Coupled heat and mass transfer model to simulate hygrothermal behavior of bio-based materials

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Introduction: To reduce energy consumption, the bio-based materials appear to be an efficient solution [1,2]. Some advantages of using bio-based materials include: its good thermal insulating properties [2], low impact on the environment [3], and moisture buffering properties [4]. In this work we numerically simulate the hygrothermal behavior of bio-based materials (Figure 1). using Comsol multiphysics. The studied problem constitutes a monolayer wall (Figure 2). exposed to variable moisture and heat flux.

Figure 1. Bio-sourced materials Sheep wool and Hemp concrete

Modeling: The mathematical model [5] of heat and mass transfer in unsaturated porous media through a wall is described as:

$$\rho_0 . Cp \frac{dT}{dt} = \nabla(\lambda \nabla T) + \rho_L . L_v . \nabla(D_{Tv} \nabla T) + \rho_L . L_v . \nabla(D_{\theta v} \nabla\theta) \quad (1)$$

$$\frac{d\theta}{dt} = \nabla(D_T \nabla T) + \nabla(D_\theta \nabla\theta) \quad (2)$$

The associated boundary conditions for heat and masse transfer are :

$$-\lambda \nabla T - \rho_L . L_v . D_{Tv} \nabla T + \rho_L . L_v . D_{\theta v} \nabla\theta = h_1 (T_{f1} - T_0) \quad (3)$$

$$-\rho_l . D_T \nabla T - \rho_l . D_\theta \nabla\theta = h_{m1}(\rho_1 - \rho_\infty) \quad (4)$$

Where (T and θ) are the temperature and water content respectively, λ, is the thermal conductivity, L_v, is the latent heat of vaporization, C_p, is the mean specific heat, (ρ_0, ρ_L), are the solid matrix density and water density respectively, and (h, hm) are the heat and masse exchange coefficient, (D_{TV} $D_{\theta V}$) are the thermal and isothermal diffusion coefficients respectively.

Numerical Simulation:

