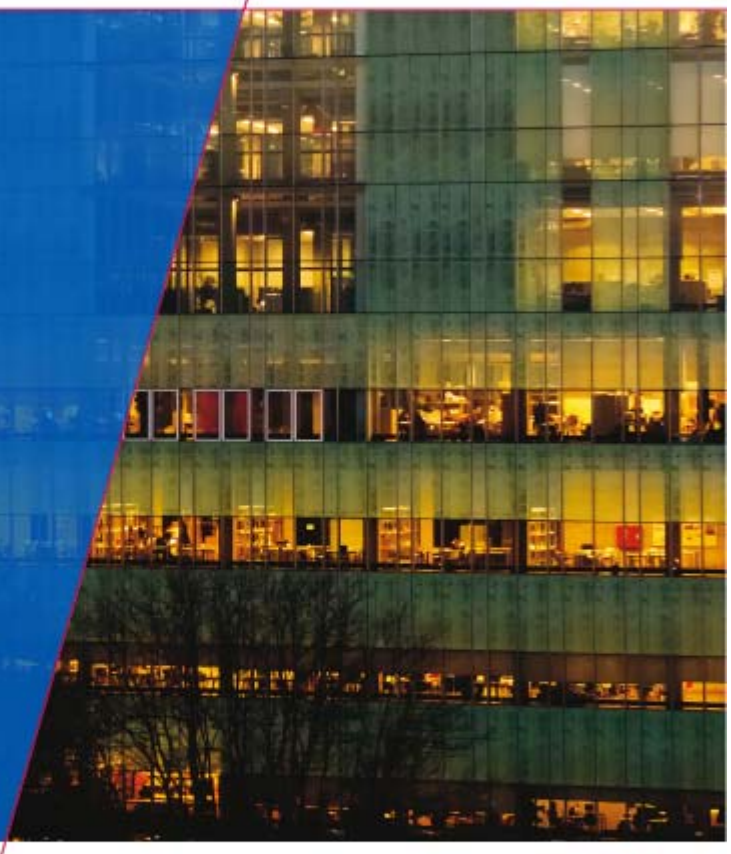
Presented at the COMSOL Conference 2008 Hannover

Heat and Moisture Modeling Using COMSOL

dr.ir.ing. Jos van Schijndel



TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

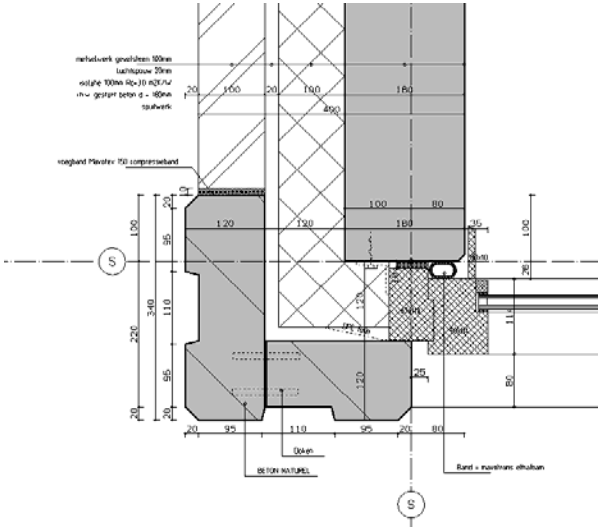
Multiphysics
Contents

- Introduction
- Heat and Moisture Transport
- Verification
- Application
- Conclusions

WHAT? Multiscale coupling time, geometry

Whole Building (scale 10 m)

Detail (scale 0.01 m)

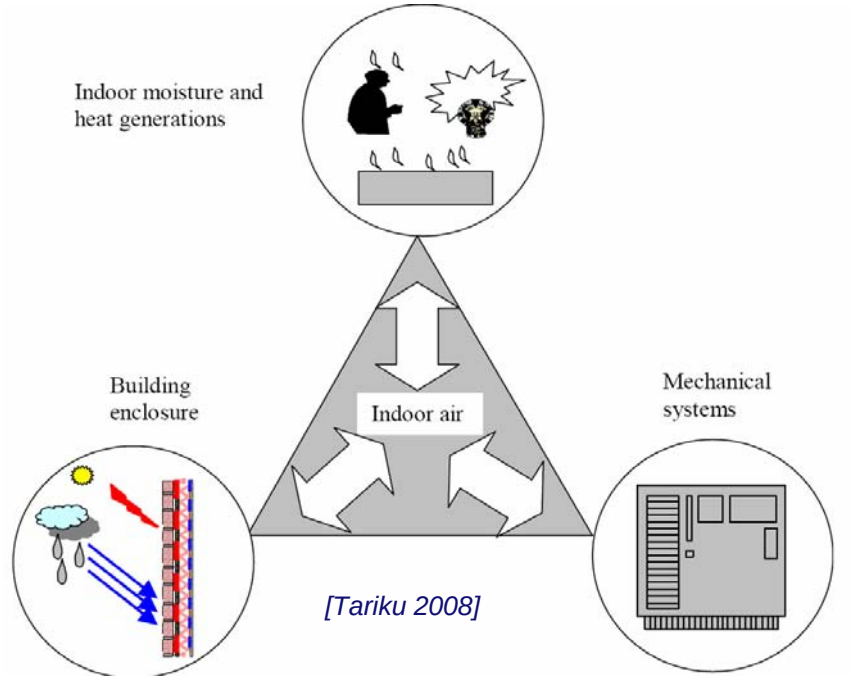


Coupled

Systems & Control
Local

Construction
Local

WHAT? Multiphysics coupling heat, air, moisture, …



[Tariku 2008]

