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Thermal performance of PCM-glazing unit under moderate climatic conditions

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ABSTRACT
Considering physical properties, transparent or translucent building components like windows or glazing facades are the weakest elements of building envelope. The heat transfer coefficient of such elements is approximately four times higher than for opaque partitions, which causes considerable increase of heat loss during winter. In summer relatively high solar transmittance is a source of heat gains which results in undesirable overheating. Application of phase change materials in glazing components affects its thermal performance by the increase of its heat capacity and decrease of solar heat gains, with regard to the current physical state of the PCM.
The aim of this paper is investigation and determination of the thermal performance of PCM-glazing unit, under real, moderate climatic conditions in summer season. Analysis conducted by the authors aims to find the proper arrangement of PCM-glazing unit and proper material properties design, allowing effective overheating control.
To meet the stated goals, dynamic simulations of thermal performance of triple-glazing unit were carried out, using ESP-r software. It was assumed that one chamber, filled with PCM will adjust the solar heat gains flux while the second one will assure required thermal resistance of the partition. Original model of heat transfer through transparent partition, taking into account latent heat storage by effective heat capacity method was applied. Different phase change materials, characterized by various phase transition temperatures were considered in the analysis.
Based on the obtained results it can be concluded that application of a PCM in the external cavity of the triple glazing window effectively affects the thermal performance of the component, stabilizing the diurnal temperature fluctuations. Simulation results revealed that transition temperature should be close to the assumed cooling set point.

KEYWORDS
latent heat, façade, simulation, overheating, solar energy

INTRODUCTION

Transparent elements of the facades, in terms of physical parameters, are one of the weakest link of the building envelope. Because of approximately four times higher value of heat transfer coefficient for windows than for opaque partitions, glazing elements are the cause of the most heat losses during the winter. In addition, in the summer, their relatively high solar transmittance is a source of unwanted heat gains that cause overheating of single rooms and entire buildings. Moreover, during the whole year, the asymmetry of radiation in the areas next to the windows causes deterioration of thermal comfort conditions. Transparent elements cause both higher heat losses in winter and are the source of undesirable heat gains from solar radiation during the summer. An additional disadvantageous physical feature of these elements is their very low heat capacity due to which dynamic processes occurring in the glazing are reflected in the dynamic changes of parameters of the internal environment. On the other hand, the transparent components are indispensable elements of the external partitions, ensuring the required amount of daylight in the rooms and the visual contact with the external environment, which is necessary for the users.

Modification of the optical and thermal properties of glass components using PCM is a relatively new issue. Nevertheless, some simulation analyses and laboratory-scale studies on this subject can be found in the literature. The first theoretical and experimental analyses concerning the determination of solar transmittance by double-glazed component filled with air and PCM were published fifteen years ago (Ismail and Henriquez, 2002). Similar studies, investigating the possibility of limitation of both heat losses and heat gains through transparent partitions by their modification with PCMs, were presented by Weinlader et al. (2005). In recent years, theoretical considerations to determine the thermal effect of PCM application with different transition temperatures under specific climatic conditions (Zhong et al. 2015) and their experimental validation (Li et al. 2014) have been also conducted. However, despite many attempts to develop the numerical model of the multi-pane system (Goia et al. 2012), the majority of experimental work was carried out for double glass unit (Goia et al. 2014) or commercially available glazing component with PCM (Grynning et al. 2015). Another important issue is analysis of the optical properties of transparent elements modified with PCM (Heim, 2011). The considerations presented in the paper start research project aiming to develop a translucent multi-layer component, adjusted for selected locations. In the framework of the project it is planned to develop and test a solution that, thanks to the use of PCM, will improve the energy efficiency of the transparent partition while maintaining (at least periodically) the physical characteristics of the translucent barrier. Theoretical analysis, presented in the paper, was carried out for moderate climate conditions, for the location of Lodz, Poland. The location have been selected due to the further experimental part of a research in a real scale, which will also be used to validate the numerical model of the developed PCM-glazing component.

