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# The influence of selected plaster coatings on the thermal performance of an ETICS system

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Abstract: The article presents the analysis of the thermal performance of an EPS-based system finished with different plaster coatings. The analysis is based on the results achieved at the field site station. The analysis took into account the type of plaster, its texture and the orientation of the exterior wall finish relative to its facing which the moisture content inside the EPS and under the plaster coating is also dependent. It is noted here that the accumulation of moisture takes place within the expanded polystyrene. It was also found that the stabilization of moisture levels in the insulation material depends on the type of external plaster coating. The actual thermal performance of the insulation material was analyzed using the results of the evaluation of the moisture properties in the expanded polystyrene under the plaster coating at the field site. The moisture results confirm that there is an accumulation of moisture in the insulation material, which has a significant impact on the value of thermal resistance, with the largest differences found in the north and west facing exterior wall finishes.

Keywords: ETICS system, facade plaster, EPS



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## Introduction

In recent years, the tightening thermal performance requirements for building partitions and energy savings have led to changes in the way walls of heated buildings are erected. Due to the thickness of the insulation, the EPS-based ETICS system (Duarte, 2011) has gained popularity. In this solution, EPS is protected by a thin-layer of plaster coating that is exposed to the external environment. The results of these interactions are changes in the moisture properties of the system, which

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are not taken into account in thermal calculations (Barreria & Freitas, 2014; Becker, 2003; Krus et al., 2006; Ksit & Horbik, 2015; Sedlbauer & Krus, 2002; Venzmer et al., 2008). The effect of moisture content on thermal conductivity is the subject of PN-EN ISO 10456. The value of the calculated thermal conductivity is obtained by conversion due to moisture content according to the following formula:

$$\lambda_{\Psi} = \lambda_D \cdot e^{f_{\Psi} \cdot (\Psi_2 - \Psi_1)} \quad (1)$$

where:
$\lambda_{\Psi}$ – the value of thermal conductivity at humidity $\Psi$;
$\lambda_D$ – the declared value of the thermal conductivity coefficient;
$f_{\Psi}$ – the conversion factor that takes humidity content of expanded polystyrene into account, assumed = 4;
$\Psi_1$ – volumetric moisture content to determine $\lambda_D$, assumed = 0;
$\Psi_2$ – volumetric moisture content ≤10%.

Under typical operation conditions, the conversion for EPS is equal to 1. The effect of the changes in moisture content on the thermal conductivity of the ETICS insulation layer was studied by J.L. Parracha et al. An increase in thermal conductivity with moisture content was obtained for all tested systems, regardless of the thermal insulation material used (EPS, ICB, or MW) (Parracha et al., 2021). Tests of thermal insulation materials carried out by Fiorkowicz-Pogorzelska (2001) showed that the conversion factor determined according to PN-EN ISO 10456 is in line with laboratory tests due to moisture content (used in the range up to 10% of moisture content). The subject literature does not contain any studies of the actual moisture content of the EPS that operates long-term in the ETICS system.

This paper presents the analysis of the EPS moisture properties under various plaster coatings after a 6-year service life. The analysis is based on the results achieved at the field site station. The analysis also takes the compass orientation of the systems into account.

## 1. Materials and methods

For the study, an ETICS system based on EPS70-042 was adopted, including two of the most popular thin-coat plaster coatings: acrylic plaster and mineral plaster, each in two texture variants (dashed plaster, filled plaster).

### 1.1. Field site station

The test stand was located in Bydgoszcz, Poland. The stand consists of four walls made of 24 cm thick aerated concrete, perimeter insulated with 15 cm thick EPS70-042. The surfaces of plaster coatings were oriented with respect to the four compass directions. Separated with expansion joint profiles: acrylic and mineral (Fig. 1a), different layers of plaster were laid on each surface. The field site station was in operating for 6 years from June 2016 to April 2022.