heat

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-\lambda \nabla T) + \rho C_p \mathbf{u} \cdot \nabla T = 0$$

air

$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \nabla \cdot \mathbb{T} + \mathbf{f},$$

moisture

$$\frac{\partial p_v}{\partial t} + \nabla \cdot (-D \nabla p_v) + \mathbf{u} \cdot \nabla p_v = 0$$

WHY?

Goal

Improve building and systems performances
durability, comfort, economics

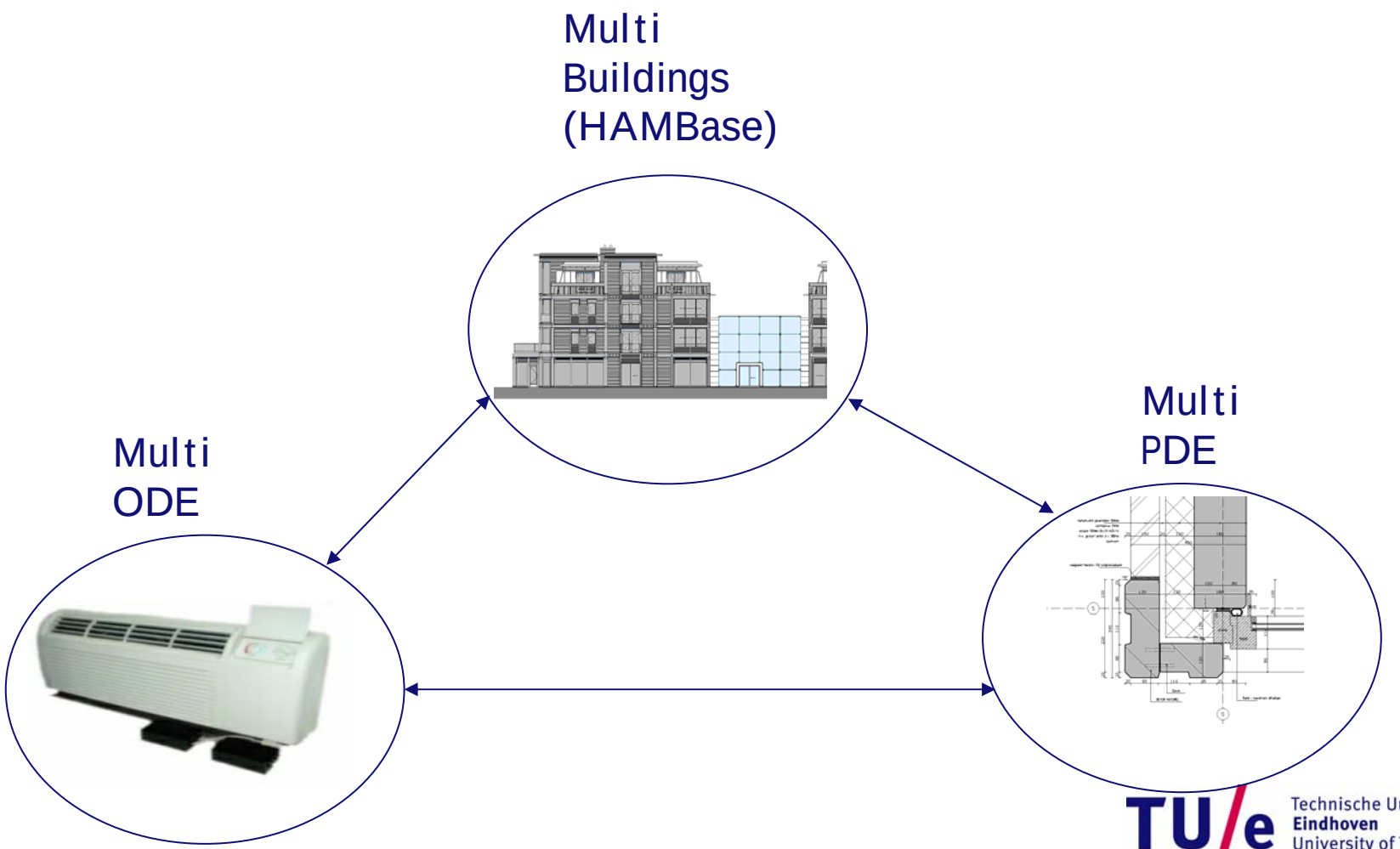
Science

Modeling is an essential and inseparable part of all scientific activity [wikipedia]

