THERMAL STORAGE OF SOLAR ENERGY IN THE WALL FOR BUILDING VENTILATION

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Building envelope, especially wall, has been used for energy storage in many ways. The review of those methods are presented with special emphasis on phase change material utilisation. In the article we present a solar wall, which absorbs solar energy into black paraffin wax as an example of phase change material (PCM). The stored heat is used for heating the air for the ventilation of the house. Experimental wall has been made and tested in the Laboratory for Heating, Sanitary and Solar Technology at the Faculty of Mechanical Engineering in Ljubljana. Charging of the heat storage wall has been done under solar simulator with heat flux G=500±50 W/m^2. Discharging has been done with the use of external air with the volume flow of 10 m^3/h. The results which are shown at the end of the article are very promising.

Introduction

Heating represents a large amount of energy use in buildings. Solar energy can drastically reduce this amount if we use it in a proper way. One of the possibility is the use of building envelope as a heat storage.

The basic idea is well known Trombe wall. Black wall absorbs solar energy and heat is transferred by conduction or convection to the interior of the building. The problem of the wall is that the temperature can be very high what cause injuries on the material.

Encapsulation of PCM into walls of a building showed very good results. P. Lamberg (2000) has researched combination of phase change material (PCM) with building material with TRNSYS. In the spring and autumn solar energy can be utilised passively by allowing solar radiation to be stored in the ceiling, walls and floor. During summertime, a large heat capacity prevents the inside air temperature from rising to the uncomfortable level. Kang and others (2000) made experimental study on latent heat energy storage system combined with night ventilation. The system can achieve prominent effect of decreasing room temperature. Yamaha (2000) made an evaluation of an air distribution systems with storage tank using phase change materials. It was found that PCM having melting temperature of 17ºC was the optimum under Japanese summer conditions.

Research on the thermal storage of PCM wallboard has been made by T. Kondo et al. (2000). They developed a PCM-wallboard by adding a PCM pellets into the plasterboard which is widely use for a based wall of a wooden house. By using the PCM wallboard to a wooden house makes a thermal capacity like that of a concrete house.

Latent heat thermal energy storage in Transparently Insulated Walls has been made by H. Weinlaender, A. Beck and J. Fricke (2000) where massive building was replaced by a thin layer of PCM with the use of transparent insulation. It was found out that latent heat thermal energy storage in transparently insulated walls is most suitable for lightweight buildings. With storage layers of a few centimetres solar efficiencies in the range of 70% are achieved. This leads to high energy gains and reduced heating demand. Due to the raised wall surface temperatures behind such systems, the operative temperature is increased. This improves thermal comfort or could lead to further energy savings if the room air temperature is decreased. Economical consideration are most promising if the latent heat transparent insulation is integrated into the wall system.

Phase change material and selection

Phase change materials (PCM) are materials which store energy in the process of changing the aggregate state from solid to liquid.

In the figure 1 we can see the increase of internal energy when energy in the form of heat is added to a substance. The well-known consequence is an increase in temperature (sensible heating) or change of phase (latent heating).

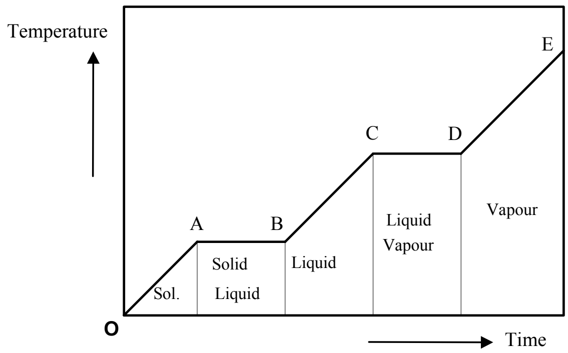

Figure 1: Temperature - time diagram for the heating of a substance

Starting with an initial solid state at point O, heat addition to the substance first causes sensible heating of the solid (region O-A) followed by a solid-to liquid phase change (region A-B), sensible heating of the liquid (region B-C), liquid-to-vapour phase change (region C-D) and sensible heating of the vapour (region D-E).