MATERIALS AND METHODS

PCM-glazing arrangement

The scope of the analysis presented in the paper covers the design of the PCM-glazing parameters that will contribute to the reduction of overheating of the building under moderate climatic conditions. Similar concept was proposed by (Komerska et al. 2015), when PCM layer was used as a part of external dynamic solar shading system. In order to meet the stated goal of the research, preliminary analysis of the PCM-glazing arrangement was conducted. Furthermore, for the stated component composition analysis of the PCM melting temperature was done.

In accordance to the current requirements regarding thermal insulation of windows, it was assumed that for moderate climatic conditions, triple-glazed windows should be considered. Such window construction gives also the possibility of filling one of the window cavities with a phase-changing material, while the second one provides required thermal insulation. Two possible PCM-glazing arrangements allowing to meet the stated assumptions were presented in Figure 1.

Besides the possibility to regulate the daylight access, the main purpose of the PCM application was to decrease the energy demand for cooling by the reduction of the excessive solar heat gains. Based on the preliminary analysis it was stated that for summer conditions PCM should be placed in a cavity located from outside (Fig. 1a). In the cooling season the PCM will play a role of dynamic insulation by storing solar energy during a period of substantial solar heat gains. In that case the active layer (PCM) is located in a distance from indoor environment. The inner cavity limits the heat transfer from PCM layer to the room. During the night when external temperature drops down below solidification point the heat will be released into external environment by conduction and radiation. Additionally, in a solid state the material is characterised by lower solar transmittance what will additionally contribute to the reduction of solar heat gains. Due to the further plan of experimental research, it was assumed that the case designed for the cooling period will be analysed for the east oriented façade, characterized by a significant heat gains in the morning hours.

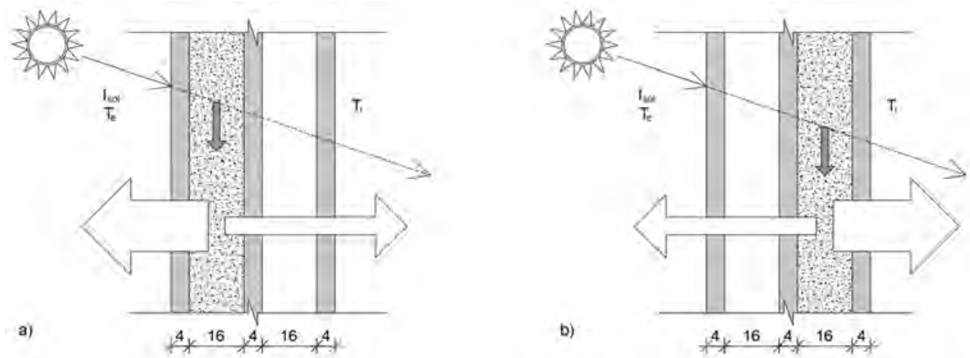


Fig. 1. Two possible arrangements of PCM glazing: a) PCM located from outside, b) PCM located from inside.

To confirm the above considerations, a simulation analysis was carried out, which allowed to compare distributions of the mean temperature in the three cases: reference one – without PCM, with PCM filling external cavity and with the PCM filling internal cavity (Fig. 2). It can be concluded that replacement of highly insulating but low capacity gaseous medium with PCM contributes to the lowering the temperature in the window. Moreover, PCM placed in the external cavity reveals greater ability to reduce the temperature rise due to solar radiation incidence on the facade, which confirms assumptions of preliminary analysis.

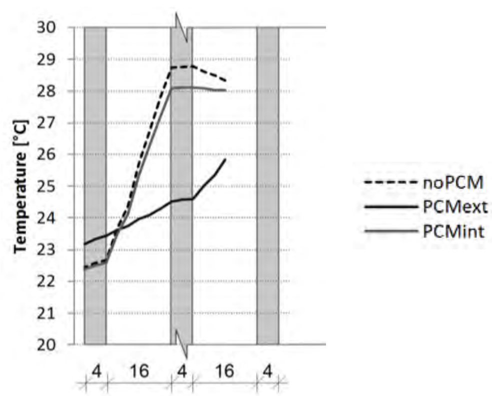


Fig. 2. Distribution of mean temperature in traditional window, PCM-glazing filled with external and internal cavity filled with PCM during cooling season.

