

## Article

# Resistance of ETICS with Fire Barriers to Cyclic Hygrothermal Impact

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**Abstract:** The article presents the results of a set of hygrothermal experiments of an external wall insulated with an ETICS. As an add-on to previous studies, thermal insulation in the form of polystyrene with an additional horizontal strip of mineral wool was used. Laboratory tests were carried out in accordance with ETAG 004. The ETICS test rig was composed of combustible expanded polystyrene foam (EPS) and horizontal strips of noncombustible mineral wool (MW) fire barriers over windows. The physical and mechanical properties of four types of finishing renders (without an additional reinforcement mesh in base coat of the fire barriers) were analyzed across full hygrothermal cycles in a climate chamber. Temperature sensors were mounted onto different ETICS layers to collect thermal data during the weathering. The testing of ETICS regarding their hygrothermal performance revealed that there were no visible defects on any renderings and over the junctions depending on the type of used insulation materials. Results also showed that the joints of EPS and MW have approximately half of their bond strength from polystyrene strength.

**Keywords:** ETICS; EPS; MW; fire barriers; hard-body impact; hygrothermal behaviour



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## 1. Introduction

External thermal-insulation composite systems (ETICS) significantly reduce energy consumption for new and existing buildings, and extend the service life of the external walls. By preventing greenhouse-gas emissions, ETICS also improve thermal indoor comfort and hygiene standards [1–4]. The effectiveness of ETICS depends on their physical and mechanical properties, and the quality of system installation [1–7]. Defects often occur as a consequence of detailing shortfalls or poor workmanship. The finishing coat of ETICS is the most vulnerable layer exposed to climatic factors [8–11]. Precipitation, solar radiation, and temperature differences may negatively impact the thermal-insulation system, causing a broad range of types of damage [1,5–7,12–16].

In spite of the thermal advantages of ETICS, their relatively low cost, and ease of application, combustible insulation materials used in ETICS have raised serious fire-safety issues [9]. In order to prevent the fast spread of fire, different provisions can be made, such as barriers of noncombustible material such as mineral wool around the openings, and horizontal isolation barriers around the buildings between different floors [4,7,9]. Parallel to the emergence of new recommendations, there are various technical doubts about the possible negative effects of such a combination [6–8,16–19]. One is the presumption that there may be cracks in the reinforcing and rendering layers due to the different thermal expansion of materials under the influence of external factors; another possibility is the discoloration of the facade, associated with the different moisture-absorption rates of thermal-insulation materials [6–8]. In some countries, there are guidelines for implementation of an additional

fiberglass mesh (identical to that of the rendering system in the current part) on fire barrier strips, overlapping at least 150 mm on either side of the strip [20]. Moreover, different countries still have different ETICS requirements and solutions for fire safety [9]. The rapid development of construction technologies, together with emerging new guidelines or recommendations, indicates the need for the practical verification of adopted solutions.

On this subject, various research papers were published [1–20]; however, there is practically no information about the performance of two different thermal-insulation materials during hygrothermal testing. Since fire barriers are an integral part of ETICS, it is very important to know what kind of testing method is being used to ensure that the building occupants can be kept safe and healthy. Therefore, results from water-absorption and mechanical-resistance testing of ETICS are presented. The aim of this research is to estimate the impact of different thermal-insulation types (i.e., EPS and MW as the fire barrier) on the hygrothermal behaviour of ETICS according to ETAG 004. Moreover, the scope is to check the possibility of appearance of cracks in the joints between EPS and MW without additional mesh covering on the fire barrier during hygrothermal testing.

## 2. Methodology and Materials

A silicate brick wall was constructed (3.0 m wide by 2.2 m high) with installed ETICS panels (Figure 1) in accordance with 5.1.3.2.1 ETAG 004 [19]. Four different types of thermal-insulation systems were applied on the wall, namely, with acrylic, silicate, mineral, and silicone finishing coats (of whitish color). Mineral rendering was painted with silicone paint. The thickness of the basecoat was 3–5 mm. In order to examine the worst-case scenario of ETICS, 1 mm thickness finishing coats were selected except for a 2 mm thickness mineral coat. Thermal-insulation boards were mechanically fixed with plastic anchors (4 pcs./m<sup>2</sup>) with supplementary adhesive.



