TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

5-B/2014

ANNA ZASTAWNA-RUMIN*

THE INFLUENCE OF PHASE CHANGE MATERIALS ON ENERGY BALANCE AND THE RISK OF OVERHEATING

WPŁYW MATERIAŁÓW FAZOWO ZMIENNYCH NA BILANS ENERGETYCZNY I RYZYKO PRZEGRZEWANIA

A b s t r a c t

The paper presents the results of a computer simulation of a building under the assumption of the presence of a phase change material in wall elements. The influence on the cooling energy requirements and, also, the risk of overheating of the low-energy building (without HVAC systems) have been analyzed. The obtained results were compared with the ones of a low-energy building without a phase change material in walls. The comparison calculations were performed for a model of a service building located in Silesia, which is built according to an energy-efficient standard. It has a light-frame construction with light covering (external panels, heat-insulation, interior plasterboard). In the study, the presence of a 1 cm thick PCM board placed under the inner surface of plasterboard is assumed. Tests were conducted for organic materials that undergo phase transition in different temperatures, such as: 23°C, 25°C and 27°C. Based on the results of operative temperature measurements, it is possible to determine the influence of PCM on the risk of building's overheating.

Keywords: heat capacity, phase change material

S t r e s z c z e n i e

W artykule przedstawiono wyniki komputerowych symulacji budynku, zakładając wbudowanie w jego przegrody materiału fazowo-zmiennego. Analizowano wpływ zastosowania różnych materiałów fazowo-zmiennych na zapotrzebowanie energii do chłodzenia budynku i ryzyko przegrzewania wnętrza obiektu (nie wyposażonego w instalację chłodzącą). Wyniki porównywano do stanu wyjściowego (bez PCM). Przedmiotem porównawczych obliczeń jest model istniejącego budynku o charakterze usługowym, zlokalizowany w województwie śląskim. Budynek ma konstrukcję szkieletową z lekkim poszyciem (blacha elewacyjna, termoizolacja, blacha konstrukcyjna). W kolejnych wariantach pod powierzchnią blachy od strony wewnętrznej założono wbudowanie PCM w postaci mat o grubości 1 cm. Materiałem ulegającym przemianie fazowej jest materiał organiczny. Analizie poddano warianty z zastosowaniem PCM o różnej temperaturze przemiany fazowej, tj. 23°C, 25°C, 27°C. Na podstawie wyników obliczeń temperatury operatywnej można określić wpływ MFZ na ryzyko przegrzewania budynku.

Słowa kluczowe: pojemność cieplna, materiał fazowo-zmienny

* M.Sc. Eng. Anna Zastawna-Rumin, Institute of Building Materials and Structures, Faculty of Civil Engineering, Cracow University of Technology.

1. Introduction

The aim of introducing PCM into building elements is to increase the heat capacity of the building envelope. Too low heat capacity results in the deficiency of heat stability in a popular light-frame construction with light filling walls that causes seasonal overheating of the building and large temperature oscillations of internal air due to temperature variations of outdoor air.

The idea of using phase change materials to accumulate heat is based on energy saving process such as latent heat of organic compounds e.g. paraffins, fatty acids or inorganic salt hydrates. Accumulation or emission of large amounts of heat occurs during phase transition and is accompanied by a small temperature change of a specific PCM.

Nowadays, there are many building energy simulation tools for studies analyzing benefits from PCMs [11]. The most popular are EnergyPlus [13], ESP-r [14], and TRNSYS [12].

ESP-r is an advanced building energy simulation tool which allows for a detailed thermal description of buildings. The software discretizes the problem domain in a control volume scheme and solves the corresponding conservation equations for mass, momentum, energy, etc. It uses the effective heat capacity method for PCM solutions.

The TRNSYS software is used for building dynamic simulation based on transfer functions technique. It contains many subroutines. The storage and release effects of PCMs can be simulated using the active layer tool Type 56 or by the implementation of a new module.

