Modeling the similarity and the potential of VOC and moisture buffering capacities of bio-based building materials on IAQ and thermal comfort

Application to hemp concrete

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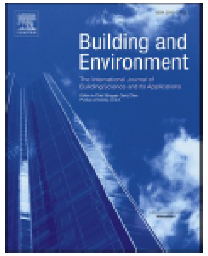

ELSEVIER

Modeling the similarity and the potential of toluene and moisture buffering capacities of hemp concrete on IAQ and thermal comfort

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A R T I C L E I N F O

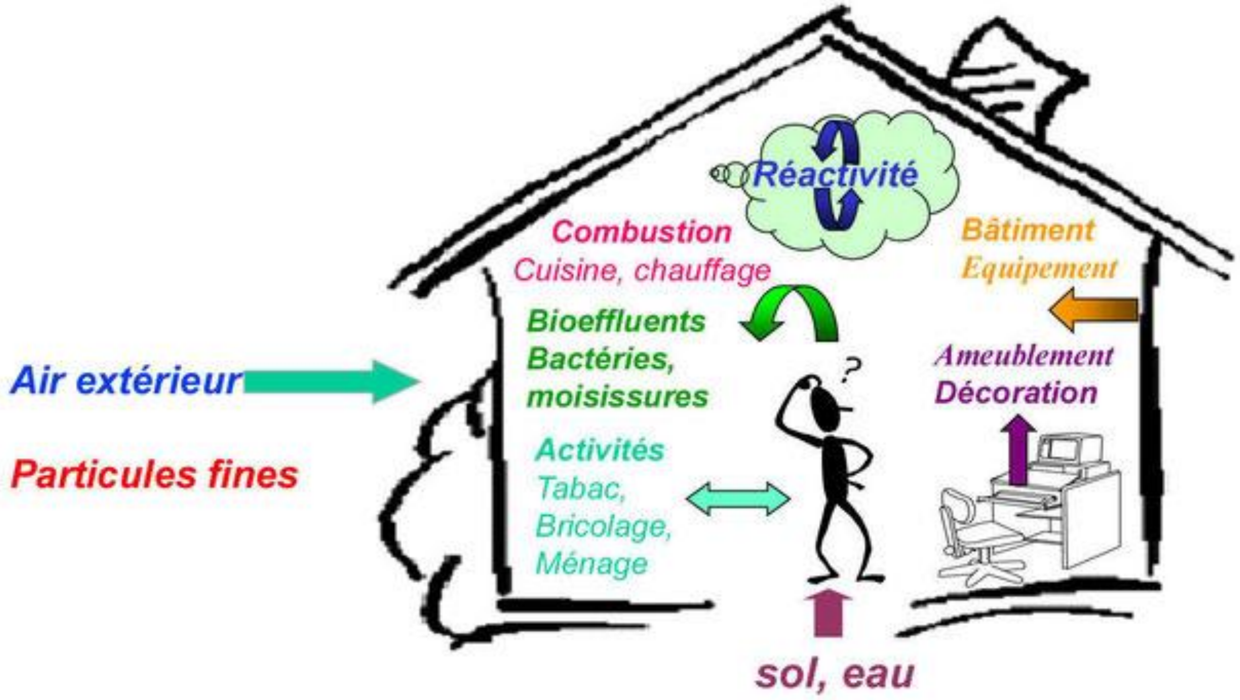
Keywords:
Hemp concrete
Toluene buffering capacity
Moisture buffering capacity
Similarity
Indoor air quality
Modeling
VOC
Moisture

Sources et impact de QAI sur la santé

Exposition à forte dose: des effets immédiats

Expositions répétées: des effets à long terme

Quelles sont les sources de pollution ?



La qualité de l'air d'un bâtiment dépend

Des **sources de pollutions** auxquels il est soumis

Pollutions venant de l'extérieur:

- Par le système de ventilation
- Par les défauts d'étanchéité de l'enveloppe

Pollutions produites à l'intérieur du bâtiment

- ***Émissions des matériaux, des produits, de l'ameublement….***
- Dues à l'occupation humaine
- Aux appareils de chauffage, équipements….
- Champignons, bactéries, moisissures….

Quel est l'impact de la capacité tampon des matériaux poreux?

Mais aussi des **moyens** mis en œuvre pour évacuer les polluants

Filtrage de l'air

Adaptation des débits de ventilation

Maintenance des équipements

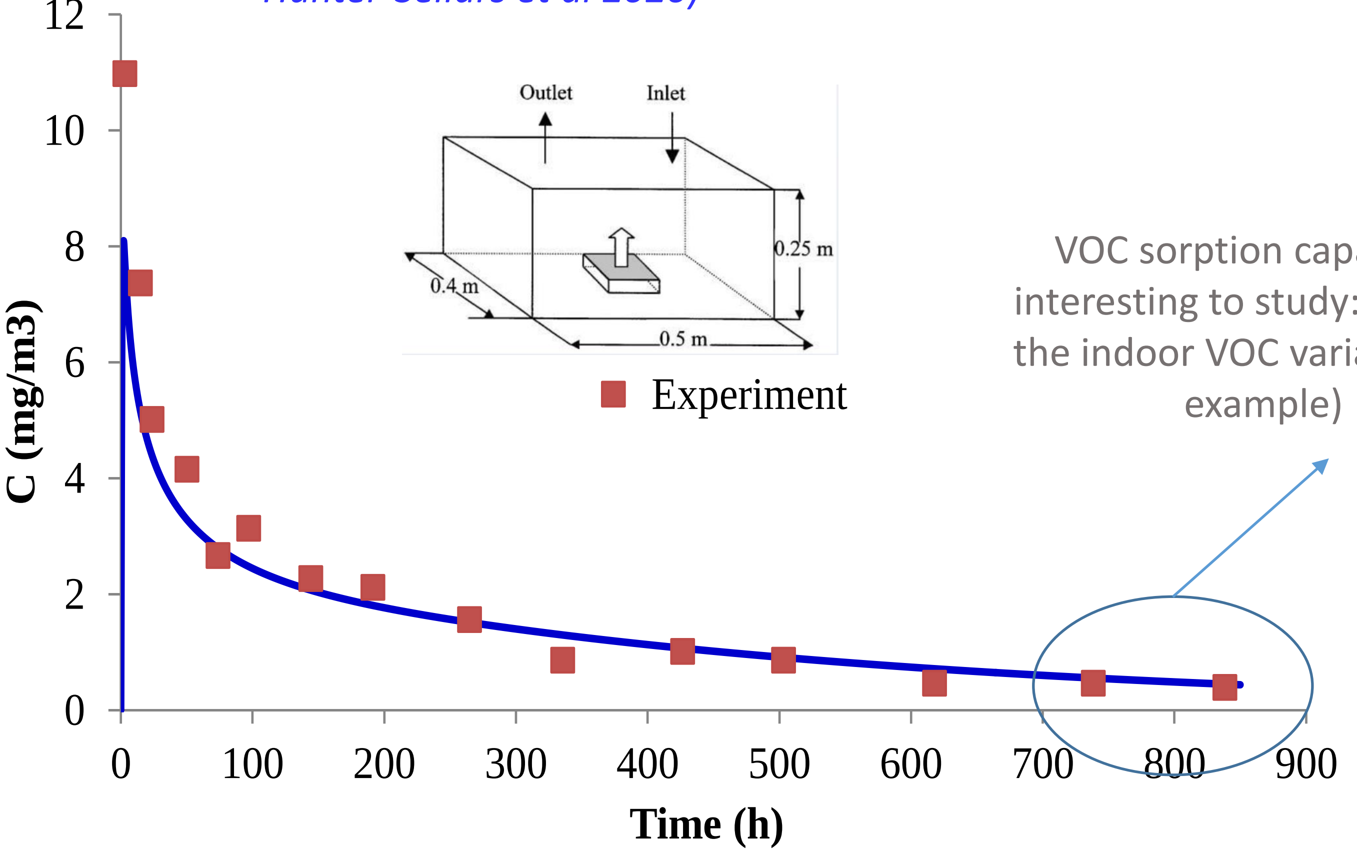
Example: TVOC concentration emitted from the particleboard

- Experimental setup consists of a small test chamber (0.4*0.5*0.25 m3) with a pollutant emitting panel material inside
- Particleboard with dimension 0.212x0.212x0.0159 m3
- Test conditions: T=23˚C, RH=50%, Air change rate= 1 1/h

The reduction of indoor VOC through adsorption processes is an important research objective due to its potential to provide improved quality of life for individuals in exposed spaces *(Elwin Hunter-Sellars et al 2020)*

