Determination of Hygrothermal Properties for Building Materials using Inverse Modeling

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Where innovation starts

Background
Hunting Lodge St. Hubertus

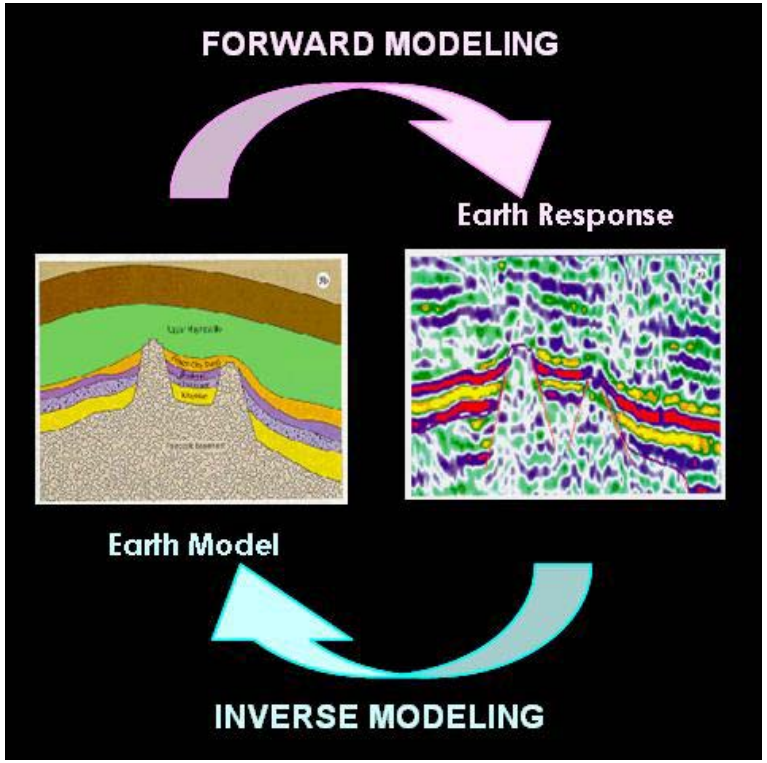
- **Conservation**
- **Moisture problems masonry**

Problem

- What we could do
  - Model current moisture problems
  - Simulate possible solutions
- But ….
- How to get material properties?
  - Taking samples not allowed!
  - No ‘spare’ masonry available

Methodology
Inverse problem

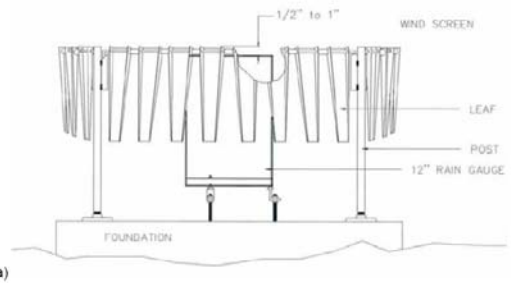
- Input data (time series)
- Objective data (time series)
- Data (signal) analysis
- Model
- Simulate data
- Compare with objective data
- Optimize parameters



Measurements in situ Sensors

- External
  - T
  - RH
  - Rain
  - Wind
  - Solar
- Internal
  - T
  - RH
- Surface
  - T
  - RH


(a)



(b)

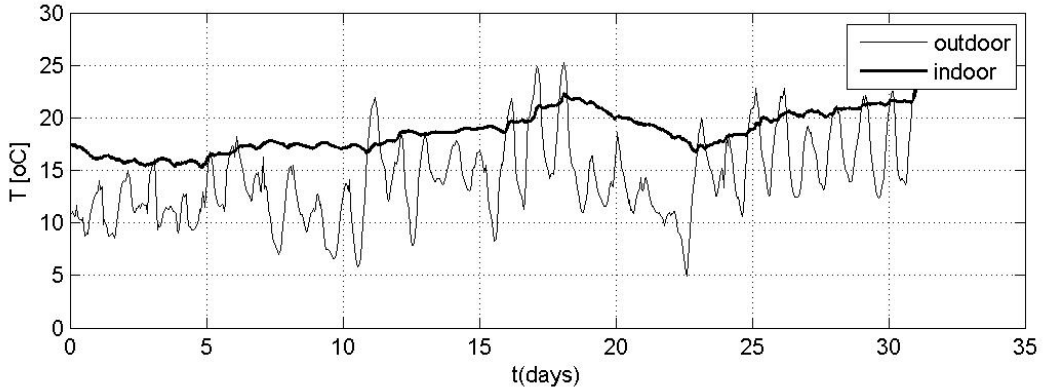
(a)

