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# Effect of transition temperature on efficiency of PV/PCM panels

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**Abstract**

Due to the fact that efficiency of PV panels decreases by approximately 0.5%/K, possibilities to stabilize the temperature on the panel's surface are considered in this paper. The aim of this investigation is to determine the transition temperature of PCM layer that allows avoiding rapid temperature fluctuations on the PV back surface. To meet the stated goal, dynamic simulations of thermal and electrical performance of PV/PCM panels were carried out using ESP-r software.

Based on the obtained results, it can be concluded that additional PCM layer on the back side of PV panel can effectively increase the efficiency of electricity production with PCM transition temperature about 20°C.



*Keywords:* Photovoltaic; Phase change material; Latent heat; Building envelope; Energy efficiency.

## 1. Introduction

Energy efficient design and sustainable use of resources are current and future requirements for the development of new technologies. In the building sector, the most effective and the easiest in application is photovoltaic technology which can be implemented as Building Attached Photovoltaic (BAPV) or Building Integrated Photovoltaic (BIPV). The first possibility is suitable for already existing buildings where PV panels are installed on

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the construction elements, such as roofs or facades. The second technology (BIPV) is more cost effective since the traditional covering and finishing building materials can be substituted by PV panels [1]. That solution gives dual functionality to PV panels, as they are both structural components and energy production devices [2].

Nevertheless, such application of PV panels is limited by the surface which can be used for installation. Thus, the amount of energy gained from unit area should be maximized. The efficiency of PV panels depends on the solar cell material, technology used and varying from approximately 10% for organic PV to almost 45% obtained for multijunction cells (still in the research and development stage) [3]. Moreover, efficiency of each technology depends on solar irradiation and temperature of the panel [4]. In the literature, there can be found many reports describing the relationship between the efficiency and temperature of the panel and it can be stated that temperature increase causes the visible drop in the efficiency of electricity production [5]. Therefore, despite the selection of a specific PV technology the key aspect to which the special attention should be paid is thermal control of PV panels.

According to the literature, six basic techniques of PV thermal management can be distinguished: natural or forced air circulation, hydraulic or thermoelectric cooling, heat pipes and implementation of phase change material (PCM) [6]. The most commonly used technology that requires no initial costs and maintenance is natural air circulation. Nevertheless, low surface heat transfer coefficient as well as heat capacity of air make this technique disadvantageous in the case of BIPV where the space behind panels and air mass flow rates are strongly limited. On the other hand, active techniques such as forced air circulation can contribute to more effective cooling, but consumes additional energy, needs maintenance and in some cases are considered to be noisy systems. The last mentioned thermal management technique utilizing PCM is very promising but requires good design in many aspects.

## 2. PV/PCM panels

Thermal management of the PV panels is crucial for their efficiency but also contributes to prevent from degradation of PV cells. The efficiency declared by the producers is measured in the Standard Test Conditions of 1 $kW/m^2$ insolation and temperature 25°C, while the effect of real weather conditions can significantly change the effective efficiency [7]. Nevertheless, the temperature of the panel should be kept at the minimal possible level, even below 25°C [8]. Application of PCM on the back side of PV panel helps to keep the temperature at the level of melting point of the material. Phase change materials are able to store specific amount of heat during changing the phase from solid to liquid and release it during reverse transition of phases. Isothermal character of this process results in stabilizing the temperature [9]. However, the transition temperature should be designed with simultaneous consideration of amount of the material and period of analysis. Proper assumption of the material properties is a quite complex task since the whole system is supposed to work under uncontrolled weather conditions. The temperature of PV panels and thus PCM change rapidly as a result of changing solar radiation, external temperature and wind speed [10] so different solutions (assumptions of material properties) may prove to be optimal [11].

