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Review paper

THERMAL BRIDGES AS INDICATORS OF INSTALLATION DEFICIENCIES IN ETICS FACADES

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Abstract

External Thermal Insulation Composite Systems (ETICS) are widely utilized to increase the energy efficiency of buildings by minimizing heat loss through exterior walls. However, when improperly installed, thermal bridges are formed, significantly decreasing the overall thermal performance of the façade system. This study aims to identify installation defects in ETICS facades by characterizing thermal bridges and their impact on energy performance. The selection of infrared thermography as the primary technique for detecting thermal bridges was based on its ability to reveal surface temperature variations quickly. In-situ thermographic examinations were performed on a case study edifice to discern prevalent installation deficiencies. This inquiry offers a methodical framework for identifying and scrutinizing ETICS installation shortcomings through thermographic imaging, thereby providing valuable insights for enhancing insulation methodologies. The investigation disclosed that thermal bridges predominantly manifested at the junctures of walls and floors, around window apertures, and at points of external element attachment, culminating in increased thermal losses, condensation issues, and risks of mold proliferation. The evaluation of the recognized deficiencies underscored a pressing necessity for elevating installation quality control measures and rigorous compliance with established protocols. The research outcomes underscore a fundamental imperative for amalgamating inspection strategies with preventive measures to bolster the energy efficiency and longevity of ETICS facades. Prospective research endeavors should concentrate on the advancement of detection methodologies.

Key words: *ETICS facades, thermal bridges, infrared thermography, installation deficiencies, energy performance*

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1. INTRODUCTION

Improving the energy efficiency of the external walls of buildings is most often achieved by applying an external thermal insulation system (ETICS) [1]. This system is widely accepted due to its affordable price, easy installation, and effective reduction of heating and cooling needs. The long-term performance of ETICS depends on the materials' thermal properties and the installation quality. Errors can lead to breaks in the insulation layer, reducing its efficiency and creating thermal bridges that impair the energy performance of the building [2].

Thermal bridges allow increased heat transfer through the facade, which leads to more significant heat losses and increases the risk of condensation and possible damage to structures [3]. These problems often occur due to incorrect insulation installation, inadequate installation, or deviations from the prescribed work standards. As a result, the facade system may degrade more quickly and provide lower energy savings than expected.

This paper investigates how installation deficiencies contribute to the formation of thermal bridges in ETICS facades and considers possible solutions to reduce these phenomena. The research combines theoretical analyses of thermal bridges as indicators of installation deficiencies in ETICS facades at the Cultural Center in Pirot, Serbia. Infrared thermography was used as the primary diagnostic method, allowing for the visualization of temperature anomalies and identifying critical areas on the facade.

The research results indicate the importance of proper installation procedures and regular inspections as key factors for the long-term and efficient operation of ETICS facades. Special emphasis is placed on the need for preventive quality controls, both in the design and construction phases, to reduce the adverse effects of thermal bridges.

Although previous research has analyzed the impact of thermal bridges on energy efficiency, few studies systematically link specific construction errors to anomalies detected by thermography. This paper fills this research gap by analyzing real-world examples of irregularities and their thermal consequences.

2. THEORETICAL BACKGROUND

2.1. Mechanisms of heat transfer and thermal bridges

Thermal bridges arise when discontinuities in the insulation layer or structural components establish a conduit for heat transmission, circumventing the designated thermal insulation barrier [4]. The vulnerabilities, characterized by markedly decreased thermal resistance compared to adjacent materials, result in heightened heat transfer and localized temperature fluctuations [5]. The leading causes include direct conduction through high thermal conductivity materials and convective losses at junctions. Depending on the shape, thermal bridges can be linear (e.g., wall-to-slab joints), punctate (e.g., fixing anchors), or surface discontinuities (Figure 1).

In addition to energy losses, thermal bridges can cause condensation on surfaces and the development of mold, which poses a risk to the durability of ETICS facades [2]. If moisture accumulates inside the system, materials can deteriorate over time, threatening both insulation performance and the structural stability of the building [6]. Therefore, the precise installation of the insulation is crucial, especially at the joints where the continuity of the thermal insulation is most vulnerable.

