5ème Ecole d'automne du GDR MBS

Eco-conception des matériaux biosourcés et géosourcés : de la ressource à la fin de vie

12 au 16 octobre 2025, Douai

Focus sur le comportement hygrothermique, du matériau au bâtiment

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GdR MBS
MATÉRIAUX de CONSTRUCTION BIOSOURCÉS

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Introduction

https://reflexscience.univ-gustave-eiffel.fr/lire/articles/la-terre-crue-un-materiau-de-construction-ancestral-plein-davenir

Le plus vieux matériau de construction au monde est aussi le plus écoresponsable

Published: March 26, 2020 6.48pm GMT

Une scène de la série « Game of Thrones » tournée au ksar d'Aït-ben-Haddou (Maroc), un site architectural en terre crue classé au patrimoine mondial de l'Unesco. HBO

https://theconversation.com/le-plus-vieux-materiau-de-construction-au-monde-est-aussi-le-plus-ecoresponsable-133587

Murs de terre crue en damiers - Occitanie

Construction en pisé - Plaine de la Limagne
Crédit Photo : Université Gustave Eiffel

CTB LES CAHIERS TECHNIQUES DU BÂTIMENT

Actualités | Coûts de construction | Technipédia | Enquêtes produits | Règles techniques | Plus | RECHERCHE | MAGAZINE

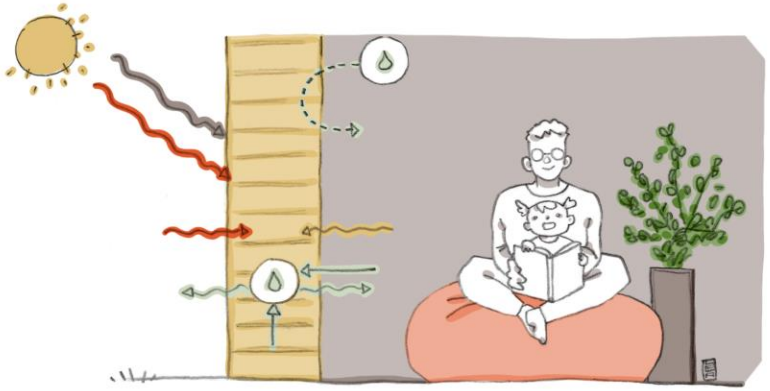
2. THERMIQUE La terre crue améliore le confort hygrothermique

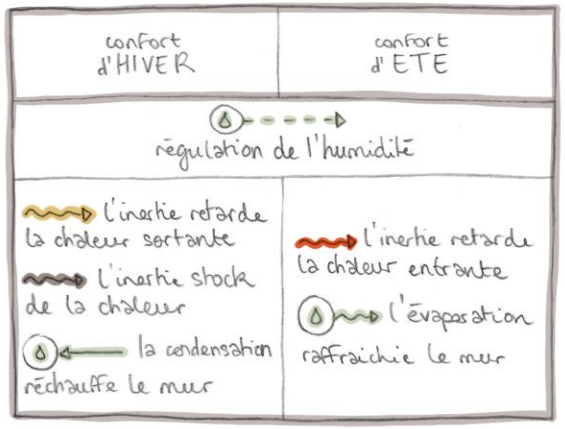
Publié le 01/03/2010 à 00h01

Sujets relatifs :
Dossier, Actualité, Thermique

Introduction

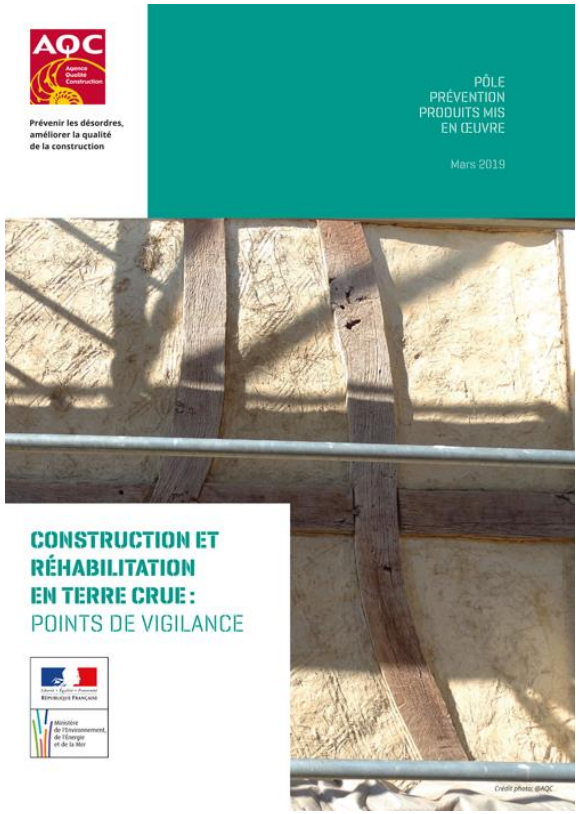
- Confort hygrothermique / performance énergétique / durabilité





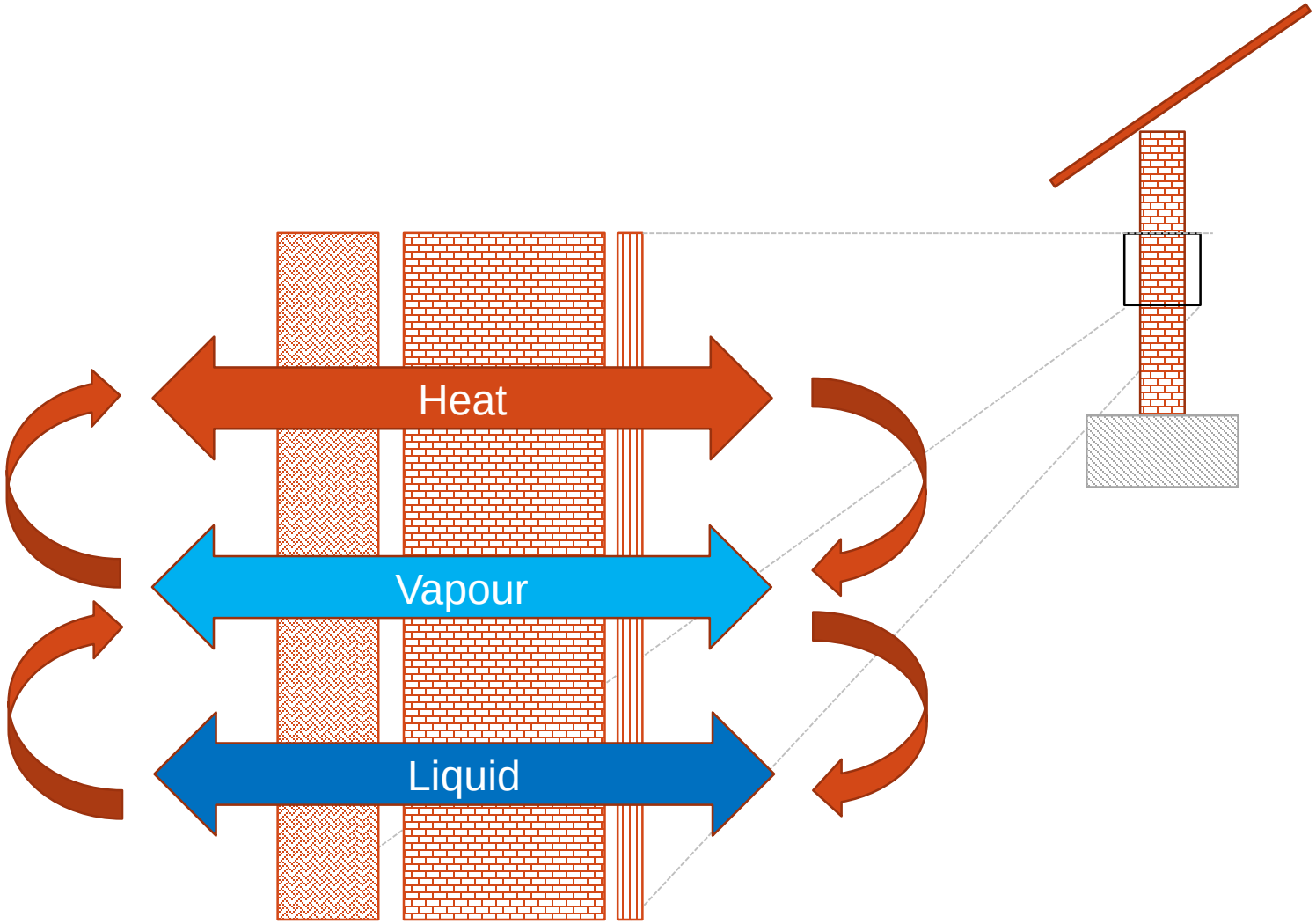
https://blog.geomaterio.fr/materiaux/la-terre-crue-amie-du-confort-interieur-dans-une-maison-ecologique/

https://www.tera-terre.org/intelligence-constructive-2/



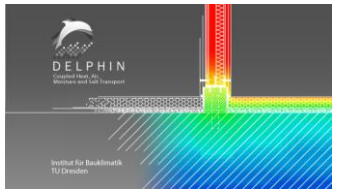
https://qualiteconstruction.com/wp-content/uploads/2024/05/Etude-Construction-Rehabilitation-Terre-Crue-Vigilance-AQC.pdf

