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Measuring the hygroscopic properties of porous media in transient regime. From the material level to the whole building HAM simulation of a coated room.

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Abstract

Moisture level inside buildings is a key factor influencing the durability of construction, indoor air quality, thermal comfort and energy performance. Numerical simulation can be used to predict the hygric inertia of a room, but reliable material data are needed as inputs for the model.
Although the advancement of numerical models for whole building HAM (Heat Air and Moisture) transfer, a general need for more experimental data able to quantify the hygroscopic performance of porous building material remains. Recent benchmark data for validating 1-D HAM simulation models proposed in international projects are based on numerical and analytical data, while well-documented and accurate data are scarce. In IEA Annex 41 new numerical models have been implemented and used to simulate the HAM interaction between indoor air and hygroscopic materials during transient changes in indoor humidity due to internal moisture gains. Some experimental data obtained in dynamic humidity regime are presented in this study. The goal is to validate models that represent the moisture buffering of hygroscopic materials in contact with indoor air,.
In order to fit the experimental data with numerical simulation and to determine the most influencing hygroscopic material properties in HAM modeling, a sensitivity analysis on the numerical fitting of measured properties relevant for indoor moisture buffering, such as the water vapour permeability and the sorption isotherm was carried out. Material data have been monitored using a climate chamber device especially designed for this purpose. In Italian buildings, especially dwellings, walls are very often plastered with gypsum plaster for levelling purposes. The gypsum plaster is generally covered with waterborne wall paint for decoration which represents a barrier for the water absorption or desorption. In order to assess the hygric performance of a room in real conditions, the influence of the water transfer properties of the painted gypsum on the whole building HAM dynamic simulation is assessed considering both an uncoated and a coated room using a waterborne paint.

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Keywords: moisture buffering; hygroscopic properties; vapour permeability; coating

1. Introduction

The moisture buffering can improve comfort, air quality and energy consumption in buildings [1,2,3]. In recent studies and international research projects [4] HAM (Heat Air and Moisture) numerical models have been developed to simulate the interaction between indoor air and hygroscopic materials during transient changes in indoor humidity due to internal moisture gains. Recent benchmark data for validating 1-D HAM simulation models [5] are based on numerical and analytical data, while well-documented and accurate data are scarce: this leads to a general need for more experimental data able to quantify the heat, air and moisture transfer between humid air and hygroscopic media during transient changes in air humidity itself. Experimental data are available from literature [6,7,8,9,10]; despite this, the measurement of hygroscopic properties of porous building materials under transient conditions leads to the characterization of the material when applied in realistic conditions, such as interior finishing for rooms, where peaks of moisture due to occupancy or vapour production occur. The un-steady regime doesn't account for reaching the moisture equilibrium content in specimens, but for load/release cycles in order to determine the hygroscopic properties in a less time-consuming way. In this study experimental data with dynamic humidity regime are obtained and presented.

Since performing a reliable and fast fitting of the measured material properties still represents an open issue [11,12] in the present study simulated data have been matched with experimental data to determine the hygroscopic material properties of gypsum plaster for HAM modelling. Objectives of this study are: 1) measuring the hygroscopic properties of gypsum plaster specimens in transient regime; 2) fitting between experimental and simulated data; 3) evaluating the hygroscopic performance of a simple room by means of numerical simulation. A sensitivity analysis on the numerical fitting of measured properties relevant for indoor moisture buffering, such as the water vapour permeability and the sorption isotherm was carried out. Material data have been monitored using a climate chamber device especially designed for this purpose [13].

