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Novel High-Performance ETICS Coatings with Cool Pigments Incorporation

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Abstract: External Thermal Insulation Composite Systems (ETICS) enhance building aesthetics and optimize thermal performance while offering protection against weather, fire, and harmful agents. Key to these capabilities are properties of ETICS rendering. We have applied specialized organic renderings, including modified acrylic resins, additives, and reflective pigments, to mitigate color bleaching and stress cracking induced by high surface temperatures, resulting in improved color stability and water protection. In a practical application at a shopping center in Portugal, we observed reduced coating layer failures, better thermal resistance, and lower maintenance costs over one year. Subsequent research reveals the benefits of Near Infrared Reflective (NIR) pigments and nanocomposites such as titanium dioxide, which increase solar reflectance, enhance resistance to dirt, and promote self-cleaning. Synthetic colored inorganic pigments improve heat stability, thermal inertia, and mechanical resistance. The application of cool pigments also reduces surface temperature by up to 10 °C. These advancements in ETICS technology mark a significant step towards sustainable building practices.

Keywords: walls refurbishment; ETICS cool pigments; in-service performance; reduced maintenance cost; walls durability

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1. Introduction

The ETICS (External Thermal Insulation Composite System) is a widespread technology used for building facades insulation in all EU countries and has proven in the last sixty years to be a reliable method to increase energy efficiency both for new construction and renovated buildings, allowing a quick and relatively inexpensive installation with good results in terms of durability and thermal properties duration [1]. According to data from Euroconstruct, the area of building facades in the Portuguese market represents 15 million m^2, with 10% of that amount referring to the tertiary sector in service buildings [2]. In this sector, the application of ETICS corresponds to 450,000 m^2, with a long-term growth trend. These systems are composed of a range of materials chosen for their distinct thermal and mechanical properties and typically include an insulation layer, often made from expanded or extruded polystyrene, mineral wool, or polyurethane foam [3]. The insulation layer is fixed to the exterior wall using either a mechanical fixing or adhesive, or a combination of both [4]. Above this, a base coat (or render) is applied, commonly composed of cement or acrylic, embedded with a reinforcing mesh for added strength [5]. The system is finished with a protective top coat, which can be textured or smooth and colored as per aesthetic requirements [6].

The building's facade contributes to most of the heat losses through the envelope; therefore, ETICS solution is an effective technology to increase energy efficiency [7]. Since the facade is an essential part that contributes to the building's overall performance and value, its design must comply with functional requirements related to safety, comfort, and durability, stipulated by national and European regulations [8]. In order to fulfill the new code requirements, the "business as usual" methods for ETICS insulation are progressing in terms of complexity and performance, driven not only by new legislation put into force but also by the new challenges, which result from architectural options in constant evolution [9]. This driving force pushes the development of new improved ETICS technologies, designed to reduce emerging pathologies related to poor design and bad execution, preserving durability and conserving properties related to fire resilience, thermal performance, weather resistance, acoustics, and water resistance [4]. The problem with conventional ETICS is the tendency for color bleaching and stress cracking caused by high surface temperatures [10]. This leads to reduced aesthetic appeal and can compromise the protective properties of the system. The solution we propose involves the application of specialized organic renderings that include modified acrylic resins and reflective pigments. The modified acrylic resins improve stress cracking resistance, while reflective pigments help lower surface temperature, reducing color bleaching [11]. This combined approach enhances the color continuity, waterproofing, and overall durability of ETICS.

