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Contribution of structural lightweight aggregate concrete to the reduction of thermal bridging effect in buildings

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HIGHLIGHTS

- The energy performance of SLWAC in residential buildings was studied.
- SLWAC proved to be able to significantly improve the thermal bridging effect.
- SLWAC can contribute to the reduction of heating energy needs anywhere in Europe.
- In the summer season, SLWAC and NWC presented similar cooling energy needs.

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ABSTRACT

In recent years, Energy Performance Building Directives have been published and adopted by all EU member states in order to promote the improvement of the energy performance of buildings within the EU, and thus coping with the growing comfort needs and consequent increase in energy consumption for space heating and cooling.

Structural lightweight aggregate concrete (SLWAC), due to its thermal properties, presents itself as an alternative to normal weight concrete (NWC) to reduce the thermal bridging effects as well as the building energy needs to maintain thermal comfort levels in buildings.

In this paper, the potential of SLWAC to improve the energy performance of buildings was assessed. An experimental study was carried out in order to determine the thermal properties of five different concrete mixtures, four SLWAC and a reference NWC for comparison purposes.

These thermal properties were then used in the two-dimensional heat transfer program *Therm* and in the whole-building energy simulation program *EnergyPlus* to assess the impact of SLWAC on the thermal bridge heat losses and building energy needs of a case study. Results showed that SLWAC can improve the energy efficiency of buildings and thus be an attractive alternative to the use of the traditional NWC.

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1. Introduction

In the last decades, building quality has improved significantly in response to the growing comfort needs due to technological development and increase of living standards of society. In today's standards, buildings need to provide adequate comfort levels, taking into account factors such as indoor air quality, lighting, acoustics and thermal environment.

In general, thermal comfort is achieved by resorting to air conditioning equipment, which represents an important part of the energy consumption attributed to buildings [1].

In 2010, buildings were responsible for 40% of the energy consumption in the European Union (EU) [2,3] (about 30% in Portugal's case [4]), 27% of which (approximately 2/3 of the total energy consumption in buildings) was expended by residential buildings [5]. Residential buildings in the European Union spent an average of 200 kWh/m^2 in 2009, with considerable variations between countries, mainly due to climatic differences [5].

Space heating represents the largest share of household energy use, on average, about 60–80% of total energy consumption [5]. In Portugal, degraded and poor quality buildings are responsible for a great part of these needs. A similar situation should occur in other countries. Actually, the problem should not be viewed only from the perspective of the new buildings but also from the viewpoint of the existing buildings. In any case, for economic and environmental reasons, it is crucial to reduce the consumption of conventional energy in buildings, which can be achieved by enhancing the quality of the thermal envelope, by using more efficient installations and by introducing renewable energy technologies. With this

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purpose, EU Energy Performance of Buildings Directives (EPBD) have been published in recent years to be adopted by all EU member states [6], such as the Directive 2002/91/EC [7] and, more recently, the Directive 2010/31/EU [3], which is an upgrade of the previous one. They both recognize a significant potential for energy savings in the buildings sector and provide guidelines to improve the energy performance of buildings within the European Union.

As outdoor climatic conditions, as well as indoor climate requirements and cost-effectiveness differ from country to country, each member state is responsible for establishing the minimum requirements for the energy performance of buildings and building units [3]. The assessment of conformity to the requirements should be conducted through a regulatory methodology accounting for all heat transfer processes and other factors (e.g. heating and air-conditioning installations, passive heating and cooling elements, shading control) impacting the building energy performance.

The building envelope is one of the most important systems affecting the energy performance of a building. A comprehensive analysis of the conduction heat losses through the building envelope is thus needed so that potential sources of poor thermal behaviour can be identified and, in accordance, the most correct design and construction decisions can be made.

Heat transfer by conduction through the building envelope involves heat transfer through envelope elements as well as heat transfer through thermal bridges. A thermal bridge is a part of the building envelope where the thermal resistance is significantly reduced as a result of full or partial penetration of the building envelope by materials with a different thermal conductivity and/or a change in thickness of the fabric and/or a difference between internal and external areas, such as wall/floor/ceiling junctions [8,9]. In general, thermal bridges result in a change of heat flow rate and of internal surface temperature [8]. According to literature [10,11], in the EU the total impact of thermal bridges on the heating energy needs of a building can be as high as 30%. Theodosiou and Papadopoulos [12] also reached similar conclusions.

