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Reduction of moisture and thermal conductivity of wet walls by special plaster

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Abstract. This paper is focused on the problems of moisture reduction in old buildings. Wet walls are very common problem of old buildings, but it can appears also in new buildings as well. The moisture in the wall influence the insulation quality; bigger heat losses continuously cause problems of worse heat balance, higher consumption of energy for heating and it can result in not sufficient indoor conditions in such a room or building. Old rural residential buildings and also agricultural buildings for housing of animals, storage of different materials, workshops etc. could be repaired and reconstructed by the used of some special methods. The application of special plaster can reduce the walls moisture as well as improve the thermal properties of the buildings by reduction of thermal conductivity. This paper includes the results of laboratory experiments focused on research of plaster properties (temperature, moisture and thermal conductivity) and tests provided in the real building. Different measuring principles, enabling mutual comparison of results were used for this research. The measurement results showed a significant effect of high wall moisture on the heat losses. Differences between the walls improved by new tested plaster and old untreated walls are discussed in this paper. Obtained results from this measurements and findings may be useful for further research in this issue as well as for the practical solutions for similar problems in many old buildings.

Key words: heat losses, measurement, natural material, rural buildings.

INTRODUCTION

In this time, there are more and more modern houses and buildings in our towns and villages. Also, there are still many old houses, which have problems with wet walls and heat losses. Wet walls and heat losses are very common problem, which can make difficulties for residents of old houses such as health problems because of mould, bad thermal conditions and higher energy consumption. It can result in not sufficient indoor conditions in such a room or building.

There are many reasons of creation of wet walls. It can be because of ruined or no hydro isolation, condensation of water steam in the interior of buildings, heavy rains, rising water from foundations of the house etc. The moisture in the wall influence the insulation quality of construction and static and physical properties, these problems can result even in the breakdown of the wall (Franzoni, 2018).

As has already been said, one of the main problems in old buildings is bad thermal conditions, which relate with thermal comfort. Thermal comfort is the state of mind, which expresses satisfaction with the thermal environment and it is an important aspect of the building design process (van Hoof et al., 2010).

Thermal comfort is important because modern people spend most of the day indoors. Air temperature and air humidity have main influence on people feelings in building environment. It is the reason why it is so important to control these two parameters in all types of buildings.

The application of insulation materials can reduce the walls moisture, improve the thermal properties of the buildings and also indoor environmental conditions. There is very important which type of insulation is used. As in some cases, bad choice of insulation can lead to worse situation than before insulation installation and the use of external insulation sometimes can lead to closing of moisture in the construction.

It is important to know structure of the wall and reasons of problems, e.g. what causes the high amount of moisture in walls. Then can be decided, which methods for insulation will be chosen, e.g. interior or exterior, which type of material, thickness etc.

There are many types of insulation materials in the market. One of new type of insulation materials is a special plaster with thermal insulation properties. These plasters often have natural composition and interesting properties and they can replace some synthetic insulation materials in the future. As the people often prefer natural products instead of synthetic materials, which have bigger negative impact on environment. Synthetic materials often consume more energy for their production, resulting in higher CO_2 emissions that contribute to global warming due to an increasing greenhouse effect (Zach et al., 2013; Pargana et al., 2014; Bakatovich, et al., 2018).

The one of the most important parameters of thermal-technical properties of materials is a thermal conductivity. It is used mainly in civil engineering and obviously coefficient of thermal conductivity λ is used in practice. Its real value is a function of several internal and external variables such as e.g. moisture, temperature, density, porosity, chemical and mineralogical composition and phase composition etc. (Muizniece et al., 2015; Kocova & Kic, 2016; Pleiksnis et al., 2016; Týbl & Kic, 2016; Valasek et al., 2016).

Another important parameter is an overall heat transfer coefficient *U*. This parameter relates to the whole multi-layer wall, not only individual materials as in the case of a coefficient of thermal conductivity. Overall heat transfer coefficient is the heat flow that passes through a unit area of a complex component or inhomogeneous material due to a temperature gradient equal to 1 K. Thermal resistance is connected with overall heat transfer coefficient, its value equals to the inverse value of overall heat transfer coefficient (Schiavoni et al., 2016).