Age: 0

PB2	TVOC
Dm (m^2/s)	$7.65x10^{-11}$
C_O ($\mu g/m^3$)	$9.86x10^7$
K_{ma}	3289



VOC sorption capacity is interesting to study: dampen the indoor VOC variation (for example)

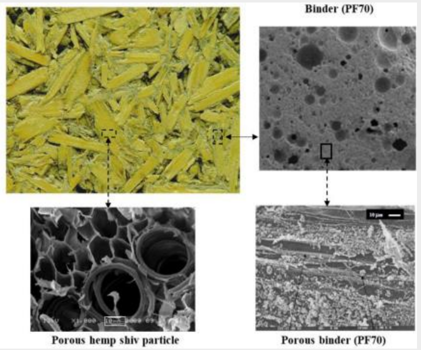
**Elwin Hunter-Sellars, J.J. Tee, Ivan P. Parkin, Daryl R. Williams, Adsorption of volatile organic compounds by industrial porous materials: impact of relative humidity, Microporous Mesoporous Mater. (2020) 298.*

Experimental results obtained by reference: Yang X, Phd Thesis, MIT USA, 1999

mCHAMPS-BBMS

The multi-scale approach to Coupled Heat, Air, Moisture and Pollutants Simulations in Bio-based Building Materials and Systems

Microscopic scale



Microscopic properties of components

Material scale

Properties (anisotropy)
Thermal
Physical
Moisture
Pollutant (VOC)

Wall scale

Hygrothermal and VOC behavior

Experimental study
Model validation

Room and house scale

Hygrothermal performance, thermal comfort et indoor air quality (QAI: VOC, CO2…), Energy consumption
Numerical and experimental studies
Model validation

HygroPo-BBM

CHAMPS-BBM

mCHAMPS-BBMS

Homogenization method

Implemented properties

CHAMPS: **C**oupled **H**eat, **A**ir, **M**oisture and **P**ollutants **S**imulations

HygroPo-BBM model: hygrothermal and Pollutant **P**roperties of **BioBased-M**aterials

mCHAMPS-BBMS model= **HygroPo-BBM** + **CHAMPS-BBM**+ Systems

CHAMPS-BBM model**: CHAMPS** model dedicated to **Bio**based Building **M**aterial

English version

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Impact of humidity on VOC key parameters of building materials

Dm and Km of Formaldehyde (a water soluble VOC)

The experimental data [19,25,26,47] for different materials gathered, compared together :

- ✓ Calcium silicate (CS),
- ✓ Medium Density Fiberboard (MDF)
- ✓ Conventional Wallboard (CWB)
- ✓ Green wallboard (GWB)

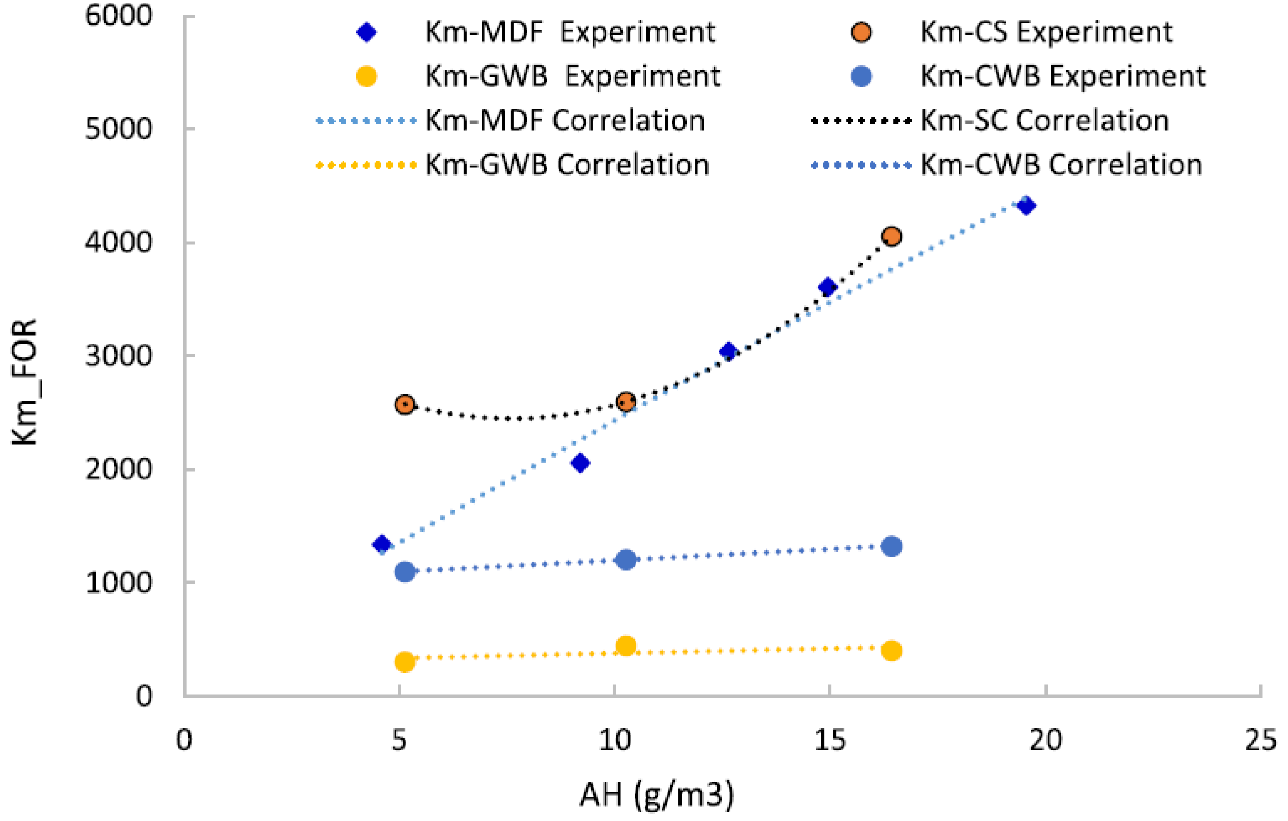

Fig. 2. Impact of AH on $K_{m,FOR}$ for formaldehyde (FOR) of different materials based on the experimental results [19,26,47].

- ✓ **Increased AH results in increased partition coefficient**: formaldehyde absorption into the liquid water under the higher humidity condition.
- ✓ **Impact is different for different materials**: different sorption capacities.
- ✓ **Km of CS is the highest**: the largest storage capacity for FOR

A.D. Tran Le, JS. Zhang, Z. Liu. ***Impact of humidity on formaldehyde and moisture buffering capacity of porous building material****, Journal of Building Engineering, 36, 2021, 102114, ISSN 2352 7102.*