Comportement hygrothermique des enveloppes



Comportement hygrothermique des enveloppes (Simulations)

Logiciel de simulation de transferts hygrothermiques



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COMSOL MULTIPHYSICS®

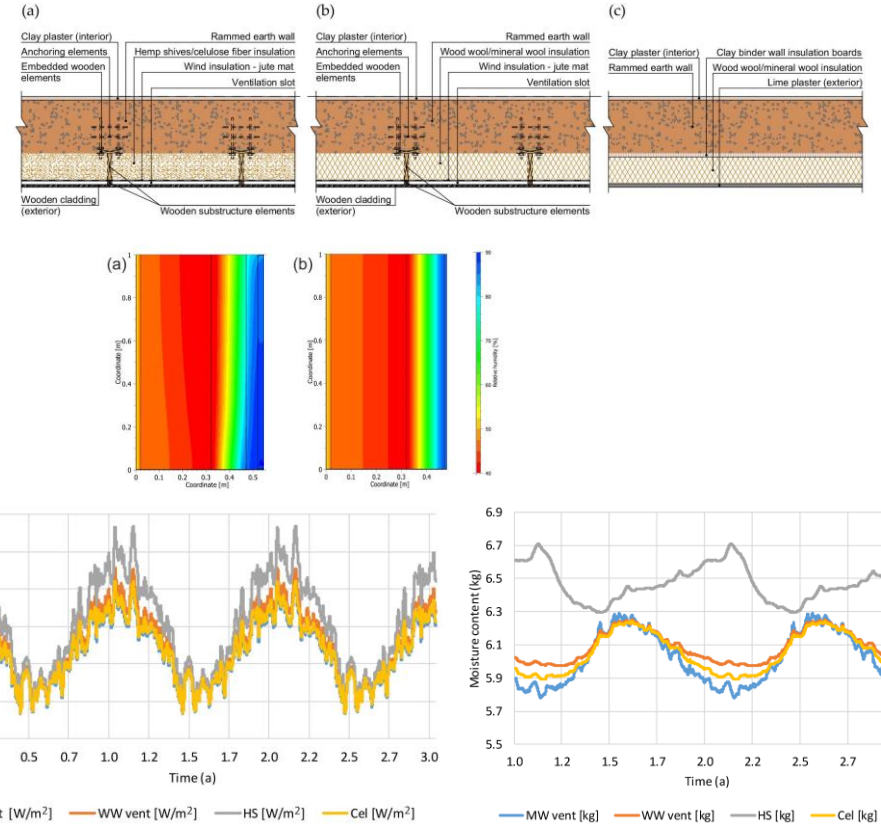
python™

Equations constitutives (+/- complexes)

$$\rho c_p \frac{\partial T}{\partial t} = \nabla(\lambda \nabla T) + h_v \nabla(\delta \nabla p_v)$$

$$\rho \frac{\partial w}{\partial \phi} \frac{\partial \phi}{\partial t} = \nabla\left(\delta \nabla p_v + D_\phi \nabla \phi\right)$$

Résultats de simulations



Kosiński et al., Parametric Analysis of Rammed Earth Walls in the Context of the Thermal Protection of Environmentally Friendly Buildings, Sustainability, 2025

Caractérisation hygrothermique des matériaux *Terre Crue*

- Général
  - Giuffrida et al., Hygrothermal Properties of Raw Earth Materials: A Literature Review, Sustainability, 2019
  - Force et al., Toward a Database for Hygrothermal Properties of Rammed Earth and Compressed Earth Blocs, to be published
- Pisé
  - Losini et al., Extended hygrothermal characterization of unstabilized rammed earth for modern construction, Const. Build. Mat., 2023
- BTC
  - **Colinart et al., Preliminary results of interlaboratory tests on hygrothermal properties of CEB, ICEC Conf., 2024**
- Terre allégée
  - Colinart et al., Hygrothermal properties of light-earth building materials, J. Build. Eng., 2020
  - Colinart et al., Thermal conductivity of biobased insulation building materials measured by hot disk - Possibilities and recommendation , J. Build. Eng., 2021
- Enduits
  - Palumbo et al., The influence of two crop by-products on the hygrothermal properties of earth plasters, Build. Env., 2016

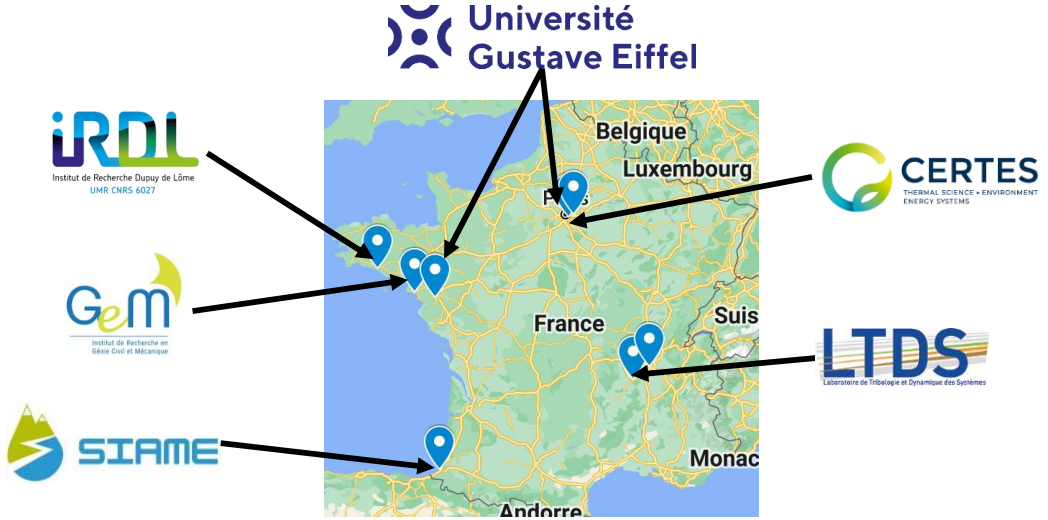
Caractérisation hygrothermique des matériaux *Terre Crue*

Compressed earth brick (20 % clay)

Methods

- Dry bulk density => ISO 12570
- Intrinsic density => Helium pycnometer
- λ, c_p => Hot Disc, HFM, DSC
- α, ε => Spectrophotometer
- Sorption isotherms => ISO 12571
- Water vapor permeability => ISO 12572