Nomenclature

RH	relative humidity [%]
t	time [s]
w	water content [kg_v/m^3]
β	surface moisture transfer coefficient [kg/(m s Pa)]
δ	water vapour permeability [kg/(m s Pa)]
φ	relative humidity [-]
MBV	Moisture Buffer Value [kg/(m^2 RH)]

2. Material and methods

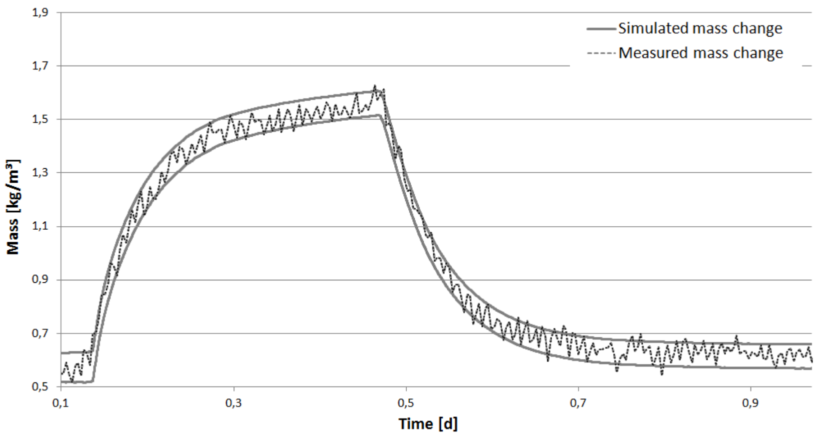
2.1. Measuring system

In order to evaluate the hygroscopic properties of gypsum plaster, some sorption/desorption step cycles were planned. The change in mass due to cyclically varying humidities was measured within a plexiglass climate chamber where conditioned air is supplied trough a pre and return hose deriving from a mixing box. Moist air is set at specified levels of temperature and relative humidity through a remote control system. The specimen inside the climate chamber is sealed in a box made of XPS, where only the front surface is subjected to the conditioned air. The gypsum plaster specimen has been automatically weighed every 60 seconds for 30 days, setting its dry density as Tara; temperature and relative humidity were also continuously monitored through sensors positioned in front of and behind the XPS box. To minimize the external influences the measuring system has been built in a controlled climate room with a temperature of 22°C and a relative humidity of 50%. Relative humidity in front and behind the specimen and change in mass were monitored for 3 different relative humidity ranges (30-50%, 50-70%, 70-90%), during both increasing and decreasing trends of air humidity (Figure 1). The covered range of relative humidity will allow the evaluation of the material behavior in the hygroscopic region, excluding liquid transport (φ > 98%). Temperature was maintained constant throughout the experiment (23°C).

2.2. Simulation of sorption and desorption cycles

The adopted methodology for the calculation of the vapour permeability and of the equilibrium moisture content at the different relative humidity steps is based on the control volumes method. The 10 mm thick specimen was discretized in 5 internal nodes (cells) and 2 surface nodes. Since the measurements in the climate chamber provided the vapour pressure to both sides of the specimen and the change in mass according to the humidity variations, the vapour permeability and the equilibrium moisture content was calculated starting from Fick's first law equation [13]. As the simulation approach neglects the effect of hysteresis in the sorption/desorption process and assumes a local equilibrium between air and material, a sensitivity analysis on the fitted measured properties relevant for indoor moisture buffering, such as the water vapour permeability and the sorption isotherm, was carried out in order to demonstrate how much their dynamic variation influences HAM simulation for whole room hygroscopic performance. Because of the oscillation due to the measurement device uncertainty, the moisture uptake and release has been fitted by two different simulated curves for each RH transient step; both curves range between the upper and lower edge of the measured data (Figure 1).

Fig. 1. The upper and lower fitting curves of sorption/desorption cycle for 30-50% RH step change. Gypsum plaster.



The described process lead to the determination of different permeability values, according to the fitting curve adopted for each transient sorption/desorption step: a range of values is therefore generated from the whole fitting process (Figure 2). In order to evaluate how much the spread on results could affect the hygroscopic performance of the material at room level within the HAM-Tools simulation, a sensitivity analysis was performed taking into account: 1) the minimum and maximum value of vapour permeability; 2) the sorption and desorption curves, as border line boundary conditions. A previous study demonstrated how the uncertainty on the choice of the vapour permeability value within the generated range of values could be neglected if compared to the influence of room factors, such as the ventilation rate [14], when the hygroscopic region is considered (φ < 0,98).