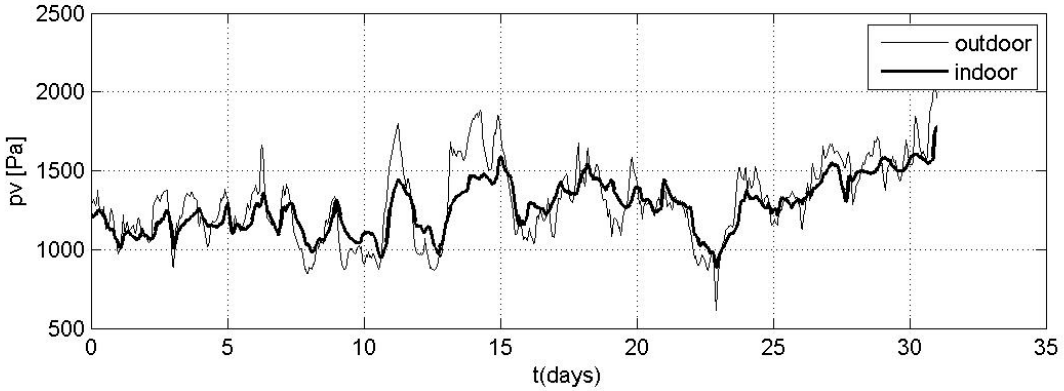
(b)


(c)

Data set
Input data 1/2

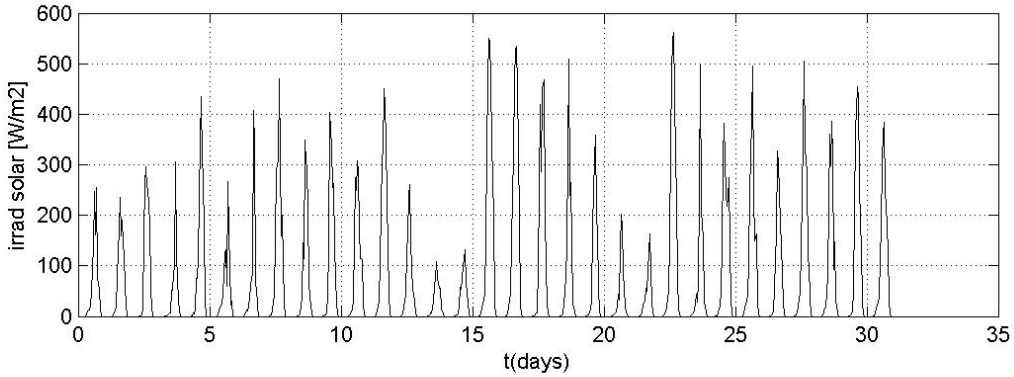
- **External**
  - **T**
  - **RH**
  - **Rain**
  - **Wind**
  - **Solar**
- **Internal**
  - **T**
  - **RH**
- **Surface**
  - **T**
  - **RH**