Based on this, new ETICS formulations must be designed to tackle pathologies associated with the inadequate selection of materials and the poor quality of their in situ application but also related to the lack of an adequate maintenance program [12]. These constraints are a challenge, not only for applicators but also for the manufacturers, designers, and other participating bodies (authority, owner, and building constructors) [13]. It is extensively tested that under conditions of correct and rigorous in situ application, along with an adequate maintenance program, the ETICS is expected to have a service life of 25 to 30 years [12,14,15]. There is also a broad consensus that for the ETICS, the characteristics of the finishing coatings are particularly relevant to the final performance of the facade since tiny failures in design methods and craftsmanship may result in rendering flaws [16]. The performance of a facade is determined by several key physical properties [17]. Thermal resistance, a primary metric, indicates how well the facade can minimize heat transfer, thus lowering energy costs. Waterproofing quality prevents moisture infiltration, reducing risks of structural damage. Fire resistance is also paramount, preventing flame spread and reducing fire risks. Lastly, facade aesthetics, which includes color stability and resistance to stress cracking, directly impacts the building's visual appeal.

For many years, the use of dark colors in conventional organic rendering led to surface cracks and several coating shortcomings, due to the high temperatures reached by the rendering as a result of major solar absorption [18]. Dark color finishing coatings will lead to cracking, permanently damaging the ETICS [19]. With the emergence of cracking, water will start penetrating the thermal insulation and the wall facade, affecting the system's performance, causing the surface coating to detach, among other construction pathology scenarios, therefore compromising the overall performance [20]. The emergence of new-generation organic rendering based on modified acrylic resins, specific additives, and cool or reflective pigments allows for mitigating anomalies related to color loss and generalized cracking due to high surface temperature, improving the stability of the color as well as its waterproofing [21,22]. For instance, when cool pigments were incorporated, the surface temperature dropped by up to 10 °C, significantly improving thermal performance. Traditional ETICS failures were reduced by approximately 30% after adopting modified acrylic resins in our study. Moreover, we observed a 20% improvement in thermal resistance, which led to an estimated 15% decrease in energy costs, contributing substantially to both financial and environmental sustainability.

The NorteShopping Mall in Matosinhos, North of Portugal, was subject to a recent facade renovation using new-generation organic ETICS renderings, based on modified acrylic resins with cool pigments. The rehabilitation works were finished in 2020 and after 1.5 years of being taken into service, an experimental study was conducted to assess the facade performance derived from exposure to severe sun radiation conditions. The renovation works were planned to meet both aesthetic and functional performance requirements, the latter related to strengthening the ETICS fire behavior as well as the facade thermal performance. The adoption of a rough texture identical to that of the original panels was also a mandatory demand to be met so that the original facade appearance could be kept. In order to meet the referred functional performance, a new ETICS solution was developed, composed of a high-density 60 mm-thick glass wool panel fixed directly to a solid substrate with a reaction to fire classification of at least class A2-s1,d0 (EN 13501-1) and a fire integrity at least equal to B-s1,d0 (EN 13501-1).

The coarse texture of the ETICS rendering was implemented according to the original facade panels' texture, and it was developed by using a specific mortar formulation based on aerial lime binders, hydraulic binders with calcined clay with pozzolanic effect and low cement content, organic binders, fibers, water repellents and fillers, tested according to the standard EN 998-1:2016—Specification for mortar for masonry. Part 1: Rending and plastering mortar. The finishing end of ETICS rendering was applied by using a primer and a colored finish applied over the textured coating consisting of acrylic resins modified with cool pigment technology. The primer is an essential element of the finishing solution as it acts as an element that protects the final painting from alkalinity coming from the support rich in lime, making the painting compatible with this substrate. As stated, a year and a half after the application of the facade rehabilitation solution, the objective of this study is to evaluate the in situ performance of the implemented rehabilitation solution by carrying out a set of performance tests.

The main objectives of the present article are to present a case study of a recently renovated facade of the NorteShopping Mall in Matosinhos, North of Portugal, using a new-generation organic ETICS rendering based on modified acrylic resins with cool pigments. The study aims to assess the facade's performance in severe sun radiation conditions after 1.5 years of being put into service. The article discusses the challenges of designing and implementing effective ETICS solutions to improve energy efficiency and comply with safety, comfort, and durability regulations. It also emphasizes the importance of selecting appropriate materials, ensuring correct in situ application, and adequate maintenance to prevent pathologies such as cracking and detachment, which can compromise the system's overall performance. The article aims to contribute to the development of improved ETICS technologies that preserve the system's properties related to fire resilience, thermal performance, weather resistance, acoustics, and water resistance, among others.