The presence of concrete columns and beams within the building envelope greatly contributes to the existence of thermal bridges, mainly due to its high thermal conductivity as opposed to the low thermal conductivity of the surrounding construction materials. On this matter, lightweight aggregate concrete can provide significant contribution. When compared to normal weight concrete (NWC), lightweight aggregate concrete, due to its lower density, is not only able to reduce the permanent load but also the thermal conductance of construction elements [13,14]. In particular, the use of structural lightweight aggregate concrete (SLWAC), as an alternative to NWC, contributes to lower the thermal bridging effect in structural elements, allowing the reduction of the global heat loss through the building envelope or the minimization of the corrective insulation systems needed to fulfil the standard thermal insulation requirements [15].

The low thermal conductivity of the air trapped in the porous structure of lightweight aggregates (LWA) [16,17] is the main reason for the higher thermal insulation capacity of SLWAC when compared to NWC of similar composition.

According to Holm and Bremner [18], the thermal conductivity of SLWAC, with an average density of about 1850 kg/m^3, typically ranges between 0.58 and 0.86 W/m K, whereas in NWC of about 2400 kg/m^3 the thermal conductivity can vary from 1.4 to 2.9 W/m K. On the other hand, ITE50 [19] suggests that the thermal conductivity may vary from 0.85 to 1.05 W/m K in SLWAC of 1400–1800 kg/m^{3}and from 1.65 to 2.0 W/m K in NWC of 2000–2600 kg/m^3. This means a reduction of about 50–70% in the thermal conductivity of SLWAC when compared to NWC.

Taking into account the most usual SLWAC produced with different types of aggregate and binder, as well as different w/b ratios, Real et al. [20] reported thermal conductivities 40–53% lower in SLWAC than in NWC of equal composition. The authors found an average reduction of 0.6% in thermal conductivity per 1% increment in aggregate porosity.

Besides the advantage of the reduction of the thermal bridging effects and energy needs, SLWAC might be applied in new constructions in a more efficient way, needing fewer resources to reach a similar end result (the construction of a building with a certain load capacity), due to the reduction of the permanent load, thus contributing to the decrease of overall costs and promoting not only environmental but also economic sustainability.

No articles were found on thermal bridges or energy efficiency studies in buildings with SLWAC elements.

This paper, based on an experimental study concerning the thermophysical characterization of different types of SLWAC, aims to analyse the potential of SLWAC for the reduction of thermal bridging effects and energy needs of a case study, taking into account the open source software programs *Therm* 7.3 [21] and *EnergyPlus* 7.1 [22], respectively. Fig. 1 illustrates the methodology used in this study.

The concrete mixtures with LWA, for which their impacts are investigated in this study, are still far from being considered typical construction materials. Moreover, they are being used for a rather non-conventional purpose, which is to perform both structural and thermal insulating functions. These particular features make the experimental characterization of such materials in terms of their fundamental properties relevant. As shown in the flowchart of Fig. 1, the properties of the various concrete mixtures are firstly obtained from the experimental program and then directly transposed to the numerical work to be applied in the *Therm* and *EnergyPlus* simulation programs. This approach is expected to obtain more reliable and realistic results for the building energy performance achieved with the use of these materials.

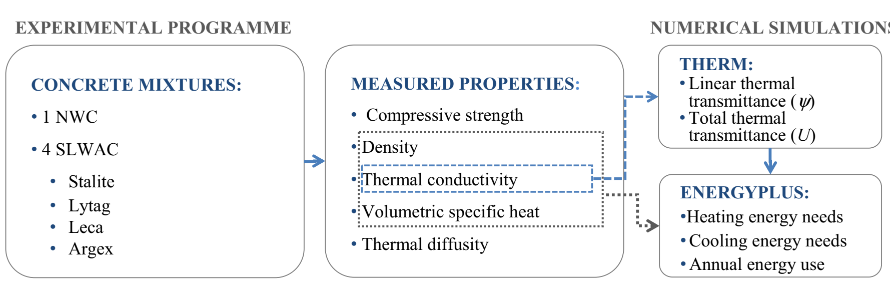

Fig. 1. Flowchart of the methodology used in this study.

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