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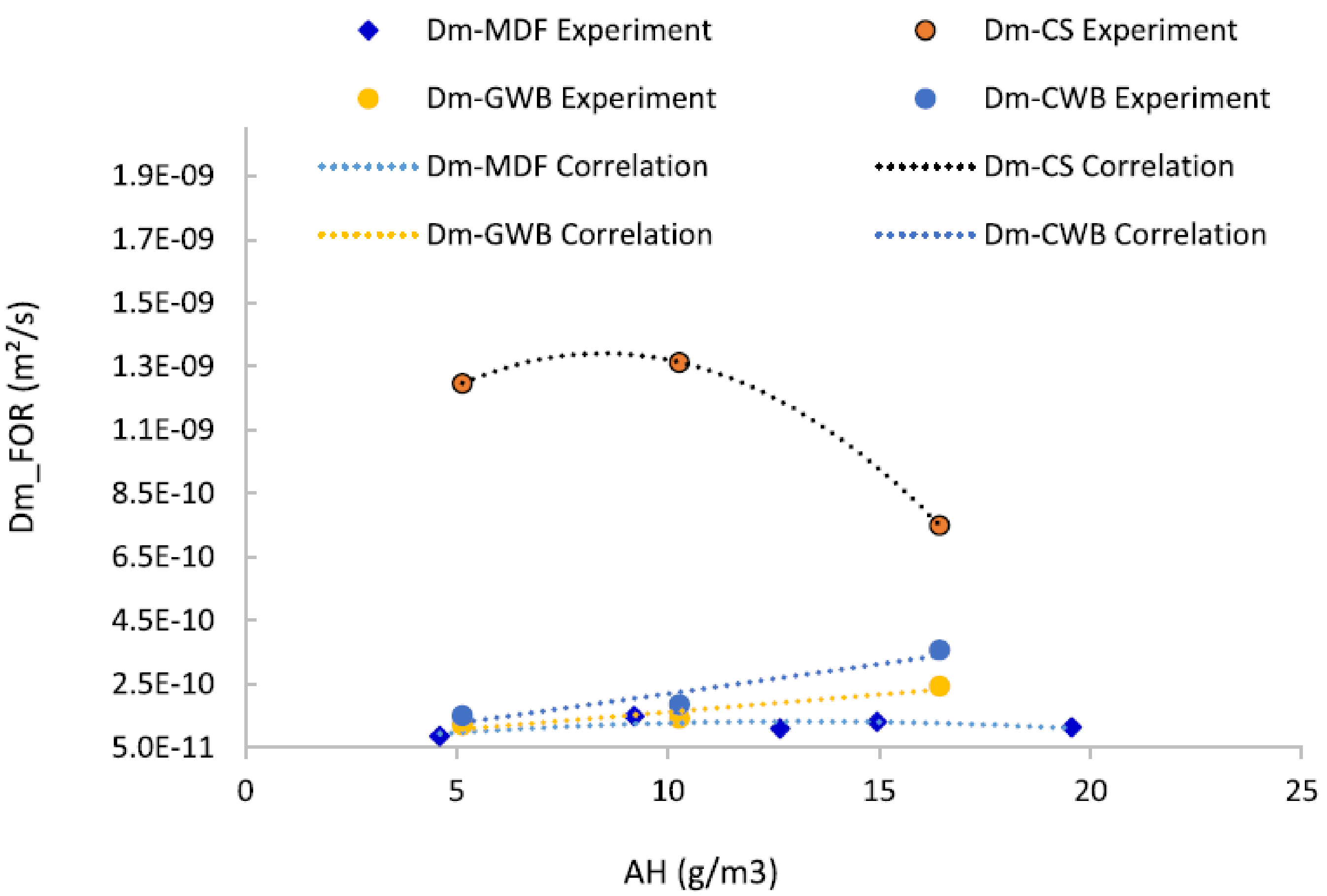
Decrease of Dm of Formaldehyde with increased humidity: considered as a competitor of formaldehyde diffusion in material (higher relative humidity ➔ higher water vapor diffusion in the pores).
Capillary condensation: pores filled with liquid water due to higher relative humidity ➔ reduce formaldehyde diffusion in the material.

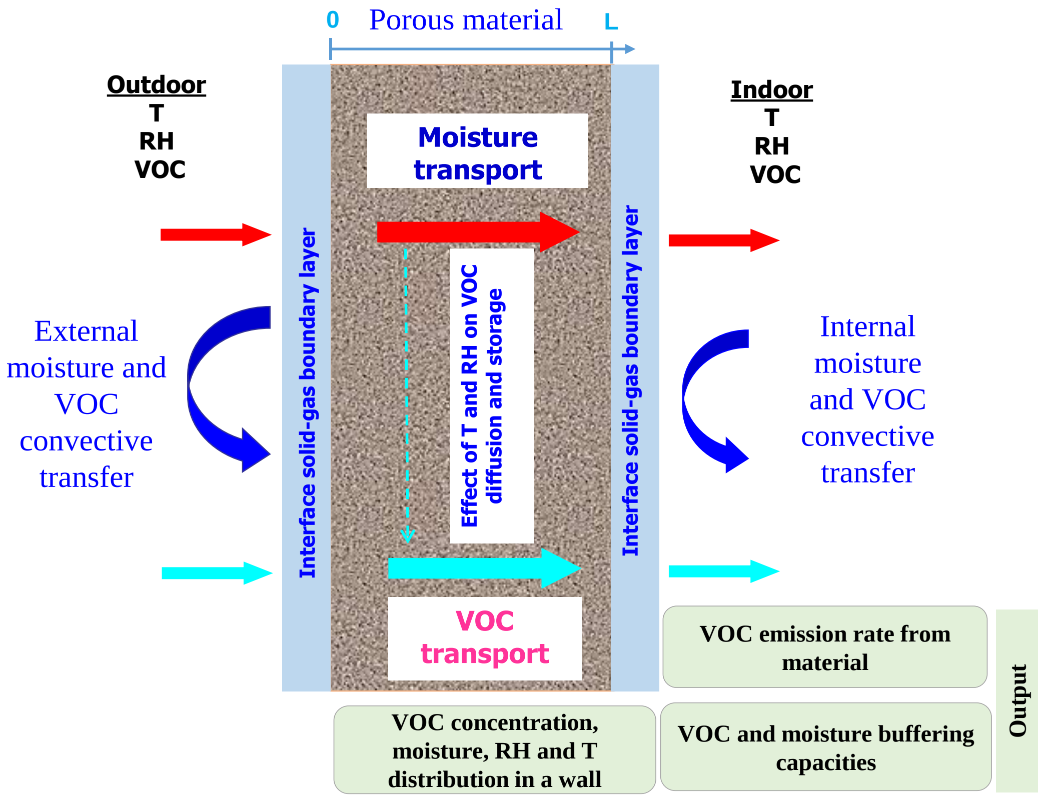


A.D. Tran Le, JS. Zhang, Z. Liu. ***Impact of humidity on formaldehyde and moisture buffering capacity of porous building material****, Journal of Building Engineering, 36, 2021, 102114, ISSN 2352 7102.*

Modelling similarity of pollutants and moisture transport models

Assumptions:

- ✓ Transport of water vapor in building materials is modelled analogously to the transport of VOC.
- ✓ Sorption of water vapor is described by the sorption isotherm curve (due to its multilayer adsorption)
- ✓ Sorption of VOC is modelled by the partition coefficient for VOC (generally considered as monolayer adsorption).



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Similarity of pollutants and moisture transport models

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For a dry material with homogeneous diffusivity, the VOC mass transport within the wall can be described by the one-dimensional diffusion [32–34]:

$$\frac{\partial C_{m,VOC}}{\partial t} = \frac{\partial}{\partial x}\left(D_{m,VOC}\frac{\partial C_{m,VOC}}{\partial x}\right) \quad (1)$$

Where $C_{m,VOC}$ is VOC concentration in the material (kg/m^3), $D_{m,VOC}$ is diffusion coefficient of the VOC in the material (m^2/s), x is abscissa (m) and t is time (s). Here, in the developed numerical model, the $D_{m,VOC}$ is a function of relative humidity/moisture in the material (if the data is available) while the dependence of $D_{m,VOC}$ on pollutants concentration is neglected as generally accepted under low VOC concentration condition.

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Similarity of pollutants and moisture transport models

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There is an equilibrium which exists between the concentration of VOC in a material ($C_{m,VOC}$) and the concentration in air ($C_{a,VOC}$), which is defined by the partition coefficient $K_{m,VOC}$:

$$C_{m,VOC} = K_{m,VOC}.C_{a,VOC} \quad (2)$$

The diffusion coefficient of VOC in the material ($D_{m,VOC}$) can be determined from the VOC diffusion coefficient in the free air (D_{VOC}^{air}) and diffusion resistance factor (μ_{VOC}) of VOC [30]:

$$D_{m,VOC} = \frac{D_{VOC}^{air}}{\mu_{VOC} K_{m,VOC}} \quad (3)$$

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Similarity of pollutants and moisture transport models

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At the material-air interface, we assume an instantaneous equilibrium between VOC concentration (kg/m^3) in the air near material surface ($C_{a,VOC,s}$) and the one in the surface layer ($C_{m,VOC,s}$):

$$C_{m,VOC,s} = K_{m,VOC} . C_{a,VOC,s} \tag{4}$$

With the following boundary conditions applied respectively for the external (x = 0) and internal (x = L) surfaces of the wall:

$$-\left(D_{m,VOC} \frac{\partial C_{m,VOC}}{\partial x} \right)_{x=0,e} = h_{m,\mathrm{VOC},e} \left(C_{a,\mathrm{VOC},e} - C_{a,VOC,s,e} \right) \tag{5}$$

$$-\left(D_{m,VOC} \frac{\partial C_{m,VOC}}{\partial x} \right)_{x=L,i} = h_{m,\mathrm{VOC},i} \left(C_{a,VOC,s,i} - C_{a,\mathrm{VOC},i} \right) \tag{6}$$

Similarity of pollutants and moisture transport models

Concerning the moisture transport model, the moisture transport within the wall can be described by the one-dimensional diffusion for using moisture content in material as driving force [35]:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left(D_{m,wv}\frac{\partial\theta}{\partial x}\right) \quad (7)$$

Where θ is moisture volumetric content in the material (m^3 of water/m^3 of material), $D_{m,wv}$ is diffusion coefficient of the moisture in the material (m^2/s) which is defined by Ref. [35,59]:

$$D_{m,wv} = \delta_{wv}\frac{P_{v,sat}}{\rho_w}\frac{1}{\partial\theta/\partial RH} = \frac{\delta_{wv}^{air}}{\mu_{wv}}\frac{P_{v,sat}}{\rho_w}\frac{1}{\partial\theta/\partial RH} \quad (8)$$