6 participating labs

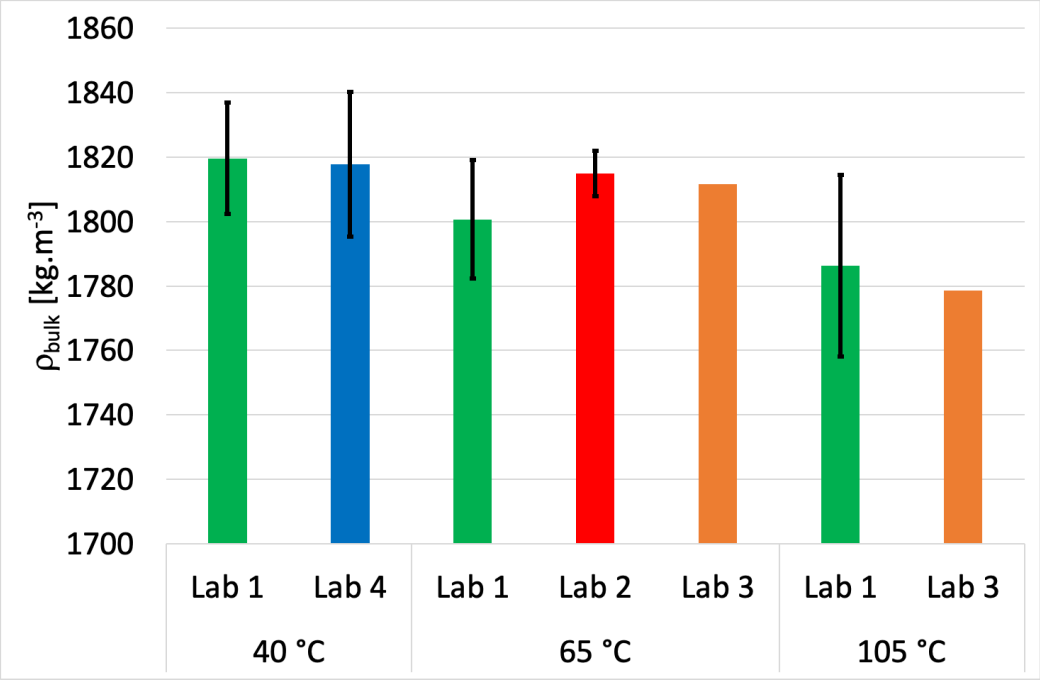


Property	IRDL Lab 1	SIAME Lab 2	GEM Lab 3	UGE Lab 4	LTDS Lab 5	CERTES Lab 6
Dry bulk density	O	O	O	O	X	X
Intrinsic density	O			O	X	
Specific heat capacity	O	O	O	O	X	O
Thermal conductivity	O	O	O	O	X	O
Radiative properties	O					O
Sorption isotherms	O	O	O		O	O
Water vapor permeability	O	X	O		X	X

Caractérisation hygrothermique des matériaux *Terre Crue*

Dry bulk density (4 labs)

- Good repeatability
- Decrease with temperature
- Agreement with technical datasheet



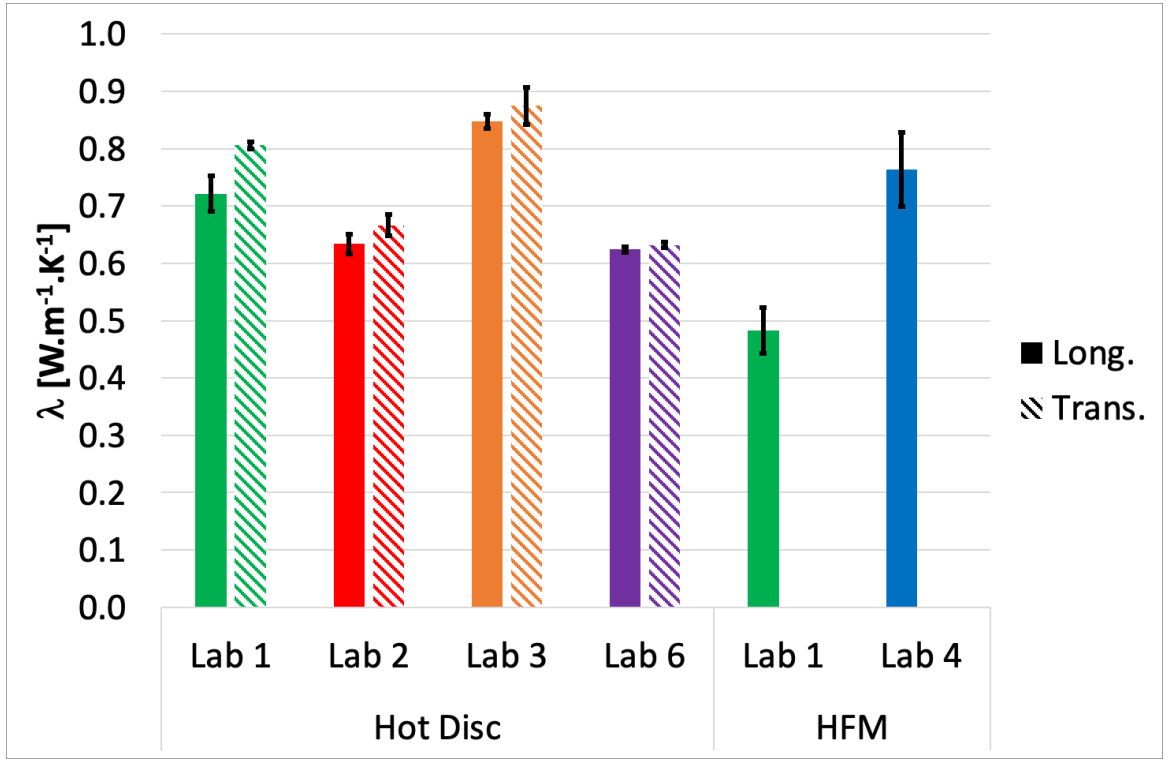
Intrinsic density (2 labs)

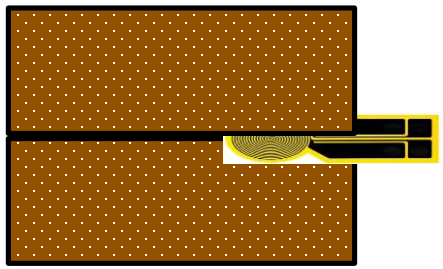
- ρ = 2640 ± 30 kg.m^{-3}
- Open porosity : 32%

Caractérisation hygrothermique des matériaux *Terre Crue*

Thermal conductivity (5 labs)

- No anisotropy
- Poor repeatability between labs
  - Hot disc : Various settings (single-sided vs. double sided, sensor radius, heating power) and analysis procedures
  - HFM : measurement performed out of recommended range and low equilibrium criteria
- HFM Lab 1 close to technical datasheet





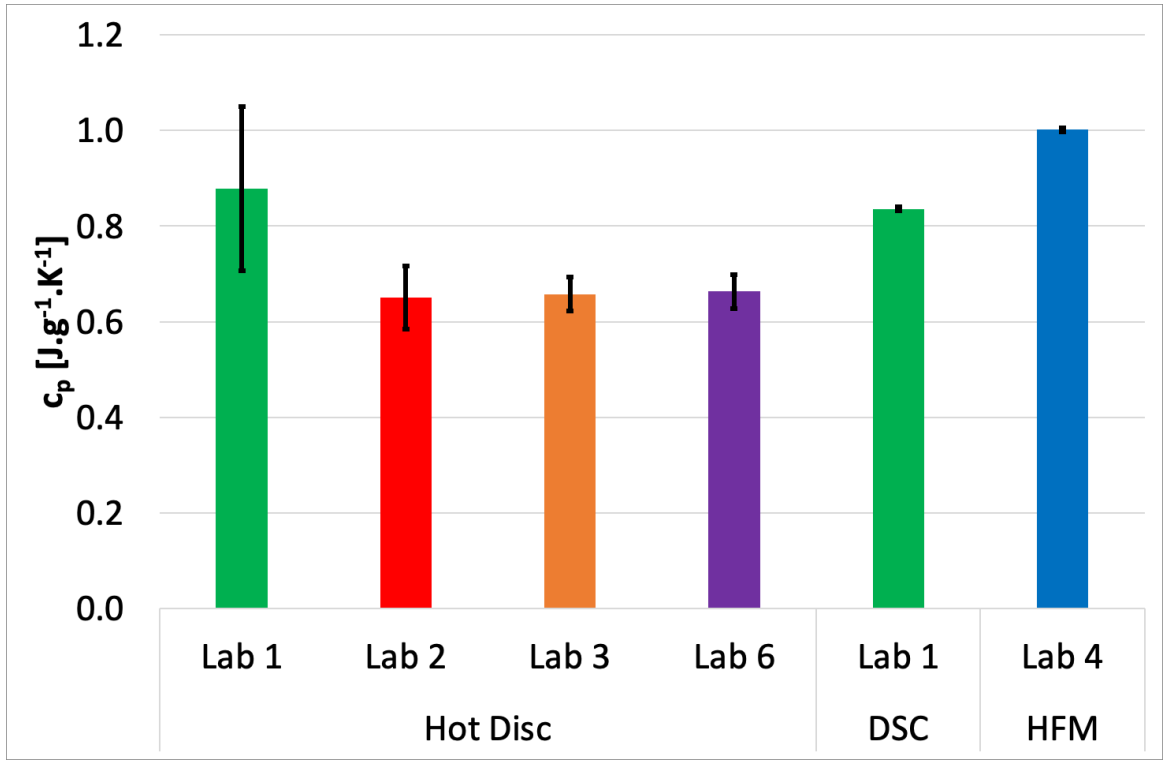
Caractérisation hygrothermique des matériaux *Terre Crue*

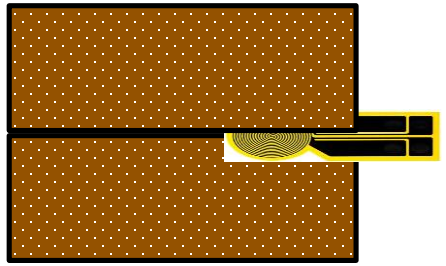
Specific heat capacity (5 labs)

