildings. For example, heat collected during periods of bright sunshine can be stored, preserved and later released for utilisation during the night in solar energy systems. Heat storage can also be applied in buildings where heating needs are

significant and electricity rates allow heat storage to be competitive with other forms of heating. The search for suitable heat storage materials has recently been directed towards the use of low melting organic materials in an effort to avoid some of the problems inherent in inorganic phase change materials, for example supercooling and segregation. An overview of the literatures on the characterisation, application and limitations of fatty acids as phase change material (PCMs) energy storage. Large thermal storage devices have been used in the past to overcome the Shortcomings of alternative cooling sources, or to avoid high demand charges. Buildings designed to make use of thermal storage include features which increase thermal mass. These may be used for storage only, or may serve both as storage and as structural elements.

1.4 ADVANTAGES

- Freeze without much supercooling
- Ability to melt congruently
- Self nucleating properties
- Compatibility with conventional material of construction
- No segregation
- Chemically stable
- High heat of fusion
- Safe and non-reactive
- Recyclable

PROJECT DESCRIPTION

DEFINITION OF PROBLEM

The objective of this work was to demonstrate the possibility of using microencapsulated PCM in concrete, achieving high energy savings in buildings. The work here presented is the experimental installation of two real size concrete cubicles to study the effect of the inclusion of a phase change material with a melting point of 26ºC, and a phase change enthalpy of110 kJ/kg. The results of this study show the energy storage in the walls by encapsulated PCMs and the

comparison with the standard concrete without phase change material. The cubicle with PCM showed higher thermal inertia than the reference cubicle, a given temperature is reached about 2 hours later in the cubicle with PCM than in the cubicle without PCM, for example in Summer this thermal inertia appears early in the morning due to freezing of the PCM and during the afternoon due to the melting of the PCM. Different experiments were performed in order to have areal behavior of a building. After seeing the results with the different cases and the comparisons among them, it can be concluded that all the cases had their advantages or disadvan-tages according to the months or seasons

II. EXISTING SYSTEM

The existing system consists the study of the inclusion of PCM in concrete, This modified concreted was then used to build one of the two identically shaped cubicles. The other cubicle was built with conventional concrete for reference The PCM used was a commercial microencapsulated PCM called Micronal PCM with a melting point of 26ºC, and a phase change enthalpy of 110 kJ/kg. Its mixture and inclusion in the concrete was developed

MODIFIED SYSTEM

The proposed system consists Gypsum wall board is coated by means of phase change materials such as paraffin wax and fatty acid such as lauric acid and air ventilation holes are present.

MATERIALS REQUIRED

- Phase change material (PCM)
- Wall Board and Gypsum material
- Temperature sensor

CONSTRUCTION

- Experimental setup with wallboard
- Pcm applied on the wall board
- Paraffin wax and lauric acid pcm
- Calculation and validation

III. METHODOLOGY

The work here presented is the experimental installation of two real size concrete cubicles to study the effect of the inclusion of a phase change material with a melting point of 26°C, and a phase change enthalpy of 110 kJ/kg. The results of this study show the energy storage in the walls by encapsulated PCMs and the comparison with the standard concrete without phase change material. The cubicle with PCM showed higher thermal inertia than the reference cubicle, a given temperature is reached about 2 hours later in the cubicle with PCM than in the cubicle without PCM, for example in Summer this thermal inertia appears early in the morning due to freezing of the PCM and during the afternoon due to the melting of the PCM. Different experiments were performed in two different cubes to observe the difference. The temperature and heat are calculated using Temperature sensor and are tabulated and calculate