$\partial\theta/\partial RH$ is the slope of the sorption isotherm curve which designates the relationship between the moisture content and the relative humidity (RH) at a fixed temperature, δ_{wv} is water vapor permeability of material

Similarity of pollutants and moisture transport models

$$\delta_{wv}^{\text{air}} = \frac{D_{wv}^{air}}{R_v T} \tag{9}$$

By replacing (9) in (8) we have:

$$D_{m,\text{wv}} = \frac{D_{wv}^{air}}{\mu_{wv} \frac{\rho_w R_v T}{P_{v,sat}} \frac{\partial \theta}{\partial RH}} = \frac{D_{wv}^{air}}{\mu_{wv} K_{m,wv}} \tag{10}$$

As with the VOC, by identifying two equations (3) and (10), the coefficient $K_{m,wv}$ introduced in (10) is the "partition coefficient" for water vapor, which is similar to $K_{m,VOC}$ in (3) for VOC and can be calculated as following:

$$K_{m,wv} = \frac{\rho_w R_v T}{P_{v,sat}} \frac{\partial \theta}{\partial RH} \tag{11}$$

Note that the partition coefficient (Km,wv) for water vapor can be calculated by relating gradients of the absorbed moisture content mass by volume of material, to gradients of the humidity of air by volume of the pores at equilibrium condition. Using this definition to calculate Km, wv, the same result was obtained.

Similarity of pollutants and moisture transport models

Concerning the sorption isotherm, in this article, the Guggenheim-Anderson-deBoer (GAB) model [60] which is extended from Langmuir and BET theories [61,62] of physical adsorption, is used to describe the sorption curve. Using the GAB model has many advantages such as having a viable theoretical background and giving a good description of the sorption behavior of hygroscopic material [37]. The GAB model can be written as follows:

$$w = \frac{w_m C_{GAB} K_{GAB} RH}{(1 - K_{GAB} RH)(1 + K_{GAB} C_{GAB} RH - K_{GAB} RH)} \quad (12)$$

Where RH is relative humidity, w is the moisture content (kg of water/kg of material), w_m is the monolayer moisture content value, C_{GAB} and K_{GAB} are energy constants of GAB model.

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Similarity of pollutants and moisture transport models

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At the material-air interface, we assume an instantaneous equilibrium between water vapor concentration (kg/m^3) in the air near material surface ($C_{a,wv,s}$) and the one in the surface layer ($C_{m,wv,s}$), which is determined by the sorption isotherm curve. The following boundary conditions applied to water vapor, respectively for the external (x = 0) and internal (x = L) surfaces of the wall:

$$-\left(\rho_w D_{m,wv}\frac{\partial\theta}{\partial x}\right)_{x=0,e} = h_{m,wv,e}\left(C_{a,wv,e} - C_{a,wv,s,e}\right) \qquad (13)$$

$$-\left(\rho_w D_{m,wv}\frac{\partial\theta}{\partial x}\right)_{x=L,i} = h_{m,wv,i}\left(C_{a,wv,s,i} - C_{a,wv,i}\right) \qquad (14)$$

Where $C_{a,wv,i}$ and $C_{a,wv,e}$ are water vapor concentrations in the room air and outside (kg/m^3), and $h_{m,wv,e}$ and $h_{m,wv,i}$ are convective water vapor transfer coefficients (m/s) for the external and internal surfaces.

Similarity of pollutants and moisture transport models

$$\frac{h_{m,\mathrm{wv}}}{h_{m,\mathrm{VOC}}} = \left(\frac{D_{wv}^{air}}{D_{VOC}^{air}}\right)^{2/3} \tag{19}$$

Equation (19) permits to determine the convective mass transfer coefficient of VOC ($h_{m,VOC}$) from the convective mass transfer coefficient of water vapor $h_{m,wv}$ (or inversely) using the diffusion coefficients of VOC and water vapor in the air, respectively.

Similarity of pollutants and moisture transport models

Similarity coefficient

The similarity coefficient for the moisture and VOC diffusion (Xu et al 2001)

$$\kappa_{\mu,VOC} = \frac{\mu_{VOC}}{\mu_{wv}} = \frac{D_{VOC}^{air}}{\mu_{wv} D_{m,\mathrm{VOC}} K_{m,VOC}}$$

Similarity coefficient for the moisture and VOC storage (Tran Le et al 2021)

$$\kappa_{K_{m,VOC}} = \frac{K_{m,VOC}}{K_{m,\mathrm{wv}}}$$

If the similarity is justified and validated by experimental results for other pollutants
➔ VOC properties can be determined directly from the vapor diffusion resistance factor (μ) and the slope of the sorption curve in the monolayer sorption range

From 0 to 20% RH, before the beginning of multilayer sorption for hemp concrete case because the VOCs sorption is generally monolayer in building materials.

Similarity of pollutants and moisture transport models
Model for a room – nodal method

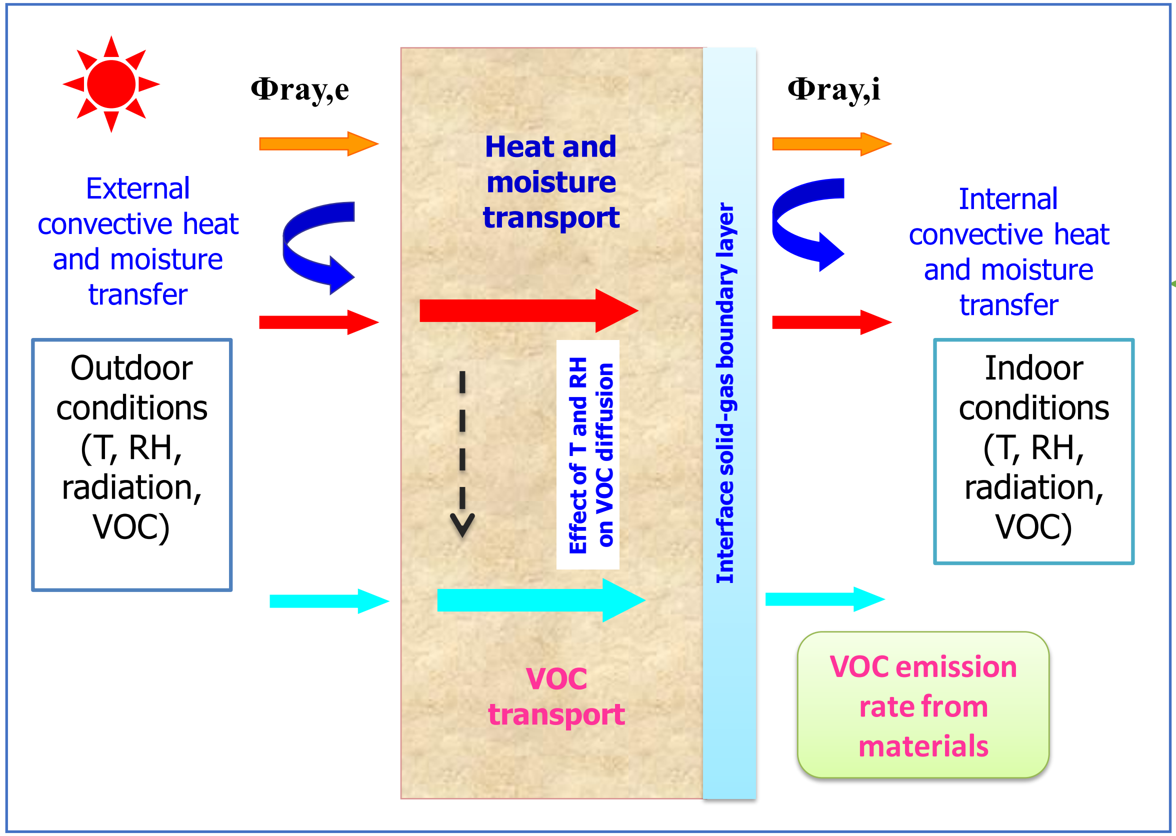
Previous equations

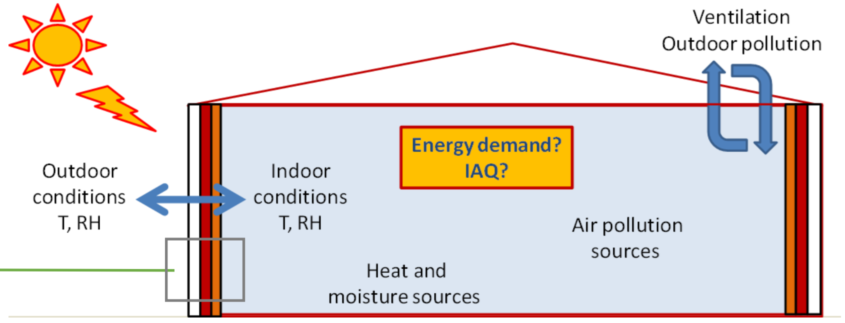
$$V\frac{\partial C_{a,i}}{\partial t} = Q\left(C_{a,o} - C_{a,i}\right) + \sum A.h_{m,i}\left(C_{as,i} - C_{a,i}\right) + G \quad (20)$$

Where $C_{a,i}$ is the VOC/water vapor concentration at time t (kg/m^3); $C_{a,o}$ is outdoor ventilation air; V is volume space (m^3); the summation symbol represents the sum of moisture/VOC exchanged between indoor air and the exposed area of the material; A is exposed area of the material (m^2); Q is the volume air flow rate into (and out) of the room (m^3/s); G is the generation rate of VOC/water vapor in the room (kg/s).