- DSC: reference value
- Hot disc, HFM: 20% uncertainty

Radiative properties (2 labs)

- Solar absorptivity = 62 ± 1.5 %
- Infrared emissivity = 96 % ± 1 %



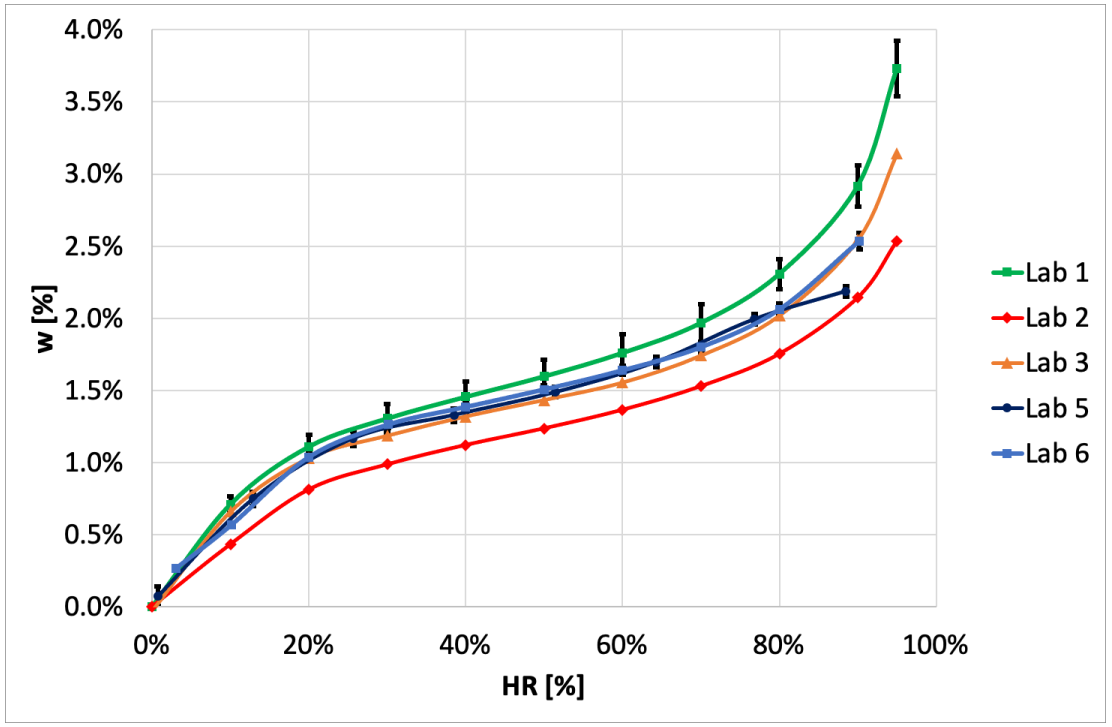


Caractérisation hygrothermique des matériaux *Terre Crue*

Sorption isotherm (5 labs)

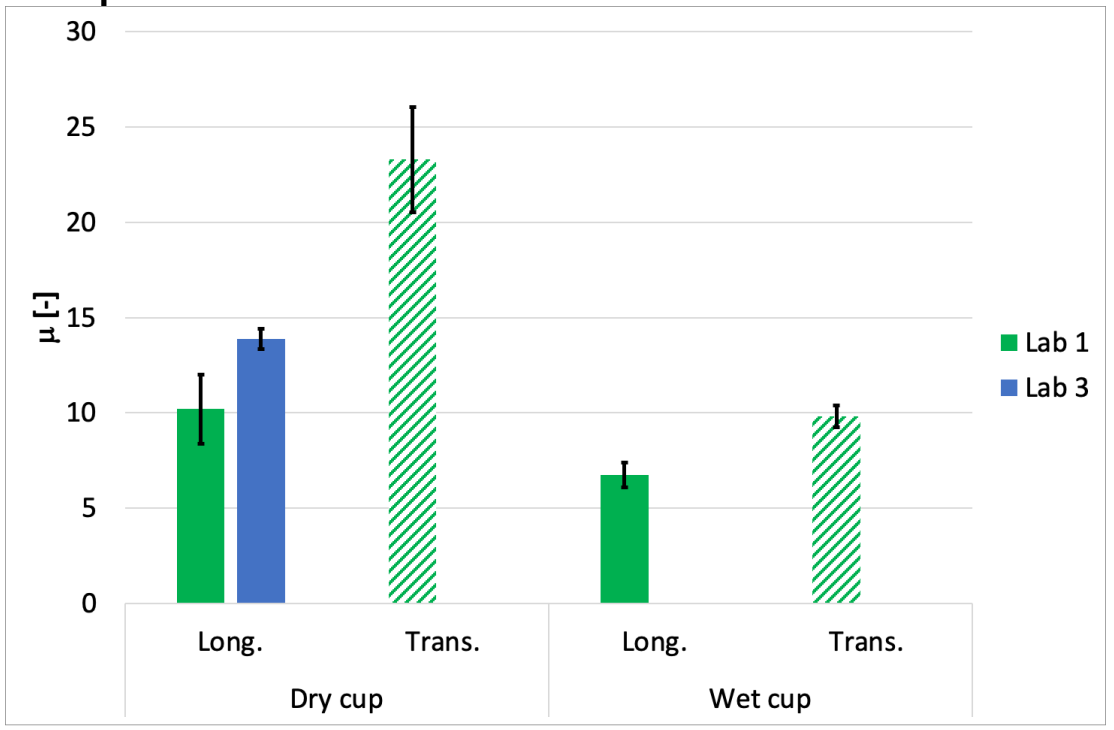
- Measurements with DVS devices
- Large discrepancy (≠ drying temperatures)