Calculate heat generated in the room:

$$Q = m.C_p.\triangle T$$

m- mass of air flow consider per unit sec

C_p- 1.005 kj/kg .s

T_1-35°c max temp of the room

T_2-28°c initial temp of room

Volume of room is 1x1x1=1 m³

Density of air = 1.165 @ 30°c

Mass=density x volume = 1.165 k

$$Q = 1.165 \times 1.005 \times (35-28)$$

$$Q = 8.19 \text{ kW}$$

Assume the heat generated in the room is absorbed by PCM wall board

Heat transfer to the wall board

$Q = \triangle T/R$

Wallboard is composite

Layer 1 gypsum with 5 mm thickness

Layer 2 pcm with 3 mm thickness

Layer 3 gypsum with 5 mm thickness

$R = 1/A[1/h + L_1/K_1 + L_2/K_2 + L_3/K_3]$

$K1 = k3 = 0.17$

$h = 0.026$

$A = 1m^2$

Pcm-lauric acid Material

Lauric acid   Melting Point 44.2   cp in solid 1.76   cp in liquid 2.27

density in solid 1,007   density in 862

Final tempersature of pcm

$$Q = m.C_p.\triangle T$$

Calculate heat generated in the room:

$$Q_{Room} = \rho_{air} . V_R . C_p . (T_{max} - T_{min})$$

C_p - 1.005 kJ/kg .k

T_{max} - 38 °c max temp of the room

T_{min} - 28 °c minimum temp of the room

V_R - Volume of room is 3x3x3=27m³

ρ_{air} - Density of air = 1.165Kg/m³ @ 30° c

$$Q_{Room} = 1.165 \times 3 \times 3 \times 3 \times 1.005 \times (38-28)$$

$$Q_{Room} = 316.122 \text{ kJ}$$

Heat is transferred to the composite wallboard as per the one dimentional steady state conduction equation.

Consider the setup is composite walldoard

Q_{room} = $Q_{wallboard}$

$Q_{wallboard}$ = $(T_{max} - T_{min})$ /$R_{thermal}$

$R_{thermal}$ = L_1/$_{K1A1}$

$Q_{wallboard}$- heat generated in the wallboard

T_{max} - 38 °c max temp of the room

T_{min} - 28 °c minimum temp of the room

$R_{thermal}$- thermal resistance of the wallboard

L_1-Thickness of the gypsum wallboard 5mm

$_{K1}$-Thermal conductivity of the wallboard 0.17w/mk

$_{A1}$-Area of the surface $3 \times 3 m^2$

$R_{thermal}$ = $5 \times 10^{-3} m/(0.17 \times 3 \times 3)$

= $3.267 \times 10^{-3} k/w$

$Q_{wallboard}$ = $(38-28)/(3.267 \times 10^{-3} k/w)$

$Q_{wallboard}$ = $3.060 \times 10^{-3} w$

In second layer we have to placed in LAURIC ACID pcm

Total heat observed by the PCM

Q_{pcm} = ρ_{pcm} . V_{pcm} .$C_{p,solid}$.$(T_{max} - T_{min})$

Q_{pcm}- heat observed by the PCM

ρ_{pcm} -Density of PCM 1007kg/m³

V_{pcm}-volume of PCM

$C_{p,solid}$-Specific heat of solid pcm 1.76kJ/kg.k

V_{pcm} = area×thickness of pcm

= $(3 \times 3) \times (3 \times 10^{-3})$

V_{pcm} = $9 \times 10^{-3} m^3$

Q_{pcm} = $1007 \times 9 \times 10^{-3} \times 1.76 \times (38-28)$

Q_{pcm} = 478526.4 kJ

Heat observed by the pcm dissipated by atmospheric air circulated in the ventilation hole

