

The characteristics of temperature fluctuations in thermal insulation covered with layer of PCM

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Abstract. Energy performance of opaque elements of building envelope can be improved by the decrease of heat losses by conduction or by effective utilization of solar heat gains. Enhancement of thermal insulation by application a thin layer of phase change material as an external finishing coating contributes to the attenuation and delay of heat flux transferred through partition. Based on the real scale experiment of one-year measurements, dynamics of temperature fluctuations in thermal insulation covered with external layer of PCM was characterized and analysed. It was concluded that outer application of PCM contributes to the attenuation of temperature fluctuations of the whole wall component.

1. Introduction

It can be observed that there is a strong need for the new, smart technologies on thermal insulation industry [1, 2]. The predicted trends of such kind materials development are moving towards application of dynamic thermal insulation materials. It means that, in the contrary to the pursuit of last decades, lowering the thermal conductivity loses its importance in favour for activating the material. There is no doubt that thermal insulation materials of the future will have to be still characterized by excellent insulating properties but simultaneously should reveal the ability of its properties adjustment to dynamic thermal conditions. There are different concepts of achieving those assumptions [3], using e.g. sensible and latent heat accumulation. The comprehensive analyses for the wide range of concretes was done by Garbalińska and Strzałkowski 2016 [4]. The authors analysed and compared the results of internal temperature and internal heat flux fluctuations. One of the alternative and most promising idea is to utilize the effect of latent heat accumulation induced by phase transition of material caused by natural, diurnal temperature fluctuation [5].

Application of phase change materials (PCM) has been considered for last 30 years [6,7,8] as an internal finishing layer, which accumulate excessive internal heat loads during the day and release it back to the internal environment during the night time what contributes to the attenuation of daily temperature fluctuations (Fig. 1a). Another approach, which has been recently investigated concerns different positioning of PCM layer [9] in heavyweight [10] and lightweight [11,12] constructions. Based on previous studies [13,14] it can be assumed that in case of external application of PCM, solar Energy is accumulated in the material and PCM layer plays a role of a thermal shield [15], attenuating the heat flux by conduction and temperature fluctuations in the whole partition (Fig 1b).



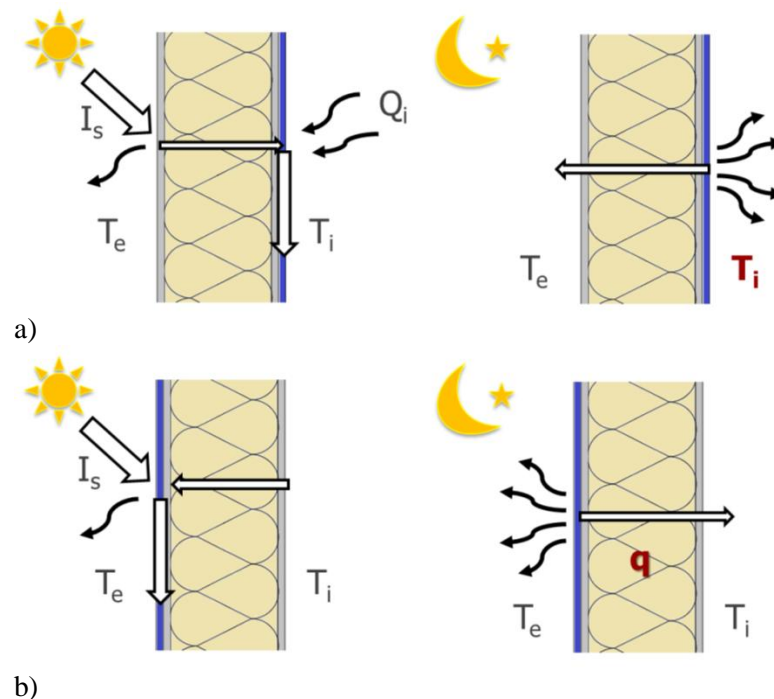


Figure 1. Dominant thermal processes occurring in the lightweight external wall enhanced with PCM layer (marked with the blue line) positioned from: a) internal, b) external side.