CHAMPS-Bio Model

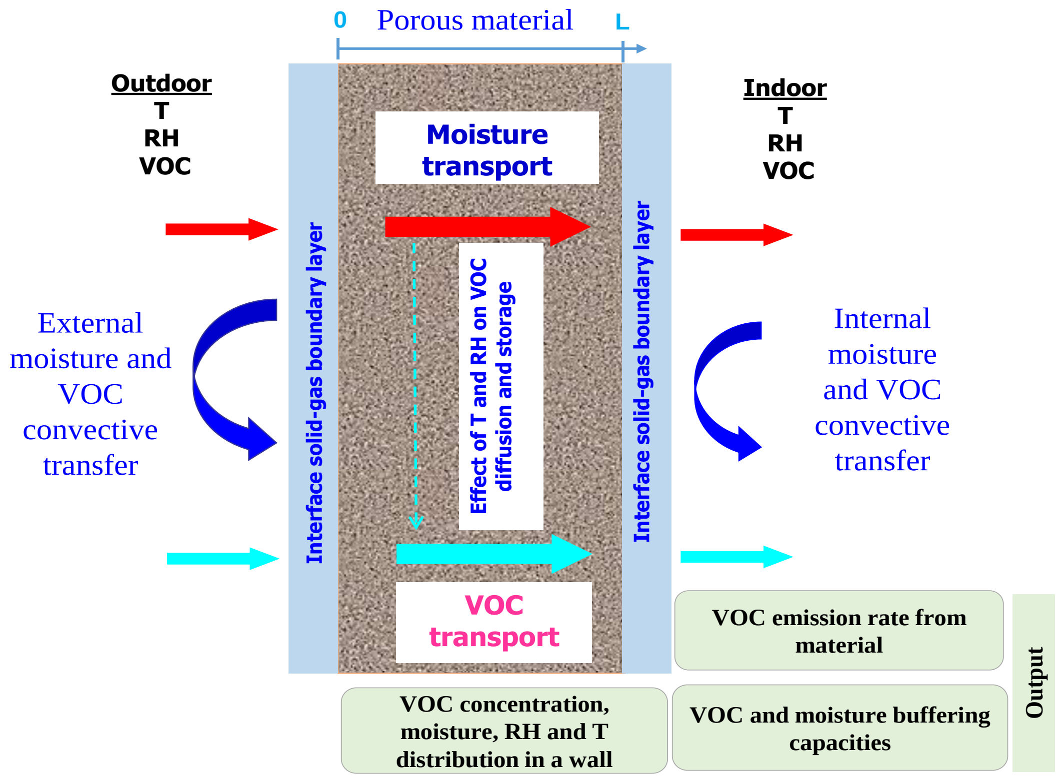
Development and Validation of a Coupled Heat, Air, Moisture and Pollutant Simulation Model Dedicated to Bio-based Materials





- Analogy between: transport of water vapor and VOC in building materials
- Sorption of water vapor: the sorption isotherm curve
- Sorption of VOC: the partition coefficient for VOC
- **Taking into account of iimpact of T and RH on VOC diffusion**
- **Focusing on Biobased building materials**

CHAMPS-Bio model



Governing moisture balance equation and boundary conditions

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(D_T \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial x}\left(D_\theta \frac{\partial \theta}{\partial x}\right)$$

$$-\rho_l\left(D_T \frac{\partial T}{\partial x} + D_\theta \frac{\partial \theta}{\partial x}\right)\bigg|_{x=0,e} = h_{M,e}\left(\rho_{ve,a,e} - \rho_{ve,s,e}\right)$$ external surface (x=0)

$$-\rho_l\left(D_T \frac{\partial T}{\partial x} + D_\theta \frac{\partial \theta}{\partial x}\right)\bigg|_{x=L,i} = h_{M,i}\left(\rho_{ve,s,i} - \rho_{ve,a,i}\right)$$ internal surface (x=L)

Energy balance equation and boundary conditions

$$\rho_0 Cp_m \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda_{app} \frac{\partial T}{\partial x}\right) + L_v \rho_l \left(\frac{\partial}{\partial x}\left(D_{T,v} \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial x}\left(D_{\theta,v} \frac{\partial \theta}{\partial x}\right)\right)$$

$$-\lambda_{app}\frac{\partial T}{\partial x} - L_v \rho_l \left(D_{T,v} \frac{\partial T}{\partial x} + D_{\theta,v} \frac{\partial \theta}{\partial x}\right)\bigg|_{x=0,e} = h_{T,e}\left(T_{a,e} - T_{s,e}\right) + L_v h_{M,e}\left(\rho_{ve,a,e} - \rho_{ve,s,e}\right) + \Phi_{ray,e}$$

$$-\lambda_{app}\frac{\partial T}{\partial x} - L_v \rho_l \left(D_{T,v} \frac{\partial T}{\partial x} + D_{\theta,v} \frac{\partial \theta}{\partial x}\right)\bigg|_{x=L,i} = h_{T,i}\left(T_{s,i} - T_{a,i}\right) + L_v h_{M,i}\left(\rho_{ve,s,i} - \rho_{ve,a,i}\right) - \Phi_{ray,i}$$

Pollutants transport equation and boundary conditions

$$\frac{\partial C_m}{\partial t} = \frac{\partial}{\partial x}\left(D_m \frac{\partial C_m}{\partial x}\right)$$

$$-D_m \frac{\partial C_m}{\partial x}\bigg|_{x=0,e} = h_{m,e}\left(C_{a,e} - C_{as,e}\right) \qquad -D_m \frac{\partial C_m}{\partial x}\bigg|_{x=L,i} = h_{m,i}\left(C_{as,i} - C_{a,i}\right)$$

For pollutants model, at the material-air interface, we assume an instantaneous equilibrium between VOC concentration (mg/m3) in the air near material surface (Cas) and the one in the surface layer (Cms)

$$C_{ms} = K.C_{as}$$

Energy and mass balance equations for room air

$$\rho_i C_p V \frac{\partial T}{\partial t} = \Phi_{West} - \Phi_{East} + \Phi_{South} - \Phi_{North} + \Phi_{Bottom} - \Phi_{Top} + \Phi_{Ventilation} + \Phi_{Source}$$

$$V \frac{\partial \rho_i}{\partial t} = Q_{mWest} - Q_{mEast} + Q_{mSouth} - Q_{mNorth} + Q_{mBottom} - Q_{mTop} + Q_{mVentilation} + Q_{mSource}$$

$$V \frac{\partial C_i}{\partial t} = Q(Ca,e - Ca,i) + AE + G_{VOC\_Source}$$ Where $E = h_{m,i}\left(C_{as,i} - C_{a,i}\right)$

Model validation: particleboard (2015)

❖Experimental setup consists of a small test chamber (0.4*0.5*0.25 m3) with a pollutant emitting panel material inside

