The parameters of the thermal panel based on a phase change materials

Martin Kolacek, and Martin Zalesak

Abstract— Article describes results of research of behavior and application of the thermal panels. These panels are based on the phase change materials under normal inner environment temperature in buildings. It was measured a several important parameters of thermal panel. Time constant, heat transfer coefficient and their changes in different surface treatment of the panels were measured. All process of measurement were done in heating mode with the thermal electric foil. The article describes the parameters of panel which were obtained by different methods measurement and calculation. The parameters were applied in simulation environment where was created a computer model. The simulation model was validated with the parameters that were measured on the real thermal panel. In the simulation environment were created a different application of these panels to determine an appropriate use

Keywords—Phase change materials, heat transfer coefficient, heat flux, thermal imager and simulation environment

I. Introduction

THE heat storage materials start to apply for increase of the thermal accumulation parameters in buildings. The area where can be PCM materials used is so enormous and a particular uses is just in storage panels. These panels are created in form of block and there are easily recovered for increase the thermal storage parameters in lightweight construction such as wooden houses. PCM material can be created from water, paraffin and salt hydrates which allow to absorb, retain and later release a certain amount of energy. The released energy can be in form of heat or cold. The change of condition in materials occurs when the temperature difference is small. In the case of PCM materials it occurs in phase changes from solid state to liquid state. This change is accompanied by a large latent heat that can be utilized for a accumulation of heat. The ability of energy storage is called latent heat because these materials are also referred as Latent heat storage systems. The PCM materials are used in building construction and these materials can be based on organic or inorganic compounds. Among of these materials are used compounds based on modified paraffin that is used for the nucleation of large latent heat. This property is important in heat storage systems. [3],[4],[6]

The thermal storage panels are composed from mixture of ethylene based polymer 40% and 60% paraffin wax. For the crystallization of wax is necessary a large latent heat, therefore these materials are suitable as heat storage. The surface is formed on the panels by shiny aluminum cladding, thickness approximately 130μm. [2]

Measurement of parameters of PCM panels was done on the thermal panel that is located in laboratory of Faculty of Applied Informatics Tomas Bata University in Zlín in Czech Republic. System consists from two panels and in the panels are imposed 12 accumulation blocks. The rear part of panel consists of insulation and between 6 layers are imposed 3 electric heat foils on performance of 600 W. There is also water tube heat exchanger for heating or cooling. The composition of thermal panel you can see in Fig.2. Dimensions of one panel are 1,25 x 0,083 x 2,07 m, and is covered with polished galvanized sheet. It is a specific equipment and all components are filled with thermally conductive mass.

Fig. 1 thermal panels which are located in the laboratory of Environmental Engineering

The basic problem of using thermal storage panels is heat transfer from panels. Main parameter of heat transfer is heat transfer coefficient. This parameter has two important parts, convection and radiation.

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M. Kolacek is with the Tomas Bata University in Zlín Faculty of Applied Informatics. Department of Automation and Control Engineering. 760 05 Zlín Czech Republic. (e-mail: kolacek@fai.utb.cz, +420 576 035 642,).

M. Zalesak is with the Tomas Bata University in Zlín Faculty of Applied Informatics. Department of Automation and Control Engineering,760 05 Zlín Czech Republic. (e-mail: zalesak@fai.utb.cz).

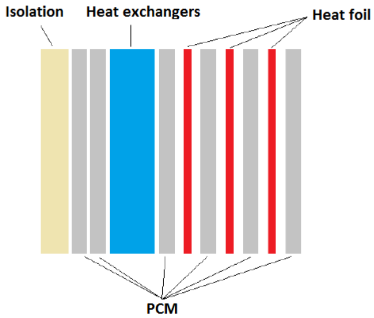

Fig. 2 Composition of thermal panel

The radiative heat transfer coefficient is influenced by surface emissivity. The emissivity of surface of measured equipment is about ε = 0,1, accumulation panels has polished surface and its emissivity is less than 0,1. The emissivity was measured by contact and contactless thermometer and results were around ε = 0,6. The surface of panel was oxidized and this high value of emissivity was inaccurate. The temperature distribution was measured by thermo imager. In this part of measurement was problem with an apparent reflected temperature in thermo imager.