Energy Plus PCM algorithm uses a one-dimensional conduction finite difference (CondFD) solution algorithm [9, 10]. The CondFD algorithm in Energy Plus uses an implicit finite difference scheme, where the user can select Crank-Nicholson or fully implicit. In the CondFD algorithm, all elements are divided or discretized automatically, which depends on a space discretization constant, the thermal diffusivity of the material, and the time step [9, 10, 11]. For the PCM algorithm, the CondFD method is coupled with an enthalpy temperature function that the user inputs to account for enthalpy changes during phase change. The enthalpy temperature function is used to develop an equivalent specific heat at each time step. The resulting model is a modified version of the enthalpy method. Here, the values of the specific enthalpy h for the PCM can be provided by the user as a function of the temperature T [9].

2. The aim of the article

The aim is to determine the influence of phase change materials on the internal temperature of examined building and on the energy demand for cooling. Both internal air temperature and internal surface temperature of the wall were tested. The study was performed with particular consideration of the thermal parameters influencing thermal comfort and the determination of building overheating risk.

The analysis refers only to a change in thermal parameters inside the building. The impact of other parameters (for example of humidity), which are important factors in the aspect of thermal comfort, is not taken into account. The analysis will show whether the use of PCM leads to significant changes and whether it is appropriate to carry out a more precise analysis using relevant indicators such as the rate of PPD (Predicted Percentage Dissatisfied). PPD will be treated as a quantitative parameter for the assessment of thermal comfort in the room.

3. The description of the calculation model

The calculations were performed for a model of a service building located in Katowice. It has a light-frame construction with light covering. The floor is constructed with a 10 cm layer of concrete which is coveredd with ceramic tiles. The building dimensions are 10 m ×10 m × 3 m (Fig. 1). The building meets the Polish regulations for energy-efficient buildings. The roof has a lightweight design packed with 30 cm layer of insulation and covered with a sheet. Inside the building, , there is an open space with no internal partitions. The model does not take into account the equipment and furniture in the office. All other material data are presented in Table 1.

For the first (base) variant, the building wall is constructed with a 30cm thermal insulation (the outside surface was finished with an OSB board, while the inside surface with the a gypsum board). In the next variants, the PCM was built in as a 1cm layer, located on the internal side of the wall (Fig. 2). For the analyses, the application of an organic Phase Change Material was assumed. In simulations available types of PCM were used. They differed regarding the temperature of phase change which was equal to 23°C, 25°C and 27°C respectively (the variants were called PCM 23, PCM 25, PCM 27, accordingly). The dependence of the material enthalpy on the temperature, for the analyzed PCMs was assumed based on the literature [2]. Adopted to calculation, the dependence of the enthalpy on the temperature, for the PCM, is illustrated in Fig. 3.

The glazing covers 40% of the south façade area. The window frames have very good thermal insulation (U = 0.8 W/m^{2}K) and are in accordance with the regulations for the total energy transmission factor g_c = 0.5. In addition, the windows have shading. It should be noted that, in the analyzed building, all passive solutions to reduce the energy needed for heating and cooling were used.

It is assumed that 5 persons are simultaneously present in the building during working hours and the additional interior lighting is also being used. To consider these, during working hours (i.e. 7 am to 6 pm) heat gains from people (80 W per person) and lighting (3 W/m^2) were added. In the simulations, the weather data for the period between 1st June and 31st August were used. The ventilation rate was assumed as 0.5 air change per hour. All the simulations were performed with the Energy Plus ver. 7.1 software which allows for the modeling of the phase transition of some materials and for considering variable external conditions.

