CCBST 15TH CANADIAN CONFERENCE ON BUILDING SCIENCE AND TECHNOLOGY

Impact of heat and moisture transfer through a multilayer wall on the comfort conditions of an occupied room

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Context of study

Insulation performance

↘ Energy consumption

↘ Indoor air quality (IAQ)

(Woloszyn, 2009)
(Trcka, 2010)
(Afram, 2014)

Heating, Ventilation and Air-Conditioning System (HVAC)

Ventilation: cleaning air of pollutants

+ Heating: thermal comfort

Bio-based materials: indoor humidity regulation

Humidification: humidity comfort, health, durability of materials

Energy consumption
Comfort conditions

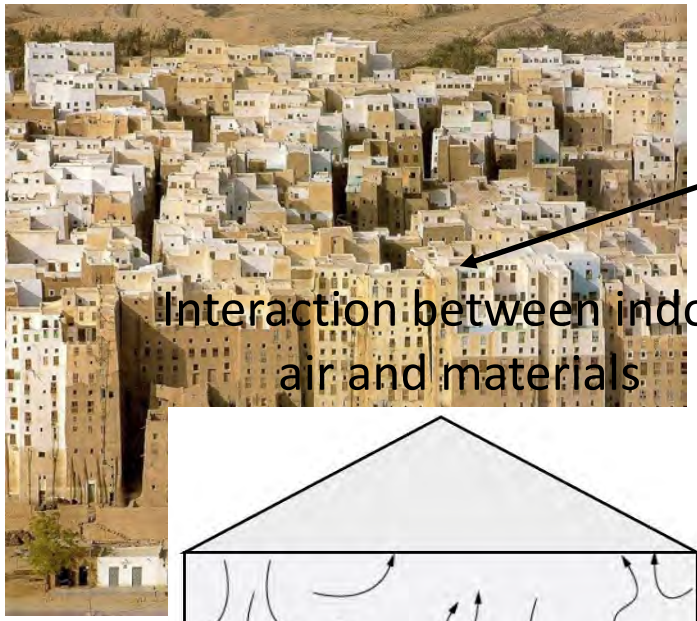
50% of the global energy consumption
(Pérez-Lombard et al., 2008)

↗ Energy consumption

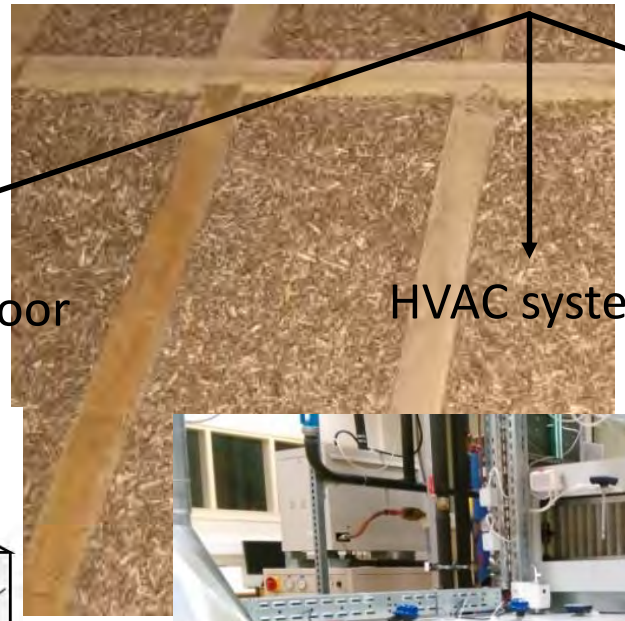
↗ Comfort conditions

Context of study – Bio-based materials

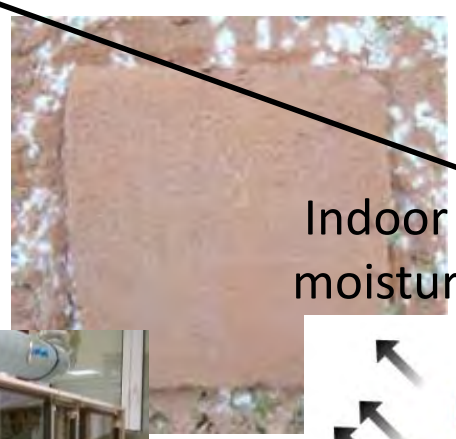
Earth construction



Hemp-based insulation



Earth-based plaster

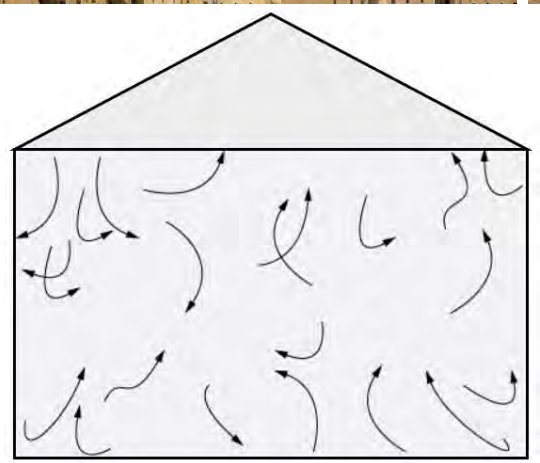


Straw-lime plaster

Interaction between indoor air and materials

HVAC system

Indoor heat and moisture sources



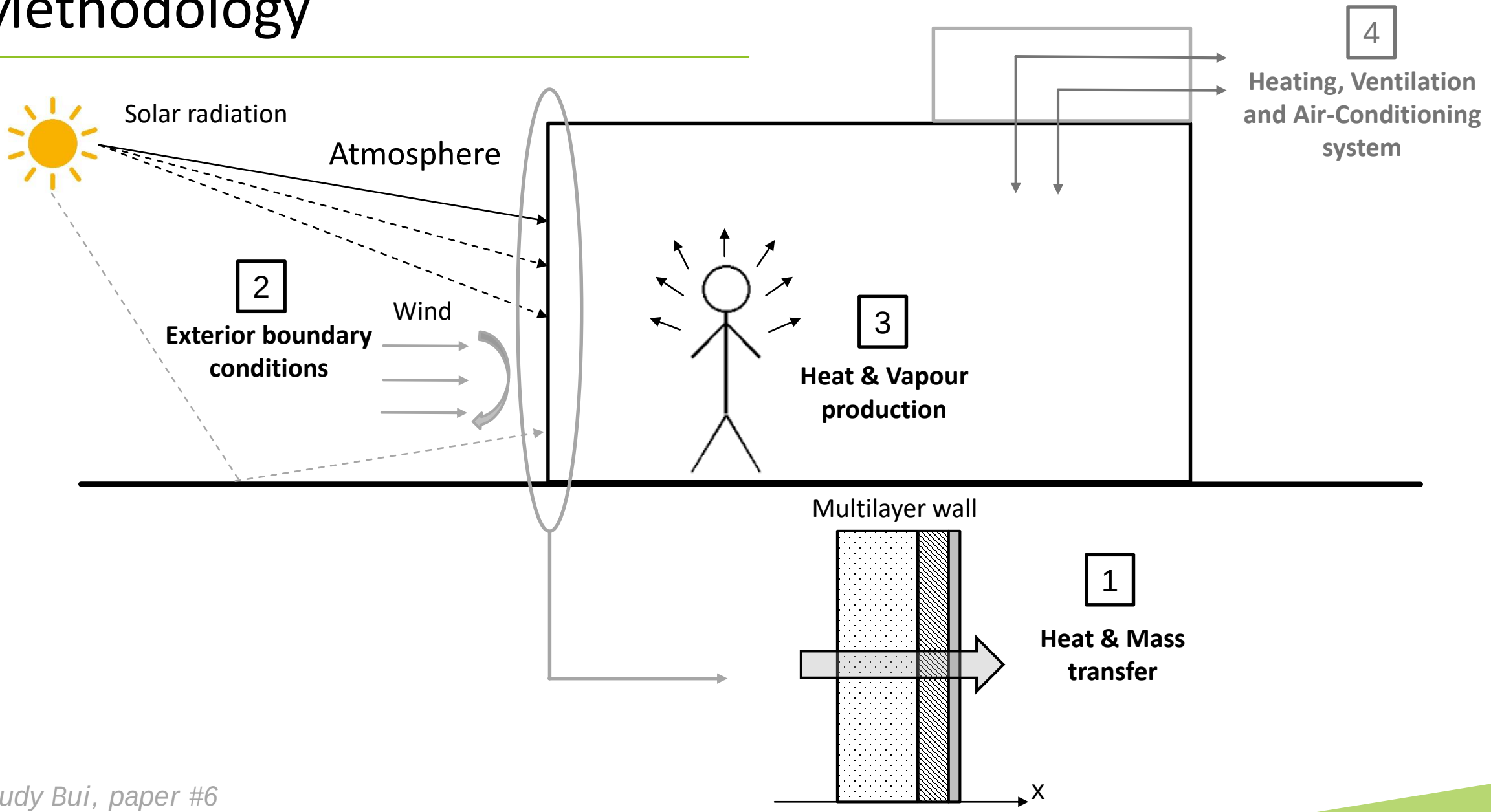
rd et al.