II. The Heat transfer coefficient

Thermal panels were heated by electric heat foils. During the cooling process occurs changes of surface temperature (36°C - 22°C) and also the heat transfer coefficient changed.

As it is seen in Fig. 3, the value of heat transfer coefficient depends on the size of temperature difference between surface of panel and environment. During the cooling process decrease the value of coefficient, therefore it was necessary to calculate the average value. For a time constant is necessary temperature difference 27-35°C, in case of the heat transfer coefficient means average value was h = 4,1 W.m^{-2}K^{-1}. Total cooling time is very long with temperature decrease by 13 K about 40 hours, therefore the value of heat transfer coefficient is very small because the temperature difference is so small.

For gaining of parameters of panel it is difficult to maintain a stable microclimate conditions in a laboratory. Air temperature fluctuates between ± 2 K.

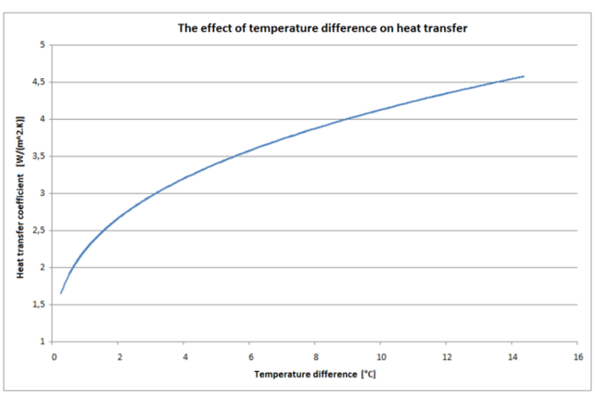

Fig. 3 the effect of temperature difference between the panel surface and surrounding environment on the heat transfer coefficient

The heat transfer coefficient was determined by a calculation involving a natural convection and radiation, below is equation.

$$Nu = 0{,}135\left(\frac{g.\beta.l^{3}.\Delta\theta}{v^{2}}\,\frac{c_P.\eta}{\lambda}\right)^{1/3} \tag{1}$$

Where Nu is Nusselt number [-]
g gravitational acceleration [m.s^{-2}]
β thermal expansion [K^{-1}]
l characteristic dimension [m]
$\Delta\theta$ temperature difference [K]
c_p specific heat capacity [J.kg^{-1}.K^{-1}]
η dynamic viscosity [Pa.s]
v kinematic viscosity [m^2.s^{-1}]
λ coefficient thermal conductivity [W.m^{-1}.K^{-1}]

$$Nu = \frac{h_C.l}{\lambda} \tag{2}$$

Where h_C is convective heat transfer coefficient [W.m^{-2}.K^{-1}]

$$h_T = \varphi_{12}.\varepsilon.10^{8}\sigma\frac{\left(\frac{T_1}{100}\right)^4-\left(\frac{T_2}{100}\right)^4}{T_1-T_2} \tag{3}$$

Where h_T is radiative heat transfer coefficient [W.m^{-2}.K^{-1}]
ε emissivity [-]
σ Stefan-Boltzmann constant [W.m^{-2}K^{-4}]
T thermodynamic temperature [K]

$$h = h_C + h_T \tag{4}$$

Where h is total value of heat transfer coefficient [W.m^{-2}.K^{-1}]

The surface temperatures were measured at different places of panels and these values were same almost in every point.

