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Evaluation of the hygrothermal properties of thermal rendering systems

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ABSTRACT

The search for building envelopes with enhanced thermal properties is pursued to comply with European directives for lowering reference U-values. Thermal renders present low thermal conductivity, compared to traditional renders, and combine good thermal properties with easy application by mechanical spraying. The main goal of this work is to evaluate and compare the hygrothermal performance of three thermal render systems for different European climates. An extensive laboratory characterisation, measuring physical and hygrothermal material properties, was performed. It was verified that thermal conductivity linearly increases with water content, so thermal performance can be directly compromised if hygric behaviour is unfavourable. Porosity and microstructure were found to have a significant impact on other properties because the distribution of open and enclosed pores lead to different results. The high proportion of mesopores contributes to relevant moisture content during the lifetime of the building. The hygrothermal simulation demonstrated that the finishing coatings have a significant impact on the hygrothermal behaviour of the whole system. The application of thermally improved facades implies an increase in the temperature difference across different layers, especially in the thermal render, which could promote thermal stresses. As exterior insulation, the analysed systems showed that the simulated External Thermal Insulation Composite System (ETICS) exhibits good performance in general. However, the condensation potential is higher for ETICS, in particular, compared to thermal render systems. Consequently, an optimum compromise among thermal, hygric, and physical properties should be made.

1. Introduction

The changes in the European thermal regulations introduced by the recast of the Energy Performance of Buildings Directive (EPBD) [1] imply a demand for a higher thermal resistance of envelope components. That demand is not only imposed by the limitation of the overall energy consumption of each dwelling but also by the limitation of specific U-values. In the Portuguese case, the current thermal regulation [2] defines reference U-values for walls ranging from 0.3 to 0.4 W/(m^2·°C), depending on the climatic region. The demand for a better wall performance has led the industry to search for new solutions, evaluating the potential benefits [3]. In the case of masonry walls, a traditional solution in southern European countries, the optimisation of masonry unit geometry [4,5] and adoption of low-conductivity materials in both masonry units [6,7] and renderings [8,9] are some of the paths being pursued.

The search for low-conductivity materials includes an increasing application of alternative aggregates such as EPS [9,10], cork [8–11], or aerogel [12,13], especially in formulations of pre-mixed mortars for renderings. The new formulations allow for a density reduction of the resulting renderings that will usually correspond to a reduction of thermal conductivity but will also imply a reduction of mechanical resistance. Hence, the key issues for manufacturers are to develop mortars for renderings that (a) present the lowest possible thermal conductivity, (b) do not compromise mechanical performance and durability, and (c) can be applied by mechanical spraying.

The experimental characterisation of thermal renders usually adopted by European manufacturers is based on existing standards. The EN 998-1 standard [14] defines specific requirements for thermal insulating rendering and plastering mortars for masonry. Those requirements include limits to compressive strength capillary water absorption, water vapour permeability, thermal conductivity, reaction to fire, and durability. However, thermal renderings are currently applied as a system layer, similar to the External Thermal Insulation Composite System (ETICS), and hygrothermal properties should be analysed for the system as a whole. ETAG 004 [15] defines a test scheme that could

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Nomenclature

a	Short-wave radiation absorptivity of the surface
A	Capillary absorption coefficient, according to ETAG 004 [kg/m^2]
A_w	Capillary absorption coefficient, according to ISO 15148 [kg/(m^2·s$^{1/2}$)]
b	Thermal effusivity [W·s$^{1/2}$/(m^2·°C)]
c	Specific heat capacity [J/(kg·°C)]
C	Finishing render
EPS	Expanded polystyrene
ETICS	External Thermal Insulation Composite System
f	Free water saturation [kg/m^3]
GHP	Guarded hot plate
HP	Helium pycnometry
HW	Hot-wire
I	Net radiation at the component surface [W/m^2]
I_e	Long-wave emission of the surface [W/m^2]
I_l	Long-wave counterradiation [W/m^2]
I_s	Short-wave solar radiation [W/m^2]
MIP	Mercury intrusion porosimetry
P	Porosity [%]
Q	Heat flow density [W/m^2]
S	Thermal render system
s_d	Vapour diffusion thickness [m]
TR	Thermal render
U	Thermal transmission coefficient [W/(m^2·°C)]
w	Water content [kg/m^3]

Greek letters

ΔT_a	Monthly mean temperature difference between indoor and outdoor air temperature [°C]
ε	Emissivity
λ	Thermal conductivity [W/(m·°C)]
μ	Water vapour resistance factor
υ	Wind speed [m/s]
ρ	Apparent density [kg/m^3]
φ	Relative humidity [%]

help in the performance evaluation of thermal rendering systems.