Case study

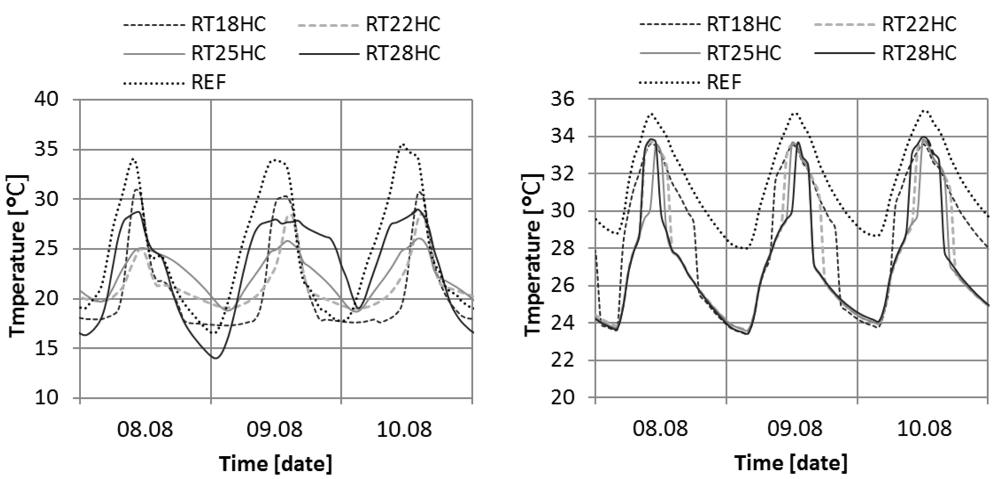
Analysis of the transition temperature of the PCM was conducted for the singe zone, office room with only one external wall equipped with centrally positioned, square window (1 m wide and high). Regarding considerations presented above, triple glazing unit with external cavity filed with PCM was further analysed. Numerical analysis was conducted in ESP-r computational environment (Clarke, 2001). Latent heat accumulation due to PCM application was calculated using effective heat capacity method, which was previously validated by the authors for opaque elements (Heim and Wieprzkowicz, 2016). Additionally, change of optical

properties of PCM-glazing was included in the analysis. Values of visible transmittance, absorbance and reflectance of solar radiation for the window component filled with liquid and solid PCM were determined based on the previously conducted measurements.
The materials considered in this research were selected based on the climate conditions analysis. It was assumed that, since the phase transition is triggered by the temperature rise, melting temperature of PCM placed in external cavity of the window should be suited for external temperature fluctuations (according to Typical Meteorological Year) characteristic for the analysed location (Lodz, Poland) and period of time (June-August). Thermal performance of the PCM-glazing window with four different paraffins (Table 1) was compared with the reference case of the triple glazed window with both cavities filled with argon. It was assumed that change of optical properties occurs at peak melting temperature, but material undergo phase transition in the whole given temperature range.

Table 1. Thermal properties of analysed paraffins.

PCM	Peak melting temperature [°C]	Phase transition temperature range [°C]	Latent heat capacity [kJ/kg]	Specific heat [kJ/kg·K]	Density [kg/m^3]
RT18HC	18	17-19	260	2000	880
RT22HC	22	19-24	190	2000	880
RT25HC	25	18-26	230	2000	880
RT28HC	28	26-29	250	2000	880

RESULTS
The analysis of the potential of PCM-glazing to limit the excessive solar heat gains was made based on the numerically calculated temperatures inside of the glazing unit and adjacent zone (Figure 3).



a) b)

Figure 3. Temperature changes during 3 selected days: a) in the external glazing cavity, b) inside the room adjacent to the façade equipped with PCM-glazing.