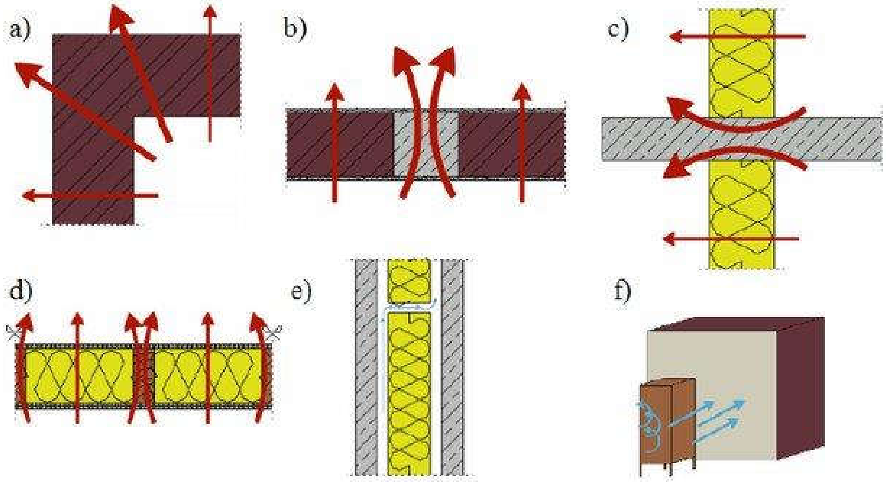

Figure 1. Types of thermal bridges: a) Geometrical, b) Material, c) Structural, d) Periodically repeating, e) Convective, f) Environmental dependent [7]

Various measures are applied to reduce thermal bridges in buildings, where it is crucial to pay attention to the critical points of the construction where heat losses are most pronounced.

One of the practical approaches is careful planning of thermal insulation, where special attention is paid to places where there may be a break in the continuity of the insulation layer [8]. Systems with a continuous layer of thermal insulation, such as ETICS facades, enable the reduction of thermal bridges by preventing breaks in the insulation [9].

Furthermore, architectural solutions play a crucial role as well. Correct positioning of openings can reduce the risk of thermal bridges at the joints of the facade and windows. Also, using quality facade joinery, such as windows with double low-emissivity glass and thermal breaks in the frames, additionally improves the insulating properties of these elements [10], [11].

In recent approaches, modern materials, such as airgel with extremely low thermal conductivity, enable even more effective protection against heat loss. However, their correct placement and the choice of materials are also crucial. The precise installation of the insulation prevents the creation of cracks and inconsistencies that can impair the building's energy efficiency. In addition, appropriate processing of joints and penetrations through the facade can significantly reduce the occurrence of localized heat losses.

Various control methods are applied to ensure the quality of the work performed, including infrared thermography, which enables the detection of problematic points at an early stage of the building's exploitation. In addition, computer simulations and optimization of design solutions help choose the most efficient combinations of materials and construction solutions, contributing to the long-term energy efficiency of buildings [12].

2.2. Common installation deficiencies in ETICS facades

One of the key challenges in achieving the continuity of thermal protection of buildings is the inadequate execution of details, where local thermal bridges most often occur due to insufficiently covered surfaces with insulation, poor joints around openings, and improperly designed structural connections [13]. Such leaks not only impair the building's energy efficiency through increased energy consumption but also contribute to the creation of conditions suitable for the occurrence of condensation and the development of mold, which further endangers the quality of the indoor environment and the health of users.

Systems of contact facades with mineral wool thermal insulation represent a modern approach to improving the energy characteristics of external walls, both in new and existing buildings. These multi-layer compositions combine several functional requirements: they provide effective thermal and sound insulation, high fire resistance, and good vapor permeability, thus creating a healthier and more energy-efficient environment; whether stone or glass wool, mineral fibers are key in stabilizing the building's thermal regime and increasing acoustic comfort.