⚠State of material

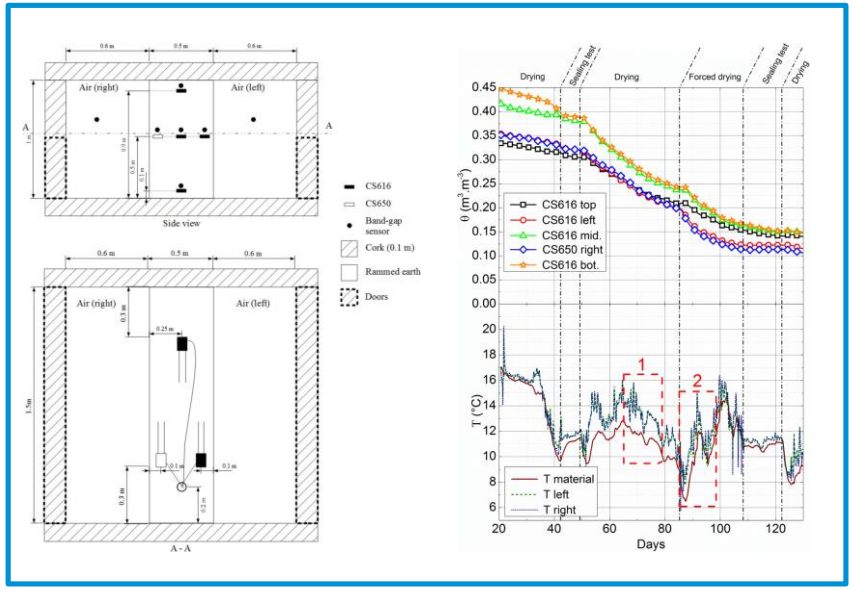


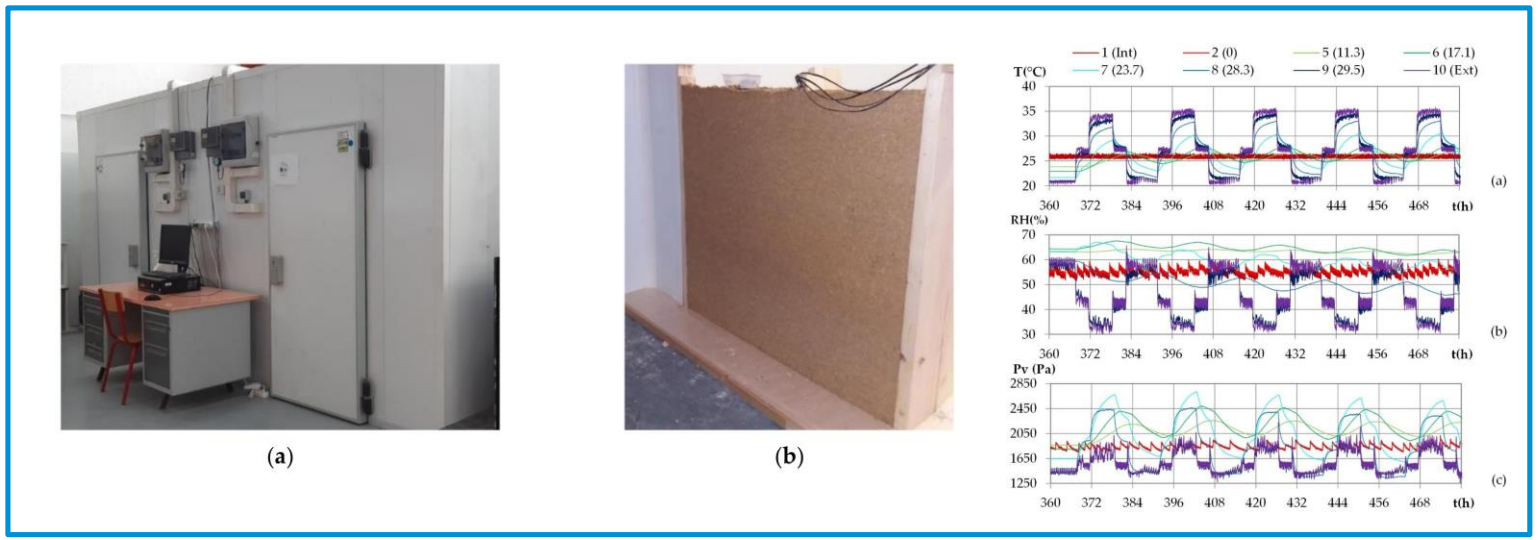
Vapor diffusion resistance factor (2 labs)

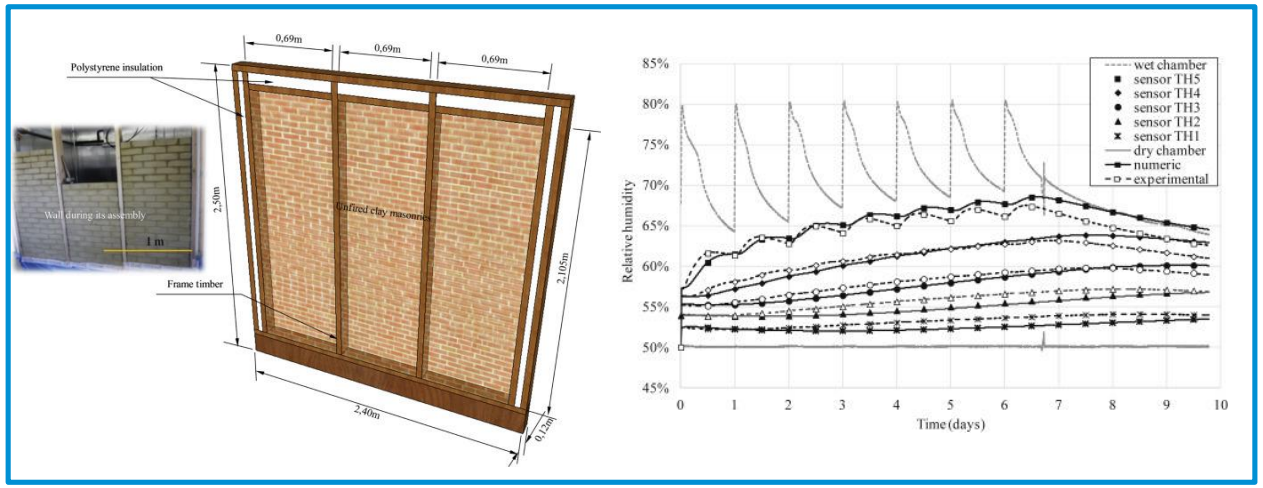
- Small differences due to measurement set-up and conditions
- Marked anisotropy due to fabrication process

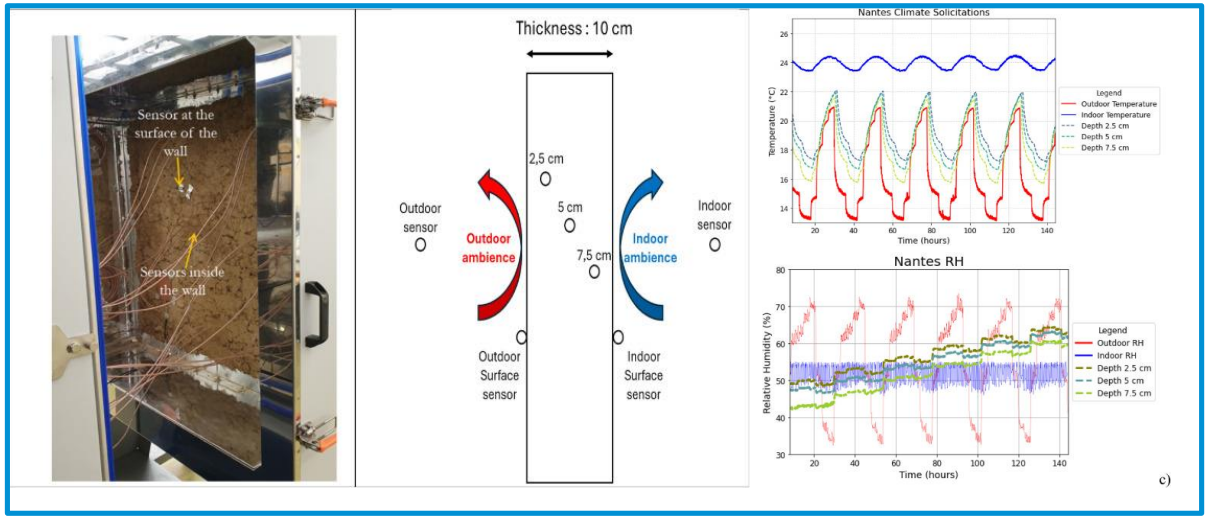


Comportement hygrothermique des enveloppes (Expériences)









Chabriac et al., A Procedure to Measure the in-Situ Hygrothermal Behavior of Earth Walls, Materials, 2014

Boumedienne et al., Hygrothermal Behavior of a Washing Fines–Hemp Wall under French and Tunisian Summer Climates: Experimental and Numerical Approach, Materials, 2022

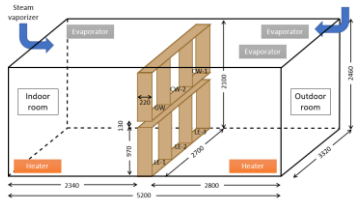
Medjelekh et al., Characterization of the coupled hygrothermal behavior of unfired clay masonries: Numerical and experimental aspects, Build Env., 2016

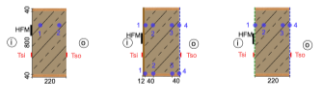
Belarbi et al., Experimental evaluation of the time lag and decrement factor of a raw earth wall for various climates: Comparison of different methods, J. Build. Eng., 2025

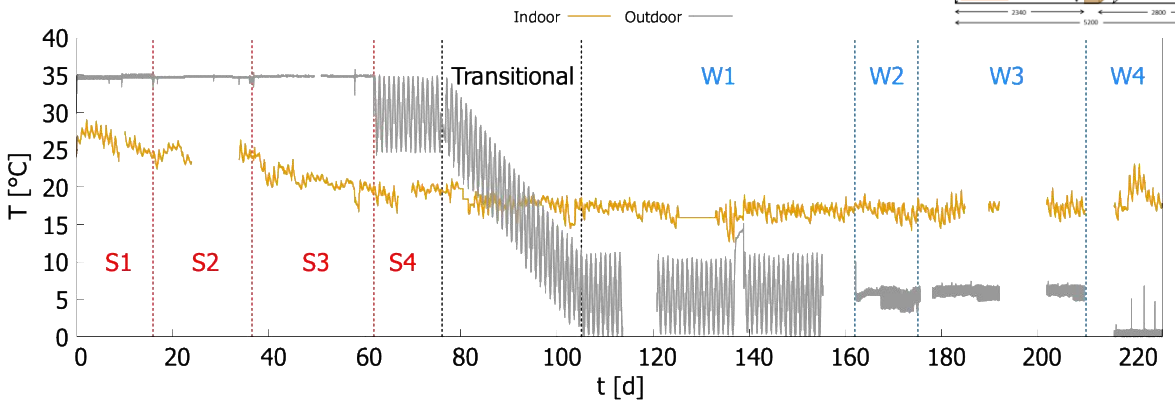
Comportement hygrothermique des enveloppes (Sim vs. Exp)