The aim of this research is to measure properties of thermal insulation and moisture-protective plaster Manto Plate (MP), which was created in Turkey (Izozek Insulation, 2012).

The results of these measurements are evaluated and compared with data which are presented by producer or other authors. Then applicability of this plaster for purpose presented by producer can be evaluated. Differences between the walls improved by new tested plaster and old untreated walls will be also discussed in this paper.

MATERIALS AND METHODS

This paper includes the results of two types of experiments. There were carried out laboratory experiments and measurements to find out properties of plaster MP such as temperature, moisture and thermal conductivity and tests provided in the real building to find out influence of the MP to properties of walls and indoor environment in the house.

Two samples of tested material were prepared for laboratory experiments. The first sample was a brick, on which 1 cm layer of MP plaster was applied. A second sample was cast into the aluminium form of shape 200 x 80 x 40 mm only from the pure MP material.

Surface temperature and moisture were measured on both samples. The purpose of these measurements were to study the properties of MP and effect of MP on moisture and temperature of the brick on which it is applied.

Partially stiff and hardened MP material sample was removed from the form and thermal conductivity was measured. Temperature and humidity of air were registered inside the laboratory each 15 minutes.

The measurements in the real building were carried out in an old family house, with the aim to test the quality of MP plaster used inside the rooms as an insulating material. Photos and schematic drawings (layout) of the house with the marks showing the measured rooms are presented on the Figs 1, 2 and 3. Areas and volumes of all measured rooms are shown in the Table 1.

Figure 1. Family house from the north, measured walls are marked.

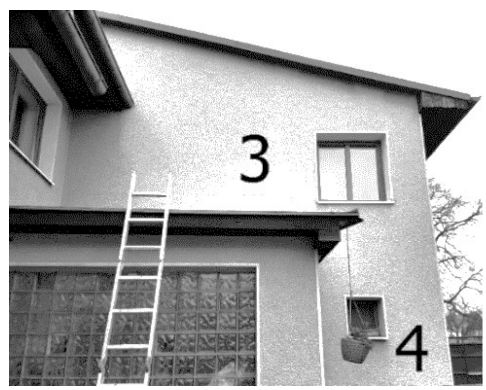

Figure 2. Family house from the south, measured walls are marked.

During the measurement there were not all rooms insulated by MP. To compare the quality of MP plaster four rooms were chosen. Two rooms covered by MP and other two which were not insulated by this plaster.

Measurement was made in winter time in December to use big temperature difference between inside and outside.

The house consists of two parts. The older one was built in the 19th century. In that time, it was only one floor house with three rooms. The new part was built during the reconstruction in 1986. Ground floor was enlarged, and second floor was built within the reconstruction. The measurements were carried out in newer part of the house.

All perimeter walls, which were used for measurement purposes, have the same structure and same width. Information about particular layers are shown in Table 1. The walls are built from Autoclaved aerated concrete (AAC), also called Plyosilicate blocks. The first layer on interior part of walls is stucco plaster and MP is the second one. The exterior surface of walls is covered by stucco plaster and Brizolit, which is scratched facade plaster.

According to the figures the living room is No.1. It is situated on the ground floor. There is installed fireplace, which has very positive influence on the local temperature. The room is insulated by plaster MP. Wall which was used for measurement purposes is oriented to the north.

Kids room (No.2) is situated on the first floor of the family house. This room is also insulated by MP and measured wall is also oriented to the north.

Table 1. Structure of walls and coefficient of thermal conductivity of each layer

Layer	Thickness (mm)	Coef. of thermal conductivity ($W\ m^{-1}\ K^{-1}$)
Plaster Manto Plate	10	0.055
Stucco plaster (interior)	10	0.99
ACC (Plyosilicate blocks)	500	0.205
Stucco plaster (exterior)	15	0.99
Brizolit (facade plaster)	10	1.1

The room (No.3) is the hall which connects ground floor and the first floor of the house. The hall is directly connected with room No.1, where is the fireplace. There is staircase. The room is not insulated by any special insulating material. The measured wall is oriented to the south.

