

Determination of total solar and visual radiation transmitted through triple glazing component with PCM layer

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Abstract. Modification of a glazing unit by application of PCM layer can lead to the increase of the heat capacity of the component and effective control of solar heat gains in buildings. The purpose of this study was to investigate the effect of the PCM layer on total solar and visual transmittance in solid, mushy (transition) and liquid state of PCM. The experiment was conducted in laboratory scale using triple glazed window unit sample and artificial sun as a source of solar radiation. The transmittance (total and visual) was calculated based on the results from pyranometers and illuminance meters taking into account the intensity of solar radiation at the level of 1000 W/m². Measurements revealed that the component is almost blind in the solid state why in the liquid the transmittance is lower than for empty - traditional triple glazing. The transmitted radiation (total and visible) depends on the location of PCM layer (internal or external window chamber). The registered total solar radiation obtained in solid state was even 0 W/m² (when material was on the inner side), while the maximum values for liquid was 142 W/m² (material is located on the outer side). The light transmittance for more transparent case was around 1.6 klx and ten times higher in liquid than solid state.

1. Introduction

The application of PCM in transparent constructions became common research challenge during last five years since the following monography became published by Heim [1]. In 2012 Goia et al. [2] determined the optical characteristics of advanced glazing system with PCM. The glazing was developed by the incorporation of a paraffin-based Phase Change Material (PCM) into a transparent component. The thickness of paraffin was e.g. 15 mm. The spectral transmissivity, reflectivity and absorptivity of the PCM glazing system were measured between 400 and 2000 nm. Based on the obtained results for the whole component the integral values of total solar transmittance were 0.75 for liquid and 0.46 for solid state respectively. These values, especially for solid phase seem to be very high in comparison with other research studies done by Gowreesunker et al. [3], where measured transmittance in solid phase was 0.20. The case studied in [3] was a double glazed unit which consisted of 4 mm glass pane and 16 mm of PCM. Moreover, the experiments done by Bianco et al. [4] for 10 mm thick, polycarbonate crystal panels gave the results of solar transmittance 0.32. Additionally, in paper [5] authors provided the transmission coefficient of glazed unit (4/15/4 mm) at the level of 0.03 in solid state. It was underlined that the transmission and reflection coefficients measured by the commercial spectrophotometer are low in comparison with basic observations of the component in practice and from previous experimental analyses [2]. With this set-up, the absorptance appears to be the dominant feature in both the visible and infrared (IR) range. This effect takes place because the high scattering phenomena cannot be fully and efficiently tackled by



means of conventional spectrophotometer and more advanced testing is necessary to fully characterise the behaviour of the PCM layer in the solid state.

Taking into account the previously published works [6] & [7] and analysis of results presented above it seems to be justified to analyse optical properties of PCM windows more realistically. The main goal of the presented study was to determine experimentally the optical properties of PCM-triple-glazing windows in solid, liquid and intermittent state. It was assumed that material can be placed in the inner and outer cavity of glazing unit. The effect of phase change was induced by constant heat radiation flux (at the level of 1000 W/m^2) emitted by halogen light source. The total and visual radiation in different configurations was measured by professional pyranometers (Hukseflux – LP02) and illuminance meters (Konica Minolta – T-10MA). The specific experimental set-up was developed for the purpose of experiments to provide non disturbance values for the whole glazing unit. The measurement results were compared to the standard – empty glazing unit and finally the transmissivity was determined.

2. Materials and methods

2.1. Experimental set-up

The experimental set up consists of the three separate elements combined together: artificial sun, sample holder equipped with triple glazing unit filled PCM and data acquisition system. As a light and radiation source an artificial sun Gunt HL 313.01 was used. This light source provides radiation flux similar to natural sunlight and enables experiments under stable, repeatable irradiation conditions. The artificial sun comprised of eight halogen lamps each with a total power of 8000 W, arranged in two vertical rows. Dimensions of this device were $L \times W \times H$: $1340 \times 810 \times 2100 \text{ mm}$. The intensity of radiation was adjusted by the distance between lamps and measurement devices – the pyranometers or illuminance meters.