The ETICS system can achieve the expected performance only if it is applied according to a carefully defined technological procedure, which includes substrate preparation, correct adhesive application, precise installation and mechanical fastening of thermal insulation boards, and final surface reinforcement (Figure 2). Each of these stages has a decisive influence on the final quality of the system and its long-term reliability.

Figure 2. Execution Elements of an ETICS with Mineral Wool [14]

The preparation of the substrate is a key initial step in the installation of the contact facade and includes the removal of all impurities, leveling the surface, and checking the load-bearing capacity of the walls. In cases where the substrate is absorbent, a primer is recommended to improve the adhesion of the adhesives. The glue is applied along the edges and in the central part of the thermal insulation boards, where it is necessary to ensure a minimum contact area of 40%. The installation is carried out horizontally, from the bottom up, whereby the outer side of the higher-density board should face outwards, opposite to the direction of the dominant wind. Special attention should be paid to the correct arrangement of the joints between the plates to avoid creating linear thermal bridges. Cross-stacking the thermal insulation elements is recommended for additional static stability of the system in the corners of the building.

Frequent mistakes in practice are related to improper installation of thermal insulation boards, poor sealing of joints, and pronounced thermal conduction at the places of mechanical fastening [15]. Such failures significantly reduce the insulation effect and contribute to the increase in energy losses [16].

Mechanical fastening with dowels is an essential step in ensuring the stability and durability of the system, especially when using stone wool, which is heavier than other types of insulation. The dowels are installed after the glue has been set, and their number and arrangement depend on the object's height and exposure to the wind. In standard conditions, installing about six dowels per square meter is recommended, while in the edge zones and the case of multi-story buildings, this number increases. Dowels are inserted into pre-drilled holes and installed by hammering or screwing, depending on the type, with mandatory alignment with the surface of the insulation to prevent the formation of spot thermal bridges. The correct selection of dowels relies on the substrate type and the insulation thickness, and each dowel must penetrate at least five centimeters into the load-bearing wall. Plastic dowels with a metal core and a broad head are recommended for better load distribution for stone wool.

The surface is strengthened by applying a polymer-cement adhesive into which a glass mesh is pressed with an overlap at the joints. This reinforcement significantly contributes to the mechanical resistance of the system and prevents the occurrence of cracks. After the base layer of glue dries, the final decorative plaster—silicone, acrylic, or mineral—previously prepared with a suitable primer, is applied. The correct installation of dowels and mesh ensures not only the functional stability of the system but also its long-term resistance and aesthetic quality.

Doweling has a significant role in contact with facade systems because improper installation can lead to the separation and collapse of parts of the facade. Proper selection of dowels, their exact position, and installation following technical requirements contribute to the safety and durability of the entire system. It is recommended to carry out a pull-off test, which checks the bearing capacity of the substrate and determines the force required to pull out the dowel, thereby confirming its adequacy. At the same time, there must be a mass of glue under each dowel to prevent moisture retention and the appearance of additional thermal bridges.

3. METHODOLOGY

Infrared thermography was used as the primary diagnostic method for detecting irregularities in the performance of the ETICS facade system, as it visually displays temperature differences on the surface, thereby clearly identifying potential thermal bridges and installation errors [17]. Thermographic tests were carried out using a FLIR infrared camera, model B20 PAL, where the emissivity value was set to 0.95, ensuring accuracy in detecting thermal anomalies on the contact facade.

The measurements were carried out during winter since there is a pronounced temperature contrast between the interior and exterior space, enabling a more precise visualization of irregularities. The recordings were made at night under stable external conditions to eliminate the influence of solar radiation and wind on the temperature readings. The process previously included stable heating of the interior space of the building to achieve a sufficient temperature difference between the interior and the outer shell of the building.