Considering PCM integration within external wall, the agent that induce the heat accumulation and release is temperature difference generating heat flux on material surface. Thus, efficiency of the system depends predominately on the occurrence of the process trigger. Depending on the assumption of the specific phase change temperature and position of the material (external, internal or intermediate), different frequency of accumulation and release processes can be observed. It means, that if material was placed in the thermally stable environment (e.g. internal surface of the wall during heating season when system keeps room temperature at lowest required level), there would be no initiator inducing the phase change. On the other hand, highly changeable thermal conditions (e.g. external surface of the wall during the summer) makes problem of proper phase change temperature selection very complicated. Since material properties should match the conditions that trigger the heat accumulation process, selection of material properties can be done only for specific conditions, characteristic for specific period of time.

Different positioning of the PCM in external wall could result in different temperature stabilization effect. Heat accumulation during phase transition is isothermal process, thus gives possibility to keep the temperature on the desired level till melting process is finished. By changing the temperature distribution in the depth of the wall, heat flux by conduction is also affected. In order to limit heat exchange between external and indoor environment, heat flux by conduction should be decreased. One of the possible ways to achieve this is to decrease the temperature difference between external and internal surfaces temperatures, by shifting one of those. In general, to limit heat losses in winter conditions, temperature of external surface should be kept on possibly highest level, while under summer conditions at the lowest.

The purpose of the study was investigation of the dynamics of temperature fluctuations in the thermal insulation covered with PCM layer from the external side of the wall. The analysis was conducted based on the measurement results from real-scale experiment. The thermal effect of PCM layer application on the temperature fluctuations in thermal insulation was evaluated in accordance to the reference case, monitored under the same boundary conditions.

2. Materials and methods

2.1. Experimental set-up

Experimental investigation of the dynamics of thermal insulation enhanced by external layer of PCM was conducted under moderate climatic conditions characteristic for the location of experimental set-up (the city of Lodz, 51°46 N & 19°27 E, Poland, Central Europe). The test stand was designed in such a way that different constructions can be examined under the unified thermal conditions simultaneously. A frame constructed external wall designed with centrally positioned square 1m² window and 12 test sections around the window, each with dimensions of 60x60 cm. The basic construction filling the spaces between steel pillars was made of 20 cm of mineral wool and internal finishing lining. The wall was constructed as a ventilated façade, covered from external side with PV panels.

For the purpose of comparative analysis of the thermal effect of PCM application, some of the test section were treated as a reference case, where no additional PCM layer was added to the basic structure.

Each test section was equipped with 6 temperature sensors, placed in the cross section of the component. Since the main goal of the research presented in the paper is characteristic of temperature fluctuations in thermal insulation, the temperature measured in the middle point of thermal insulation layer was analysed. Additionally, temperature in the ventilation gap was registered. The measurements were done with 5-minute time step. Two types of digital temperature sensors were used: TSic 506 and TSic 306. The first one is characterized by very high accuracy of ± 0.1 K in a range of 40 K (from 5 to 45°C), but the measurement range of this sensor is -10 to 60°C. Since the temperature in the ventilation cavity could exceed this range, sensors with a lower accuracy (of ± 0.3 K in a range from 10 to 90°C) but wider measurement range (-50 to 150°C) were applied. The temperature recorded in the ventilation gap was treated as an external one.

In the paper results from the measurements performed for two test sections of east directed facade were presented and analysed: for the basic – reference case and one enhanced with novel PCM layer.