## 1.2. The evaluation of moisture content in expanded polystyrene

The test samples were sections of the ETICS system with the full thickness of expanded polystyrene, taken from the test stand. Samples were taken in April 2022, after a 2-week period without precipitation. For each plaster coating solution, three 100x100 mm samples were cut from each exterior wall finish orientation (Fig. 1b). Immediately after cutting, each collected sample was divided into strips, parallel to the plane of the plaster coating, with a thickness of 1.5 cm (Fig. 1c). The samples prepared with this method were weighed to the nearest 0.01 g, dried to a constant weight at +40±2°C and weighed again.

a) Field site station – 2016 b) Field site station – 2022 c) Moisture test samples


**Fig. 1.** Preparation of testing material (*author archive*)

The mass and volumetric moisture content of the samples was determined according to the following formulas:

– Mass moisture content – the ratio of the mass of water in the material to the total mass of wet material:

$$\mu_m = \frac{m - m_0}{m_0} \cdot 100\% \tag{2}$$

where:
$m$ – sample weight before drying [g],
$m_0$ – sample weight after drying [g],

– Volumetric moisture content – the ratio of the water volume in the material to the total volume of the sample before drying:

$$\theta = \frac{V_w}{V} \cdot 100\% \tag{3}$$

where:
$V_w$ – water content volume in the sample [m$^3$],
$V$ – total sample volume before drying [m$^3$].

## 1.3. Declared values of thermal properties and their conversion with respect to moisture content

The declared thermal conductivity value of expanded polystyrene was taken from the manufacturer tests. For each sample strip, the partial thermal resistance was determined using the design value of thermal conductivity, obtained by conversion due to moisture content, according to the procedure of PN-EN ISO 10456.

$$\lambda_{\Psi} = 0.042\, e^{4 \cdot \Psi_2} \quad (4)$$

The total thermal resistance of the expanded polystyrene layer under the ETICS system is the sum of partial resistances of the sample strips (Dylla, 2009):

$$R_{\Psi} = \sum_{and=1}^{n} \frac{d_{and}}{\lambda_{\Psi_{and}}} \quad (5)$$

where:
$d_i$ – sample strip thickness [m],
$\lambda_{\Psi i}$ – the value of the thermal conductivity coefficient of expanded polystyrene in the "I" strip, at volumetric moisture content $\Psi i$ [W/mK].

## 2. Test results and discussion

### 2.1. Moisture content properties of insulation material under plaster coating

The results of the mass and volumetric moisture content of the insulation material were determined as partial moisture content of the samples and presented in Table 1 and Table 2 as well as Figure 2.

**Table 1.** Moisture content of samples with dashed plaster texture (*own research*)

| Plaster coating | Sample thickness [cm] | Moisture content | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mass [%] | | | | Volume [%] | | | |
| | | Orientation | | | | | | | |
| | | N | S | E | W | N | S | E | W |
| Acrylic | 0 | 2.935 | 0.448 | 0.897 | 1.034 | 1.707 | 0.260 | 0.573 | 0.453 |
| | 1.5 | 2.703 | 1.402 | 1.493 | 3.279 | 0.040 | 0.020 | 0.013 | 0.040 |
| | 3 | 1.724 | 1.778 | 1.333 | 1.778 | 0.027 | 0.027 | 0.013 | 0.027 |
| | 4.5 | 1.288 | 2.222 | 0.676 | 0.844 | 0.020 | 0.033 | 0.007 | 0.013 |
| | 6 | 1.288 | 2.193 | 0.671 | 1.210 | 0.020 | 0.033 | 0.007 | 0.020 |
| | 7.5 | 0.909 | 1.333 | 0.585 | 0.816 | 0.013 | 0.020 | 0.007 | 0.013 |
| | 9 | 0.858 | 0.437 | 0.575 | 0.398 | 0.013 | 0.007 | 0.007 | 0.007 |
| Mineral | 0 | 2.631 | 0.333 | 0.225 | 0.828 | 1.747 | 0.200 | 0.147 | 0.567 |
| | 1.5 | 2.326 | 1.053 | 0.680 | 2.484 | 0.033 | 0.013 | 0.007 | 0.027 |
| | 3 | 1.869 | 1.843 | 0.610 | 2.235 | 0.027 | 0.027 | 0.007 | 0.027 |
| | 4.5 | 1.770 | 1.794 | 0.602 | 1.685 | 0.027 | 0.027 | 0.007 | 0.020 |
| | 6 | 1.660 | 2.212 | 0.526 | 1.648 | 0.027 | 0.033 | 0.007 | 0.020 |
| | 7.5 | 1.619 | 2.222 | 0.500 | 0.962 | 0.027 | 0.033 | 0.007 | 0.013 |
| | 9 | 1.613 | 1.786 | 0.498 | 0.948 | 0.027 | 0.027 | 0.007 | 0.013 |