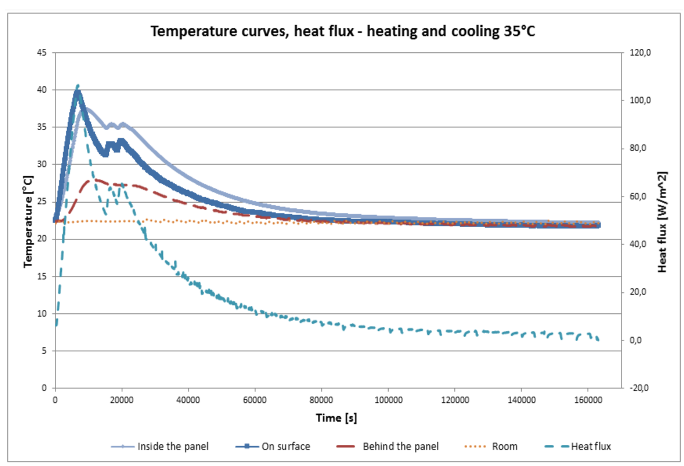

Fig. 4 temperatures in different locations of panel, the heat flux from the front surface of the panel

The temperatures are shown in Fig. 4, where the temperatures are in different part of panel, heat flux and ambient temperature in the laboratory. Temperature curves are representing the average temperature.

Effects of heat accumulation are very difficult to evident from graph in Fig. 3, the reasons are that composition of panels is very extensive, but especially due to measure the impact of accumulation during the heating.

The value of Biot criterium was validated for verification thermal dynamic behavior of the panel from values in Table. 1. A specific heat capacity is the value of this system without latent heat in the temperature range 22-33 °C.

Table 1 measured and calculated parameters panel

Name	Symbol	Unit	Value
Heat transfer coefficient	h	[$W.m^{-2}.K^{-1}$]	4.1
Specific heat capacity	c_P	[$J.kg^{-1}.K^{-1}$]	8400
Density	ρ	[$kg.m^{-3}$]	810

The value of Biot number was less than 0.1, therefore the system was possible evaluated by the thermal transient state with differential equations of the 1. order. [3]

Table 2 values of Biot number

Name	Dimensions (H,W,D)[m]	Biot number
1x PCM plate	1x1,2x0,0054	0,078
Thermal system	2,07x1,25x0,08	0,00429

The next possibility of identify the heat transfer coefficient was done from measure the heat flux. The value of heat transfer coefficient was obtained from heat flux was different than the value determined by calculation. The heat flux was measured by heat flux plate which was fixed on the surface of the thermal panel. The difference could be caused imperfect contact surface of the sensor and thermal panel, and a small measuring surface of the sensor. Because the difference of values is small it is possible to use this method to determine the heat transfer coefficient. In Fig.5 you can see temperatures, heat flux and heat transfer coefficient which were measured.

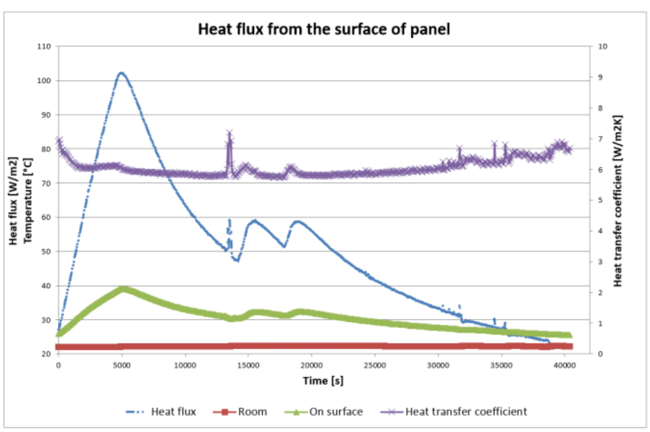

Fig. 5 Heat flux and result of the heat transfer coefficient

Table 3 The values of heat transfer coefficient their comparison

Name	Methods	Value
Heat transfer coefficient	*Calculated*	4.1
Heat transfer coefficient	*From the heat flux*	6

Another possibility determining of the heat transfer coefficient was to use a time constant. But in this case it is problem in parameters of thermal panels as density and specific heat capacity. The thermal panel is composed of several different materials and therefore it is difficult to identify these parameters of the whole panel.