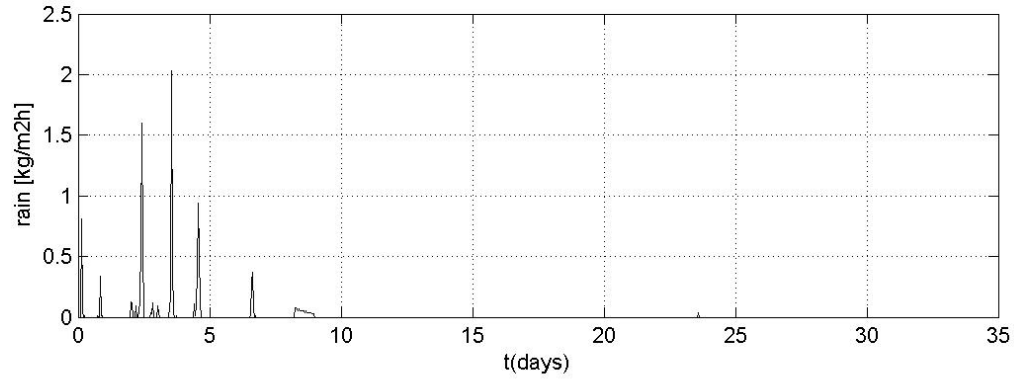




Data set
Input data 2/2

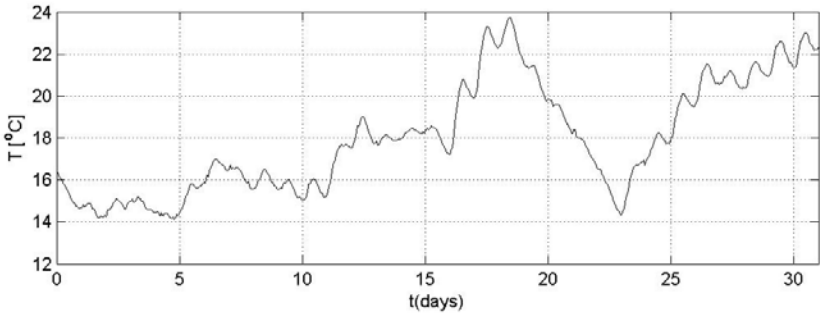
- **External**
  - T
  - RH
  - **Rain**
  - Wind
  - **Solar**
- Internal
  - T
  - RH
- Surface
  - T
  - RH

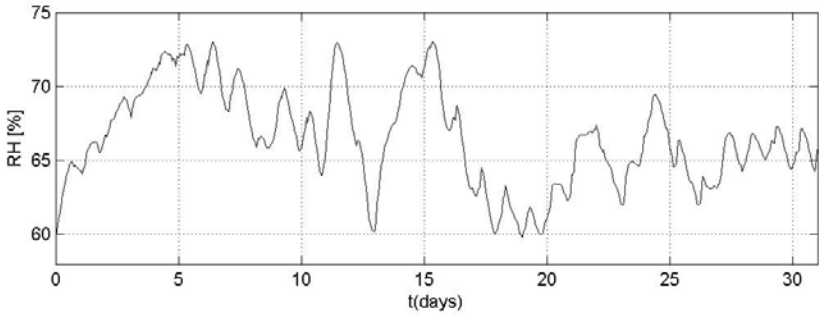




Data set
Objective data

- External
  - T
  - RH
  - Rain
  - Wind
  - Solar
- Internal
  - T
  - RH
- **Surface**
  - **T**
  - **RH**





Modeling PDEs

- **Potential T, LPc**
- **PDE coefficients formulation**
  - **Material properties**
  - **function of T, LPc**

$$C_T \frac{\partial T}{\partial t} = \nabla \cdot (K_{11} \nabla T + K_{12} \nabla LPc)$$

$$C_{LPc} \frac{\partial LPc}{\partial t} = \nabla \cdot (K_{21} \nabla T + K_{22} \nabla LPc)$$

$$LPc = {}^{10}\log(Pc)$$

$$C_T = \rho \cdot c$$

$$K_{11} = \lambda$$

$$K_{12} = -l_{lv} \cdot \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT},$$

$$C_{LPc} = \frac{\partial w}{\partial Pc} \cdot \frac{\partial Pc}{\partial LPc}$$

$$K_{22} = -K \cdot \frac{\partial Pc}{\partial LPc} - \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT},$$

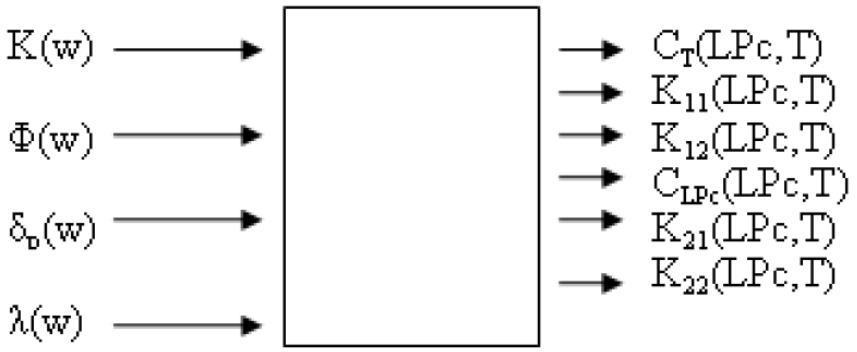
$$K_{21} = \delta_p \cdot \phi \cdot \frac{\partial Psat}{\partial T},$$

