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Increasing Construction Quality of External Thermal Insulation Composite System (ETICS) by Revealing on-site Degradation Factors

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Abstract

The installation of External Thermal Insulation Composite System (ETICS) enables to protect building envelope from natural weather effects and increase energy efficiency. As the system can be installed externally with simple work methods the usage is growing in European countries. The quality of the outcome is influenced by design, material selection, and on-site construction process. The on-site fixing process of ETICS is guided by numerous regulations and guidelines which have an insignificant impact on the actual construction technology. A list of Degradation Factors (DF) is created to classify the relevant on-site activities.
Categorised on-site Degradation Factors are basing on various studies, standards, and regulations set for products. The shortcomings are categorised in eight sets: substrate, mixtures, adhesive, insulation, anchors, reinforcement, finishing layer and auxiliary materials. Additionally, a field study has been conducted to test the occurrence of on-site shortcomings in Estonia. The collected measurements and observations did not reveal severe and systematic installation failures, but random deviations occurred in most layers which might lead to the degradation of ETICS.
The paper categorises on-site shortcomings which can lead to the loss of technical performance during the service life of the façade.

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Keywords: Degradation of facades; thin-layer rendering system; External Thermal Insulation Composite System; ETICS; construction process

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1. Introduction

Energy efficiency of the existing buildings can be increased by improving the external envelope of the building. One of the often used solutions in Europe is to install External Thermal Insulation Composite System (ETICS). The system can be applied externally with simple work methods. Each layer of the system is designated to provide particular value and has a significant role in the long-term durability. The outcome of the façade is influenced by numerous factors which alter the quality of the building[1]. Arising defects and reduced thermal properties of the building are related to on-site activities for 66% of the cases[2]. To evaluate the economic and technical impact of construction technology, on-site activities which modify essential characteristics need to be identified. The application process directly influences the calculated energy consumption, performance requirements and the technical properties of building materials. The conducted analysis identifies and categorises relevant activities which can alter the performance of the façade system.

2. The Field Study to test technology shortcomings on construction sites

Based on quality control requirements established by product manufacturers' guidelines a field study has been conducted to reveal additional on-site construction process shortcomings in Estonia. Seven buildings were selected, and observations repeated four times on each construction site during the autumn season which is the most problematic for facades. Although the layers of ETICS are installed and covered swiftly, the field study enabled to investigate the activities of craftsmen during the application of different layers.

The collected measurements and observations revealed no severe and systematic installation failures, but random deviations occurred in most layers. It can be pointed out that the characteristics of work methods are craftsmen specific and repeated by the person during the ongoing application. The most common shortcomings were:

- application during unsuitable climate conditions,
- increased gap width between insulation plates,
- reduced overlap of reinforcement mesh, and
- crossed joints of the insulation plates.

In autumn season of Nordic climate, the temperature might fall unexpectedly below zero degrees during night time, and the amount of rainfall is high. The applied thin layers have an increased risk of freezing, and the environment should be controlled to reduce the risk of unsuitable climate conditions. During the observations, it is noted that three facades from seven were covered with tarpaulin, and one of them was also heated. The results lead to the assumption that the potential risk of short-term freezing is relatively high.

Gaps between insulation plates affect the thermal resistance of the external envelope and cause reduced long-term resistance in the areas. During the field study, the gap width between insulation panels was measured, and the after treatment observed. The recommended gap width (2mm) was exceeded by most of the measured areas. 69% of them were filled with foam or wedge, 31% were left unfilled. Although the slightly wider unfilled gap has no significant effect on thermal conductivity, the intruding mortar causes different thermal expansion in the area increasing the risk of crack formation.

Occasional failures have been noted during the application of reinforcement layer. To ensure the ability to bypass tensions the overlapping of mesh should be at least 100mm, diagonal mesh placed on the corners of the openings, and the crossed joints for insulation plates avoided. Observations revealed that these requirements are mostly met, but individual shortcomings for each of the mentioned requirement were noted on the construction site. The layers of ETICS need to provide sufficient technical performance. If one layer in a given area has a critical shortcoming, a degradation will occur. To ensure economic and technical efficiency for the owner the occurrence of relevant Degradation Factors should be minimised.

