# NUMERICAL MODELLING OF UNSTEADY HUMIDITY TRANSPORT AND ACCUMULATION IN WALLS

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## ABSTRACT

The purpose of the work is the determination of unsteady variation of the moisture content in the walls. The mathematical model is based on humidity transport equations in porous media. The humidity transport takes place as a result of the presence of both moisture content and vapour pressure differences.
Using the proposed mathematical model, a computer program was developed in EES (Engineering Equations Solver). Numerical simulations were made for an office room, considering interior walls containing a gypsum board layer.
The results showed that humidity absorbtion-desorbtion in an interior wall depends on: wall structure, materials properties, inlet air parameters, initial relative air humidity in the wall and room occupancy.

## KEYWORDS

Modelling, absorbtion-desorbtion, humidity, transport, interior walls.

## 1. INTRODUCTION

The present paper proposes a new mathematical model necessary in the study of humidity absorption or desorption in interior walls, a model that is also useful for a detailed humidity balance. According to this model, simulations were made for an office room.
Such studies are important for maintaining hygro-thermal comfort in interior, ventilated atmosphere and also for reducing energetic costs related to interior spaces humidification in cold periods.

## 2. HUMIDITY TRANSPORT IN POROUS MATERIALS. THEORETICAL BASES.

The main support for modelling was the humidity transport equation in porous materials, to determine the dynamic variation of humidity content in the material under study. The analysis focused on an interior wall having a gypsum board layer as its component.
Humidity transport is possible through the water and/or water vapours transport.
In the presented model, the following hypotheses are taken into account:
- vapour diffusion is determined by the vapour pressure gradient
- vapour pressure difference can be established according to the humidity content, by means of absorption (isothermal) curves of humidity
- Fick's diffusion law is applied

- materials analysed have homogeneous properties
- the air flow through the considered structure is neglected
- the dry material density remains constant during the absorption process.

Humidity transport takes place as a consequence of potential differences: concentration difference (u) and vapour pressure difference ($p_v$).
The general humidity transport equation is:

$$\rho_{mat} \frac{\partial u}{\partial t} = -\nabla \dot{m}_m \qquad [1]$$

where: $\rho_{mat}$ = dry porous material density, kg/m$^3$
u = moisture content of material, kg water/kg material
t = time, s
$\dot{m}_m$ = moisture flow, kg/(m$^2$ s).

The humidity transport equation is particularised for materials with large pores and for capillary materials.
The moisture flow for *macroporous materials* (where the capillary effect is low) is:

$$\dot{m}_m = -\delta_p \cdot \nabla p_v \qquad [2]$$

where :$\delta_p$ = water vapour permeability, kg/(m s Pa)
$p_v$ = water vapour pressure, Pa.

The moisture flow in *capillary materials* is rendered by:

$$\dot{m}_m = -\rho_{mat} D_w \nabla u - \delta_p \nabla p_v \qquad [3]$$

where :$D_w$ = water vapour diffusivity, m$^2$/s.
Thus, the general humidity transport equation [Karagiozis] for capillary materials becomes:

$$\rho_{mat} \frac{\partial u}{\partial t} = -\frac{\partial}{\partial x}\left[ -D_w \rho_{mat} \frac{\partial u}{\partial x} - \delta_p \frac{\partial p_v}{\partial x} \right] \qquad [4]$$

where: x = the humidity propagation direction.

## 3. HUMIDITY ABSORPTION MODELLING FOR AN INTERIOR WALL

Humidity transport and accumulation phenomenon modelling in interior walls had, as a starting point, the general humidity propagation equation for porous materials [Karagiozis]. This equation was integrated by using the finite difference method, for a material layer of thickness $\Delta x$. The resulting equation is:

$$\rho_{mat} \cdot A = -\left[ \frac{-D_w \cdot \rho_{mat} \cdot B - \delta_p \cdot C}{\Delta x} \right] \qquad [5]$$

The following notations were used:

$$A = \frac{\Delta u}{\Delta t} \qquad B = \frac{\Delta u}{\Delta x} \qquad C = \frac{\Delta p_v}{\Delta x} \qquad [6]$$

The differences of potential occurring in the humidity transport were stressed out as follows:
- *the moisture content difference* in the wall structure:

$$\Delta u = u_{wall,new} - u_{wall,old} \qquad [7]$$

where: $u_{wall,new}$ = moisture content in the wall, at the actual moment

$u_{wall,old}$ = moisture content in the wall, at the preceding moment.

- *the vapour pressure difference*:

$$\Delta p_v = p_{v,room} - p_{v,wall,new} \qquad [8]$$

where: $p_{v,room}$ = partial water vapour pressure in the room

$p_{v,wall,new}$ = wall vapour pressure, at the actual moment.