**Table 2.** Moisture content of samples with filled plaster texture (*own research*)

| Plaster coating | Sample thickness [cm] | Moisture content | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mass [%] | | | | Volume [%] | | | |
| | | Orientation | | | | | | | |
| | | N | S | E | W | N | S | E | W |
| Acrylic | 0 | 2.007 | 0.254 | 0.838 | 0.659 | 1.167 | 0.133 | 0.447 | 0.440 |
| | 1.5 | 2.703 | 2.381 | 1.639 | 1.274 | 0.040 | 0.033 | 0.013 | 0.013 |
| | 3 | 1.724 | 0.873 | 2.439 | 1.010 | 0.027 | 0.013 | 0.020 | 0.013 |
| | 4.5 | 1.288 | 0.866 | 1.626 | 0.488 | 0.020 | 0.013 | 0.013 | 0.007 |
| | 6 | 1.293 | 0.855 | 1.942 | 0.493 | 0.020 | 0.013 | 0.013 | 0.007 |
| | 7.5 | 0.909 | 1.282 | 2.239 | 0.980 | 0.013 | 0.020 | 0.020 | 0.013 |
| | 9 | 0.429 | 0.855 | 0.913 | 0.995 | 0.007 | 0.013 | 0.013 | 0.013 |
| Mineral | 0 | 2.559 | 0.386 | 0.287 | 0.395 | 1.700 | 0.240 | 0.153 | 0.193 |
| | 1.5 | 2.804 | 3.371 | 1.714 | 2.727 | 0.040 | 0.060 | 0.020 | 0.020 |
| | 3 | 1.869 | 0.680 | 1.587 | 2.290 | 0.027 | 0.013 | 0.020 | 0.020 |
| | 4.5 | 1.322 | 1.007 | 1.563 | 0.746 | 0.020 | 0.020 | 0.020 | 0.007 |
| | 6 | 1.660 | 0.676 | 0.948 | 1.538 | 0.027 | 0.013 | 0.013 | 0.013 |
| | 7.5 | 1.613 | 0.671 | 0.893 | 0.781 | 0.027 | 0.013 | 0.013 | 0.007 |
| | 9 | 1.619 | 0.000 | 1.402 | 0.787 | 0.027 | 0.000 | 0.020 | 0.007 |