III. Time Constant

Time constant was determined by several methods from measuring the cooling process, calculation or in simulation environment. The average value of time constant is τ = 6,8 hours, time constant of one PCM plate is then τ = 75 min. Calculations were carried out according to the following equations.

$$\frac{\theta}{\theta_i} = \frac{\theta - \theta_\infty}{\theta_i - \theta_\infty} = e^{(-Bi.Fo)} \tag{5}$$

Where θ is initial temperature [°C]
θ_i temperature reached [°C]
θ_∞ temperature stabilization [°C]
Bi Biot number [-]
F_o Fourier number [-]

$$\frac{\theta}{\theta_i} = e^{\left(\frac{h.L_C}{\lambda}.\frac{a.\tau}{L_C^2}\right)} \tag{6}$$

Where L_C is characteristic dimension [m]
a Thermal conductivity [$m^2.s^{-1}$]
τ time constant [s]

$$\tau = \frac{\rho.V.c_P}{h.A} \tag{7}$$

Where ρ is density [$kg.m^{-3}$]
V volume [m^{-3}]
A area [m^{-2}]

IV. Surface Temperature to Measure by a Thermal Imager

The surface temperature of panel was measured by using the thermal imager. The surface of panel is made from polished galvanized sheet therefore a view of thermogram is distorted. The problem is in very low value of emissivity. The thermal imager showed a reflected apparent temperature, this temperature is shown in Fig. 6.

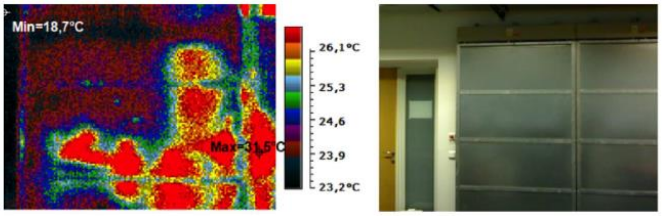

Fig. 6 thermogram of shiny surface, ε = 0,39, temperature surface θ= 32,7 °C, temperature ambient θ= 25 °C, humidity φ = 40 %, distance from panel 3,5 m

It was necessary to perform change of the surface, which shows the surface temperature without influence of inhomogeneity. One panel was painted black matte paint, than a measurements were performed again with a modified surface of panel.

On thermogram in Fig. 7 can be seen uniform distribution of surface temperature of the panel. This temperature distribution was verified by thermocouples, which confirmed uniform distribution of surface temperature as it was captured by thermo imager.

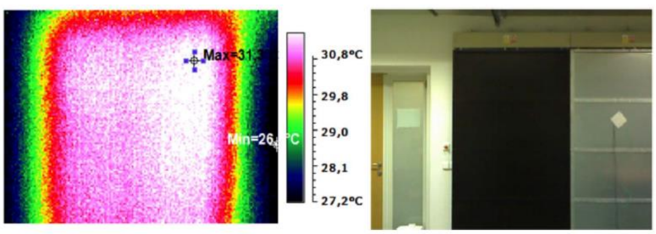

Fig. 7 thermogram of modified surface, ε = 0,97, temperature surface θ = 29,5 °C, temperature ambient θ = 24,8 °C, humidity φ= 40 %, distance from panel 3,5 m

The modified surface caused an increase in heat transfer by radiation, value of emissivity is ε = 0,97. This change caused the rapid cooling. Total value of heat transfer coefficient was h = 8,29 W.m^{-2}.K^{-1} (increase of value). The time constant decreased to value τ = 5,5 hour.

The value of heat transfer coefficient which was obtained from heat flux was 7,5 W.m^{-2}.K^{-1}. So in this case it is seen the increase which caused the change of surface panel.

Problems of change the surface properties of the storage panels is important in terms for heat transfer efficiency and also in terms of placement in construction. A manufacturer of storage panels guarantees a stability of paraffin wax in a higher temperature and panels are placed under the inner lining as plasterboard or wooden cladding. [2] The thickness of cover material is very important for the heat transfer efficiency. The measurement was performed on thermal panels which have a cover layer from galvanized sheet 2 mm thick. This layer minimizes thermal resistance and the surface of the responsibility are similar as storage plate which are placed inside the thermal panel.