3. Relevant on-site Degradation Factors

The on-site Degradation Factors (DFs) are classified by the layer of ETICS – substrate, adhesive, insulation, mechanical anchors, reinforcement and finishing layer. Common factors for mixtures and auxiliary details are considered separately.

3.1. Substrate

The existing exterior wall of the building should be able to resist the additional loads caused by ETICS and is responsible in large extent for the stability or adhesive characteristics of the system. The relevant on-site DFs are summarised in Table 1.

Layers surface conditions influence the adhesive bond between applied and existing materials. To provide sufficient adhesive properties and bear additional loads the substrate irregularities should be pre-treated. The minimum bond strength (0.08 N/mm^2) needs to be fulfilled to tolerate wind suction load, natural weight, hygrothermal loads, and internal movements of the structure[3]. The penetration rate of viscous fluids depends on various preparation works which aim to increase the access to pores[4]. Substrates with biological growth, dirt, oil or similar create an adhesion prohibiting layer while old paint can create a chemical reaction between the layers, causing loss of stability of insulation plates. Beside the adhesion properties, unfavourable climate conditions during construction process influence the physical properties of the substrate[5]. Humid substrates affect the cracking sensitivity, increase flexural strength (flexural strength) and bending modulus (flexural modulus) of the mortar[6].

Table 1. Degradation factors for the substrate preparation.

ID	Degradation Factor
S1	Substrate is covered with grease/oil
S2	Substrate is covered with dust/dirt
S3	Substrate is covered with biological growth
S4	Substrate is covered with paint or other material which can chemically react with adhesive
S5	Substrate is under required load bearing capacity
S6	Substrate has defects, detached areas or is uneven
S7	Smooth substrate surface or the adhesive is not suitable
S8	Substrate has low humidity
S9	Substrate is wet; internal moisture level is high

3.2. Common factors for mixtures

The properties of the mixtures depend on the ingredients, storage conditions and application process. The potential DFs for the mixtures are summarized in Table 2.

Table 2. Common Degradation Factors for mixtures.

ID	Degradation Factor
M1	Wrong material storage conditions
M2	The mixing procedures do not remove clots
M3	High share of kneading water
M4	Low share of kneading water
M5	High purity of kneading water
M6	Increased aggregate (i.e. sand) share
M7	Increased binder (i.e. cement) content
M8	Not recommended ingredients added to adhesive mixture
M9	Low temperature (freezing) during application and/or curing process
M10	Hot curing conditions
M11	Dry curing conditions
M12	Usage of winter mixtures if weather conditions are not suitable

Only laboratory tested specific ingredients are allowed to be added if the product manufacturer foresees it. The prefabricated mixtures are not authorised to be altered on site and preparation works need to hold the right dosage of kneading water and sufficient mixing process[7–9].

During the application process, it is important to follow the climatic conditions foreseen by the producer of the material. High temperatures lead to fast dehydration and cracking due to tensions caused by rapid shrinkage. Low temperatures cause frost damage, which can be seen if snowflake shaped minor cracks occur shortly after application. They result to detachment of layer.

3.3. Adhesive

Correctly applied adhesive layer reduces stability concerns of the whole sysem[10]. To limit the DFs, only insulations based on polystyrene and mineral wool are examined in this study. For the application of the adhesive mainly bead-point method is used for polystyrene based insulation and the full area is covered with mineral wool based insulation materials.

The bead-point method foresees that the insulation plate's border zones and the middle section are covered with adhesive. The size of adhesive should be between 40% to 100% depending on the type of fixture (bonded and/or fixed) and insulation material. The possible DFs are summarized in Table 3.

If it is required to cover the full area (bonded ETICS) or the substrate layer is very smooth, treatment with notch towel should be conducted to be able to level the substrate unevenness[3]. It ensures the needed bond strength and prevents the bowing out of the insulation plate if the application is carried out with enough pressure. Without the pressure, the adhesion strength between adhesive and substrate will be too weak due to hollow areas.

The middle adhesive dots (bead-point method) prevent the arching out, which can cause a crack formation near the edges, slightly inner the side. Summer season increases linear thermal expansions and affects the aspect of stability. The adhesive on the borders prevents the bending out of the sides, which causes crack formation directly on the edge of the plate. During the winter season, peeling stresses in adhesive layer are higher than in summer, and thermal effects increase tensions near the edges. Additionally, correct adhesive installation prevents airflow behind insulation, improving safety in case of fire[11].