❖Particleboard with dimension 0.212x0.212x0.0159 m3

❖Test conditions: T=23˚C, RH=50%, Air change rate= 1 1/h

Age: 0

PB2	TVOC
Dm (m^2/s)	7.65×10^{-11}
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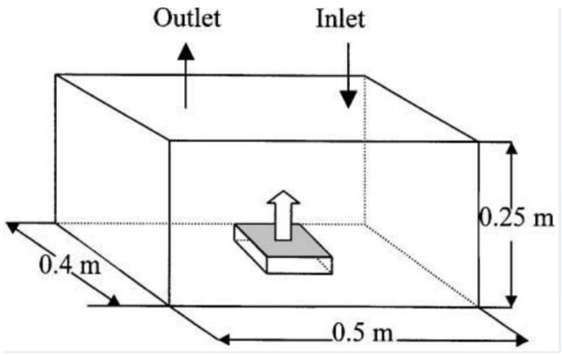
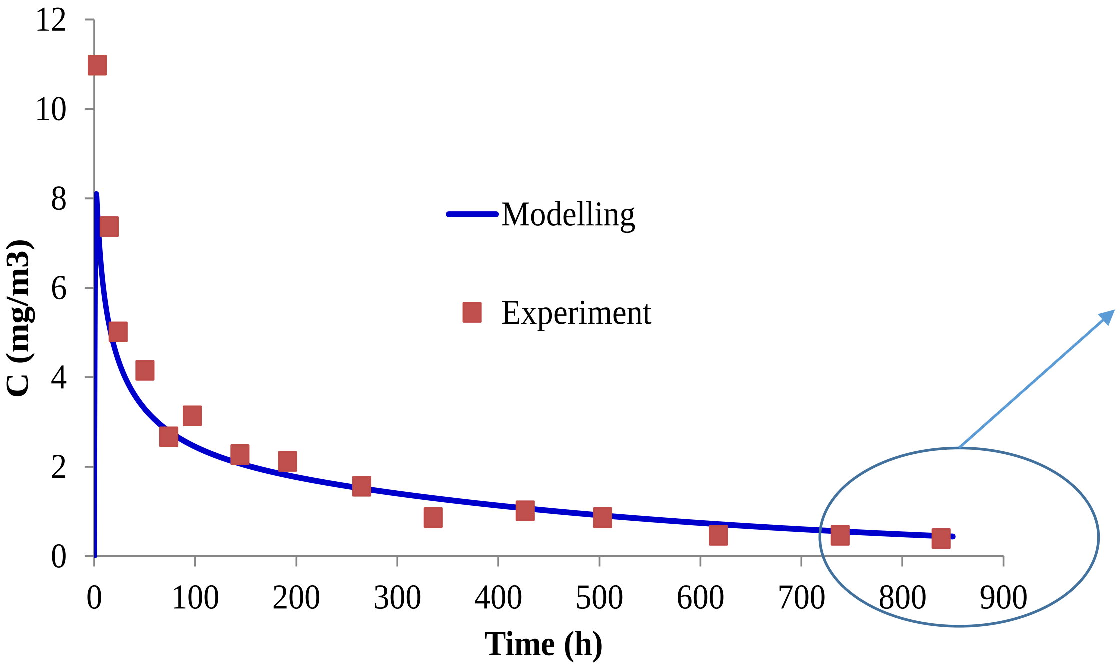


For multilayered wall ?



VOC sorption capacity is interesting to study: dampen the indoor VOC variation (for example)

Validating for TVOC concentration emitted from the particleboard

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Model validation (2020)

FULBRIGHT France
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Laureat

TRAN LE Anh Dung

Institution d'origine: Université de Picardie Jules Verne

Institution d'accueil: Syracuse University

Discipline: Ingénierie

Biographie : Anh Dung TRAN LE est enseignant chercheur à l'Université de Picardie Jules Verne (Laboratoire des Technologies Innovantes). Ses principaux travaux de recherche portent sur les études numérique et expérimentale du comportement hygrothermique des matériaux bio-sourcés, et leurs applications dans le bâtiment. Il s'intéresse depuis 2015 au développement d'un modèle multi-physique et multi-échelle de transferts couplés de chaleur, d'humidité et de polluants pour la prédiction des performances hygrothermique et sanitaire des matériaux bio-sourcés soumis à des conditions dynamiques en température et en humidité.

Titre du projet : Développement et validation expérimentale d'un modèle de transferts couplés de chaleur, d'air, d'humidité et de polluants dédié aux matériaux bio-sourcés (modèle **CHAMPS-Bio**).

Résumé du projet : Pour évaluer la qualité de l'air intérieur, il est nécessaire de connaître les taux de COV (composés organiques volatils) émis par les matériaux de construction. L'objectif du projet est de développer et valider expérimentalement un modèle de transferts couplés de chaleur, d'air, d'humidité et de polluants permettant de prédire le comportement hygrothermique et les émissions de COV par les matériaux bio-sourcés dans des conditions hygrothermiques dynamiques (**C**oupled **H**eat, **A**ir, **M**oisture and **P**ollutant Simulation transport model dedicated to **Bio**-based materials, **CHAMPS-Bio** model). Le modèle proposé est très utile pour l'optimisation de la conception des bâtiments car il permet une évaluation rapide du confort hygrothermique et de la qualité de l'air intérieur.

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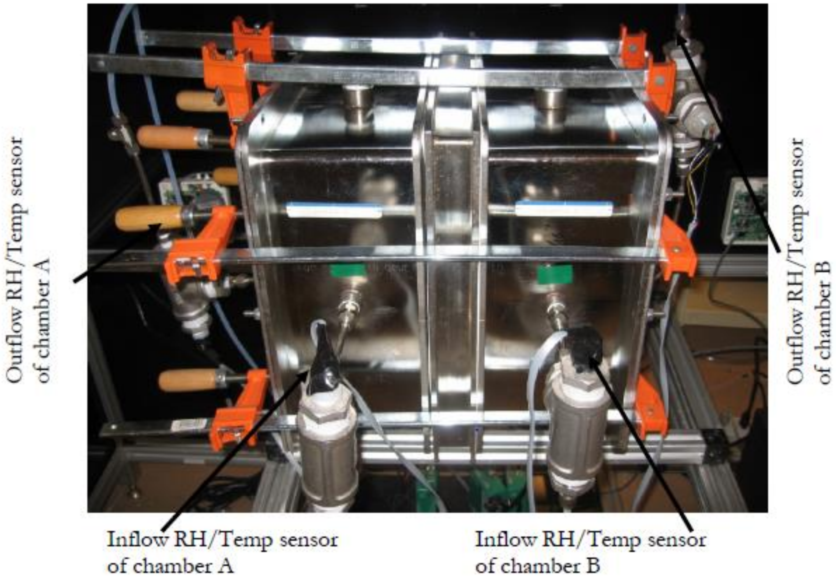
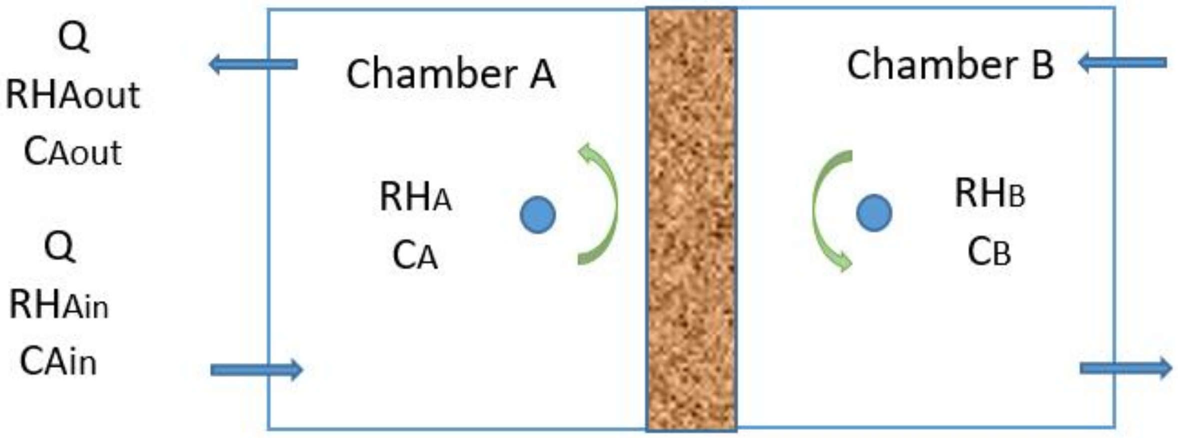
Model validation (2020)



