CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 2

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Comparison of different PCMs impact on indoor comfort in a energy positive house

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Abstract

Phase change materials (PCM) can be an efficient way to improve indoor comfort and to reduce the energy consumption. To study the impact of different PCMs on interior thermal comfort we have used the EFdeN House Project which is a research and educational project representing Romania at Solar Decathlon Europe 2014 from Versailles, France. The EFdeN house proposed the implementation of several active and passive strategies. These performant and innovative strategies were designed in order to obtain the perfect indoor conditions and desired comfort with minimum energy consumption. Using these strategies, the prototype became a energy plus house, which produces more energy than it consumes and it has the features of a passive house. One of the most innovative solutions implemented in the EFdeN prototype was the integration of phase changing materials (PCMs) in the building interior and exterior walls. Using multiple simulations, realized using DesignBuilder software based on the Energy Plus engine for the Bucharest climate (hot during summer and cold during winter), we have obtained several interesting conclusions. During summer the impact of PCMs on interior comfort is higher, reducing the amplitude of interior temperature variations and the interior temperature during peak moments. During winter the impact of PCMs on interior comfort is lower because of the highly insulated house. The results rely very much on the phase changing temperature, the capacity of latent heat storage and PCM quantity. Several types of materials where studied. The results are widely presented in this paper.

Keywords – Phase changing materials; PCM; indoor confort; energy efficiency; energy plus house; interior temperature variation; latent heat storage; phase change temperature; Rigips Alba Balance; BioPCM

1. Introduction

Improving indoor thermal comfort with minimum energy consumption is, nowadays, the main goal of many researchers.

It can be observed, in the scientific literature, that the use of Phase Changing Materials (PCMs) could help in order to:

- improve thermal mass of a building [1, 2, 3, 6, 8];
- reduce the amplitude of interior temperature variations during summer and also during winter, especially in case of the buildings with low thermal inertia (light structure) [4, 5, 6, 7, 12];
- reduce (during summer) or increase (during winter) the indoor temperature in the peak moments (reducing also the cooling/heating loads and energy consumptions) [1, 9, 10, 11].

The impact of PCMs on energy consumptions or interior comfort on normal buildings is important if the type of material is correctly chosen. But what happens in case of highly insulated houses, passive houses or energy plus houses?

EFdeN Project is a research and educational project which has represented Romania at Solar Decathlon Europe 2014, a competition based on solar architecture and energy efficiency of the buildings. Now the house has become the first Research Center of Indoor Comfort Conditions from Romania and it is placed in the courtyard of Faculty of Building Services from Bucharest. In order to obtain maximum points in the competition, the project proposed the implementation of many active and passive systems to obtain the optimum comfort with minimum energy consumption [13]. One of the innovative ways to obtain these goals was the implementation of Phase Changing materials.

The objectives of this paper are to analyze the impact of PCMs on a energy efficient building, a energy plus house. The results in this case are highly influenced by the highly insulated house, the complex scenarios and thermotehnical characteristics of the building.

2. House Description

The house was constructed as a light structure with steel superstructure and exterior sandwich walls made out of OSB panels, mineral wool and metal substructure. Inside the walls, terrace, and floor, multiple layers of insulations (25 cm to 40 cm) were mounted in order to obtain an energy efficient construction. The U-values of the construction elements are the following:

- external walls: U=0.129 W/m^2K;
- terrace: U=0.121 W/m^2K;
- floor: U=0.124 W/m^2K.

The glazing of the house is made out of three layers (U=0.8 W/m^{2}K with low-E protection). The interior face of the exterior walls and the interior walls are made out of PCM panels or radiant panels for heating/cooling or gypsum plasterboards, depending on the zone and mounting possibilities.

The characteristics of the building are:

- height of the level: 2.5m;
- 133 m^2 net surface area;
- 96 m^2 footprint;
- 170 m^2 built surface area;
- 118 m^2 heated area;
- 200 m^3 conditioned volume.

The house has one windfang, two technical rooms, two bathrooms, one kitchen, one living room, two bedrooms and a greenhouse.

