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Dataset for validating 1-D heat and mass transfer models within building walls with hygroscopic materials

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ABSTRACT

To assist with the correct design of buildings, many computational models have been developed to assess the transient heat, air, and moisture (HAM) transfer within building walls. Validation of these computational models is essential to gain confidence in the codes.

This paper provides datasets for validating 1-D heat and mass transfer models step by step, gradually increasing the complexity of a multilayer wall with hygroscopic components. The experiments were performed using a double climatic chamber. The climatic conditions on either side of the wall progress from the simplest boundary conditions (isothermal) to more complex ones with oscillations that mimic the mid-season period. To assess the hygrothermal response of the tested walls under such climatic conditions, the conditions of ambient air and the temperature and humidity profiles within the wall thickness are monitored during the test. This paper gives some detailed information on the chamber design, the instrumentation, the materials, and the climatic conditions so that other researchers can use the collected data for validation of their models or to build future test facilities. The results obtained with the test facility highlight the coupling that exists between heat and mass transfers across multilayer walls using hygroscopic components. The heat release by moisture adsorption is observed in the temperatures profiles. During the mid-season period, the results show the differences of the phase shift and the amplitude attenuation of the temperature and the water vapour pressure across the wall thickness.
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1. Introduction

The design of modern buildings requires consideration of energy efficiency, environmental and indoor air quality, and cost limitations. To meet these requirements, new building structures and systems for heating and ventilation have become increasingly complicated. A greater risk of moisture damage occurs for low-energy buildings when wrong choices are made regarding energy saving. In parallel, these requirements have increased the use of wood and bio-based materials in the building walls. Several researchers have shown that such hygroscopic materials are able to moderate the indoor humidity levels, which improves the thermal comfort, increases the perceived air quality, reduces the risks of biological growth in the wall materials, and can provide low energy consumption [1–5].

To assist with the correct design of buildings, many computational models have been developed over the years to assess the transient heat, air, and moisture (HAM) transfer within building walls [6–10]. Validation of these computational models is essential to gain confidence in the codes. In this way, some experimental works were done either on a single hygroscopic material in some specific configuration [11–14] or on a multilayer wall [15–17]. In the latter case, a differentiation can be made between tested walls of which one side is exposed to real atmospheric boundary conditions [15,17] and tested walls submitted to controlled conditions on both sides [13,16]. However, several of these works [7,16–18] found some differences between the measurements and numerical simulations in the case of climatic conditions having transient boundaries with highly hygroscopic materials like wood and wood-based material.

The main purpose of this paper is to provide datasets for validating 1-D heat and mass transfer models step by step, gradually increasing the complexity of the multilayer wall with hygroscopic components. The walls are subjected to boundary conditions from the simplest to the more complex. It is unusual for generated datasets to be made available for other researchers to validate their own models. Like the data collected by Desta et al. [15] and Belleghem et al. [13], our data are made available. The first part of this

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paper describes the experimental set-up. This section gives some detailed information on the climatic chamber design, the instrumentation, the materials, and the climatic conditions so that other researchers can use the collected data for validation of their models or to build future test facilities. In the second part, the measured data are presented and analysed. The last part of the paper provides the main material properties of the tested walls for supplying the computational models.

2. Material and methods

2.1. Experimental setup

A new double climatic chamber (Fig. 1) was built in 2009–2010 at the Laboratory of Studies and Research on Wood Material (LERMAB) at the School of Wood Science and Timber Engineering (ENSTIB) in Epinal, France. This test facility was designed for the study of the hygrothermal behaviour of building envelope materials exposed to controlled boundary conditions. The equipment consists of an outer chamber and an inner chamber between which the tested wall is installed. Each chamber measures 2.80 m wide and 3 m long with a height of 2.80 m. Thus the facility allows testing of wall samples with a measuring area of up to 2.80 m × 2.80 m. A schematic diagram of the double climatic chamber is given in Fig. 2. The outer and inner chamber walls are insulated and made air- and vapour-tight by using 120 mm of polyurethane and aluminium foil sandwich panels. To avoid heat and moisture exchange with the surroundings and to ensure mono-dimensional heat and mass transfer in the tested walls, the wall perimeter is enveloped with the following material layers: 100 mm of mineral wool/60 mm of polyurethane and aluminium foil sandwich panels/vapour barrier.