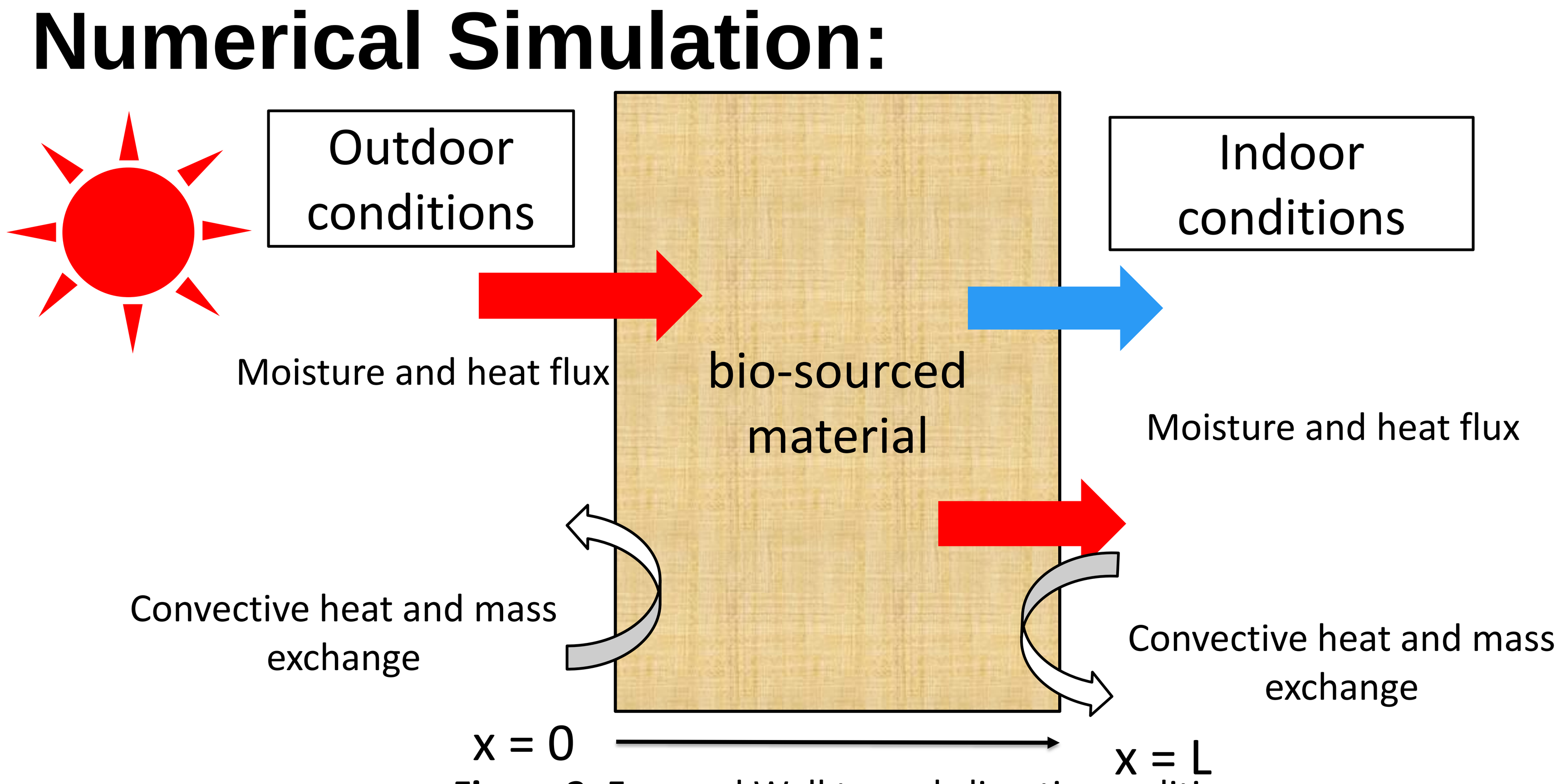

Figure 2. Exposed Wall to real climatic conditions

The wall subjected to summer conditions, sinusoidal fluctuation of temperature and relative humidity.

The simulated results are obtained for hemp concrete wall of (2300 x 2100 x 17) mm. some of the properties are measured in the laboratory and the rest are taken from the literature [6], (table1).

Variable	Value	Units
Density	450	Kg/m3
Specific heat	1000	J/Kg.K
Thermal conductivity	0,105 + 0,77(θ)	W/m.K
Water vapor permeability	$5{,}3 \times 10^{-11}$	Kg/m.s.Pa

Table 1. Hemp concrete properties

Results: To solve the coupled equations (1) and (2), Comsol 5.0 is used [7]. The software is based on the finite volume method, which solves various nonlinear PDE systems of equations

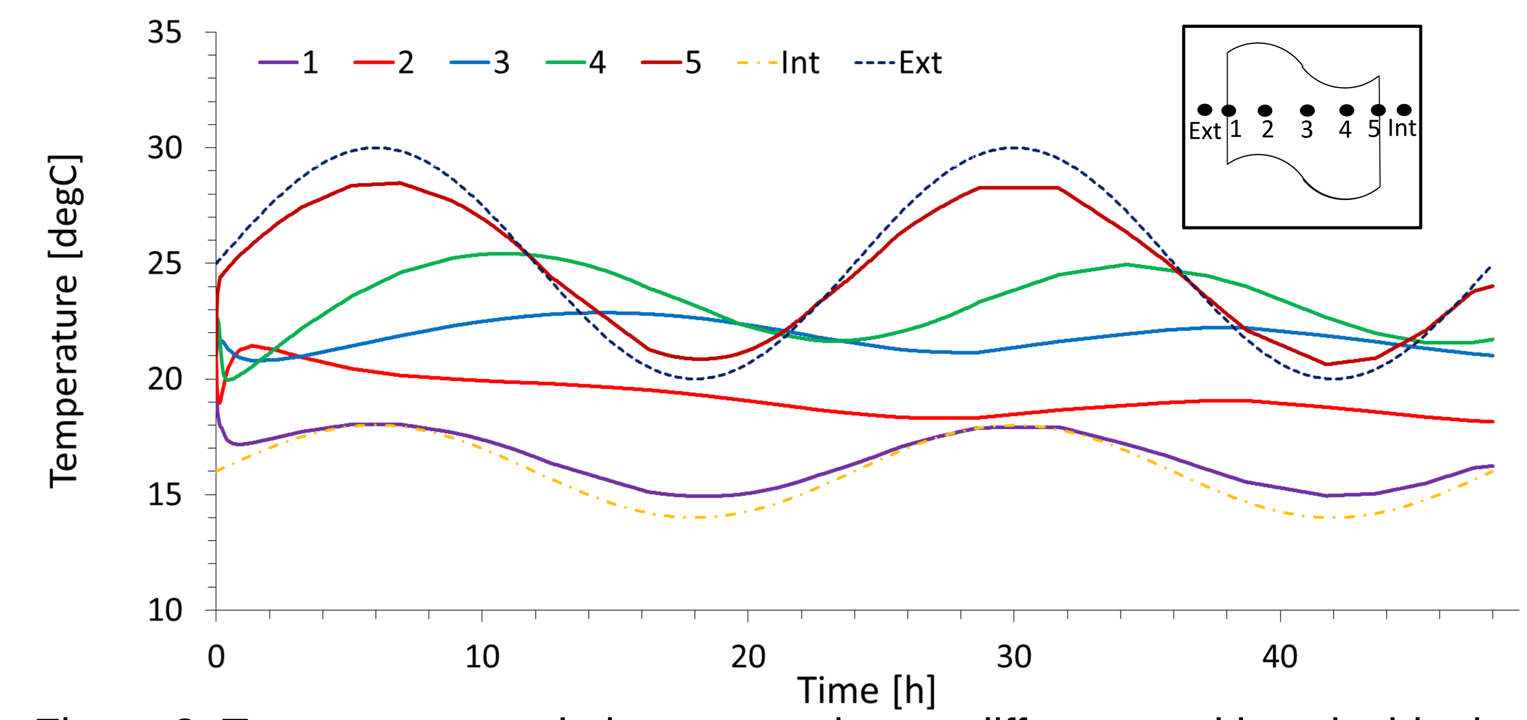

Figure 3. Temperature evolution versus time at different positions inside the wall

The simulation study was performed for [48h], and give the following results :

the distribution of temperature and relative humidity versus time inside the wall are given at different positions and reported in (Figure 3) and (Figure 4), respectively.