2. State of the Art on the Incorporation of Cool Pigments in ETICS Coatings

2.1. Advancements in Enhancing the Performance of ETICS

The ETICS consists of specific mortars and a set of complementary previously tested accessories, with its compatibility validated through an ETA guideline (European Technical Approval) [23]. Additionally, the guidelines set out in the ETAG 004 specification aim to specify the functional performance that the ETICS system must guarantee so that it can be used as external insulation for building walls [24]. Focused on the system performance, the ETAG 004 specification prescribes methods for evaluating ETICS assessment under different design scenarios as well as distinct in situ applications, highlighting for both situations the importance of visual comfort, such as surfaces without cracks, detachments, or loss of homogeneity in brightness and color, and surface regularity, with flat surfaces, joints and, straight edges [4]. The selection of dark colors can lead to premature aging of the ETICS coating, just like cracking and loss of color [25]. On the other hand, the choice of light colors, even if the formulation of the coating includes fungicide agents, can lead to the occurrence of leachates, favoring the appearance of fungi and algae [26]. To prevent premature aging, ETAG 004 specification considers 80 °C the maximum surface temperature for any ETICS coating. However, the new EAD 040083-00-0404 standard, which replaces the ETAG 004 specification, does not refer to this practical recommendation [27]. On the other hand, the EAE (European Guideline for the Application of ETICS) recommends a minimum value for solar reflectance between 0.2 and 0.3, restrictions which have led to the frequent use of light colors on ETICS facades [28]. As a general rule, traditional ETICS coatings are essentially organic based, relying on conventional pigments and resins, showing strong limitations in terms of resistance to the proliferation of fungi and algae, color stability, and the possibility of using intense colors on facades [29].

By incorporating Near Infrared Reflective (NIR) pigments that have high solar reflectance (TSR—Total Solar Reflectance), the use of intensely colored coatings can reduce solar absorption and increase the durability of the ETICS coating [30]. The addition of nanocomposites such as the inorganic pigment TiO_2 (titanium dioxide), for example, reinforces the surface solar radiation reflection, improves resistance to dirt, and stimulates the self-cleaning effect [31]. The Synthetic colored inorganic pigments (CICP—Complex Inorganic Color Pigments) show high performance at high temperatures due to their ceramic nature, increasing the coating's heat stability, thermal inertia, and mechanical resistance [32]. It has been widely reported that the application of cool pigments increases the facade coating's TSR value, enabling a reduction in surface temperature of 10 °C [33]. In the same direction, other studies state that applying similar pigments (CICP) in the ETICS surface coating composition of intensely colored facades enables an increase in the TSR to near-infrared radiation, between 0.16 and 0.38, avoiding the increase in surface temperature for the southeast and southwest facade orientations at a value greater than 55 °C [34]. Identically, the use of cool pigments allows for reducing the cooling energy consumption of residential buildings by 10 to 20% [35]. Experimental assessment by using infrared thermography allows us to conclude that the surface temperature of a facade coated with reflective paints of intense colors, with the incorporation of cool pigments, can decrease to 11 °C [36]. Moreover, it is reported that the application of cool pigments can reduce the energy consumption of buildings, mainly in tropical regions with strong sun radiation, emphasizing the use of specific pigments such as iron oxide (hematite) with titanium dioxide [37]. Specific investigations included laboratory tests on the pigment's composition and the powder's morphology by using X-ray powder diffraction (XRD by the powder method), scanning electron microscopy and transmission electron microscopy and showed that titanium oxide delayed the crystallization of the iron oxide, enhancing NIR reflection [38]. It is well documented that the impact of incorporating near-infrared radiation reflection pigments in ETICS coatings can lead to color stability by increasing the durability of the rendering.