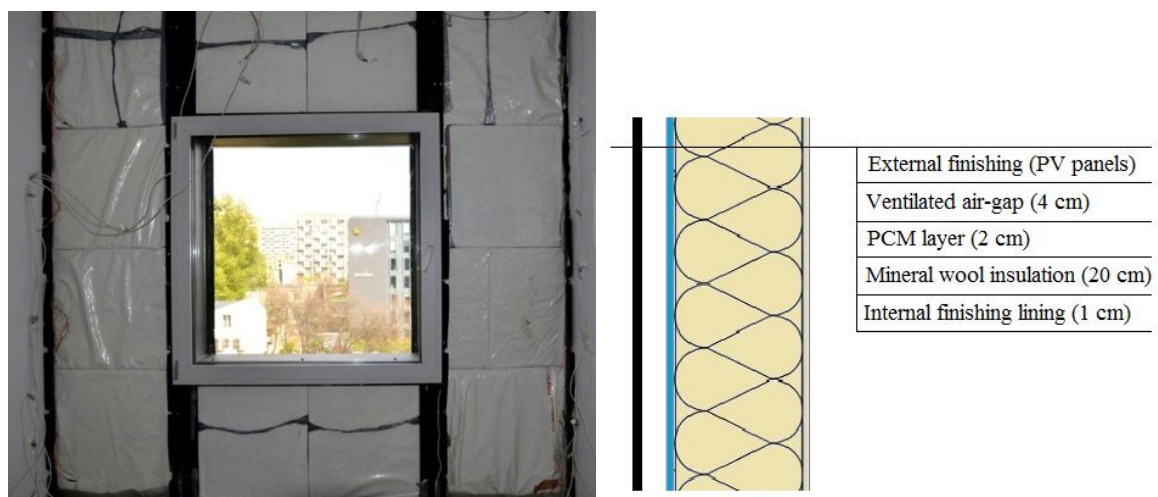


Figure 2. Façade view from inside and detailed cross section of the partition.

2.2. PCM composite

Based on theoretical considerations a novel methods of PCM applications were developed and tested. The basic assumption was to develop cheap and easy way of encapsulation. The first step to achieve this goal was a choice of the material that could work as a matrix that can hold melted material. On the experimental stage of the analysis perlite with different partition size was tested. Furthermore, due to better impregnability, availability and costs, perlite with 1÷6 mm fraction was chosen to be applied in the façade construction.

Furthermore, optimal weight proportion between paraffin and perlite was experimentally investigated. Different proportions were tested and it occurred that maximum content of PCM without

further leakage can be obtained with ratio 1:1. The core material was soaked with paraffin wax and coated with liquid foil to additionally prevent from leakage. The minimum weight proportion between perlite and liquid foil, which assured full coverage of the perlite particles surfaces was 1:4. Tested sample was exposed to high temperature (above melting point) and observed for two weeks. After that time no leakage was noted what confirmed proper design.

In order to speed up solidification process after mixing all products perlite and liquid foil were previously cooled down. During the preparation temperature sensors were placed in the component. In the paper, results obtained for the paraffin RT25HC were presented and analysed. Due to the melting temperature of the paraffin around 25°C, it was expected that application of such PCM will be beneficial during the summer period, under high external temperatures and solar radiation. Due to that assumption, measurements conducted during four hottest months were analysed, from May to August.

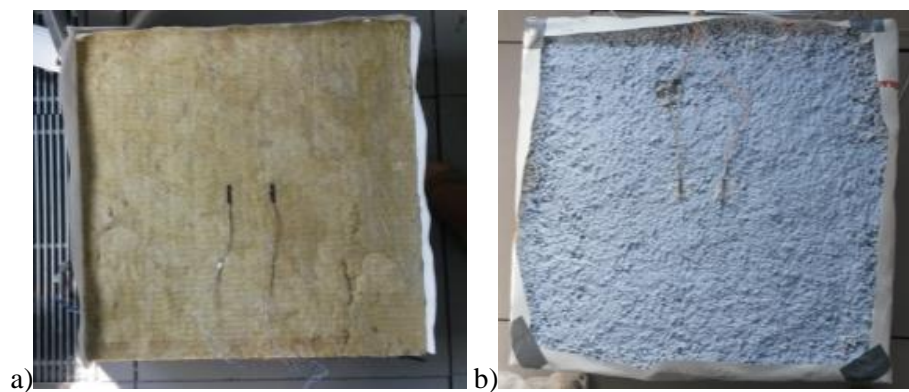


Figure 3. Analysed panels: a) reference, b) modified with PCM layer.

The total thickness of PCM-perlite composite external layer was 2 cm, and the total density 694 kg/m³. The latent heat capacity of the composite was estimated by DSC measurements. Heating and cooling cycles were proceeded with 1.0 K/min rate. Based on the results presented in Figure 4 calculated value of latent heat capacity of the composite equalled 54 J/g.