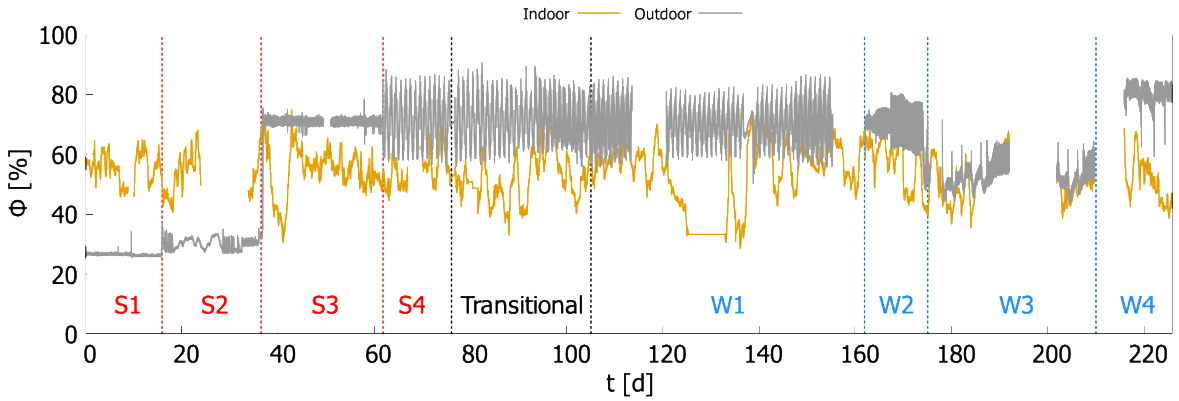
Indoor

Outdoor







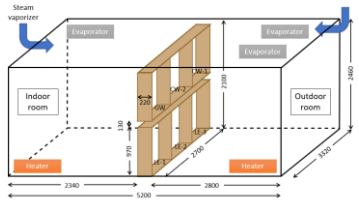


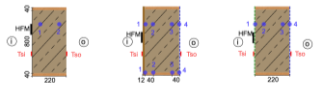
El Assaad, Toward an estimation of real building energy consumption : performance analysis of bio-based and conventional insulation building materials, PhD thesis

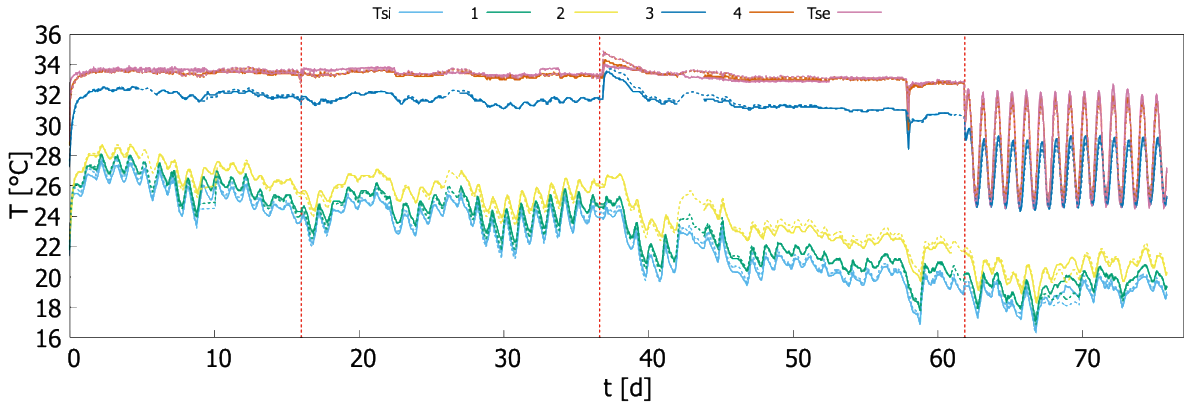
Comportement hygrothermique des enveloppes (Sim vs. Exp)

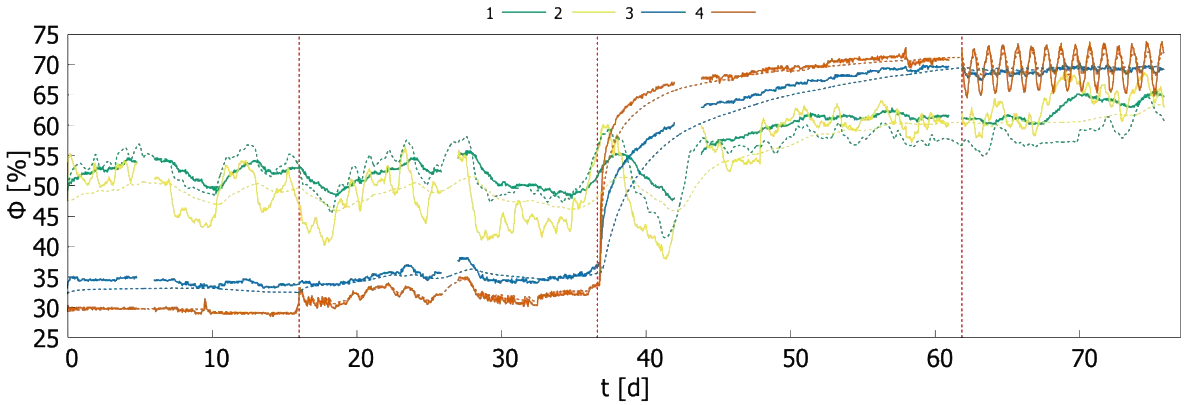
Indoor

Outdoor



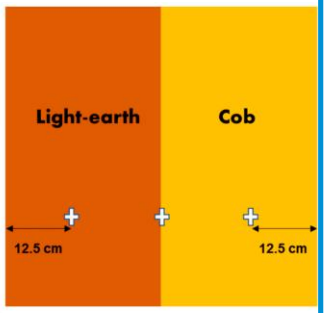


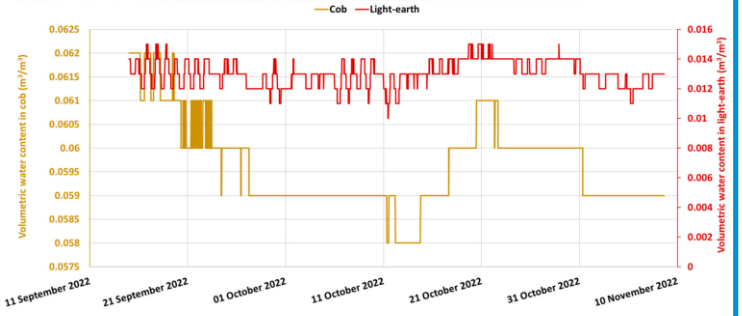


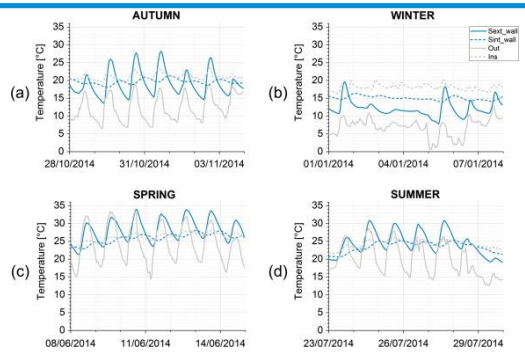


El Assaad, Toward an estimation of real building energy consumption : performance analysis of bio-based and conventional insulation building materials, PhD thesis

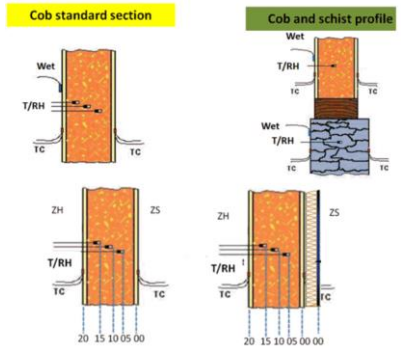
Comportement hygrothermique des enveloppes (in situu)

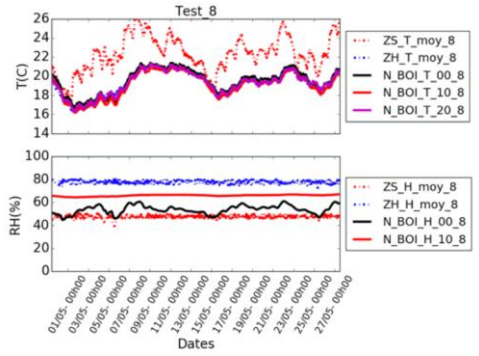






Rammed earth walls





Touati et al., Hygrothermal and Economic Analysis of an Earth-Based Building Using In Situ Investigations and Artificial Neural Network Modeling for Normandy's Climate Conditions, Sustainability, 2023