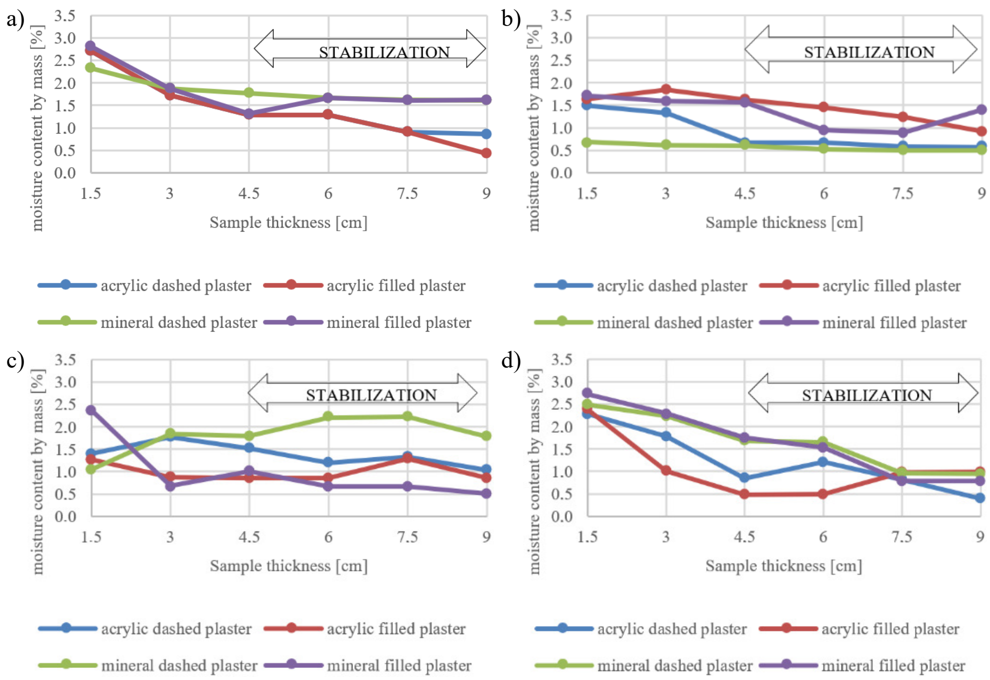


**Fig. 2.** Mass moisture content for plaster samples with the orientation: a) north, b) east, c) south, d) west (*own research*)

In case of the northern and western exterior wall finish, the mass moisture content of the insulation located under the acrylic and mineral plaster coating (Fig. 2a, 2d), is almost twice as high as of the southern and eastern exterior wall finish (Fig. 2b, 2c). Moisture content decreases with the depth of the insulation layer where it stabilizes at 4.5 cm from the face of the plaster coating. Stabilization in the northern direction of the exterior wall finish occurs at mass moisture levels in the range of 1-2%, unlike the other orientations with the values of 0.5-1.5%. In both texture variants, dashed plaster and filled plaster, the trend is the same.

The mass moisture content of the insulation under the eastern and southern plaster coatings features an even distribution, with no characteristic increase directly under the plaster coating that is observable for the northern and western exterior wall finishes.

## 2.2. Thermal performance of the insulating material

The EPS moisture content under the thin-coat plaster coatings depends their compass orientation The accumulation of moisture takes place in the expanded polystyrene and has a significant impact on the value of thermal resistance. As a result of evaluating the moisture properties of the EPS under the plaster coating on the field site station, the actual thermal performance of the insulation material was analyzed. The declared thermal resistance value for the 15 cm thick EPS70-042 layer based on the manufacturer data was $R_D$ = 3.57 m²K/W.

After introducing the conversion due to the actual volumetric moisture content, the resistance values shown in Figures 3 and 4 were obtained.

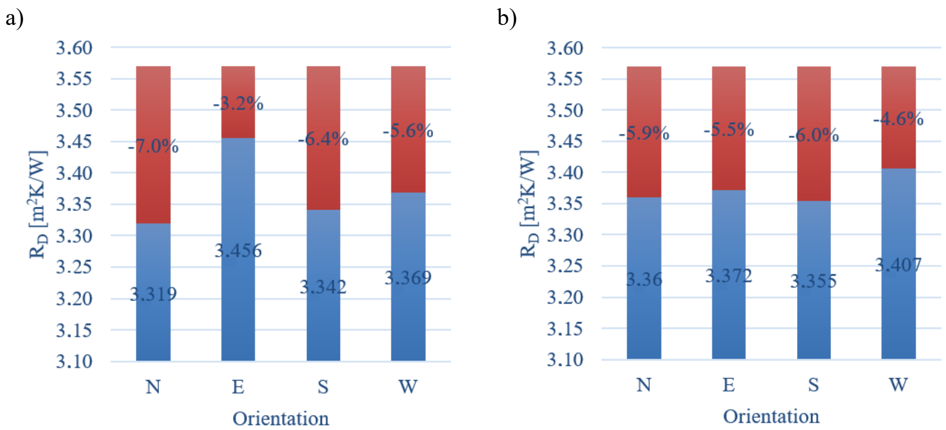


**Fig. 3.** Effect of EPS moisture content on thermal resistance for acrylic plaster: a) dashed plaster, b) filled plaster (*own research*)

Evaluating the influence of the insulation material moisture content on thermal resistance of the acrylic plaster, the highest EPS resistance losses are indicated by samples from the northern orientation with a dashed plaster texture of 7.0% and the filled plaster texture of 5.9%. The resistance losses for other orientations are similar, and in the case of the south exterior wall finish for the dashed plaster texture, its resistance dropped by 6.4%, and the filled plaster texture by 6.0%. The western exterior wall finish shows losses of 5.6% for the samples with the dashed plaster texture, and 4.6% for the filled plaster texture. For the eastern exterior wall finish, a reduction in the thermal resistance of the insulation of 3.2% for the dashed plaster texture and 5.5% for the filled plaster texture was determined (Fig. 3).