Calculating PDE coefficients using material properties, method 1/2

- **PDE coefficients lookup tables calculated in MatLab using:**
  - **heat conduction coefficients**
  - **specific heat**
  - **density**
  - **liquid permeability**
  - **moisture retention curve**
  - **vapour permeability**

$$C_T \frac{\partial T}{\partial t} = \nabla \cdot (K_{11} \nabla T + K_{12} \nabla LPc)$$

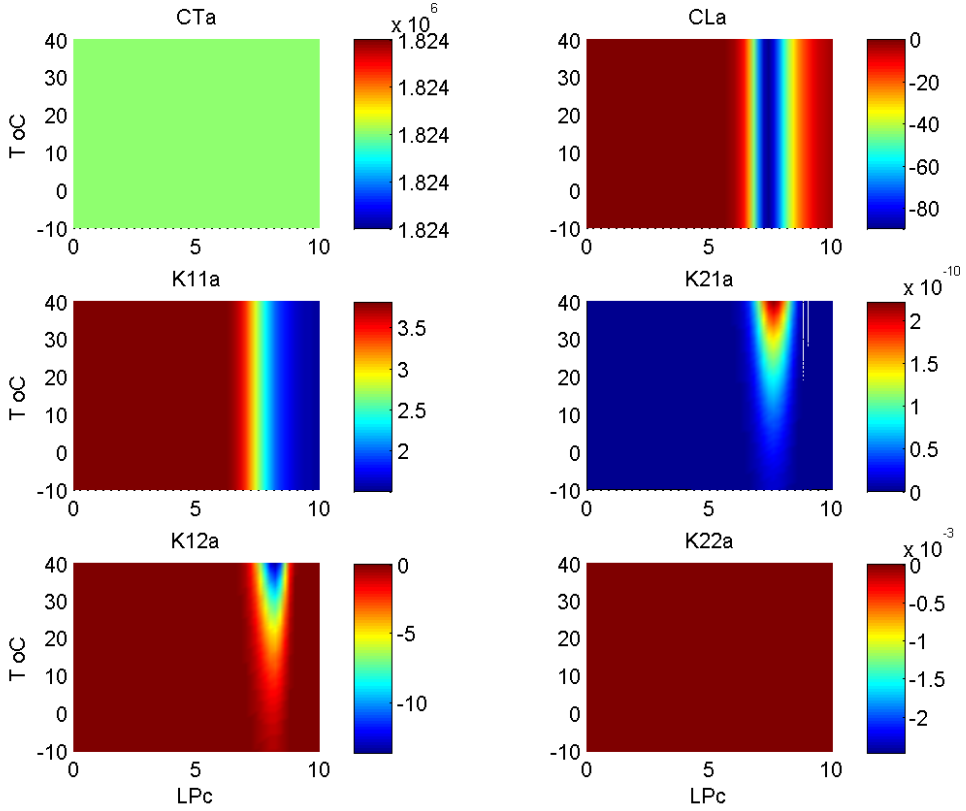
$$C_{LPc} \frac{\partial LPc}{\partial t} = \nabla \cdot (K_{21} \nabla T + K_{22} \nabla LPc)$$



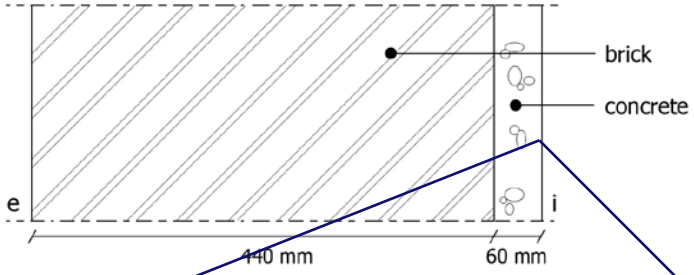
Calculating PDE coefficients using material properties, result 2/2

$$C_T \frac{\partial T}{\partial t} = \nabla \cdot (K_{11} \nabla T + K_{12} \nabla LPc)$$

$$C_{LPc} \frac{\partial LPc}{\partial t} = \nabla \cdot (K_{21} \nabla T + K_{22} \nabla LPc)$$