As demonstrated, several studies have been conducted regarding the application of various techniques to enhance the performance of the External Thermal Insulation Composite System (ETICS) [39,40]. These techniques include the use of Near Infrared Reflective (NIR) pigments, synthetic colored inorganic pigments (CICP), and cool pigments, which aim to increase durability and resistance to dirt and improve thermal insulation, thus reducing energy consumption in residential buildings [41]. Laboratory tests, using X-ray powder diffraction, scanning electron microscopy, and transmission electron microscopy, were conducted to investigate the pigment's composition and powder morphology to enhance NIR reflection and improve color stability [42]. Additionally, a study compared the ETAG 004 specification with the new EAD 040083-00-0404 standard, which does not provide practical recommendations such as the maximum surface temperature for any ETICS coating [28]. Recently, some researchers explored the potential of waste glass powder (WGP) as a partial replacement for cement in ETICS mortars [43]. The study demonstrated that the addition of WGP could effectively enhance the workability and compressive strength of ETICS mortars while reducing their environmental impact. Another research group focused on the incorporation of phase change materials (PCMs) into ETICS mortars to improve their thermal performance [44]. The results showed that PCM-enhanced ETICS systems could effectively reduce indoor temperature fluctuations and enhance the energy efficiency of buildings, particularly in regions with extreme temperature variations. Additionally, some studies have investigated the incorporation of waste eggshell powder (WEP) as a sustainable solution to enhance the mechanical properties of ETICS mortars while reducing their environmental impact [45]. The results showed that WEP could effectively improve the compressive strength, flexural strength, and thermal conductivity of ETICS mortars, while also reducing their water absorption and shrinkage. More recently, a study explored the potential of graphene oxide (GO) as a reinforcement material for ETICS coatings, and the results indicated that the addition of GO could improve the mechanical properties and durability of ETICS coatings, particularly in harsh environments where resistance to water and UV radiation is crucial [46]. The study suggests that GO has great potential for enhancing the performance of ETICS coatings.

2.2. Polymer-Based and Modified Acrylic Resin Development

The progress in the development of polymer-based materials and modified acrylic resins has sparked significant advancements in various industries, notably in construction [47]. Polymer-based materials, owing to their exceptional attributes such as light weight, high strength, durability, and design flexibility, have revolutionized modern engineering and construction practices [48]. These polymers can either be natural, such as cellulose, or synthetic, such as polyethylene, each having unique properties that can be tailored according to specific needs [49]. The evolution of these materials has seen notable milestones. The advent of polymers with superior heat and chemical resistance, such as polyvinyl chloride (PVC) and polystyrene, marked significant advancements in construction [50]. The development of advanced polymer composites—polymers reinforced with other materials to enhance their properties—paved the way for high-strength, lightweight materials with improved insulation properties [51].

Another advancement is the emergence of modified acrylic resins [52]. Modified acrylic resins are produced by polymerizing acrylic or methacrylic acid with other monomers, enhancing the resin's overall properties, including adhesion, flexibility, and resistance to UV radiation, weathering, and chemicals [53]. Acrylic resins are notably versatile, allowing for a wide range of modifications to meet various application requirements [54]. Their use in ETICS has led to the development of coatings that show improved resistance to color loss, cracking, and degradation due to weathering, thus increasing the life span of buildings.

Choosing the right polymer or modified acrylic resin for a specific application requires careful consideration of several factors. Firstly, the material's properties must align with the intended application. For instance, materials intended for outdoor applications must exhibit high resistance to UV radiation and weathering. Secondly, environmental impact and sustainability considerations are also key. The material should be recyclable, energy-efficient, or derived from renewable sources whenever possible. Lastly, cost-effectiveness is a vital criterion—the material's benefits should outweigh its costs over its lifetime, including installation, maintenance, and eventual disposal costs [55].

