PAPER • OPEN ACCESS

Damage risk assessment of building materials with moisture hysteresis

To cite this article: Michele Libralato *et al* 2021 *J. Phys.: Conf. Ser.* **2069** 012043
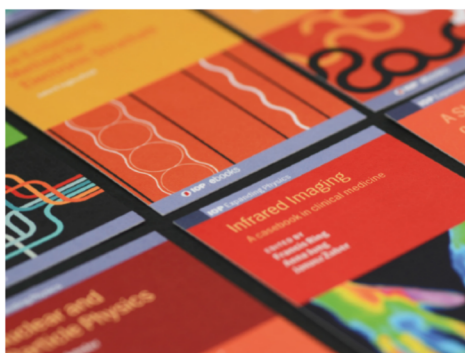
View the article online for updates and enhancements.

Damage risk assessment of building materials with moisture hysteresis

Michele Libralato[1] , Alessandra De Angelis[1] , Paola D'Agaro[1] , Giovanni Cortella[1] , Menghao Qin[2] and Carsten Rode[2]

[1] Polytechnic Department of Engineering and Architecture, University of Udine, via delle Scienze 206, 33100, Udine, Italy
[2] Department of Civil Engineering, Technical University of Denmark, Brovej, Building 118 DK-2800 Kongens Lyngby, Denmark

E-mail: `michele.libralato@uniud.it`

Abstract. Heat and Moisture Transfer (HMT) simulations are used to evaluate moisture related damage risks in building envelopes. HMT simulations are commonly performed accepting the hypothesis of not considering the moisture hysteresis of materials. The results of HMT simulation of a timber wall with hysteresis are presented, and compared to the results of three simplified models, showing the effects of hysteresis on the simulation results and on the assessment of the risk of decay. Moisture content is the most influenced variable, while temperature and relative humidity are slightly affected. The wood decay risk analysis is performed using the simplified 20% moisture content rule. Similar temperature values and relative humidity values are calculated as simplified models, while the moisture content annual average values have differences up to 2.3%. The wood decay risk obtained with the simplified models could be overestimated if the simulation is performed using the desorption curve, while it could be underestimated with the adsorption curve. The best approximation is obtained with the mean sorption curve, while the desorption curve and the adsorption curve could be used to calculate the upper and lower boundary of the moisture contents respectively.

1. Introduction
To reduce the carbon footprint and energy consumption of buildings it is possible to produce high performance envelopes using sustainable materials. Unfortunately, moisture related damages could affect bio-based materials causing health hazards and structural damages. These could be avoided with careful design procedure and risk assessment. These are commonly performed using Heat and Moisture Transfer (HMT) simulations, for example, according the standard EN 15026:2007. The commonly used HMT models describe the coupled transport of heat and moisture in the building materials, which are considered as porous materials. The most accurate models consider transport properties that are variable with moisture content (and eventually with temperature). Even if the intent of the HMT model is to obtain a high level of accuracy, several uncertainties are introduced in the models, like the boundary conditions and the material properties. The adsorption property of the porous media is described by the sorption function, which associates to every value of relative humidity (RH) a single value of moisture content (MC) and vice-versa. This is an accepted simplification of the moisture accumulation behaviour, but as experience shows, several materials (especially bio-based materials such as wood) can reach

equilibrium at different moisture contents. The equilibrium states are dependent on the history of the previous equilibrium states. This behaviour, known as moisture hysteresis, could be modelled implementing the hysteresis of the sorption function in the heat and moisture transfer models, instead of using bijective sorption isotherm functions.

Different models of hysteresis are found in literature, [1] presents a comparison between two hysteresis formulations (the empirical model [2] and the phenomenological model, obtained as a modification of the Mualem model [3]), showing that the hysteresis has a small influence on air RH in the room, while MC at the surface of the wall has larger differences, due to the difference of the considered sorption curves. In [4] the modification of the phenomenological model is compared with another model, presented in [5], considering hemp concrete.

In this work, the empirical model [2] will be used, and its results will be compared with three bijective sorption curves (the adsorption curve, the desorption curve and the mean sorption curve). A timber building envelope will be simulated and a simplified wood decay risk analysis will be performed on the timber structure, using the 20% MC threshold method, considered as lower limit value for wood decay with a reasonable margin of safety ([6, 7, 8]).