Advanta

- I ct
- Local production
- Natural humidity regulator

How to realistically estimate th ffering effect?

Methodology



Outline of the presentation

1. Heat and Moisture transfer model (RM)
   - Governing equations
   - Validation example

2. Exterior boundary conditions

3. Interior boundary conditions
   - Indoor air balance
   - No-MASS
   - Coupling No-MASS with RM

4. Case study

5. Conclusion and perspectives

RM – Governing equations

Mass conservation equation

$$\frac{\partial w}{\partial t} = -\vec{\nabla}(\delta_l \vec{\nabla} p_c - \delta_v \vec{\nabla} p_v)$$

Energy conservation equation

$$\underbrace{\left(\rho_s c_s + \sum_i w_i c_{p,i}\right)\frac{\partial T}{\partial t}}_{\text{Storage of energy}} = \underbrace{k_{mat}\vec{\nabla}^2 T}_{\text{Conduction}} - \underbrace{\sum_i w_i \vec{V}_i c_{p,i} \vec{\nabla} T}_{\text{Enthalpy transport due to the mass flux}} - \underbrace{[(c_{p,l} - c_{p,v})T - L_v] S_l}_{\text{Phase change}}$$

From mass balance

$$\underbrace{\left(\frac{1}{1 - \frac{\rho_v}{\rho_l}}\right)\frac{\partial w}{\partial t}}_{\text{Storage of liquid water}} = \underbrace{-\vec{\nabla}(\delta_l \vec{\nabla} p_c)}_{\text{Liquid transfer}} + S_l$$

S_l → Liquid water source

No air transfer

RM – Governing equations

Temperature T [K] and **Capillary Pressure** p_c [Pa] *(Janssen, 2014), (Li et al., 2009)*

$$\frac{\partial w}{\partial p_c} \cdot \boxed{\frac{\partial p_c}{\partial t}} = -\vec{\nabla}\left[\left(\delta_l + \delta_v \frac{\rho_v}{\rho_l}\right)\vec{\nabla} p_c - \delta_v \left(\Psi \frac{\partial p_{v,sat}}{\partial t} - p_v \frac{ln(\Psi)}{T}\right)\vec{\nabla} T\right]$$

Mass conservation

$$\left(\rho_s c_s + \sum_i w_i c_{p,i}\right)\boxed{\frac{\partial T}{\partial t}} = k_{mat}\vec{\nabla}^2 T - \sum_i w_i \vec{V}_i c_{p,i}\vec{\nabla} T - [(c_{p,l} - c_{p,v})T - L_v]S_l$$

Energy conservation

$$\left(\frac{1}{1 - \frac{\rho_v}{\rho_l}}\right)\frac{\partial w}{\partial p_c} \cdot \boxed{\frac{\partial p_c}{\partial t}} = -\vec{\nabla}(\delta_l \vec{\nabla} p_c) + S_l$$

Coupled non linear set of equations ➔ Numerical method: Finite differences (1D), implicit scheme

(Patankar and Baliga, 1978), (Patankar, 1980)