The contact facade of the House of Culture in Pirot, immediately after the recent rehabilitation, was analyzed. The inspection is focused on the characteristic points of joints, such as the joints of wall and mezzanine constructions, window frames, and places of mechanical fastening, since in these zones, the most common are the leaks that lead to the formation of thermal bridges [18]. Temperature differences greater than 2°C concerning neighboring zones were considered a threshold for identifying a performance error. In addition to quantitative readings, a qualitative analysis of thermographic patterns was also applied, and temperature irregularities associated with specific failures in assembly were observed.

The results were systematically compared with the reference guidelines for correctly installing the ETICS system to identify frequent errors such as incorrect installation of the thermal insulation layer, discontinuities in thermal protection, and inadequate fastening technique. In this context, infrared thermography has proven to be a handy tool for diagnostics and quality control of performed works, offering a reliable basis for preventing errors and improving the system's energy efficiency.

4. RESULTS AND DISCUSSION

4.1 identified deficiencies and their impact

Thermal bridges are most often identified at the points of joints and penetrations through the facade system, where there is a significant increase in heat losses and an increase in the building's heating needs. Thermographic analysis indicated the presence of pronounced thermal anomalies in the area of the fastening points and along the perimeter of the window openings, which means inadequate covering with thermal insulation and omissions in execution. The observed deficiencies contribute to increased heat loss and the risk of condensation, especially in the winter [19].

Additional analysis of the available photo-documentation and technical reports indicated several irregularities that led to the partial collapse of the facade of the House of Culture in Pirot carried out in the ETICS system. Among the key causes, inadequate preparation of the substrate was singled out, whereby basic mechanical operations, such as rough treatment ("scratching" or "etching"), necessary to ensure adequate adhesion, were not carried out. Of particular concern is that the thermal insulation system was applied directly over the wall and painted with an acrylic mural without prior treatment, which seriously impaired the stability and adhesion of the layers of the system.