If an insufficient amount of adhesive is applied during the construction process, the stability of the system is reduced while increased adhesive area can decrease the soundproof properties up to 3dB[3].

Table 3. Degradation factors of the adhesive layer.

ID	Degradation Factor
D1	Missing insulation on the edges (polystyrene)
D2	Missing insulation in the centre (polystyrene)
D3	Insufficient adhesive
D4	Adhesive not rubbed into insulation plate (mineral wool)
D5	Adhesive is not treated with notch towel
D6	Increased area covered with adhesive
D7	Working time of the adhesive is exceeded
D8	Lack of pressure during application of insulation plates
D9	Large unevenness of the adhesive layer

3.4. Insulation

The characteristics of the insulation material influence mainly the thermal conductivity of the façade. Shortcomings in the construction technology shown in Table 4 can additionally alter to a significant extent the stability of the system and corrosion protection characteristics. The properties can be modified with UV-Radiation, short drying-out period, usage of wet material or by shortcomings during application activities.

After the first months of production of the product, moisture diffusion initiates the shrinking process. To avoid cracking the insulation plates must have finished the diffusion process[3]. If the materials get wet during storage or application, the moisture will be trapped in the system for a longer period, and internal moisture decreases expected corrosion protection[12]. The drying-out period is depending on vapour diffusion resistance of the system and is causing the reduction of pull-off strength after the first four months of application and reduce adhesion properties[13]. Laboratory tests show that the drying-out period might last up to 12 years[14]. Usually, the duration of drying out period of mineral wool in ETICS is up to six months and up to two years polystyrene based insulation. Internal moisture level determines the activation of corrosion protection. Besides wetting, exposure to UV radiation alters the material structure on the exposed side reducing adhesion.

Table 4. Degradation factors for insulation material application.

ID	Degradation Factor
I1	Material is exposed to UV-radiation for a longer period
I2	Insulation plates are installed shortly after manufacturing
I3	Wet insulation plates
I4	Continuous gaps between substrate and insulation material (opened to air entry)
I5	Insulation plate vertical joints are crossed or too close
I6	Corners of the openings have crossed joints
I7	Insulation plates joint width is too wide or not aligned
I8	Height difference between insulation plates
I9	Broken areas of the insulation plates are not filled
I10	Missing or too narrow fire reluctant areas

During the installation process, the crossed joints between insulation plates should be avoided as they cause gaps between insulation plates and increase the risk of height difference. The height difference creates thinner layers in reinforcement layer and the risk of cracking increases. Gaps between insulation plate joints should be avoided by installing the plates tightly next to each other. If gaps are present, the mixture fills the areas to some extent, causing thicker layer in the particular region, resulting cracks due to the shrinking of materials[3].

3.5. Mechanically fixed anchors

The performance requirements set for mechanical anchors can be altered by using an unsuitable anchor or by the poor application. The DFs are presented in Table 5. Mainly plastic anchors which have a screw or a nail as expansion element are used. To bear wind suction load calculated amount of anchors, with specified length and load bearing class need to be used. As a secondary effect, it is also noted that the increased number of mechanical anchors decrease the soundproofing of the system in some extent[3].

Table 5. Degradation factors for insulation material application.

ID	Degradation Factor
A1	Increased diameter of drilled anchor hole
A2	Decreased diameter of anchor plate
A3	Decreased amount of anchors
A4	Increased amount of anchors
A5	Location is not as foreseen
A6	Anchor plate is installed too deeply into insulation material
A7	Anchor plate is placed too high
A8	Amount of anchors is not increased in the corners
A9	Unsuitable anchor type
A10	Hole of the anchor is not cleaned

During the application process, a decreased depth of an anchor hole can cause height difference of the anchor plate. In the case when the plate lies on the higher level, decreased render thickness will dry out faster in comparison to other areas. During repeated wetting and drying the durability will decrease to 10 years as the hygrothermal tests have shown[3]. Frictional strength between the cavity wall and the anchor can be influenced by increased diameter of drilled anchor hole or no dust removal.

3.6. Reinforcement layer

The stresses caused in the system are transmitted to the reinforcement layer and in the applied mesh. The ability to transmit stresses can be modified during mesh or mortar application with DFs summarised in Table 6.

