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Performance of a lime-based insulating render for heritage buildings

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HIGHLIGHTS

- Moisture is stored for a longer time when multiple NHL top layers are applied.
- The considered insulating lime render has got a low risk to develop frost damage.
- Replacing imitative renderwork by lime-perlite mortar encourages moisture migration.
- The render's thermal insulation efficiency is lower in winter compared to summertime.

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ABSTRACT

Insulating heritage buildings in order to provide a comfortable indoor climate, to reduce energy consumption and avoid thermal stresses into the structure, is generally not in accordance with architectural preservation guidelines. Without compromising historic features, insulation renders may however upgrade rendered heritage of which the original materiality is considered inferior compared to its design. This study evaluates the hygrothermal performance of 49 insulating lime-perlite render configurations on brick masonry, by combining characterisation experiments with numerical modelling. The effects of the coupled heat-moisture transport are finally validated by ageing cycles and bond strength tests. It is found that insulating renders cause smaller shifts in temperature in the structure compared to historic renders, but the moisture level of the support may increase significantly. In addition, the insulation layers store a lot of moisture during winter, affecting the expected insulation capacity.

1. Introduction

Throughout hundreds of years, a high number of historic façades has been finished with mortar layers. Although these renders were primarily employed as a protecting envelope against weathering to provide a longer life span for the underlying building materials, their decorative aspects were also of great importance to strive for aesthetical perfection [1]. Literature shows that the older mortars consist of air lime or hydraulic lime mixed with sand or crushed aggregates derived from stone or brick [2], while a significant share of our young architectural heritage is associated with render layers based on cement [3,4]. Whereas the decorative hybrid lime-cement renders were extensively applied for stone imitation purposes during the interwar period [5], pure Portland cement renders were frequently used for finishes like glass-sprinkled cimorné and bright coloured tyrolean mortars for Modernist architecture [6,7]. Such finishes were commonly obtained as a thin top layer on a less expensive rendering layer of 5–30 mm thickness, to ensure an adequate adhesion and levelling in relation to the masonry structure underneath. Despite the valuable decorative aspects of these traditional render systems, their thermal conductivity is high compared to the EN 998-1 definition of a thermal insulating render ($\lambda \leq 0.20$ W/mK), and typically ranging from 0.12 to 0.80 W/mK in dry condition [8–11]. As a consequence, their insulation capacity is rather low and insufficient at the given thickness, especially when the air volume within the pores is largely replaced by rainwater, which leads to an increase of the thermal

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conductivity. Lacking insulation is generally accompanied by pathological effects, generated by surface condensation near thermal bridges. Long-lasting moisture levels may trigger the growth of moulds that affect the air quality of the building occupants. Also the thermal comfort may be undermined due to unpleasant radiance from cold inner surfaces, making these valuable historic buildings less suitable for exploiting a residential function. Because they additionally consume a lot of energy, resulting in high greenhouse gas emissions and high heating costs, the refurbishment of the existing building stock is recently extensively promoted by the EU government [12,13]. However, it appears to be a challenge to find the right balance between preservation of heritage values and an improvement of the occupant comfort. Within this context, a considerable number of European research projects were initiated in recent years [14–16].