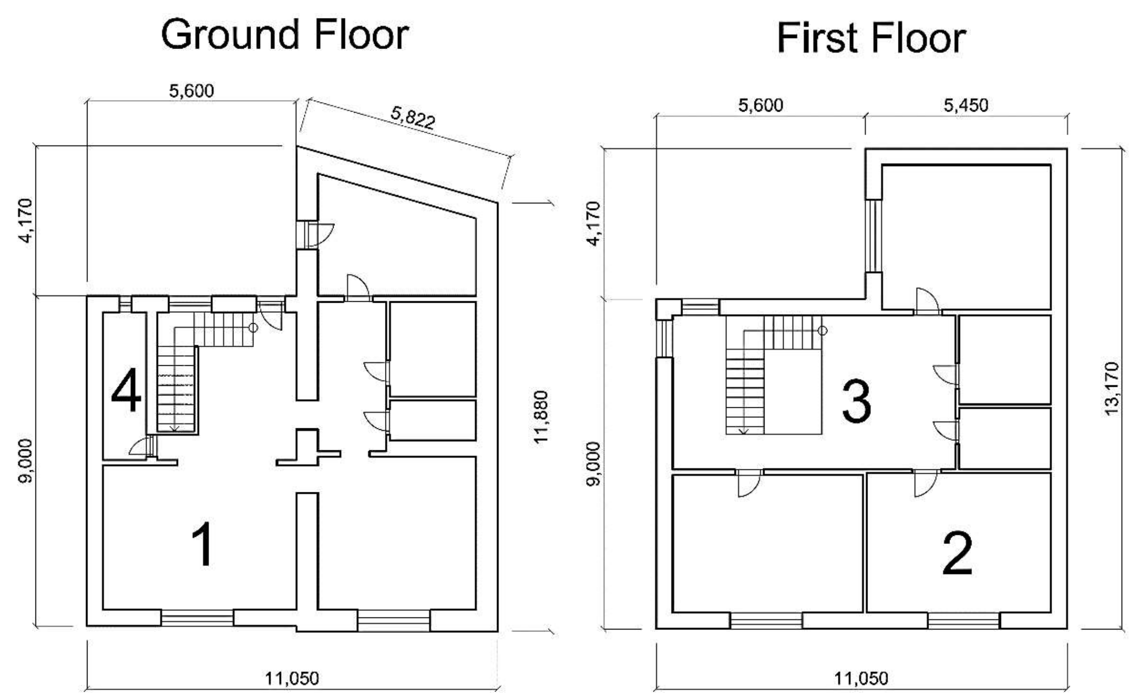

Figure 3. Layout of the house, where measured rooms are märked.

Room No.4 is the chamber. This room is not heated. There is not used any insulating material and measured wall is oriented to the south.

Data about the rooms which were used for the measurement such as area and volumes are given in Table 2.

Based on the measured data in the family house, principal parameters which are internal and external surface heat transfer coefficient, internal and external thermal resistance of walls, total thermal resistance of construction and overall heat transfer coefficient, are calculated according to the following formulas (1) to (8).

Table 2. Areas and volumes of measured rooms

Room number	Area (m^2)	Volume (m^3)
No. 1	21.44	60.032
No.2	19.82	55.496
No.3	24.87	69.636
No.4	4.92	13.776

$$\Delta t = t_{si} - t_{se} \tag{1}$$

where Δt – temperature difference of the wall (K); t_{si} – internal surface temperature of the wall (°C); t_{se} – External surface temperature of the wall (°C)

$$h_{si} = \frac{q}{t_{ai} - t_{si}} \tag{2}$$

where h_{si} – heat transfer coefficient of internal surface (W m^{-2} K^{-1}); q – heat flux (W m^{-2}); t_{ai} – internal air temperature by the wall (°C); t_{si} – internal surface temperature of the wall (°C)