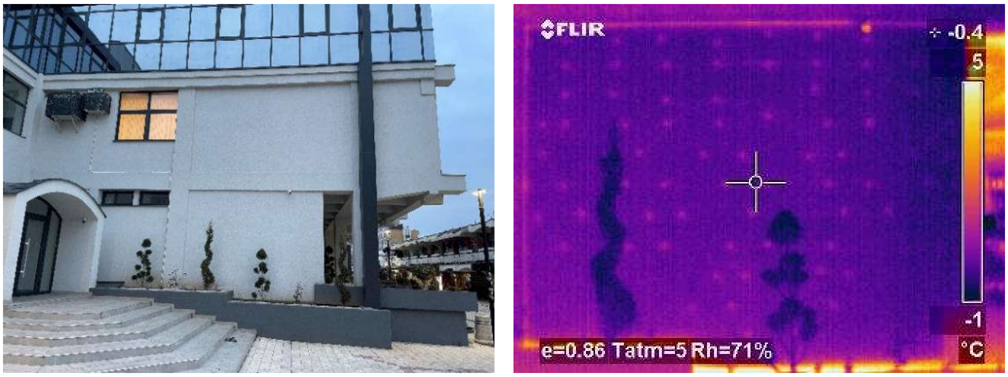

Figure 3. Part of the South-East Façade and Its Thermographic Image

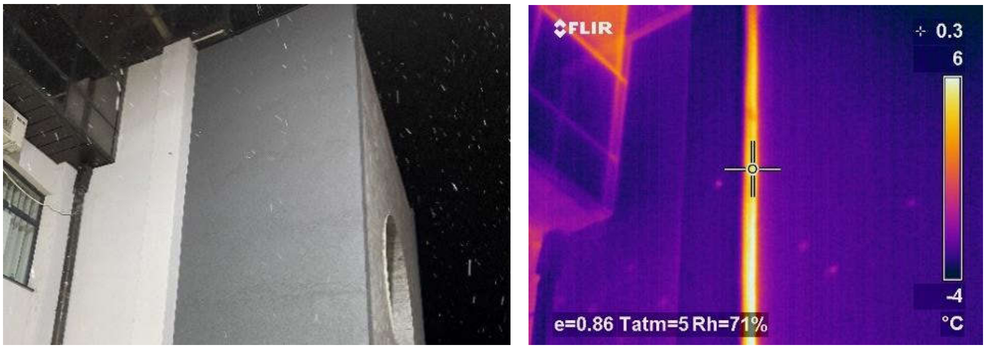

Figure 4. Part of the North-West Façade and Its Thermographic Image

The photo-documentation additionally indicated the improper application of the glue on the thermal insulation boards made of mineral wool, which resulted in uneven adhesion and weakening of the adhesive properties of the facade system (Figure 3). Inadequate installation of panels in the corner area of the building was observed without applying the so-called "binding" (alternate overlapping), which resulted in the structural weakening of the facade covering in critical places (Figure 4). Improper processing of edges and corners, as well as incorrectly placed reinforcing mesh, additionally contributed to the reduction of mechanical resistance and overall stability of the system.

One of the most serious omissions is reflected in the complete absence of doweling, which is the essential structural element for the mechanical fastening of thermal insulation boards. Thermographic images clearly showed the lack of dowels on specific facade segments, jeopardizing the system's resistance to external influences and long-term stability. According to the basic technical standards, installing dowels is a mandatory measure to achieve durability and reliability of the ETICS system, and their absence is considered a gross failure in the execution of works (Figure 5).

Figure 5. Part of the North-West Façade and Its Thermographic Image

The absence of technical and certification documentation made it even more challenging to analyze the state of the facade system. The attached documentation did not contain data on the installed components or confirmation of their mutual compatibility, which indicates the possibility of using non-compliant materials. Such practice is contrary to European standards, which require the application of system solutions with certified components from one manufacturer.

The identified irregularities point to systemic deficiencies in the preparation of the substrate, the installation of thermal insulation boards, and the general quality of the work performed, which resulted in the partial collapse of the facade. Based on the findings, it is recommended that the critical parts of the facade be reconstructed with strict adherence to project documentation.

The research results indicate that the prevention of the appearance of thermal bridges in ETICS facades depends on precisely defined installation methods and planned thermographic inspections. Previous research confirms that the combination of infrared thermography and field measurements represents a key diagnostic method for detecting construction errors and assessing their impact on the energy performance of the building [20], [21]. The findings indicate the need for stricter quality control measures during construction and post-construction inspections to minimize the effects of thermal bridges. Advanced anchoring techniques and improved joint sealing practices are recommended [13].

5. CONCLUSION

This study points to the key role of proper installation in reducing thermal bridging in ETICS facade systems. Effective control and timely detection of irregularities through precise detection methods must be integral to every project to ensure greater energy efficiency and a longer service life of the building's outer envelope. Thermal bridges are visible indicators of performance failures, which significantly impair the thermal characteristics of the building. Improving energy efficiency requires immediate repair of existing defects and prevention of long-term deterioration of the facade system. The systematic introduction of thermographic tests following the guidelines for proper installation should become a standard procedure in the execution and quality control phase.

Infrared thermography has proven to be an extremely effective diagnostic tool for detecting problems arising during the performance of the ETICS system. Defects invisible to the eye, such as poorly applied glue or insufficient thermal protection, become visible thanks to thermographic images. These analyses enable the timely detection of irregularities and thus become irreplaceable in the quality control of performed works. Identifying fundamental installation problems using thermography creates conditions for developing long-term solutions that reduce energy losses and improve the thermal characteristics of the facade.

Although surface irregularities were quickly detected by thermography, more precise information on heat losses was obtained by in situ measurements. Numerical simulations that followed the field tests further confirmed the observations and enabled the prediction of energy performance in the long term. Based on the results of this research, the systematic application of the thermographic method as part of regular inspections of ETICS facades is recommended. Future directions of research should be focused on the improvement of detection methods and the adoption of advanced performance techniques. Additionally, efforts should be directed toward developing higher-quality thermal insulation materials that are less prone to forming thermal bridges.

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