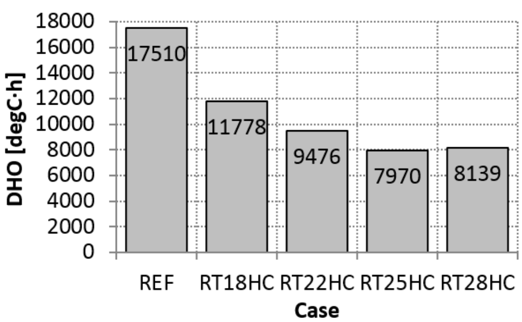
Based in the results presented in Figure 3a it can be observed that in each case of PCM application the temperature is stabilized at the melting temperature level, during specific periods of time, during analysed days. It means that in all analysed cases the phase transition and latent heat accumulation occurred, but with different thermal effect. Analysing the

temperatures in the external cavity of the window, it can be observed that the highest daily peak temperatures were obtained for the paraffin with the lowest melting temperature, which stores the thermal energy mostly in the night hours. The lowest daily peak temperatures in that location were obtained for the paraffin RT25HC, which allowed to keep the temperature in the thermal comfort range for almost whole analysed 3-days period of time.
As the main purpose of the PCM application in the glazing unit was reduction of the temperature inside the adjacent room the results presented in Figure 3b reflects the thermal performance of four analysed paraffins compared to the reference case. Due to diversified melting temperatures, the increased rate of temperature rise can be observed in a different moments of the day. The material that allows to keep the possibly lowest zone temperature is paraffin with the melting temperature around 25°C.
Further, quantitative evaluation of the thermal effect of PCM-glazing application on the overheating control inside adjacent zone was done using the value of Degree-Hours of Overheating *(DHO)*, which reflects the time and level of exceedance of maximum temperature of thermal comfort, calculated as:

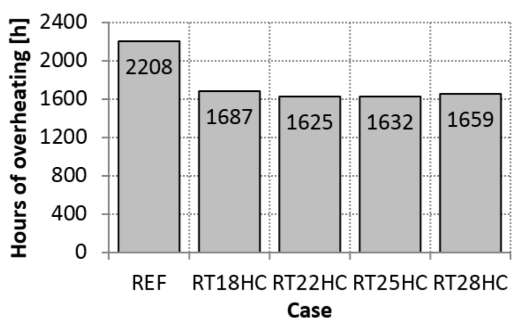
$$DHO = \sum_{i=1}^{n} (T_i - 25) \cdot t \quad [\mathrm{degC} \cdot \mathrm{h}] \tag{1}$$

were T_i is instantaneous value of the room temperature [°C], t is length of the time step of calculation [h] , i is subsequent number of the time step [-] and n is number of the time steps of analysis [-].

Additionally, number of hours of overheating was calculated (Fig. 4b), which showed that none of the analysed materials filling the cavity of glazing unit is able to totally prevent from overheating. For all analysed paraffins very similar number of hours of overheating was obtained, which confirmed the phenomena that could be observed for 3 selected days presented in Figure 3, that temperature below 25°C was register during the same periods of time. Together with the analysis of the calculated values of *DHO* parameter (Fig. 4a), it also proves (for the whole analysed period of time) that application of PCM contributes to the reduction of overheating but efficiency of such solution depends on the transition temperature of the material. The lowest value of *DHO* was obtained for the paraffin with melting temperature around upper limit of thermal comfort. Application of such kind of PCM in the glazing component allowed to obtain twice lower value of *DHO* parameter and reduces number of hours when overheating occurred by 26%.



a)



b)

Figure 4. Calculated values of: a) Degree-Days of Overheating, b) Hours of overheating, for 5 analysed cases.

CONCLUSIONS

The paper presents the results of the theoretical analysis aiming to determine the basic technical parameters of the translucent construction component and thermal properties of the PCM filling the external window cavity. It was assumed that the component is to be designed for storing thermal energy of solar radiation and reducing overheating. The PCM-glazing arrangement dedicated to the selected location and the characteristic climatic conditions have been analysed. The main purpose of the presented research was selection of the phase change materials that could effectively reduce heat gains through a transparent partition.

On the basis of the analysis of the material transition temperature, the material recommended for further experimental investigation was selected. It was stated that the most effective performance was observed for paraffin with melting temperature of 25°C, which will be further experimentally tested in the real scale PCM-glazing component under moderate climatic conditions.

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