The total amount of heat can be written in the following formula:

$$\mathbf{Q} = \mathbf{m}\left[\int_{T_o}^{T_A} \mathbf{c}_{ps}(\mathbf{T})\mathbf{dT} + \mathbf{q}_t + \int_{T_B}^{T_C} \mathbf{c}_{pl}(\mathbf{T})\mathbf{dT} + \mathbf{q}_i + \int_{T_D}^{T_E} \mathbf{c}_{pv}(\mathbf{T})\mathbf{dT}\right] \qquad (1)$$

Candidates of phase change materials are grouped into the families of organic and inorganic compounds and their eutectics as seen in figure 2.

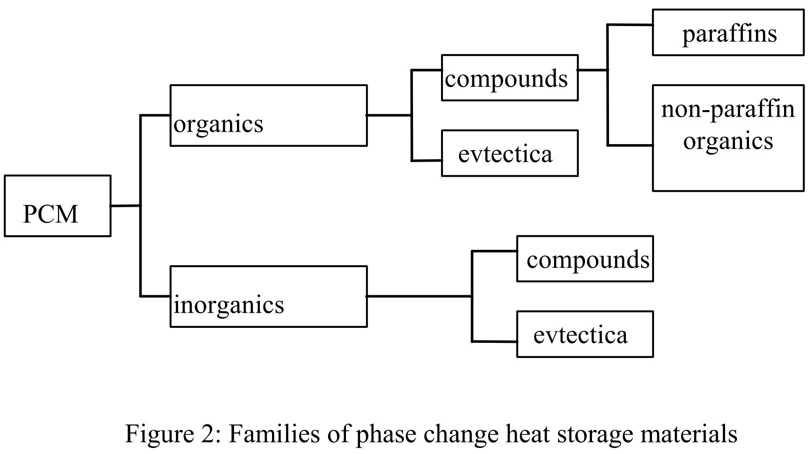

Figure 2: Families of phase change heat storage materials

In table 1 we can see selected phase change heat storage materials in the temperature range 20-80°C proposed by Abhat (1983).

Table 1: Groups of phase change materials

PARAFFIN	ORGANIC COMPOUNDS	INORGANIC COMPOUNDS	EVTECTICS
1. PARAFIN 5913	8. Capric acid	21. H_2O	40. Propionamid +
2. PARAFIN 6106	9. Poliglikol E600	22. $LiClO_3 \cdot 3H_2O$	Palmitin acid
3. PARAFIN 5838	10. Caprinic acid	23. $LaOH \cdot 3{,}5H_2O$	41. $Mg(NO_3)_2 \cdot 6H_2O$ +
4. PARAFIN 6035	11. Laurinic acid	24. $KF \cdot 4H_2O$	$MGCl_2 \cdot 2H_2O$
5. PARAFIN 6403	12. Miristic acid	25. $NO_3 \cdot 3H_2O$	42. $LaNO_3 + Lh_2NO_3$ +
6. PARAFIN 6499	13. Poliglikol E6000	26. $CaCl_2 \cdot 6H_2O$	NH_4Cl
7. OKTADEKAN	14. Laksiol	27. $Na_2SO_4 \cdot 10H_2O$	
	15. Palmitin acid	28. $La_2CO_3 \cdot 10H_2O$	
	16. Stearin acid	29. $LiClO_3 \cdot 3H_2O$	
	17. Bifenil	30. $Zn(NO_3)_2 \cdot 10H_2O$	
	18. Propionamid	31. $CaBr_4 \cdot 6H_2O$	
	19. Naftalen	32. $KF \cdot 2H_2O$	
	20. Acetamid	33. $Na_2S_2O_3 \cdot 5H_2O$	
		34. $Ni(NO_3)_2 \cdot 6H_2O$	
		35. $NaCH_4COO \cdot 3H_2O$	
		36. $NaOH \cdot H_2O$	
		37. $Na(OH)_2 \cdot 8H_2O$	
		38. $Na(NO_2)_2 \cdot 6H_2O$	
		39. $MgCl_2 \cdot 16H_2O$	

Paraffins are compounds which are at the room temperature in shape of waxes. Chemically they are hydrocarbons with alkans C_nH_{2n+2}. The melting point increases with increasing of C atoms. The majority of organic nonparaffins are acids. They can be characterised with the formula $CH_3(CH_2)_{2n}COOH$. Their melting point is similar to those at paraffin. Their badness is poisonous and the reason they are more expensive as paraffin. Inorganic compounds are known by the formula $M \cdot nH_2O$ and have been studied for many years. They have relatively high latent heat but their melting-solidification processes are irreversible since of segregation. Eutectics are mixture of two or three compounds and are melted without segregation.

