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ScienceDirect

Energy Procedia 133 (2017) 68–75

Energy Procedia

www.elsevier.com/locate/procedia

Climamed 2017 – Mediterranean Conference of HVAC; Historical buildings retrofit in the Mediterranean area, 12-13 May 2017, Matera, Italy

A PC-tool to calculate the Moisture Buffer Value

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Abstract

Hygroscopic building materials have the ability to moderate the relative humidity variation without the need for active systems. The moisture buffer phenomenon can be assessed by way of the Moisture Buffer Value (MBV). Some authors have pointed out that the MBV is sensitive to several parameters, however, there is no model that involves all them.

The aim of the developed PC-tool is to take into account all these variables to calculate the MBV of hygroscopic building materials. The material hygroscopic properties will be needed to solve the moisture storage and transport inside the porous materials and consequently to predict its MBV.

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Peer-review under responsibility of the scientific committee of the Climamed 2017 – Mediterranean Conference of HVAC; Historical buildings retrofit in the Mediterranean area

Keywords: Moisture Buffer Value; Moisture buffering; PC-tool; Hygroscopic building materials; Humidity.

1. Introduction

Related literature shows that indoor humidity has a significant effect on a variety of requirements: occupant comfort and health [1,2], indoor air quality [3], building durability [4] and energy consumption [5]. Besides, to satisfy the requirements of European Directives of Energy Efficiency [6], it is necessary to reduce both the energy consumption and the greenhouse gas emissions associated with the use of HVAC systems. As a consequence, the development of strategies based on passive systems to reduce the dependency of active systems in order to control the indoor humidity level has a research interest.

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Peer-review under responsibility of the scientific committee of the Climamed 2017 – Mediterranean Conference of HVAC; Historical buildings retrofit in the Mediterranean area
10.1016/j.egypro.2017.09.373

Hygroscopic inner coating materials and furnishing materials have the ability to naturally moderate the peaks of indoor relative humidity through their moisture capacity. This ability is called Moisture Buffering. To quantify this buffering ability it can be used the Moisture Buffer Value (MBV) proposed by Nordtest protocol [7]. This property quantifies the amount of moisture that a material can storage and release when the material is subjected to cyclic variations of the surrounding relative humidity.

Several authors [5,8-11] have pointed out that some hygroscopic building materials can affect the indoor air quality and the energy consumption of buildings by transferring, storing and releasing moisture. Predicting the moisture behavior of building materials and their buffering capacity can help to design and build buildings that maintain adequate indoor moisture levels in an efficient and sustainable way.

In this work we present a tool to simulate and predict the MBV of building materials considering all the parameters that have an impact on the phenomenon.

Nomenclature

A	exposed area, [m^2]
MBV_{ideal}	ideal Moisture Buffer Value, [$kg/(m^2 \cdot \%RH)$]
$MBV_{practical}$	practical Moisture Buffer Value, [$kg/(m^2 \cdot \%RH)$]
p_{sat}	saturation vapour pressure, [Pa]
b_m	moisture effusivity, [$kg/(m^2 \cdot Pa \cdot s^{1/2})$]
t_p	time period, [$s^{1/2}$]
w	moisture content, [kg/m^3]
m_{max}	maximum moisture mass, [kg]
m_{min}	minimum moisture mass, [kg]
δ	water vapour permeability, [$kg/(m \cdot s \cdot Pa)$]
φ	relative humidity, [º/1]
μ	water vapour resistance factor, [-]

2. Methodology

As has already been said, Nordtest protocol [7] defines the Moisture Buffer Value property. The protocol differentiates various definitions of the MBV depending on the factors that take part in the phenomenon of moisture buffering. The definition scheme is divided into three levels: material level, system level, and room level.

The material level is obtained from material properties without taking into account the influence of the surrounding climate. This definition is based on material properties which are determined under steady-state and equilibrium conditions.

The system level should be seen as a parameter that can describe the behavior of different components, such as interior surfaces with a surface coating. At this level, an experimental method proposed by Nordtest protocol [7] can be used so as to obtain the MBV. The time period for the moisture variations needs to be taken into account, which is not considered on the material level since the properties are obtained from a steady state. Likewise, other parameters such as the air velocity, have a significant effect on the results.

The last level considers the whole room, including the parameters of ventilation, heating, and cooling as well as all the building materials and interior objects.

The developed tool is focused on the material and system level where the MBV depends on the standard properties of the material analyzed and the tests conditions respectively.

