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Experimental assessment of the water content influence on thermo-acoustic performance of building insulation materials

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HIGHLIGHTS

- Five different materials were tested with a hot disk and an impedance tube.
- Samples were conditioned in order to make tests at different water contents.
- 190 tests of thermal conductivity and 370 tests of sound absorption were performed.
- Thermal conductivity increases with water content, as expected.
- Sound absorption coefficient is almost independent from water content.

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ABSTRACT

Nowadays, a large number of materials for thermal and acoustic insulation are available on the market. Therefore, some criteria need to be defined to support designers in the selection, which should be based, among other properties, on the overall assessment of the thermo-acoustic and hygrometric performance, at the aim of ensuring good energy performance of the buildings and adequate acoustic comfort conditions. The influence of water content on thermo-acoustic performance of insulating materials is a topic that deserves special attention. However, the analysis of the scientific literature shows that this aspect has always been underestimated, especially in the acoustic field. Insulating materials react differently to the absorption of water, which depends mainly on its origin and structure. If placed in a high humidity environment, an insulating material may adsorb part of the water vapour contained in the air. Then, water vapour can be accumulated inside its porous structure, even in significant quantities, in relation to the weight of the material, so affecting its thermal and acoustic properties. Five different insulating materials used in the building sector were selected for the present study: mineral wool, polyurethane foam, melamine foam, kenaf and cork. Samples were conditioned in a climatic chamber at defined conditions of temperature and relative humidity, and tests of thermal conductivity with a hot disk apparatus and of sound absorption coefficient with an impedance tube were performed. A total number of 190 tests of thermal conductivity and 370 tests of sound absorption coefficient allowed to collect data in order to assess how these properties are affected by water content and if the effect varies for different materials. Results of thermal conductivity tests show a raise with increasing water contents; this outcome was expected, since water is worse than air as a thermal insulator, however, the way water content and thermal conductivity are correlated is different for the studied materials. As far as the influence of water content on sound absorption, which data are hard to find in scientific literature, results demonstrate that moisture does not affect significantly acoustic performance; nevertheless, for some of the examined materials, i.e. those of natural origin, a correlation between the two parameters exists.

1. Introduction

Buildings thermal and energy performance strongly depends on the thermal characteristics of the envelope [1,2]. In particular, for opaque walls, thermal conductivity of each component determines its thermal transmittance, which is the main descriptor of thermal insulation. The influence of operating temperature and moisture content on thermal conductivity varies with the type of insulation, and depends on the composition, properties and internal structure of the materials, which in turn determines the heat transfer mode

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and the ability of the material to accumulate the humidity, i.e. its hygroscopicity.

The effect of moisture content on the thermal performance of building insulating materials has been the subject of numerous studies in literature, while limited contributions were found for the acoustic performance.

Concerning thermal properties, the majority focused mainly on the effect of varying operating temperature, giving only some hints about moisture content. A research performed by Gur'ev et al. [3] on fibrous materials showed that the moisture content influences considerably their thermal conductivity. In particular, comparing their results with those already present in the literature, they observed that a 1% increase in volume of the water content in a fibrous structure with density up to 150 kg/m^3 results in an increase of the thermal conductivity equal to 8%.

Jerman et al. [4] studied two common materials used for the thermal insulation, namely mineral wool and expanded polystyrene. They observed that the thermal conductivity of mineral wool rises very quickly with increasing humidity, passing from a λ-value equal to 0.041 W/mK in dry conditions, to 0.700 ÷ 0.900 W/mK in saturated conditions (achieved by immersing the specimens in water), while in the case of relatively low moisture contents, equal to 5 ÷ 20% in volume, the thermal conductivity was typically between 0.10 and 0.14 W/mK. On the contrary, expanded polystyrene is scarcely affected by moisture content: λ-value was 0.037 W/mK in dry conditions and 0.051 W/mK in saturated conditions; in case of moisture content equal to 5 ÷ 20% in volume, the influence of water content was undetectable.