$$h_{se} = \frac{q}{t_{ae} - t_{se}} \tag{3}$$

where h_{se} – heat transfer coefficient of external surface (W m^{-2} K^{-1}); q – heat flux (W m^{--2}); t_{ae} – external air temperature by the wall (°C); t_{se} – external surface temperature of the wall (°C)

$$R_i = \frac{1}{h_{si}} \tag{4}$$

where R_i – internal thermal resistance (m^2 K W^{-1}); h_{si} – heat transfer coefficient of internal surface (W m^{-2} K^{-1})

$$R_e = \frac{1}{h_{se}} \tag{5}$$

where R_e – external thermal resistance (m^2 K W^{-1}); h_{se} – heat transfer coefficient of external surface (W m^{-2} K^{-1})

$$R = \sum \frac{d_i}{\lambda_i} \tag{6}$$

where R – thermal resistance of the wall (m^2 K W^{-1}); d_i – thickness of layer (m); λ_i – coefficient of thermal conductivity of the layer (W m^{-1} K^{-1})

$$R_T = R_i + R + R_e \tag{7}$$

where R_T – total thermal resistance of the wall (m^2 K W^{-1}); R_i – internal resistance of heat transfer (m^2 K W^{-1}); R – Thermal resistance of the wall (m^2 K W^{-1}); R_e – external resistance of heat transfer (m^2 K W^{-1})

$$U = \frac{1}{R_T} \tag{8}$$

where U – overall heat transfer coefficient (W m^{-2} K^{-1}); R_T – external resistance of heat transfer (m^2 K W^{-1})

Plaster MP is a moisture-protective plaster consisting of 80% perlite, 10% pumice stone, 10% inorganic binders and binders based on water, cellulose and glass fibres. It consists only of natural and recycling materials and does not contain any carcinogenic substances.

Plaster MP, thanks to its main components, perlite and pumice, is a porous and breathable material. No kind of diluent is used in, after mixing it is immediately ready to apply. Application of the material can be done indoors or outdoors, even on wet walls.

Before the application, the plaster must be mixed by electric stirrer or drilling machine with a stirrer. Stirring takes about 2 minutes at 700 rpm. As longer the mixing is, as the plaster is thinner. It is not diluted with water.

No anchors or adhesives are not needed for application. It is applied by spraying or steel trowel. The thickness of plaster MP layer on the inside surface of walls is 1 cm. It can be used for up to 6 hours after mixing. Not fixed material does not harden and can be used after a long time. The drying time is influenced by ambient temperature and by ventilation, at a temperature in the range of 20 to 30 °C, the material deposited in the 1 cm layer is dried for approximately 48 hours. To create 1 m^2 of 1 cm thick layer is needed about 7 kg of material.

The thermal conductivity was measured by the instrument Isomet 2104 (Applied Precision Ltd, Bratislava). According to the physical properties of the tested material the surface sensor was used in this research. To improve the adhesion of the probe to the measured material, the contact surfaces were painted with thin layer silicone grease. The calibration was provided by the constant stored in the sensors memory. The permissible measurement error of thermal conductivity is 5% of reading + 0.003 W m^{-1} K^{-1}. The instrument was powered from AC during the measurement. The measured values were stored in the internal instrument memory and transferred via RS-232 interface to the PC after the measurement.

Air temperatures and relative humidity inside and outside the building were measured by data loggers ZTH65 with registration at intervals of 15 minutes during two cold winter days (long-time measurement). Parameters of ZTH65 are: temperature operative range –30 to +70 °C with accuracy ± 0.4 °C and operative range of relative humidity 5 – 95% with accuracy ± 2.5%. The same sensor was used for measurement in the laboratory during the tests of MP.