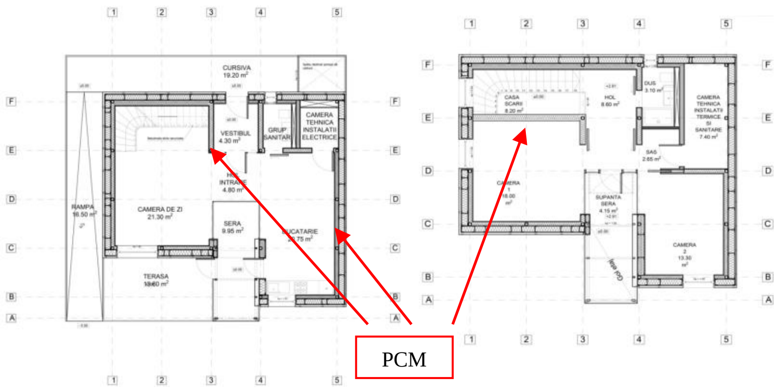

Fig. 1 Ground floor and first floor – EFdeN Project. The placement of PCMs

PCMs were implemented in order to improve the thermal mass of the building, the interior comfort and to reduce energy consumptions and thermal loads [14].

Several other passive strategies and active strategies were implemented and the result was a energy plus house which produces more energy that consumes during a year, with characteristics of a passive house [15].

3. Simulation Methods. Results

The 3D model of the house (figure 2), its thermotechnical characteristics, its function and systems were one by one introduced and numerical modeled in DesignBuilder software (based on Energy Plus dynamic simulation engine) and various simulations were launched.

The PCM used in EFdeN Project is type: Rigips Alba Balance 23 (plasterboards with microcapsules of PCM – figure 3) with the main characteristics presented in table 1.

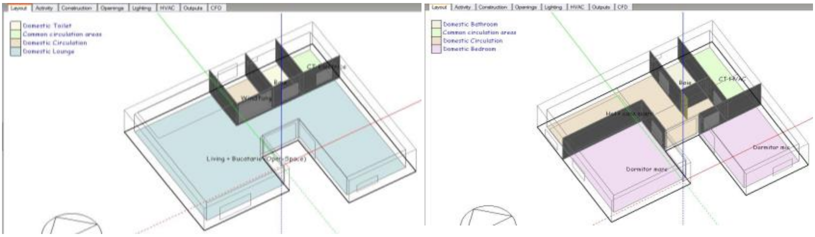

Fig. 2 Thermal zones – 3D model of the house

The DesignBuilder software includes several predefined materials and the equivalent material for the PCM used in EFdeN Project is BioPCM M27/Q23. Other materials with different phase change temperatures and different capacity of latent heat storage were used in simulations (M27/Q25, M51, M91, M182). The main characteristics of the materials with relevant results are presented in table 1 also.

Table 1. Types of PCMs used in simulations

Material type	Phase change temperature [°C]	Latent heat storage [Wh/m2]
Rigips Alba Balance 23	23	83
BioPCM M27/Q23	23	85
BioPCM M27/Q25	25	85
BioPCM M182/Q23	23	574
BioPCM M182/Q25	25	574

Fig. 3 Rigips Alba Balance plasterboard used in EFdeN house (source: rigips_alba_balance_infobro_de_low_en_korr_arial.pdf)

The following results are presented for the living room (living room + kitchen + lobby) because it is the most representative zone of the house (approximately 51 m^2).

In figure 4 it can be observed a comparison between the house without PCMs and the house with PCMs type M27/Q23 in the interior layer of the external walls and in the internal walls, during a day from typical summer week. The difference in amplitude of temperature variations between the two cases is about 0.6°C and we could observe a difference of approximately 0.9

°C for the peak moments (ex: 18 p.m.). Moreover, in a typical summer day, the temperatures are lower when using PCMs.

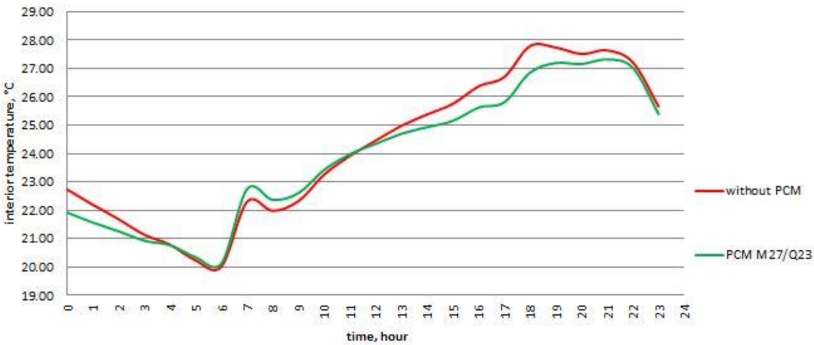

Fig. 4 Interior temperature variation during a day from tipical summer week (11th July): without PCM vs. reference case (M27/Q23)

In figure 5 it can be observed a comparison between the house without PCMs and the house with PCMs type M182/Q25 in the interior layer of the external walls and in the internal walls, during a day from typical summer week. The difference in amplitude of temperature variations between the two cases is about 1.3°C and we could observe a difference of approximately 2.2 °C for the peak moments. Moreover, in a typical summer day, the interior temperatures are lower when using PCMs also.