Figure 3 show the latent heat of fusion per unit volume of some phase change heat storage materials.

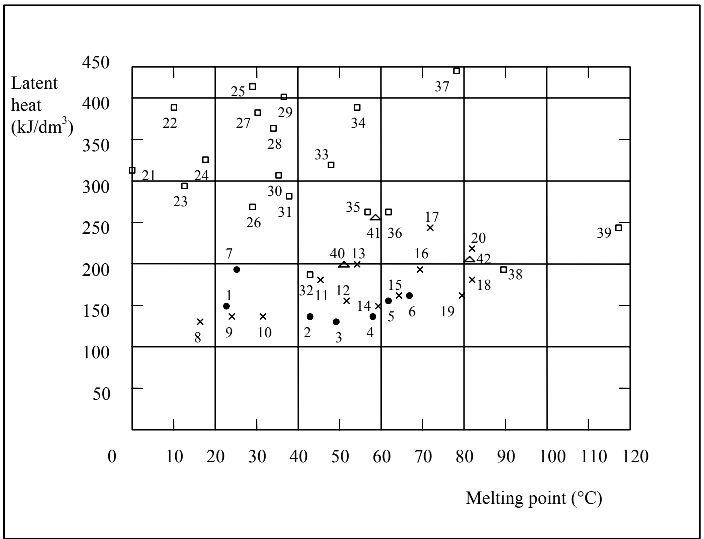

Figure 3: Latent heat of fusion per unit volume

Criteria which help us to choose the best phase change material for our system are listed at the end of first chapter. PCM can be selected on the basis of thermodynamic, kinetic, chemical and economical criteria.

Wall construction

A facade construction designed for storing the heat of solar radiation falling on the absorber plate with PCM was developed in the Laboratory for Heating, Sanitary and Solar Technology at the Faculty of Mechanical Engineering in Ljubljana by Novak, Medved and Stritih (1994, 1996). The wall consists of six main components and it is presented in Figure 4.

The wall construction operates on the following principles. Short-wave solar radiation passes through glass with TIM (Transparent Insulation Material) (1,2) which at the same time prevents convective and short-wave radiation heat transfer. Black paraffin wax (3) in a transparent plastic casing made of polycarbonate, absorbs and stores energy mostly as latent heat. The air for the house ventilation is heated in the air channel (4) and it is led into the room. Insulation (5) and plaster (6) are standard elements in the room.

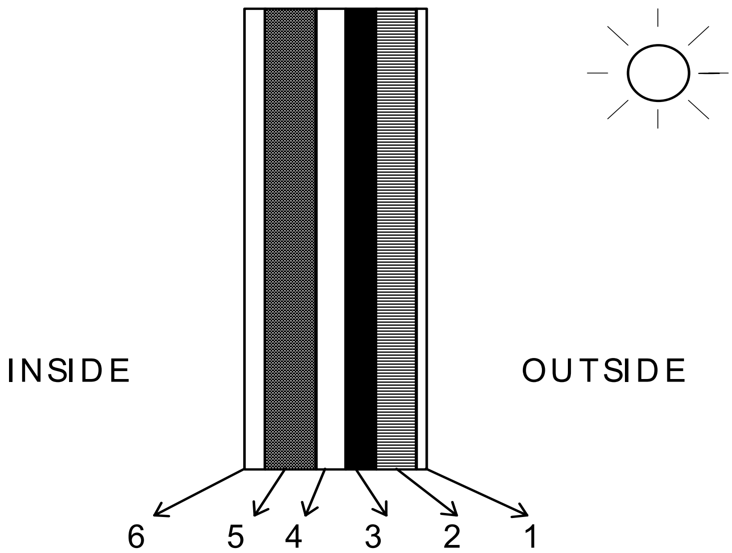

Figure 4: Elements of PCM solar wall

As phase change material we have used Rubitherm product RT30 (1995). The characteristics of used PCM are presented in Table 2. The optimal melting point of 25-30°C and the thickness of the panel (50 mm) were achieved by simulation.