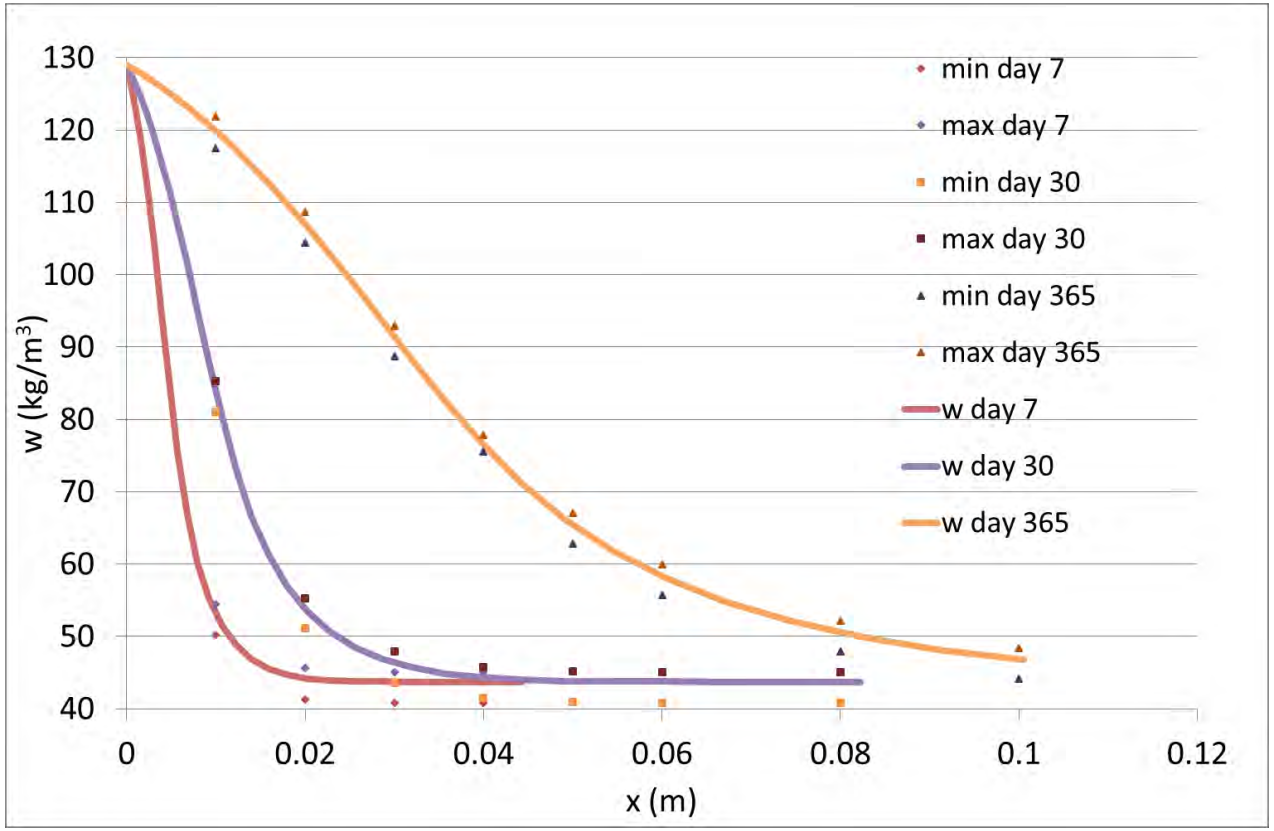
python™

RM – Validation example

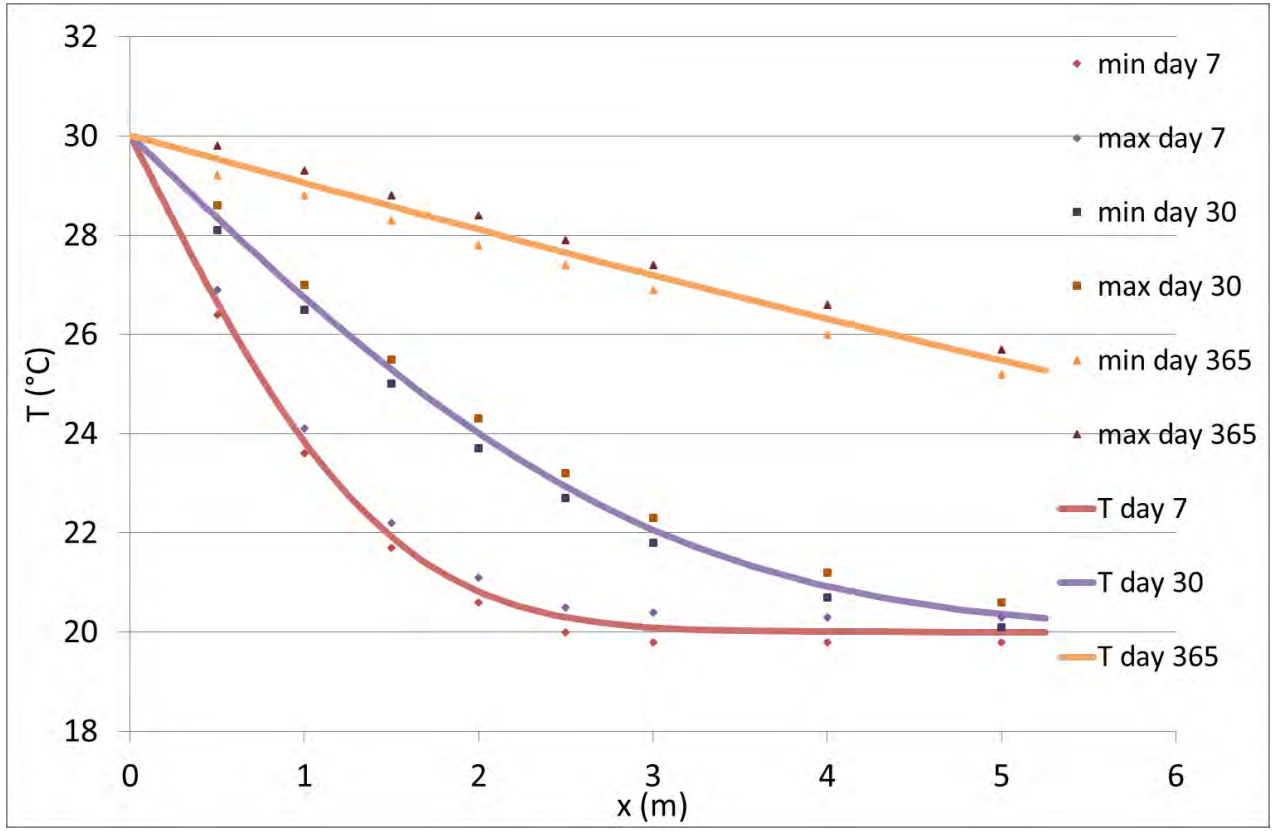
Standard EN 15026 *(AFNOR, 2007)*

- Semi-infinite wall
- Dirichlet boundary conditions: T=30°C, RH = 95%
- Initial conditions: T = 20°C, RH = 50%

Material's properties specified in the standard

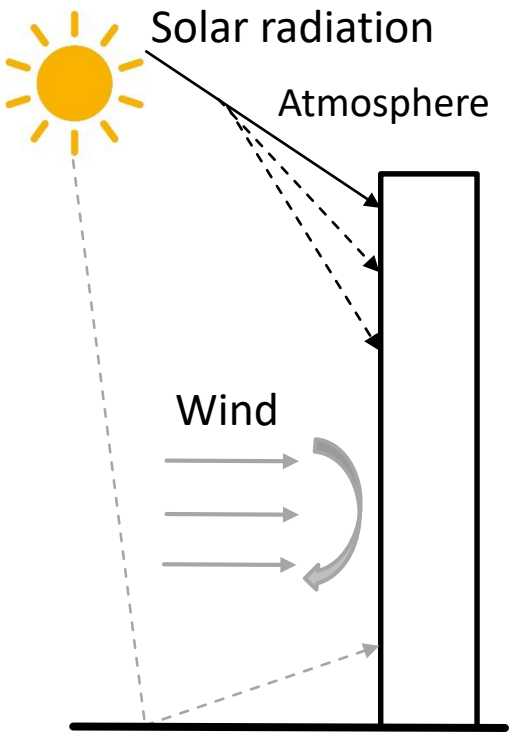


Max deviation: 1,87% (0,80 kg/m³)



Max deviation: 0,25% (0,04 °C)

Exterior boundary conditions



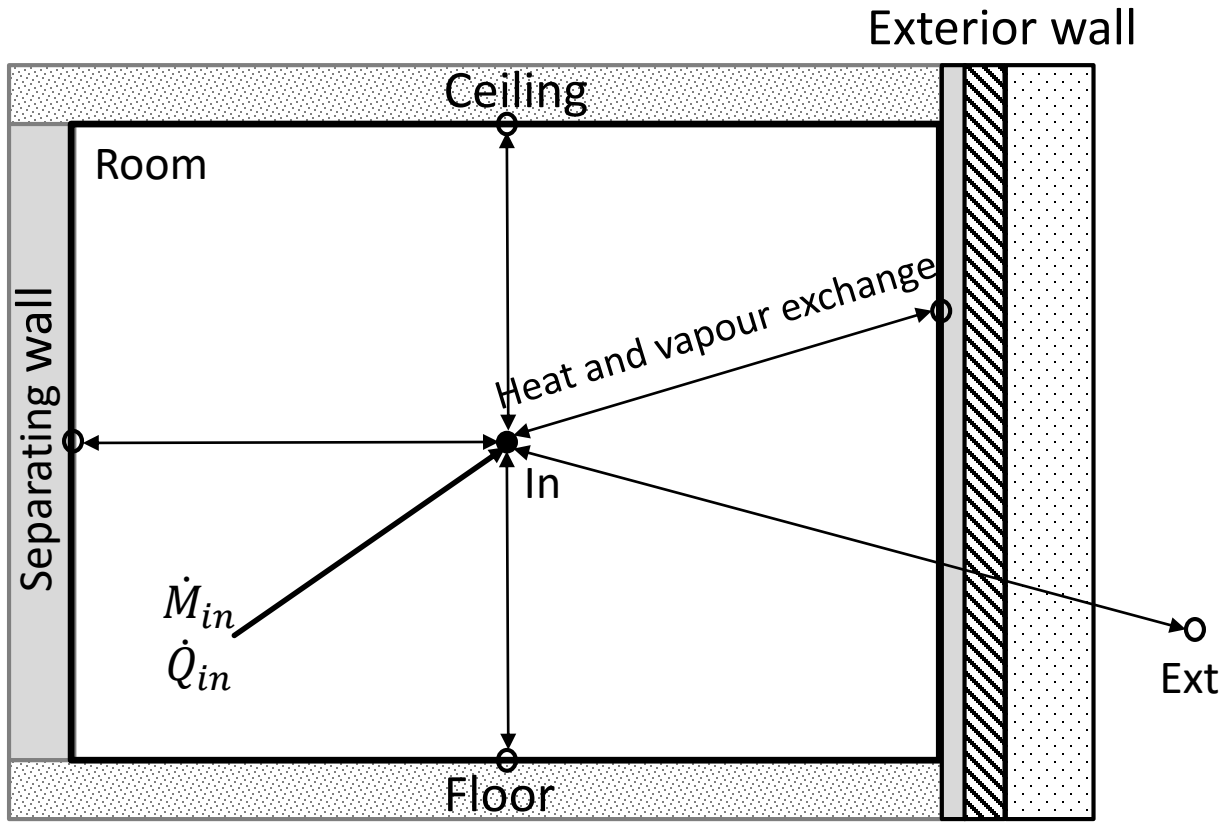
Convective heat and mass transfer → Impact of the wind

