2nd International Conference on Sustainable
Energy Storage, June 19-21, Trinity College
Dublin, Ireland

Investigation of the effect of applying Phase Change Materials (PCM) on the envelope of a test cubicle in Cyprus

Panayiotou, G.P.*,, Kalogirou, S.A.* and Tassou S.A.****

** Department of Mechanical Engineering and Materials Science and Engineering, Cyprus University of Technology*

*** School of Engineering and Design, Brunel University*

Email: soteris.kalogirou@cut.ac.cy

Keywords*: Phase change materials, Cyprus, macroencapsulated*

1. INTRODUCTION

The use of thermal storage in building envelopes is of great importance since it can smooth out daily temperature fluctuations and as a result lower the energy demand for heating and cooling. A way to increase thermal inertia of buildings is by integrating or including PCM on the buildings envelope and thus store energy in the form of latent heat. The main advantage of latent heat storage is that it has high storage density in small temperature interval [1]. The general principle of operation of PCM is that they store heat using their chemical bonds when they change phase from liquid to solid and release heat in the opposite way. The PCM that can be used in building applications should have a melting temperature range between 20-32ºC.

PCMs have been under study by many researchers around the world for over 30 years and thus many PCM are available in literature while some kinds are also commercially available by some companies such as BASF.

The main categories of PCM that can be used for this purpose are organic, inorganic and eutectics. In a very interesting and comprehensive work Cabeza et al. [1] reviewed all available PCM along with their classification, problems and possible solutions on their application in buildings. In their work, Baetens et al. [2] also reviewed the state-of-the-art on the current knowledge of PCM applications in buildings.

In their work, Tyagi and Buddhi [3] gave emphasis on the ways PCM can be applied in buildings such as PCM trombe wall, PCM wallboards, PCM shutters and PCM building blocks. Their results showed that there is a great potential on reducing the energy for covering heating and cooling demands.

A very promising application of microencapsulated PCM is their inclusion into construction materials such as concrete. This technology was studied in depth at the University of Lleida, Spain in 2004 but several drawbacks were observed. Consequently, Arce et al. [4] tried to overcome these problems. More specifically, the main drawback was the effect of the severe summer conditions (temperature and solar radiation) on the PCM that diminished their achievable potential benefits.

Although the inclusion of PCM into buildings materials such as concrete is considered to have numerous advantages it also has a very important drawback which lies to the fact that it can be used only in new buildings during the built up phase and not in existing buildings.

Additionally, in spite of the fact that a great number of studies have been performed for the incorporation of PCM in several construction materials only very few studies have been made for brick constructions. In his work, Alawadhi [5] numerically studied the application of PCM in bricks and obtained good results concerning the reduction of heat flow to the inner space during summer.

In a comprehensive work, Castell et al. [6] experimentally investigated the application of macroencapsulated PCM in two types of bricks namely conventional and alveolar brick. Their tests were performed under real conditions using five different cubicles located in Puigverd de Lleida. Two types of experiments were performed namely the free-floating temperature test and the controlled temperature test. The results showed good behavior, energy savings and technical viability. In spite of the promising results, a problem occurred during the experiments with the solidification of the PCM during night time. The authors suggested that this can be overcome by implementing a cooling strategy.

In this work the effect of the application of PCM in the thermal behavior of a test cubicle in Cyprus will be theoretically investigated using several suitable models of the TRNSYS software library. It should be noted that this is the first time the application of such materials is evaluated for Cyprus.

2. MODEL DESIGN

The model design process is carried out using the environment of Transient SYsten Simulation software (TRNSYS). The main component that simulates the PCM layer located in a structural element of a dwelling is Type 1270. This is obtained from Thermal Energy System Specialists (TESS) Company and is described below. The other main component of this model is Type56 which simulates the building (test cubicle).