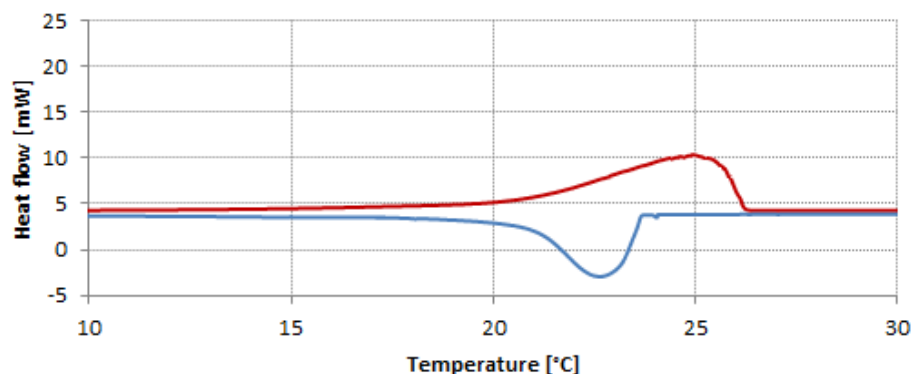


Figure 4. Results of DCS measurement of PCM-perlite composite.

2.3. Evaluation method

2.3.1. Daily temperature fluctuations

Temperature values analysed with 5-minute time step, for modified and reference panel directly reveal the differences in the thermal performance of subsequent test sections. Nevertheless, considering large amount of data only selected, representative period of time can be presented in the paper.

2.3.2. Dynamics of thermal insulation.

In order to describe the dynamics of temperature fluctuations in thermal insulation a novel index was proposed. It describes the speed of temperature increase in thermal insulation layer during the day. Temperature rise rate was calculated taking into account the value of maximum temperature and time when it occurred. This factor was calculated separately for each analysed test section and for each day. Nevertheless, designation of this factor was possible only for days with sinusoidal temperature fluctuations. Dynamics of thermal insulation (Figure 5) was calculated by the following formula:

$$DOTI^n = \frac{\Delta T_i^n}{\Delta t_{Ti}^n} = \frac{T_{i_{max}}^n - T_{i_0}^n}{t_{Ti_{max}}^n - t_{Ti_0}^n} \left[\frac{K}{h} \right] \quad (1)$$

where:

- $T_{i_{max}}^n$ - maximum temperature measured in the half of the thermal insulation thickness in panel n
- $T_{i_0}^n$ - temperature measured in the half of the thermal insulation thickness in panel n in time 0
- $t_{Ti_{max}}^n$ - hour when temperature $T_{i_{max}}^n$ occurred
- $t_{Ti_0}^n$ - time 0 (beginning of the day)

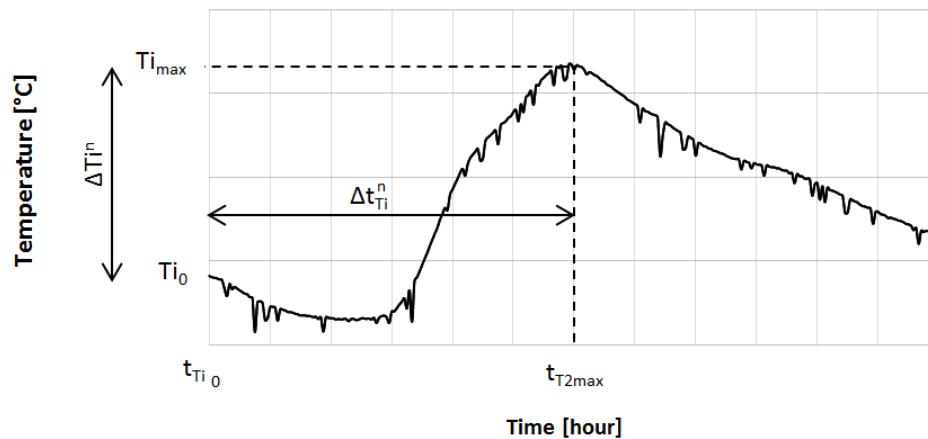


Figure 5. Example values used for dynamics of thermal insulation (DOTI) calculation.