The first definition, the ideal MBV, is calculated by the Fourier transform when the material is exposed to a periodic variation of relative humidity (33-75%) and constant temperature, which is defined as theoretical or ideal MBV. The definition assumes that the material has a thickness equal or greater than the moisture penetration depth. Furthermore, the surface film resistance and the nonlinearity of the material properties are negligible.

$$MBV_{ideal} \approx 0.00568 \cdot p_{sat} \cdot b_m \cdot \sqrt{t_p} \tag{1}$$

where p_{sat} [Pa] is the saturation vapour pressure, b_m [kg/(m^2·Pa·s$^{1/2}$)] is the moisture effusivity, and t_p [s$^{1/2}$] the time period.

The moisture effusivity is required to obtain the ideal MBV in equation (1). As shown in equation (2), the material properties (sorption isotherm and permeability) are needed in its calculation. Therefore, hygroscopic sorption test and cup test are essential to know them previously.

$$b_m = \sqrt{\frac{\delta_p \cdot \frac{\partial w}{\partial \varphi}}{p_{sat}}} \tag{2}$$

where δ_p [kg/(m·s·Pa)] is the water vapour permeability and $\partial w/\partial \varphi$ [kg/m^3] is the moisture capacity, which in turn means the slope of the sorption isotherm.

Although, it is not clear which is the best RH in order to calculate the ideal MBV, Roels and Janssen [12] point out that the mean value of the Nordtest protocol (54% RH) can be an acceptable estimation.

The system level definition is based on an experimental method where a sample is exposed to a cyclic variation of relative humidity obtaining the practical MBV. This definition takes into account the air velocity and the thickness of the sample. The test conditions can be reached by saturated salt solutions or a climatic chamber. In this case, the definition of the MBV is given by:

$$MBV = \frac{m_{\max} - m_{\min}}{A \cdot \left(\varphi_{high} - \varphi_{low}\right)} \tag{3}$$

where $m_{max/min}$ [kg] are the maximum and minimum moisture mass of the sample during the experiment, A [m^2] is the exposed surface of the sample, and $\varphi_{high/low}$ are the relative humidity levels used in the test.

3. The pc program

A PC tool has been designed in order to help the user to calculate the MBV of the materials. The program is able to calculate the ideal MBV using as input the sorption isotherm and the water vapour diffusion resistance factor. Furthermore, the user can calculate the practical MBV introducing the thickness of the sample and the air velocity of the simulated experiment.

3.1. Sorption isotherm

The user can choose between introducing the sorption isotherm function (in case the user knows it) or introducing the experimental data form of the hygroscopic sorption test. The test is performed acording to the standard ISO 12571 [13].

If the user introduces manually the experimental data, the tool is able to choose the best goodness of fit among several sorption isotherm models. Different functions are included to fit the experimental data obtained from the hygroscopic sorption test.

One fitting model is proposed by Künzel [14], which is used in the WUFI moisture transport simulation software. Unlike the other models, it has a simple approach, but it is useful when there is little information about the material.

$$w = w_{cap} \cdot \frac{(b-1) \cdot \varphi}{b - \varphi} \tag{4}$$

where w_{cap} [kg/m³] is the capillary moisture content, b (b>1) [-] is a fitting coefficient, and φ [º/1] the relative humidity.

Another model is proposed by Kumaran [15], wich is included in Annex 14 of the International Energy Agency. The function suggested is:

$$w = \frac{\varphi}{a\varphi^2 + b\varphi + c} \tag{5}$$

where a [-], b [-], and c [-] are fitting coefficients and φ [º/1] the relative humidity.

Another model proposed is the model included in the MOIST program, according to equation (6):

$$w = A \cdot \left(\frac{1}{1-\varphi} - 1 \right)^B \tag{6}$$

where A [-] and B [-] are fitting coefficients and φ [º/1] the relative humidity.

The last model included in the PC-program is the model proposed by Roels and Janssen [12]. As a result of several adjustments, it could be said that this model has a good approximation.

$$w = w_{sat} \cdot \left(1 + \left(m \cdot LN\left(\varphi\right)\right)^n\right)^{\left(\frac{1-n}{n}\right)} \tag{7}$$

where w_{sat} [kg/m³] is the saturation moisture content, m [-] and n [-] are fitting coefficients, and φ [º/1] the relative humidity.

For now, the tool do not include hysteresis effects and only one sorption curve is used. Depending on the materials, the effect of sorption hysteresis may to a greater or lesser extent affect the effective moisture capacity. It is recommended to use the adsorption curve in order not to overestimate the moisture capacity.