Radiative heat transfer
- Short-wave radiation
- Long-wave radiation

Latent and sensible heat transfer

No wind-driven rain

Interior boundary conditions – Indoor air balance



Mass balance

$$\frac{R_a}{R_v} \cdot \frac{\rho_a V}{p_{atm} - p_{v,in}} \frac{\partial p_{v,in}}{\partial t} = \text{Convection}$$

$$+ \text{ Air renewal } + \underbrace{\dot{M}_{in}}_{\text{Sources/sinks}}$$

Energy balance

$$\rho_a V \cdot C_{p,a} \frac{\partial T_{in}}{\partial t} + \frac{R_a}{R_v} \cdot \frac{\rho_a V \cdot L_v}{p_{atm} - p_{v,in}} \cdot \frac{\partial p_{v,in}}{\partial t}$$

$$= \text{Convection} + \text{Air renewal} + \underbrace{\dot{Q}_{in}}_{\text{Sources/sinks}}$$

Occupants' presence and activities

Modelling of occupants' presence and activities

- Constant indoor source *(Hutcheon, 1955), (TenWolde and Walker, 2001)*
- Deterministic representation *(Künzel et al., 2005), (Qin et al., 2011)*
- Stochastic approaches *(Wang et al., 2011), (Wilke, 2013), (Feng et al., 2015)*

Nottingham Multi-Agent Stochastic Simulation (No-MASS) platform
(Chapman, 2017)

Presence model
(Page et al., 2008)

Calibrated and validated with experimental data

Activity model
(Jaboob, 2015)

Calibrated and validated with Time Use Survey Data

Metabolic heat gains ISO 7730 *(AFNOR, 2005)*
Moisture production *(Johansson et al., 2010)*

No-MASS – Presence model *(Page et al., 2008)*

Based on an inhomogeneous Markov chain

Output
- 0: absence
- 1: presence

Time →

~~0 0 1 1 1 0 1 0 1 1 0 1~~ 1 1 …

Input:

- Time-dependent profile of presence *P(t)* over a week
- Parameter of mobility μ ⇒ Constant

Probabilities of transition

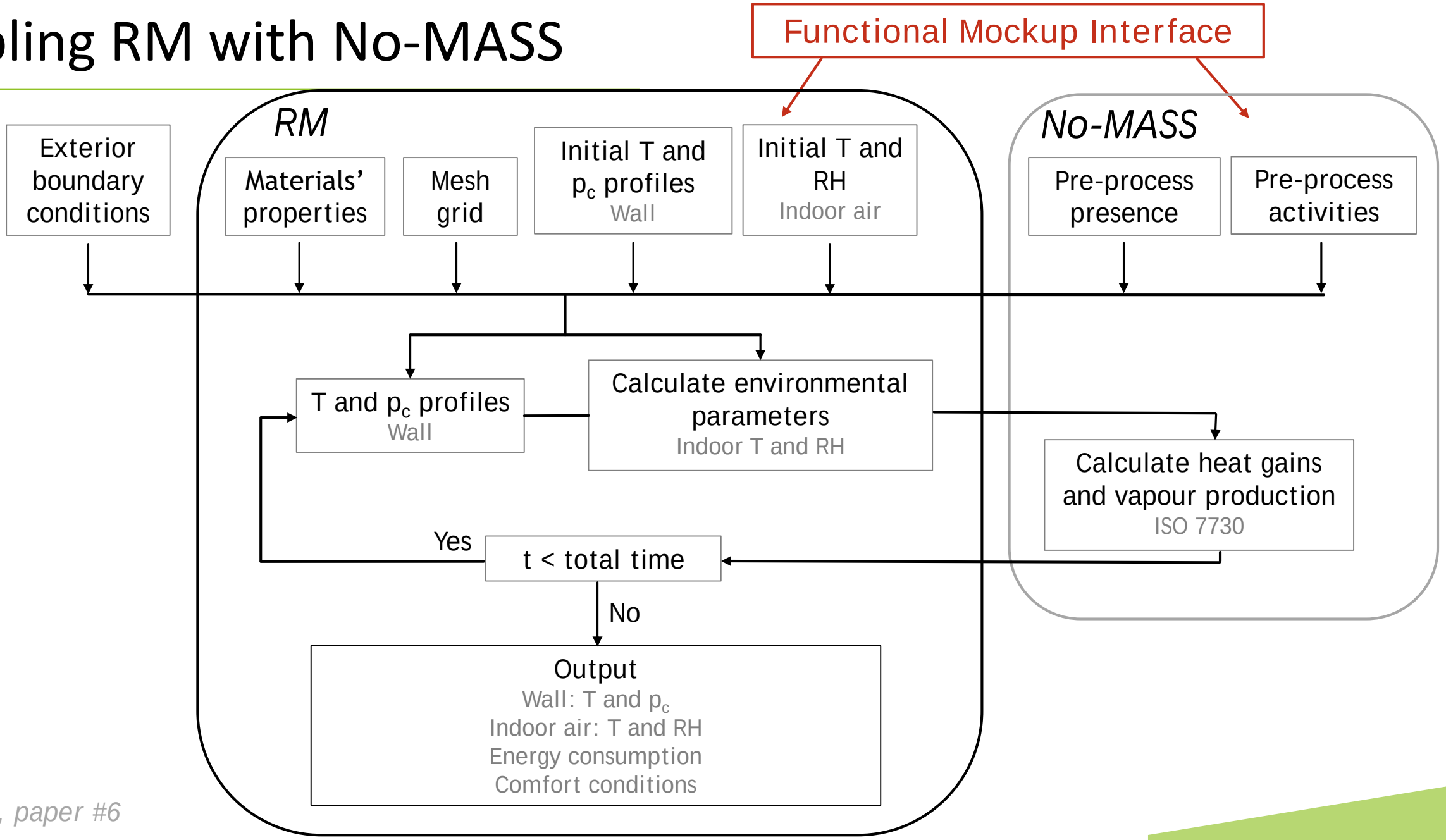
$$T_{11}(t) = \frac{P(t)-1}{P(t)}\left[\frac{\mu-1}{\mu+1}P(t)+P(t+1)\right]+\frac{P(t+1)}{P(t)}$$ *Present to Present*