The stresses can be directed successfully only if the mortar fills the inner areas of the net. During the installation process, the layer should be applied in wet to wet conditions and the mesh should be pressed into the mixture. The covering layer should be installed shortly, as the mixture is not cured to prevent separation of layers[3]. During construction works, it is needed to spectate whether the mesh is free of folds, not broken not without hollow areas. Compatible meshes with enough overlapping are necessary. Otherwise the ability to resist to occurring tensile forces is harmed.

Diagonally placed additional nets should be applied on the corners of openings as notch stresses occur. The supplementary mesh should be installed together with the main mesh and covered as usually in not cured conditions (wet to wet). In the circumstance of missed mesh, diagonal cracks occur[3].

Table 6. Degradation Factors of the reinforcement layer.

ID	Degradation Factor
R1	Too smooth external layer of the insulation plate
R2	Decreased overlap of the mesh
R3	Folded mesh
R4	Missing diagonal mesh
R5	Mesh not filled with mortar, unsuitable placement in the layer
R6	Thin mortar layer
R7	Layer is not applied in wet to wet conditions
R8	Not compatible mesh is used

3.7. Finishing coat

The external layer is beside aesthetic function responsible for weather protection. Natural conditions comprise of a combination of effects - the wind, rain, pollutants, relative humidity, temperature and solar radiation[15]. As failure occurs, water penetrates into the system and causes moisture-induced problems. Possible construction technology related DFs are summarised in Table 7.

Table 7. Degradation Factors of the finishing coat.

ID	Degradation Factor
F1	Missing primer
F2	Reinforcement mixture or primary coat is not cured
F3	Thick render layer/ differences in thickness
F4	Thin render layer (thinner than single grain diameter)

The cracks can be considered dangerous if they are 0.2mm wide for polystyrene based insulation and 0.3mm for mineral wool based insulations[3]. To prevent crack formation, a primer should be applied if the system producer requires it. It ensures the necessary adhesive properties between render and reinforcement layer. In the case of failure the reduced adhesive properties detaching can occur due to capillary water uptake and storage between the layers.

The application process is important to follow the required climatic conditions and thickness of the layer. Increased thickness and high temperatures lead to fast dehydration and cracking due to tensions caused by fast shrinkage.

3.8. Details and specific regions

Specific technical solutions for particular areas of ETICS are developed rapidly by product manufacturers, and an increased amount of technical installation options are provided by the product manufacturers or by the designers. To reveal a comparative overview of problematic areas in the further research the construction technology related problems of auxiliary details and specific regions are summarised in Table 8 in a more holistic perspective.

Table 8. Degradation Factors for specific details.

ID	Degradation Factor
X1	Structural expansion joint is not installed/finished properly
X2	Windowsill is not finished properly (i.e. curved upwards, proper sealants)
X3	Unsolved rainwater drainage (i.e. drainpipe or drip profiles not used)
X4	Fixed frame connection is not finished accurately (i.e. missing sealants)
X5	Roof edge covers are not installed properly (i.e. vertical detail too short)
X6	Shock resistance solution is unsuitable (i.e. no double reinforcement mesh, corner details with metal or additional protective plate installed)
X7	Unfinished penetrations through the system (i.e. fixed without sealants)
X8	Plinth details are not installed properly (i.e. incorrect fixing, overlapping of details, protruding from render)

The areas to be evaluated are structural expansion joints, windowsills, rainwater drainage, fixed frames, roof edge covers, plinth details, penetration through the system and solutions for shock resistance. The summarised DFs consist of the most problematic areas of the façade which have an impact on the performance. The auxiliary details should be planned and applied in a way that water could not penetrate into the system, and internal tensions do not harm the layers. Therefore, during the design and construction works the holistic requirements set for the system should be met.

4. Conclusions

Each layer of ETICS needs to fulfil specific requirements while the performance of the layer can be altered by material selection, design, and on-site construction activities. Shortcomings during construction often cause defects on the facade or reduced thermal efficiency of the building. To reveal most relevant on-site shortcomings the lists of Degradation Factors is proposed by the applied layers. Each of the DF has an impact on the system performance and should be conducted with care. Critical shortcomings during construction process can lead to the loss of technical performance during the service life of the façade and have an economic and social impact to the owners. By revealing the on-site Degradation Factors, it is possible to evaluate the technical and economic relevance of each factor. The knowledge enables to improve the quality of on-site construction process.

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