3.2. Water vapour diffusion resistance factor

In this case, the experiment is carried out according to the standard ISO 12572 [16]. Sometimes it is expected this property to be a constant, independent of the relative humidity. However, for some materials it shows a dependancy on the relative humidity. Due to the possibility that some users assume a constant value, they can choose between to introduce a constant value of the water vapour diffusion resistance factor or introduce the property as a function of relative humidity for the material. If the last option is chosen, the analytic function is given by equation (8) [12]:

$$\mu = \frac{1}{a + b \cdot e^{c \cdot \varphi}} \tag{8}$$

where μ [-] is the water vapour resistance factor, a [-], b [-], and c [-] are fitting coefficients, and φ [º/1] the relative humidity.

3.3. Practical example

To illustrate how the program interface is and how it is used, it is presented an example in this section. The material chosen is a sample of a pozolanic ceramic material tested by Gómez [17].

The parameter values of the sorption isotherm are presented in Table 1. In this case, the sorption isotherm function selected is the proposed by Roels and Janssen [12].

Table 1. Fitting parameters of the sorption isotherm.

Fitting parameters	
wsat	400
m	-95.12
n	1.541

Table 2 shows the fitting parameters of the water vapour resistance factor function. In this case, the property is considered as a function of relative humidity.

Table 2. Fitting parameters of the water vapour resistance factor.

Fitting parameters	
a	0.048
b	6.05E-03
c	4

Firstly, the user has to introduce the fitting parameters for each property. In the case of the sorption isotherm, the user has to choose the model of adjustment used in his/her calculation. In this example, the model selected is the one proposed in [12] (see Figure 1). Secondly, the fitting parameters for the water vapour resistance factor have to be typed in the boxes of "fitting parameters", as it is shown in Figure 1. Furthermore, the ambient pressure and the temperature of the cup test is needed. The graphical representation of each property is shown in figure 1.

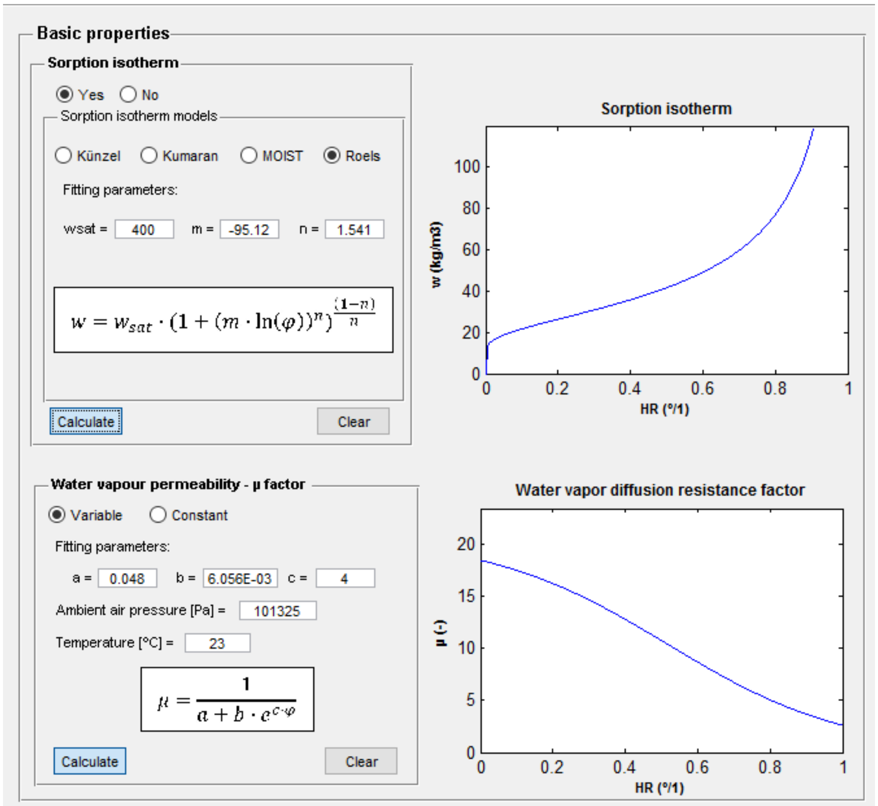

Fig. 1. Introduction of the material properties.

Upon the completion of this task, the user will obtain the ideal MBV, which is represented in function of relative humidity. The calculated value represents the MBV at 54% of relative humidity, which in turn means the mean of the step change between the high and low relative humidity (75-33%) of the Nordtest protocol.