The main element of the installation was the sample holder in which the triple glazing unit and sensors were located. Dimensions of glazing were $L \times W \times H$: $150 \times 45 \times 150 \text{ mm}$. One cavity was constantly filled with argon, while the second one for the first series of measurements was treated as a reference one and filled with air. For the purpose of the further, primary measurements the second cavity was fully filled up with Rubitherm RT 21HC.

The distance between the glass and the sensors has been calculated and adjusted to eliminate reflections to sensors from the aluminum distance piece. The diameter of the outer hole was 120 mm while the internal was 51.5mm. Schematically it was shown in Fig. 1. Experiments were carried out with the simultaneous use of two calibrated sensors where one was the reference (without covering from outside).

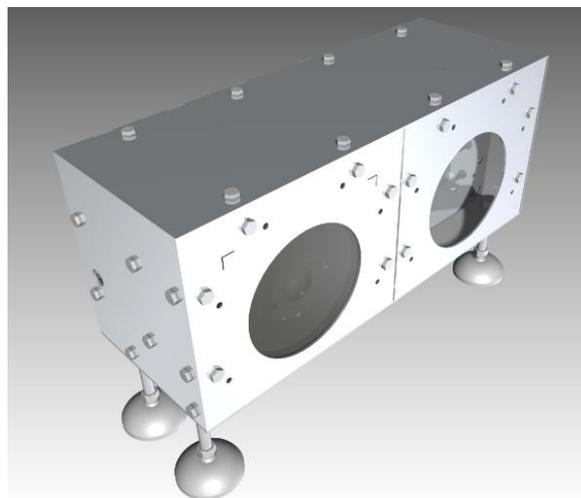


Figure 1. Sample holder with sensors.

2.2. Control and data acquisition system

To measure luminous flux per unit area Konica Minolta T-10MA Illuminance Meter with two mini receptor heads was used. The data was transmitted to a computer via the RS232 interface. The measurement was performed with a 30-second interval. The second class (specifications of the ISO 9060) solar radiation sensors Hukseflux LP02 were used. These sensors measure the solar radiation received by a plane surface from a 180° field of view angle therefore the interior of the sample holder was covered with a black light absorber. The measurements were carried out continuously using National Instruments cDAQ-9181 with the 9219 module. The data was collected using program written in the LabView.

2.3. Experimental procedure

The experiment was divided on calibration part and real measurements. Calibration was used to unify output data from sensors as well as to stabilize the radiation source. It was assumed that experiments will be conducted under the intensity of irradiation on the glazing surface of 1000 W/m^2 . The spectral radiation of the artificial sun slightly differs from the real sun and is the same as for halogen lamps. It means that the maximum relative irradiance occurs for 750 nm. Moreover:

- the radiation in ultraviolet range is lower,
- the radiation in near infrared range is higher.

in comparison with spectral characteristic of solar radiation.

The samples were prepared by conditioning the whole glazing with PCM in 8°C during 24 hours before the experiment started. It means that material fully solidified and was cooled down 5 degree below the point when phase change begins. The air temperature in the experimental zone was 20°C . Any other light or heat radiation sources were turned off. The halogen lamps were preheated for 5 minutes before each set of measurement.

The experiment was done for standard value of irradiance 1000 W/m^2 in two window configurations. The first one, fig. 2a, when cavity with PCM was on the outer side of the window (was exposed directly to radiation). The second one, fig. 2b, when PCM layer was located on the inner side. All dimensions are given in millimetres. Each experimental procedure lasted for more than 2 hours from the beginning to fully melting of PCM. During experiments the irradiance and illuminance were registered every 30 seconds. Additionally, the image of the material was registered in 60 seconds interval using digital camera.