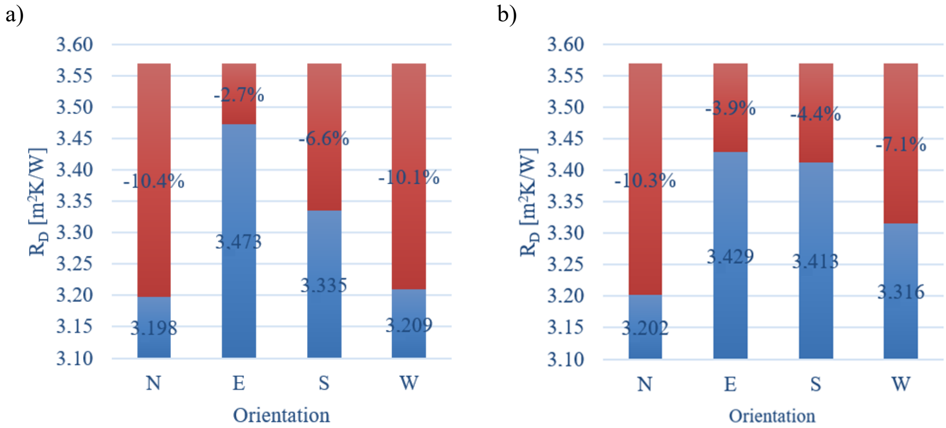


**Fig. 4.** Effect of EPS moisture content on thermal resistance for mineral plaster: a) dashed plaster, b) filled plaster (*own research*)

Mineral plaster in both texture variants is featured by the highest influence of moisture content of the insulating material on thermal resistance of 10.4% for the dashed plaster texture and 10.3% for the filled plaster texture. In the case of the south exterior wall finish, the thermal resistance losses are 6.6% for the dashed plaster texture, and 4.4% for the filled plaster texture. The western exterior wall finish shows losses of 10.1% for the samples with the dashed plaster texture, and 7.1% for the filled plaster texture. For the eastern exterior wall finish, a reduction in the thermal resistance of the insulation of 2.7% for the dashed plaster texture and 3.9% for the filled plaster texture was determined (Fig. 3).

## Conclusions

Obtained moisture content results confirm that the moisture content of expanded polystyrene under the thin-coat plaster coating is dependent on the following factors:

1. Orientation to compass directions – the accumulation of moisture content takes place in the expanded polystyrene, which is higher for the northern and western orientations than for the southern and eastern orientations. The highest moisture content occurs in the layer under the plaster coating. The moisture content value stabilizes at the same depth of the insulation material of 4.5 cm from the surface of the plaster coating for each type. The mass moisture content of the insulation

under the plaster coating for the east and south exterior wall finishes features even distribution. The texture of the plaster coating does not affect moisture differences.

2. Type of plaster – plays an important role in the case of northern and western orientations for which the mineral plaster coating features a higher mass moisture content than in case of acrylic plaster coating. this trend was not found for other orientations.

The performed analyses indicated that changes in the moisture content of the thermal insulation material translate into a reduction in thermal resistance, with the largest differences occurring in case of north and west exterior wall finishes (10% relative to the calculated value).

For other orientations, the difference is smaller (about 5% or less). The greatest resistance drop, based on the directions and used plaster coatings, is characterized by EPS under mineral plaster coating in both texture variants.

The levels of EPS moisture content found results in a thermal insulation deficit that translates into the heating demand of a particular building. Therefore, it is appropriate to take into consideration and make the thermal conversion of the insulation material under thin-film plaster coatings mandatory, based on the actual moisture content of the material in the most unfavorable orientations (in this case, north and west).

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