$$T_{01}(t) = \frac{\mu-1}{\mu+1}P(t)+P(t+1)$$ *Absent to Present*

$$T_{10} = 1 - T_{11}$$ *Present to Absent*

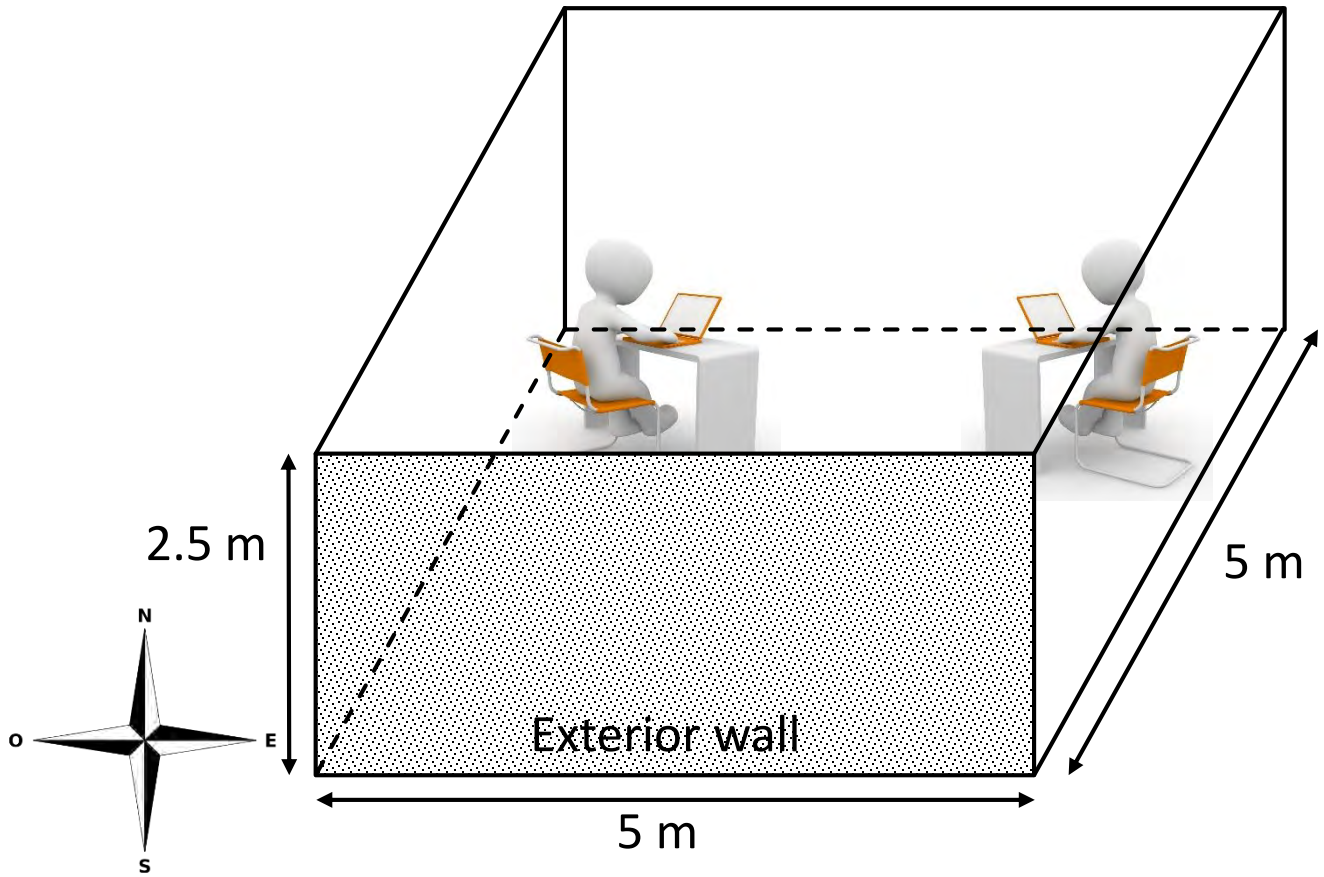
$$T_{00} = 1 - T_{01}$$ *Absent to Absent*

Coupling RM with No-MASS



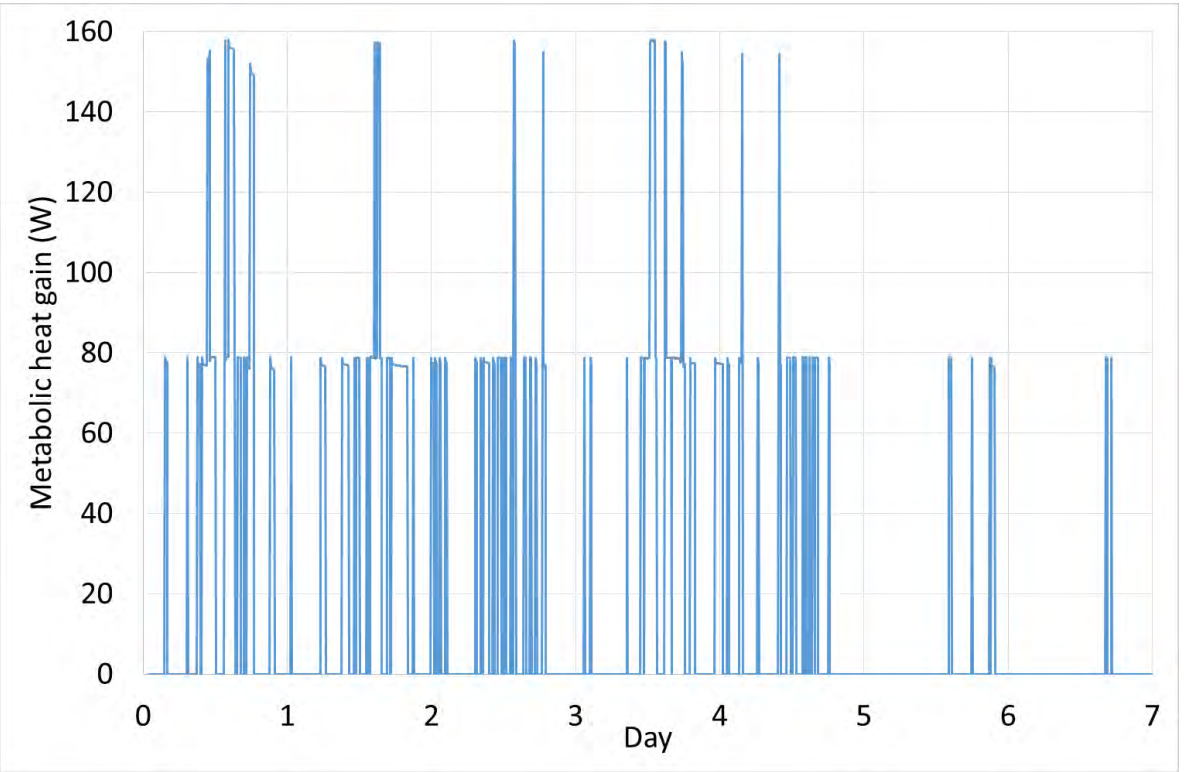
Case study

Office room located in Trappes (France)
Surrounded by offices at 20°C, 40%RH



No window or shading device simulated

Exterior boundary conditions *(RT Bâtiment, 2012)*
Interior boundary conditions: **two agents** (No-MASS)
Activity: Information Technology (IT)