3. Results and analysis

3.1. Daily temperature fluctuations.

Due to large amount of measured data (more than 35 thousands readouts for one test section during analysed period of four months), temperature fluctuations were presented only for selected, representative period of time – one week. Temperature distribution in the middle point of thermal insulation layer in two test sections: reference (REF) and modified (PCM) were presented in Figure 6.

It can be observed that temperature of the insulation covered with PCM is visibly lower during the day and higher during the night-time, comparing to the reference panel. It can be stated that application of PCM reduced daily amplitudes of insulation temperature. It can be also observed that due to highly intense and sudden occurrence of solar radiation during the accumulation of latent heat by PCM, temperature rise can be observed, but slower than for reference panel. Moreover, when temperature dropped to solidification temperature of paraffin, release of accumulated heat caused very slow decrease of temperature.

The temperature in the mineral wool varied from 20°C to 32°C for test section with PCM while for reference panel from 16°C to 40°C. It can be concluded that for panels with paraffin temperature was kept in the phase transition range and maximum temperature peak was shifted in time.

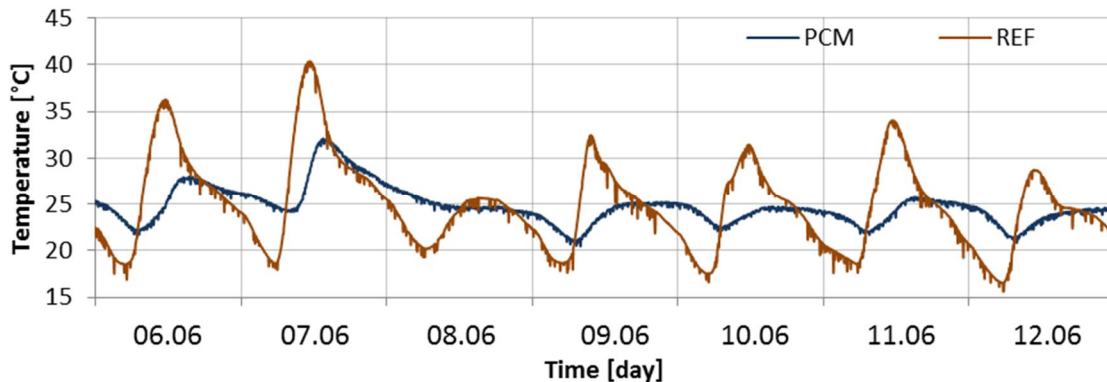


Figure 6. Temperature fluctuations in the middle point of mineral wool measured for reference and modified test section.

3.2. Dynamics of thermal insulation (DOTI).

To assess the attenuation of the influence of external temperature fluctuations on the thermal performance of insulation layer, another parameter - DOTI was introduced. It reveals the speed of temperature rise in the material, so reflects the ability of the material to attenuate the influence of thermal fluctuations of the surrounding conditions. Based on the results presented in Figure 7 it can be observed that the rate of temperature increase for the case with PCM do not exceeds 0.5 K/h for the most of analysed days, while for reference case mostly varies between 0.5 and 1.5 K/h.