$Q_{dissipation}$= h.A. $(T_{max} - T_{min})$

$Q_{dissipation}$ − dissipation by air circulation

h − heat transfer coefficient

So Calculate free convection method of vertical surface of a plate

Calculate grash number

G_{rx} = $g.\beta.x^3./v^2$

β - $1/T_F$

T_F - Film coefficient

T_F = $(T_{max} - T_{min})/2$

= (38+28)/2

T_F = 33 °c

β = 1/33=0.03

x^3-thickness of the hole 0.003m

v^2-Kinematic viscosity of the air 16.00×10^{-3} m²/s

G_{rx} = $9.81 \times 0.03 \times 0.003 \times (38-28)/ 16.00 \times 10^{-3}$

G_{rx} = 5.518×10^{-7}

If the condition is laminar flow G_{rx} . $p_r < 10^9$

p_r-Prandtl number of atm air 0.701

G_{rx} . p_r = $5.518 \times 10^{-7} \times 0.701$

G_{rx} . p_r = 3.868×10^{-7}

System is laminar flow,

Constant wall temperature

$^{NU}_X = 0.508 p_r^{0.5}(0.952 + p_r)^{0.25} G_{rx}^{0.25}$ for constant heat flux

$^{NU}_X = 0.508(0.701)^{0.5}(0.952 + 0.701)^{0.25} (5.518 \times 10^{-7})^{0.25}$

$^{NU}_X$ =0.013

$^{NU}_X$=hd/k

$^{NU}_X$=local Nusselt number

h - convection heat transfer coefficient

d - diameter of the hole 0.003m

k - thermal conductivity of atm air 0.02675W/mk

$^{NU}_X$ = hd/k

0.013= $h \times 0,003/0.02675$

h = 0.16m²k/w

$Q_{dissipation}$=h.A. $(T_{max} - T_{min})$

=$0.16 \times 3 \times 3 \times (38-10)$

$Q_{dissipation}$=14.4w

PHYSICAL PROPERTIES OF PCM

Table 1: Oleochemical with potential use as PCM. [2, 3-7]

Compound	Melting temperature (°C)	Heat of fusion (kJ/kg)	Thermal conductivity (W/m K)	Density (kg/m³)
Propyl palmiate	10[b]	186[a]	n.a	n.a
Isopropyl palmiate	11[a]	95-100[b]	n.a	n.a
Capric-lauric acids + pentadecane (90:10)	13.3[a]	142.2[a]	n.a	n.a
Isopropyl stearate	14-18[a]	140-142[a]	n.a	n.a
Caprylic acid	16[a] 16.3[a] 16.7[b]	148.5[a] 149[a]	0.149 (liquid,38.6°C)[a] 0.145 (liquid,67.7°C)[a] 0.148 (liquid,20°C)[a]	901 (liquid, 30°C)[a] 862 (liquid, 80°C)[b] 866 (liquid, 75°C)[a] 981 (solid, 13°C)[a] 1033 (solid, 10°C)[a]
Capric-lauric acids (65mol%-35mol%)	18.0[a]	148[b]	n.a	n.a
Butyl stearate	19[a]	140[b] 123-200[a]	n.a	n.a
Capric-lauric acids (45-55%)	21[a]	143[a]	n.a	n.a
Dimethyl sabacate	21[a]	120-135[a]	n.a	n.a
34% Miristic acid + 66% Capric acid	24[a]	147.7[a]	0.164(liquid,39.1°C)[a] 0.154(liquid,61.2°C)[a]	888(liquid, 25°C)[a] 1018 (solid, 1°C)[a]
Vinyl stearate	27-29[a]	122[a]	n.a	n.a
Capric acid	32[a] 31.5[a] 31.6[c]	152.7[a] 153[a]	0.153(liquid,38.5°C)[a] 0.152(liquid,55.5°C)[a] 0.149(liquid,40°C)[a]	878(liquid,45°C)[a] 886(liquid,40°C)[a] 858(liquid,75°C)[a] 853(liquid,80°C)[a] 1004(solid,24°C)[a]
Methyl-12 hydroxy-stearate	42-43[a]	120-126	n.a	n.a
Lauric acid	42-44[a] 44[a] 44.2[c]	178[b] 177.4[a]	0.147 (liquid, 50°C)[a]	862 (liquid, 60°C)[a] 870 (liquid, 50°C)[a] 852 (liquid, 75°C)[a] 848 (liquid,80°C)[a] 1007 (solid, 24°C)[a]
Myristic acid	49-51[a] 54[a] 58[a] 54.4[c]	204.5[a] 187[a] 186.6[a]	n.a	861 (liquid, 55°C)[a] 849 (liquid, 75°C)[a] 844 (liquid, 80°C)[a] 990 (solid, 24°C)[a]
Palmitic acid	64[a] 61[a] 63[a] 62.9[c]	185.4[a] 203.4[a] 187[b]	0.162 (liquid,68.4°C)[a] 0.159(liquid, 80.1°C)[a] 0.165 (liquid, 80°C)[a]	850 (liquid, 65°C)[a] 845 (liquid, 75°C)[a] 847 (liquid, 80°C)[a] 989 (solid, 24°C)[a]
Stearic acid	69[a] 60-61[a] 70[a] 69.6[c]	202.5[a] 186.5[a] 203[a]	0.172 (liquid, 70°C)[a]	848 (liquid, 70°C)[a] 843 (liquid, 75°C)[a] 839 (liquid, 80kC)[a] 965 (solid, 24°C)[a]