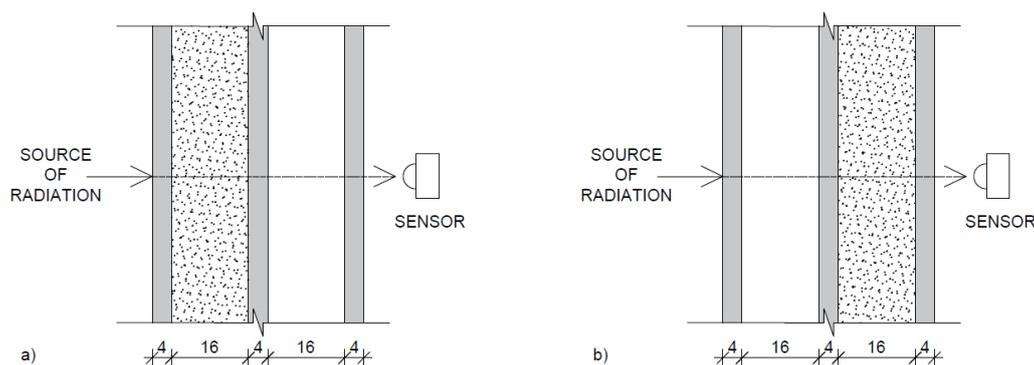


Figure 2. Two configurations of PCM layer towards solar radiation, a - case A (from the front side of radiation), b - case B (from the back side of radiation).

3. Results and analysis

3.1. Total solar energy transmittance

As it was stated in the introduction, the PCM layer in transparent construction affects the overall solar energy performance dependently on the physical state. Using traditional techniques and laboratory equipment it is very difficult or almost impossible to analyse the optical properties as a function of

temperature of material. Therefore, the main goal of this research was to use a standard pyranometer to monitor transmitted solar radiation during change of phase under standardized and stable conditions.

The results of measured solar radiation were presented in figure 3 (case A) and 4 (case B), respectively. The analysis of presented results shows that position of PCM layer determine the amount of radiation transmitted through triple glazing unit. When material is located on the outer side (the first cavity from radiation source), the radiation is higher in both, solid and liquid states. It can be explained by the transmittance processes in complex glazing structures where PCM plays a role of additional, reflective surface. When PCM is located behind the two sheets of glass the inter-reflection in the unit enhanced the effect of reemission. The irradiation values measured for solid state were 5 W/m² in case A and 0 W/m² in case B. For liquid state the irradiation were 142 and 118 W/m² respectively. Zero value registered for a solid PCM can be also a result of sensor sensitivity. Nevertheless, the melting process was also shifted in time due to the lower radiation incident on the PCM external surface and transferred to heat. Registered delay was around 25 minutes until the material achieved fully mushy state.

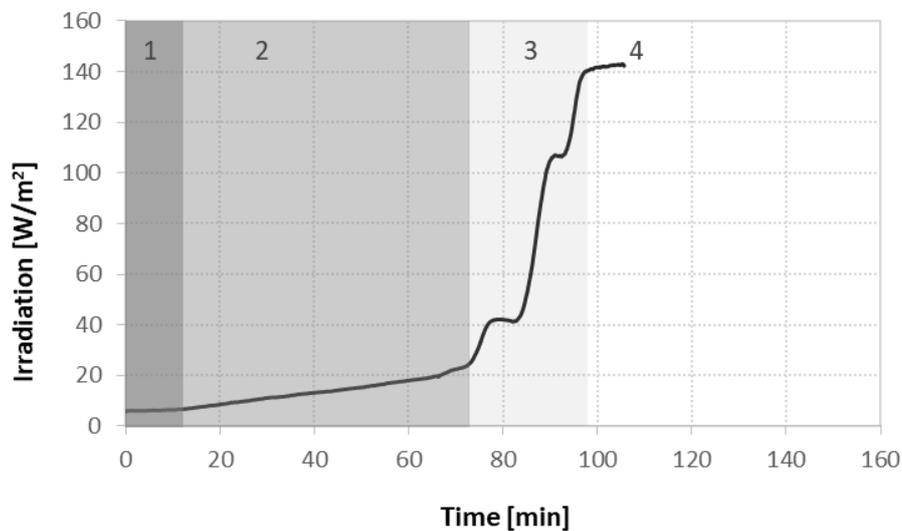


Figure 3. Radiation transmitted through PCM-triple glazing vs. time during change of phase – case A (PCM located in the outer cavity of the window).