3. Materials and Methods

3.1. Detailed Material Composition and Case Study Analysis

This investigation concentrates on the expansion of Centro Comercial NorteShopping, a high-impact shopping center in Matosinhos, Northern Portugal. The refurbishment took place from February 2019 to March 2020, with an in situ performance assessment of the renovated facades conducted in October 2021, enabling us to evaluate the durability of the applied ETICS rendering after a summer-winter weather cycle. The examined facade is south-facing, constructed of concrete block masonry. The masonry was treated with a cement-type mortar, which ensures surface leveling and protection, providing a fine finish. This was then coated with an ETICS rendering comprising materials with a low modulus of elasticity, designed to manage tensions from both the facade wall and thermal stress from weather exposure.

The ETICS rendering employed for this application provides high adherence and flexibility. The rendering was applied using an airless spray gun, controlling water absorption and ensuring system impermeability with consistent coloration. To meet the requisite fire behavior performance, a high-density glass wool insulating board with fire reaction A2-s1, d0, and a fire reaction class B-s1, d0 for the system (EN 13501-1) was employed.

The final rough-textured finish was achieved with a specially developed mortar, composed of quicklime, hydraulic binders (calcined clay with pozzolanic capacity), water repellents, resinous organic binders, and fibers. The lime-based mortar, combined with fibers, decreases cracking while maintaining a low modulus of elasticity. Hydraulic binders enhance workability, accelerate curing and hardening, and water repellents control water absorption. The rendering's water absorption behavior is primarily determined by the final paint applied.

The finishing paint, selected in beige, orange, and dark grey, was based on modified acrylic resins and high reflectance pigments applied airless over the textured lime coating. The solution's performance was evaluated through in situ tests, examining color stability, surface temperature, and cracking analysis in the outer layers. These metrics were critical for assessing the ETICS system's degradation level. The study primarily focused on the south-facing facade, where the three chosen finish colors were applied on the same type of support, ensuring the sole variable under study was the applied color.

3.2. Performance Evaluation Tests

3.2.1. Thermographic Inspection and Surface Temperature Measurement

To evaluate the thermal performance in situ, the thermographic survey was carried out on 21 October 2021, with an outdoor air temperature of 27 °C. The type of assessment is essentially a qualitative evaluation and relied on the evaluation of the surface temperature variation along the coating, which may induce some construction fault caused by poor building or motivated by pathological scenarios that occurred in the meantime. A thermographic camera model, Testo Thermal Imager 882, was used to conduct thermographic tests and analyze surface temperature.

3.2.2. Color Stability Measurement

To evaluate the aesthetic performance, the measurement of color stability was carried out by comparing the values obtained in the laboratory with the values collected in the in situ tests. In the laboratory, the color stability analysis was carried out by measuring the CIELAB parameter, developed by the CIE (Commission Internationale de l'Eclairage, Vienna, Austria) in 1976 [56], and which defines the color in three numerical values, as represented in Figure 1.

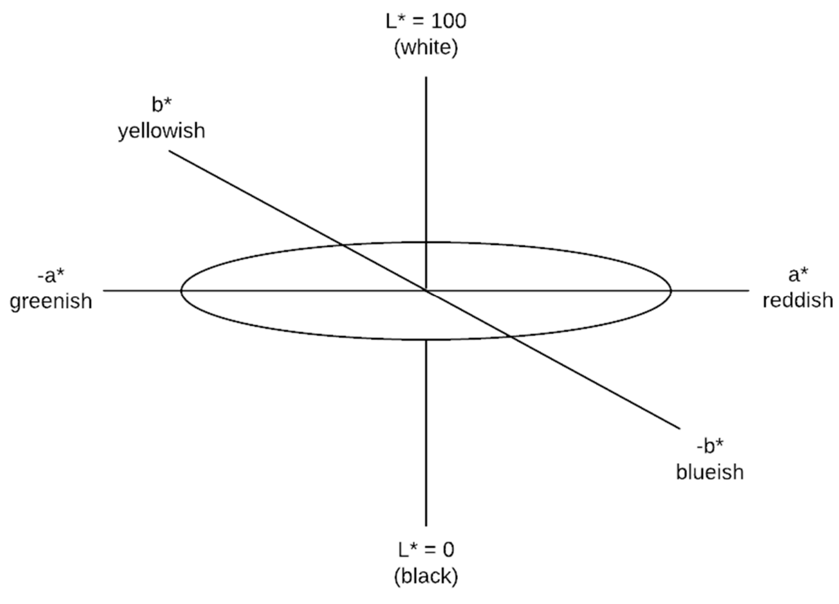

Figure 1. CIELAB color space (adapted from [57]).

