Key Engineering Materials Vol. 604 (2014) pp 227-231
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doi:10.4028/www.scientific.net/KEM.604.227

An Assessment of the PCM/Timber Composite in Buildings

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Keywords: PCM, thermal energy storage, computer simulation.

Abstract. This paper reviews a modeling study on PCM/timber composite materials and their incorporation in building materials, particularly in passive applications. Commercially available paraffin PCMs (RT21 and RT27) were incorporated in timber for increasing its thermal mass. In order to evaluate PCM/timber composite material behavior in building, computer simulation was performed. The obtained results showed that by using this technique it is possible to increase the thermal mass and reduce cooling loads in summer conditions.

Introduction

Nowadays, the energy demand and its costs are increasing continuously [1]. Use of phase change materials (PCM) can lower energy consumption of private demand. PCMs have high latent heats and therefore they are promising energy sources for storing thermal energy and providing heat for residential buildings [2]. When temperature of the environment increases, PCM melts and accumulates heat. But when decrease of temperature occurs, PCM crystallizes and gives the heat back to the environment. In this way indoor temperature is being regulated and excess heat is used rationally [3]. PCMs can be located in the floor, walls and ceiling, in or next to glazing, even in furniture [3], [4].

Due to the phase change, PCMs can store higher amounts of thermal energy than the traditional building materials alone and can be used together with timber to add thermal inertia to a lightweight construction without adding physical mass [4]. Popular PCMs are salt hydrates, paraffin waxes, fatty acids and eutectics of organic and non-organic compounds [3]. The commercial paraffin waxes are inexpensive with moderate thermal storage densities (≈200kJ/kg or 150MJ/m^3) and a wide range of melting temperatures [3]. Timber is a traditional material used in a variety of applications, making it very suitable for PCM encapsulation. It should be noted that timber has natural porosity and therefore its impregnation with various substances has been known for a long time [5].

This work is dedicated to the simulation of PCM/timber composite materials as a part of building structure. Modeling is a useful tool in the viability analysis of applications that involve thermal energy storage by solid–liquid phase change materials [6].

Materials and methods

Materials. PCM/timber composites for the purposes of this study were made of black alder wood (*Alnus Glutinosa*) and commercial PCMs – RT21 and RT27 from Rubitherm GmbH. The theoretical phase change temperatures were 21°C and 27°C, respectively. PCM was introduced in timber by means of vacuum impregnation. The later procedure was performed in vacuum desiccator. Air from desiccator was evacuated till 200 or 500 mbar approximately. Then PCM was poured on to the samples and allowed to impregnate the wood structure. The amount of impregnated PCMs in timber was 20 or 30wt% of RT21 or RT27. Average size of the timber samples was

30×15×5 mm. In addition, all samples were coated with polystyrene to avoid seeping of PCM during the phase change process.

Methods. Thermophysical characterization (melting enthalpy and melting temperature of PCM) of PCM/timber composites and pure PCMs was done by means of differential scanning calorimetry (DSC). Heating rate during the DSC measurements was 0,5°C/min. Evaluation of the DSC results was performed with STARe Software from Mettler Toledo.

The assessment of PCM/timber composite in buildings and its effect to internal microclimate improvement was carried out using whole building energy simulation program EnergyPlus. EnergyPlus is a whole building energy simulation program used by engineers, architects, and researchers for modeling the energy and water use in buildings. EnergyPlus models heating, cooling, lighting, ventilation, other energy flows, and water use.

Simulation model. The test stand of plywood is chosen for the simulation due to the low thermal inertia. The aim of plywood test stand with inner dimensions of 3×3×3 m is to verify PCM usage.

The thermo physical properties and layers of the constructions were created according to the best practice guidelines. The heat transfer coefficient for wall was set to 0.154 W/m^{2}K, floor 0.170 W/m^{2}K, roof 0.158 W/m^{2}K, and triple glazed windows 1 W/m^{2}K. Walls were made of 200 mm of mineral wool and 20 mm of plywood on both sides, roof - 254 mm of mineral wool and 12 and 9 mm of plywood on both sides, floor - 271 mm of mineral wool and 21 mm of plywood on both sides. The window is added on the South side. The PCM/timber composite was placed on inner surface of the walls and ceiling with the total thickness of 5 or 10 mm.

Main parameters of the described building zone are:

- Total volume [m^3]	27.0	External wall area [m^2]	34.2
- External transparent area [m^2]	1.8	Total PCM area [m^2]	43.2
- Floor area/PCM area [m^2]	0.26	PCM/timber thickness [mm]	5 or 10

To define the outside conditions, weather data for Riga, Latvia, were taken and average temperatures were used with the time step 1 hour. The summer period of three months - June, July, August, was selected for detailed analysis.

To simplify the model, no inner heat gains from people or lightings were selected. However, it has to be noted that the main factor for effective usage of PCM is night cooling for the PCM solidification.

Results and discussion

Thermal properties. In order to model the behavior of PCM/timber composite materials in building, thermophysical properties of PCMs has to be determined - phase change enthalpy and temperature (Table 1). Melting enthalpies and melting temperatures of analyzed composite materials are presented in Table 2.