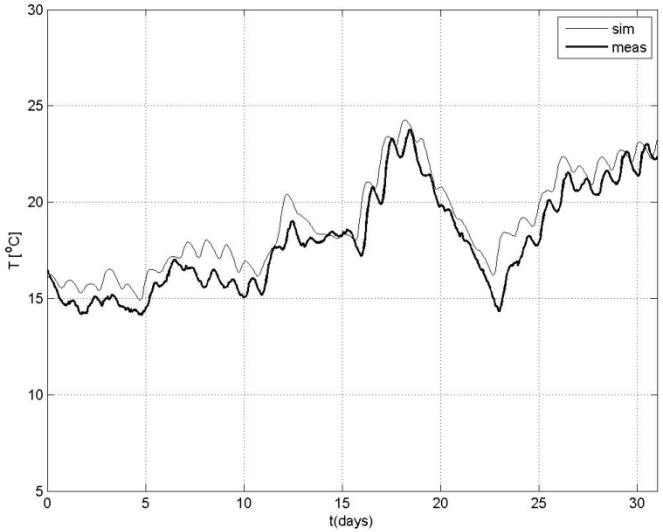


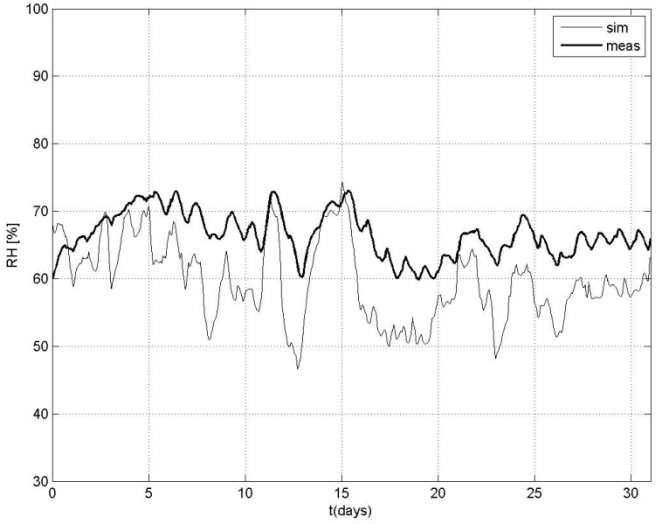
Simulation vs Measurements



Ti

RHi