The variable that allows the human eye to perceive when there is a color difference is called ΔE and is defined by Equation (1):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

For ΔE values between 2 and 10, the color difference is perceptible to the human eye; when the value is greater than 10, these colors are considered more opposite than similar. The smaller the ΔE value, the greater the color stability over time. The in situ measurement of the CIELAB parameters was carried out on 25 October 2021 for later comparison with the reference values measured in the laboratory with the standard samples. A Konica Minolta Color Reader CR-10 was used for color measurement tests.

3.2.3. Visual Inspection

To further assess the aesthetic and functional performance, an in situ visual inspection was carried out, which consisted of detecting any pathologies along the facade, with particular attention to the appearance of cracks and localized or differential color loss, depending on the level of exposure, or eventual appearance of surface carbonation; the latter pathology is an indication of possible cracking or discontinuity in the external finishing layer.

3.2.4. Testing Standards Compliance

In this study, the performance evaluation tests were carried out in accordance with recognized international standards, ensuring both the accuracy and reproducibility of the results. The thermographic inspection and surface temperature measurement, as described in Section 3.2.1, followed the procedures outlined in the ISO 6781-1:2015 standard. This standard provides guidelines for the thermographic inspection of buildings, ensuring that the conditions of the test and the use of the Testo Thermal Imager 882 are appropriate. The evaluation of color stability, detailed in Section 3.2.2, adhered to the ASTM D2244-16 standard. This method covers the calculation of color tolerances and color differences from instrumentally measured color coordinates, such as the CIELAB parameters. The Konica Minolta Color Reader CR-10 used for color measurement tests is widely accepted for use under this standard. The visual inspection carried out as outlined in Section 3.2.3 was based on the guidelines of the ISO 4628-10:2003 standard. This standard describes a method for the assessment of the degree of cracking and/or flaking in coatings by visual examination or by using a micro-series of defined images.

4. Results and Discussion

4.1. Thermographic Inspection and Surface Temperature Assessment

In the quest for energy-efficient buildings and the promotion of sustainable practices, one of the areas of primary focus is the thermal properties of the facades. This focus is informed by the understanding that building facades significantly contribute to the energy performance of buildings due to their interaction with the external environment, particularly solar radiation. The section of the facade under inspection, represented in Figure 2, was coated with three colors: beige, orange, and dark grey. The choice of these colors is not arbitrary; rather, it was driven by an intent to examine the relationship between color and surface temperature, given that color has been identified as a significant factor affecting surface temperature. Light colors, for instance, reflect more sunlight and heat, while dark colors absorb more, causing higher surface temperatures. Upon taking the readings, the surface temperature values obtained for these colors varied from 41.5 °C to 45.1 °C. As expected, the lightest color, beige, registered the lowest temperature, whereas the darkest color, dark grey, marked the highest temperature. This observation confirmed the established premise regarding the relationship between color and surface temperature. It is also pertinent to highlight the ambient conditions during this observation period. The outside air temperature was recorded at 27 °C, with the facade experiencing direct solar radiation. These conditions are integral to understanding and interpreting the thermal behavior of the facade.

Figure 2. ETICS solution with three colors on a south-facing facade (**left**); Corresponding thermographic image (**right**).

The low surface variation in the same plane as the facade with different colors benefits its longevity, as there is a certain stability in the surface temperature. A thermal shock due to significant temperature variations can cause cracking at this connection interface.

