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Application of thermal insulating plaster for retrofitting of a building under conservation protection

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Abstract

The article presents the results of measurements of selected thermal, moisture and mechanical properties of thermal insulating plaster, which is one of the alternatives to traditional methods of retrofitting the walls of buildings under conservation protection. An insulating plaster based on perlite was tested. Its thermal conductivity, vapor permeability and compression strength were determined. Images of the tested plaster under the microscope, at a magnification of 10-45x, were also taken. Through computer simulations, the possibility of improving the energy efficiency of an educational building by applying a layer of such plaster on external walls was determined. Changes in the heat loss structure were analyzed, and the obtained results were compared with the effectiveness of reducing heat loss through the walls using a traditional thermal insulation material. It turned out that the thermal conductivity coefficient of the tested plaster obtained by measurement was 0.0877 W/(m·K), which confirmed the value declared by the manufacturer. Application of thermal insulating plaster with a thickness of 5 cm on the walls of the analyzed building, with other partitions of good thermal quality, reduced its energy demand by over 20%.

Keywords: thermal insulating plaster, measurements of insulation material properties, the protection of the monument conservator, retrofitting, improving energy efficiency

1 Introduction

Reduction in energy consumption, necessary to achieve climate goals, is one of the greatest and toughest challenges facing humankind today [1]. On the one hand, the steady progress of economic development is significantly increasing the demand for energy [2], and on the other hand, greater environmental awareness and rising energy prices are causing such widespread interest in energy-saving solutions. It is estimated that the construction of a building consumes only about 10% of the energy, demolition 1%, while the rest is related to the operating period, where as much as 70% of the energy is used for heating [3-6].

The condition of the thermal insulation of the building envelope and the type of material used have a direct impact on the amount of energy consumption. Thermal modernization of the partitions of an educational building can bring energy savings of 60% for heating [7], however, the best results are obtained by comprehensive thermal modernization combined with the use of renewable energy sources [8, 9, 10]. It should be emphasized that before

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planning retrofit work, the necessity of analyzing the need to strengthen the existing building structure for further safe use should be considered [11].

Currently, the most popular wall insulation technique is an External Thermal Insulation Composite System (ETICS), with expanded polystyrene or mineral wool [12]. In the case of historic buildings, this method is usually not suitable due to the requirement to preserve the façade appearance. [13, 14]. Therefore, insulation of external walls from the inside or thermal insulating plaster can be considered [15, 16]. Internal insulation of outer walls allows a reduction in the heat transfer coefficient, similarly to insulation from the outside, but if it is implemented incorrectly, it can cause problems with moisture in the walls and thermal bridges [17, 18]. Thermal insulated plaster, which is the outer layer, does not cause such problems, but the achieved improvement in thermal insulation is less.

2 Properties of thermal insulated plasters

Thermal insulating plasters are produced on the basis of mineral binders, as well as fine lightweight aggregates or lightweight organic or inorganic fillers, which are designed to improve the thermal insulation of the plaster. One variety is perlite thermal insulating plaster, in which perlite is used instead of sand. It is a white or gray mineral produced from volcanic rocks. Its porous structure makes it an effective thermal and acoustic insulator, so can be used in solutions for thermal insulation of buildings. Perlite plasters are recommended for insulating the walls of historic buildings, because not only do they make it possible to preserve the original appearance of the facade, but they also allow the restoration of damaged or broken architectural elements. In addition, perlite is a biologically inert material, which means that it is not harmful to the environment or human health. Perlite plaster is characterized by high durability, fire resistance, resistance to frost, moisture, both biological and microbiological corrosion, and vapor permeability, which prevents moisture condensation inside the partition. The application of perlite plaster on the walls of the building is very similar to traditional cement-lime plasters, i.e., it can be done manually or mechanically by using a plaster aggregate. The total thickness is from 2 cm to even 10 cm and consists of several layers. The next layers of plaster can be applied after the previous layer has dried.

