



Comparison of the Saturated Salt Solution and the Dynamic Vapor Sorption techniques based on the measured sorption isotherm of barley straw



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HIGHLIGHTS

- Sorption isotherm of barley straw was measured with two techniques.
- An experimental procedure was developed for the DVS technique.
- The DVS technique gave excellent repeatability and reproducibility results.
- The differences between the two sorption isotherm were within the uncertainty range.

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ABSTRACT

For Heat, Air and Moisture modelling, one of the most crucial hygrothermal properties of porous construction materials is the sorption isotherm. Current techniques for measuring the sorption isotherm rely on the standardized Saturated Salt Solution (SSS) method which is known to be time consuming. Recently, a device called Dynamic Vapor Sorption was applied on building materials allowing faster measurements but limiting the mass and volume of the sample. As this technique is not yet standardized, an experimental procedure was developed and validated on barley straw. Results were also in good agreement with the measurements from the SSS technique.

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1. Introduction

In buildings, moisture has an influence on comfort, energy consumption and durability [1]. Most construction materials exchange water vapor with their surroundings, and this water vapor makes up as much as one third of the total moisture released into the indoor air according to [2]. Hence, assessing moisture transfer at room or building scale is crucial and relies on simulation through Heat, Air and Moisture (HAM) models. Nowadays, as many as 50 different models can be found as noted in [3]. Although every model has its own specificities, they all rely on the water mass balance [4], which can be expressed as follows:

$$\frac{\partial w}{\partial t} = -\nabla(\vec{g}) \quad (1)$$

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Most of the time, the models differ on the expression of the flux (right hand side of (1)). For the left hand term, however, there is a stronger consensus that it can be decomposed as presented in [5] when the moisture transfer is limited to the hygroscopic area:

$$\frac{\partial w}{\partial t} = \frac{\partial w}{\partial \varphi} \cdot \frac{\partial \varphi}{\partial t} = \xi \cdot \frac{\partial \varphi}{\partial t} \quad (2)$$

ξ , sometimes referred to as the sorption capacity, represents the variation of the moisture content of the material for a given variation of relative humidity (φ). It also corresponds to the slope of the sorption isotherm, which has to be determined experimentally. Consequently, knowing the sorption isotherm is a key step in the comprehension of moisture transfer and its modelling. To determine the sorption curves, samples are exposed to constant temperature and relative humidity until their mass stabilizes. By comparison with the mass obtained in the dry state (i.e. the mass obtained for $\varphi = 0\%$), it is possible to determine the moisture content for the relative humidity in question. Then, samples are exposed to monotonically increasing values of relative humidity

Nomenclature

Latin symbols

A, B, C	fitting parameters, –
b	moisture effusivity, $\text{kg}\cdot\text{s}^{-1}\cdot\text{m}^{-1}\cdot\text{Pa}^{-1}$
g	flux, $\text{kg}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
k	coverage factor, –
l	fitting parameter, –
M	molar mass, $\text{kg}\cdot\text{mol}^{-1}$
m	mass of the sample, kg
n	number of points, –
N	number of samples, –
P	pressure, Pa
p	fitting parameter, –
q	number of parameters, –
R	ideal gas constant, $\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
u	uncertainty, –
T	temperature, K
t	time, s
U	global uncertainty, –
x	variable, –

w water content, %

Greek symbols

δ	water vapor permeability, $\text{kg}\cdot(\text{m}^2\cdot\text{s}\cdot\text{Pa})^{-1}$
μ	mean value, –
ρ	density, $\text{kg}\cdot\text{m}^{-3}$
ξ	sorption capacity, $(\text{kg}\cdot\text{kg}^{-1})$
σ	standard deviation, –
ϕ	relative humidity, [0:1]

Subscripts

a	A-type (or random)
b	B-type (or systematic)
Disp	display
h	holder
Lin	linearity
o	dry state
s	saturation
v	vapor
w	water

so that the absorption curve can be plotted. Repeating the procedure for monotonically decreasing values of relative humidity allows the desorption curve to be plotted. The complete method is described in standard NF EN ISO 12571 [6].