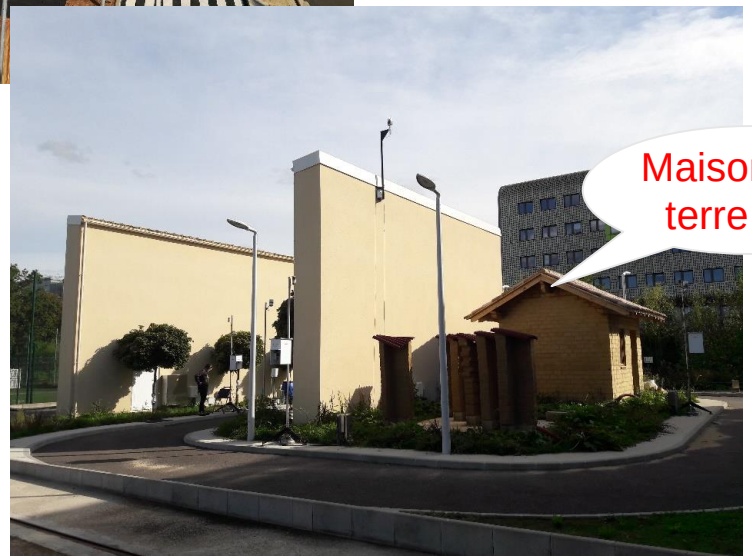
Soudani et al., Energy evaluation of rammed earth walls using long term in-situ measurements, Solar Energy, 2017

Guernouti et al., Assessment of hygrothermal behaviour of an experimental timber-framed house, 2nd ICBBM, 2017

Comportement hygrothermique des enveloppes (in situ)

- Composition of the earthen house walls
- Exterior coating (earth+sand ULTIBAT)
- 30cm raw earth brick
- No interior coating

Mini-Ville 1

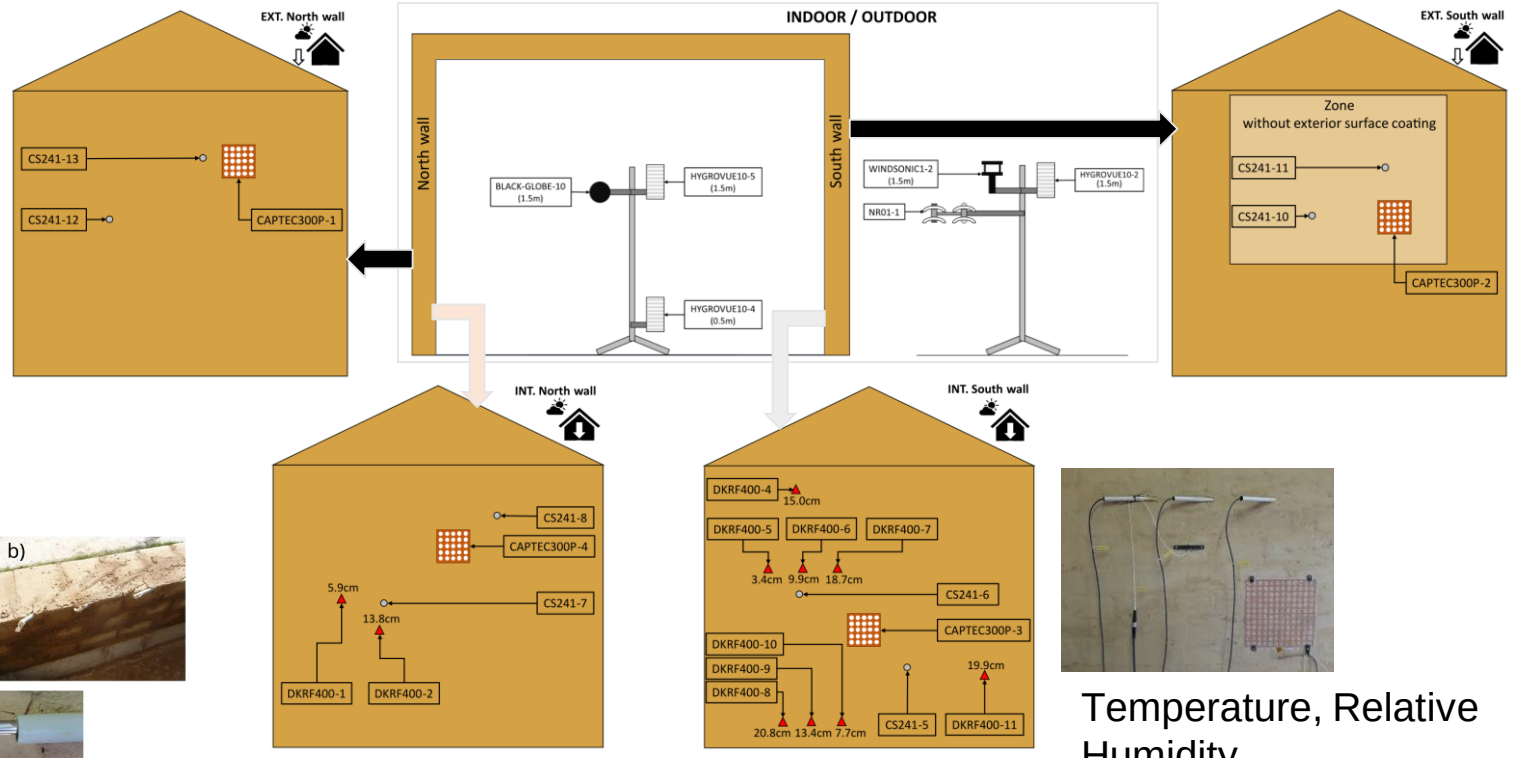


Mini-Ville 2

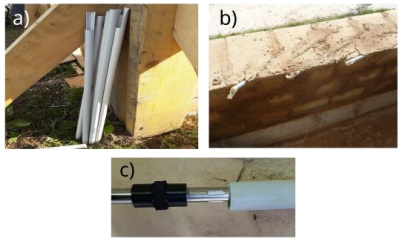
Waeytens et al., Instrumentation and experimental hygrothermal investigations of a raw compressed earth brick house in Sense-City equipment - From material to building scale. Case stud. in Const. Mat., 2025

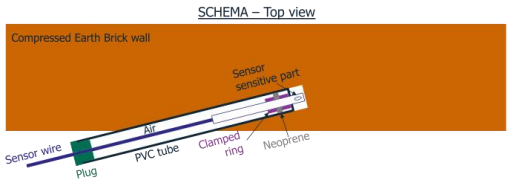
Comportement hygrothermique des enveloppes (in situ)

- Deployment of 39 sensors in the room, walls and outside
- Measurement of temperature and relative humidity inside the walls at different depths