% in weight; n.a. : not available.
[a] : [3]
[b] : [4]
[c] : [2, 5-7]

Table 4: Boiling point of some fatty acids [15]

Pressure (mm Hg)	Boiling Point (°C)						
	Caproic	Caprylic	Capric	Lauric	Myristic	Palmitic	Stearic
1	61.7	87.5	110.3	130.2	149.2	167.4	183.6
2	71.9	97.9	121.1	141.8	161.1	179.0	195.9
4	82.8	109.1	132.7	154.1	173.9	192.2	209.2
8	94.6	121.3	145.5	167.4	187.6	206.1	224.1
16	107.3	134.6	159.4	181.8	202.4	221.5	240.0
32	120.8	149.2	174.6	197.4	218.3	238.4	257.1
64	136.0	165.3	191.3	214.6	236.3	257.1	276.8
128	152.5	183.3	209.8	234.3	257.3	278.7	299.7
256	171.5	203.0	230.6	256.6	281.5	303.6	324.8
512	192.5	225.6	254.9	282.5	309.0	332.6	355.2
760	205.8	239.7	270.0	298.9	326.2	351.5	376.1

Table 2: Thermal and physical properties of some fatty acids [8-34]

Acid	Latent heat of fusion (kJ/kg)	Specific heat (kJ/kg °C)		Heat of vaporization (kJ/kg)	Refractive Indexes (_D)
		Solid	Liquid		
Caproic	130.60	1.8815 (-33 to -10)	2.1369(0-23)	-	1.3972(70°C) 1.3944(75°C)
Caprylic	148.18	2.1139(18-46)	1.9464(0-12)	406.02[a]	1.4089(70°C) 1.4069(75°C)
Capric	162.83	2.0967(0-24)	2.0883(35-65)	355.79[a]	1.4169(70°C) 1.4149(75°C)
Lauric	182.92	2.1416(19-39)	2.1540(48-78)	288.82[a]	1.4230(70°C) 1.4208(75°C)
Myristic	197.15	2.1804(26-43)	2.1586(xo84)	372.54[a] 380.91[b]	1.4273(70°C) 1.4251(75°C)
Palmitic	211.80	2.0594(22-53)	2.2670(xo68)	246.96[a] 359.98[b]	1.4209(70°C) 1.4288(75°C)
Stearic	-	-	-	234.10[b] 334.86[b]	1.4337(70°C) 1.4318(75°C)

[a] Calculated for atmospheric pressure
[b] Calculated for 1-20mm Hg

Table 3: Thermal conductivities of commercial fatty acids [4]

Fatty acids	Temperature (°C)	Thermal Conductivity (W/m °C)
Lauric	72.5	0.1921
	90	0.1852
	106	0.1748
	148	0.1390
Oleic	72.5	0.1886
	90	0.1783
	106	0.1560
	148	0.1158
Palmitic	72.5	0.1719
	90	0.1573
	106	0.1384
	148	0.1026
Stearic	72.5	0.1603
	90	0.1468
	106	0.1321
	148	0.0966