**Figure 1.** (a) EPS thermal insulation with mineral wool fire barriers; (b) test rig with 4 types of plastering during the test.

Expanded polystyrene EPS70 (140 mm thickness) was used as an insulation material with mineral wool as a fire barrier (140 mm thickness). The general characteristics of thermal insulation indicated by the producers are shown in Table 1.

**Table 1.** General characteristics of thermal insulation.

Insulation	Vapour Diffusion Resistance Factor ( $\mu$ )	Density, kg/m <sup>3</sup>	Thermal Conductivity, W/(m·K)	Water Absorption (W <sub>24</sub> ), kg/m <sup>2</sup>	Compressive Strength, kPa
MW	1	136	0.036	≤3	≥20
EPS	30	14.5	0.039	≤0.04	≥70

General characteristics of all finishing coats: density, 1.8–1.9 kg/dm<sup>3</sup>; thermal conductivity, 0.70 (W/m·K); long-term water absorption, 0.1–0.5 kg/m<sup>2</sup>; water-vapour diffusion resistance factor, 15 ÷ 150.

The same mineral base coat together with a reinforcing mesh was applied to all ETICS without additional reinforcement mesh on the fire barriers. The horizontal strip of mineral wool (200 mm width) was installed in the lower part of the rig and above the openings. ETICS were installed according manufacturer's instructions; this was submitted to laboratory conditions (temperature  $20 \pm 5$  °C) for 4 weeks. During the first 20 days, the rig was subjected to 80 heat–rain cycles and 5 heat–cold cycles:

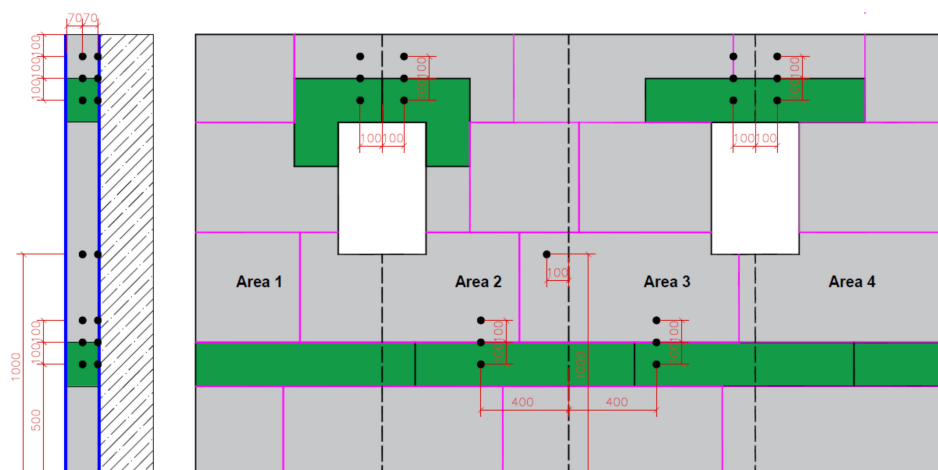
Heat–rain cycling:

- heating to 70 °C and maintaining this temperature at  $70 \pm 5$  °C and relative humidity at the level of 10–30% for 2 h (3 h in total);
- sprinkling with water at a temperature of  $15 \pm 5$  °C in the amount of 1 L/m<sup>2</sup> for 1 h and leaving the rig for a period of 2 h.

Heat–cold cycling:

- heating to  $50 \pm 5$  °C and 30% RH for 7 h;
- freezing to  $-20 \pm 5$  °C for 14 h.

In order to follow the temperature in different layers of ETICS and in the junction between EPS and MW, 38 pieces of temperature sensors were installed (see Figure 2). Duplex insulated Omega TT-T-30 T-type thermocouples were used. Measuring ranged from  $-200$  to 350 °C, and accuracy was  $\pm 1.0$  °C or  $\pm 0.75\%$ . Temperature sensors were installed at each of the assumed heights. One was at the junction of the thermal insulation with the structural layer, and the other in the middle of the thermal-insulation thickness. This is depicted in Figure 2. The rig was divided into four vertical areas (dotted lines). Pink lines reflect the EPS boards, and green areas the mineral wool.



