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Investigation of Effect Additive Phase Change Materials on the Thermal Conductivity

Magdalena Nakielska [1], Mariusz Chalamoński [1], Krzysztof Pawłowski [1]

[1] UTP University of Science and Technology, Faculty of Civil and Environmental Engineering and Architecture, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland

magdalena.nakielska@gmail.com

Abstract. The aim of worldwide policy is to reduce the amount of consumed energy and conventional fuels. An important branch of the economy that affects the energy balance of the country is construction industry. In Poland, since January 1st, 2017 new limit values have been valid regarding energy saving and thermal insulation of buildings. To meet the requirements of more and more stringent technical and environmental standards, new technological solutions are currently being looked for. When it comes to the use of new materials, phase-change materials are being widely introduced into construction industry. Thanks to phase-change materials, we can increase the amount of heat storage. Great thermal inertia of the building provides more stable conditions inside the rooms and allows the use of unconventional sources of energy such as solar energy. A way to reduce the energy consumption of the object is the use of modern solutions for ventilation systems. An example is the solar chimney, which supports natural ventilation in order to improve internal comfort of the rooms. Numerous studies are being carried out in order to determine the optimal construction of solar chimneys in terms of materials and construction parameters. One of the elements of solar chimneys is an absorption plate, which affects the amount of accumulated heat in the construction. In order to carry out the research on the thermal capacity of the absorption plate, the first research work has been already planned. The work presents the research results of a heat-transfer coefficient of the absorption plates samples made of cement, aggregate, water, and phase-change material in different volume percentage. The work also presents methodology and the research process of phase-change material samples.

1. Introduction

A today's adult spends most of his or her life in a closed area where he or she wants to feel comfortable. In order to ensure thermal comfort of the room, people design heating and cooling systems that consume a lot of energy. In Poland, for the last few years there has been a continuous increase in the number of air conditioning systems that have been installed to improve the level of thermal comfort in rooms during the summer. Although the operating time of cooling devices in relation to the number of days in the year is not long, one may notice an increase in energy consumption in this period. Reduced demand for cooling power that is used to lower the temperature in the room can be achieved, among other things, by supplying cooler air from the outside, direct cooling the building partitions or cooling the ventilation air by means of heat exchangers [1].

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Current legal provisions in "The National Plan to Increase Low Energy Consumption Building Number" [2] enumerate specific solutions how to eliminate or reduce significantly the power of the cooling systems for air conditioning that uses a refrigeration unit. Namely, it is important to:

- reduce heat gains (the reduction of solar gains by using sun protection and limiting internal gains),
- adjust air streams to the actual load,
- use alternative cooling methods (night cooling, the use of ground energy, free cooling, passive cooling).

With respect to the use of alternative cooling methods, the purpose of this article is to present initial research on the design of thermal mass as a part of the solar chimney made with an addition of the phase-change material. The solar chimney is used as the element that intensifies air change in the room. The principle of operation of the solar chimney is similar to the mode of action of a traditional chimney, except one difference: there is an additional stream of heat flux supplied to the air that is removed from the room in order to reduce its density in the glazed space of the chimney. The storage of thermal energy supplied through the glazing is another issue to be analysed wider. The element that stores the additional thermal energy is thermal mass in the form of the absorption plate. The authors of the publication [3,4] conducted the research that involved the analysis of functioning of the chimney with the use of phase-change materials (PCM). The experimental study indicated that the airflow rate and air outlet temperature of the solar chimney without PCM can reach their maximum values in a short time, the air flow rate and air outlet temperature would drop sharply when the discharging period started [4].

Phase-change materials have diversified properties and when comes to the use of a particular material the following features should be considered [5,6]:

- Thermal capacity. The ability of PCM materials to accumulate heat depends mainly on the heat of the phase change.
- The temperature of the phase change. Most of the energy is absorbed (and released) through the PCM material during the phase change. This material should be chosen in such a way so that its melting point is within the range of temperatures that occur in a given layout.
- Thermal conductivity. Phase-change materials absorb or release heat effectively if the substance is of a high thermal conductivity.
- The lack of overcooling during the solidification.
- Stability in lots of melting-solidification cycles. In construction industry, the phase-change material is usually subjected to twenty-four hours melting-solidification cycles, so it should keep its properties during a few to several thousands of such cycles.

Among the available phase-change materials, three categories can be distinguished: organic compounds (constant hydrocarbons, fatty acids), inorganic compounds (hydrates of salts, metals) and eutectic mixtures [5]. Organic materials are saturated hydrocarbons (alkanes, paraffins) having the number of carbon atoms in the chain from 16 to 20 (for the use in the construction industry), fatty acids, esters, alcohols and other hydrocarbons derivatives. High thermal conductivity will support giving up and the absorption of thermal energy. In the case of organic materials, thermal conductivity is low and is recognized as a defect of these materials. Whereas, inorganic materials have at least twice higher thermal conduction than paraffin's have. The value of the thermal conductivity coefficient for these materials is about 0.6 W/(mK).

The use of phase-change materials is still insufficiently researched. It is worth to carry out simulations and experiments in order to learn about their properties. The following article presents the plates with an additive of the phase-change material and shows the influence of the volume fraction of the phase-change material in the full sample on the thermal conductivity coefficient.

