The effect of micro air movement on the heat and moisture characteristics of building constructions

the cost to replace the bridge by the length and width of the bridge, then dividing the sum by the total length of the bridges. The results are presented in Table 3.

4. Conclusions

The impact of vehicles hauling forestry products on the maintenance and rehabilitation of Louisiana state bridges under current and proposed loads was evaluated. Forestry products accounts for almost 22 percent of the total agricultural production in Louisiana. The results of this study indicate that the current $10/truck/year permit fee on a FHWA class 9 vehicle (AASHTO 3S2) will not cover the additional maintenance and repair costs for bridges due to the new proposed loads. Since forestry is such an important part of Louisiana's economic base, any changes in the legal weight or overweight permit structure for Louisiana must consider the additional costs for bridge fatigue, as reported in the study, and the amount the state will provide to subsidize the forestry product industry.

5. Recommendations

Based on the results of this study and in order to assist the forestry product industry in Louisiana and reduce the bridge fatigue damage on the state system, the new proposed truck loads should be supplemented with modifications to the timber truck trailer (FHWA class 9 vehicle). The axle configuration should be modified from a tandem axle to a triple axle, and the gross vehicle weight should be at 86,600 pounds uniformly distributed among these axles.

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The contents of this study reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Louisiana Department of Transportation or the Louisiana Transportation Research Center. This paper does not constitute a standard, specification, or regulation.

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The Effect of Micro Air Movement on the Heat and Moisture Characteristics of Building Constructions

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Abstract: The research focuses on the effect of air movement through building constructions. Although the typical air movement inside building constructions is quite small (velocity is of order ~10-5 m/s), this research shows the impact on the heat and moisture characteristics. The paper presents a case study on the modeling and simulation of 2D heat and moisture transport with and without air movement for a building construction using a state-of-art multiphysics FEM software tool. Most other heat and moisture related models don't include airflow or use a steady airflow through the construction during the simulation period. However, in this model, the wind induced pressure is dynamic and thus also the airflow through the construction is dynamic. For this particular case study, the results indicate that at the internal surface, the vapor pressure is almost not influenced by both the 2D effect and the wind speed. The temperatures at the inner surface are mostly influenced by the 2D effect. Only at wind pressure differences above 30 Pa, the airflow has a significant effect. At the external surface, the temperatures are not influenced by both the 2D effect and the wind speed. However, the vapor pressure seems to be quite dependent on the wind induced pressure. Overall it is concluded that air movement through building materials seems to have a significant impact on the heat and moisture characteristics. In order to verify this statement and validate the models, new in-depth experiments including air flow through materials are recommended.

Key words: Construction, heat, moisture, transfer, air movement, modeling.

1. Introduction

The reduction of energy consumption related to buildings is of great importance. In order to calculate the energy consumption of a building, the heat transfer modeling of constructions is important. Moreover, some software tools also simulate moisture transport simultaneously to improve the design of building constructions [1]. If we look more closely to these combined heat and moisture models, the effect of air movement inside the construction is not taking into account by almost all models [2]. The main reasons are twofold: First, in practice it seems to have only a minor effect on the energy consumption. Second, the modeling and simulation of the air movement is quite complicated and probably therefore only occasionally implemented in heat, air and moisture (HAM) models. Experimental studies that include air movement through building materials seem to be quite rare. Hens et al. [3] and Janssens [4] show that the effects of airflow are substantial and often more significant than the effects of variations in material properties. During the IEA Annex 41 project the problem of the effect of air movement in constructions was encountered at Subtask 1. Starting point of the research is the earlier work of van Schijndel [5]. This paper presents a first modeling guide for the modeling and simulation of up to full 3D dynamic Heat, Air & Moisture (HAM) transport of building constructions using COMSOL. Furthermore, all modeling files and results are public domain [6]. The changes in this research, compared to the reference HAM2D model of van Schijndel [7] were twofold: First, the internal and external boundary conditions of temperature and humidity are now based on a typical Dutch climate instead of the more or less extreme climate of Denver. Second, in the reference model the wind induced pressure was steady, thus also the airflow through the construction was steady during

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the simulation period. However, the model in this paper also includes a dynamic wind induced pressure and thus also a dynamic airflow through the construction. The research approach was to study the effect of (micro) air movement through materials on the heat and moisture characteristics of building constructions using the latest multiphysics modeling tools [8-10]. The method of research for was as follows: Firstly, a selection of a common building construction type which was also used at the several Common exercises of the Annex 41. Secondly, the modeling of the 2D heat and moisture transport each with and without air movement based on the selected construction. The used internal and external boundary conditions (i.e., temperature, humidity and wind induced pressures) were based on a typical Dutch climate. Thirdly, the simulation of both models and comparison of the different results.

