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Original Research Article

THE USE OF PHASE CHANGE MATERIALS TO IMPROVE THE EXTERNAL WALLS' THERMAL PARAMETERS OF HEATED BUILDINGS

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A b s t r a c t

Currently, it is estimated that the construction sector consumes over 40% of the energy produced and about 50% of the mass of processed materials. As a consequence, there is a challenge to look for alternative material solutions allowing for the storage and conversion of energy. Phase change materials give us such opportunities. Their introduction leads to additional benefits related to thermal parameters. The work presents a short overview of PCMs along with the possibility of their application. Then, as part of the research, the selected phase change material was applied to the internal plaster layer of an external wall to check its activity. The obtained results were compared to the values of reference samples (without PCM). The proposed solution leads to the improvement of the analyzed partitions' thermal parameters.

Keywords: phase change material (PCM), reducing energy consumption, thermal conductivity coefficient, laboratory tests

1. INTRODUCTION

In recent years, there has been a noticeable search for alternative technological solutions that make it possible to reduce energy consumption when operating buildings [1]. Rising energy costs and restrictive thermal and humidity requirements introduce the need for changes. For this purpose, placing phase change materials (PCM) into building elements has become noticeable [2]. These materials used for traditional solutions allow for the so-called thermoregulation effect. Their task is to absorb energy from the environment, which they can release due to phase changes [3,4,5]. Therefore, the process of phase changes is significantly influenced by the ambient temperature and the type of material used, which mainly depends on the amount of thermal energy collected and released [6,7,8]. It is also essential that when phase change materials are used, their application method should be considered. Thus, there are two options: an active system and a passive system. In a dynamic solution, we introduce PCM material, for example, into solar collectors. PCM is presented as an addition to building materials in the passive

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system. Such a solution should be integrated with the base material. An essential advantage of this system is the lack of supervision, which minimizes costs compared to the active system. The disadvantage is its inability to modify and influence behavior [9]. The literature on the subject indicates a high potential of this type of material to accumulate heat and thus improve thermal conditions inside rooms [10,11,12,13,14].

Research on phase change materials (PCM) has been undertaken many times. According to the authors [15], phase change materials are an innovative and promising way to make buildings more energy efficient. However, there is still demand for new material solutions and new applications of existing PCMs [16]. Figure 1 shows wall materials that have most often been and are the subject of research using the thermoregulation process.

WALL MATERIALS WITH THE PCM ADDITION			
WALLBOARDS: GYPSUM	CONSTRUCTION MATERIALS: BRICKS, BLOCKS, CONCRETE	PLASTER: GYPSUM, CEMENT-LIME	INSULATING MATERIALS: CELLULOSE, POLYURETHANE FOAM

Fig. 1. Wall materials with the addition of phase change material - the most described in the literature [2]

The presented list includes using PCM materials in wall partitions from the inside. Similar solutions for using materials are presented in [17], where additional attention is paid to their impact on improving thermal comfort in rooms of heated buildings. Therefore, it can be concluded that the use of PCM improves the thermal balance of the building [18]. As a result, parameters related to the energy efficiency of buildings improve.

The article presents a selected phase change material used as an addition to the internal plaster layer of external walls of heated buildings. These studies continue the previously undertaken topic, where the phase change material was used as a priming layer for thin-layer plaster. The results obtained then confirmed the activity of PCMu and its impact on improving thermal properties [9]. The article aims to check the activity of the selected PCM introduced into the internal plaster layer on the obtained thermal parameters with the traditional solution.

2. PHASE CHANGE MATERIALS USED IN CONSTRUCTION

Improving the energy efficiency of buildings and thermal comfort has become a priority in the era of increasing energy demand [19]. Introducing phase change materials in the building's structural elements leads to thermal energy storage, which minimizes room temperature fluctuations, ensuring thermal comfort for users and thus reducing energy consumption [20,21].

Phase change materials can be incorporated into building partitions [19] or added appropriately to building materials, such as lime or cement. Properly introduced PCM undergoes phase transformation at a temperature close to the desired room temperature, allowing for storing a significant amount of heat in a relatively small volume. Phase change processes are helpful both for cooling and heating rooms. Still, it should be remembered that the amount of energy accumulated in the phase change material depends on its heat capacity, and for construction, it ranges from 100 kJ/kg - ready-made materials in the form of microcapsules, up to 250 kJ/kg – raw homogeneous substances [22,23,24]. The use of PCM in construction is justified in the case of a moderate climate zone due to the variable ambient temperatures: higher and significantly lower (both in the annual and daily cycle) than the temperature of the expected thermal comfort. In such conditions, the phase change material should undergo a cyclic phase change, accumulating and releasing latent heat.