**Figure 2.** Temperature-sensor placement, cross-section, and elevation (area 1, acrylic render; area 2, silicate render; area 3, mineral render; area 4, silicon render).

After going through the weathering, the specimens' moisture contents mass by mass of thermal insulation directly under the rendering were determined according to EN ISO 12570 on the hygrothermal performance of building materials and products. Moisture content was determined by drying at elevated temperature.

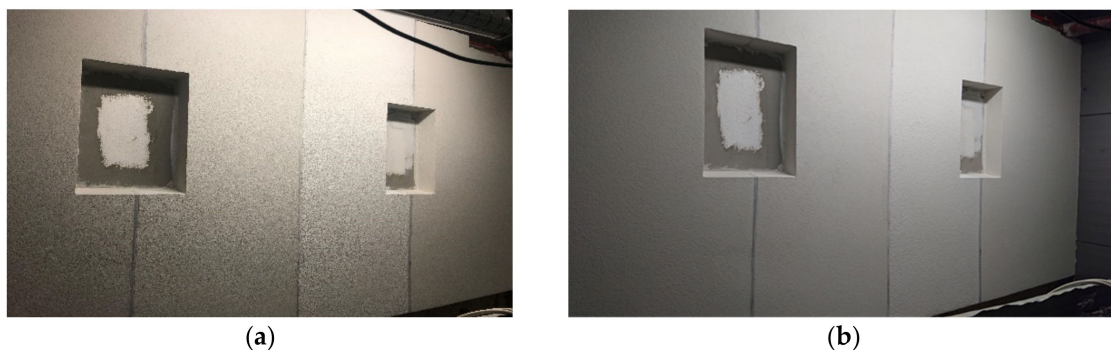
Furthermore, hard-body impact (as per ETAG 004 5.1.3.2.1 [19]) and bond-strength (as per ETAG 004 5.1.4.1.1 [19]) tests were performed. The test was performed with adhesion tester CONTROLS 58-C0215/T (Figure 3). The plates were pulled at a speed of 1 to 10 mm/min. Individual and average values were recorded and are expressed in MPa. The pull of the test was performed at  $18 \pm 2$  °C at SD =  $50 \pm 5\%$ .



**Figure 3.** Testing of the bond strength of ETICS.

### 3. Results and Discussion

Following the conclusion of the heat–rain and heat–cold cycles, on the basis of macroscopic tests, no irregularities were found on all analysed types of thin-layer rendering surfaces. No cracks, scratches, or hairline superficial crevasses of any kind were observed; this implies that the joints of the EPS/MW remained intact, suggesting that there was no water penetration into the insulation layer (Figure 4). Therefore, the above-mentioned ETICS are resistant to hygrothermal cycles neglecting to absence of additional reinforcement mesh over MW fire barriers.



**Figure 4.** Photo fixation set of the ETICS (a) before and (b) after testing.

#### 3.1. Moisture Transfer

The obtained moisture-testing results show that the actual moisture content slightly varied depending on the type of applied render and used thermal insulation. The calculation of mass by mass-moisture content for individual types of render and thermal insulation after 80 heat–rain cycles showed different results. With EPS thermal insulation, the highest moisture level was recorded for ETICS with a silicone render ( $w = 2.3\%$ ). In the case of mineral wool, the highest achieved value was for acrylic and silicone render ( $w = 0.5\%$ ) (Table 2).