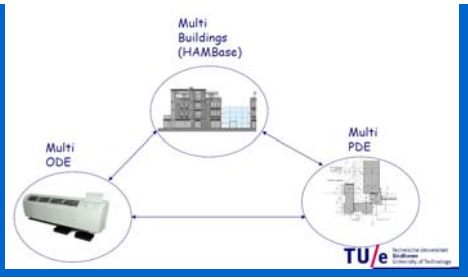
Design

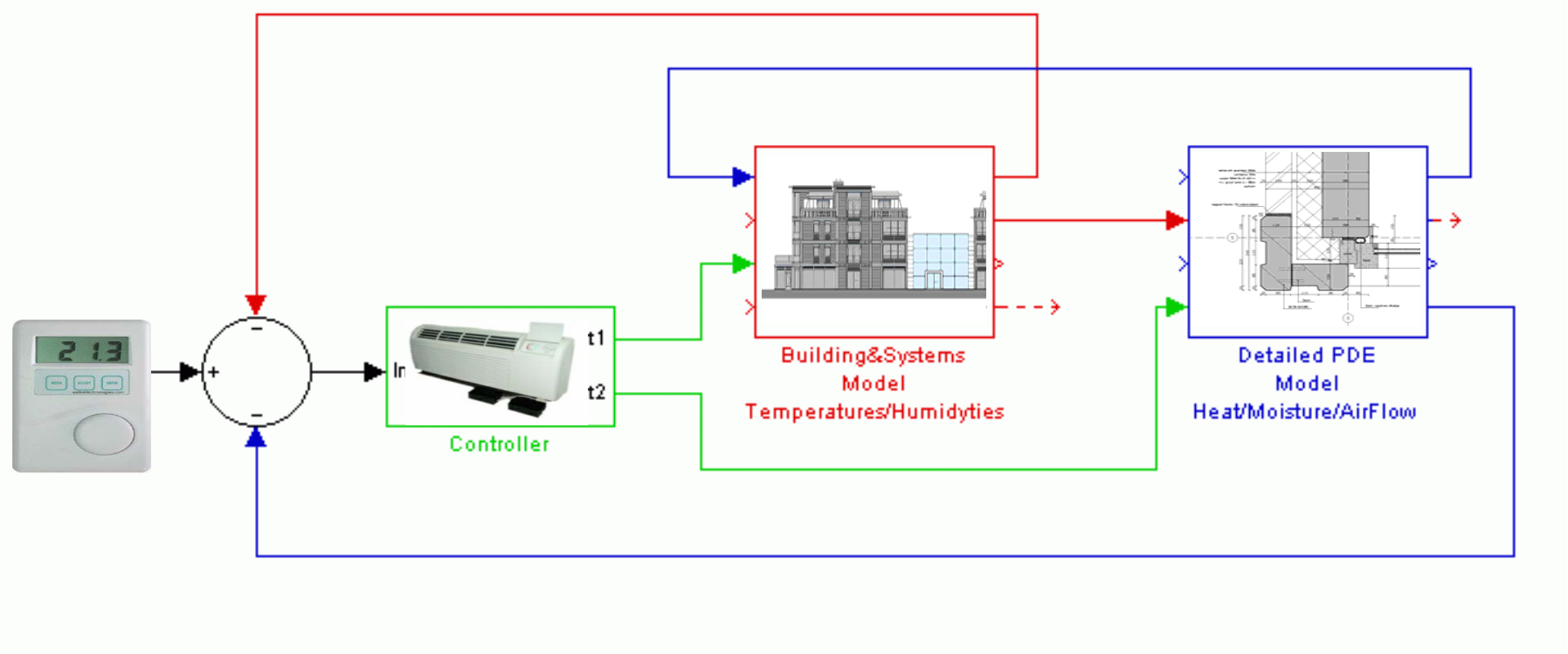
Application of Knowledge to Control

HOW? Modeling based on physics