The surface temperatures in some specific places of tested walls were measured by special surface sensor S 106 9R (NiCr-Ni, with adapter G017R) connected to the instrument THERM 2253-2 (Ahlborn GmbH, Germany) for contact temperature measurement. This instrument was used also with sensor for air temperature measurement AMR TK 127 10R. This instrument and sensors can be used in operative range from –100 to +1,370 °C, with display resolution 0.1 °C and with accuracy ± 1% from the measured value.

There was used for the indirect measurement of wall moisture capacitive sensor FH A696–MF with operative range of mineral construction materials from 0 to 20% with accuracy 0.1%. The sensor was connected to the data logger ALMEMO 2690–8 (Ahlborn GmbH, Germany).

The heat flux density were measured by special heat flux sensor FQA018C (Ahlborn GmbH, Germany) which has dimensions 120 x 120 x 1.5 mm. It is made from epoxy resin with the resistance to 80°C and calibration constant 9.69 W m^{-2} mV^{-1} and relative measurement uncertainty 5%.

RESULTS AND DISCUSSION

Main parameters measured in family house which are heat flux q, interior air temperature near the wall t_{ai}, internal surface temperature of the wall t_{si}, external surface temperature of the wall t_{se}, exterior air temperature by the wall t_{ae}, moisture of the wall (interior) r_i, moisture of the wall (exterior) r_e, relative air humidity in the room φ_i, average air temperature t_i in the room and dew point temperature t_{dp} are given in the Table 3. The data are the mean values ± SD (standard deviation).

Table 3. Measured data in the family house

Parameter	Room No.1	Room No.2	Room No.3	Room No.4
q ± SD (W m^{-2})	25.49 ± 1.5	25.80 ± 0.9	39.81 ± 2.0	27.65 ± 1.6
t_{ai} ± SD (°C)	25.10 ± 0.7	19.62 ± 0.6	23.7 ± 0.73	15.97 ± 1.1
t_{si} ± SD (°C)	21.51 ± 0.3	16.74 ± 0.3	20.05 ± 0.7	12.28 ± 0.5
t_{se} ± SD (°C)	-0.59 ± 0.3	-0.81 ± 0.2	-0.33 ± 0.1	-0.27 ± 0.1
t_{ae} ± SD (°C)	-1.38 ± 0.2	-1.47 ± 0.1	-0.91 ± 0.2	-1.46 ± 0.1
r_i ± SD (°C)	3.60 ± 0.2	1.89 ± 0.2	3.91 ± 0.3	4.31 ± 0.2
r_e ± SD (°C)	4.79 ± 0.27	4.87 ± 0.3	4.63 ± 0.5	4.68 ± 0.4
φ_i ± SD (°C)	37.24 ± 1.9	60.72 ± 2.5	48.74 ± 1.9	52.19 ± 1.5
t_i ± SD (°C)	25.61 ± 0.9	18.46 ± 0.3	20.95 ± 0.6	15.97 ± 0.3
t_{dp} ± SD (°C)	9.90 ± 0.6	10.71 ± 0.6	9.74 ± 0.5	6.16 ± 0.6

q – heat flux; t_{ai} – interior air temperature by the wall; t_{si} – internal surface temperature of the wall; t_{se} – external surface temperature of the wall; t_{ae} – exterior air temperature by the wall; r_i – moisture of the wall (interior); r_e – moisture of the wall (exterior); ϕ_i – relative air humidity in the room; t_i – average air temperature in the room; t_{dp} – dew point temperature.

SD – Standard deviation.

The air temperature t_i in the room No. 1 is the highest from all measured rooms, its value is 25.61 ± 0.9 °C. On the other side the air relative humidity φ_i is the lowest one (37.24 ± 1.9%). The reason of this situation that fireplace is installed there. The humidity in the room No.2 is the highest from all measured rooms (60.72 ± 2.5%). The reason is that there is a large number of plants, which are there during the winter season. Local temperature in the room No.3 is the second highest (20.95 ± 0.6 °C), because this room is directly connected with room No.1. The room No. 4 is not heated, because of it there is the lowest temperature among measured rooms, 15.97 ± 0.3 °C.