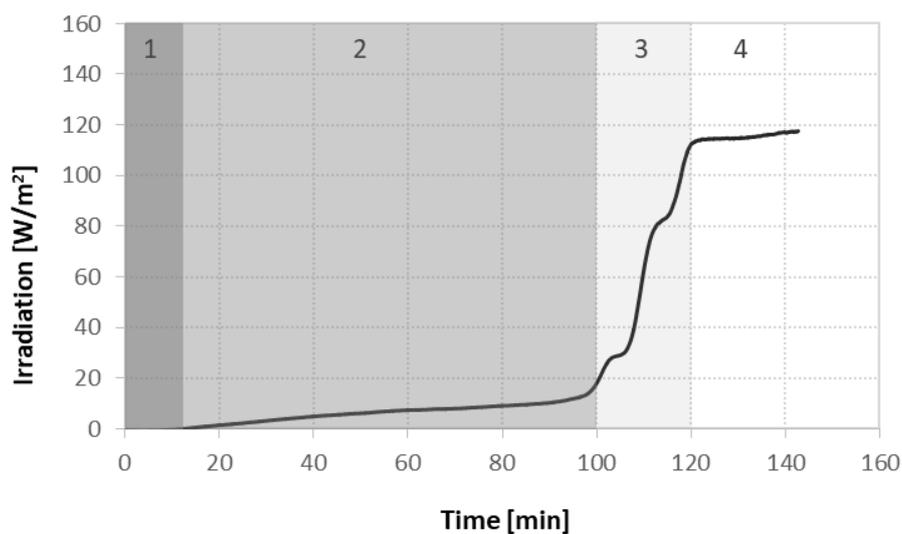


Figure 4. Radiation transmitted through PCM-triple glazing vs. time during change of phase – case B (PCM located in the inner cavity of the window).

Analysis of the presented results allowed to specify the four characteristic periods when material was in a specific state. These periods were highlighted in figures 3 and 4 and indicated from 1 to 4. In period 1 the material was fully solid and its transmissivity was constant. In period 2 material melted and became more translucent but still homogenous. Its transparency was slowly rising. In period 3 the material was partly liquid (from upper side) and partly mushy (from the bottom). The mushy part was moving down letting more radiation to be transmitted through the glazing unit. This period ends up relatively quickly. The characteristic plateau, which is visible two times in that period can be explained as an artefact caused by uncovering of the sensor by the mushy slice of PCM moving down. In period 4 the material was fully melted and transmissivity became constant again. This effect was confirmed by the sets of images registered by digital camera and presented in 3.3.

3.2. Light transmittance

The total irradiation presented in figures 3 and 4 corresponds to light transmittance measured by illuminance meter. The experimental procedure presented in 2.3 was repeated for the second sets of the sensors. The illuminance was measured for the same sample and under the same conditions as irradiance was. The results for case A and B were presented in figure 5. The characteristic of the curves are similar. The effect of PCM location reduced the light transmittance in similar ratio as total radiation transmittance. The differences between solid and liquid phase were around 10 times, for both cases. The maximum illuminance for case A was above 16 klx when for case B was slightly below 14 klx. The luminance efficacy of the light transmitted through liquid PCM was around 115 lm/W.