Optimal Abstraction level

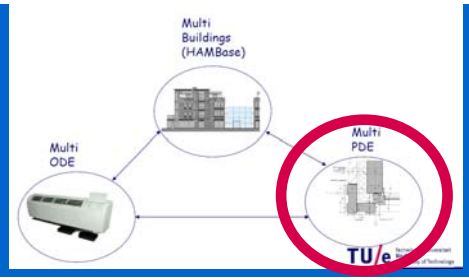


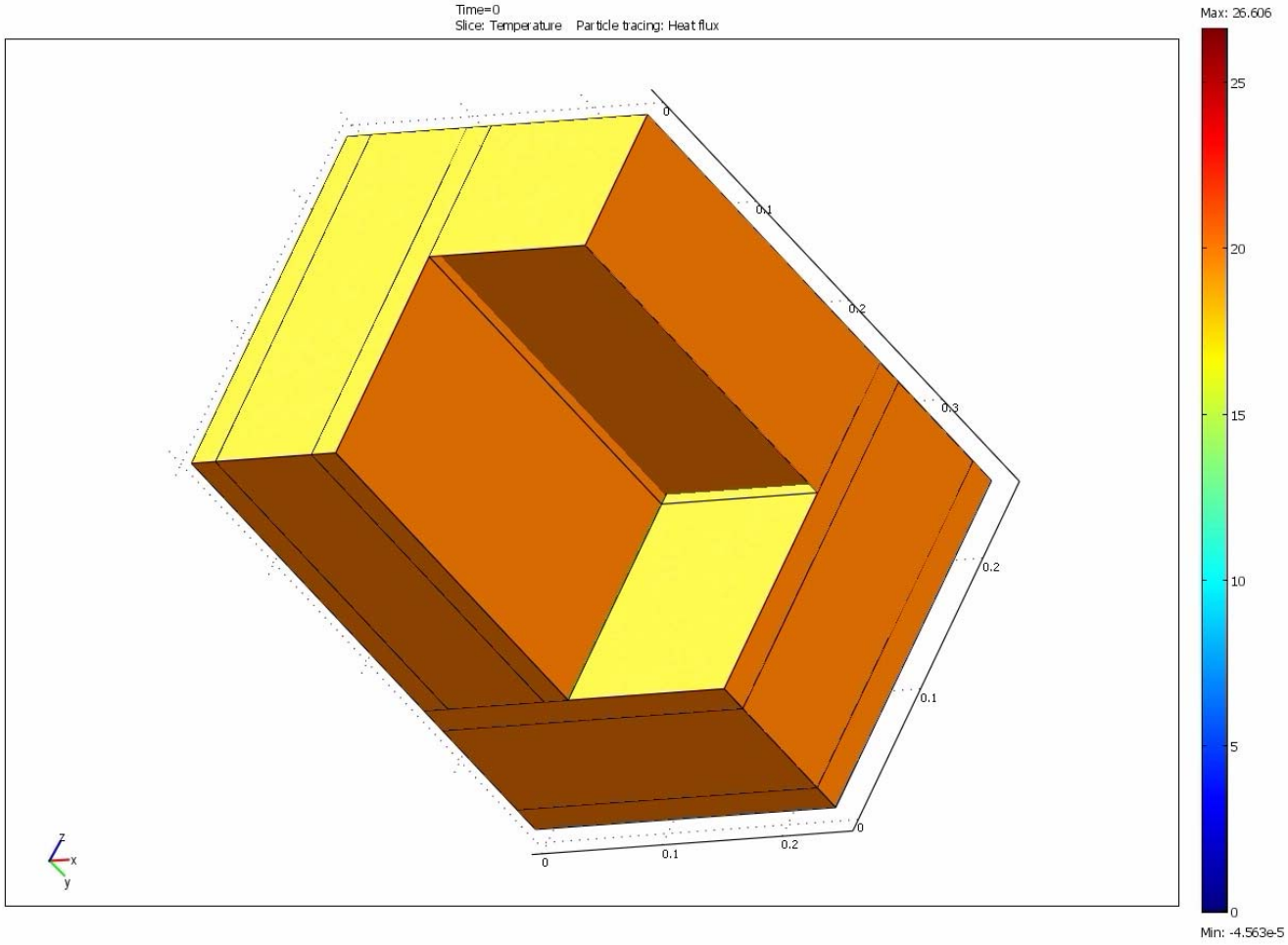
HOW? Implementation MatLab/SimuLink/COMSOL