3 Measurement of selected properties of thermal insulated plaster and determination of the effect of its application on improving the energy efficiency of the building

The article presents the results of measurements of selected properties of thermal insulated plaster, as well as the effects of its application on one of the educational buildings of the Military University of Technology. The conducted research [19] can be divided into two parts. In the first part, selected higrothermal and mechanical properties of the plaster were examined. In the second part, referring to the whole building, the reduction of heat demand in the building after plastering was calculated. The range of tested plaster properties included thermal conductivity, vapor permeability and compression strength. Images of the tested plaster under the microscope, at a magnification of 10-45x, were also taken.

For the modernization of the analyzed building, a light heat-insulating mortar TESOROMONT TLC based on perlite was used. The samples were taken directly from the construction site, so that the material subjected to testing reproduced as accurately as possible the one that was used to modernize the facade of the building. A total of 6 samples of 10x10x10 cm were taken.

Microscopic images

On the images taken under the microscope, fibers in the plaster constituting reinforcement, large pores of the material and pearlite grains are visible. The characteristic image of the structure is shown in Fig. 1. Only the largest pores can be seen under the optical microscope at this magnification. The pores observed in this material have sizes of 0.05-0.2 mm, i.e., 50,000-200,000 nm. According to the IUPAC classification, they are among the largest macropores. The material probably also contains smaller pores, as evidenced by the diffusivity of water vapor, close to the parameters of mineral wool. The reinforcing fibers contribute to the strength of the material and are probably composite.

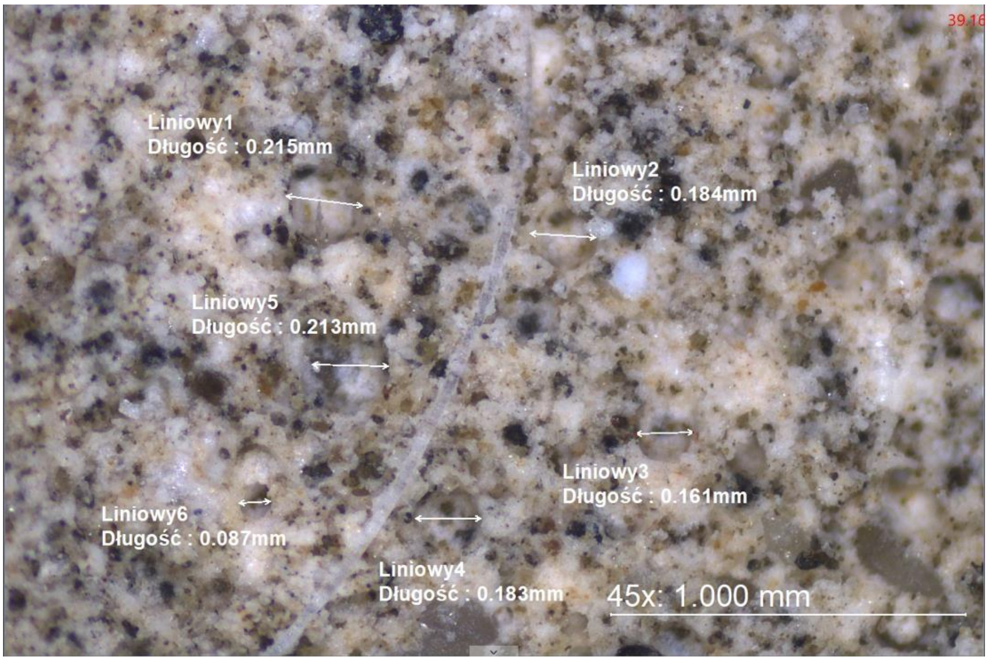

Figure 1. *Image of the tested plaster under the microscope at 45x magnification*

Thermal conductivity coefficient

The aim of the measurements was to determine the thermal conductivity coefficient of the tested plaster, and then to compare the results with the data published by the manufacturer. The ISOMET 2114 instrument, which is a portable device designed to measure heat flow parameters through materials such as: porous insulation materials, isotopes, plastics, minerals, and glass, was used to carry out the study.

A needle probe was used to test the thermal conductivity coefficient. The first measurement was taken 5 days after sampling. The measurement was then repeated at intervals of several days to check the behavior of the thermal conductivity value as the material matured. The results obtained are summarized in Table 1.

