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Cork-based mortars for thermal bridges correction in a dwelling: Thermal performance and cost evaluation

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ABSTRACT

The aim of the present work was to simulate the behaviour of cork-based mortars in the minimization of energy consumption and condensation effects in an existing dwelling from the 1980s built in Lisbon, Portugal. Tests were carried out on hydraulic lime mortars and cement mortars with several proportions of cork as regards rheological characterization, thermal behaviour in and water vapour permeability. The first assessment of the behaviour of an existing dwelling showed that the power of heat dissipation in the dwellings' thermal bridges is of the same magnitude order than heat loss in roof and much higher than in vertical opaque envelopes or openings, which enhances the need to reduce thermal bridges in the building. The selection of the most adequate mortar was then carried out in view of several scenarios. The best solution corresponds to the correction of thermal bridges using a Hydraulic lime mortar with 70% of cork granulate (CH70). An economic evaluation was also done concerning electric energy cost and its annual growing rate in Portuguese residential buildings. The results show that the use of CH70 mortar for thermal bridge correction has a payback of 3 years when compared to the simple repair of the original external plaster.

1. Introduction

In the last decades, the energy consumption for heating in buildings has been reduced due to boundaries established by European regulations [1]. In Portugal this type of regulation was set in 1990, with the RCCTE (Regulation of the characteristics of thermal performance of buildings), which aimed to satisfy the thermal comfort conditions in buildings and to minimize pathological effects derived from the condensation surface [2,3]. However, before the emergence of this regulation, there was lack of care concerning these issues, particularly with regard to correction of thermal bridges in buildings.

A thermal bridge is a building element where there is a significant change in the thermal resistance for the remaining surrounding due to the presence of materials with higher thermal conductivity and changes in thickness of vertical opaque envelope elements. Several studies show that thermal bridges are responsible for about 30% of heat losses in the winter period, increasing significantly the energy consumption for heating needs [4–6].

Other effect of thermal bridges is the cooling of the interior surfaces in these areas, resulting in higher condensations and the growth of moulds and fungi, generating a lack of air quality conditions [5,7,8]. This leads consequently to the production of allergens known to be associated with allergies and asthma and also other toxins and irritants that affect the respiratory health, which has a relevant impact on the occupant's health [9,10]. Additionally, the presence of higher condensations and the growth of moulds lead to material degradation and other pathologies, increasing the need for maintenance and for more severe cases the need of rehabilitation. The prevention of this kind of problems is important, especially because there is a high number of buildings in Portugal that reveal such pathologies [7].

In order to test how each solution scenarios lead to the minimization of condensation problems in the thermal bridges, Glaser method may be used to evaluate any formation of condensation in the layers of the conjectured solutions. Condensation is defined according to the Glaser approach, which is a practical tool in building design, recommended by the DIN 4108 and EN ISO 13788 standards. Several works have focus on this subject [11].

The first one [11] describes an iterative technique for the definition of condensation across two-dimensional elements via the boundary element method (BEM). Using the Glaser approach, the vapour pressure is equalized to the vapour saturation pressure, and then the vapour equilibrium is redefined by means of the

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BEM solution until vapour pressure does not exceed vapour saturation pressure. This method provides an accurate identification of the condensation zone and its applicability was demonstrate by defining the condensation zone and the amount of liquid water generated on a T-shaped wall when subjected to different boundary conditions.

In [12] BEM method is applied to the curved wall models, identifying the zones where condensation occurs and quantifying the amount of liquid water generated. Previously to the application of BEM, the iterative process is first implemented and validated by applying it to the definition of condensation patterns across a hollow cylinder, for which the solution is calculated analytically.

Building rehabilitation becomes increasingly a necessity in Portugal, pushing this theme progressively towards sustainability. Currently there are good solutions targeted to the referred problems. However, these solutions require a high initial investment. The high energy consumption of buildings and the financial crisis are leading to the need of seeking solutions at an affordable cost, promoting energy rehabilitation [1,3].

A good approach to achieve this goal could be the incorporation in traditional mortars of low-priced and thermal resistant materials, such as industrial by-products or other materials which are considered waste. Cork granulates are included in this group. Accordingly, Europe produces more than 80% of worlds cork and annually 68,000 to 85,000 t of that production is considered waste due to granulates' small dimension or high density [13–15].