2. Background and Description

As already explained, the starting point of this case is the earlier work of van Schijndel [5]. The HAM2D construction model of van Schijndel [5] is presented in Fig. 1.

The material properties (partly also used at common exercises of IEA Annex 41 (IEA Annex 41 2008)) are provided at Tables 1 and 2.

Where λ is the heat conduction coefficient; d the thickness; U the U-value; R the heat resistance; ρ the density; Cp the heat capacity; K the air permeability.

The internal and external conditions are provided in Fig. 2.

The changes compared to the reference HAM2D model of van Schijndel [7] were twofold:

(1) Internal and external boundary conditions (Fig. 2) are now based on a typical Dutch climate instead of the more or less extreme climate of Denver;

(2) In the reference model [7] the wind induced pressure was steady, thus also the airflow through the construction was steady during the simulation period. However, in this paper, the wind induced pressure is

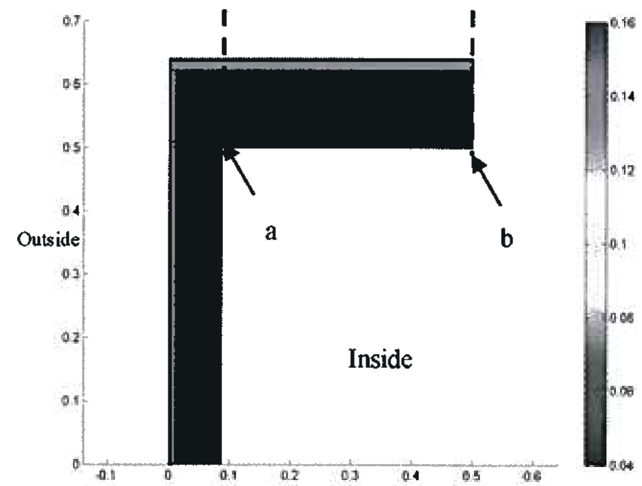

Fig. 1 The 2D construction.

Table 1 Material properties part 1

	λ (W/mK)	d (m)	U (W/m²K)
Exterior wall (inside to outside)			
Int. surf. coeff.			8.29
Wood panels	0.160	0.012	13.333
Cellulose ins.	0.040	0.066	0.606
Wood siding	0.140	0.009	15.556
Ext. surf. coeff			29.300
Total air-air			0.514
Roof (inside to outside)			
Int. surf coeff			8.29
Wood panels	0.160	0.010	16.000
Cellulose ins.	0.040	0.1118	0.358
Roof deck	0.140	0.019	7.368
Ext. surf. coeff			29.300
Total air-air			0.318

Table 2 Material properties part 2.

	R (m²K/W)	ρ (kg/m³)	C_p (J/kgK)	K (kg/msPa)
Exterior wall (inside to outside)				
Int. surf. coeff.	0.121			
Wood panels	0.075	395	1880	10^{-9}
Cellulose ins.	1.650	55.0	1880	5.5×10^{-5}
Wood siding	0.064	530	900	10^{-9}
Ext. surf. coeff	0.034			
Total air-air	1.944			
Roof (inside to outside)				
Int. surf coeff	0.121			
Wood panels	0.063	395	1880	10^{-9}
Cellulose ins.	2.794	55.0	1880	5.5×10^{-5}
Roof deck	0.136	530	1880	10^{-9}
Ext. surf. coeff	0.034			
Total air-air	3.147			

