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Influence of a period of wet weather on the heat transfer across a wall covered with uncoated medium density expanded cork

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ABSTRACT

A building materials' properties have a great influence on its energy performance, and this is particularly true of the hygrothermal properties of the insulation material. The variation in moisture content generated by weather conditions can have a strong impact on heat transport. The phenomena involved are very complex and difficult to fully simulate numerically, particularly when the moisture variation occurs under exposure to rain. In the case of the medium density expanded cork agglomerate that is increasingly used without any coating as an external thermal insulation layer of buildings, these phenomena can be particularly relevant. Thus, this paper evaluates the importance of varying moisture content on the thermal behavior of a wall covered with uncoated medium density cork agglomerate when exposed to rain. A simple analytical model that simulates the heat transfer phenomenon was used to quantify its importance by comparing the mathematical results with those obtained experimentally.

Steady and unsteady state conditions were simulated. For comparison purposes, winter and summer environmental conditions for both dry and wet weather were assumed. The results show that the thermal behavior of the wall is only affected in the rainy period, until the first few hours when the expanded cork board starts to dry. When rain is simulated, the temperature of the water has a key effect on the wall's behavior. The moisture transport phenomenon and changes in the hygrothermal material properties are almost entirely confined to the upper layers of expanded cork board and to the rainy period.

1. Introduction

Buildings are the largest energy consuming sector in the world. They account for over one-third of the total final energy consumption and are an equally important source of carbon dioxide (CO_2) emissions [1]. Article 9 of European Directive 2010/31/EU on the energy performance of buildings states that by 31 December 2020 all new buildings must have almost zero energy needs. For public buildings, this date has been brought forward to 2018. Therefore, energy efficiency in buildings is a priority, and the use of efficient technologies and solutions is essential, for both new buildings and for rehabilitation works. This ambitious objective will be more easily achieved through the use of eco-efficient insulation materials which can be easily recycled at the end of their life cycle.

Because of its resistance to adverse weather conditions, cork is the only thermal insulation material that can be used, uncoated, on the exterior [2]. It is a solution in line with the objectives established by Horizon 2020 for more sustainable development, thanks both to its known hygrothermal and mechanical properties and to it being a renewable material. Cork comes from the outer sheath of bark of the *Quercus Suber L.*, a type of oak tree that is native to the western Mediterranean region, being a natural resource that grows without chemical herbicides, fertilizers or irrigation. After harvesting, cork is subjected to a cooking process that yields two product categories: natural cork, from which stoppers are produced, and granules, a by-product of the first quality cork [3,4]. Some raw cork is automatically rejected because it is poor quality. However, this rejected raw material is used to produce cork granules [5–7]. These are agglutinated with their own resin, suberin, in a pressure and heating process [8–10] to form a compact block of expanded cork, which then are cut with the desired thickness. This material has been the subject of environmental life cycle assessment by several authors [4,11]. Silvestre et al. [11] confirmed that expanded cork boards can be seen as a sustainable choice for the thermal insulation of buildings.

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The heat and moisture transfer that occurs through the building envelope determines its hygrothermal performance and, consequently, its energy consumption [12]. If there is an excessive level of moisture in porous building materials then, besides its effect on the hygrothermal properties of building materials, it can lead to the development of pathologies like such as frost attack, steel corrosion, timber rot, cracking and mould growth.

The combined effect of surface condensation, wind-driven rain, drying, and the hygrothermal behavior of the exterior wall layer can lead to high surface moisture content [13]. As concluded by Coelho et al. [14], wind-driven rain has a key influence on the hygrothermal behavior of high capillary water uptake walls, such as solid brick walls. In their work, Finken et al. [15] conclude that the façade should be protected against driving rain when rehabilitating solid bare masonry walls using internal capillary active insulation. Regarding concrete walls, in which water seepage is a common problem, Yu et al. [16] developed an engineered cementitious composite for waterproofing applications in concrete walls. In their review about the implemented approaches to waterproof concrete, Muhammad et al. [17] concluded that the technique adopted by the majority of the researchers is the use of waterproofing surface coatings. Therefore, researchers and building industry players have been developing construction techniques to prevent water seepage through the building envelope.

Since expanded cork board of medium density (140–160 kg/m^3) is used as an uncoated wall cover without any protection, it is not technically feasible to prevent water absorption. In addition to water absorption by capillarity, common to most of building materials in current use, rainwater gets into the expanded cork boards by percolation through the channels created by the spaces between the cork granules. The wind-driving effect [18] probably helps this process of water penetration. It should be noted that those small channels might also help the incoming rainwater to seep out of the material more easily. Previous work performed by the authors [19] confirmed that once expanded cork board was fully saturated and left to dry it lost more than a half of its initial water content in the first nine hours of drying, mostly due to the action of gravity.