Walls which are insulated by the plaster MP (rooms No.1 and No.2), have lower surface moisture r_i than the walls which are not insulated by this plaster (room No.3 and No.4). The lowest value of internal surface moisture was in the room No.2, it was 1.89 ± 0.2% and the highest one was in the room No.4 it was 4.31 ± 0.2%. Exterior surface moisture r_{se} of walls insulated by MP plaster is higher than moisture of walls without insulation. But the difference is very small, and it is probably not caused by the internal plaster, but it is influenced by the walls orientation. The walls insulated by MP plaster are oriented to the north and not insulated walls to the south. The values of the heat flux q were in the rooms No.1, No.2 and No.4 very similar, they were in the range of 25.49 ± 1.5 to 27.65 ± 1.6 W m^{-2}. At the same time the highest value was measured in the room No. 3 (39.81 ± 2.0 W m^{-2})

Table 4 shows data which are calculated from the measured data shown in the Tables 1 and 3.

Table 4. Calculated data of family house

Parameter	Room No. 1	Room No. 2	Room No. 3	Room No. 4
Δt (K)	22.10	17.55	20.38	12.55
h_{si} (W m^{-2} K^{-1})	7.30	8.78	10.91	8.47
h_{se} (W m^{-2} K^{-1})	32.27	31.02	68.64	26.26
R (m^2 K W^{-1})	2.66	2.66	2.47	2.47
R_i (m^2 K W^{-1})	0.14	0.11	0.09	0.12
R_e (m^2 K W^{-1})	0.031	0.032	0.015	0.038
R_T (m^2 K W^{-1})	2.83	2.81	2.58	2.63
U (W m^{-2} K^{-1})	0.35	0.35	0.39	0.38

Δt – temperature difference of the wall; h_{si} – heat transfer coefficient of internal surface; h_{se} – heat transfer coefficient of external surface; *R* – thermal resistance of wall; R_i – internal thermal resistance; R_e – external thermal resistance; R_T – total thermal resistance of construction; *U* - overall heat transfer coefficient.

The highest temperature difference *Δt* between internal and external surfaces of the wall were in the rooms 1 and 3. These rooms had the warmest evironment of all measured rooms, in the room No.1 it was 22.10 K and 20.38 K in No.3. The lowest value of heat transfer coefficient h_{si} of internal surface was in room No.1 (7.30 W m^{-2} K^{-1}) and the highest in the room No.3 (10.91 W m^{-2} K^{-1}). Different situation in the case of external value of this coefficient h_{se}, where the lowest value was in the room No.4 (26.26 W m^{-2} K^{-1}) and second in the room No.2 (31.02 W m^{-2} K^{-1}). On the other side highest value of external surface coefficient of heat transfer was measured in the room No.3 (68.64 W m^{-2} K^{-1}). Total thermal resistance of construction R_T and overall heat transfer coefficient *U* had better results in cases of rooms, where the plaster MP was used. In the room No.1 $U = 0.35$ W m^{-2} K^{-1} and $R_T = 0.35$ m^2 K W^{-1}, in the room No.2 $U = 0.35$ W m^{-2} K^{-1}and and $R_T = 0.35$ m^2 K W^{-1}, values are in these cases very similar.