Multiphysics
3D Heat





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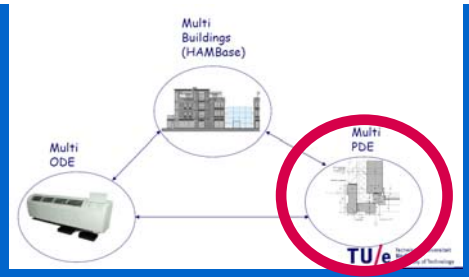
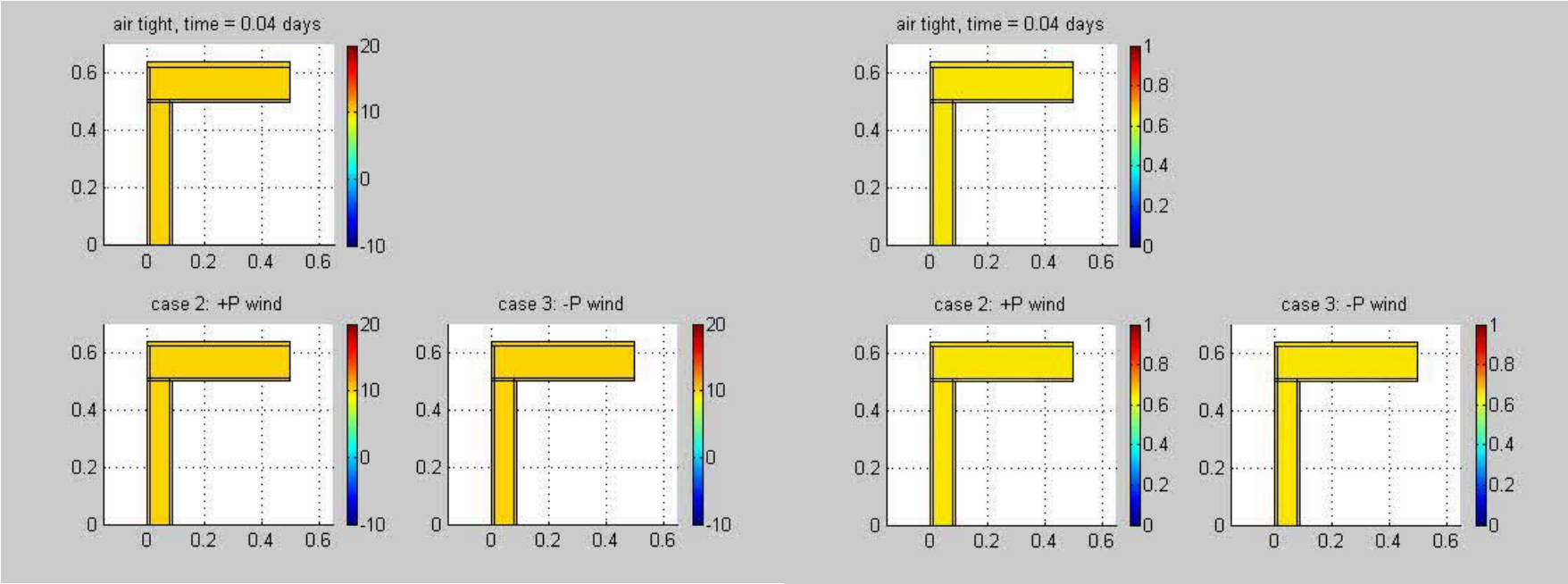
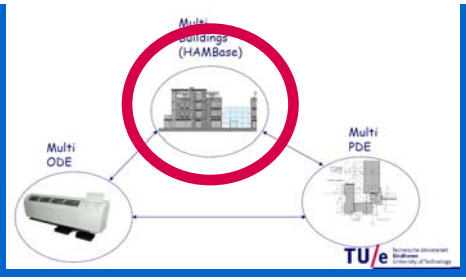
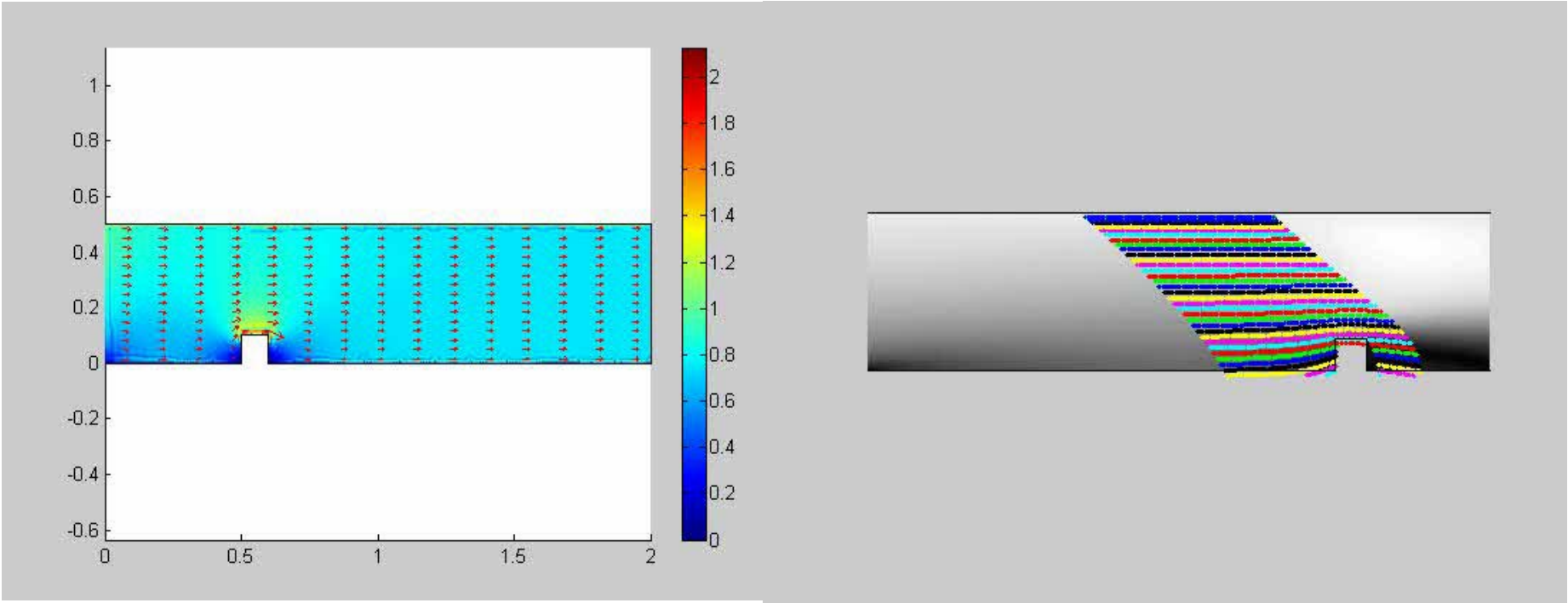
Multiphysics
2D heat & air & vapour