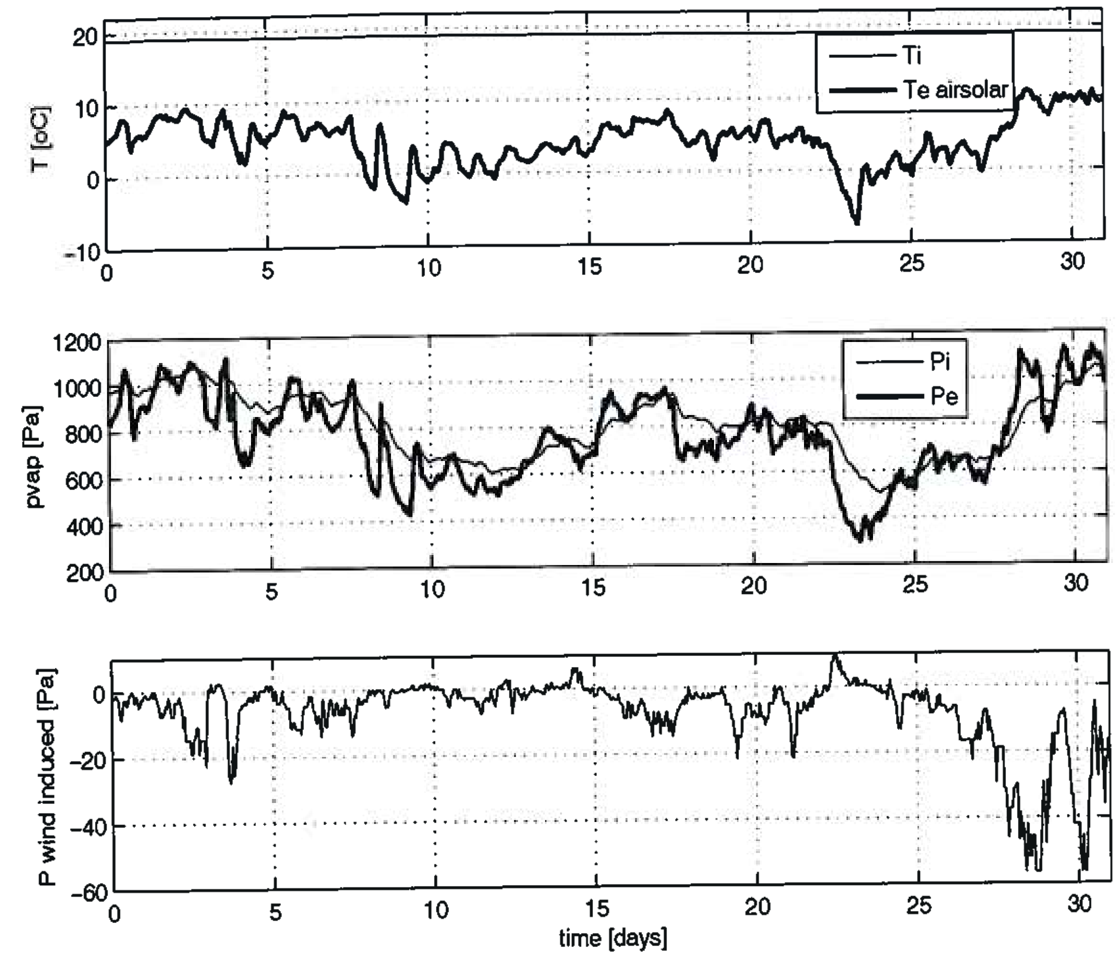

Fig. 2 Top: Indoor and outside air temperatures; Middle: Indoor and outside air vapor pressures; Bottom: The wind induced pressure; Horizontal all: number of days after January 1.

dynamic (Fig. 2, bottom) and thus also the airflow through the construction.

3. Modeling

3.1 The PDEs

The Partial Differential Equations (PDEs) are:

$$Heat: \rho C_p \frac{\partial T}{\partial t} + \nabla\cdot(-\lambda \nabla T) + \rho C_p \mathbf{u}\cdot\nabla T = 0$$

$$Air: \frac{\partial P}{\partial t} + \nabla\cdot(-K\nabla P) = 0; \mathbf{u} = K\nabla P \quad (1)$$

$$Moisture: \frac{\partial p_v}{\partial t} + \nabla\cdot(-D\nabla p_v) + \mathbf{u}\cdot\nabla p_v = 0$$

Where **u** is air velocity [m/s]; P is (scaled) atmospheric pressure [Pa]; p_v is vapor pressure [Pa]; D = diffusion coefficient [m²/s] equals $(p_{vsat}\cdot\delta_a)/(\mu\cdot\xi)$; p_{vsat} is saturation vapor pressure [Pa]; δ_a is vapor permeability coefficient (1.8×10^{-10} s); μ is vapor diffusion resistance factor [-]; ξ is specific moisture capacity related to RH [kg/m³]; K = permeability