Temperature, Relative Humidity
And Heat flux sensors

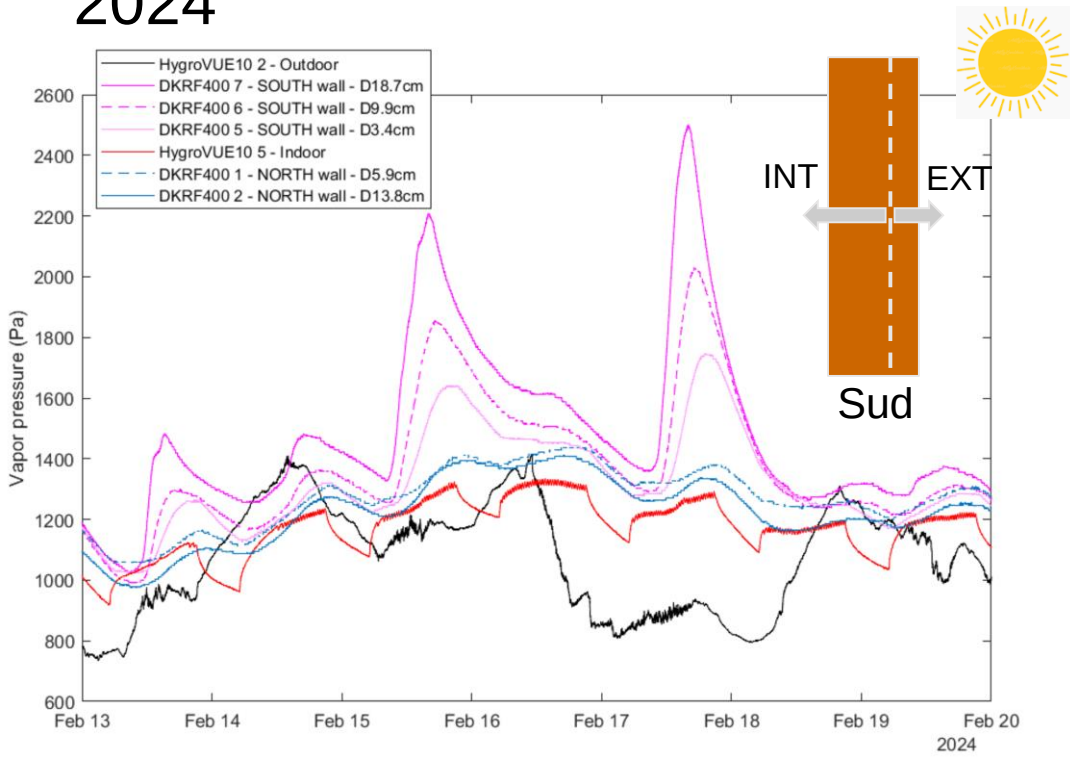


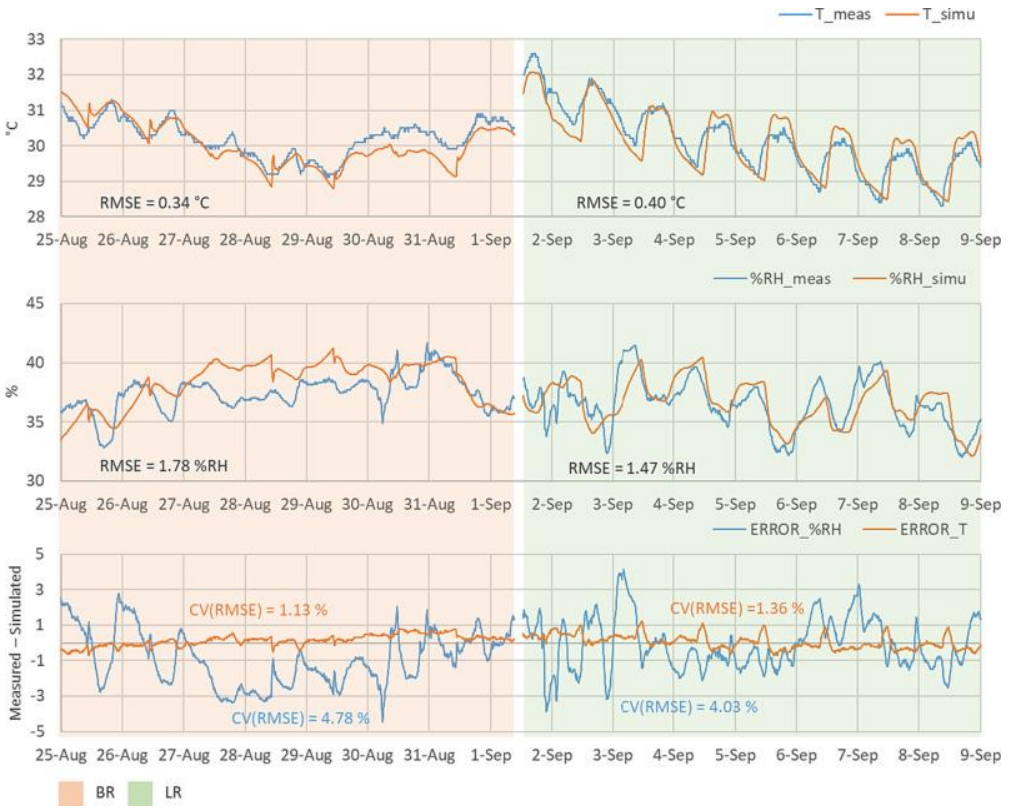


Waeytens et al., Instrumentation and experimental hygrothermal investigations of a raw compressed earth brick house in Sense-City equipment - From material to building scale. Case stud. in Const. Mat., 2025

Comportement hygrothermique des enveloppes (in situ)

- Experimental campaigns in real weather conditions in winter 2024 (heating), in spring and summer 2024

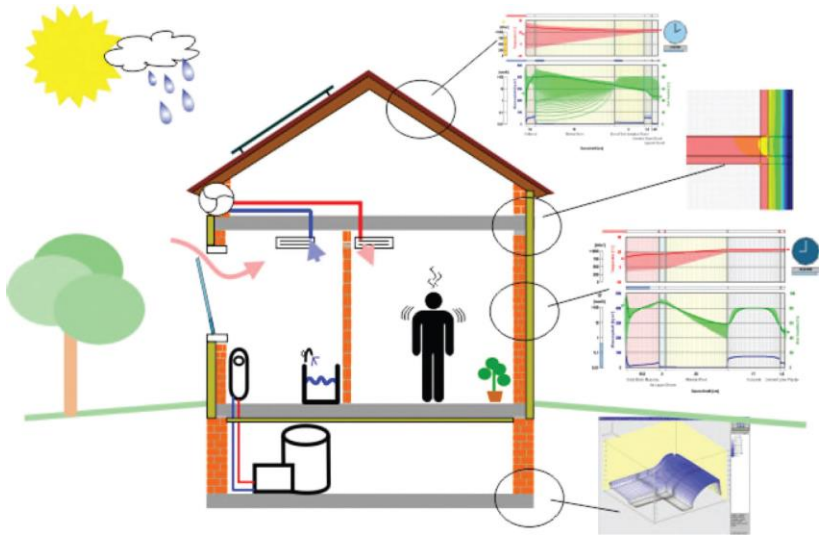


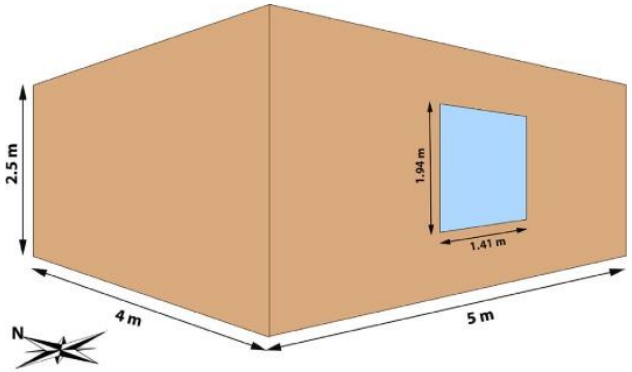


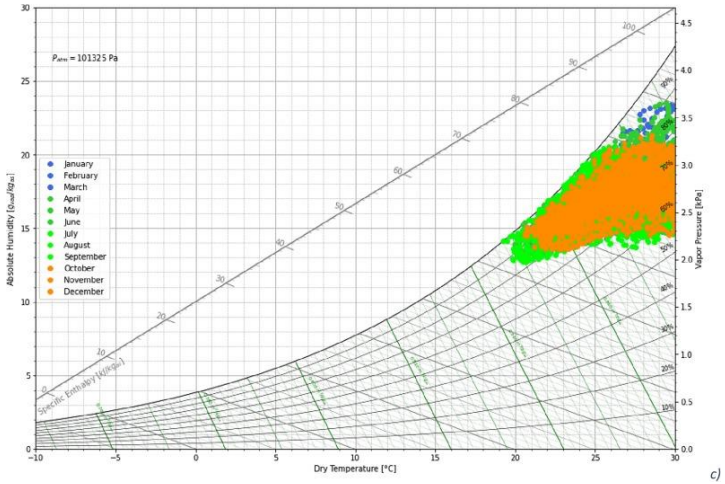
Waeytens et al., Dataset of hygrothermal and energy measurements for a raw compressed earth brick house of Sense-City equipment during different seasons, Data in Brief, 2025

Es-sakali et al., Energy efficiency and hygrothermal performance of hemp clay walls for Moroccan residential buildings: An integrated lab-scale, in-situ and simulation-based assessment, App. Energy, 2023

Comportement hygrothermique des bâtiments







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WUFI® Passive Version 3.5

TRNSYS 18

Künzel, H., & Dewsbury, M. (2022). Moisture control design has to respond to all relevant hygrothermal loads. UCL Open Environment, 4.
Belarbi et al., Assessment of hygrothermal performance of raw earth envelope at overall building scale, Energy Build., 2024

Conclusions

- Différents matériaux à base de terre crue avec un large spectre de propriétés hygrothermiques
- Caractérisation hygrothermique ok (si réalisée correctement)
- Comportement hygrothermique de parois mono/multicouches
  - Quelques expériences de références
  - Comparaison simulation / expérience
    - Bonne en conditions contrôlées
    - Perfectible en conditions *in situ*
- Comportement hygrothermique de bâtiments
  - Peu de données expérimentales, difficiles à analyser finement
  - Simulations complexes et sensibles à d'autres phénomènes que les transferts dans les parois