Cork is a natural, durable and renewable raw material, extracted from the oak *Quercus sober* L. which is common in Mediterranean area, with many uses as a composite material [16–18]. This material has the advantage of presenting low density due to its hollow cellular structure and high gas content, which assigns a low thermal conductivity, being thus a good material for thermal insulation [13,16,19,20].

The approach of using this waste on traditional mortars might give a relevant contribution for its recycling and, furthermore, it will contribute to the decrease of initial costs, since the incorporation of cork granulates in mortars increases its yield.

2. Objectives and motivation

It was intended to develop specific rendering mortars able to be applied in thermal bridges to reduce condensation effects and heat transfer in buildings' vertical opaque envelopes. The purpose was to simulate the application of the best mortar compositions developed (from a thermal behaviour point of view) in a specific dwelling of the 1980 decade built in Lisbon, Portugal, where energy and condensation problems were assessed and observed.

In view of the previous, several hydraulic lime–cork mortars (HL5 and NHL5), for rendering application in thermal bridges, were developed and optimized. Different cork granulate dosages (from 0% to 80% in volume) were tested (as sand replacement by mass). The main challenge consists in developing a rendering mortar, with the maximum cork dosage as possible, while minimizing mortar thermal conductivity and cost changes.

Cork granulate is an industrial by-product and its use has environmental advantages. It is produced from scrap of cutting and trimming operations; some granules are subsequently used in the production of agglomerated products while others are though rejected. Hence, its cost is considerably lower compared with that of virgin cork. Thus, the aim of this work is also to transform this cork by-product into a highly value composite product.

The tests carried out on the studied mortars are listed below:

- flow table test and rheological characterization;
- thermal conductivity;
- thermal behaviour in unsteady state;
- water vapour permeability.

A comparison between the performance of referred NHL5 and HL5 – cork mortars – and a traditional cement mortar with or without cork aggregates was also made.

Afterwards, it was intended to assess the energy performance of an existing dwelling without thermal insulation. The purpose was to study how specific corrections of thermal bridges with the previous mortars lead to important energy savings and minimization of condensation effects.

Based on the original design stage of the existing dwelling, different scenarios were investigated in the thermal performance simulation in order to study how the specific corrections with the developed mortars may imply as regards energy consumption for heating. An economic evaluation was done taking into account the electric energy cost and its annual growing rate in Portuguese residential buildings. This analysis will enable to choose the best solution from a technical and economical point of view.

3. Material characteristics

For the mortars' formulation several materials were used namely: binders, a type of sand, a water reducer and a cork granulate, whose characteristics are presented herein:

– *Binders:* a natural hydraulic lime type NHL5, a hydraulic lime type HL5 and cement type CEM II B-L 32,5 N produced in Portugal by Secil with the characteristics presented in Tables 1 and 2.

Table 1
Chemical and physical characteristics of NHL5 and HL5 provided by the manufacturer.

	NHL5		HL5		Standard
Physical characteristics	Value		Value		
Density (g/cm^3)	2.7		2.8		
Fineness %	90 mm	**15.0%**	90 mm	**15.0%**	EN
	200 mm	**5.0%**	200 mm	**5.0%**	459-1
Blaine (cm^2/g)	5780		5780		
Expandability alternative method (mm)	≤2.0		≤2.0		EN 459-1
Free water (%)	≤2.0		≤2.0		EN 459-1
Air content (%)	≤5.0		≤5.0		EN 459-1
Setting time (h)	Start	>1.0	Start	>1.0	EN 459-1
	End	≤15.0	End	≤15.0	EN 459-1
Mechanical characteristics					
Mechanical compressive strength at 7 days (MPa)	≥2.0		≥2.0		EN 459-1
Mechanical compressive strength at 28 days (MPa)	≥5.0 and ≤15.00		≥5.0		EN 459-1
Chemical characteristics					
Sulphates (SO_3) (%)	≤2.0		≤3.0		EN 459-1
Free lime ($Ca(OH)_2$)(%)	≥15.00		≥4.00		EN 459-1