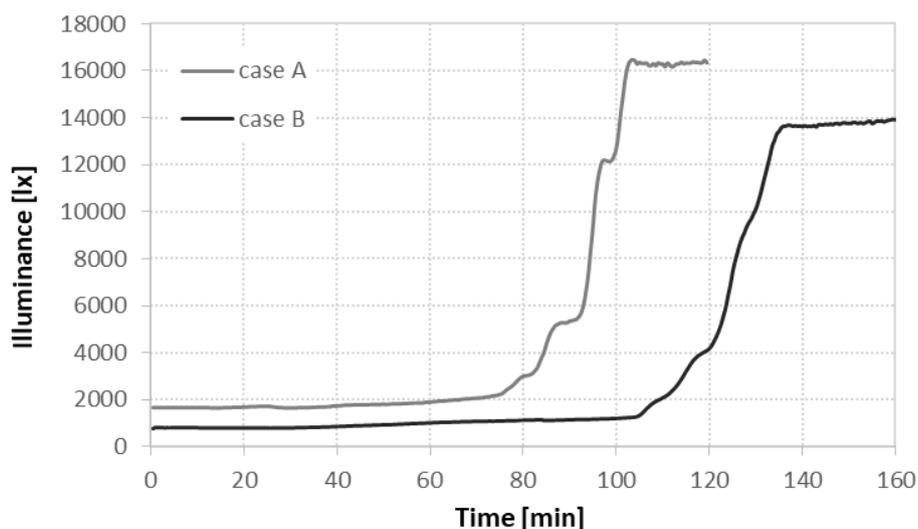
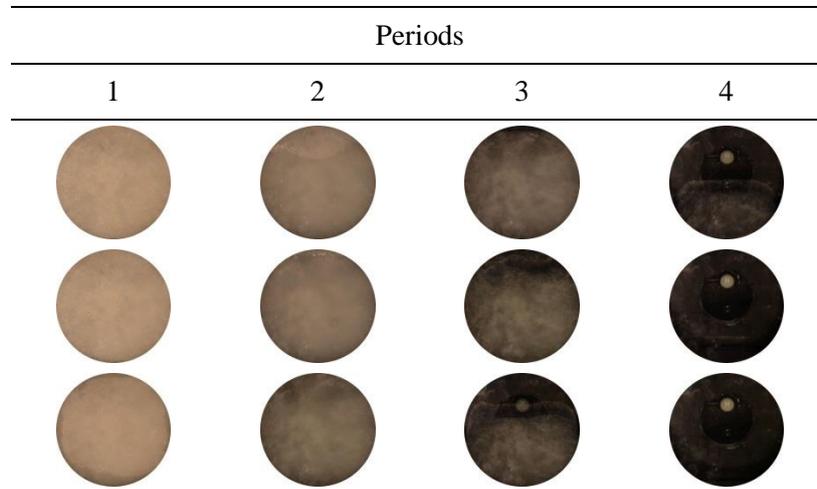


Figure 5. Light transmitted through PCM-triple glazing vs. time during change of phase – case A (PCM located in the outer cavity of the window) and B (PCM located in the inner cavity of the window).

3.3. Overall aspects of PCM glazing in different physical states

The results presented in table 1 were registered during experiment and divided into four characteristic periods. The photos show the colour changes as well. When material was in a liquid phase the material was fully transparent and colouristically neutral. In intermittent phase material became rather translucent than transparent, while when it was fully solid it became less transparent and light grey-white. The darker colour means more melted state and higher transmissivity of the PCM layer. The interesting remark is that material was melted non homogeneously during whole period. Completely liquid phase appeared on the top and finally the boundary front between melted and mushy parts moved down of the glazing.

Table 1. The view of glazing surface with PCM layer from outside in selected periods of transition.

4. Conclusions

The experimental results of radiation transmission through triple glazing PCM structure were presented in the paper. The authors developed the original experimental set up and used artificial sun made of the halogen lamps to conduct the experiment under constant irradiation.

The results showed that total and visual part of solar energy transmitted through glazing is very low when PCM is in a solid or even mushy state. The thickness of the PCM layer (16 mm) caused that the glazing unit become almost fully blind, especially when PCM is located on the back side from the radiation source. It can cause the serious problem in daylighting the building interior during that time. When material was fully melted the transmitted radiation was much higher. In case of illuminance these values can be even around ten times higher.

Acknowledgement

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