Effectiveness of PV-PCM system depends on the thermal, physical and kinetic properties of the phase change material [12]. The basic properties that influence the amount of absorbed heat are latent heat of fusion and heat capacity. Their high values and good thermal conductivity contribute to efficient heat removal and its release. The amount of the heat that can be absorbed depends also on the density of the material and subsequently its weight – thickness of the applied layer. Additionally, special material should be characterized by good crystallization rate and reversible phase change to ensure diurnal response of the material. Moreover, as a building material, it should comply with safety regulations about flammability, explosiveness and toxicity.

Another issue that should be discussed on the design stage of PV-PCM system is a form of the PCM application. The first attempt to develop such a system was made by Hausler et al. in 1998 [4]. Phase change material was placed in a glass tank and connected with PV module. Nevertheless, such a solution was not effective due to low thermal conductivity of a container and its small contact area with the panel. Based on the most recent reports in the literature, PCM can effectively influence temperature of PV panel when it is placed in the plastic bag [10], aluminum container with different fins [13,14] or when being integrated within building envelope as a PCM gypsum board [15].

In order to enhance the heat exchange and heat removal from PV panel, thermal conductivity of the material in which PCM is closed should be maximized. Additionally, to prove homogenous change of phases in the whole PCM layer, the container can be subdivided by additional aluminum fins or can be made in form of aluminum honeycomb. The last approach was precisely analysed in this paper.

As stated before, the temperature of PV panels is very sensitive to the weather conditions and it is impossible to choose parameters of PCM that will effectively stabilize the temperature during the whole year. Therefore, phase change temperature should be designed to lower the overheating effect during the most extreme summer months (this period of time depends on the location of the analysed façade).

In the literature there can be found many mathematical models describing PV-PCM systems [11, 16, 17] and their experimental validation [18]. Nevertheless, most of research work concerning this issue assumes the analysis under stable, standardized conditions. The aim of this paper is to investigate and determine the transition temperature of PCM layer that allows avoiding rapid temperature fluctuations on the PV back surface. Analysis conducted by the authors aims to find the optimal solution that will be beneficial during the whole year under dynamically changeable climatic conditions of central Europe location.

## 3. Problem formulation

Effect of transition temperature of PCM on efficiency of PV panels was estimated for a single office. It was assumed that the whole surrounding partitions of the room – except for the external wall – was defined as an internal with the same parameters of indoor conditions. The analysed facade is 3 m high and 2.4 m wide with the square window located in the middle (Fig. 1). The ventilated cavity between external wall and PV panels is 0.1 m deep.

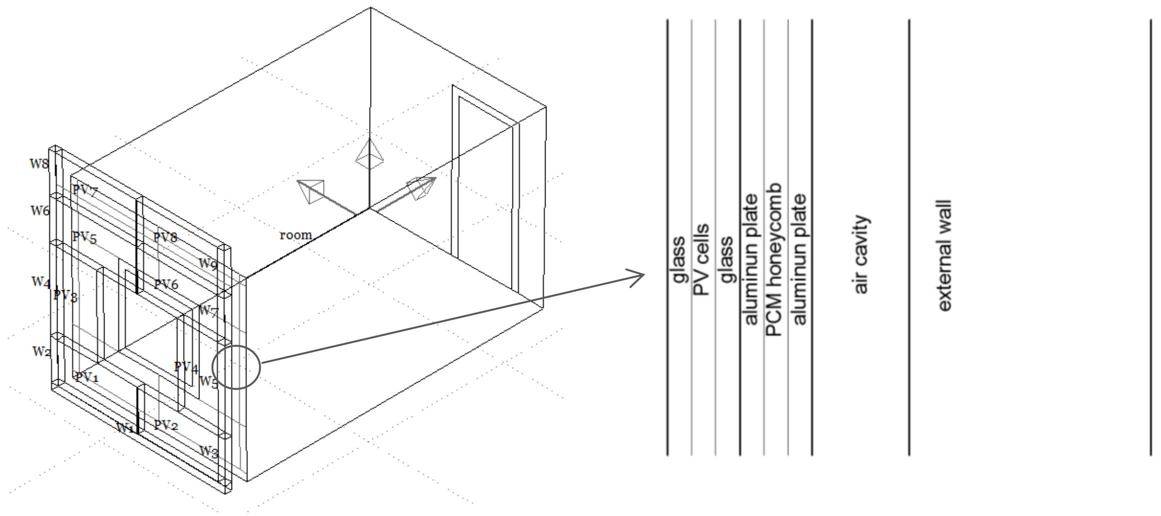


Fig. 1.Model of the simulated façade and its layers.