Type 1270 is designed to interact with Type 56 and can model a PCM located in any position in the thickness of a Type 56 wall. The complete TRNSYS model developed is shown in Fig. 1. There are two options for setting the physical properties of the PCM the manual option and the built-in option. More specifically, in the manual option the user can specify the physical properties such as density, specific heat, melting temperature, freezing temperature, and latent heat of fusion. In the second option the user can utilize the built-in values of this component which concern a specific brand of PCM and the user may select a model number directly by setting a single parameter. It should be noted that Type 1270 models a pure PCM (as opposed to a mixture of a PCM with an inert material). From a physical point of view, this means that the PCM is assumed to go through its freeze/thaw process at constant temperature, to have a constant specific heat in the solid phase and to have a constant specific heat in the liquid phase. This is done in order to simplify the analysis of the PCM by treating the phase change layer in bulk; it does not account for the wave front of freeze/thaw propagating through the material over time.

The PCM layer can be applied in any structural element of a house such as external walls, internal walls and roof. The selection of the structural element on which the PCM layer will be applied is very important since it changes the procedure of utilizing the model. Due to the specific weather conditions of Cyprus (hot dry summer) the model will only be applied to the external walls and the roof since this is considered to be much more important than applying the PCM on internal walls.

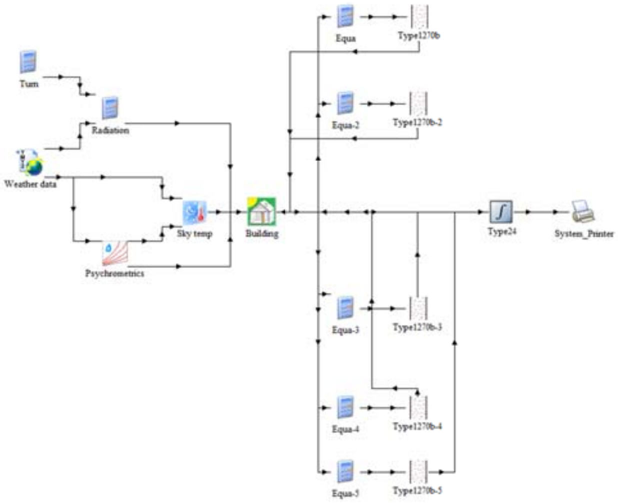

Fig. 1 Configuration of the complete model

3. INPUT DATA

The dimensions of the test cubicle are 3m x 2m x 3m and the orientation of the various walls is depicted in Figure 2. As mentioned above the introduction of a direct airnode is necessary for the utilisation of Type 1270, thus in every orientation a direct airnode is introduced with a width of 0.01m as is also shown in Figure 2.

3.1 Position of the PCM layer

For the purposes of this work, the PCM layer is installed in three different positions in order to cover both existing and new dwellings. In the first one, the PCM layer is placed in the middle of a double brick wall, which can be applied only in a new dwelling. In the second and third, it is placed in the inner and the outer side of the wall between the brick and the plaster layer respectively and these can be applied in both new and existing dwellings. In all cases examined, the PCM layer applied on the roof of the building is positioned in the inner side of the concrete slab just behind the plaster. This is due to practical issues such as the protection of the material from walking on it and the fact that it cannot be placed inside the concrete slab in the form of this product; this can be done by using microencapsulated PCM as described in many articles in the literature.

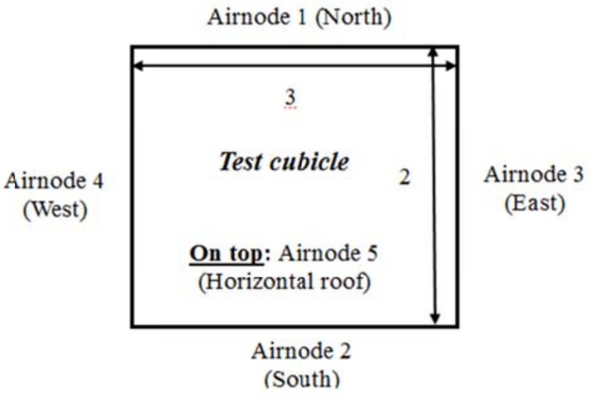

Fig. 2 Test cubicle dimensions, orientation and adjacent airnodes

3.2 Physical properties and characteristics of the PCM used

During the simulation procedure the PCMs used were those of the built-in option. These PCMs concern specific commercial materials manufactured by Phase Change Energy Solutions Company and their series is BioPCmat™. These materials are the M27, M51 and M91 and their physical properties and characteristics are listed in Table 1. These products are offered in four different melting temperatures namely 23, 25, 27 and 29°C.