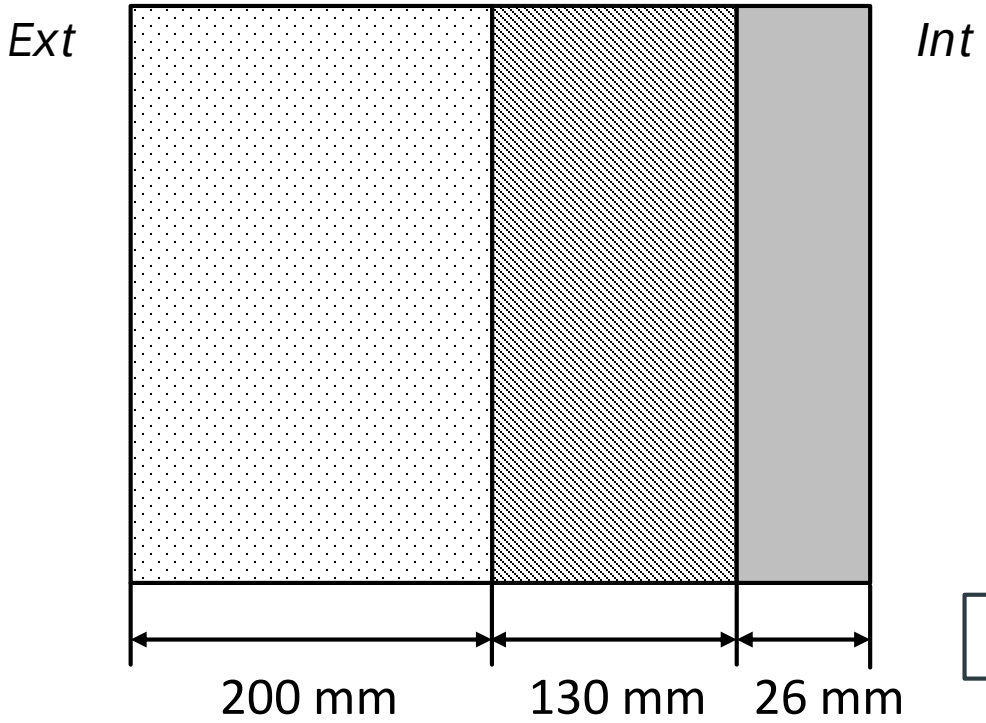
Vapour production: 87 g/h per occupant *(ASHRAE, 1997)*
+ Lights: 10 W/m² *(Steeman, 2009)*
+ Ideal heating system

Case study

Separating walls: Plaster boards (2*13 mm)
Floor and Ceiling: Concrete (200 mm)

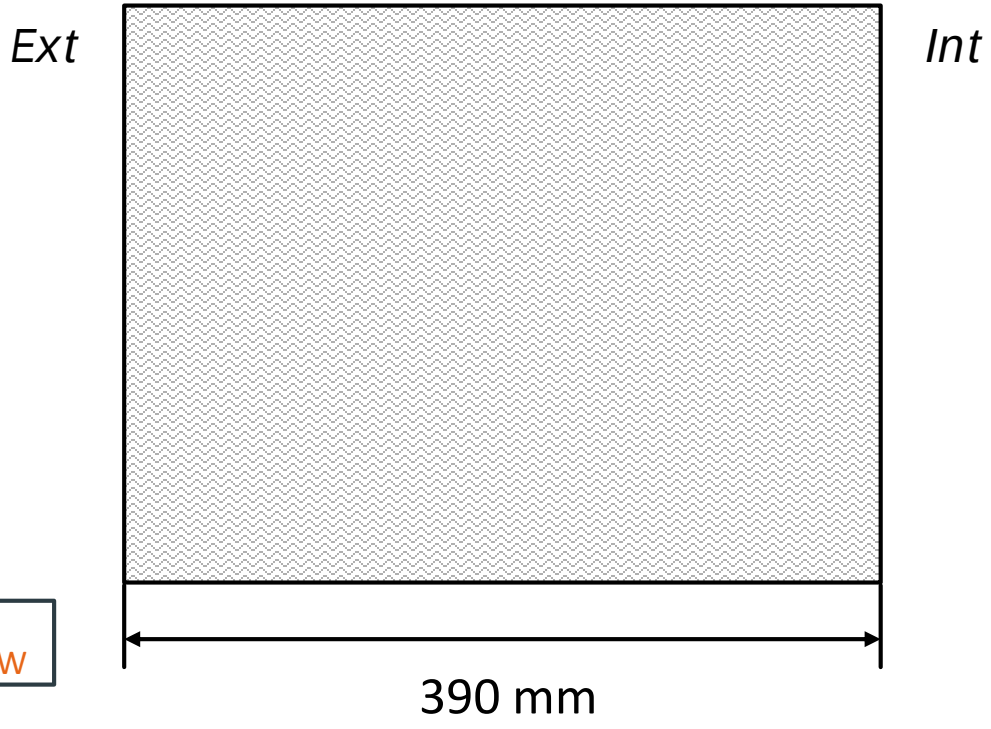
Conventional Wall (CW)

Concrete – Polystyrene – Plaster



Hygroscopic Wall (HW)