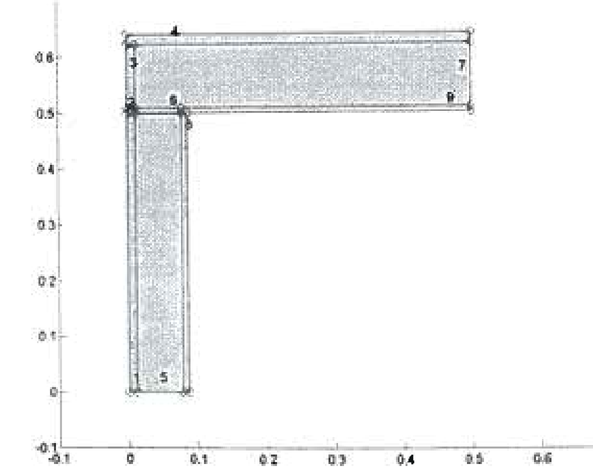

Fig. 3 Sub-domains & numbering.

Table 3 Sub domain PDE coefficients.

Sub-domain	1-4	5-7	8-9
λ	0.14	0.04	0.16
ρ	530	55	395
C_p	1880	1880	1880
$D = (p_{vsat} \cdot \delta_a)/(\mu \cdot \xi)$	psatf(T)*1.8e-10/(120*95)	psatf(T)*1.8e-10/(14*1.4)	psatf(T)*1.8e-10/(101*2.1)
K	1e-9	5.5e-5	1e-9

[kg m^{-1} s^{-1} Pa $^{-1}$]. In Fig. 3 the sub-domains are presented. Table 3 provides the PDE coefficients of the sub-domains.

3.2 The Boundary Values

The boundary values are:

$$\begin{aligned}&\text{Heat}: \; Flux: \mathbf{n}\cdot(\lambda\nabla T) = h(T_{inf} - T); Insulation: \mathbf{n}\cdot(\lambda\nabla T) = 0\\&\text{Air}: \; Pressure: P = P_0; Insulation: \mathbf{n}\cdot K\nabla P = 0\\&\text{Moisture}: \; Flux: \mathbf{n}\cdot(D\nabla p_v) = \beta(p_{vinf} - p_v); Insulation: \mathbf{n}\cdot(D\nabla p_v) = 0\end{aligned} \qquad (2)$$

Where **n** is normal vector of surface [-]; h is surface coefficient of heat transfer [W/m^{2}K]; β is surface coefficient of vapor transfer [s/m]. In Fig. 4 the boundaries are presented. Table 4 provides the boundary coefficients.

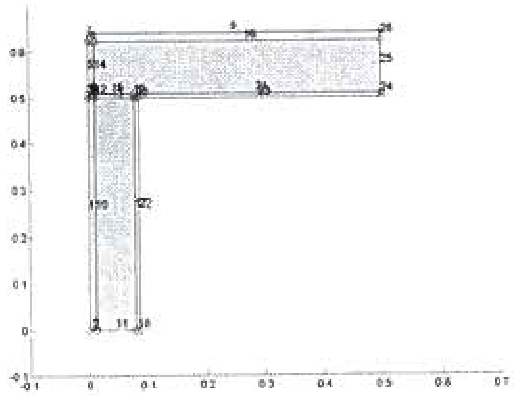

Fig.4 Boundary values & numbering.

Table 4 Sub domain boundary value coefficients.

Boundary	1, 5, 7, 9	2-3, 11, 18, 24-26	22-23
Type	Flux	Insulation	Flux
Heat (h)	29.3	0	8.29
Heat ($Tinf$)	Te airsolar	-	Ti
Moisture Inward flux	8e-8*(pe-p$_v$)	0	2e-8*(pi-p$_v$)
Air Pressure (P_0)	Pwind	0	0

Where Ti, Te airsolar, pi, pe and Pwind are time dependent input signals as provided in Fig. 2.

4. Simulation Results

Three cases are considered, each with different wind induced pressure difference between internal and external (ΔP):

(1) ΔP = 0 (reference case)

(2) ΔP = Pwind (see Fig. 2, bottom) and

(3) ΔP = - Pwind

The simulation results are visualized in two ways:

Firstly, movies (downloadable from http://archbps1.campus.tue.nl/bpswiki/index.php/Hamlab). This is probably the best way to analyze the results.