1.1. Searching compatible interventions

In order to retain the aesthetic and historic integrity of a façade, and at the same time to reduce unnecessary heat losses, an internal insulation layer is often preferred. However, this retrofitting strategy has an adverse effect on the spatial perception of the inner spaces and may lead to moisture accumulation within the façade with potential interstitial condensation. According to the level of heritage protection, an external insulation system can be taken into consideration. Historic façades that enjoy integral protection are unfortunately not eligible for such interventions, because the materiality of their surface is unique and has to be preserved. Nevertheless, a larger share of our patrimony contributes particularly to the cultural identity of townscapes or cities, and allows energetic rehabilitation measures if the façade appearance is maintained or reconstructed to conserve its identity. Yet, the application of external insulation layers can be quite encroaching when the original rendering is replaced by a new render with a different appearance and thickness which distorts the initial façade proportions. Especially when a façade is characterized by ornamental elements, the attachment of traditional insulation panels as part of an ETICS is very time-consuming. Instead, stylistic elements may be replicated using insulation mortars without increasing the finishing's thickness significantly. This radical strategy does not intend to comply with the current energy standards, because the authentic façade concept and design are considered more important than optimal thermal comfort. Therefore, only a limited render thickness is appropriate to reduce energy losses and improve the comfort level of occupants. However, before the feasibility level of an upgraded reconstruction strategy towards historic features can be evaluated, the technical compatibility and durability of an insulating render package on a historic support needs to be investigated. The awareness that heritage buildings should fulfill certain minimum requirements towards thermal comfort has recently grown, and the development of improved insulating mortars is trending [17]. Researchers have tried to lower the thermal conductivity of mortars by substituting the traditional aggregates with lightweight components. *Barreca & Fichera* performed some experiments with the addition of olive stone to lime-cement mortars [18], *Brás* et al. considered hydraulic lime renders containing different cork percentages instead of conventional aggregates [19] and *Stefanidou* incorporated respectively silica sand, glass particles and glass spheres in different lime-cement renders [20]. Most studies within this topic only focus on the characterisation of the thermal performance, but the assessment of their general durability and hygric behaviour under weathering conditions is often forgotten. Only a minority considers an on-site measurement of the thermal conductivity and takes into account the moisture behaviour of the façade, but unfortunately their focus usually lies on interior applications [17,21,22]. Insulation renders should guarantee a constant performance in time, but their behaviour is still unclear under external conditions. Therefore, the aim of this research is to evaluate the overall performance of multiple insulation render configurations on clay units masonry, and compare their hygrothermal behaviour with a traditional solution. The render configurations are established by combining one particular insulation render with different finishing layers or by adding an undercoat. A parameter study should decide which configuration performs best with regard to insulation capacity, moisture transport and ageing.

2. Methodology

To understand the moisture balance within the render and its support, and to assess and mitigate all risks for future degradation, the necessary experiments are carried out to determine the density, thermal conductivity, capillary water absorption, drying rate and porosity properties of the individual render layers. Although these experiments provide fundamental information on the behaviour of each individual render layer, their combined hygrothermal behaviour is difficult to assess experimentally. Therefore, these parameters are implemented into a numerical model (DELPHIN) to simulate their water uptake, mutual moisture exchange, drying behaviour and change of insulation capacity over a time period of 2 years. Different render configurations with variable insulation thicknesses, base and top layers are evaluated in terms of their yearly moisture content, indoor temperature and condensation risks.

In addition, the experiments involve ageing cycles, as well as impact and adhesion tests on wall specimens with combined render layers to validate their resistance against weathering. Finally, the best insulating geometries are assessed against two traditional façade sections: one without renderwork, and one containing an interwar stone imitation finish.

3. Materials and samples

3.1. Selection of the insulating render system

The thermal conductivity of innovative and experimental insulation renders is situated between 0.06 and 1.33 W/mK [18–20,23–25]. Aerogel mortars form an exception and serve as the best insulators (up to 0.028 W/mK), making their potential towards the building conservation industry a hot topic [26–28]. However, heritage agencies often prefer a more traditional render composition, due to compatibility concerns with regard to the water repellent properties of an aerogel render [28]. Therefore, this study concentrates on a dry premixed commercial render basically composed of natural hydraulic lime (NHL5), sand and perlite fragments. Its prescribed insulation capacity (λ = 0.066 W/mK) is substantially higher in comparison to other insulating mineral renders (Class 1 render according to EN 998-1), which makes it convenient for obtaining higher thermal comfort levels for identical layer thicknesses. One of the advantages is that lime-based mortars can easily be removed from their substrate, so their reversibility aspect is guaranteed.

3.2. Sample preparation and curing

A common insulating render system is composed of an adhesive spritz coating (render A), an insulation layer (render B), an intermediate layer (render C) and a decorative layer (render D). X-ray diffraction (XRD) was used to characterize the crystalline phases of the ingredients from each render in powdered condition. The XRD patterns indicate that the adhesive render (A), as well as the