Multiphysics
2D wind & driving rain





Multiphysics
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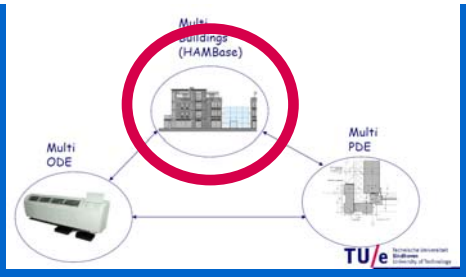
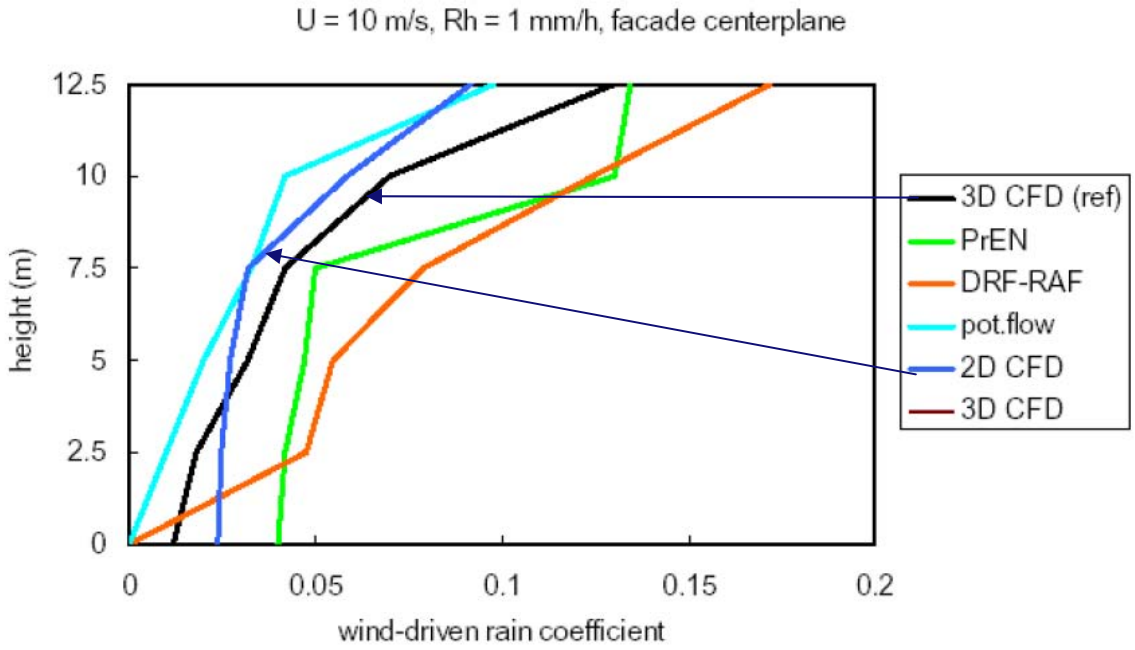
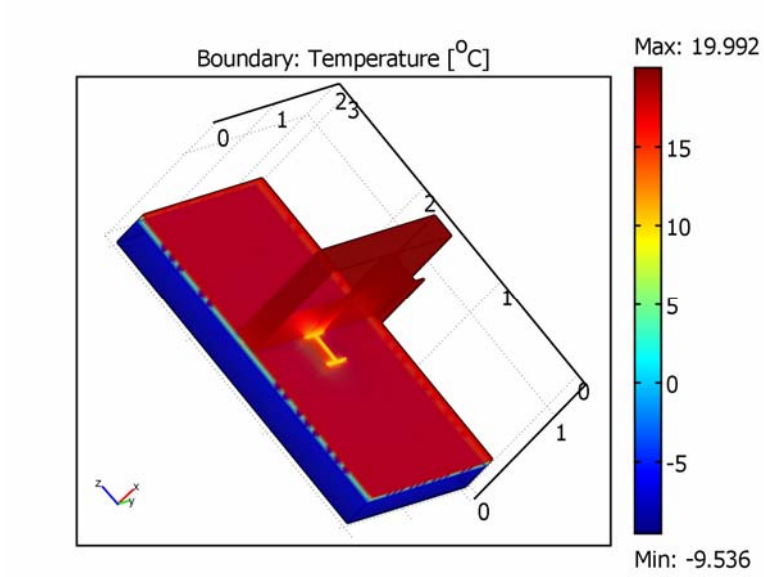