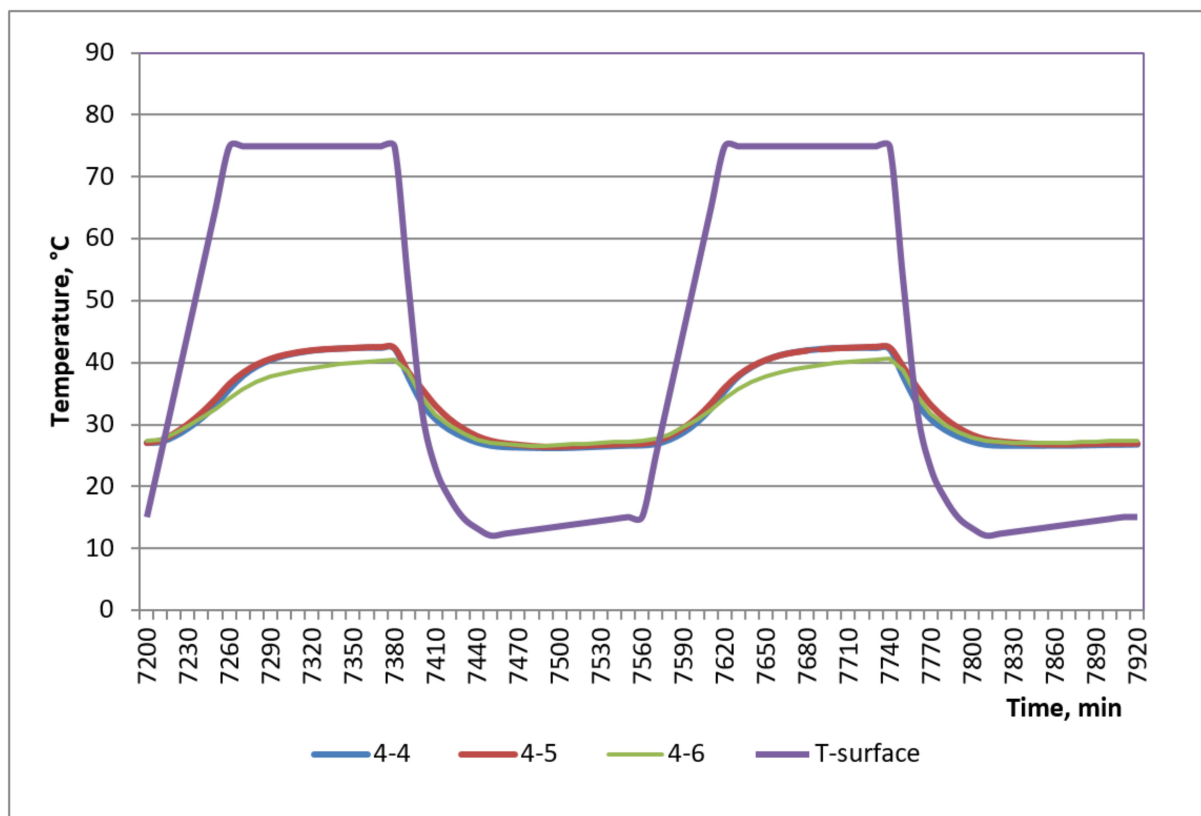
#### 3.2. Temperature Profile

When thermocouple data were analysed, the temperature profile across the whole depth of thermal-insulation layers, and at the interface of the different layers during

the hygrothermal cycle, remained similar, and did not depend on the type of thermal-insulation layer. The typical profile of temperature variations is given in Figure 5 (ETICS no. 2/silicate). The trend of temperature differences at different measuring locations on surface finishes and in the middle of insulating layer are very similar; these had a rectangular plateau-wave shape. The temperature at the masonry base ranged from 26 to 27 °C. The temperature in the middle of the thermal-insulation materials (7–8 cm from the surface) ranged from 26 to 40 and 42.5 °C. Temperature at the junction of EPS/MW had a value closer to that of the temperature in the middle of MW than to that of the temperature in the middle of EPS. The heterogeneity of the material structure can cause local thermal anomalies. Temperature differences on the EPS and base-wall interface, and in the junction of EPS/MW were insignificant and amounted to  $\Delta t_{\text{average}} = 0.2$  °C.

**Table 2.** Moisture content of thermal insulation right under finishing coat (sample thickness, 30 mm) of the ETICS after testing in the ageing chamber.