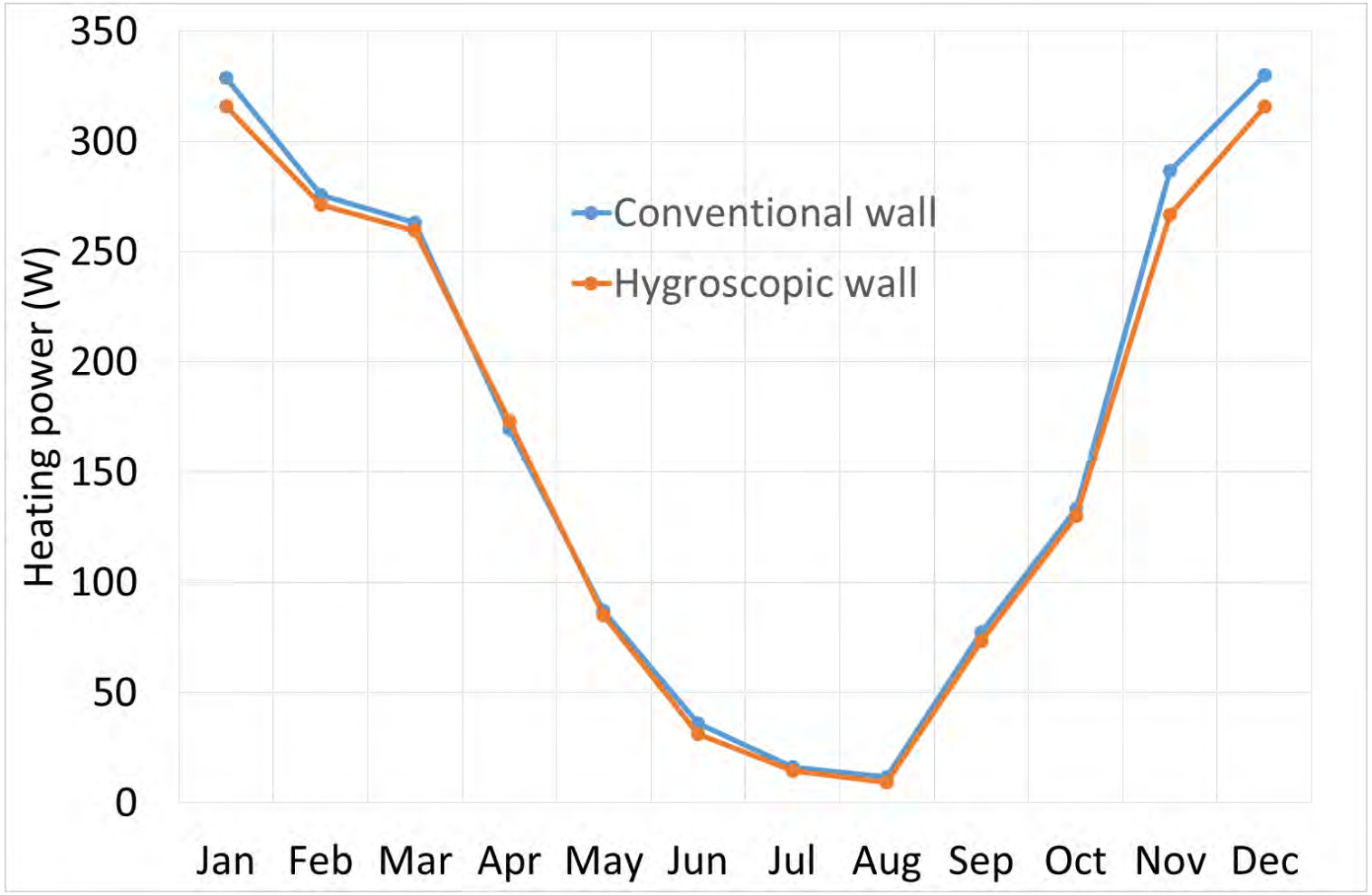
Hemp Concrete

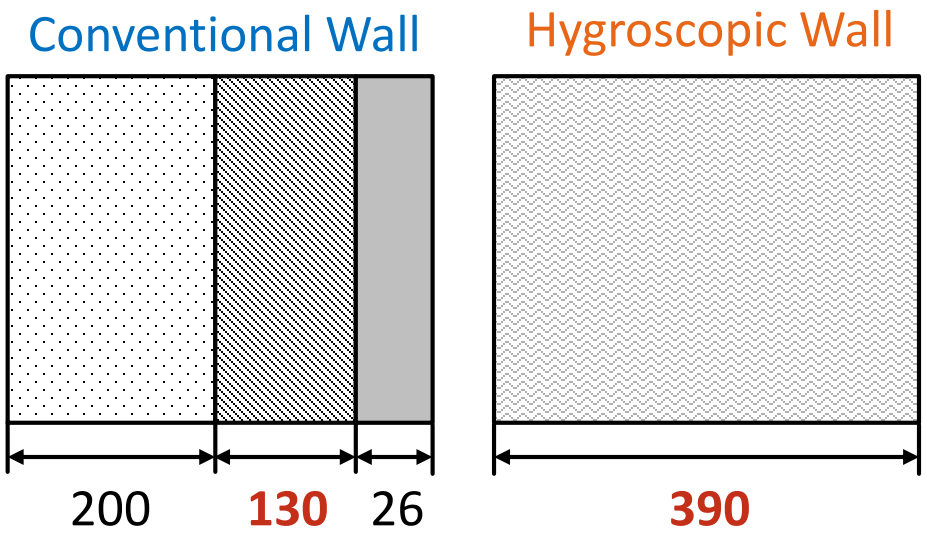


$R_{th,\ CW} \approx R_{th,\ HW}$

1 year period simulated
Initial conditions: 20°C, 40%RH

Case study – Energy consumption



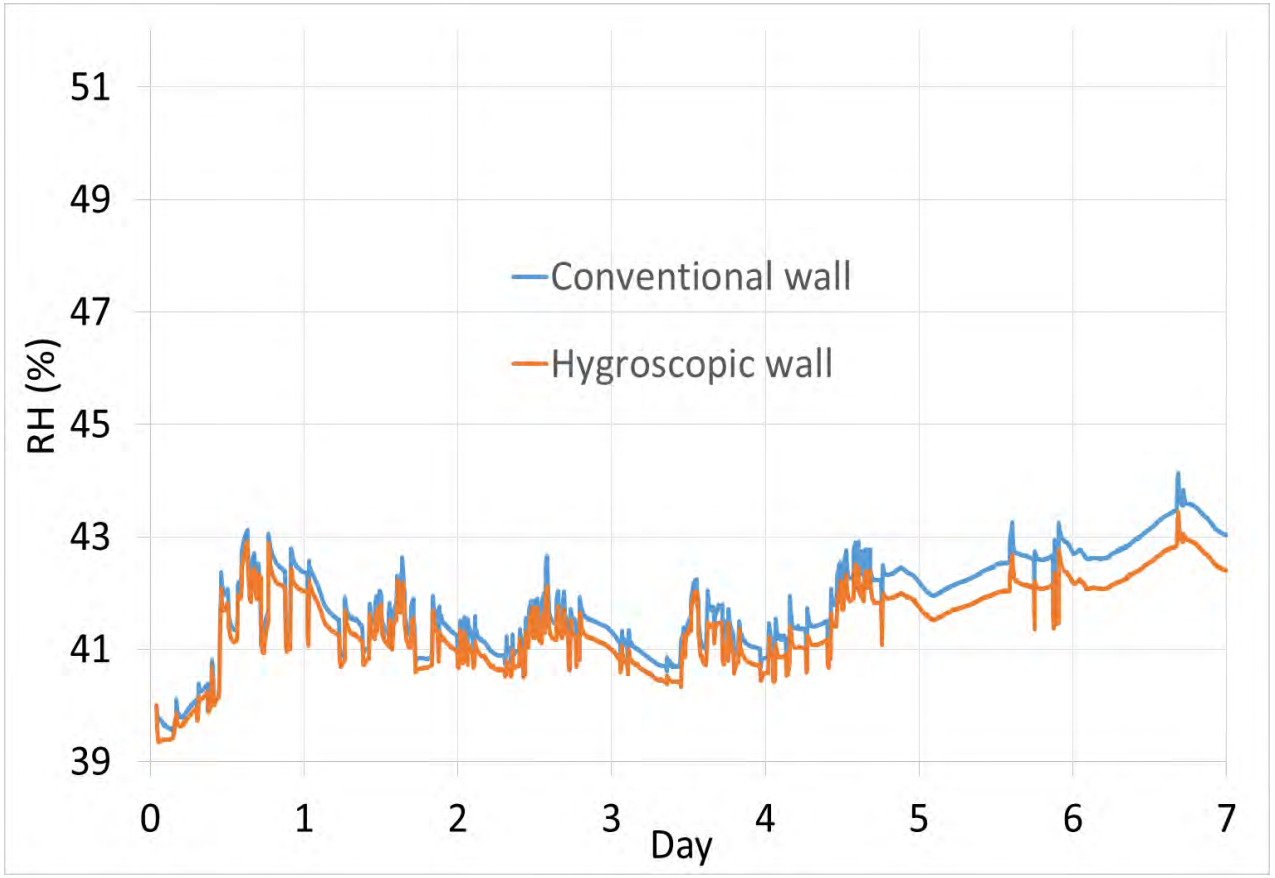


Same stationary thermal resistance

- Conventional wall: interior insulation
- Hygroscopic wall: insulation spread throughout the wall