The data presented in Table 1 provide key insights into the influence of facade color on surface temperature, an essential consideration for energy-efficient and sustainable building design. Each color—beige, orange, and dark grey—offers a snapshot into a spectrum of light to dark hues, with surface temperature readings of 41.5 °C, 43.5 °C, and 45.1 °C, respectively. With an outdoor air temperature of 27 °C, each of these facade colors elevates surface temperature considerably, albeit to varying degrees. The lightest shade, beige, registers the smallest rise in surface temperature, a testament to its reflective properties. Conversely, dark grey, as the darkest color in the evaluation, shows the highest surface temperature, evidencing its capacity for heat absorption. Interestingly, the orange facade, positioned midway in terms of hue intensity, presents a surface temperature that is predictably intermediate, underscoring the direct relationship between color darkness and surface temperature.

Table 1. Surface temperatures that were recorded in the thermography test for the three existing colors.

Reading Point	Color	Surface Temperature (°C)
M1	Beige	41.5
M2	Orange	43.5
M3	Dark grey	45.1

Solar radiation is a major heat source that significantly influences the surface temperature of facades [58–60]. Comparing the results obtained with those documented in the specialized literature, such as those from Zhang et al. (2019) or Domínguez-Torres et al. (2022), reveals an interesting phenomenon [61,62]. Although our findings align broadly with the literature, there are notable differences for the orange and dark grey colors. The indicated values in the literature are higher, with orange at 47 °C and dark grey at 64 °C. Our comparative analysis indicates a variation of 3.5 °C for the orange color and a staggering 18.9 °C for the dark grey. This disparity prompts us to explore the factors that might account for such differences. Variations in solar radiation intensity, material properties, and climatic conditions can lead to differences in recorded surface temperatures. Furthermore, factors such as the angle of incidence of sunlight, time of day, and season can also significantly affect the readings. Furthermore, the composition of the pigments can also influence these results. High-performance pigments, or "cool" pigments, are designed to reflect more infrared radiation, thus reducing heat absorption even in darker colors. The pigment composition for our facade colors is an area to delve into for further understanding.

4.2. Performance Evaluation in Terms of Color Stability

Table 2 presents the color variation values resulting from the comparative analysis between color measurements carried out in situ and color measurements carried out on standard samples existing in the laboratory for the various color references. The values obtained for each color result from the average value of five measurements and were considered to reduce the reading error that could result from the fact that the analyzed support has a rough texture and this makes it difficult to measure the CIELAB parameters.

Table 2. Result of the colorimetric analysis between the standard sample and the finishing applied on site.

Parameter	**Color**		
	Beige	**Orange**	**Dark Grey**
ΔL	−0.2	−0.1	−1.2
Δa	0.0	0.1	−0.1
Δb	0.5	−0.1	0.3
ΔE	0.6	0.1	1.2

The results presented in Table 2 provide valuable insights into the colorimetric analysis conducted between the standard sample and the finishing applied on site for the three colors under examination: beige, orange, and dark grey. The parameters analyzed include ΔL, which indicates the variation in lightness; Δa, representing the change in the red-green axis; Δb, denoting the alteration in the yellow-blue axis; and ΔE, indicating the overall color difference between the standard sample and the on-site finish. For the beige color, the ΔL value indicates a marginal decrease of −0.2, suggesting a slight darkening of the color. The Δa value remains relatively stable at 0.0, indicating no significant shift in the red-green axis. However, there is a slight increase in the yellow-blue axis, as represented by the Δb value of 0.5. Overall, the ΔE value of 0.6 signifies a minimal color difference, confirming the successful matching of the on-site finish with the standard sample for the beige color. Similarly, for the orange color, the ΔL value shows a negligible decrease of −0.1, indicating a minor darkening effect. The Δa value slightly increases by 0.1, suggesting a slight shift towards the red axis. Conversely, the Δb value decreases marginally by −0.1, signifying a subtle movement towards the blue axis. The resulting ΔE value of 0.1 confirms a minimal color difference, further validating the successful replication of the orange color in the on-site finish. In contrast, the dark grey color exhibits more noticeable variations. The ΔL value reveals a significant decrease of −1.2, indicating a considerable darkening of the color. The Δa and Δb values show minor fluctuations, with Δa decreasing by −0.1 (suggesting a slight shift towards the green axis) and Δb increasing by 0.3 (indicating a slight movement towards the blue axis). Consequently, the ΔE value registers at 1.2, signifying a noticeable color difference between the on-site finish and the standard sample for the dark grey color. These results demonstrate the success in achieving color consistency for the beige and orange colors, with negligible differences between the on-site finish and the standard sample. However, the dark grey color exhibits a more prominent color deviation, suggesting the need for further attention and optimization in replicating this specific shade accurately.

