# Coupled Heat and Mass Transfer Model to Simulate Hygrothermal Behavior of Bio-Based Materials

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## Abstract

This paper presents a numerical modeling approach for hygrothermal behavior of bio-based materials. The mathematical model describes the heat and moisture transfer through a wall of bio-based materials. The studied wall is subjected to both convective heat transfer and moisture flux transfer with the surroundings. Moreover, a parametric study was performed to analyze the effect of varying the model's key parameters on the overall thermal performance of the wall. Consequently, an optimal proposal can be suggested to attain the main objective, which is reducing energy consumption for winter heating and summer cooling.

Introduction
In dealing with energy consumption issues, the bio-based materials appear to be an efficient solution [1]. These materials present high moisture buffing capacity and a good balance between low mass and storage capacity when compared to the classical insulation materials. Several works investigated the bio-based materials efficiency[2][3]. In this paper we numerically simulate the hygrothermal behavior of bio-based materials using COMSOL Multiphysics®.

The studied problem constitutes a monolayer wall exposed to variable heat flux, taken into consideration the coupled heat and mass effect with real boundary conditions (variable ambient conditions), and the diffusion of heat and moisture through the wall subjected to the real climatic conditions.
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Modeling
The mathematical model [4] of heat and moisture transfer in unsaturated porous media through a wall is described
as: $\rho.C_p\, dT/dt=\nabla(\lambda\, \nabla T)+\rho_L L_v\, \nabla(D_{Tv}\, \nabla T)+ \rho_L L_v\, \nabla(D_{\theta v}\, \nabla\theta)$ (1)
$d\theta/dt=\nabla\, (D_T\, .\, \nabla T)+ \nabla\, (D_\theta\, .\, \nabla\theta)$ (2)
Where T, $\theta$ are the temperature and water content respectively, $\lambda$, is the thermal conductivity, $L_v$, is the latent heat of vaporization, Cp, is the mean specific heat, ($\rho$, $\rho_L$), are the solid matrix density and water density respectively, and (h, $h_m$) are the heat and mass exchange coefficient.
To solve the coupled equations (1) and (2), COMSOL is used [6]. The software is based on the finite volume method, which solves various nonlinear PDE systems of equations having the following general form and valid in the domain:
$e_a\, (d^2 u)/(dt)^2 + d_a\, du/dt+ \nabla.(-c\, \nabla u-\alpha\, u+\gamma)+\beta.\nabla u+a\, u=f$

The simulated results are obtained for hemp concrete materials, whose properties are measured in the laboratory. The dry density is evaluated by 450 kg m-3, and the heat capacity by 1000 J Kg-1 K1. The water vapor permeability for hemp concrete is given by [5] to be 5.3 x 10-11 Kg m-1 s-1 Pa-1. While the thermal conductivity of hemp concrete is related to moisture content using $\lambda = 0.1058 + 0.77(\theta)$. The problem is solved using a mesh size of 2mm and a time step of 300 s.

Results

The distribution of temperature and relative humidity versus time inside the porous layer are given at different positions and reported in figure 1 and 2 respectively.

Fig.3. represents the effect of density variation on the temperature profile, with ± 25% of the reference density. The temperature evolution on the middle of wall is plotted for different density values.

## Reference

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[6] COMSOL Multiphysics Software. (2011). http://www.comsol.com/products/multiphysics/

## Figures used in the abstract

**Figure 1**: The distribution of temperature versus time at different positions in the wall

**Figure 2**: The distribution of relative humidity versus time at different positions in the wall

**Figure 3**: the effect of density variation on the temperature profile

**Figure 4**