Table 1 Physical properties and characteristics of the PCMs used

Melting temperature*	29°C		
Product	M27	M51	M91
Thickness (mm)	14		
Weight per unit area (kg/m^2)	2.49	3.56	6.15
Total unit thickness (mm)	6.35 - 8.89	10.16 - 15.24	25.4
Dimensions/Width (mm)	419.1		
Latent heat storage capacity (J/g)**	165 - 200		

* The temperatures shown are close proximities of the 'true' melting temperatures since PCMs are melting within a small range of temperatures

** Depending on formulation and application of the product

As it can be seen, the main difference between these products is their weight per unit area (kg/m^2) which indicates the mass of the PCM within the product. According to literature, the most commonly used melting temperatures for the application of PCM in hot environments is between 26-29ºC. Thus, in our case since Cyprus is a predominant hot weather environment the product with a melting temperature of 29ºC is employed.

4. METHODOLOGY

Once the detailed model of the test cubicle is setup the simulation is carried for the 'basic case' where the building is considered to have no insulation installed in any structural element. The simulation is carried out for a complete typical year (8,760 hours) lasting from the 1st of January until the 31st of December.

For the definition of the optimum PCM layer case, the energy rate control test is conducted with which the total energy demand for heating and cooling are estimated. More specifically, the results of each case examined are compared to the results of the 'basic case' in order to calculate the consequent energy savings. In this test, the set temperature for heating and cooling are set to be 20ºC and 26ºC respectively while the power of the heating and cooling system is set to be unlimited in order to maintain comfort conditions at all times. The results are in the form of energy consumption per square meter per year (kWh/m^2/yr). As part of this work, the three different PCM products shown in Table 1 are evaluated in three different positions through modeling and simulation.

When the optimum case is defined then a second simulation is carried out using the temperature level control, which is a test showing the effect of applying the optimum PCM layer on the fluctuation of the mean air temperature of the cubicle. In this simulation the cubicle is considered to be unconditioned and thus the heating and cooling systems are both switched off. The results of this test are presented for the hottest day of summer which is the 26th of July according to the TMY2 for Nicosia, Cyprus.

Additionally, the temperature fluctuation of the test cubicle, when it is insulated using common insulation materials used in Cyprus, is presented. More specifically the insulation used is 3.5cm of thermal insulation plaster applied on the outer surface of the envelope of the test cubicle and 4cm of extruded polystyrene applied on the outer surface of the roof.

Finally, the insulated cubicle is combined with the optimum PCM case and the temperature fluctuation is calculated.

5. RESULTS AND DISCUSSION

The results concerning the energy rate simulation are presented in Table 2 for all 9 PCM cases examined (3 types of materials times three positions). As it can be seen the optimum PCM case is that in position III with the 2991 material (29ºC melting temperature, material type 91) where the overall energy savings achieved is 28.59% (118.5 kWh/yr/m^2). Additionally, this case has the highest energy saving percentage in both heating and cooling which are 23.57% (62.585 kWh/yr/m^2) and 37.52% (55.925 kWh/yr/m^2) respectively. As expected, the energy savings in cooling are much higher than those of heating since essentially the PCM freezing/melting procedure is operating much better under the summer conditions. As aforementioned, the melting temperature of this PCM material is 29ºC and the only reason it is working in the winter is the fact that the space is conditioned and a part of the heat is absorbed by the PCM and released with a time lag and this is contributing to the decrease of the heating demand.

The reason for the superiority of this material against the others is that per unit area it has the higher weight and thus it contains a bigger amount of PCM material.

The results of the energy rate simulation concerning the insulated case and the combined case are presented in Table 3 where it can be observed that the combined (PCM and insulation) case achieves higher energy savings than the insulation case (66.17% instead of 60.95%) which is equal to 21.65 kWh/yr/m^2.