The influence of gravity and water percolation are considered negligible in the drying process of most porous building materials and therefore they have not been regarded as very relevant in heat and moisture transfer modelling tools.

The literature contains various numerical simulation tools that can handle the coupled heat, air and moisture phenomena and accurately capture the hygrothermal behavior of building components and their influence on the indoor environment. To study the moisture transport in building walls and the interface phenomena, Freitas et al. [20] developed a finite difference computer program based on the Luiykov and Philip-De Vries theory. The numerical results were found to be satisfactory when compared with experimental water content profiles obtained by using gamma-ray equipment. Künzel [21] developed a calculation method for one and two dimensional simultaneous heat and moisture transport in multi-layered building components, using vapor pressure and relative humidity as driving potentials for vapor and liquid transport. The model also takes into account rain and solar radiation so that the effect of the weather conditions on the heat and moisture transfer in building components could be calculated more realistically. The validation of the model against several experimental results shows its relative suitability for simulating two-dimensional moisture transport processes in building components. Škerget et al. [22] developed a two-dimensional time dependent boundary element formulation to solve the coupled heat and mass transfer through a porous medium. The numerical results were found to be in good agreement with benchmark examples, even in the presence of highly nonlinear coupled heat and moisture transfer. The authors concluded that, in this case, because of the several orders of magnitude difference between heat and mass diffusion coefficients, the time and length scales are very different, and the numerical solution becomes arduous. More recently, Škerget et al. [23] further developed that formulation to include the airflow through the porous medium. A good agreement was achieved between the numerical results and benchmark examples, indicating that this technique can be used to simulate the hygrothermal performance of building envelope components. Evrard et al. [24] simulated the hygrothermal performance of a brick wall insulated on its interior surface with LH plaster, which was coated with a traditional lime render and no vapor barrier was considered. The simulations were performed using WUFI® Pro. The liquid transfer coefficients were calculated based on the absorption coefficient, following Künzel's exponential law. The results showed that results can be unrealistic if the absorption coefficient of materials is neglected, especially when the wall is exposed to high levels of driving rain.

Besides the complexity of the algorithms, they all require a reliable set of properties of porous materials that are very difficult to evaluate and not always available in the literature. The experimental approach is an alternative to the numerical simulation tools. Some researchers conducted their studies using external test cells or in situ monitoring. Ibrahima et al. [25] used the south wall test cell of a small-scale building to evaluate the hygrothermal performance, under real weather conditions, of an insulating rendering based on silica–aerogels. The results were used to validate a numerical model developed using WUFI® pro 5.1. Bianco et al. [26], used a test cell located in Turin and a long term monitoring campaign to assess both the biometric parameters and the energy-related issues of a vertical greenery module system. Barreira and Freitas [27] monitored a building with four façades covered with ETICS for one year to assess its hygrothermal behavior, that is, to study the influence of cardinal orientation on surface humidification induced by wind-driven rain and condensation.

Although the use of exterior test cells or in-situ monitoring will yield results for real weather conditions, these methods require long term monitoring, with long term availability of the measurement devices. An alternative for both steady-state and transient conditions is to use a hot box, which can test full-scale samples such as construction elements of building envelopes. It has many advantages: the desired conditions in both chambers are easily imposed; transient or steady-state regimes that simulate winter and summer weather conditions can be studied in a relatively short period of time; and the same test conditions can be replicated for other wall assemblies. Research on building elements using a hot box apparatus has been carried out by several authors. Gao et al. [28] focused their research on heat transfer thought two types of walls made of small-size hollow concrete blocks in dynamic conditions. To validate a simplified numerical tool developed by the authors, a hot box apparatus was used to validate the numerical model. Adam and Jones [29] defined the thermal properties of stabilized hollow earth blocks using the guarded hot box method. A calibrated hot box was used by Wakili and Tanner to study the U-value of a dried wall made from vertically perforated porous clay bricks [30]. The heterogeneity and rough surface characteristics of wall blocks made of pumice aggregate concrete, which are increasingly used as a masonry wall unit in Turkey, led Kus et al. [31] to conduct a study on the hygrothermal performance of these blocks using the calibrated hot box method. Nardi et al. [32] validated the thermographic methods used to determine the thermal transmittance of building components by imposing different operational conditions on the controlled environment of a guarded hot box.

In this work, a hot box is adapted to simulate the action of driving rain. A wetting apparatus that creates horizontal water spray was developed to study the hygrothermal behavior of medium density expanded cork boards under exposure to various weather conditions, in both dry and wet conditions.