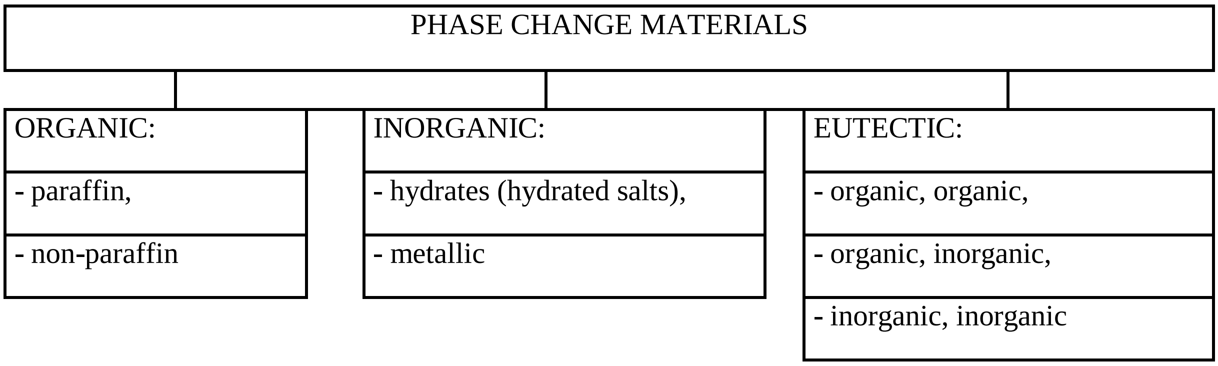

Fig. 2. Phase change materials classification

Figure 2 shows three primary groups of PCMs, divided into organic, inorganic, and eutectic.
Several requirements must be met to incorporate PCM into concrete mixes, mortars, etc. Firstly, the introduced PCM should not interact with the mixture components during the cement hydration because this may negatively affect the properties of the mature concrete or composite in the future. Secondly, the phase transformation period of the PCM should be within the favorable temperature range for the hydration process. The range is from 19oC to 34oC. The last requirement is that the PCM has a high heat capacity [25,26,27].

3. TESTED MATERIAL AND RESEARCH METHODS

As part studies [9] to check the activity and method of application of the phase change material, its optimal percentage in the quantitative and qualitative composition of the cement composite was determined. The results obtained in this way constituted the basis for further modifications. The currently tested cement composite with the assumed proportions of ingredients was used as a layer of internal plaster with a thickness of 10 mm.

A passive heat accumulation system was used in this research. The tests used a phase change material in the form of polymer microspheres, which were directly incorporated into the composition of the internal plaster (Fig. 3).

Fig. 3. PCM used in the research

Per the properties declared by the manufacturer, the phase change material used is characterized by the technical parameters in the table. 1.

Table 1. Technical parameters of the PCM used [9]

Form, particle size	Microgranulate in powder form, 50-300µm
Volume density	300-400kg/m3
Solubility in water	Insoluble
Phase change (melting)	25°C +/- 1°C
Phase change (crystallization)	20°C +/- 1°C
Melting heat (10°C -35°C)	>97 J/g

The above solution creates a safe protection for the core system made of high-purity paraffin wax. Per the manufacturer's recommendations, this material is used as an addition to external and internal plasters, where it was used as part of current research.
The quantitative and qualitative composition of the tested cement plaster applied on the inside of the partition is summarized in the table. 2.

Table 2. Quantitative and qualitative composition of the tested material samples [MB]

Tested material	Reference sample	Sample from PCM
Portland cement CEM I (g)	450	450
Standard sand (g)	1350	1350
Water (cm3)	225	225
PCM (g)	-	22,5
Plasticizer improving workability (cm3)	-	3,5

In the work, two types of samples were made to check the activity of the layer with phase change material. The first group was the reference solution, i.e., without using PCM. The second group was modified by adding 5% PCM about the amount of cement (the remaining ingredients were left unchanged). The quantitative and qualitative selection of individual components resulted from striving to obtain consistency according to the Abrams cone 6-8. A more significant amount of PCM material caused problems with workability in the adopted mixture composition. Even at 5% PCM, it was necessary to introduce a plasticizer to counteract the thickening effects. The quantitative and qualitative composition used for research is summarized in the table. 2.