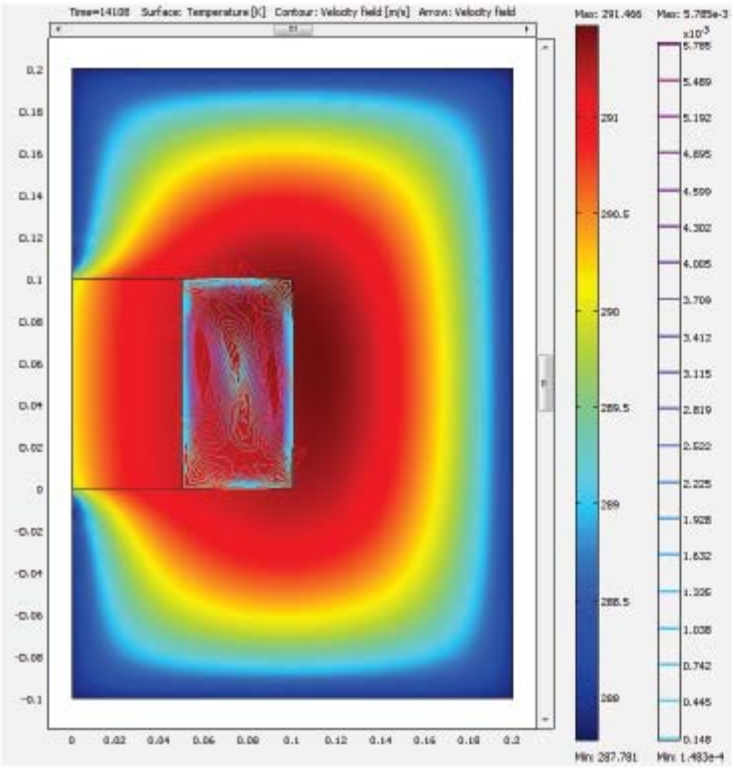


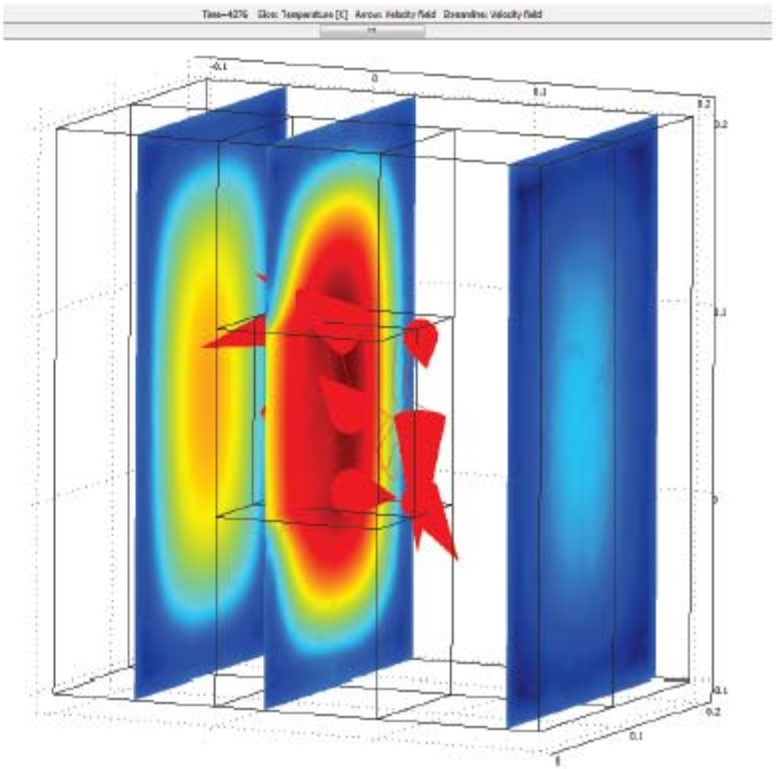


Problem

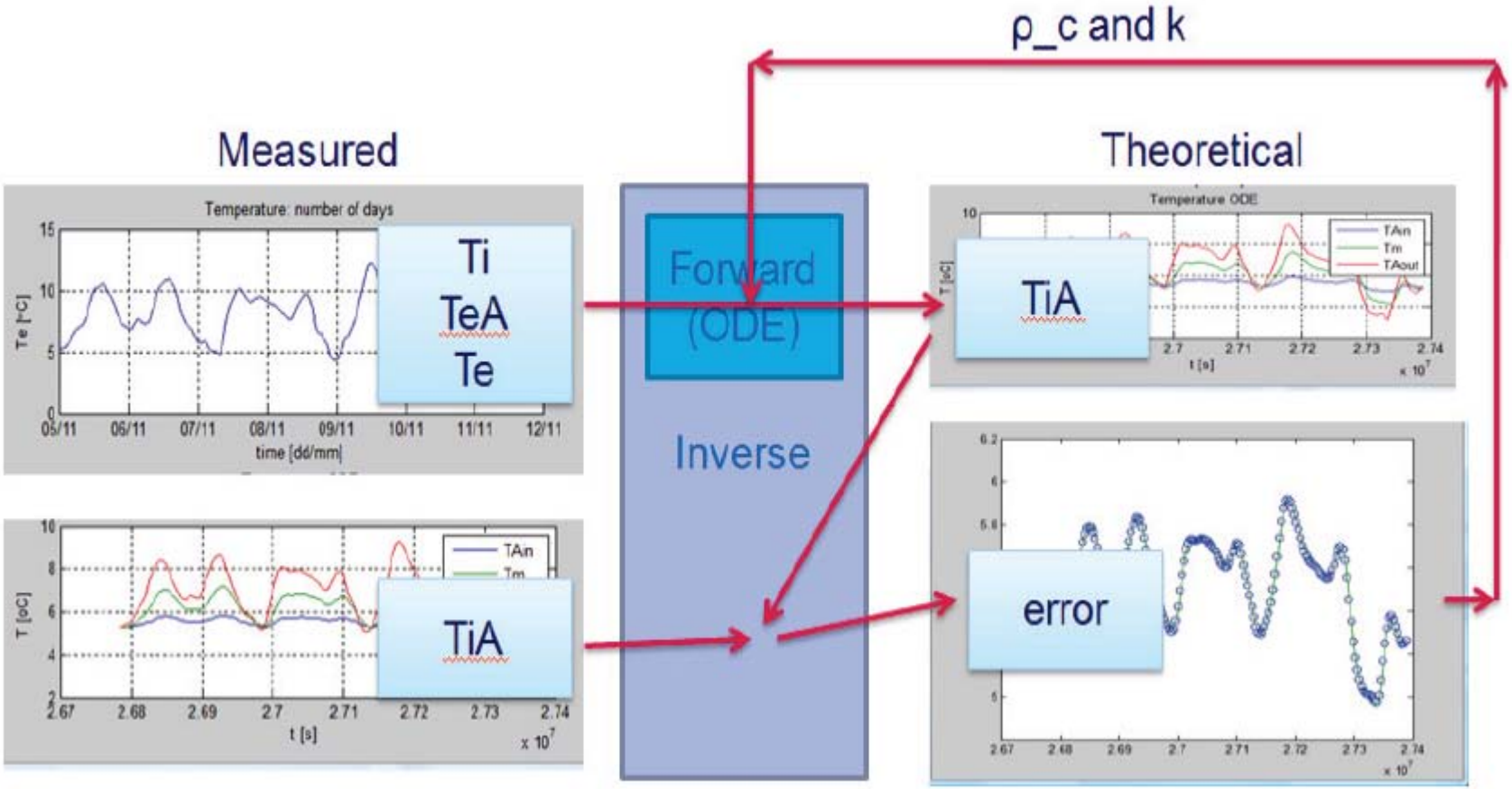
Is it possible at all?