Secondly, time series at six locations: Two points at the inner surface (Fig. 5), two points at the inside wood-insulation surface (Fig. 6) and two points at the outside wood-insulation surface (Fig. 7).

The first three sub-figures each show six variants (two positions , each with 3 different wind induced pressures at the external boundary) of temperature (top), vapor pressure (second) and RH (third). The sub-figure at the bottom shows the wind induced pressure. The results of indoor surface temperatures (Fig. 5, top) show a quite steady difference of about 1℃ between the continuous lines representing position a, and the dotted lines representing position b. This is due to the (corner) thermal bridge effect. Only at high wind induced pressure differences (for example day 28) the airflow due the wind has some significant effect on the temperatures. This means that thermally, at the internal surface the multi-dimensional effect is far more dominant than the

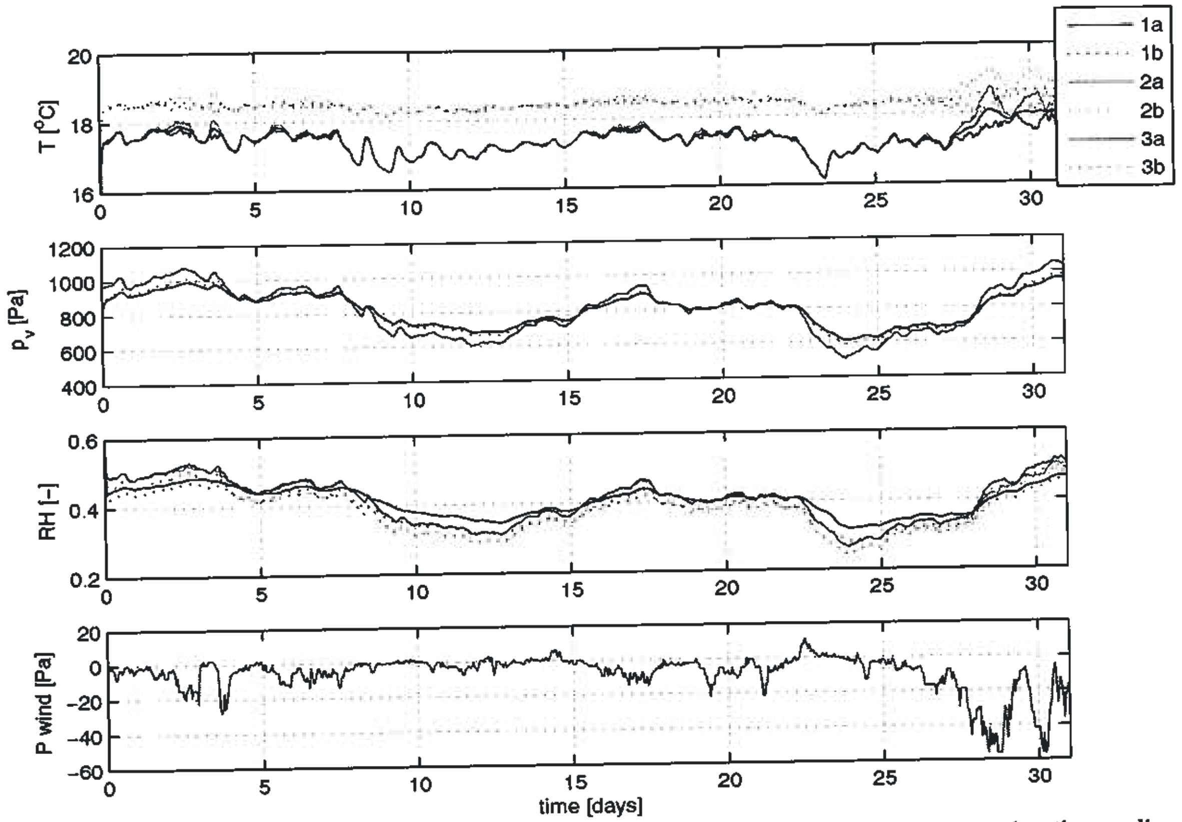

Fig. 5 Time series at inner surface (This figure relies on color: see digital version of paper; pos a (continuous lines) & b (dotted lines) see Fig. 1; explanation see below).