Relative humidity is expressed according to partial vapour pressure and to maximal vapour pressure, $p_{sat}$.

$$RH_{room} = \frac{p_{v,room}}{p_{sat}} \qquad RH_{wall,new} = \frac{p_{v,wall,new}}{p_{sat}} \qquad [9]$$

where: $RH_{room}$ = relative humidity of room air

$RH_{wall,new}$ = relative humidity of wall air, at the actual moment.

By means of the humidity transport equation, the moisture content in a wall structure could be determined, at different moments. The model was rendered in the computer program EES (Engineering Equation Solver).

The water flow that can be accumulated in the mass of room walls is calculated by the equation:

$$\dot{M}_{wall} = m_{wall} \cdot \frac{\Delta u}{\Delta t} \qquad [10]$$

where: $\dot{M}_{wall}$ = moisture flow absorbed by the walls, kg water/s

$m_{wall}$ = total wall mass, kg

$\frac{\Delta u}{\Delta t}$ = moisture content variation in the wall, kg water/kg material

This equation was used in the room humidity balance:

$$\dot{m}_{puls} \cdot w_{puls} - \dot{m}_{ex} \cdot w_{ex} + \dot{M}_{oc} - \dot{M}_{wall} = 0 \qquad [11]$$

where: $\dot{m}_{puls} = \dot{m}_{ex}$ = air mass flow rate inlet and exhaust, kg/s

$w_{puls}$ = inlet air humidity ratio, kg water/kg air

$w_{ex}$ = exhaust air humidity ratio, kg water/kg air

$w_{ex} = w_{in}$ = inside air humidity ratio

$\dot{M}_{oc}$ = humidity flow from persons, kg/s.

$$\dot{M}_{oc} = Nbr \cdot g_0 \qquad [12]$$

where: Nbr = number of persons in the room

$g_0$ = specific humidity flow rate, kg/s/pers.

By solving the equation system [5], [10], and [11] the relative humidity of inside air and of wall air can be determined, as well as the variation of these parameters in the given time intervals.

## 4. HUMIDITY ABSORPTION SIMULATION IN INTERIOR WALLS STRUCTURE

The simulation was made in the following conditions:
- the considered room has a surface of 15.12 $m^2$ and three interior walls having a layer of gypsum board with the thickness $\Delta x = 0.018$ m.
- the gypsum board layer is initially dry: $RH_{wall} = 20\%$, corresponding to a moisture content of u = 0.82 g water/kg material.
- inlet air temperature in the room is equal to the inside air temperature:
$t_{puls} = t_{in} = 20°C$
- inlet air relative humidity: $RH_{puls} = 80\%$
- the ventilation airflow rate is of 40 $m^3$/h/person
- two cases were analysed: the office is empty (Nbr = 0, which happens at night), and the office is occupied (Nbr = 2, which happens during day-time)
- the specific humidity flow rate is $g_0 = 33$ g/h/pers. ($0.92 \cdot 10^{-5}$ kg/s), in winter, for a $t_{in} = 20°C$ and occupants resting.

*Note:* The initial wall relative humidity (20%) is rarely met in actual fact. This value was chosen in order to ensure the limit conditions for the study.