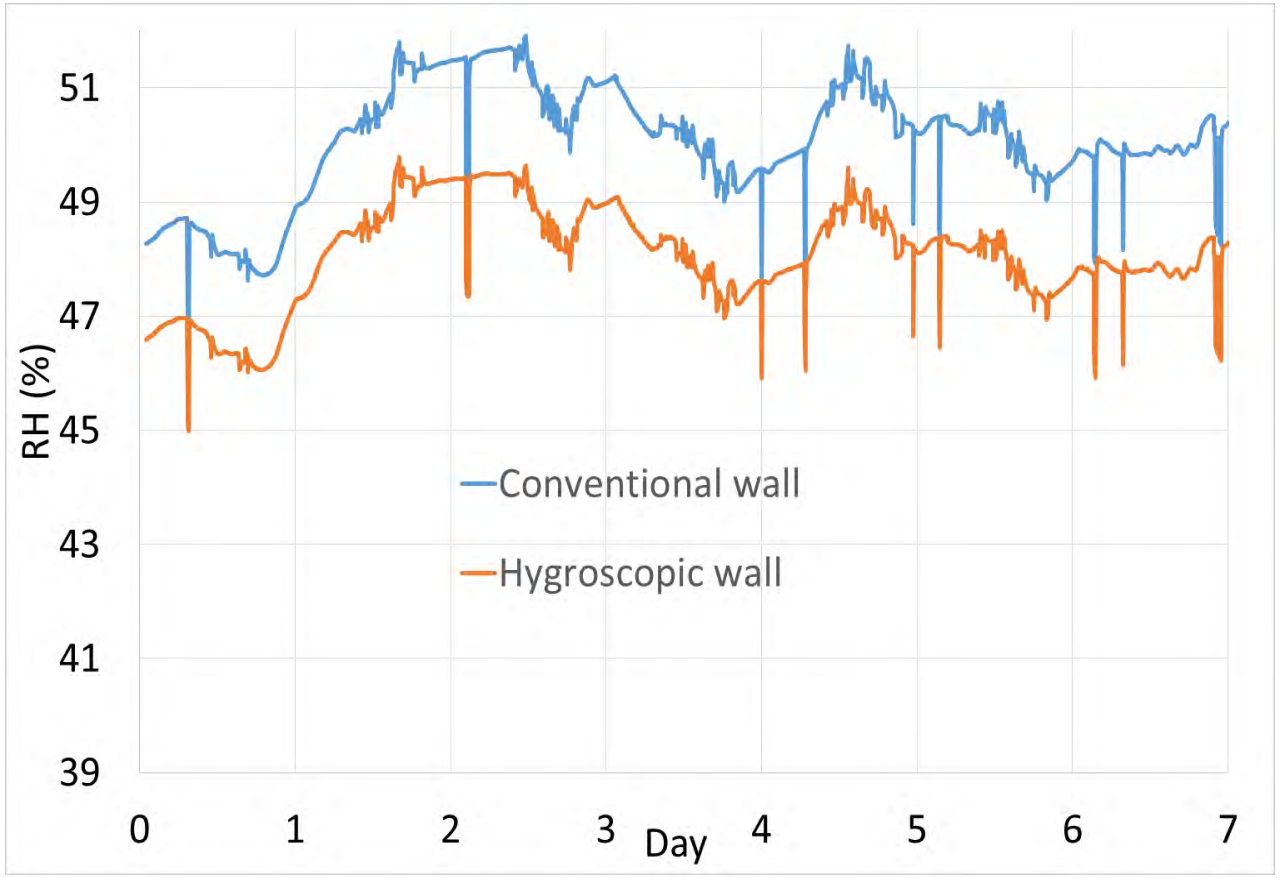
Hygroscopic wall → -3,6% energy consumption

Case study – Indoor relative humidity



January 1st – 7th

Max RH difference: 1%

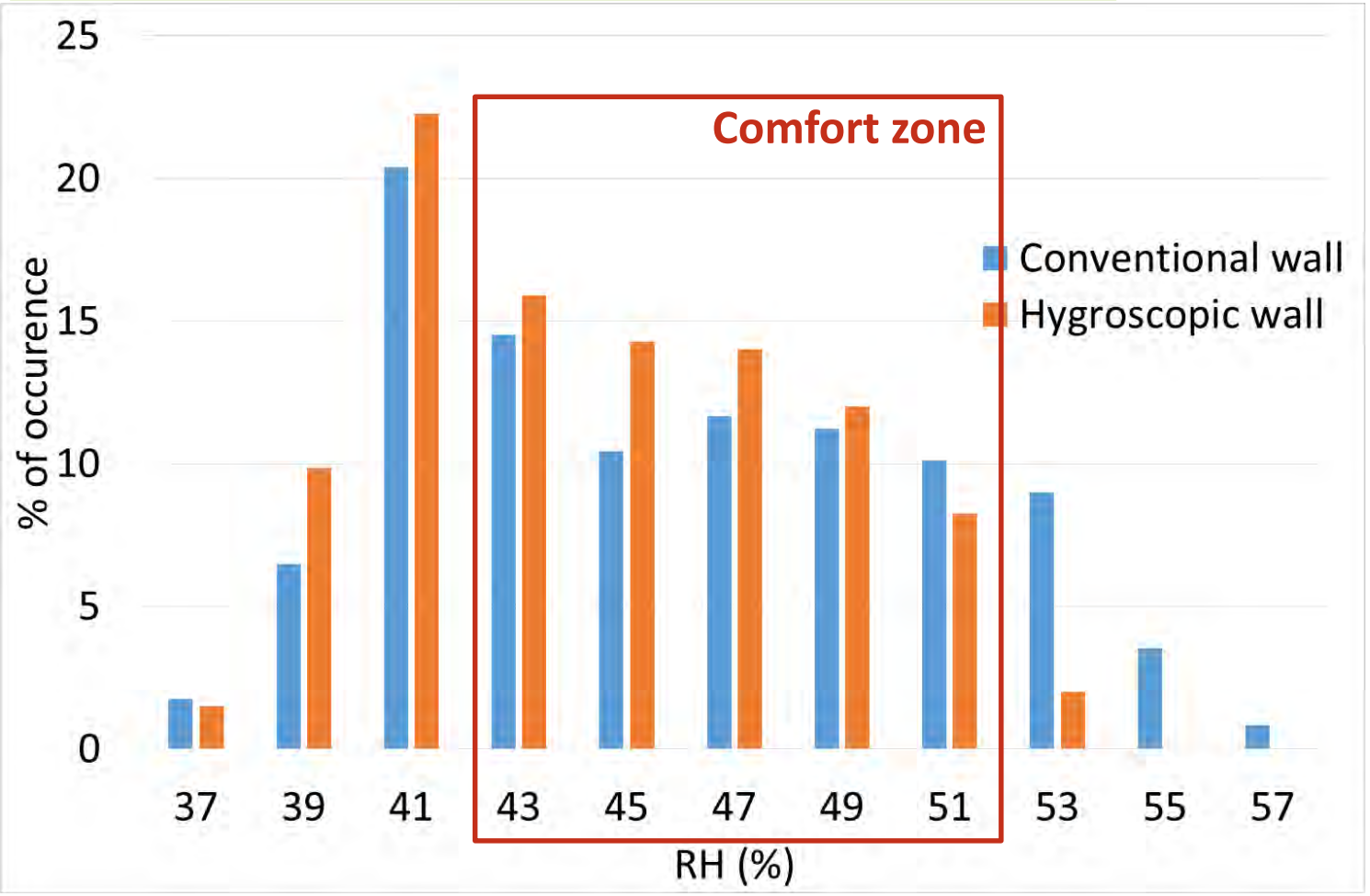


July 1st – 7th

Max RH difference: 2,5%

$R_{vap,\,CW} = 10^{11} < R_{vap,\,HW} = 10^{9}$

Case study – Comfort conditions



Comfort criteria ISO 7730 *(AFNOR, 2005)*

	Max PMV	Max PPD
CW	0.74	16.44 %
HW	0.72	16.01 %

- No relevant conclusion
- Calculation based on an energy balance equation ➔ limited impact of the RH

➡ **Other comfort criteria**

Comfort zone [40; 50]%RH *(Wolkoff and Soren, 2007)*

Conventional wall ➔ 68%

Hygroscopic wall ➔ 78% ➡ **Better prediction of the comfort range**

Conclusion and perspectives

Wall scale

Validated heat and mass transfer model

T and p_c profiles in the wall

Room scale

Modelling of the occupants' presence and activities

Estimation of the indoor T and RH

Moisture buffering of materials

HVAC System

Energy consumption

Comfort conditions

Heating/cooling system

Humidification/dehumidification system

Perspectives

Simulations

- Composition of the wall
- Heating strategy
- Ventilation rate
- Number of occupants
- …

Compared to a reference case study

→ Cost-efficiency

Wall scale	Room scale
Durability of materials	Energy consumption
	Comfort conditions

Thank you for your attention

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