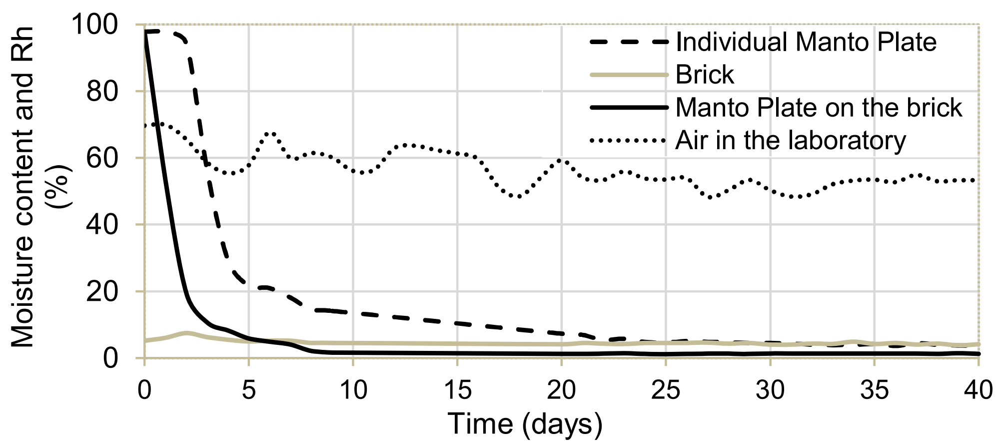

Figure 4. Measured data in the laboratory – moisture content of samples and relative humidity of air Rh during 40 days.

The graphs in the Fig. 4 show changes of moisture of samples during 40 days. It shows that moisture of both samples was the same on the beginning of measurement, it was about 97%. The moisture in the brick was very stable. The moisture of MP plaster layer on the brick decreased faster than individual sample of the MP. The relative humidity of air in laboratory was in range of approximately 50 to 65%. The air humidity had not big influence to moisture of the samples.

The graph in Fig. 5 shows change of moisture content of measured samples within first 10 days. It follows that the moisture content of layer of the plaster on the brick decreased faster than individual sample of plaster. From graph it is clear that moisture content of the brick was not influenced by the layer of the plaster. The sixth day of measurement the moisture content of layer of MP and the brick had same value. From this day the moisture of the layer had the lowest value among all samples.

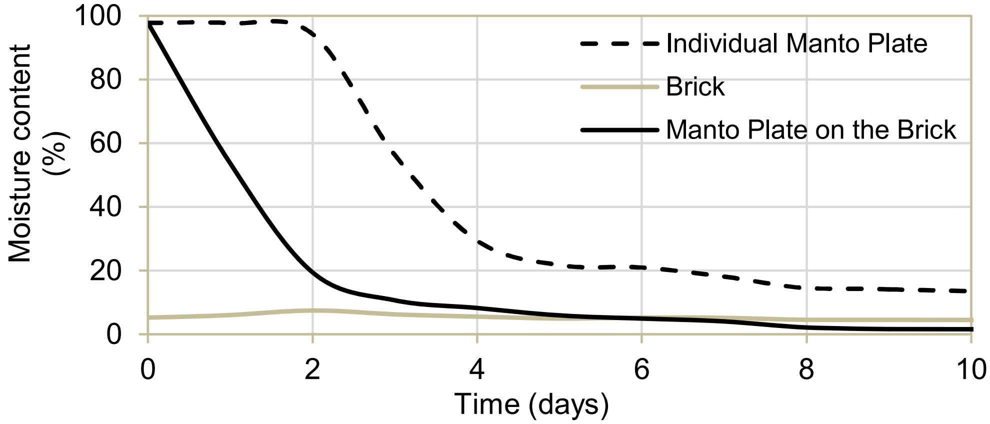

Figure 5. Measured data in the laboratory – the moisture content of samples during the first 10 days.

The graph in Fig. 6 shows the values of moisture content of the brick and individual sample of MP was very similar in the last 10 days of measurement. Value of layer of MP was very stable, there were only small fluctuations.