Whole analysis was conducted using ESP-r simulation software [19]. The power output of the PV modules was calculated using WATSUN-PV model which assumes that short circuit current and open-circuit voltage are temperature dependent [20]. The PV parameters were assumed as for typical thin film CIS panels. Furthermore, to calculate additional latent heat storage by PCM the effective heat capacity method was used [21]. This method represents the additional capacity of the material as a function of the temperature during a change of phases, which has a narrow and finite width peak between melting and solidification temperatures.

In the analysis it was assumed that phase change material will be closed in 2 cm thick aluminum honeycomb structure sealed between two aluminum plates. Four paraffin waxes with different transition temperatures were considered. The parameters that were used in simulation are summarized in Table 1. Thermal conductivity of PCM-aluminum structure was recalculated, taking into account properties of both materials, and equaled 12 W/m·K.

Table 1. Material properties used in simulation.

| Name of PCM / Case | Melting temperature [°C] | Solidification temperature [°C] | Latent heat [kJ/kg] | Specific heat capacity [kJ/kg·K] | Thermal conductivity * [W/m·K] |
|---|---|---|---|---|---|
| RT10HC | 9 | 10 | 126 | 2 | 0.2 |
| RT18HC | 17 | 19 | 222 | 2 | 0.2 |
| RT25HC | 22 | 26 | 177 | 2 | 0.2 |
| RT35HC | 34 | 36 | 197 | 2 | 0.2 |

*For both phases

Simulations were carried out for a typical meteorological year and developed for a specific location of Central Europe. The analysis was conducted for the whole year, with a five-minute time step.

## 4. Results

### *4.1. Temperature of PV cell*

The first parameter that was analysed was temperature of PV panel with different transition temperatures of PCM. Results for four selected days are presented in Fig. 2. It can be observed that for each day, accordingly to the weather parameters, different transition temperature contributes to the most noticeable reduction of PV panel's temperature. Therefore, it reveals that the choice of the optimum transition temperature cannot be made once for the entire year. Transition temperature should be possibly low but in the range of external temperature fluctuations. PCM with too low transition temperature is constantly melted while too high temperature causes that the temperature of PV is maintained at a higher level than for standard PV panel without PCM.