System or Kind of Rendering	Moisture Content Mass by Mass, %	
	EPS	MW
ETICS no. 1/acrylic	1.2	0.5
ETICS no. 2/silicate	1.1	0.1
ETICS no. 3/mineral/silicone paint	1.7	0.1
ETICS No. 4/silicone	2.3	0.5



**Figure 5.** Temperature variation in ETICS fragment layers during hygrothermal cycles: (4-4) temperature in the middle of mineral wool; (4-5) temperature at the junction of mineral wool and polystyrene foam, (4-6) temperature in the middle of polystyrene foam.



### 3.3. Bond Strength

After the hygrothermal cycle had ended, the obtained adhesion strength was 0.11 MPa. This was measured at the points where pulling was performed from the polystyrene foam; at the points where pulling was performed from the mineral wool, adhesion strength was 0.1 MPa; when measuring connections between polystyrene foam and mineral wool, such pulling pressure stood at  $-0.05$  MPa (Table 3, Figure 6). Test results showed that the joints of EPS/MW had approximately half the bond strength of that of EPS. This was evident at the intersection of the two substances, polystyrene and mineral wool.

**Table 3.** Results of adhesion-strength tests of mineral wool, EPS, and joints between EPS and MW with base layer after hygrothermal cycles (touch drying, cooling–heating).

Adhesion Strength after Hygrothermal Cycles			
System	Place	Average Value, MPa	Rupture Description
ETICS no. 1	From EPS	0.11	cohesive
	At the joint EPS/MW	0.05	cohesive
	From MW	0.01	cohesive
ETICS no. 2	From EPS	0.11	cohesive
	At the joint EPS/MW	0.05	cohesive
	From MW	0.01	cohesive
ETICS no. 3	From EPS	0.10	cohesive
	At the joint EPS/MW	0.05	cohesive
	From MW	0.01	cohesive
ETICS no. 4	From EPS	0.10	cohesive
	At the joint EPS/MW	0.05	cohesive
	From MW	0.01	cohesive



**Figure 6.** Testing of the bond strength of ETICS: an example of the typical pull-off at the joint of EPS/MW.

### 3.4. Impact Resistance

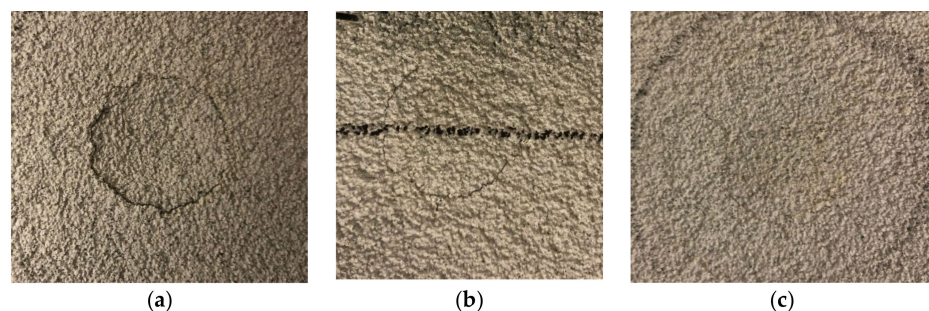
Following the impact-resistance experiments, results indicated that the type and size of damage have practically no influence on the type of thermoinsulating material, EPS or MW. Moreover, the joints of these materials (EPS/MW) showed no movement. However, where thermal insulation material—mineral wool (MW) and two thermal-insulation material

were connected (EPS/MW)—impacted the ETICS samples, caused less damage compared to the impact where only polystyrene foam was used. In the case of ETICS no. 3 (mineral render), damage was greater when the base layer was applied on EPS, and in places where there is mineral wool and at the joints, the damage was smaller or nonexistent. The results of impact-resistance testing are given in Table 4; examples of the typical hard body impact on EPS and on the joint of EPS/MW are shown in Figure 7.