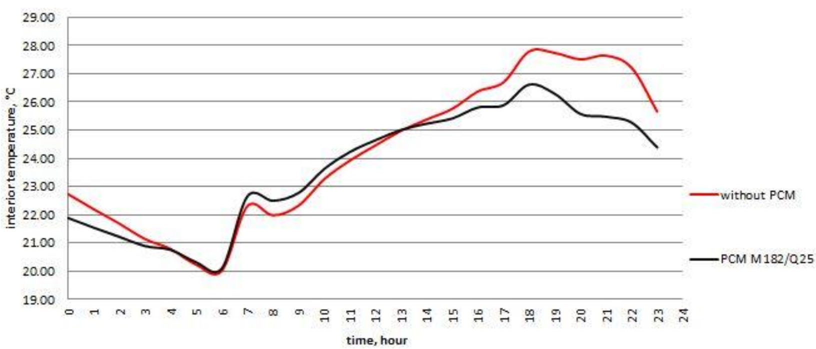

Fig. 5 Interior temperature variation during a day from tipical summer week (11th July): without PCM vs. best case (M182/Q25)

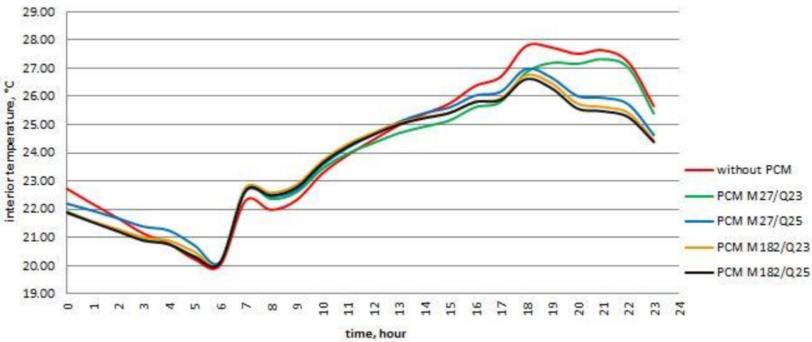

Fig. 6 Interior temperature variation during a day from tipical summer week (11th July): all the cases – comparison

In figure 6 it can be observed a comparison between the house without PCMs and the house with all types of PCMs proposed with relevant results. During a day from typical summer week, the PCM type M27/Q25 has better results than M27/Q23 which means that the impact of PCMs on interior thermal comfort is more important if the phase change temperature is near to the interior setpoint (ex: 26 °C). The difference in amplitude of temperature variations between the two cases (without PCMs and PCM type M27/Q25) is about 1°C and we could observe a difference of approximately 1.7 °C for the peak moments.

If the phase change temperature is higher than the setpoint (ex: Q27), the PCM fails to perform their phase changing cycle and it results a negative impact on interior comfort and energy consumption for cooling.

It is important to mention that the impact of PCMs on interior thermal comfort is more important if the latent heat storage capacity is higher (ex: in case of M182/Q23).

In all the cases, for all the PCMs types used the thermal comfort is improved during summer. The scenarios implemented during winter (occupancy, ventilation rate, night ventilation, internal gains and temperatures set-points) can bring important changes in PCMs impact on indoor thermal comfort. If the ventilation is not properly realized the PCMs can fail to perform their phase changing cycle and it can result a negative impact because the heat will not be released during night.

In figure 7 it can be observed a comparison between the house without PCMs and the house with PCMs type M27/Q23 in the interior layer of the external walls and in the internal walls, during a day from typical winter week. The difference in amplitude of temperature variations between the two cases is about 0.1°C and we could observe a difference of approximately 0.2

°C for the peak moments (ex: 7 a.m.). Moreover, in a typical winter day, the interior temperatures are higher when using PCMs type M27/Q23.