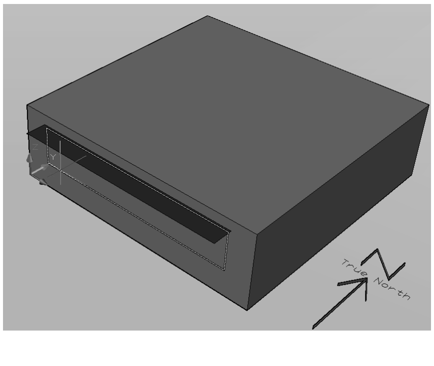

Fig. 1. The schematics of the analyzed building

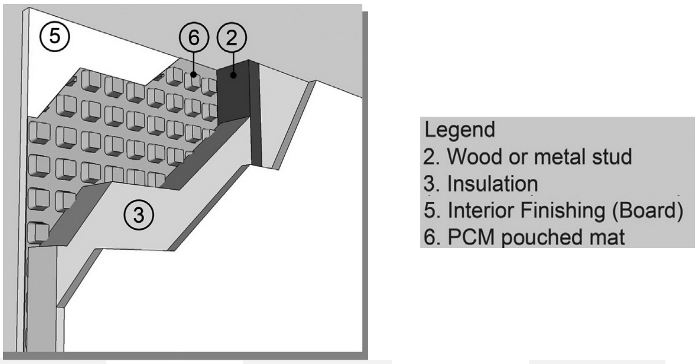

Fig. 2. The location of the PCM layer in the walls of buildings [3]

Table 1

Material data

Material	Thickness, [m]	λ, [W/mK]	Specific heat, [J/kgK]	Thermal absorptance	Solar absorptance
external metal sheet	0.001	58	500	0.9	0.4
termal-insulation	0.3	0.04	1381	0.9	0.5
gypsum board	0.013	0.16	1150	0.9	0.42
PCM	0.01	0.2	c_w (T)	0.9	0.7

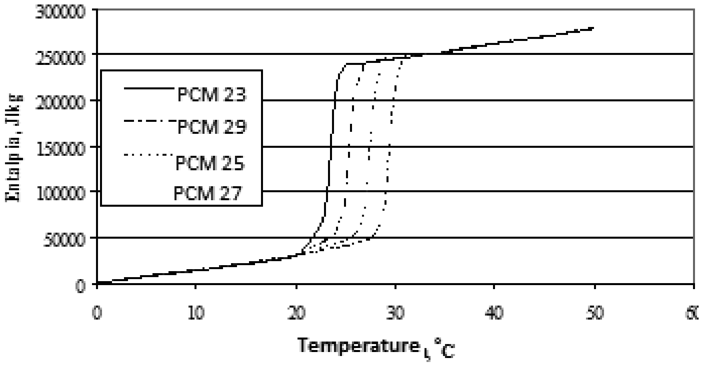

Fig. 3. The relationship between enthalpy and temperature for the analyzed PCM [2]

4. Results

4.1. The influence of the PCM on the overheating risk

Operative temperatures inside the building, for the walls without PCM and with different kinds of PCMs, have been analyzed. Both the interior air temperature and the temperature of internal surfaces have influence on the operative temperature (wind chill).