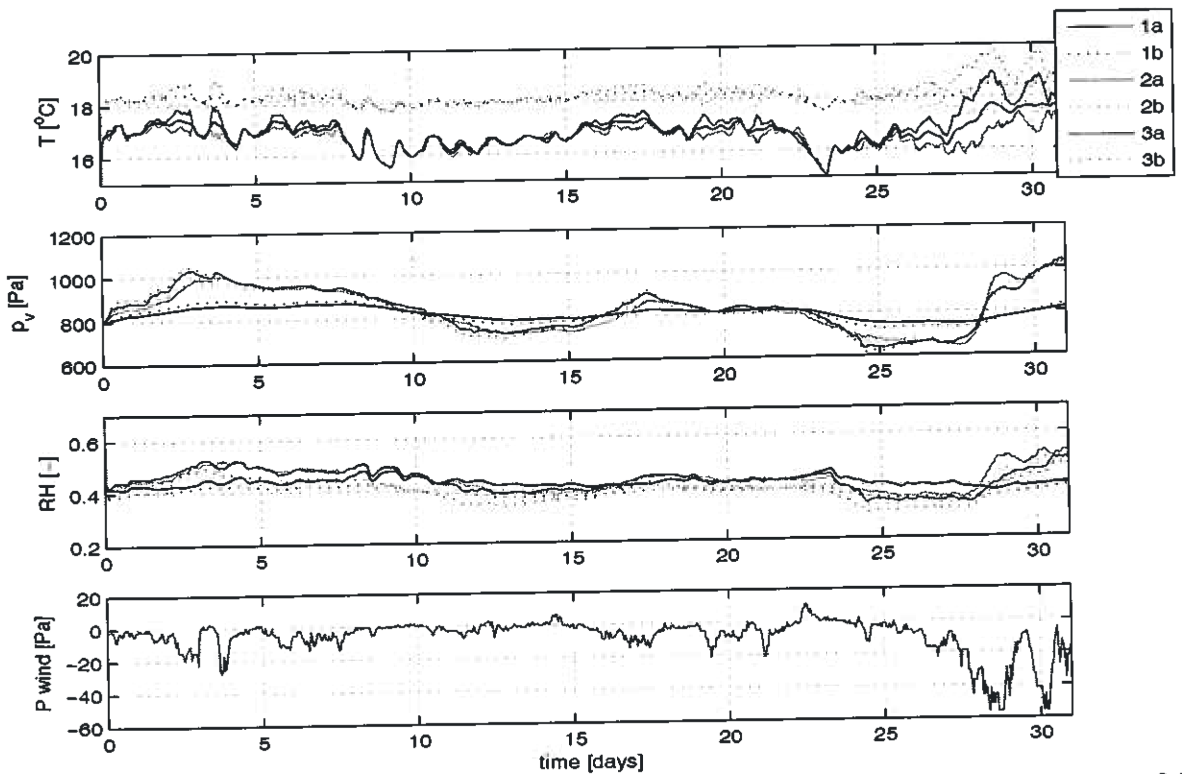

Fig. 6 Time series at inside wood-insulation surface (This figure relies on color: see digital version of paper; pos a & b see Fig. 1; explanation see below).