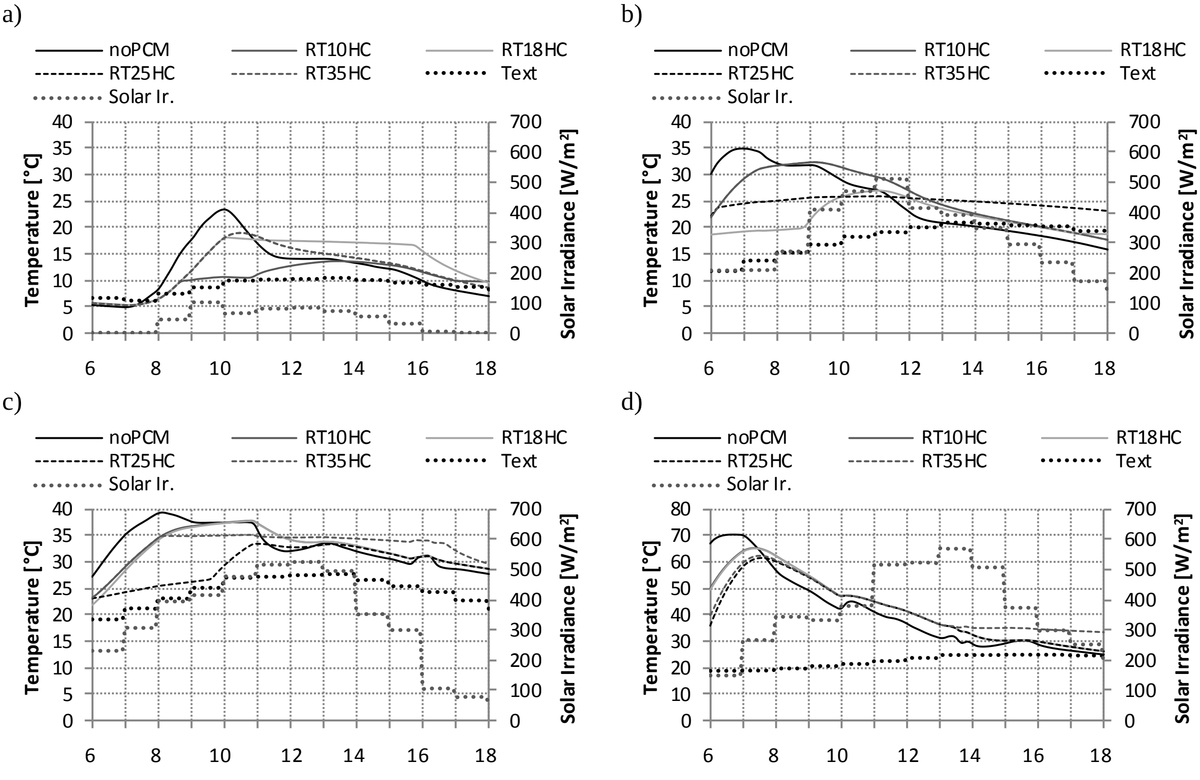


Fig. 2. Temperature of PV/PCM panel for selected days: (a) 4.11; (b) 4.06; (c) 28.06; (d) 29.06.

### *4.2. Efficiency of PV/PCM panels*

In Fig. 3, relative change in efficiency of PV is presented (heating season is marked by the gray background). The values were calculated with respect to the case of PV panel without PCM. It occurred that depending on the transition temperatures of PCM varied change in efficiency of PV panel was obtained. Nevertheless, each case contributes to the temporary increase in efficiency but also causes the decrease in power production for the specific periods of time. It can be observed that the lowest transition temperature (case RT10HC) results in the smallest negative effect during the winter season while the highest temperature causes the biggest decrease in efficiency during the summer period. Very similar performance was obtained for cases shown in Fig. 3 (b) and (c) – during the summer season give the biggest positive effect on the PV efficiency.

a) b)