**Table 4.** Results of hard-body impact tests on EPS, MW, and on junctions of EPS/MW.

Place No	10 J Impact from a Height of 1.02 m (EPS)	10 J Impact from a Height of 1.02 m (MW)	10 J Impact from a Height of 1.02 m (EPS/MW)
	Explanation/Diameter of Damage, mm	Explanation/Diameter of Damage, mm	Explanation/Diameter of Damage, mm
<b>ETICS No. 1</b>			
1.	Not penetrated/41	Not penetrated/37	Not penetrated/42
2.	Not penetrated/44	Not penetrated/40	Not penetrated/47
3.	Not penetrated/37	Not penetrated/42	Not penetrated/36
4.	Not penetrated/39	Not penetrated/35	Not penetrated/45
5.	Not penetrated/48	Not penetrated/43	Not penetrated/41
<b>ETICS No. 2</b>			
1.	No deterioration/30	No deterioration	Not penetrated/31
2.	No deterioration/27	No deterioration	No deterioration/39
3.	Not penetrated/36	No deterioration	Not penetrated/40
4.	Not penetrated/37	No deterioration	Not penetrated/38
5.	Not penetrated/48	No deterioration	Not penetrated/43
<b>ETICS No. 3</b>			
1.	Not penetrated/40	No deterioration/33	No deterioration/44
2.	Not penetrated/42	No deterioration/28	No deterioration/39
3.	Not penetrated/46	No deterioration	No deterioration
4.	Not penetrated/33	No deterioration	No deterioration
5.	Not penetrated/47	No deterioration	No deterioration
<b>ETICS No. 4</b>			
1.	Not penetrated/38	Not penetrated/40	Not penetrated/41
2.	Not penetrated/37	Not penetrated/40	Not penetrated/43
3.	Not penetrated/40	Not penetrated/38	Not penetrated/39
4.	Not penetrated/39	Not penetrated/42	Not penetrated/33
5.	Not penetrated/33	Not penetrated/39	Not penetrated/35

Explanation: No deterioration, superficial damage, provided there was no cracking; not penetrated, superficial damage, circular cracking did not reach the insulation product.



**Figure 7.** Hard-body impact testing: example of typical hard-body impact on (a) ETICS no. 2: EPS, (b) joint of EPS/MW, (c) MW.

#### 4. Conclusions

In this study, the performance of a sample of ETICS without additional reinforcement mesh in base coat of the fire barriers was rigorously tested. This included the effects of temperature changes, dynamic moisture fluctuations (hygrothermal cycles), impact-load durability, and resistance of fire barriers, all as part of the study of overall service life. The following conclusions were drawn.

The joints of polystyrene and mineral wool had approximately half of their bond strength from polystyrene. The hard-body impacts to all tested ETICS were similar on all analysed types of thin-layer render surfaces. Only in the case of ETICS no. 3 (mineral render) was the damage greater when the base layer was applied on EPS, and in places where there was mineral wool and at the joints, the damage was smaller or nonexistent.

There were no visible defects on the external rendering layer of ETICS following the hygrothermal tests. EPS insulation with a layer of horizontal MW strips, located within the solid wall and wall openings, showed reasonable resistance to the hygrothermal cycle. Results allowed for a safe prediction of ETICS behaviour when subjected to weathering and performance (over time). All tested systems showed satisfactory behaviour during and after accelerated artificial ageing, which indicated the fact that durability was ensured, especially given their difficult access for maintenance or replacement. This also increased its longevity, thus achieving a higher sustainability index. Therefore, high-quality ETICS present good durability overall, on top of their expected thermal performance.

The tests demonstrated only a slight variation in the temperature difference within the wafered wall panels ( $<1$  °C). This took place despite a clear temporary temperature difference on the surfaces in the areas of polystyrene and mineral wool, related to their density. Analysis of the measurement results showed that the horizontal strip of mineral wool used in the ETICS thermal-insulation system should not cause significant changes in the thermal-protection status of external walls in summer.

In conclusion, this study is a solid contribution to the existing body of knowledge related to similar studies of ETICS. Results satisfy energy efficiency and resilience in the modern building industry, and in attaining practical, long-lasting cladding systems for end users.

**Author Contributions:** All authors contributed equally to this work. All authors discussed the results and commented on the manuscript at all stages. R.N. and A.B. prepared the methodology of hygrothermal-behaviour testing and performed the experiments; P.K. and R.N. analysed the data and results. R.N. and V.B. wrote, supervised, and reviewed the paper. All authors have read and agreed to the published version of the manuscript.

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