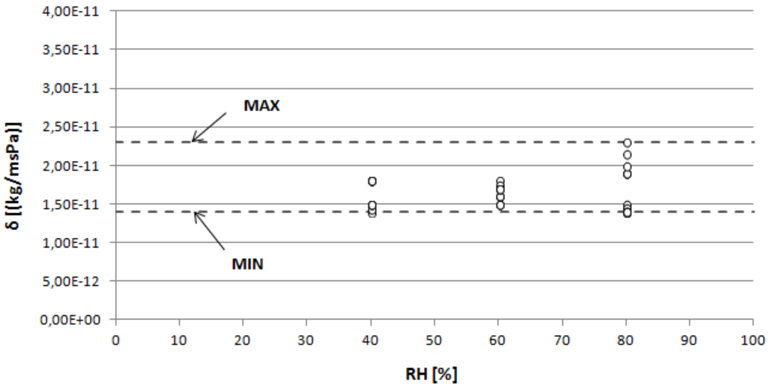


Fig. 2. The calculated cloud of vapour permeability values for gypsum plaster.

For this reason a unique RH step change of 33-75 % ΔRH as for the Moisture Buffer Value (MBV – see section below) was recommended to evaluate the hygroscopic properties of the material by means of numerical fitting, instead of considering the whole range of relative humidity (30-90% in 3 steps). This aims to perform reliable and time-saving measurements campaigns but also to calculate a parameter internationally acknowledged for comparing the hygric performances of different materials such as the MBV.

3. Results

3.1. MBV test simulation

The adopted numerical model was then validated by fitting the measured data for a coated gypsum plaster specimen during the Moisture Buffer Value RH step cycle, which was carried out according to the NORDTEST Protocol scheme [15]. The adopted coating was a commercially available waterborne paint. The results obtained from the adopted numerical model where compared to those achieved with MBVsim, a specific arrangement of HAM-Tools – a library for dynamic simulation on the Simulink platform of building physics phenomena in transient regime [12].

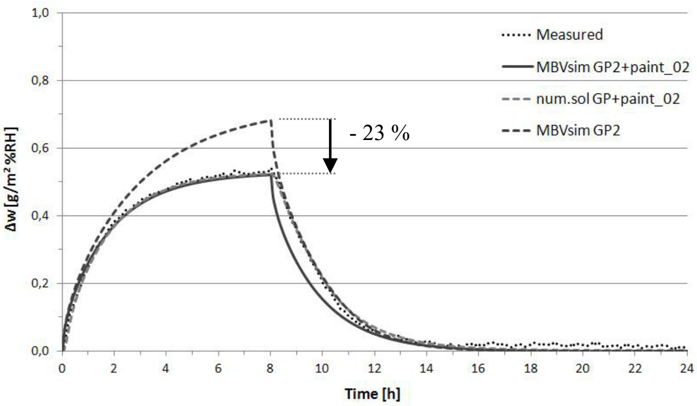


Fig. 3. The MBV test simulation according to the adopted numerical model and to HAM-Tools. The fitting with the measured data and the comparison to the MBV test simulation for the uncoated material is provided.

Figure 3 shows how the numerical solutions of both models fit the real behaviour with good agreement, validating the reliability of MBVsim. A comparison with the MBV test simulation for the uncoated element was carried out in order to highlight the influence of the coating on the hygroscopic performance of the plaster at material level: a 23% decrease of the MBV level was performed by the coated specimen.

3.2. Whole room simulation

Once the behaviour of the coated and uncoated gypsum plaster was calculated at material level depending on a defined RH step change of the indoor RH, the simulation at room level was carried out in order to evaluate the influence of hygroscopic performance of the plaster on the environment. The whole room simulation was performed by using HAM-Tools. A simple room with 3 layers exterior walls was chosen as case study: 10 cm foam insulation, 25 cm aerated concrete, 3 cm gypsum plaster. The walls and the ceiling were considered covered with the plaster. The simulation has been carried out for the first week of January with Turin weather data by using HAM-Tools. In the 55 m^3 volume room the air temperature was maintained constant (20°C), while the relative humidity was left floating and monitored; no solar radiation through openings is taken into account [16]. A moisture gain of 40 g/h per person was set for 10 people from 9 to 17 h. The outdoor and indoor moisture transfer coefficient are $\beta_e = 2 \cdot 10^{-7}$ and $\beta_i = 2 \cdot 10^{-8}$ kg/(m·s·Pa) respectively; an air change rate of 0-0,3-1 h^{-1} through a mechanical ventilation system with outdoor relative humidity is simulated.