V. Heat Exchanger

As another possibility of heating the thermal panel was used heat exchanger. This heating method is much more difficult not only in terms of energy but also the time. The temperature sensors are placed in specific cooper tubing which are placed near the tubular heat exchanger, it caused very fast temperature reaction. The regulation of regulator was difficult and time consuming. To reach of the desired temperature of thermal panel took longer because it was difficult to obtain warmed of individual plates. In fig. 8 you can see individual temperature curves.

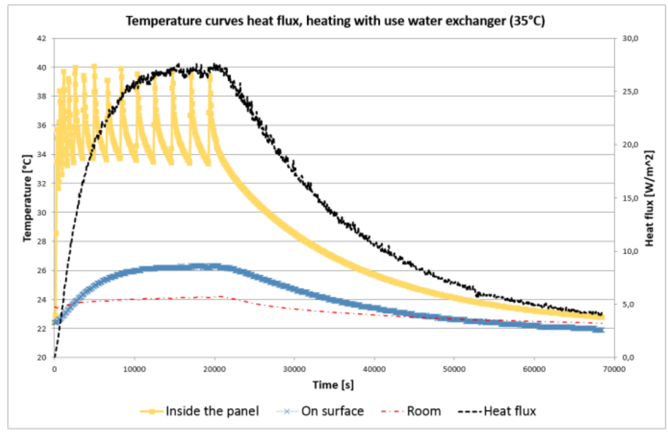

Fig. 8 the measurement of the thermal panel by use heat exchanger

In fig.8 you can also see that after 5 hours increased the surface temperature only 26 °C in the case of heating electric foil that was 33°C.

This method is not advantageous from an economic aspect because the heating of PCM panels takes a long time and leads to thermal losses. The advantage is the necessity of using low temperature substance heated in heat exchanger because of maximum temperature in PCM materials 40°C. We can use for heating a solar collectors or waste heat from different heat sources.

VI. The Use of PCM Materials

Part of the research of panel was to applicate into the upper layers of heating devices, heating wall. The research of behavior of panel was simulated and results were verified experimentally. Maximum temperature of panels is 40 °C therefore the direct application is suitable for large-scale low-temperature systems (underfloor heating, heating walls and ceilings).

The panels were heated to a temperature 35°C, maximum heat flux was 65 W.m^{-2}. Charging the panel took 85 min and this ensured surface temperature in the range 27-35°C lasting for 6,8 hour. The panels can be used under cover layer of underfloor heating. Another usage can be in heating ceiling it was applied in a simulation model.

VII. The Simulation Model of the Storage Panel

The effective heat capacity was only used as the average value for principle of modeling phase changes in a simulation. A model of thermal panel was also created but its complexity of the composition cased difficulty in a simulation. A simple simulation caused the calculation time took almost 18 days yet it was used a powerful computing units. For a simulation model was created a simple accumulation plate and boundary conditions were used from measured values of thermal panels.

To verify the measured data was created a simple room in dimensions 3,7 x 3 x 3 m, thickness of wall and floor was 0,35 m. Under storage panel was placed 0,03 m isolation. Ambient conditions were set on constant temperature θ = 21 °C, initial temperature of panel was θ = 33 °C.

Time constant obtained from simulation was τ = 80 min, the calculated value was τ = 75 min.

The usual use is placement of these panels on wall and ceilings. The panels have an ability to accumulate an excess of heat inside the room and they can reduce the temperature peaks up to 7 °C (reduce of operating temperature).

Another simulation model was created to locate panels in the floor and its dimensions were 8,7 x 8 x 3 m. In this case was much more efficient release of energy than in the case of placement in the wall, Fig. 10. The results confirmed an appropriate use of PCM a application in underfloor heating.