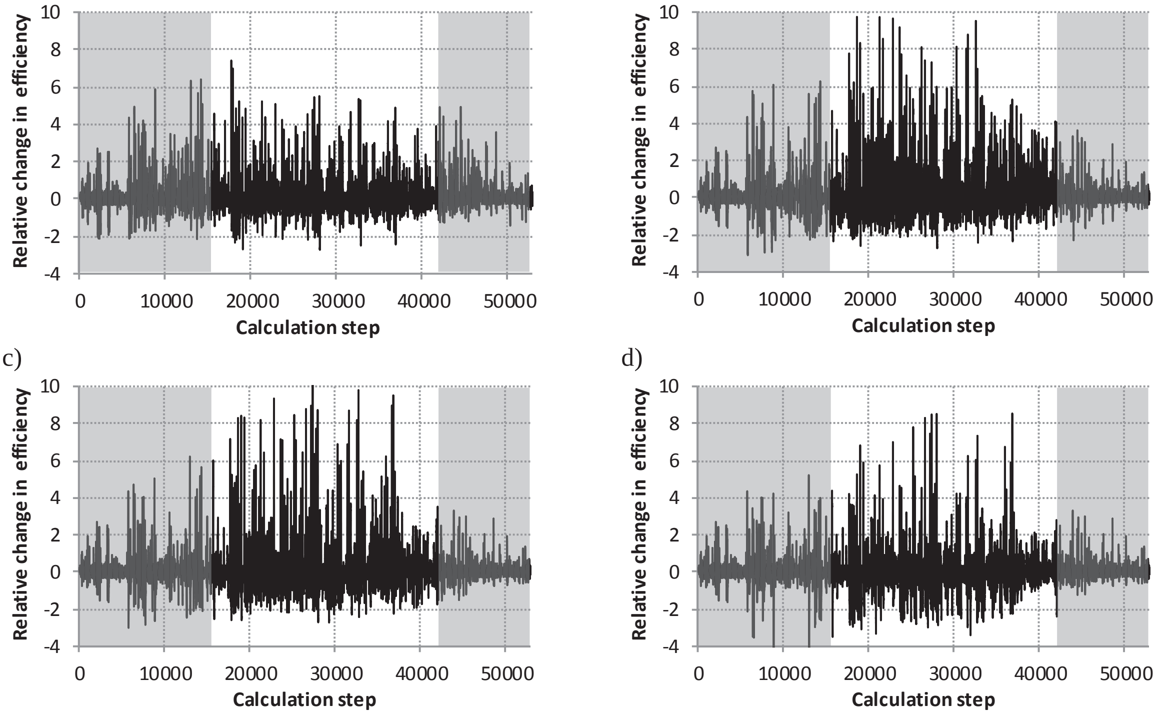


Fig. 3. Relative change in efficiency of PV panel with PCM during the whole year for (a) RT10HC; (b) RT18HC; (c) RT25HC; (d) RT35HC.

Additionally, the values of average and maximum relative increase in efficiency were calculated for each case (Fig. 4). It confirmed that the most effective performance was obtained for the transition temperatures of 18 and 25 °C.

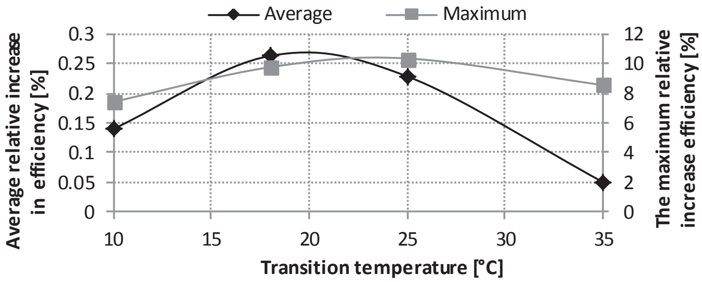


Fig. 4. Average and maximum relative increase in efficiency for different transition temperatures.

## 5. Conclusions

Based on the presented simulation results, it can be concluded that incorporation of PCM on the back surface of PV panel has slight influence on power production efficiency. Maximum relative increase in efficiency equaled approximately 10%, but its average value during the whole year decreased to only 0.25% - taking into account both temporary decrease and increases in efficiency. Application of PCM in the form of presented PCM-aluminum honeycomb structure contributes to stabilization of temperature at the level of transition temperature. During the specific periods of time, when PCM is melting, it means holding the higher temperature of PV panel.

The choice of specific transition temperature of PCM should be made with special consideration to weather parameters characteristic for particular location and direction of the construction. The efficiency of energy production by PV panels increases with its temperature decrease, thus PCM temperature should be as low as possible. Nevertheless, too low transition temperature beyond external temperature fluctuation makes PCM inactive during some periods of time. On the other hand, too high temperature can impede heat transfer and its dissipation. Based on the presented results, it can be stated that optimum temperature should be around 20 °C, but further analysis should be done, considering individually shorter periods of time, e.g., summer season.

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