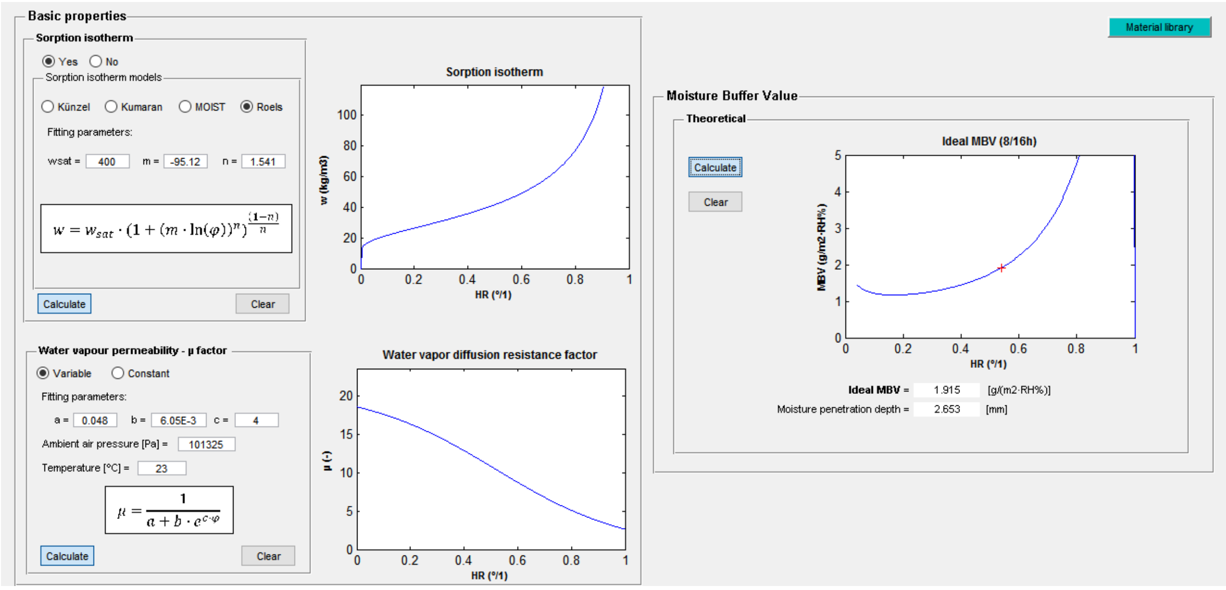

Fig. 2. Calculation of the ideal MBV.

Finally, the tool also notifies the user which is the moisture penetration depth. This information allows the user to know what is the minimum thickness to take advantage of the whole buffering potential of the material.

Furthermore, there is a small material library that includes a list of some building material properties. The data is obtained from several scientific articles, all of them referenced. Figure 3 is an example of a sample of lightweight ceramic clay tested by Gómez [18].