Photograph



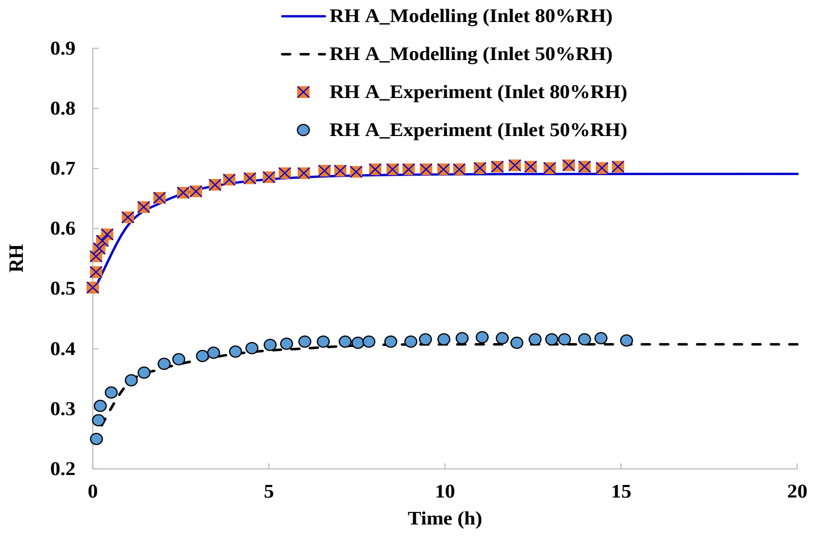
Schematic

Schematic of dual chamber system (Xu and Zhang 2011)

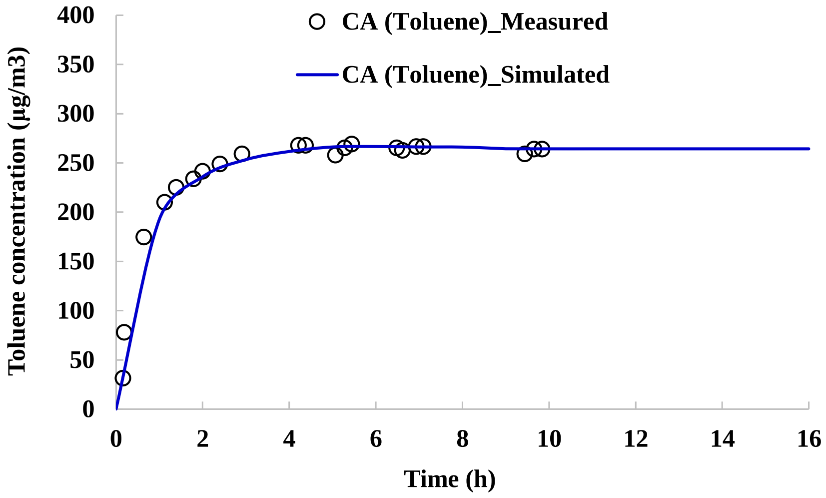
References: Xu. J., Zhang, JS. An experimental study of relative humidity effect on VOCs' effective diffusion coefficient and partition coefficient in a porous medium. Build Environ 46 (2011), 1785-96.

CHAMPS-Bio model validation

- **Model has been developed and validated in recent works :**
  - *In framework of Commission Fulbright Franco-Américaine-HdF/Fulbright Scholar program in 2020*
  - *Collaboration between UPJV (France) and SU (USA)*



Model validation for moisture diffusion model



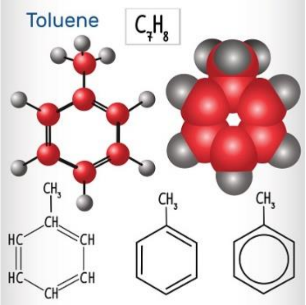
Model validation for formaldehyde (FOR)

Significant Impact of RH on VOC diffusion

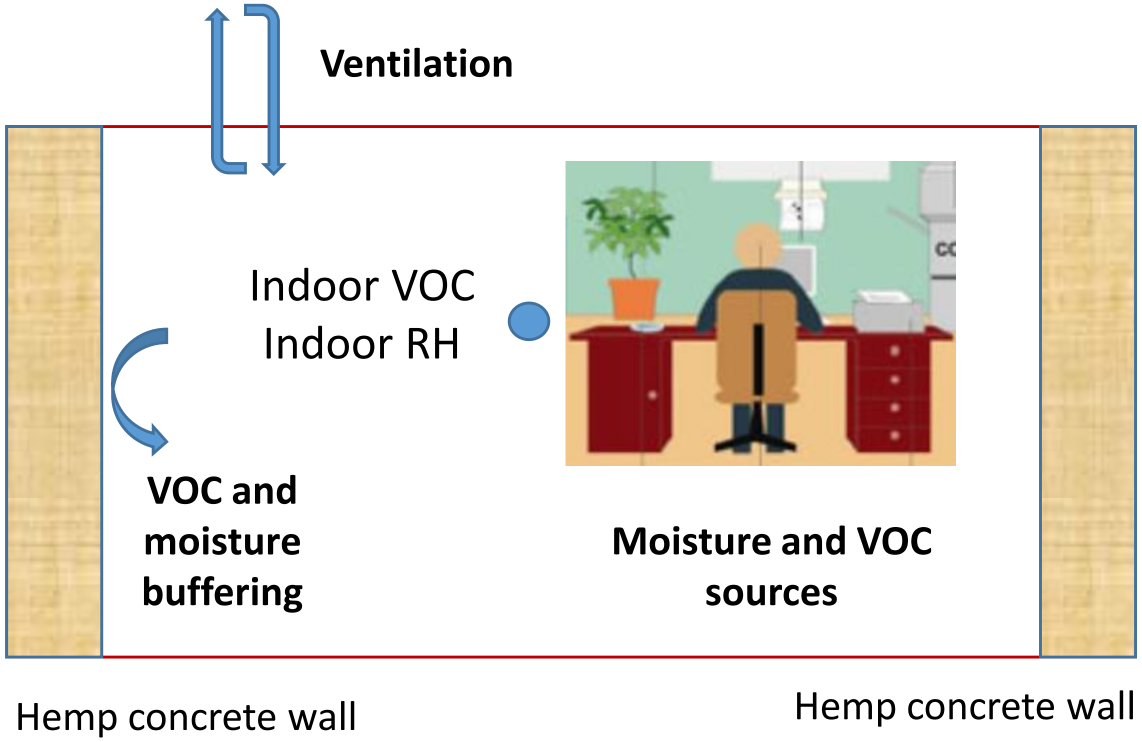
A.D. Tran Le, JS. Zhang, Z. Liu. **Impact of humidity on formaldehyde and moisture buffering capacity of porous building material**, *Journal of Building Engineering*, 36, 2021, 102114, ISSN 2352 7102.

A.D. Tran Le, JS. Zhang, Z. Liu, D Samri, T. Langlet. **Modeling the similarity and the potential of toluene and moisture buffering capacities of hemp concrete on IAQ and thermal comfort**, *Building and Environment*, 188,2021,107455.

Effect of toluene (VOC) and moisture buffering capacities of hemp concrete wall on indoor relative humidity and toluene concentration



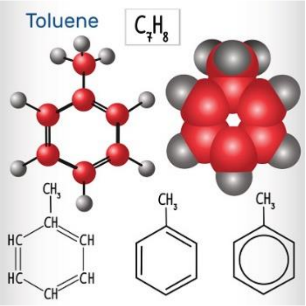
- Reference room: V=5*4*2.5 m^3
- Ventilation rate of 0.72 ACH (Air Changes per Hour)
- Exposed surface area S=25 m^2
- A toluene source scheme : 12 hours of 1000 µg/h followed intermittently 12 hours of 0 µg/h
- Room is occupied by two persons from 8.00 am to 17.00 pm (the water vapor source is 142 g/h).



- **Model with buffering capacity (BC** model)
- **Model without buffering capacity (Without-BC** model**)**

Effect of toluene (VOC) and moisture buffering capacities of hemp concrete wall on indoor relative humidity and toluene concentration

Modeling toluene properties from moisture properties of hemp concrete



Hygric properties of hemp concrete to model toluene properties.