Table 2: Characteristics of used PCM

QUANTITY	*VALUE*
melting point	*25-30 °C*
latent heat	*150 kJ/kg*
viscosity	*1,9 mm²/s*
density	*1,412 g/cm³*
oil contain	*5,5 %*
specific heat - solid	*2,1 kJ/kgK*
specific heat - liquid	*2,4 kJ/kgK*
conductivity - solid	*0,2 W/mK*
conductivity - liquid	*0,15 W/mK*
absorbtion coefficient	*0,95-0,97*

Experimental investigation

The measurement of wall element has been tested in the Laboratory for Heating, Sanitary and solar Technology under solar simulator.

The following characteristics has been measured:

- radiation G(W/m^2)
- volume flow of the air V(m^3/s)
- temperatures (T)

On the next picture we can see the experimental wall.

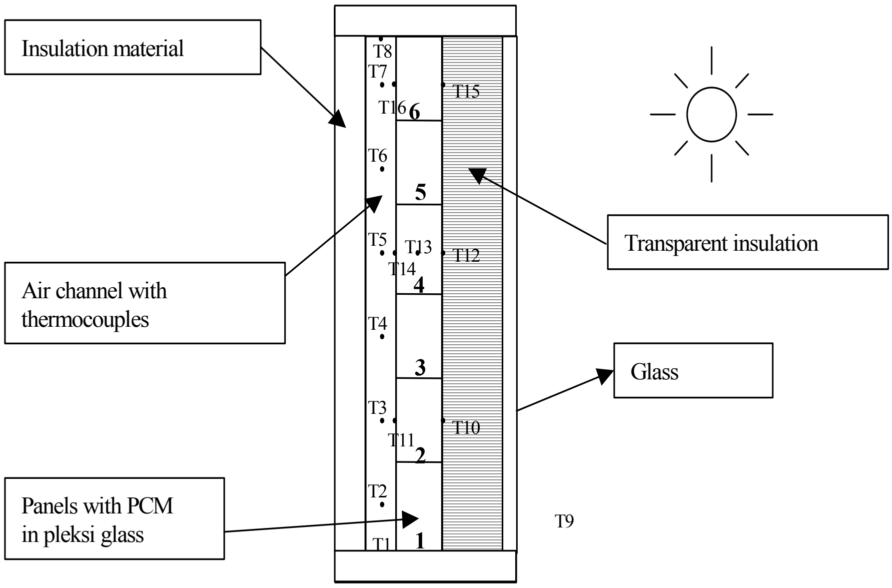

Figure 5: Thermocouples placement

In the table 3 we can see the measured temperatures:

Table 3: Measured temperatures

Symbol	Measured quantity
T1	Temperature of inlet air
T2	Temperature of air near the panel 1 (first on the botom)
T3	Temperature of air near the panel 2
T4	Temperature of air near the panel 3
T5	Temperature of air near the panel 4
T6	Temperature of air near the panel 5
T7	Temperature of air near the panel 6 (last on the top)
T8	Temperature of outlet air
T9	Temperature of the surrounding
T10	Temperature of external temperature of panel 2
T11	Temperature of external temperature of panel 4
T12	Temperature of external temperature of panel 6
T13	Temperature of the paraffin in the panel 4
T14	Temperature of the interior surface of the panel 2
T15	Temperature of the interior surface of the panel 4
T16	Temperature of the interior surface of the panel 6

Measurement of charging characteristics

The measurement has been done under solar simulator with the radiation G=500±50 W/m^2 without volume flow of the air.

On the following figures we can see melting characteristics:

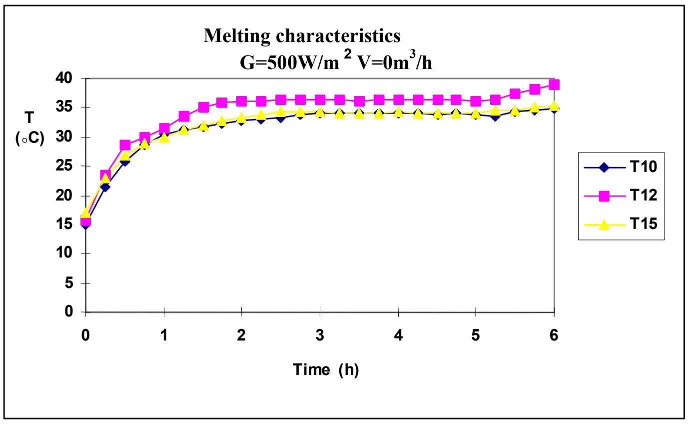

Figure 6: Temperatures of the bottom panel at melting

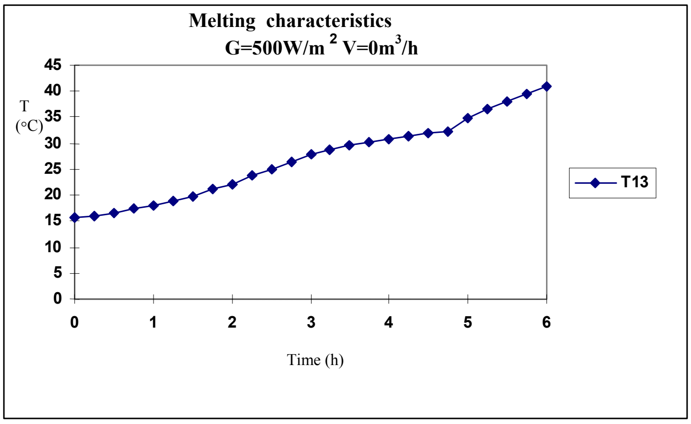

Figure 7: Temperature of the paraffin at melting

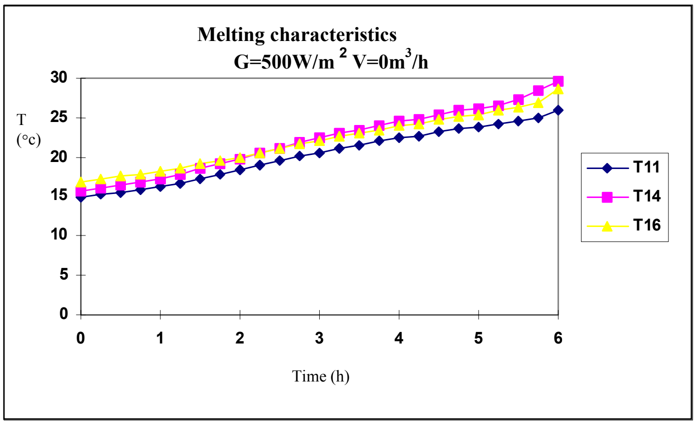

Figure 8: Temperature of top panel at melting

From the data we can get the efficiency at melting; this is the ration between the accumulated heat and the radiation (equation 2):

$$\eta_s = \frac{Q}{H} \qquad (2)$$

Where is: Q received heat (J)
H radiation (J)

Radiation can be calculated with the equation 3:

$$H = G \cdot A \cdot \tau \qquad (3)$$

Where is: G radiation (W/m^2)
A surface (m^2)
τ time (s)

We get:

$$H = 500 \cdot 1{,}44 \cdot (6 \cdot 3600) = 15552000 J = 4320(1 \pm 0{,}05) \quad Wh$$

Accumulated heat can be calculated via equation 4. We suppose the constant temperature in the panels:

$$Q = m(c_{ps}\Delta T + q_t + c_{pl}\Delta T) \qquad (4)$$

Where is:

m mass (kg)
c_{ps} specific heat of solid (J/kgK)
c_{pl} specific heat of liquid (J/kgK)
ΔT temperature difference (K)
q_τ melting heat (J/kg)

We get:

$$Q = 60 \cdot (2100 \cdot (30 - 15) + 150000 + 2400 \cdot (40 - 30))$$
$$Q = 12330000 J = 3425(1 \pm 0{,}03) \quad Wh$$

The efficiency can be calculated via equation 2:

$$\eta_s = \frac{Q}{H} = \frac{12330000}{15552000} = 0{,}79 \pm 0{,}08$$

Measurement of discharging characteristics

Discharging was investigated with the air volume flow of 10 m^3/h.