Numerical Verification of the method
3D Simulation as reference





Numerical Verification of the method Inverse modeling

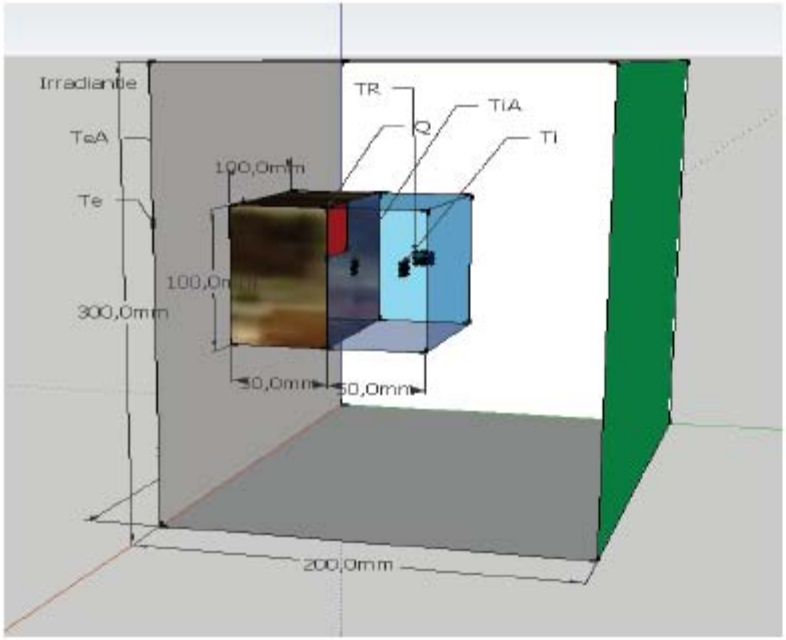


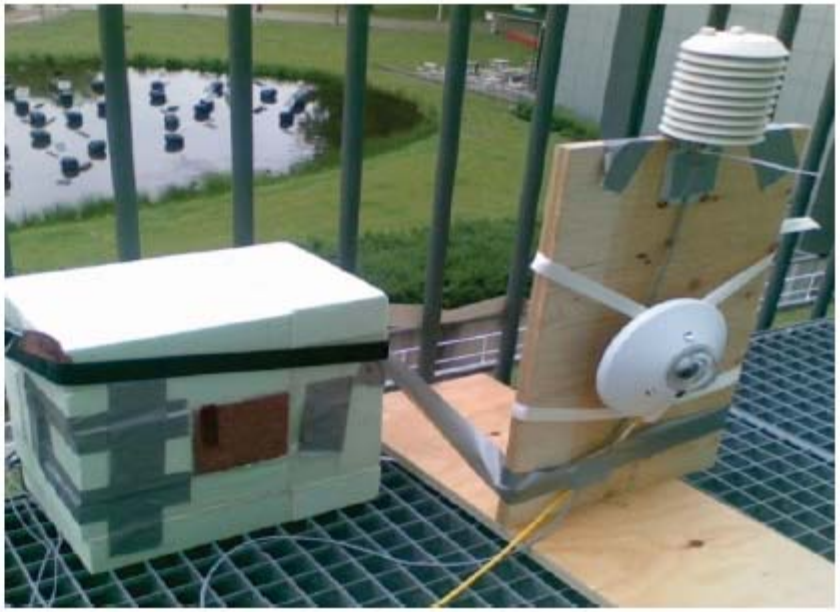
Numerical Verification of the method Result (OK)