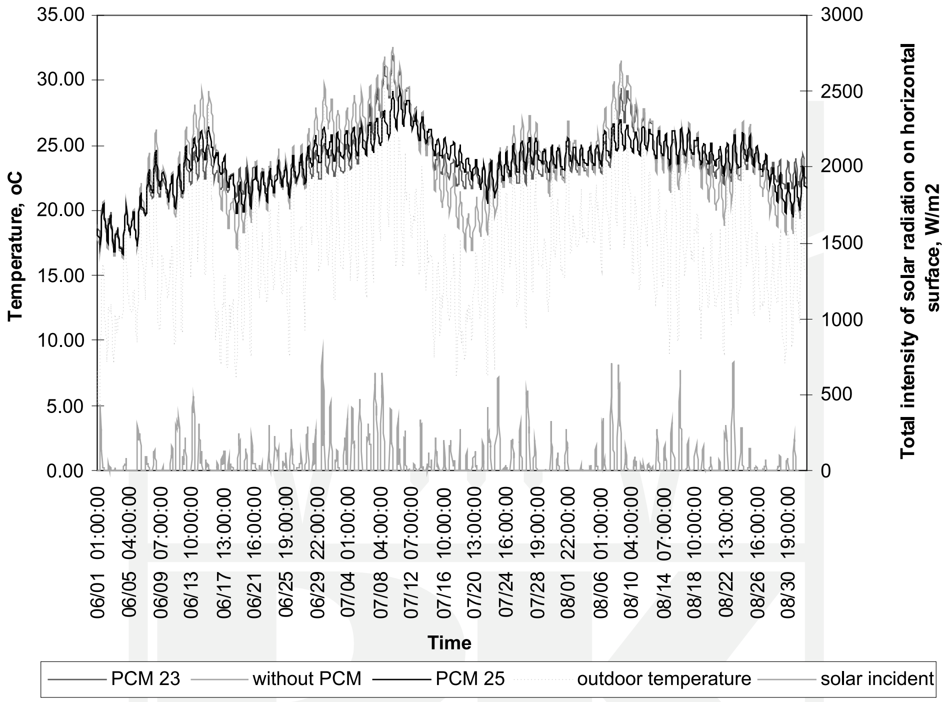

Fig. 4. The operative temperature inside the building in the analyzed period, the cases: without PCM, with 23 PCM and with 25 PCM

Fig. 4 shows the graph of operative temperature inside the building during the analyzed period for different material variants (without PCM and with PCMs of different point of phase change: 23°C and 25°C).

Regardless of the PCM type, it is always visible that the temperature has smaller oscillations in comparison to the base case (without PCM). This demonstrates the much higher thermal stability of the building rooms and the reduced impact of outdoor temperature. The maximum wind chill that occurs for the base variant is at 32.6°C, 32.2°C for PCM 23, and 29.21°C for PCM 25. Thus, the most significant reduction of the maximum temperature can be achieved by using PCM 25.

The largest reduction of the period duration with exceeded temperature of 24°C can be achieved by using PCM 23, but the shortest period with temperature exceeding 27°C can be achieved by using PCM 25 (Fig. 5).

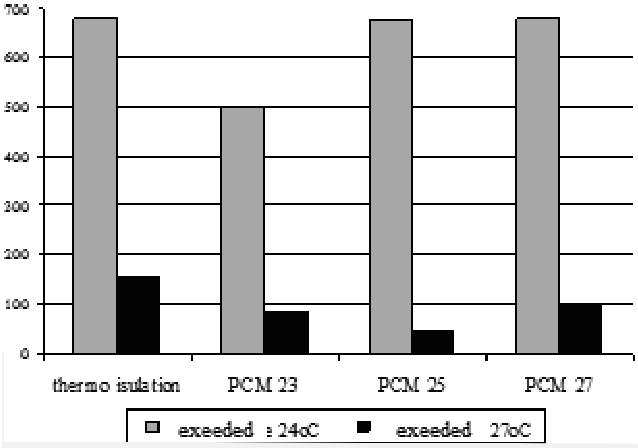

Fig. 5. The amount of hours with exceeded temperature of 24°C and 27°C

4.2. The influence on the cooling energy requirements

It is assumed that, in the building, there are heating and cooling systems. The cooling system works according to the following scheme: from 7:00 to 18:00 it works above 24°C, outside this time period: above 27°C. The ventilation rate was assumed as 0.5 air change per hour. The analysis showed that the best results are achieved for PCM 23. For the base variant, the energy demand for cooling is 1.98 GJ. After the application of the PCM, it decreases to 1.62 GJ.

5. Conclusions

The analyzed building uses all possible passive energy sources in order to minimize its energy demand. The application of PCM inside the building walls causes a risk of interior overheating. The simulation results indicate that the most efficient solution is the application of PCM which has the phase change point at 23°C. This is probably due to the highest frequency of the temperature passing in the phase change point for the material. The application of PCM 23 can potentially reduce 18% of the energy demand for cooling in the analyzed period from 1st June till 30th August. The application of PCM 23 causes the most significant reduction in the total time with the temperature over 24°C. The solutions with PCM 25 and PCM 27 perform effectively only in the case of higher temperature. To determine which option is more comfortable for the people inside a building, it would be required to analyze the thermal comfort, considering the length of the peak temperatures period for each day more precisely. It also seems necessary to carry out an analysis, which takes into account the other parameters of thermal comfort (eg. effect of humidity). The analysis should refer to relevant indicators such as the rate of PPD (Predicted Percentage Dissatisfied). This will be the subject of future research.

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