No	Date of measurement	Thermal conductivity coefficient λ [W/(m·K)]
1	09.06.2022 r.	0,3625
2	11.06.2022 r.	0,2756
3	14.06.2022 r.	0,2325
4	21.06.2022 r.	0,1037
5	28.06.2022 r.	0,0885
6	04.07.2022 r.	0,0877

Table 1. Measurement results of the thermal conductivity coefficient of the tested plaster

The thermal conductivity coefficient of the thermal insulated plaster reached 0,0877 W/(m·K), and the properties declared by the manufacturer ($\lambda<0,1$ W/(m·K)) were achieved after about 20 days. Figure 2 shows the change in λ-value over the duration of the test.

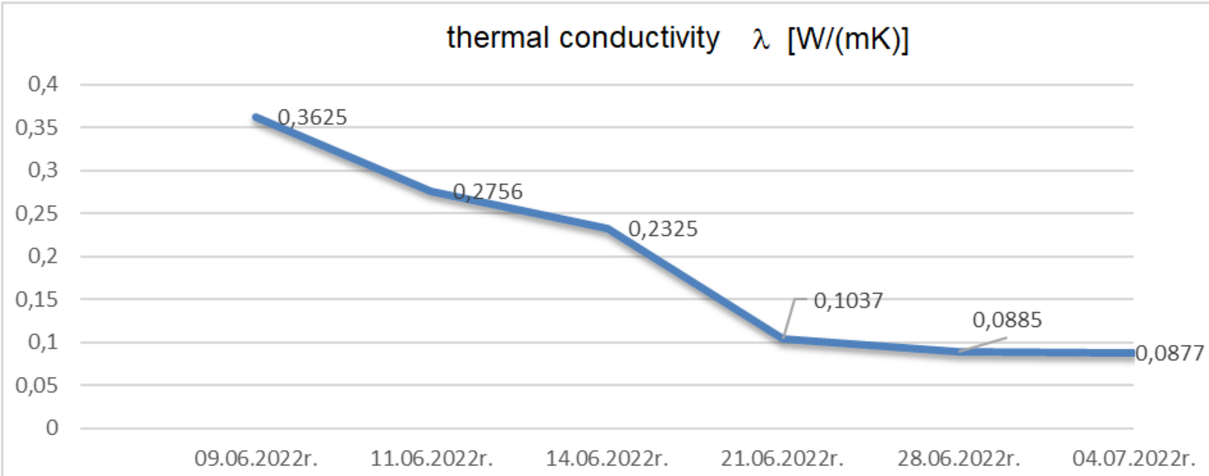

Figure 2. *The thermal conductivity coefficient of the tested plaster.*

The decreasing value of the thermal conductivity coefficient also shows the setting and drying process of the plaster. After 25 days of sampling, the coefficient stopped changing, indicating that equilibrium moisture had been reached.

Diffusion properties

The vapor conductivity of a material is determined by the coefficient of water vapor diffusion resistance. The mentioned coefficient for a particular material gives its vapor permeability with respect to the conditions specified by the standard for air. The measurements were carried out in accordance with the PN-EN-ISO 12572 standard on thermal and moisture properties of building materials and products, and specifically consisted in determining properties related to water vapor transport.

To carry out this measurement, a 10x10x5cm sample was prepared, which was then placed in a specially made test dish. Water was poured into the lower part of the test dish, and then after measuring the thickness of the sample and the surface of the sample inside the dish, as well as its outer surface, the material was placed in the upper part of the testing instrument so that it was above the surface of the water surface. The dish with the test sample was then weighed daily, the temperature and humidity were measured, as well as the measurement time, and all the collected results were recorded. The final step was to summarize the results from the five-day observation, which are presented in Table 2.