Table 1 PCM properties

PCM	λ, (Heat conductivity) [W/(m·K)]	ρ, (Density) [kg/m^3]	ΔT, (Melting range) [°C]	H, (Enthalpy) [kJ/kg]
RT21	0.2	870	18..23	116
RT27	0.2	870	25..28	142

Table 2 PCM/timber properties

Sample	PCM	Amount of PCM [wt%]	H, (Enthalpy) [kJ/kg]	T (Melting peak temperature) [°C]
20%RT21	RT21	20	8,8	19,09
30%RT21	RT21	30	18,85	19,67
20%RT27	RT27	20	12,84	25,17
30%RT27	RT27	30	20,62	26,18

Model results. EnergyPlus was used for the summer period simulation, where free cooling night ventilation was applied and the window was opened at 30% by area from 20:00 to 8:00. Two cases of controlled maximum temperatures of 25°C and 24°C were selected from 8:00 to 20:00. Cooling loads were measured.

To estimate the reduction in cooling loads in summer due to the usage of PCM, summer months June, July and August were simulated.

The effect of PCM/timber composite for 25°C controlled temperature conditions can be seen in Table 3. It is visible that the PCM/timber composition with RT27 is more effective than the one with RT21, which could be explained by better melting-solidification temperature range suitability for the Latvian climate. The cooling energy savings range from 4.0 to 19.9%. The best energy savings of 19.9% are for 10mm 30%RT27. For PCM/timber composition with RT21, the best result was only 8.5% for 10mm 30%RT21. It has also been observed that by increasing RT21 amount in PCM/timber composition the cooling load reduction is really low, for example, for 5mm 20%RT21 it was 4%, but for 5mm 30%RT21 4.5%; there is only a 0.5% difference. Also increasing the PCM/timber composite layer from 5mm to 10mm on the walls and ceiling, the energy savings do not double due to a lower heat distribution through the material, which prevents the PCM from melting and solidifying more efficiently.

Table 3 Cooling loads for 25°C controlled temperature conditions

PCM/timber composite type	PCM/timber composite thickness		Energy consumption	Energy savings	
	5 [mm]	10 [mm]	[kWh]	[kWh]	[%]
No PCM	-	-	348.8	0.0	0.0%
5mm 20%RT21	5 mm	-	334.7	14.1	4.0%
10mm 20%RT21	-	10 mm	322.0	26.8	7.7%
5mm 20%RT27	5 mm	-	319.5	29.3	8.4%
10mm 20%RT27	-	10 mm	294.8	54.1	15.5%
5mm 30%RT21	5 mm	-	333.0	15.8	4.5%
10mm 30%RT21	-	10 mm	319.3	29.5	8.5%
5mm 30%RT27	5 mm	-	309.2	39.6	11.4%
10mm 30%RT27	-	10 mm	279.3	69.6	19.9%

In Table 4 the results for 24°C controlled temperature conditions are presented. Comparing with the 25°C controlled temperature conditions, it can be seen that the energy savings in kWh and in % are lower. The explanation is that the raw PCM melting and solidifying range does not match so well with the controlled temperature regime. The whole behavior is similar like it was in the previous controlled temperature range, although, here the maximum energy savings are lower by 4.2% (for 10mm 30%RT27).

Table 4 Cooling loads for 24°C controlled temperature conditions

PCM/timber composite type	PCM/timber composite thickness		Energy consumption	Energy savings	
	5 [mm]	10 [mm]	[kWh]	[kWh]	[%]
No PCM	-	-	384.3	0.0	0.0%
5mm 20%RT21	5 mm	-	371.0	13.3	3.5%
10mm 20%RT21	-	10 mm	359.0	25.3	6.6%
5mm 20%RT27	5 mm	-	359.4	24.9	6.5%
10mm 20%RT27	-	10 mm	337.5	46.8	12.2%
5mm 30%RT21	5 mm	-	369.2	15.1	3.9%
10mm 30%RT21	-	10 mm	356.2	28.1	7.3%
5mm 30%RT27	5 mm	-	350.8	33.4	8.7%
10mm 30%RT27	-	10 mm	324.0	60.3	15.7%

Summary

The aim of this work was to verify PCM/timber composite usage on a real plywood test stand of polygon using theoretical simulation software. The results show that the PCM could be useful for passive cooling in the Latvian weather conditions.

In the controlled temperature conditions of 25°C PCM/timber composite usage on walls and ceilings in summer days together with night ventilation can significantly decrease the cooling load demand till 19.9% using 10mm thick layer of 30%RT27.

For controlled temperature conditions of 24°C PCM/timber composite usage was less effective with the maximum cooling load of 15.7%, which can be achieved using 10mm thick layer of 30%RT27.

These materials are promising in the field of energy saving in buildings. The next step could be comparison of the results obtained in these experiments with the results obtained from the constructions, which are similar to the ones used in the theoretical calculations.

Acknowledgement

The authors would like to thank the COST Action TU0802 for funding STSM "Testing of Hybrid and Composite Materials Containing PCM" and the research work was carried out in the frame of the ESF project number 2013/0027/1DP/1.1.1.2.0/13/APIA/VIAA/007 „ Development of sustainable and systemic solutions suitable for Latvian climate conditions and providing qualitative living environment in nearly zero energy buildings".

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