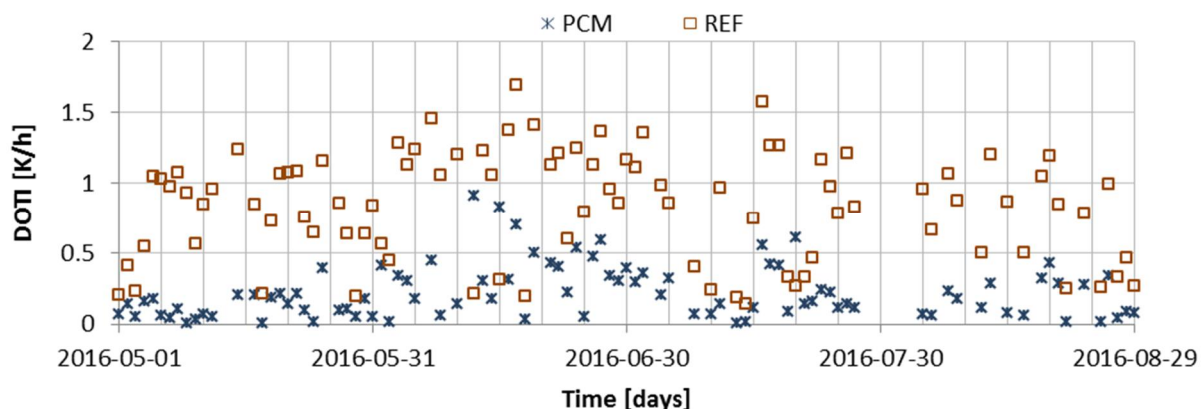


Figure 7. Values of DOTI parameter calculated for modified and reference test sections, in the analysed period of time.

It can be found obvious that for the lower external temperature fluctuation the lower temperature fluctuations should be noted in the inside layers of the wall. Nevertheless, based on the results presented in Figure 8 it can be observed that in case of PCM application values of DOTI index remain almost constant, independently to daily amplitude of external temperature. On the contrary, for the reference case it can be visibly noted that insulation temperature increases with the increase of external temperature fluctuations. It confirms that application of an additional layer of PCM contributes to the attenuation of temperature fluctuations in the layer characterized by low thermal mass even under highly variable external thermal conditions.

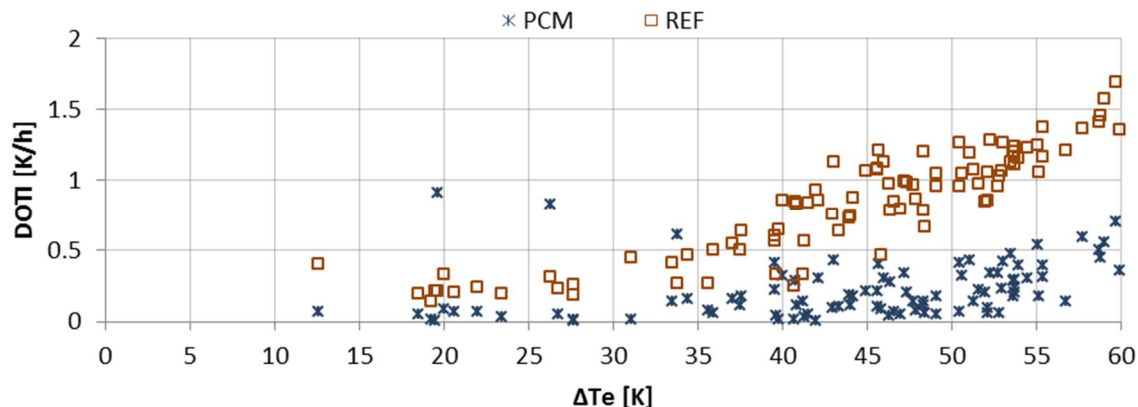


Figure 8. Values of DOTI parameter calculated for modified and reference test sections, in accordance to daily external temperature fluctuations.

4. Conclusions

The technical solution described and analysed in that paper is devoted to increase thermal inertia of external surface of thermal insulation. It is expected that such concept of external wall will stabilize daily temperature fluctuations and effect on the solar heat gains through opaque partition. Usually, this type of gains are omitted in standard buildings but in passive and zero-energy ones can play a significant role in energy cooling demand.

The technical solution presented in the paper is based on monolithic, external plaster pasted to the surface of thermal insulation. That solution was originally developed by authors and further tested in laboratory and real scale application. The observation and analyses showed that composite material is tight and thermally stable during long term period.

Analysing experimental results obtained for selected 7 days of June, characterised by high solar radiation it can be stated that daily fluctuations of external surface temperature can be even four times higher for standard insulation than in case of PCM modified material. Moreover, the temperature surface with PCM did not exceed 27°C, while for standard partition it reached up to 40°C. The dynamics of thermal insulation expressed by the DOTI index is strongly changeable and depends on daily external temperature fluctuations.

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