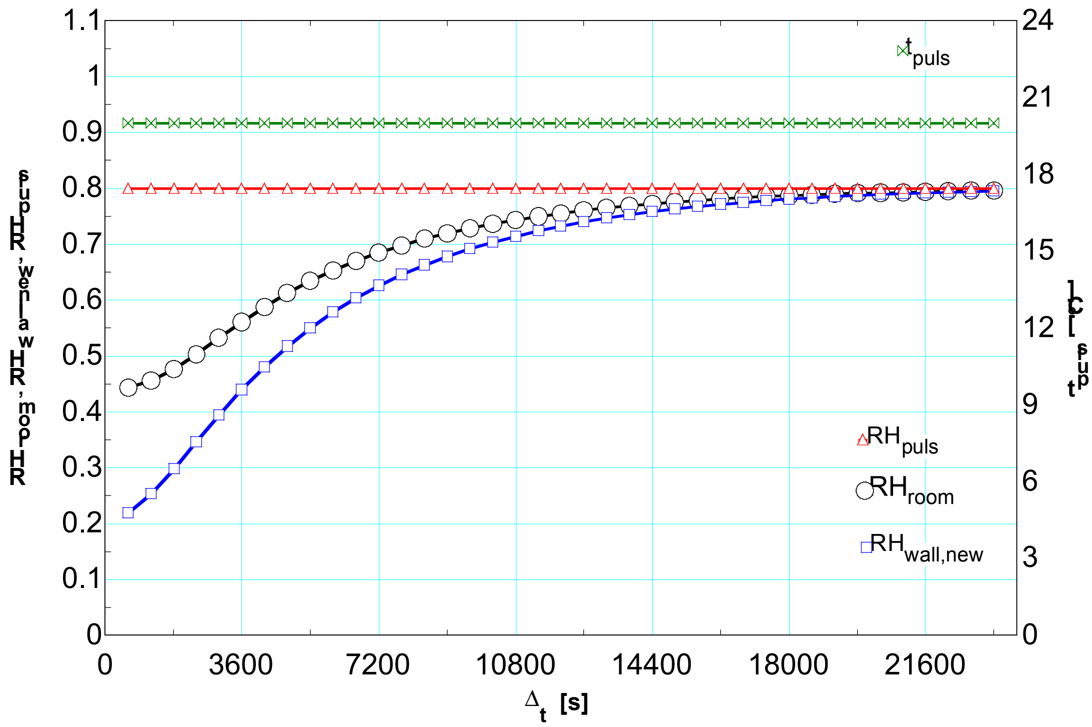


Figure 1: Relative humidity values evolution for an empty space

Simulations made in the first case (Figure 1) stress out the fact that the inside air relative humidity and the wall air relative humidity tend to reach the inlet air relative humidity value. After approximately 4 hours, the wall that was initially dry becomes saturated in water vapours.

In the case of complete occupation of the room (Figure 2), one can note the same behaviour for the wall and inside air relative humidity. They tend to reach a saturation level, higher than the inlet air relative humidity.

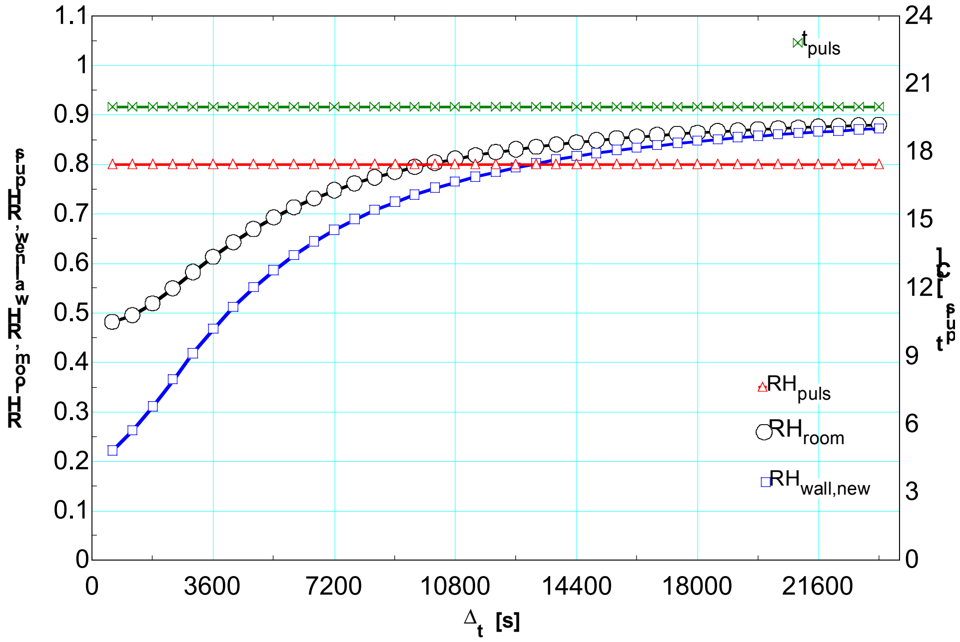


Figure 2: Evolution of relative humidity values during day-time

The way in which the water flow absorbed into the walls mass varies can be traced in Figure 3. For a dry wall, the absorption phenomenon is more intense at the beginning, while, after 5-6 hours, the wall reaches the saturation point. In the case of an occupied office, the water quantity absorbed by the wall is higher than for an empty space.