The pilot tests included a series of essential determinations (absorption, bulk density, compressive strength) to check the impact of PCM on the basic parameters of the composite. In this case, commonly used procedures were used: cuboidal samples with dimensions of 40x40x160mm were prepared, six pieces for each determination (reference samples and PCM samples) [28,29,30]. After 28 days of conditioning, the samples were dried to a constant weight at +105C ±5C. A soak test was carried out on the samples prepared there. The test consisted of gradually pouring water over the samples until they were completely submerged. The results, in the form of an arithmetic mean of the six measurements, are presented in Table 3. For the volumetric density test, the prepared samples were weighed in their natural wet state and after drying to a constant weight. Their dimensions were then determined using callipers with an accuracy of 0.1 mm. The results, in the form of an arithmetic mean of the six measurements, are presented in Table 3. Compressive strength testing was carried out on the six barrel halves. In this way, the maximum stresses that the specimen is able to carry in relation to the surface of the compression plates (1600mm) were determined. The results are the arithmetic mean of the six measurements (Table 3). None of the partial results obtained deviated from the mean value by more than 10%.

The obtained results of basic tests were following applicable standards; their summary is presented in the table. 3. The obtained values are acceptable and do not negatively affect the advisability of using the composite as an internal plaster layer. They constitute the basis for further research.

Table 3. Basic research results

Tested material	Water absorption [%]	Volume density [kg/m3]	Compressive strength [MPa]
Reference samples	3.2	2250	48.5
Samples from 5% PCM	1.5	1980	39.3

The internal plaster layer prepared in this way was applied to a 100 mm thick sample of autoclaved aerated concrete. The autoclaved aerated concrete used, 100 mm wide, was characterized by a thermal conductivity coefficient declared by the manufacturer of λ = 0.17 W/(m·K). The assumed material thickness of 100 mm constitutes a layer that can accumulate heat and influence the thermal comfort of rooms [31].

To check the value of the thermal conductivity coefficient of samples with phase change material and samples without PCM, the Thermal Conductivity Tester TCA 300 DTX (Fig. 4) [23] and the procedures contained in [32] were used.

Fig. 4. Thermal Conductivity Tester TCA 300 DTX used for research

For the test, six reference samples and six samples with the addition of 5% PCM with dimensions of 300x300x100 mm were made (Fig. 3). The samples were tested in three temperature ranges, i.e., 5ºC, 15ºC, and 25ºC.

The base layer for both types of samples was autoclaved aerated concrete with a thickness of 100 mm, density class 600, and thermal conductivity coefficient λ = 0.17 W/(m·K), on which a prepared layer of internal plaster without PCM and with a 5% share, with a thickness of 10 mm, was applied. The results obtained from the study are summarized in the table. 4.

Table 4. Thermal conductivity coefficient test results for the analyzed samples

Tested material	λ coefficient value [W/mK] 5oC	λ coefficient value [W/mK] 15oC	λ coefficient value [W/mK] 25oC
Reference samples	0.168	0.172	0.172
Samples from 5% PCM	0.171	0.176	0.181

After the thermal conductivity test was performed to determine the PCM activity, the prepared samples were placed in a climatic chamber with various temperature cycles and constant humidity.

The experiment consisted of the following sequence of temperature transitions:

- 60 min. temperature 5°C air humidity 55% ± 1%
- transition period 30 minutes.
- 60 min. temperature 15°C air humidity 55% ± 1%
- transition period 30 minutes.
- 60 min. temperature 25°C air humidity 55% ± 1%
- transition period 30 minutes.
- 60 min. temperature 5°C air humidity 55% ± 1%.

After each temperature cycle, samples were measured with a thermal imaging camera (Testo 882) to check the activity of the phase change material (Fig. 5).