Time [h]	Mass change over time	Vapor saturation pressure p_{si}	Actual vapor pressure p_{pi}	Vapor saturation pressure p_{si}	Actual vapor pressure p_{pi}	$\Delta p_p = p_{pi} - p_{pe}$	Vapour permeability [g/(m·h·Pa)]
		internal		external			
0		2737,433	2627,935	2737,433	1251,007	1376,929	
25	0,0360	2787,617	2676,112	2787,617	1307,392	1368,720	1,551e-4
46	0,0381	2607,446	2503,148	2607,446	1285,471	1217,677	1,8445e-4
71	0,0360	2639,426	2533,849	2639,426	1216,775	1317,074	1,6115e-4
99	0,0536	2943,02	2825,299	2943,02	1203,695	1621,604	1,948e-4

Table 2. Measurement results of the vapor permeability coefficient

The average vapor permeability of the tested plaster is 1.74e-4 [g/(m·h·Pa)], which corresponds to the diffusion resistance coefficient μ=4.2. This value is much better than declared by the manufacturer (μ<15). Moisture of walls in historic buildings is often high, exceeding 10%, hence the low diffusion resistance of the outer layer of the partition is beneficial.

Compression strength

Three 10x10x10cm plaster samples were tested. A QC-505B1 universal testing machine was used for this purpose. The results obtained are presented in the form of graphs and compared with the compression strength of polystyrene and mineral wool. The graph for one of the samples is shown in Figure 3.

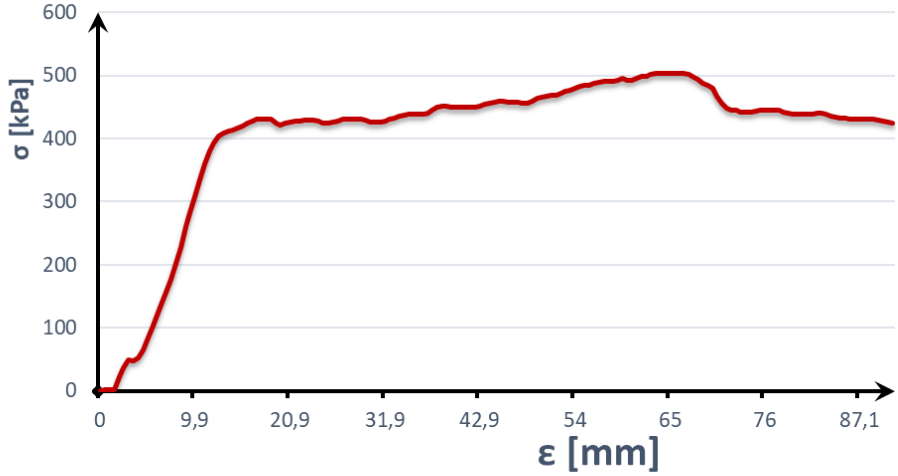

Figure 3. *Compression strength test results of sample No 2.*

Thanks to its porous structure, the material has good insulating properties, but lower compressive strength than traditional plaster. Its average tested compressive strength is 578 kPa. Thus, the tested plaster, compared to polystyrene foam and mineral wool, is characterized by five times higher compressive strength (which is for polystyrene foam, for example, about 100 kPa, and for mineral wool about 20-50 kPa).

Reduction of heat demand in the building after application of plaster layer

The object where a layer of thermal insulated plaster was applied, as part of thermal modernization, is the educational building No. 58 of the Faculty of Civil Engineering and Geodesy of the Military University of Technology in Warsaw. It is a two-story building with a partial basement and with a flat roof and unheated attic space, with a usable area of 2140.8 m^2 and a height of 8.69 m. The building contains lecture, classroom and computer rooms, staff offices, storage rooms and bathrooms. The main entrance to the building is located on the northeast side. The walls of the building were made of solid ceramic brick and were the only ones that did not meet the requirements of thermal protection according to Technical Conditions 2021 [20], so they were subjected to a thermal modernization process. Heat transfer coefficients of individual partitions are presented in Table 3.

Partition	Heat transfer coefficient U [W/(m^2·K)]	
	before thermomodernization	after thermomodernization
External walls	1,13	0,69
Roof	0,14	
Floor on the ground	0,17	
Windows	0,90	
External doors	1,50	

Table 3. Heat transfer coefficients of the analyzed building

Due to the historic value of the building, making it impossible to insulate the walls from the outside using the most common method (ETICS), the retrofit was performed with 5 cm thick thermal insulated plaster. Energy demand indicators were determined for the building before and after the retrofitting. Additional calculations were made for improving the energy efficiency of the building, assuming that polystyrene foam was used for thermal insulation of the walls (15 cm thick, at λ=0,04 W/(m·K)). The calculations were performed according to the Polish methodology [21], using the ArCADia TERMOCAD software.