Budaiwi and Abdou have conducted two interesting researches to investigate this topic. The first one [5] was focused on the influence of temperature on λ-value and was conducted on several samples of glass wool, mineral wool, polyethylene, expanded polystyrene and extruded polystyrene. They found that higher operating temperatures are always associated with higher thermal conductivity. Furthermore, the effects of temperature result higher for materials with lower density, a circumstance that may be explained by the presence of a higher amount of air and, consequently, by more pronounced convective and radiative heat transfer phenomena. In their second paper [6], authors measured the thermal conductivity of several samples of glass and mineral wool at different temperatures and moisture content. They found that, for fibrous materials, higher temperature and moisture content are always associated with higher λ-value, and that λ-value is influenced by the initial value of the moisture content and by the wetting/drying history.

Hedlin [7] measured the variability of the heat flux transmitted through a flat roof insulated with glass wool in presence of several degrees of moisture. Tests were performed in the summer period, when daily temperature variations become important and condensation-evaporation phenomena occur inside the insulating material. The author showed that a significant increase in energy exchange exists for moisture contents lower than 1% by volume.

Karamanos et al. [8] investigated how temperature and moisture affect the thermal conductivity of mineral wool. Moisture is non-influential at high temperatures, since water evaporates and temperature is the only parameter affecting thermal conductivity. On the contrary, at lower temperatures, such as the ones of building applications, moisture is the most important factor, because of the condensed vapour trapped beneath the fibres. In particular, when mineral wool is exposed to long term humidity, its thermal conductivity becomes similar to that of masonry, i.e. it cannot be considered an insulating material anymore. However, when dry conditions are restored, thermal conductivity returns to its initial value, since water does not influence the fibres constituting the mineral wool.

Opposite to what is seen for thermal insulation, very few studies dealing with the effect of the water content on the sound absorption properties of porous materials can be found in scientific literature. Furthermore, all the models currently used to assess the acoustic properties of porous materials are based on the Biot's theory on wave propagation inside poro-elastic materials, and do not take into account the influence of water. The general behaviour of sound absorbing materials is thoroughly exposed in [9–11].

Ando et al. [12] tested a layer of mineral wool in environments with different relative humidity and, even if they did not measure the material water content, they concluded that the absorption depends on humidity. On the contrary, Godshall et al. [13] tested wood-based panels and found no detectable correlations between sound absorption and environmental humidity. The most recent and accurate paper is the one by Green et al. [14]. Again, this study showed that the sound absorption of all the investigated materials (resinated cotton, cotton, polyamide and polyurethane foam, microfiber plaster, rigid glass and PET fibre) was not clearly influenced by their water content.

A recent paper by D'Alessandro et al. [15] evaluated experimentally the influence of water content on normal incidence sound absorption coefficient of two natural materials, namely straw and reeds. As far as loose straw, the results highlighted no correlation between the water content and the sound absorption coefficient. The effect becomes more evident for reed samples, since water seems affecting directly the matrix of the porous material: the diameters of the reeds stalks tend to increase with higher values of water content. Two configurations of reed panels were tested: longitudinal and perpendicular, where the reed stalks are respectively parallel and perpendicular to the direction of the plane incident acoustic wave inside the impedance tube. In longitudinal samples, the water content increase led to a slight improvement of sound absorption and the coefficient of determination R^2 between water content and sound absorption coefficient was about 0.95. The influence of water content was more significant for perpendicular samples: in this case, the increase of water content caused a substantial decrease of sound absorption, with a reduction of the amplitude of the absorption peak and a shift towards lowest frequencies, with the coefficient of determination R^2 equal to about 0.80.

At the light of the previous analyses, the present study is aimed at investigating the influence of the water content on both the thermal and acoustic performance of different materials currently used as building insulators. Materials were conditioned using an environmental chamber and then tested at different water contents with a hot disk apparatus and with an impedance tube, in order to assess thermal conductivity and normal incidence sound absorption coefficient, respectively. More than 500 tests (190 for thermal conductivity and 370 for sound absorption coefficient) allowed to obtain a large set of data. Processing of the experimental data and the subsequent critical analysis were used to suggest hypotheses about the relationship between the thermo-acoustic performance of the investigated materials and the water content.

2. Material and methods

2.1. Materials selection and characteristics

In recent decades the thermal resistance of buildings has undergone many changes and, consequently, the same happened to materials used as insulators. Nowadays, a large variety of building thermo-acoustic materials is available on the market. They can be classified in different ways, considering their physical or chemical structure, origin and composition.