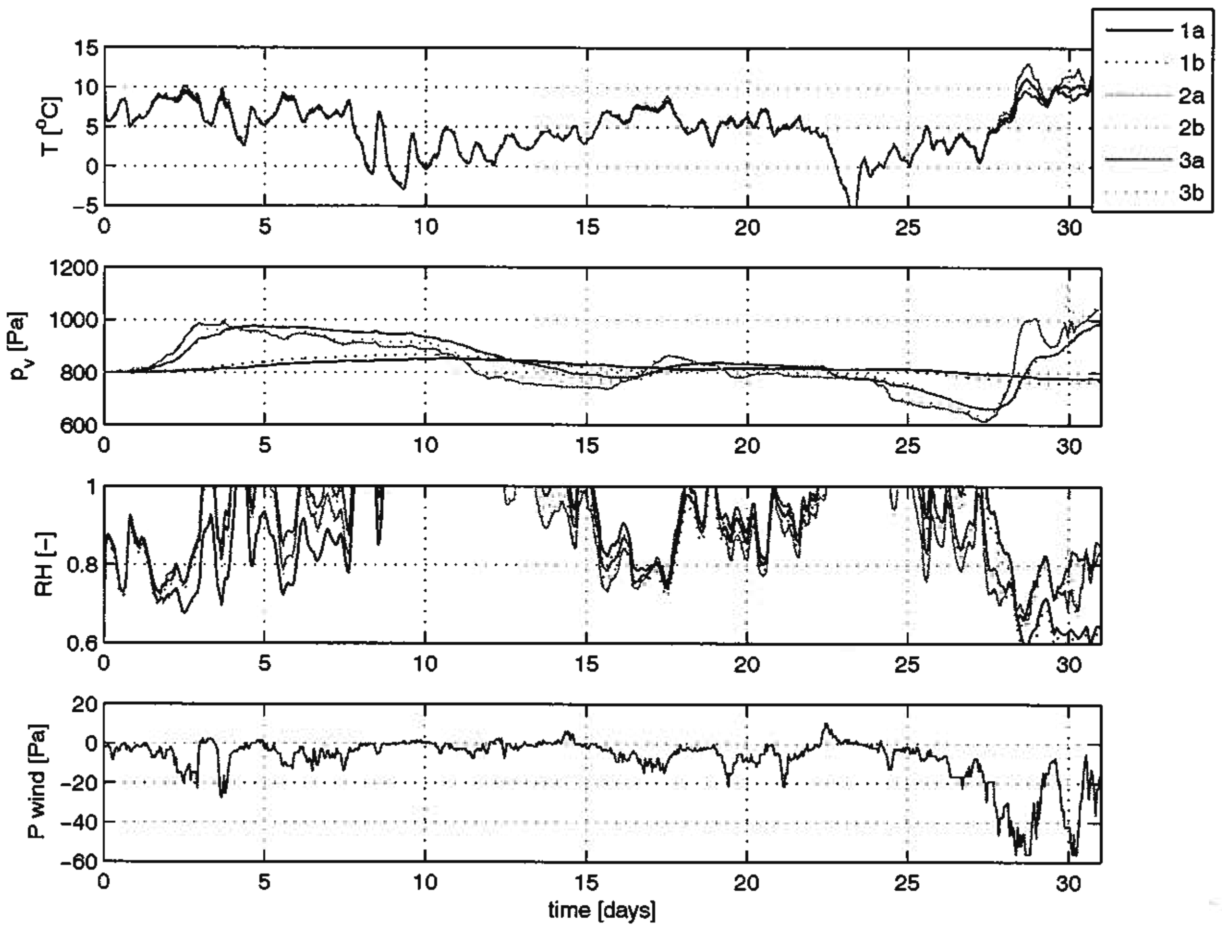

Fig. 7 Time series at outside wood-insulation surface (This figure relies on color: see digital version of paper; pos a & b see Fig. 1; explanation see below).

effect of airflow through the construction. The results of the surface vapor pressures are very different. The vapor pressures are almost not influenced by both the 2D effect and the wind speed (four curves: 2a; 2b; 3a & 3b coincide during the whole simulation period). The RH has roughly the same shape as the vapor pressure.

The temperatures of Fig. 6 (top) show the same pattern as Fig. 5. However the vapor pressure (second sub-figure) is influenced by the wind induced pressures (see difference between 1a, 2a & 3a). This clearly shows the effect of air movement. Again, the RH (third sub-figure) has roughly the same shape as the vapor pressure.

The temperatures profiles of Fig. 7 (top) are almost the same (all curves coincide). Thus there is no effect of airflow. The vapor pressures of Fig. 7 (second) have roughly the same shapes as the previous Fig. 6, again showing clearly the effect of air flow. The RH (third sub-figure) shows the dependency of the temperature as well as the air flow.

5. Discussion

The moisture transport is based on vapor transport, so for example rain penetration and condensation are not included (yet). This means that the results are not accurate for RH above 90%. Currently we are working on a model which also includes these phenomena. Furthermore (experimental) results are needed to confirm or contradict our computational findings on the impact of airflow.

6. General Conclusion

Multiphysics FEM software can be used to simulate

2D (and in principle also 3D) full dynamic HAM models of building constructions. Our simulation results indicate, for this particular case, that air movement through building materials seems to have significant impact on the heat and moisture characteristics. In order to verify this statement and validate the models, new in-depth experiments including air flow through materials are recommended.

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