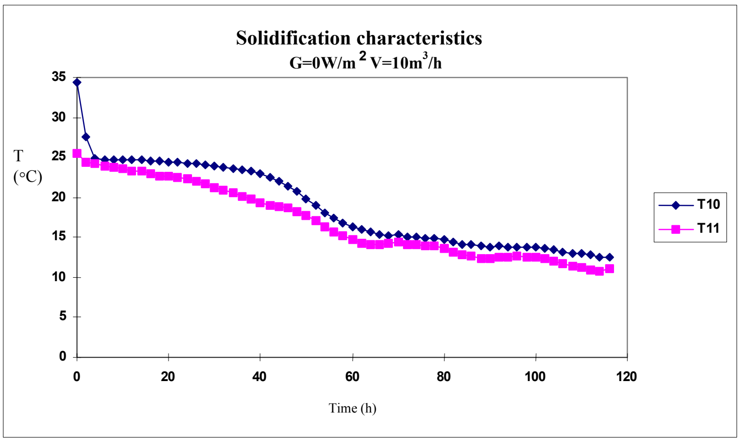

Figure 9: Temperatures at the bottom panel

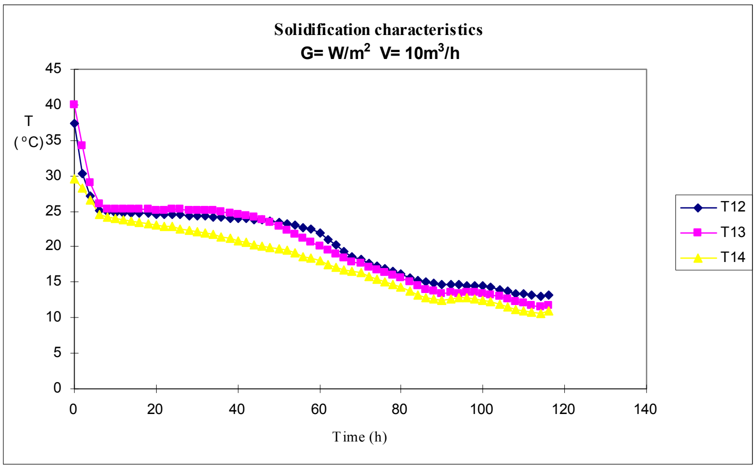

Figure 10: Temperatures at the middle panel

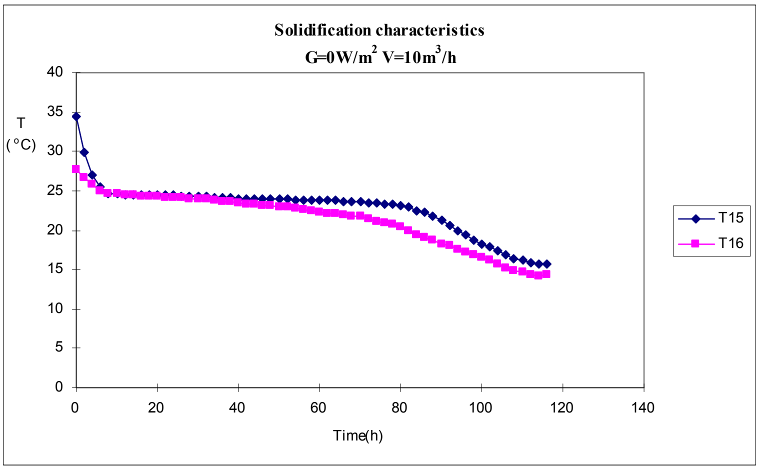

Figure 11: Temperatures at the top panel

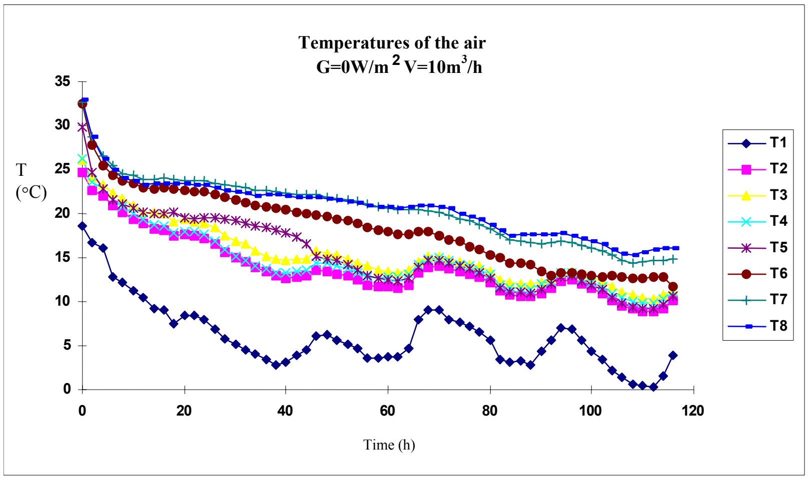

Figure 12: Temperatures of the air in the air channel

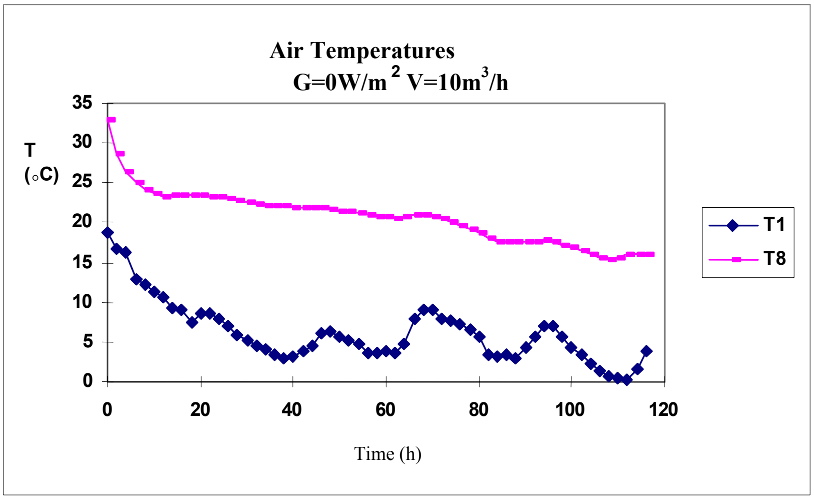

Figure 13: Temperatures of the inlet and outlet air

From the results we can calculate the efficiency at discharging process. This is the ratio between the received heat and the heat which was stored in the paraffin:

$$\eta_o = \frac{Q_z}{Q} \qquad (5)$$

Where is: Q_z heat to the air
Q heat stored in the paraffin (equation 4)

Heat which transfers to the air flow can be calculated via equation:

$$Q_z = \dot{m}_z \cdot c_{pz} \cdot \Delta \overline{T} \cdot \tau \qquad (6)$$

Where is: m_z air mass flow
c_{pz} specific heat of the air
ΔT temperature difference between inlet and outlet air
τ time

So we receive:

$$Q_z = w \cdot A \cdot \rho \cdot c_{pz} \cdot \Delta \overline{T} \cdot \tau \qquad (7)$$

Where is: w air speed
A surface
ρ air density

$$Q_z = 10 \cdot \pi \cdot 0{,}009^2 \cdot 1{,}3 \cdot 1005 \cdot (22-8) \cdot 3 \cdot 24 \cdot 3600$$

$$Q_z = 11457212 J = 3182(1 \pm 0{,}03) \quad Wh$$

So we get the efficiency:

$$\eta_0 = \frac{11457212}{12330000} = 0{,}93 \pm 0{,}03$$

Conclusion

Energy storage in phase change material has a lot of advantages over sensible systems because of the lower mass and volume of the system and since the energy is stored at relatively constant temperature energy losses to the surroundings are lower as at the conventional systems.

Salts are not suitable for latent energy storage because their irreversibility and subcooling. Acids are poisonous and their price is relatively high. Paraffin has from all materials the best characteristics. Their problems are flammability and low thermal conductivity. Flammability can be decreased with special additives. Thermal conductivity is important at the problems where heat must be transferred at the short period of time (high heat fluxes). In our case this is not so important.

The solar wall has a lot of advantages. The solar energy is absorbed directly into black paraffin and stored at the same media. We have absorber and heat storage at the same material. Plastic glass is at the same time insulation material. Because of the energy storage at the lower temperature level losses to the surroundings are lower as at other systems (Trombe wall).

The most important characteristic is the solidification of the paraffin which occurs from the bottom to the top what causes relatively constant temperature of the outlet air.

Acknowledgement

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