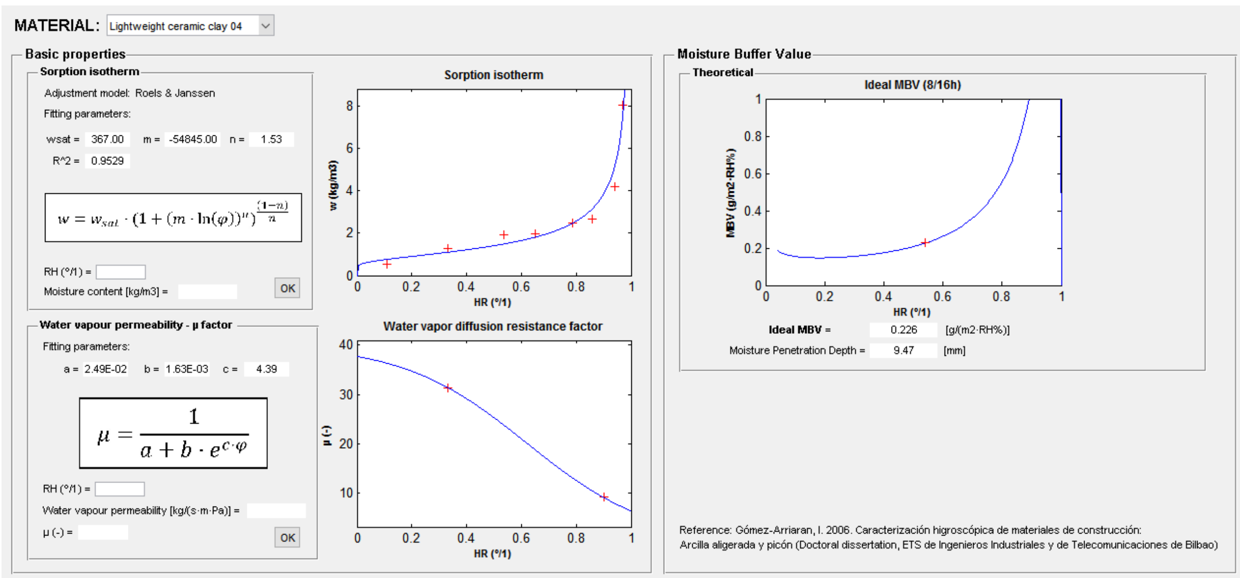

Fig. 3. Example material library.

The option of the practical MVB calculation is available for some materials from the library. The user can select different values for the air velocity, obtaining the practical MBV estimated. Figure 4 is an example of the pozolanic sample tested by Gómez [17].

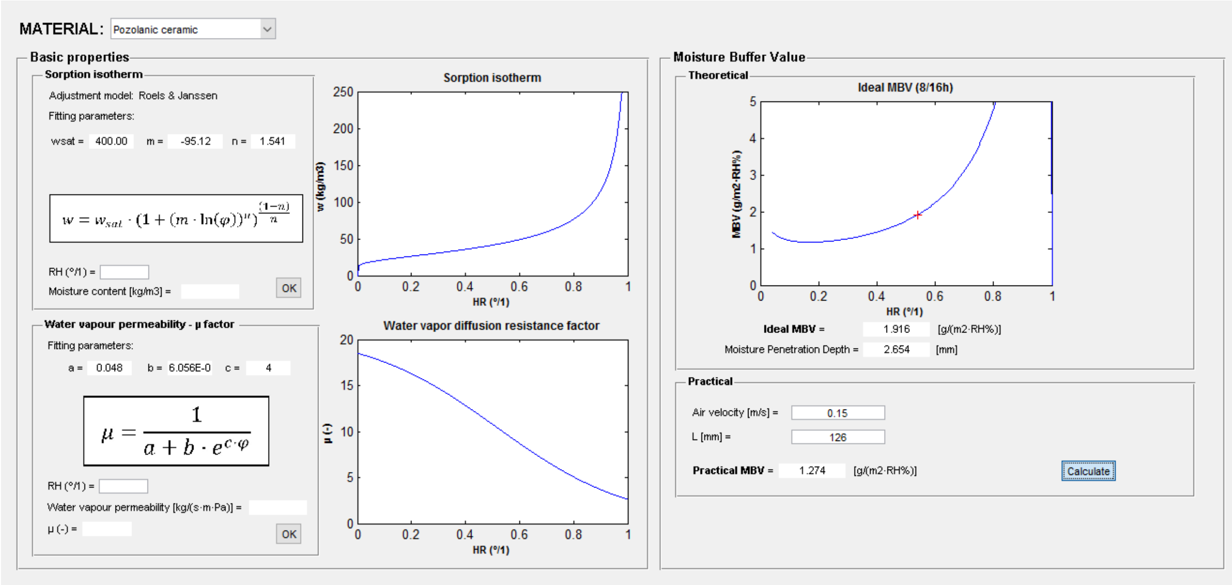

Fig. 4. Calculation of the practical MBV.

4. Conclusions

The practical MBV depends on different parameters such as the air velocity and the thickness of the sample. Being the ideal MBV an approximation, it can be different from the practical MBV depending on the test conditions [7,12]. Various authors [12,17] have demonstrated that the practical MBV is clearly sensitive to the test conditions. In this sense, the tool is able to estimate the practical MBV of some building materials from the material library for different air speed conditions.

Different materials were tested in dynamic conditions through a climatic chamber and the results were compared with the calculations obtained using the PC-program. The comparisons showed a good agreement between measurements and calculations of the tested materials.

The MBV will help the user to characterize and to classify the material according to the Nordtest protocol. The moisture buffering effect can be significant for the moisture performance of a room, for this reason, this information will be important to the user in order to compare the effect of different materials. In addition, in the future it is expected that advanced building energy simulation programs will incorporate this property as input as well as the hygrothermal properties of building materials.

The tool will be in continuous improvement and will incorporate new complements; furthermore, the material library will be continuously updated.

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