Previous work of different authors on the laboratory characterisation of hardened thermal insulating mortars focused not only on standard properties but also on additional ones. In the study described in Ref. [8], EPS and cork cement mortars were compared based on the results of flexural and compressive strength, open porosity and pore size distribution, capillary water absorption, and thermal conductivity. The conclusions included the determination of the strength decrease with the increase of cork or EPS dosage and the identification of a lower decrease in thermal conductivity with EPS dosage increase if compared to cork.

The study of mortars containing EPS and paper sludge ash (PSA) [9] explored the reduction of thermal conductivity and compressive strength compared to control mortars. A variation of the reduction in both properties was observed, but that reduction was influenced by the EPS being ground or powdered. In addition, in Ref. [10], the authors checked whether it is beneficial to use an EPS render on the external walls of the building instead of a cement render. A large reduction in thermal conductivity was found but adhesion was compromised.

The study of mortar containing waste cork conducted in Ref. [16] identified a thermal conductivity reduction influenced by the percentage of cork and not by the cork size and cork gradation.

To test the products resulting from the utilisation of ground waste seashells in cement mortars [17], along with compressive strength and thermal conductivity, drying shrinkage was also analysed. The expected reduction of resistance and conductivity was found but the shrinkage effect was highly affected by the type of seashells used in the mixture.

The durability of EPS mortars [18] was tested with capillary absorption, impedance spectroscopy, open porosity, and pore size distribution and also with durability by reproducing heat and freeze-thaw cycles. Mercury intrusion porosimetry did not prove to be suitable owing to the inner porous structure of the EPS particles and impedance spectroscopy did not result in a clear relationship with other properties. However, increasing EPS dosage reduces capillary absorption, EPS mixtures improved compressive strength after heat cycles, and EPS did not reduce the durability of samples after freeze-thaw cycles.

The inclusion of less common aggregates such as date palm fibres [19] was explored, leading to acceptable results regarding compressive strength and thermal conductivity.

The concern with hygric properties in addition to the thermal behaviour of plasters can be found in other contributions [20,21], stressing the importance of a holistic view for the correct evaluation of product performance.

In summary, existing standards [14] provide a framework for thermal insulating mortar assessment and the previously presented research systematically uses compressive strength and thermal conductivity as preferred means for characterisation, paying little attention to the hygric behaviour. Although the standards do not emphasise the need for a detailed moisture performance characterisation of mortars, thermal insulating mortars may be very sensitive to it owing to their porous structure. Hence, further knowledge of the moisture storage function, moisture absorption, vapour permeability, and the moisture dependence of the thermal conductivity can be decisive for evaluation of the durability and of thermal transmission in real-life applications. Moreover, thermal insulating renders are usually applied as part of multilayer systems. Consequently, an investigation of their hygrothermal behaviour would contribute to fill the knowledge gap.

The objective of this article is to evaluate and compare the hygrothermal performance of different thermal render systems. To achieve this main goal, an extensive laboratory characterisation of the different thermal renders will be performed by measuring several physical and hygrothermal properties of the industrial thermal render systems that will be used as input to hygrothermal simulation. The relevance of those properties is highlighted with the hygrothermal impact analysis of the referred systems in scenarios, adapted to European climatic conditions.

2. Materials and methods

2.1. Materials

Six different materials, constituting three different rendering systems, were tested. Each system (S) consists of a thermal render (TR) and a finishing render (C). The selected materials for this study are described in Table 1. Each system is provided by a different manufacturer, implying that detailed knowledge of the formulations is not available owing to the industrial confidentiality of the materials available on the market. To be admitted in the tests, all the materials had to be guaranteed for adequate applicability by mechanical spraying and workability according to the industrial partner standards, which means that all the tested products were already candidates for industrial production. The focus of the tests was therefore on the performance of the hardened products.

The thermal renders also have special additives in their constitution, which introduce air into the mixture. If the kneading time is exceeded, the combination of the amount of water and mechanical spraying could