From this results, The bio-based material can be used as hemp-concrete to function as a shock absorber to external fluctuation conditions.

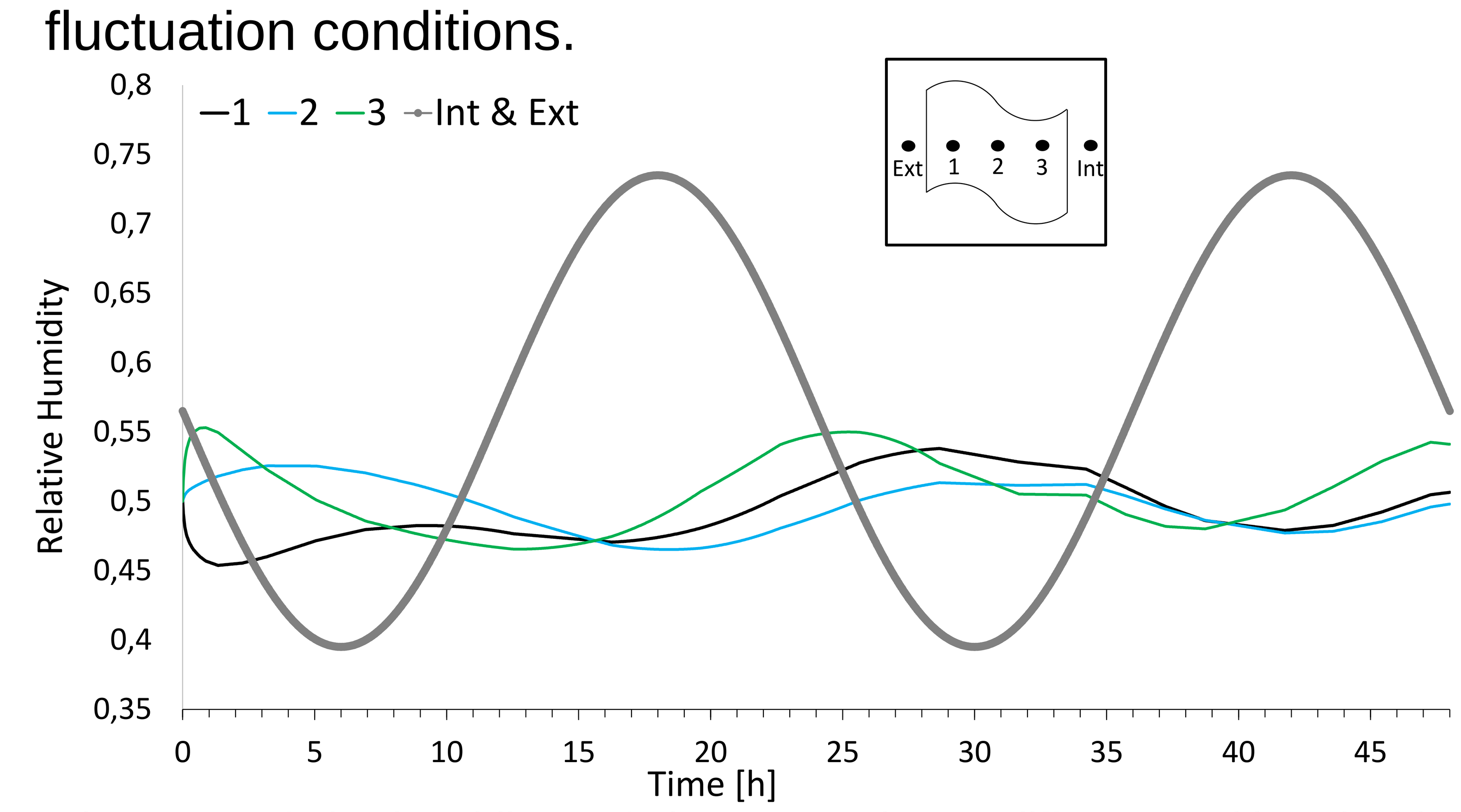

Figure 4. Relative humidity evolution versus time at different positions inside the wall

Conclusions: The aims of the study is to predict the hygrothermal behavior of bio-based material, to attain this, we have conducted a numerical study using Comsol multiphysics. We took into account all the phenomena, heat transfer, diffusion and vapor effusion, transportation of liquid water, which make the modeling very complicated. The study show that Comsol Multiphysics is adequate for modeling heat and mass transfer coupled problems with simplicity and efficacy.

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