The most common technique relies on the use of Saturated Salt Solution (SSS) to obtain a stable value of relative humidity. It should be underlined that SSS were used for calibrating relative humidity sensors [7] until recently. Consequently, SSS should be used if very good accuracy is desired. However, several researchers have acknowledged that this method is very time-consuming, as stated by [8] for example. It was also acknowledged that the increase of the experiment's duration leads to a greater chance of experimental errors. Improving the accuracy of such measurements is an on-going topic, as poor reproducibility of hygric properties has been reported in [9–11]. Even though the discrepancies in the sorption values were reasonable compared to other hygric properties, they should be determined precisely so that the reliability of simulation works can be addressed. This can be handled by determining the experimental uncertainty using well-established calculations, as presented in [12], and allows the most influential sources to be identified. For example, Feng et al. [11] concluded that reliable results could be obtained with the SSS technique by one laboratory but that significantly higher differences were observed when the results obtained by different laboratories were compared. This conclusion also stresses the need for a precisely defined experimental protocol. Finally, knowledge of the uncertainty of the material properties is required if a sensitivity analysis is to be achieved, as in [13] for example. This technique determines how the uncertainty of the inputs influences the outputs. In the last mentioned study, it was concluded that the influence of the sorption isotherm on the modelling outcome (namely, the RH of indoor air) was not negligible.

For this reason, attempts have been made to reduce the duration of the tests. By assuming an excellent homogeneity of all the samples, one could divide the samples into small groups and subject each group to a different relative humidity. Feng et al. [14] used this method on autoclaved aerated concrete and compared the results to those obtained using the method proposed by NF EN ISO 12571. Alternatively, some authors have proposed relying on numerical techniques to predict the material properties, based on the analysis of dynamic behaviors. For example, inverse modelling of a MBV test (see [15] for a complete description)

was proposed in [16] using Bayesian techniques. Similarly, Rouchier et al. [17] used the Covariance Matrix Adaptation evolution strategy to solve an inverse HAM problem in a multi-layer wall exposed to real climatic conditions. Reasonable agreement was obtained between computed and measured sorption curves but significant differences were observed above 70% RH. Even though these approaches sound promising, they first have to be tested with respect to reliable values.

In recent years, a technique initially used in the pharmaceutical field and known as Dynamic Vapor Sorption (DVS) has been developed. This technique relies on the observation that the time for mass stabilization to be obtained depends directly on the mass. In consequence, using lighter samples leads to shorter tests. However, this is not straightforward as smaller samples may not be representative, especially for construction materials such as concrete, which is very heterogeneous. Having a representative material is of utmost importance for the DVS technique, this may explain why it is currently not very popular in the field of civil engineering. Nevertheless, some examples can be found in the literature as it can still be used for many construction materials. It was successfully used in [18] for 5 materials (autoclaved aerated concrete, lightweight ceramic brick, a phase change material, lime plaster and an old fashioned ceramic brick), in [19,20] for unfired clay bricks and earth blocks, and in [21] for natural fibers. Taking advantage of the shorter time needed to complete the experiment, some authors used the DVS technique to get a more comprehensive understanding of the physical phenomena. For example, Fort et al. [22] used this technique to investigate the influence of temperature on the sorption isotherm. In [23], it was stated that the particle size/surface area and pore diameter has a crucial role on the water sorption and desorption process for drug substances.

The SSS and the DVS techniques were already compared in the literature, as in [24] for 5 different materials (flax insulation, perlite insulation, cellulose insulation, glass wool insulation and cellular concrete). No significant difference was observed between the two techniques but it was pointed out that the determination of the dry mass had a significant effect. Good agreement was also obtained in [8] based on 5 different types of food. Despite the extensive use of this technique, it was observed that the literature is poor on detailed statistical analysis to compare the DVS and SSS techniques. Therefore, these comparisons are rather qualitative. Moreover, some other examples can be found where a lesser agree-

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