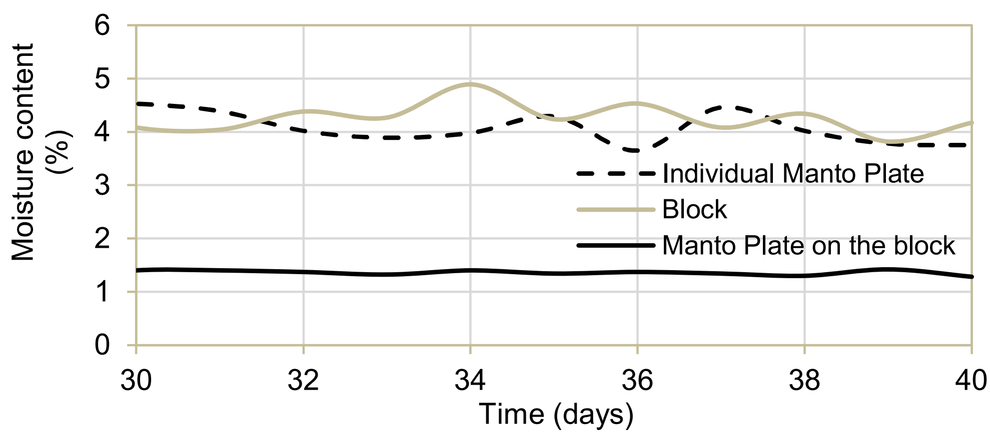

Figure 6. Measured data in the laboratory – the moisture content of samples during the last 10 days.

There was only a small difference between the temperatures of measured samples in the laboratory presented in the Table 5. Temperatures of samples were influenced by the air temperature in the laboratory. Small differences between the temperatures during the beginning of measurement were caused by the changes of materials moisture.

The influence of moisture content of the plaster measured on the individual MP sample on the coefficient of thermal conductivity is obvious from the Table 6. The lower the moisture content is, the smaller the coefficient of thermal conductivity is, and better thermal insulation properties of the material are.

Table 5. Measured data in the laboratory – the temperature and standard deviation (SD) of samples and air temperature in the laboratory

Sample	Temperature ± SD (°C)
Individual Manto Plate	20.19 ± 0.74
Brick	20.71 ± 0.51
Manto Plate on the brick	21.07 ± 0.90
Temperature in the laboratory	20.33 ± 0.38

The result is that the walls covered by MP have better thermal insulation properties than those that have not yet been insulated by any insulating material. The MP plaster also has a positive effect on the surface moisture of the walls. The surface moisture of the walls insulated by MP was lower than that of the other walls that were not insulated by the MP layer.

Table 6. Moisture content and coefficient of thermal conductivity of the plaster MP

Moisture of the plaster Manto Plate (%)	Coefficient of thermal conductivity (W m^{-1} K^{-1})
91.78	0.38
18.22	0.29
11.03	0.18
8.15	0.19
4.95	0.12
4.88	0.12
4.15	0.11
3.89	0.11

The measured value of the thermal conductivity coefficient differed from that stated by the manufacturer. The manufacturer presents the thermal conductivity value of 0.05 W m^{-1} K^{-1}. The value of this coefficient measured in the Thermal Measurement Laboratory at University of Salford in Manchester is 0.05547 W m^{-1} K^{-1} (Thermal conductivity of Manto Plate heat insulation plaster and render, 2014).

During the laboratory measurement, the lowest coefficient of thermal conductivity 0.11 W m^{-1} K^{-1} was measured, so the result is different from the value measured at University of Salford about 0.05453 W m^{-1} K^{-1}. The reason of different results can be caused by different measuring methods. The measurement methods presented in this paper is based on the dynamic principle measurement using the instrument Isomet 2104, which needs more massive and thicker sample of tested material. Another reason of different results can be caused by different temperature and humidity of surrounding environment.

CONCLUSIONS

The results of the measurement in the reconstructed old building in this research confirm that the plaster MP has suitable thermal properties and can be successfully applied for improvement of the walls inside the old buildings. The surface moisture of the walls the rooms in which the plaster was used was lower than moisture in the rooms without MP plaster. It influenced positively also the relative humidity of air inside the rooms during the measurement.

The layer of MP plaster improved also the thermal insulation of the rooms. The overall heat transfer coefficient, which expresses the thermal properties of the construction, was lower in the isolated rooms than in rooms that have not yet been insulated by MP.

The measurements in the laboratory have shown that the moisture of MP plaster influences the coefficient of thermal conductivity significantly. The lower the moisture content is, the smaller the coefficient of thermal conductivity is, and better thermal insulation properties of the material are.

It can be said that MP plaster is a good alternative for people who want to use natural materials that has the lower environmental impact than synthetic materials. It can be used for old and for new buildings as well.

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