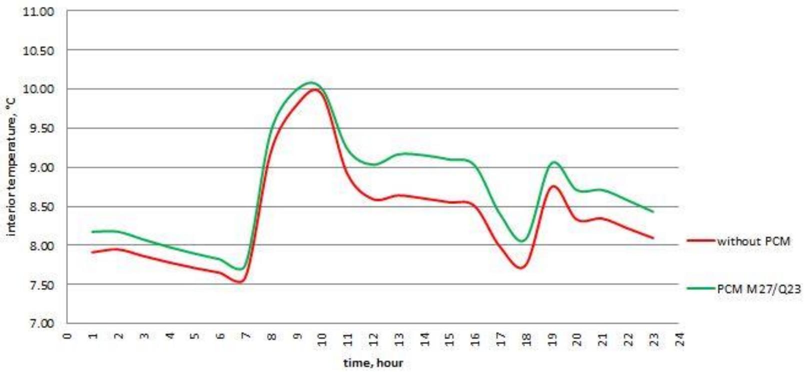

Fig. 7 Interior temperature variation during a day from tipical winter week (15th December): without PCM vs. PCM M27/Q23

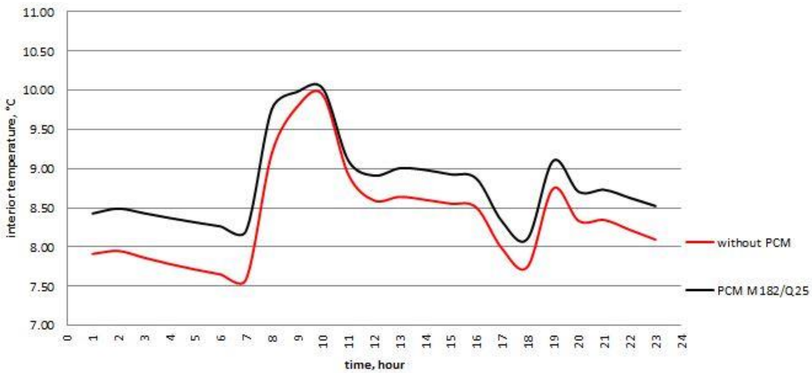

Fig. 8 Interior temperature variation during a day from tipical winter week (15th December): without PCM vs. M182/Q25

In figure 8 it can be observed a comparison between the house without PCMs and the house with PCMs type M182/Q25 in the interior layer of the external walls and in the internal walls, during a day from typical winter week. The difference in amplitude of temperature variations between the two cases is about 0.4°C and we could observe a difference of approximately 0.6 °C for the peak moments (ex: 7 a.m.). Moreover, in a typical winter day, the interior temperatures are higher when using PCMs type M182/Q25.

During winter the PCMs are improving the thermal mass of the house. The impact of PCMs on interior thermal comfort during winter is lower because of the highly insulated house and because variable scenarios.

4. Conclusions

Using multiple dynamic simulations, realized using DesignBuilder software for the Bucharest climate (hot during summer and cold during winter), we have obtained several interesting conclusions regarding the use of PCMs in a energy plus house

We have determined that, during a summer day, the fluctuations of the temperatures for a room with PCMs type M27/Q23 in the walls are lower than for an ordinary case, without PCMs. This material has a latent heat storage value of 85 Wh/m^2 and a phase change temperature of 23°C. The difference in amplitude of temperature variations between the two cases is about 0.6°C and we could observe a difference of 0.9 °C for peak moments. Moreover, in a typical summer day, the temperatures are lower when using PCM. We also observed that the impact of PCMs on interior comfort conditions is more important if the material has higher latent heat storage and the phase changing temperature near the interior setpoint. We have conducted other tests with different PCM materials and the best one was found to be the PCM type M182/Q25, with a latent heat storage of 574 Wh/m^2 and a phase changing temperature of 25°C and which had a great impact on indoor comfort: a difference in amplitude of temperature variations of 1.3°C and a difference of 2.2°C in the peak moment. During winter, the impact of PCMs on indoor comfort is lower because of the highly insulated house. We also have conducted several tests with different PCM materials and the best one was found to be the PCM type M182/Q25 which had a good impact: a difference in amplitude of temperature variations of 0.4°C and a difference of 0.6°C for the peak moments. Moreover, in a typical winter day, the temperatures are higher when using PCM because of the additional thermal mass and because the EFdeN house has a light structure. The improvement of temperature variations when using different types and amounts of PCM can greatly vary for an energy efficient house based on variable scenarios (occupancy, ventilation rate, night ventilation, internal gains and temperatures set-points).

Acknowledgment

The authors would like to thank the company Saint-Gobain Romania for supporting the EFdeN Project with the Phase Changing Materials (Rigips Alba Balance 23) and not only, especially for the competition.

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