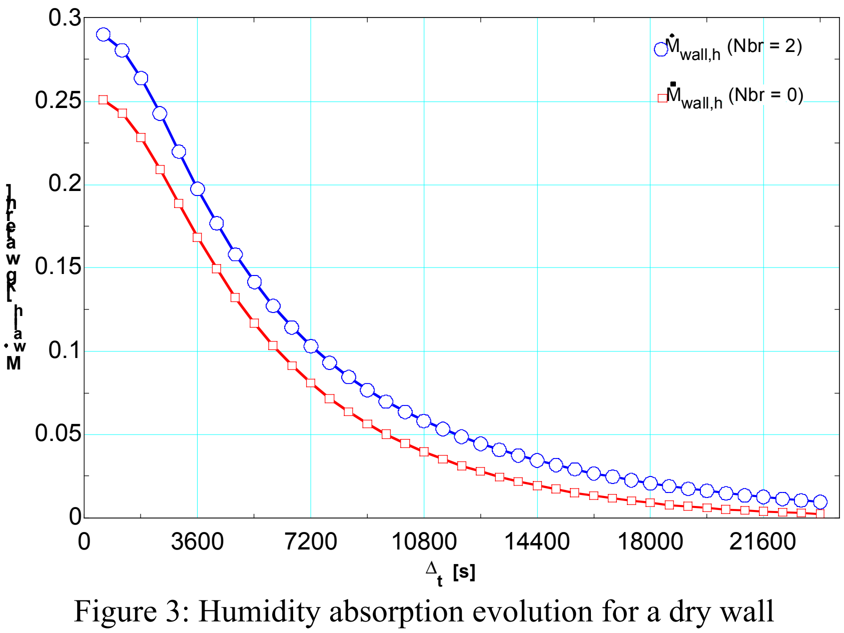


Figure 3: Humidity absorption evolution for a dry wall

An overall image of the dynamic behaviour of a wall, according to the evolution of inlet air relative humidity, is presented in Figure 4.
The office was considered occupied, and the initial wall relative humidity is of 40%. Three situations can be singled out in the diagram:

- when $RH_{puls}$ = 90%, the inside air relative humidity, and that of the wall air tend to increase towards the balance state, reached after 4-5 hours. The phenomenon of humidity absorption into wall structure is similar to the previously defined situation.
- when $RH_{puls}$ = 40%, the relative humidity of the inside air increases a little, and reaches the balance state after 1 hour of evolution.

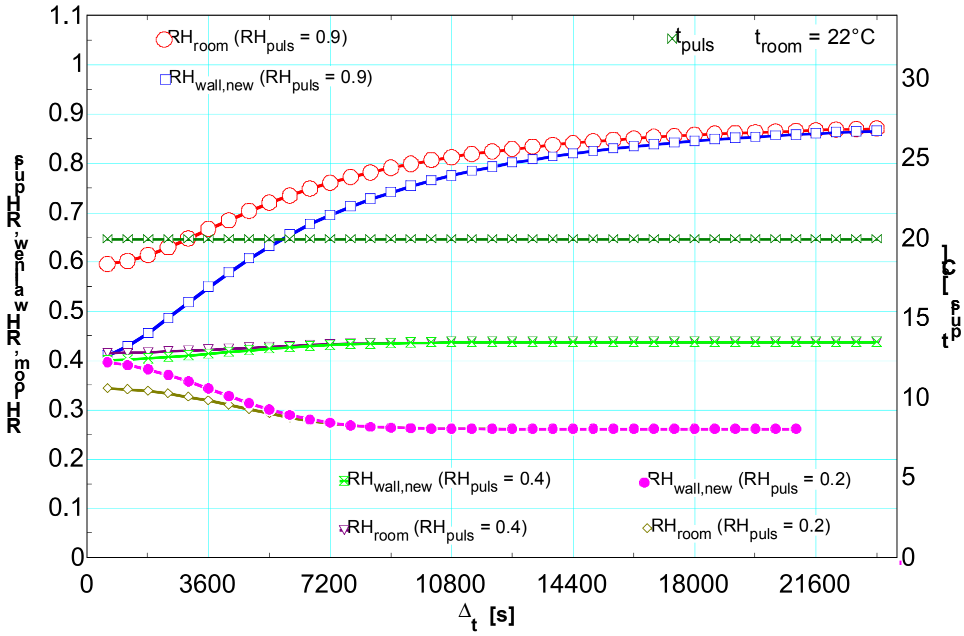


Figure 4: Variation of inside air relative humidity, and of wall air, according to the relative humidity of the ventilation air

- when $RH_{puls}$ = 20%, the conditions achieved in the room are no longer favourable for the occupants' hygro-thermal state of comfort. The inside air relative humidity and that of the wall air reach a balance state after 1 _ - 2 hours of evolution. In this final case, a process of humidity desorption in the mass of the walls takes place. The interior walls will give away part of the water amount accumulated into their structure by the room air.

## 5. CONCLUSIONS

Humidity absorption – desorption in an interior wall depends on several factors: the wall structure and the properties of the materials used, the inlet air parameters, the initial relative air humidity in the wall and the room occupancy.
When the office is occupied, the inside air and wall air relative humidity reaches a balanced state after 4-5 hours, while, if the room is empty, the balance takes place after 4 hours.
If the wall initial relative humidity is of 40%, and the inlet air has a level of 90% relative humidity, the room balance is reached after 5 hours. Also, if the inlet air has a 20% relative humidity, the interior walls will give off the accumulated humidity in an interval of 1 _ - 2 hours. This study can prove useful in determining the rooms humidifying degree necessary during the cold season.

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