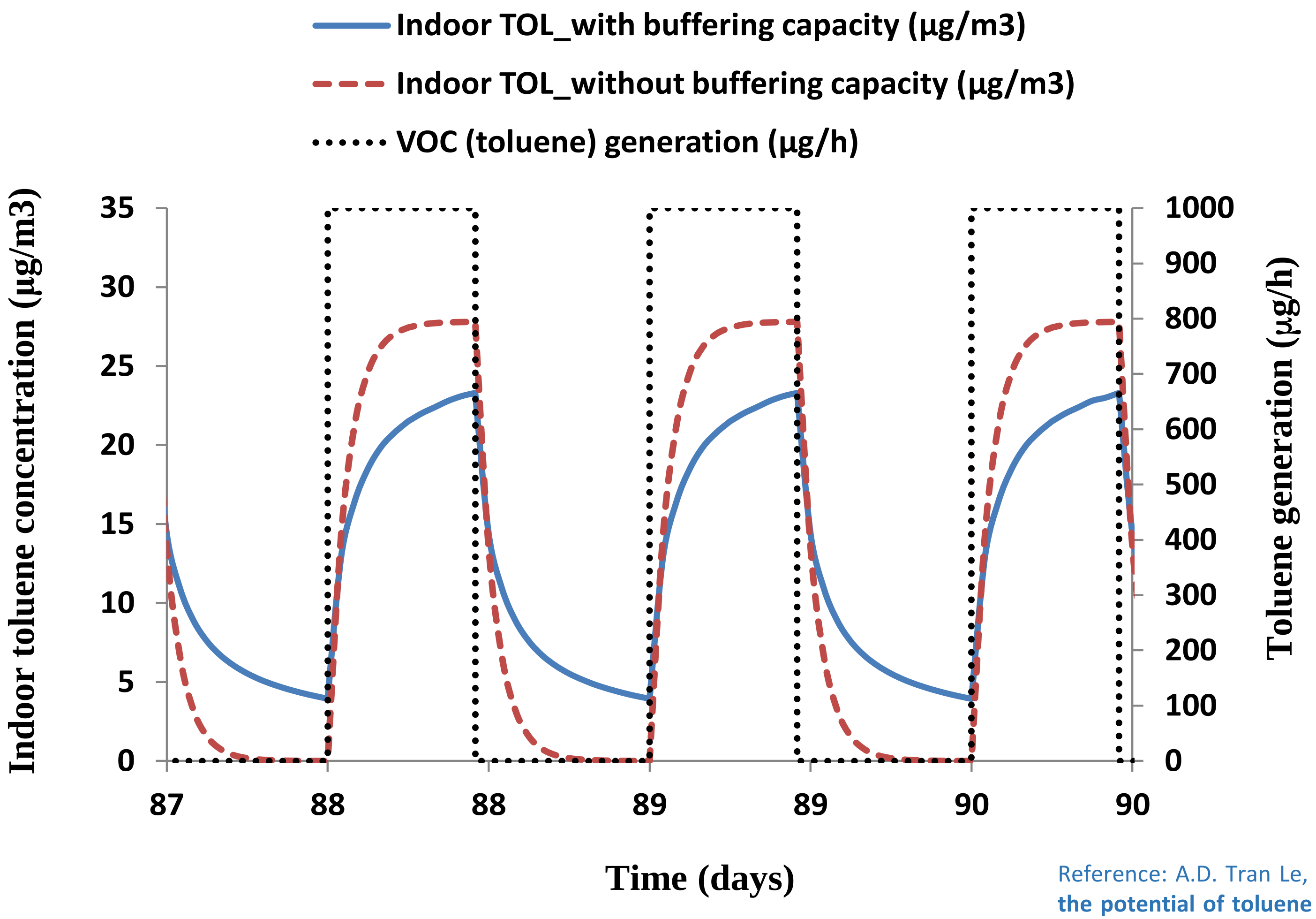
Dry density (kg/m^3)	Total porosity (%)	Open porosity (%)	μ_{wv}	Sorption isotherm (GAB model parameters)
450	78	66	5	$w_m = 0.02$; $C_{GAB} = 7$; $K_{GAB} = 0.89$

Toluene (TOL) and moisture properties of hemp concrete for the simulation.

μ_{TOL}	μ_{wv}	$K_{m,wv}$	$K_{m,TOL}$	$D_{m,TOL}$ (m^2/s)
2.8	5	1434 (at 10% RH)	550	5.5×10^{-9}

Effect of toluene (VOC) and moisture buffering capacities of hemp concrete wall on indoor relative humidity and toluene concentration

Effect of toluene (TOL) sorption capacity of hemp concrete on indoor toluene concentration



Peak reduced factor-PRF

C_0 : without buffering capacity

C: with buffering capacity

$$PRF = \frac{C_0 - C}{C_0}$$

Maximum values

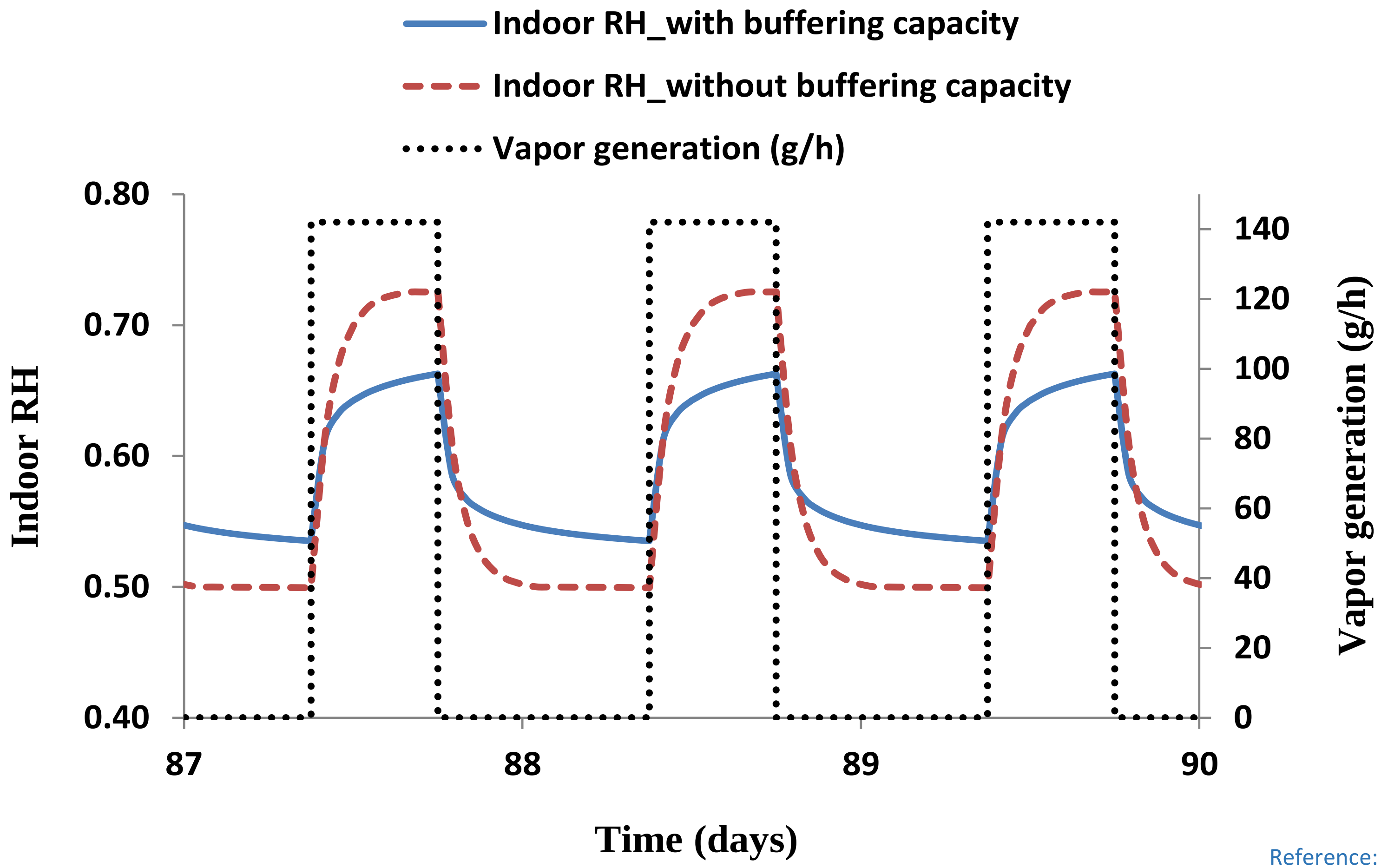
- **BC** model: 23.6 µg/m^3
- **Without-BC** model: 27.8 µg/m^3

PRF_{TOL} = 15%

Reference: A.D. Tran Le, JS. Zhang, Z. Liu, D Samri, T. Langlet. **Modeling the similarity and the potential of toluene and moisture buffering capacities of hemp concrete on IAQ and thermal comfort**, *Building and Environment*, 188,2021,107455.

Effect of toluene (VOC) and moisture buffering capacities of hemp concrete wall on indoor relative humidity and toluene concentration

Effect of moisture sorption capacity of hemp concrete on indoor RH



- Maximum indoor RH values decrease from 72.5 % to 66.3% RH for **Without-BC** and **BC** models
- A difference of 6.2 % RH and PRF_{RH}=8.6 %

Reference: A.D. Tran Le, JS. Zhang, Z. Liu, D Samri, T. Langlet. **Modeling the similarity and the potential of toluene and moisture buffering capacities of hemp concrete on IAQ and thermal comfort**, *Building and Environment*, 188,2021,107455.

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Thank you for your attention

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