The results of the temperature level control simulation for the hottest day (July 26) are depicted in Figure 3. In this the free-floating temperature for the optimum PCM case, the case where only insulation is used (insulation case) and the combined case (insulation plus PCM) is presented. As can be seen, the optimum case is the combined case, where the PCM is combined with the insulation. Additionally, the mean air temperature of the test cubicle is much smoother than in all other cases and is also 3-4ºC lower than the case with no insulation (base case). A very interesting thing to observe is the fact that the mean air temperature for the insulation case between 04:00-12:00 is exceeding the mean air temperature for the case with no insulation because the heat that entered the space is trapped into the cubicle and it cannot escape. When a PCM layer is also installed on the walls and roof however, this is not happening. In addition, it should be noted that the PCM case is also slightly better than the insulation case with a difference between 0.1-1.1ºC.

Table 2 Results of the energy rate control simulation for the PCMs examined

	PCM MATERIAL	**2927**		**2951**		**2991**	
		Q_{HEAT}	Q_{COOL}	Q_{HEAT}	Q_{COOL}	Q_{HEAT}	Q_{COOL}
POSITION I	Heating and cooling demand per m^2 (kWh/yr m^2)	224.88	99.89	224.82	99.57	224.73	99.28
	Total energy demand (kWh/yr m^2)	324.77		324.38		324.00	
	Heating and cooling energy savings per m^2 (kWh/yr m^2)	40.61	49.13	40.67	49.45	40.76	49.74
	Total energy savings (kWh/yr m^2)	89.74		90.13		90.51	
	Heating and cooling energy savings percentage per m^2 (% kWh/yr m^2)	15.30%	32.97%	15.32%	33.19%	15.35%	33.38%
	Total energy savings percentage (% kWh/yr m^2)	21.65%		21.74%		21.83%	
POSITION II	Heating and cooling demand per m^2 (kWh/yr m^2)	225.85	99.84	225.78	99.59	225.65	99.19
	Total energy demand (kWh/yr m^2)	325.70		325.37		324.84	
	Heating and cooling energy savings per m^2 (kWh/yr m^2)	39.64	49.18	39.71	49.43	39.84	49.83
	Total energy savings (kWh/yr m^2)	88.81		89.14		89.67	
	Heating and cooling energy savings percentage per m^2 (% kWh/yr m^2)	14.93%	33.00%	14.96%	33.17%	15.01%	33.44%
	Total energy savings percentage (% kWh/yr m^2)	21.43%		21.50%		21.63%	
POSITION III	Heating and cooling demand per m^2 (kWh/yr m^2)	203.01	93.42	202.97	93.26	202.91	93.10
	Total energy demand (kWh/yr m^2)	296.43		296.23		296.01	
	Heating and cooling energy savings per m^2 (kWh/yr m^2)	62.48	55.60	62.52	55.76	62.58	55.92
	Total energy savings (kWh/yr m^2)	118.08		118.28		118.50	
	Heating and cooling energy savings percentage per m^2 (% kWh/yr m^2)	23.53%	37.31%	23.55%	37.42%	23.57%	37.52%
	Total energy savings percentage (% kWh/yr m^2)	28.49%		28.54%		28.59%	

Table 3 Results of the energy rate control simulation for the insulation case and the combined case

Examined case	**Insulation case**		**Combined case**	
	Q_{HEAT}	Q_{COOL}	Q_{HEAT}	Q_{COOL}
Heating and cooling demand per m^2 (kWh/yr m^2)	64.29	97.58	89.93	50.29
Total energy demand (kWh/yr m^2)	161.87		140.22	
Heating and cooling energy savings per m^2 (kWh/yr m^2)	201.20	51.44	175.56	98.73
Total energy savings (kWh/yr m^2)	252.64		274.29	
Heating and cooling energy savings percentage per m^2 (% kWh/yr m^2)	75.78%	34.52%	66.13%	66.26%
Total energy savings percentage (% kWh/yr m^2)	60.95%		66.17%	