Figure 4 shows the indicators for usable energy (*EU*), final energy (*EK*) and non-renewable primary energy demand (*EP*) for the building in its existing state and after insulating the walls, divided into heating with ventilation (EU_H, EK_H, EP_H) and hot water preparation (EU_W, EK_W, EP_W).

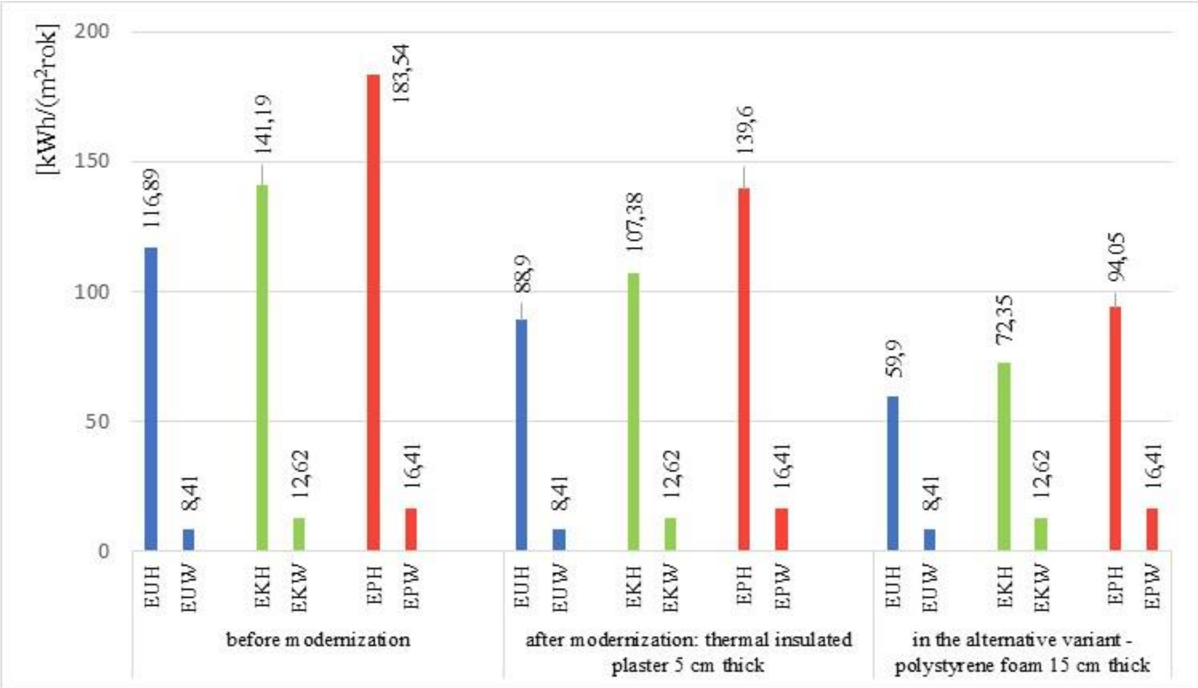

Figure 4. *Results of calculations of the energy demand of the analyzed building*

The application of a 5 cm thick layer of thermal insulated plaster on the walls of the building resulted in a 23,9% reduction in energy demand for heating. Including the demand for hot water, these reductions were 22,3% of usable energy and 22,0% of final energy (usually considered a measure of energy efficiency) and non-renewable final energy, respectively. If it had been possible to use polystyrene foam (15 cm thick) these percentage reductions would have been about twice as large. Such large achievable percentage savings were made possible by the good thermal quality of the rest of the building's exterior envelope. In the building in the pre-retrofit (Figure 5), the heat takeoff rate through the walls was as high as 44,9%, while all the other envelopes combined accounted for only 13,4%. The remaining heat loss of the building (41,6%) was related to the natural ventilation system.