The color variation, generically evaluated by the ΔE value obtained, shows that the color variation in the finish applied to the building under analysis is considerably low for the three colors. It should be noted that the value of ΔE is, in all cases, less than two, which means that the existing variations are not perceptible to the human eye. Correlating the analysis of the color variation with the surface temperature measured by thermographic analysis, it can be seen that the low color variation registered in the three colors is also accompanied by a very slight variation in the value of the surface temperature for the various color tones (41.5 °C for the beige color and 45.1 °C for the dark grey color), which indicates that the low surface temperature variation provides greater color stability.

4.3. Visual Inspection

During the visual inspection conducted on 21 October 2021, it was evident that the aesthetic outcome of the facade was highly satisfactory. Whether examining the selected area or considering the facade as a whole, including its various orientations, the coloring displayed remarkable uniformity. This pleasing aesthetic outcome is a testament to the meticulous application of the finishing materials and the attention to detail exhibited by all involved. After more than a year and a half since the completion of the facade works, the client expresses great satisfaction with the overall results. The absence of any discernible pathology or notable issues in the facade under analysis is a testament to the effectiveness of the chosen ETICS solution and the high-quality workmanship executed by the project team. The successful preservation of the facade's structural integrity and aesthetic appeal is of utmost importance, as it contributes to the overall longevity and value of the building. Such positive outcomes not only reflect the dedication and expertise of the various stakeholders involved, including designers, builders, applicators, inspectors, and manufacturers, but also highlight the importance of effective coordination among these parties. The successful integration of both aspects ensures that the facade not only meets functional requirements but also enhances the overall aesthetic appeal of the building, creating a harmonious and visually pleasing environment for all stakeholders and users.

5. Conclusions

Building facades demand a combination of safety, comfort, and durability. Innovations in construction solutions, if not carefully designed and implemented, can result in premature issues due to inappropriate material selection, poor quality application, and lack of maintenance. A key example is a leading shopping center in northern Portugal, which recently underwent an expansion and facade rehabilitation. The applied solution leveraged an innovative ETICS, which included mineral wool boards coated with lime mortar and finished with cool pigments. A successful coordination between various stakeholders, such as designers, builders, applicators, inspectors, and manufacturers, was crucial to overcome aesthetic and functional compatibility challenges. The in situ performance was assessed through an experimental campaign, comparing results to known lab data, and contributing to the evaluation of facade rehabilitation solutions with cool pigments-based ETICS. The results indicated a satisfactory performance, with homogeneous appearance, absence of functional issues, stable surface temperature, and negligible color variation perceptible to the human eye. Limitations include the impossibility of destructive tests or those likely to affect the facade finish, which could give additional insights into the performance and durability of the applied solution. Furthermore, our study is limited to a single case study, thus potentially limiting the generalizability of the findings. Future work could further validate these findings by testing similar solutions in various settings and geographic locations, and for a longer period. Additionally, exploring ways to implement non-invasive testing methods could provide more detailed insights into the durability and performance of these innovative solutions. Improving upon these high-performance and sustainable ETICS solutions would involve a continued focus on material innovation, construction quality, and comprehensive maintenance programs.

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