The outer chamber is used to mimic the temperature and humidity of the outdoor climate, while the inner chamber reproduces an indoor climate. For this purpose, heating, cooling, humidification, and dehumidification units are installed inside each chamber. This equipment makes it possible to reproduce conditions in the ranges of [−15; +45] °C for the dry bulb temperature (T) and [30; 95]% for the relative humidity (RH) in the outer chamber and [0; +30] °C for T and [30; 95]% for RH in the inner chamber. The double climatic chamber also includes a data acquisition system based on National Instruments technology and a computer-controlled program to manage the temperature and humidity regulation. To achieve fast and accurate humidity regulation in both

Fig. 1. The double climatic chamber.

chambers, the control of humidity by the computer program is based on the absolute humidity of the ambient air measured in the chamber. With this method, humidity fluctuations due to the regulation are significantly reduced compared to regulation with relative humidity because absolute humidity is independent of temperature variations.

Note that the regulation units and the acquisition systems are more extensively described in Rafidiarison et al. [18–20].

2.2. Instrumentation

To assess the hygrothermal response of the tested wall under defined climatic conditions, the ambient air (in the outer and inner chambers) conditions and the temperature and humidity profiles within the wall thickness are monitored during the test.

For ambient air monitoring, temperature and relative humidity are measured with a total of nine SHT 75 sensors from the company Sensirion. These sensors include a capacitive sensor for humidity measurement and a band-gap sensor for temperature measurement. SHT 75 sensors have the advantages of having long-term stability and being individually calibrated to ±1.8% RH and ±0.3 °C in our test temperature and RH ranges. In each chamber, the sensors are installed at nine locations according to a regular grid: at heights of 0.607, 1.257, and 1.907 m and widths of 0.626, 1.276, and 1.927 m, as shown in Fig. 3.

A total of nine T-type thermocouples (0.25 mm diameter wires) with an accuracy of ±0.5 °C are used to measure the wall surface temperature, as shown in Fig. 3. The humidity close to the wall surface is measured with SHT 75 sensors.

To minimize turbulence and ensure a uniform air flow distribution along the test walls, a fine mesh net was installed in both chambers between the regulation units and the ambient air.

Air speeds in the chambers' ambient air are also measured on three different heights (0.6 m, 1.25 m et 1.9 m from the floor) at a distance of 0.15 m from the wall surfaces. In the inner chamber, HD 4V3 TS2 Omni-directional anemometers of Delta Ohm are used: ± (0.03 m/s + 2% of measured value)) in the range [0; 5] m/s. As the HD 4V3 TS2 cannot be used at negative temperature, air speed in the outer chamber was then measured with two types of hot wire anemometers:

- HD 103 T-O of Delta Ohm (±0, 04 m/s in the range[0, 05; 0.99] m/s and ±0. 2 m/s in the range [1; 5] m/s),
- EE75 of E + E Elektronik: ± (0. 1 m/s + 1% of measured value) in the range [0; 10] m/s.

The distribution and measured values (maximum of 0.1 m/s, values available with all datasets) of air speed show a uniform and low air flow along the test walls.

The evolution of temperature and humidity within the tested wall materials is monitored using SHT 75 temperature and humidity sensors. The method used in this study for material humidity measurement is based on the assessment of the hygrothermal characteristic of the air in contact with a porous material. In the transient stage, the time characteristics of the heat and mass change are much lower in the air than within the porous material (some seconds compared with some minutes or hours). Consequently, the transfer in the air can be considered as a quasi-steady state [21]. This means that the measured hygrothermal response of the air depends mainly on the variation of boundary conditions with the porous material: the air around the material can then be assumed to be in instantaneous equilibrium with the material. For the measurement, SHT 75 sensors are installed in little gaps at different locations in the materials and provide the temperature and RH of the air gap around the material. Thanks to the

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