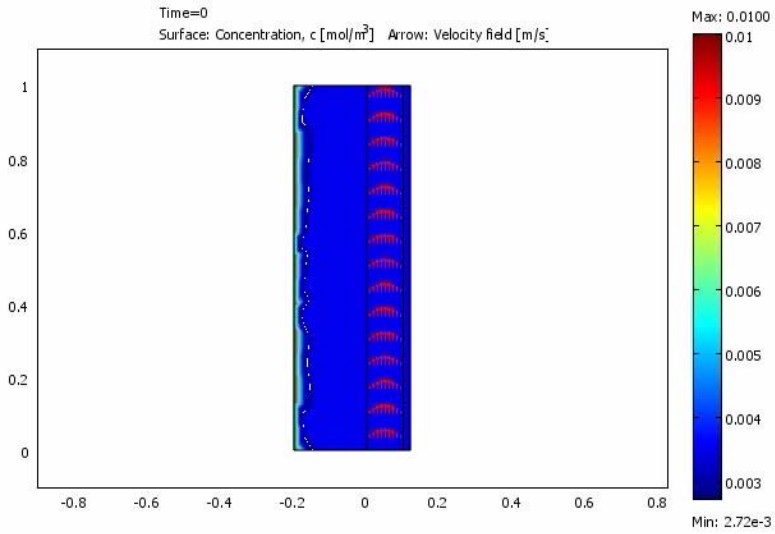
Multiphysics Education

- **Master Course, 2 ECTS**
- **Exemplary results**
- **Course Available at http://sts.bwk.tue.nl/7s532/**

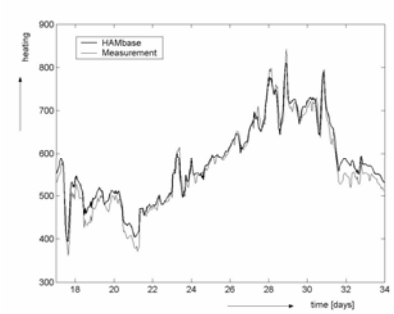
3D thermal

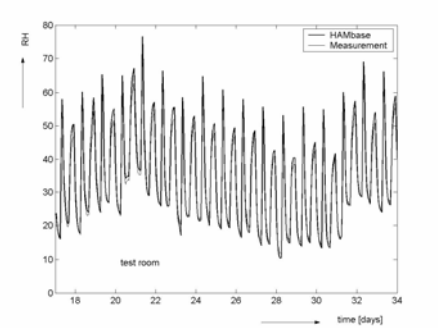


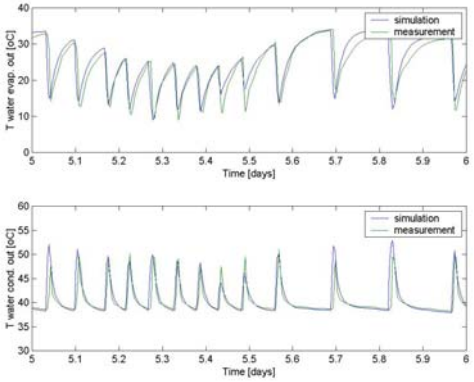
2D heat & air & vapour

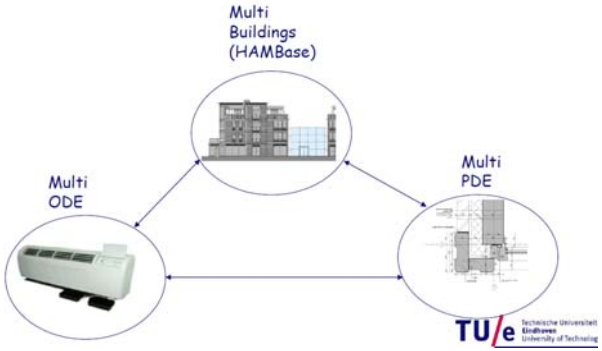


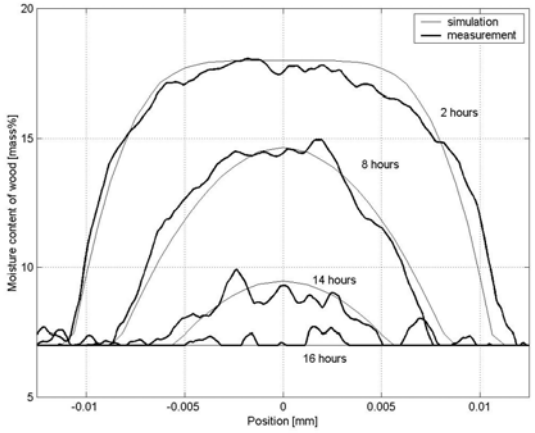
Multiphysics Modeling Validated











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Guidelines FEM Heat and Moisture Modeling
(1) Use LPc as potential

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

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

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

$$C_T = \rho \cdot c$$

$$K_{11} = \lambda$$

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

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

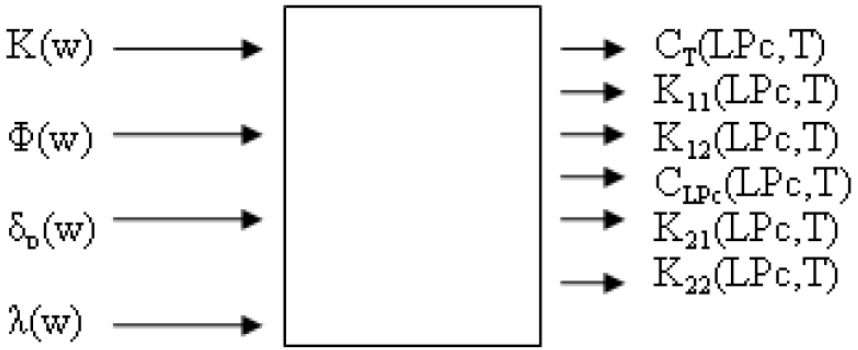
$$K_{22} = -K \cdot \frac{\partial Pc}{\partial LPc} - \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT},$$