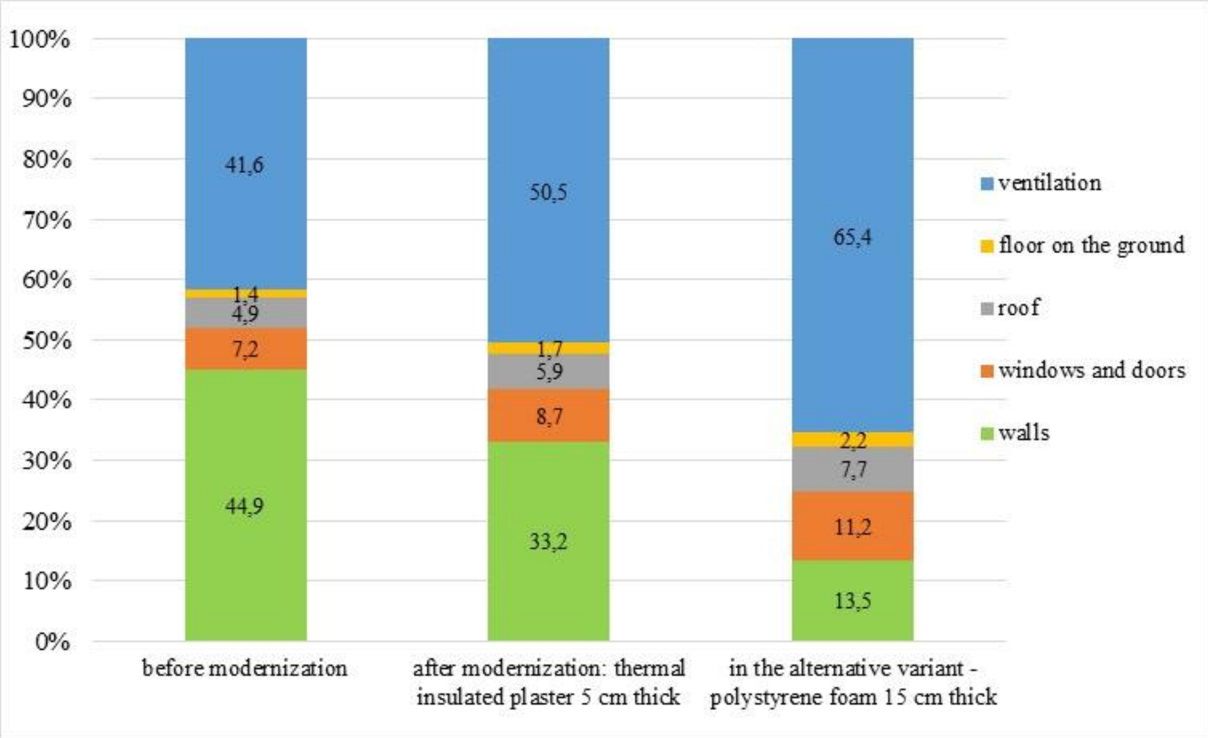

Figure 5. *Structure of heat loss in the building*

After thermal modernization, the share of heat loss through the walls in the total heat loss coefficient was reduced to 33,2% when thermally insulated plaster was used and to 13,5% when polystyrene was used (however, this method was not possible in the building under the protection of the monument conservator).

4 Conclusions

Measurements of the analyzed perlite-based thermal insulating plaster:

- confirmed the thermal conductivity coefficient declared by the manufacturer, which on testing was 0,088 W/(m·K),

- determined that the specified water vapor diffusion coefficient of δ=1.74·10-4 g/(m·h·Pa) for the analyzed plaster was about 2,5 times worse than for mineral wool (δ=4,31·10-4g/(m·h·Pa)), but much better than for polystyrene foam (δ=0,21·10-4g/(m·h·Pa)),

- determined the average compression strength of thermal plaster to be 578 kPa, which was found to be higher compared to that of polystyrene (which was 100 kPa) and that of mineral wool (at 20-50 kPa).

The use of thermally insulated plaster on the walls of the educational building no. 58 of the Faculty of Civil Engineering and Geodesy of the Military University of Technology, under the protection of the monument conservator, with other partitions of good thermal quality, resulted in an improvement of its energy quality by over 20%. The percentage savings that can be achieved depend to a large extent on the initial condition of the building and the structure of heat loss through individual elements, therefore, before commencing thermal modernization of the building, it is reasonable to perform an energy audit to identify projects with the greatest potential for improving energy efficiency.

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