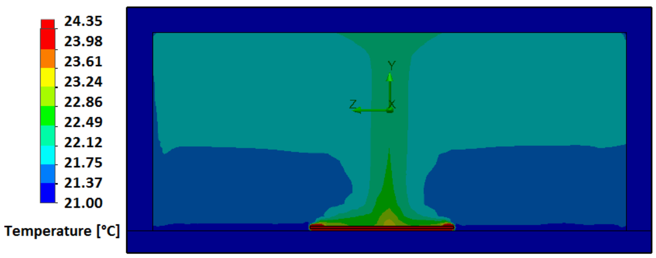

Fig. 9 the temperature of the room and panel, placement on the floor (view cut)

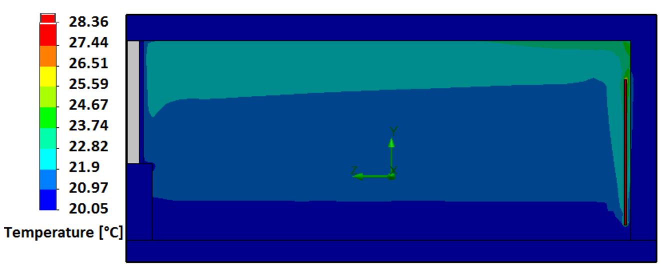

Fig. 10 the temperature of the room and panel, placement in the wall (view cut)

For the heat transfer efficiency is important a sheathing of panels. In another model was validated an application of the cover layer by drywall of the PCM materials. This application of PCM materials was done to verify of effectiveness the heating in ceiling. An important element was primarily radiation heat transfer. The dimension of simulation room were the same as in the previously model, where the panels were placed in the ceiling and 5mm thickness of drywall as cover layer. Initial conditions were set: air temperature surrounding walls and internal environment θ = 18 °C, temperature of PCM material θ = 35 °C. The experiment showed a heat discharging took 2 hours where these values were: the average air temperature increased to 24,3 °C, surface temperature of drywall 30,5 °C.

Another situation was used PCM materials without cover layer. The results were achieved as these: the average air temperature in room 26 °C, surface temperature of PCM's after 2 hours of discharging 32,3 °C. Results from these simulation showed importance to ensure an adequate cover layer of PCM panels. This cover layer must ensure an efficient heat transfer due to its minimum thickness and suitable emissivity.

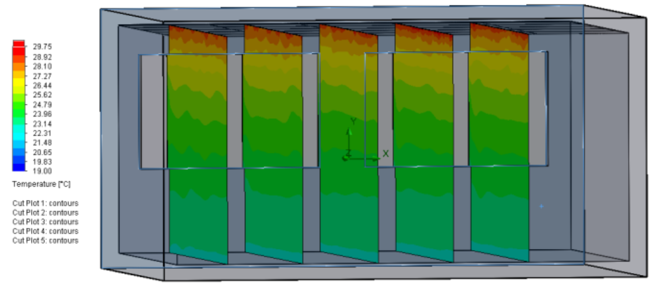

Fig. 11 the temperature distribution in the room, cover layer drywall

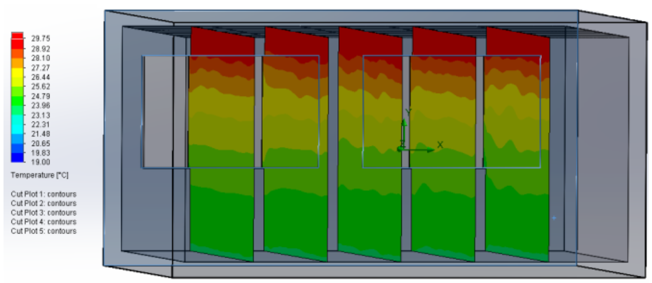

Fig. 12 the temperature distribution in the room, without cover layer

VIII. Conclusion

The main activity was to measure the parameters of thermal panel based on PCM materials. Calculation and simulation validated the results. Another part of presented work was to modify the surface of thermal panel and compare it with initial properties. The obtained values were allowed to perform the simulation and the possibility of usage were checked. The parameters obtained by simulations showed good agreement and the simulation can be used to optimize the solution storage parameters of buildings. [7] The research of using the PCM materials will continue making changes to the surface convective parameters and application these materials in cooling devices.

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