Impact of VOC and moisture buffering capacities of bio-based building materials on IAQ and indoor RH: the case of hemp concrete

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Impact of VOC and moisture buffering capacities of bio-based building materials on IAQ and thermal comfort

Hygrothermal comfort
Indoor air quality (IAQ)
Acoustical and visual comforts

Use of vegetable particles (hemp shives, flax shives, straw bales, etc.) as building material aggregates:
• bio-based materials
• low embodied energy

Goal for building design

One passive way by using hygroscopic materials (release or adsorb water vapor depending on the surrounding air conditions)
Impact of VOC and moisture buffering capacities of bio-based building materials on IAQ and thermal comfort

Rape (rapeseed)

Hemp

Flax

Miscanthus

Bamboo

National availability (France)

Hemp availability in the world

France is the first producer of hemp in Europe

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THE USES OF HEMP

STALK

TEXTILES

SEED

U.S.S. COCOATE

LEAVES

PHARMACEUTICALS

ROOTS

MEDICINE

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Hemp mortar discovered in Merovingian bridge built in the 6th century in Saint Céneri le Gérei, in France

Now: hemp concrete

✓ environmentally friendly building material

✓ reference bio-based material

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Valorization of Hemp in building construction

Hemp

partly decorticated hemp stalk

Hemp concrete

Hemp shiv

Fiber

Hemp plaster

Hemp insulation

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mCHAMPS-BBMS

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

Microscopic scale

Material scale

Wall scale

Room and house scale

Homogenization method

Hygrothermal and VOC behavior

Experimental study

Model validation

Hygrothermal performance, thermal comfort and indoor air quality (QAI: VOC, CO2...), Energy consumption

Numerical and experimental studies

Model validation

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English version
mCHAMPS-BBMS

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

What is the impact of VOC and moisture buffering capacities of hemp concrete building envelope on IAQ and indoor RH?

CHAMPS-Bio Model

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

- Heat and moisture transport in building materials
- Adsorption or desorption heat due to water vapor sorption in building materials
- Diffusion and sorption of VOC
- Taking into account impact of T and RH on VOC diffusion and sorption (if data are available)
- Focusing on Biobased building materials
Selected references
- etc.

The Simulation Problem Analysis and Research Kernel (SPARK)*


CHAMPS-Bio model validation (1)

Case of a particleboard: prediction of VOC emission rate

Experimental setup consists of a small test chamber (0.40 × 0.50 × 0.25 m) with a pollutant emitting panel material inside

Particleboard with dimension 0.212x0.212x0.0159 m

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

Age: 0

CHAMPS-Bio model validation (2)

CHAMPS-Bio model has been validated recently

✓ In framework of Fulbright Scholar program in 2020 (Commission Fulbright Franco-Américaine and Hauts-de-France region, FR)
✓ In collaboration with BEESL lab, Syracuse University, USA (referent Pr. ZHANG Jensen)
✓ Model validation with two indoor typical VOCs (Formaldehyde and Toluene) based on experimental results obtained with calcium silicate (Xu and Zhang 2011*)

Impact of humidity on VOC behavior of porous materials and on IAQ: important to study

Model validation for moisture diffusion model


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

Hemp concrete
well known in the literature

✓ used widely in the world
✓ low environmental impact
✓ good compromise between insulation and thermal inertia
✓ high moisture buffering capacity

Similarity between VOC and moisture buffering?
If yes, what is the impact of pollutant (VOC) buffering capacity on IAQ?

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

- Reference room: V=5*4*2.5 m³
- Ventilation rate of 0.72 ACH (Air Changes per Hour)
- Exposed surface area S=25 m²
- 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).

Hygrothermal properties of hemp concrete measured by many research teams (selected references):
- Etc.

Hygroscopic source

Toluene properties of hemp concrete

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Effect of toluene 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

Peak reduced factor-PRF.

\[ PRF = \frac{R_{H_0} - R_H}{R_{H_0}} = \frac{RH_0 - RH}{RH_0} \]

Maximum values
- BC model: 66.3% RH
- Without-BC model: 72.5% RH
- \( PRF_{RH} = 8.6 \% \)

Amplitude reduced factor-RFa

\[ RF_a = \frac{A_0 - A}{A_0} \]

RAa value of 43.4%: moisture buffering capacity can reduce the indoor RH variation amplitude by 43.4%.


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

Discussion: Effect of moisture sorption capacity of hemp concrete on health benefits

Moisture buffering capacity - passive way to keep the variation in RH between threshold levels

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

Peak reduced factor - PRF

\[ PRF = \frac{C_0 - C}{C_0} \]

Maximum values
- BC model: 23.6 μg/m³
- Without-BC model: 27.8 μg/m³

PRF_{TOL} = 15%

Cumulative Exposure Reduction Factor, ERFc

takes into account the concentration reduction and exposure time

\[ ERFc = \int_0^t PRF dt \]

The ERFc for toluene is 210.5% for 12 h exposure

Health benefits?

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

Conclusions

✓ Similarity between toluene (VOC) and moisture buffering capacities of hemp concrete (a reference bio-based building material)
✓ Impact of buffering capacities (toluene-VOC and moisture) of hemp concrete on indoor RH and IAQ: important to study

VOC buffering capacity: special attention at health benefits?

- Needed further experiments and analyses
- If confirmed: buffering capacity toward moisture/pollutant (VOC) as an approach to improving IAQ as well as hygrothermal performance of buildings in future standards and design

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