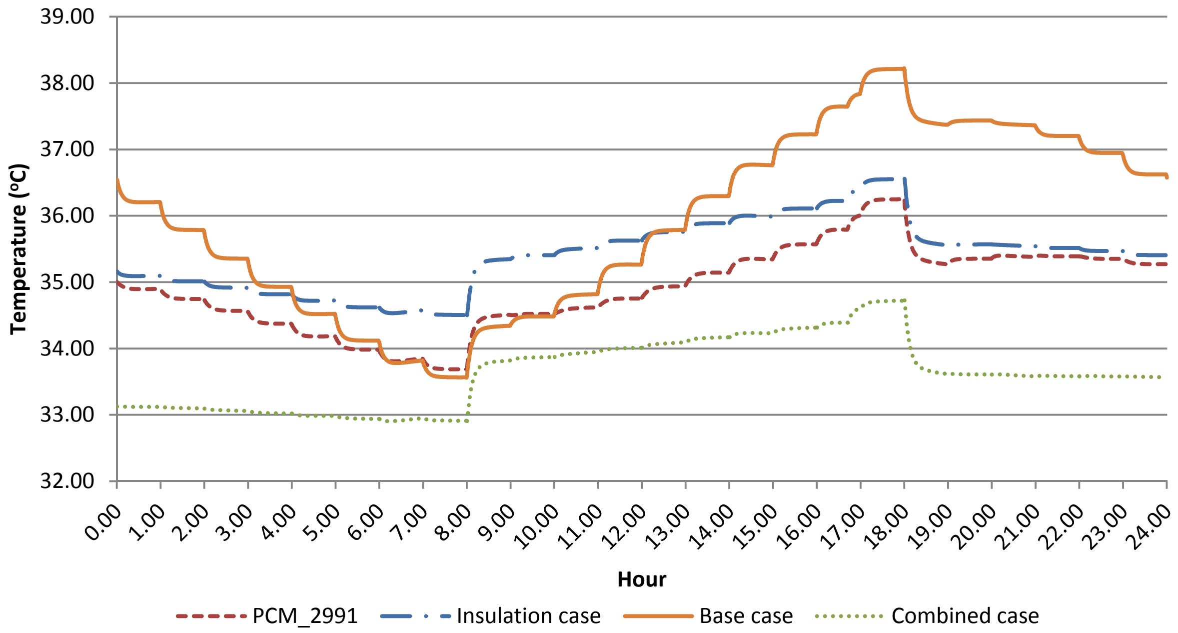

Fig. 3 Temperature fluctuation of the mean air temperature of all cases examined

6. CONCLUSIONS

In this work the effect of the application of macroencapsulated PCM in the thermal behaviour of a test cubicle in Cyprus was theoretically investigated for the first time using several suitable models from the TRNSYS software library.

The results indicate that the application of such material in Cyprus is very attractive and advantageous since they operate very well in the specific weather conditions of Cyprus. More specifically, the optimum energy savings achieved by applying a PCM material with a melting temperature of 29ºC on the outer surface of a wall and inner side of the concrete slab just behind the plaster is 28.59% (118.5 kWh/yr/m^2).

A very interesting option is when the PCM layer is used in combination with thermal insulation where the results showed that an energy saving of 66.17% (274.29 kWh/yr/m^2) could be achieved while the energy savings achieved by the insulation alone is 60.95% (252.64 kWh/yr/m^2).

REFERENCES

1. L.F. Cabeza, A. Castell, C. Barreneche, A. de Gracia, A.I. Fernández, Materials used as PCM in thermal energy storage in buildings: A review, Renewable and Sustainable Energy Reviews, vol. 15, pp. 1675-1695, 2011.
2. R. Baetens, B. Petter Jelle, A. Gustavsen, Phase change materials for building applications: A state-of-the-art review, Energy and Buildings, vol. 42, pp. 1361-1368, 2010.
3. V.V. Tyagi, D. Buddhi, PCM thermal storage in buildings: A state of art, Renewable and Sustainable Energy Reviews, vol. 11, pp. 1146-1166, 2007.
4. P. Arce, C. Castellón, A. Castell, L.F. Cabeza, Use of microencapsulated PCM in buildings and the effect of adding awnings, Energy and Buildings, vol. 44, pp. 88-93, 2012.
5. E.M. Alawadhi, Thermal analysis of a building brick containing phase change material, Energy and Buildings, vol. 40, pp. 351-357, 2008.
6. A. Castell, I. Martorell, M. Medrano, G. Pérez, L.F. Cabeza, Experimental study of using PCM in brick constructive solutions for passive cooling, Energy and Buildings, vol. 42, pp. 534-540, 2010.