The relevance of considering moisture hysteresis in simulations depends on the studied phenomena and on the applications. In the last decade examples of research work on moisture hysteresis are found in literature, not only for bio-based materials, but also for cementitious materials ([9, 10, 11, 12, 13, 14]).

An analysis of the effect of hysteresis on advanced wood decay damage models is presented in [15], where the effect of external environment is evaluated using VTT wood decay model and the simplified dose-response model. In this work the effects of hysteresis have been found to be relevant for advanced wood decay models based on MC values and temperatures. The effect on the RH values and temperature is of a small order, and not relevant to advanced decay models.

2. Method

To evaluate the influence of hysteresis on the risk assessment procedure the case of wood decay of a timber wall is considered. The study case is chosen to be an extreme case with high moisture levels, in order to evaluate the different risk calculated by different sorption curve models.

The results of the model considering hysteresis is compared with three commonly used simplifications based on bijective sorption functions:

- **Adsorption curve**: obtained measuring the moisture contents with a gravimetric test starting from a dry state;

- **Desorption curve**: obtained starting the gravimetric test from the saturated state of the material;

- **Mean sorption curve**: obtained averaging the MC values of adsorption curve and desorption curve.

The sorption models used in the simulations are qualitatively presented in Figure 1.

2.1. Moisture Hysteresis

The simulations are performed using the software MATCH, which considers the "empirical hysteresis model", presented in [2]. This model defines the moisture capacity ξ at each time step. Moisture capacity is defined as follows:

$$\xi = \frac{\partial u}{\partial \varphi} \tag{1}$$

ad thus, if hysteresis is neglected it can be obtained before any calculation, from the sorption curve of the material.
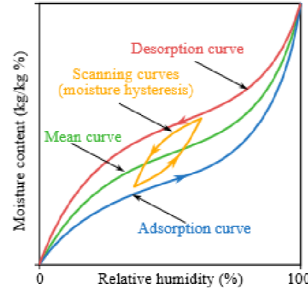
Figure 1. Qualitative description of the hysteretic behaviour of a material and the simplified sorption curves used in the simulations.

In the software MATCH, moisture capacity is calculated at each time and position from the MC of the previous time step and the direction of the sorption process, adsorption or desorption. Once the moisture capacity is calculated, the MC and RH of the next time step are obtained. The moisture history of the material is accounted considering only the state at the previous time step. The ξ value is calculated from the values of ξ of the adsorption curve ξ_a and the desorption curve ξ_d, which are given as material properties. The ξ could be calculated with Eq.2, while u is obtained from the variation of relative humidity $d\varphi$ in the time step $t+1$ with Equation 3.

$$\xi = \begin{cases} \frac{(u-u_a)^2 \cdot \xi_d + 0.1 \cdot (u-u_d)^2 \cdot \xi_a}{(u_d-u_a)^2} & \text{for desorption} \\ \frac{0.1 \cdot (u-u_a)^2 \cdot \xi_d + (u-u_d)^2 \cdot \xi_a}{(u_d-u_a)^2} & \text{for adsorption} \end{cases} \qquad (2)$$

$$u_{t+1} = u + \xi \cdot d\varphi \qquad (3)$$

Where:

- u_a = MC for the current RH, according to the adsorption curve   (-)
- u_d = MC for the current RH, according to the desorption curve   (-)
- ξ_a = moisture capacity for the current RH, according to the adsorption curve   (-)
- ξ_d = moisture capacity for the current RH, according to the desorption curve   (-)
- u = MC at the actual time step   (-)
- ξ = moisture capacity at the actual time step   (-)
- u_{t+1} = MC at the next time step   (-)
- $d\varphi$ = variation of RH   (-)

The empirical model is defined using only the adsorption and desorption curve and it is not defined on physical phenomena, but it could be adapted to different hysteretic behaviours. The coefficients 0.1 of Equation 2 could be substituted with fitting parameters, obtaining an accurate representation of the hygrothermal states of the material.

2.2. Study case
The damage risk assessment is performed on a vertical timber wall located in Copenhagen, facing North with a 10-year-long simulation. The material properties are presented in Table 1 while the build-up of the wall is presented in Figure 2. The material properties for Spruce and the Fibre cement board are taken from [16] and the sorption curves considered are obtained