2. Experimental research

Experimental research has been carried out at the Experimental Research Institution at the Faculty of Civil and Environmental Engineering and Architecture at the UTP University of Science and

Technology in Bydgoszcz. The aim of the study was to determine the thermal conductivity coefficient of cement plates with the phase-change material. The test was carried out on 4 concrete samples which measure 150 cm x 150 cm x 35 cm (Figure 1). The samples were made of CEM II 425 R cement mortar and standard specification aggregate (sand) according to PN EN 196-1 standard. The content of volume fraction of the phase-change material in the samples was as follows: 0%; 5%; 7.5%; 10%. The material used was Micronal DS 5001 X phase change material produced by BASF. The properties of the phase-change material that was used in the test are shown in Table 1.

Table. 1 Technical data of the phase change material Micronal DS 5001X [7]

Technical data	**Micronal DS 5001 X**
Solids content	in powder form
Particle size	ca. 0.1 – 0.3 mm
Bulk density	ca. 350 kg/m^3
Melting point	26 °C
Latent heat capacity	ca. 110 kJ/kg
Overall storage capacity (Integration range 10 – 30 °C)	ca. 145 kJ/kg

Building material modified by means of Micronal DS 5001 X is designed for the use in rooms with a constant temperature about 26°C.

The test of the thermal conductivity coefficient was done on TCA 300 TAURUS INSTRUMENTS device. This is the measuring system that helps to determine the thermal conductivity of samples preparations by means of a heat flow meter in accordance with ISO 8301, DIN 52616, DIN EN 1946-3, EN 12664, EN 12667 and EN 12939 (Figure 2). This device is equipped with an insulated testing chamber in order to avoid the heat supply from the outside. Other functional units are: a touch screen, a cooling plate with a heat flow meter and a heating plate with a heat flow meter.



Figure 1. The samples after surface grinding



Figure 2. TCA 300 TAURUS INSTRUMENTS device

The tested samples were prepared in the following way: aggregate and cement were measured on a WPT 5 laboratory balance, a brand: RADWAG. After adding cement, aggregate, water and the phase-change material, the components were mixed in an automatic mortar mixer according to EN 196 1 program. After the mixing process, the received mixtures were poured into the moulds and shaken. The process aimed at removing air out of the sample. After 24 hours, the absorption plates were taken

out of the moulds and placed in a plastic container filled with water for 7 days - the process of curing of the samples. After the process of curing, the samples were ground. The next step was a drying process. Then, the samples were tested in TCA 300 TAURUS INSTRUMENTS device. The testing cycle lasted about 8 hours. On the basis of the research, the coefficients λ of individual samples were determined for the temperatures of 10°C, 20°C and 30°C.

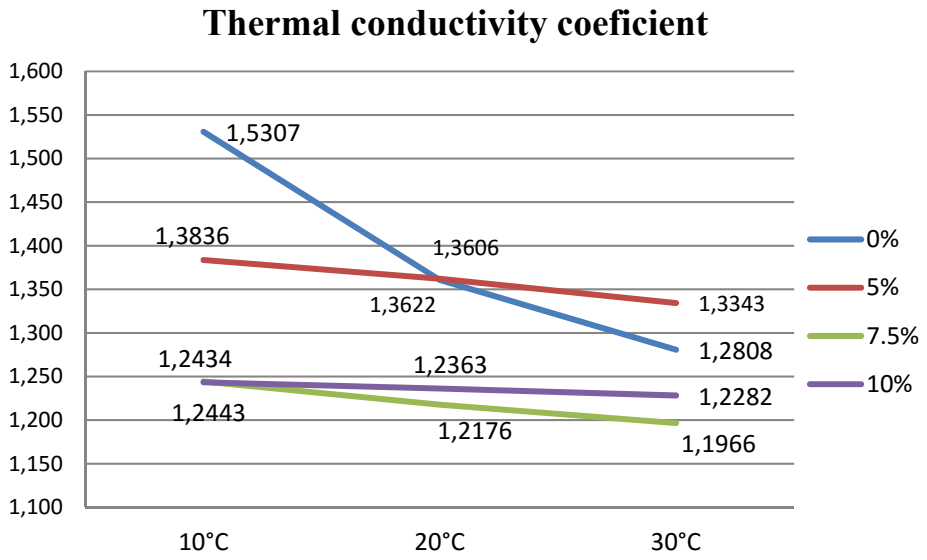


Figure 3. The comparison of the results of the tested factor λ for all the samples

For the temperature of 10 °C, the measured thermal conductivity coefficient λ of the sample with 0% contents of the phase-change material in the concrete mix was λ = 1.5307 W/(m · K). For comparison, in the same temperature with 10% contents of Micronal DS 5001 X, the value of the thermal conductivity coefficient was λ = 1.2434 W/(m · K). The use of Micronal DS 5001 X in 7.5% volume of the concrete mix resulted in the lowest values of the lambda coefficient. The value of the thermal conductivity coefficient was λ = 1.1966 W/(m · K) for the temperature of 30 °C.

3. Conclusions

The research was carried out to examine the thermal conductivity coefficient of cement plates with the phase-change material. The results allow to conclude that the use of Micronal DS. 5001 X phase-change material reduces the thermal conductivity coefficient λ. As for the contents of the volume fraction of the phase-change material in a sample that equals 7.5%, obtained values of the thermal conductivity coefficient in all tested temperatures are the lowest. The plans for the next research include constructing the element that stores the heat in a solar chimney, with the use of the phase-change material as an additive to concrete, and carrying out the series of research aiming at checking the effectiveness of the solar chimney.

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