THERMAL PERFORMANCE

Table 1: PCM Wallboard¹ Characteristics				
Wallboard	Density	Specific Heat	Conductivity	Latent Heat
	kg/m³	kJ/kg-K	W/m-K	kJ/kg
Conventional	696	1.089	0.173	0
10% PCM	720	1.215	0.187	19.3
16% PCM	760	1.299	0.192	31.0
20% PCM	800	1.341	0.204	38.9
30% PCM	998	1.467	0.232	58.3

Physical Properties of Treated Wallboard

As all organic PCM will continue to burn in normal atmospheric conditions after Igniting, potentially severe fire-hazards related to PCM-treated wallboard exist.

Two tested methods have shown promising results in eliminating the fire hazard For treated wallboards: limiting the amount of PCM to 20%, and sequentially treating the plasterboard with PCM, and with an insoluble fire retardant Only ultra-pure paraffins melt and freeze sharply at a given temperature. Mixtures of PCM show a region of temperatures where melting takes place.
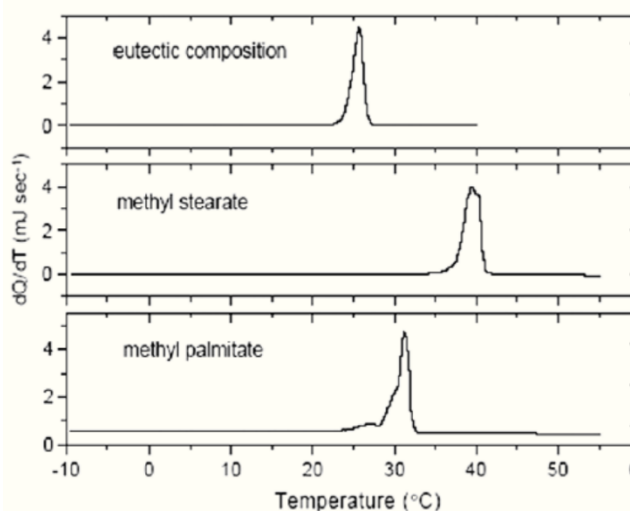
The endothermic DSC thermograms of: (a) methyl palmitate methyl stearate and (c) their eutectic mixture

Results from experimental studies and simulation exercises showed clearly that the treated wallboard does not act like an ideal storage material, which would melt and freeze at a specific temperature. Comparison between measured data and simulation results for the dynamic behavior of a stack of wall boards showed that the best agreement was obtained if the specific heat as a function of temperature was modeled by the typical triangular-shaped curve. Numerical Description of Phase Change Material As the specific heat is taken as the temperature derivative of the specific enthalpy h, the specific heat as a function of temperature shows a discontinuity at the melting temperature Tm.

IV. CONCLUSION

PCM-treated wallboard has the potential to convert light buildings, as often found in earthquake-prone areas, into thermally heavy constructions. thermally heavy residences can be kept thermally comfortable by using night-time ventilation to discharge the latent storage of the wallboard. Therefore, mechanical cooling or evaporative cooling could be eliminated by applying PCM-treated wallboard. The high surface-to-volume ratio of the wallboard helps to utilize the

storage capacity over a short cycle (24 hours). Compared to strictly sensible thermal storage, the storage density of PCM-treated wallboard is much higher, which allows to provide the necessary storage in a relatively thin layer. Longer cycles between charge and discharge can be mastered with higher thermal storage capacity. The additional storage capacity can be provided by multiple layers or thicker layers of treated wallboard. Cooling the envelope of a room by means of air transport through the room provides a very inefficient way of heat transfer. Air movement close to the walls, which determines the amount of heat being transferred, is relatively small. Particularly in periods of relatively high ambient temperatures during the night, it would be beneficial to force the supply air along the wall surfaces to facilitate good heat exchange.