TAB. I

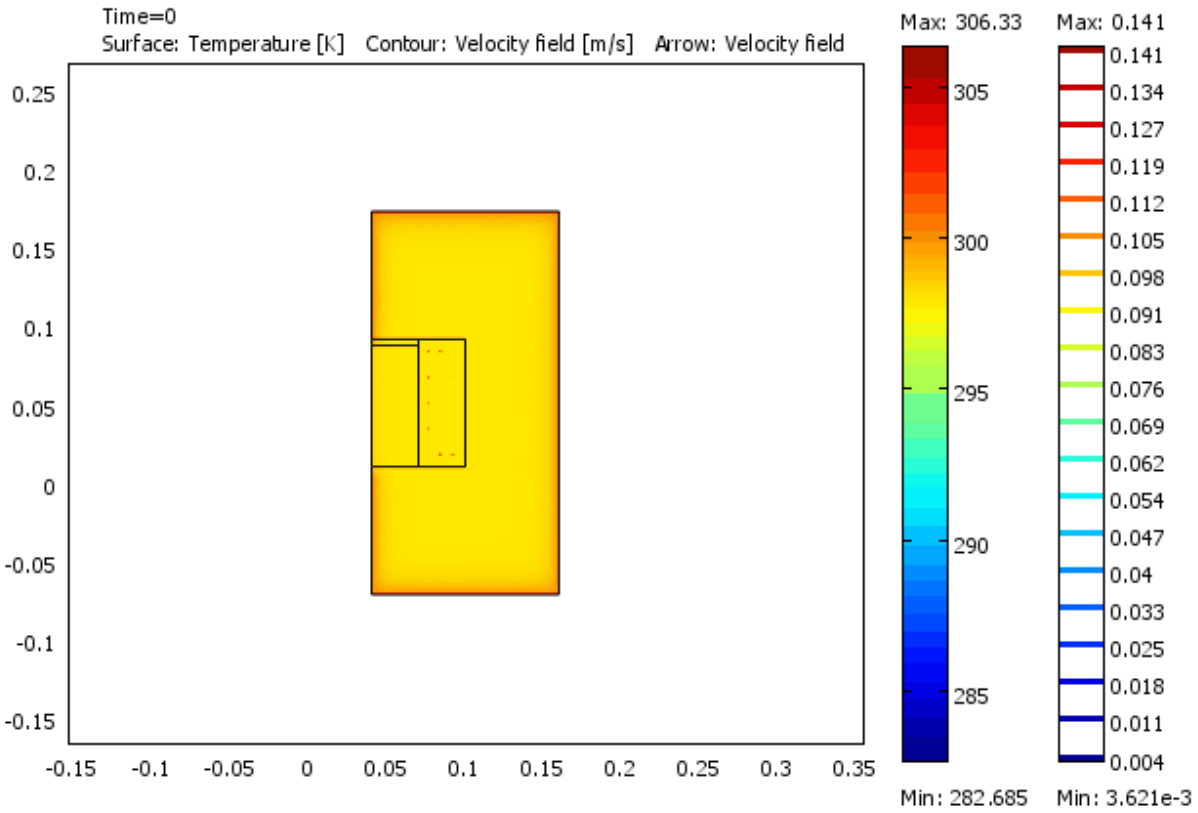
	MatLab Inverse model	Comsol reference value
k	0,999	1
rho_c	1008500	1008000

Experimental Verification of the method
Measurements near the lab





Experimental Verification of the method Measurements near the lab



Problem with airtightness

Conclusion

- **Determination of Hygrothermal Properties for Building Materials using Inverse Modeling. Does it work?**
  - **Using in situ hygrothermal measurements at building constructions: Still under investigation**
  - **Using thermal numerical simulation as input: Yes**
  - **Using thermal near lab measurements at samples: Probably yes**

Research to do, for testing the method

- **Improving thermal near lab measurements at samples**
- **Starting hygrothermal near lab measurements**
- **Revisit in situ hygrothermal measurements at building constructions**

- **Thank you**
- **Questions ?**