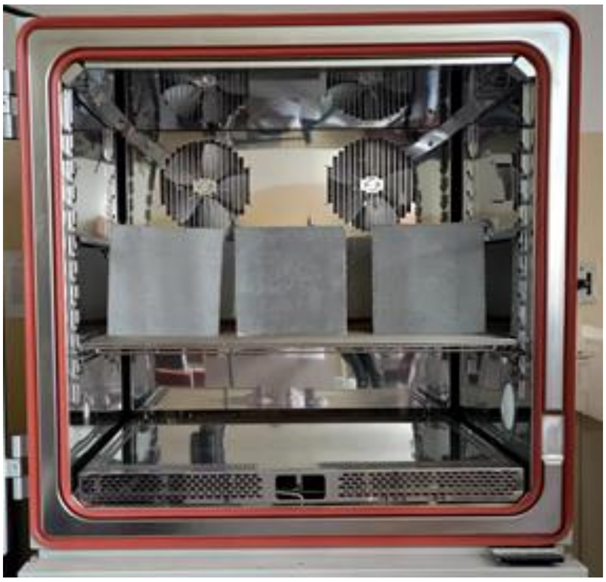

Fig. 5. View of the tested samples in the climatic chamber

4. SUMMARY AND CONCLUSION

As a result of the tests, the activity of the introduced phase change material was confirmed. Its small contribution contributed to improving the thermal parameters of the external envelope of the heated building.

The obtained values indicate higher activity of internal plaster samples with added phase change material than reference samples. The thermal conductivity coefficient values have a similar trend - increasing with temperature, the obtained values of the lambda coefficient for PCM samples are more favorable.

In PCM samples, when the ambient temperature increases, the wax contained in the tanks melts, and when the temperature drops, it solidifies, which is reflected in the obtained values. As the temperature increases, heat is stored in the samples. At around 20oC, the material begins to release latent heat, and its thermal conductivity coefficient is the most favorable.

It should be emphasized that the thickness of the internal plaster layer was 10 mm, and the PCM share was only 5% with the mass of the binder. The obtained results indicate the positive activity of the phase change material used. They constitute an optimistic forecast for further research [Fig. 6].

Additionally, to illustrate the activity of the introduced phase change material, samples were measured with a thermal imaging camera after each passage of the temperature cycle. The measurements obtained in this way confirmed the greatest activity of the PCM used at a temperature of about 20oC, where the stored heat was released. According to the temperature histogram, PCM samples achieved an average of 4°C higher values than the reference samples.

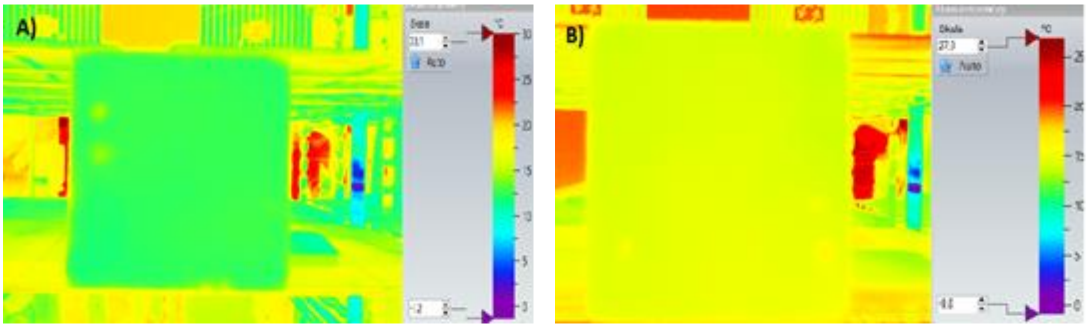

Fig. 6. Example measurement of samples with a thermal imaging camera: a) reference sample, b) sample from PCM

Introducing phase change materials to traditional solutions is a beneficial solution from the point of view of thermal parameters. Photographs taken with a thermal imaging camera are not a practice used in scientific studies. The photographs presented here were intended to illustrate the uniformity of PCM distribution in the samples studied. Should be noted that determining the optimal amount of PCM material will result in their more practical use. Undoubtedly emerging difficulties related to the workability of the mixture should be eliminated through appropriate quantitative and qualitative selection of the adopted recipe, which is also noted by [33]. When applied correctly, phase change materials can obtain significant heat accumulation potential and thus allow for improvement in the thermal conditions inside rooms [14, 34, 35].

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