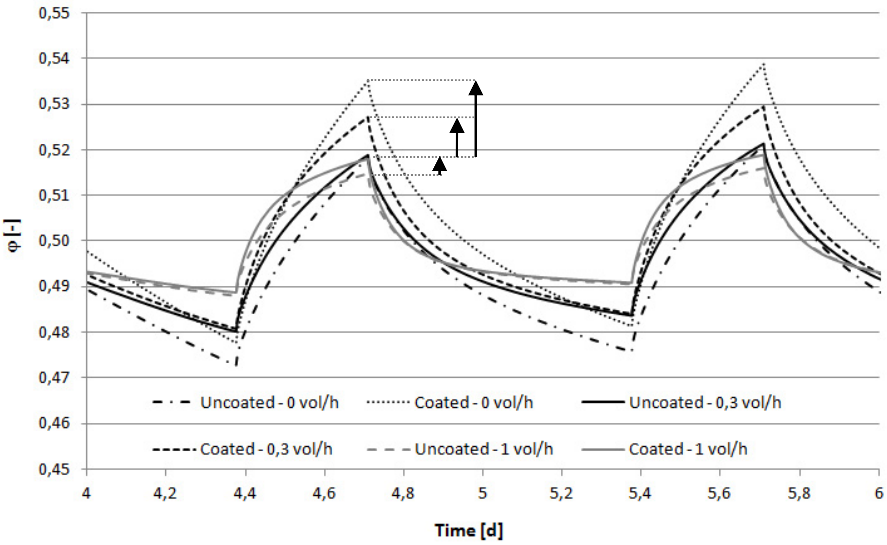


Fig. 4. Simulations of the RH trends inside the simple room (4^{th}-5^{th} day). Results for 0-0,3-1 h^{-1} ventilation rate for both coated and uncoated gypsum plaster finishing.

In the considered scenarios the effect of a painted or unpainted room on the RH trend is visible, as the influence of the ventilation on the hygroscopic performance of the building components. Starting from the unventilated conditions, the increase of the air flow rate leads to a decrease of the plaster contribute in dampening the RH peaks. For the presented case study and materials, the maximum ΔRH is achieved for the unventilated room scenario with an average value of about 2% at the peaks. It is visible how the application of the paint affects the permeability of the material, and consequently the slope of the RH curve, due to a much slower absorption and desorption phase. By increasing the ventilation rate to 0,3 and 1 h^{-1} the distance between the 2 peaks decreases, since the outdoor air humidity becomes the dominant parameter and the influence of the material properties is gradually reduced as well as the moisture gain impact on the oscillation amplitude of indoor RH.

4. Conclusions

Performing a reliable and fast fitting of the measured material properties still represents an open issue. The determination of the hygroscopic properties still rely largely on time-consuming measurements in steady-state conditions (dry-wet cup tests), while the real behaviour of the material in transient conditions would deserve special attention. In this study a methodology for matching simulated and measured data to determine the hygroscopic material properties of building materials was presented. A simplified numerical model for fitting experimental data from measurements in transient conditions was used to calculate the vapour permeability and the sorption isotherm of gypsum plaster, in order to simulate a whole room hygroscopic performance by means of HAM modelling. A comparison between coated and uncoated interior finishing aimed at demonstrating how common and widespread habits as that of painting the interior of residential environments may affect the indoor hygrothermal comfort, i.e. the increase of the relative humidity level. In the study was also identified how much the most influencing parameter among material properties, moisture gain and ventilation, or rather the air flow rate, affects the indoor RH trend.

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