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

Material Function in MatLab
(2) Calculate PDE coeffients fun(Lpc,T)

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

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



Material Function in MatLab
(2) Calculate PDE coefficients fun(LPc,T)

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

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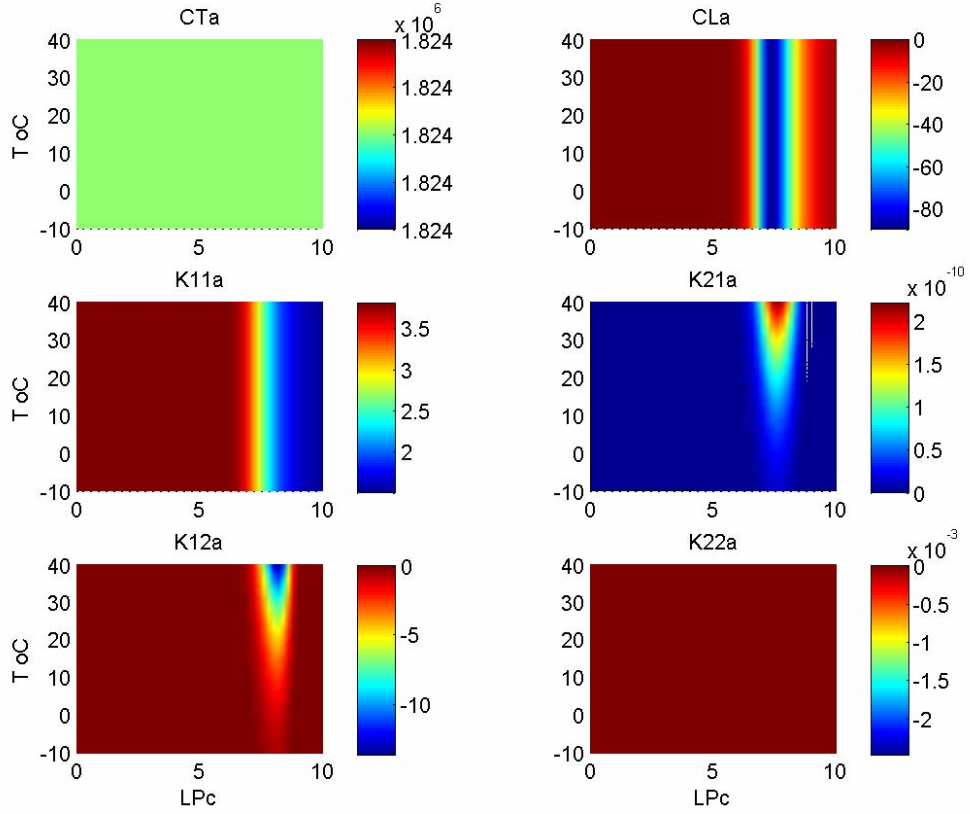
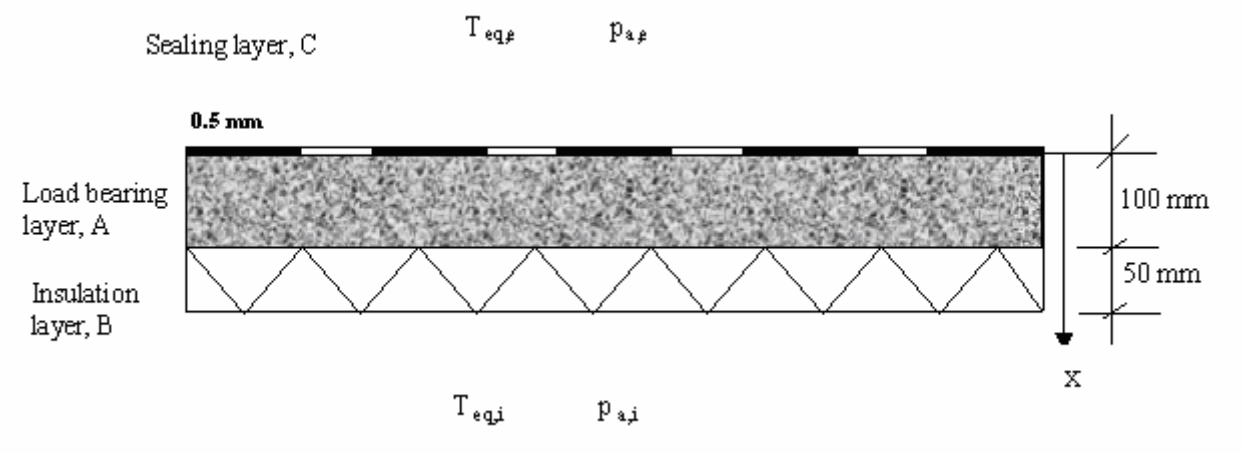


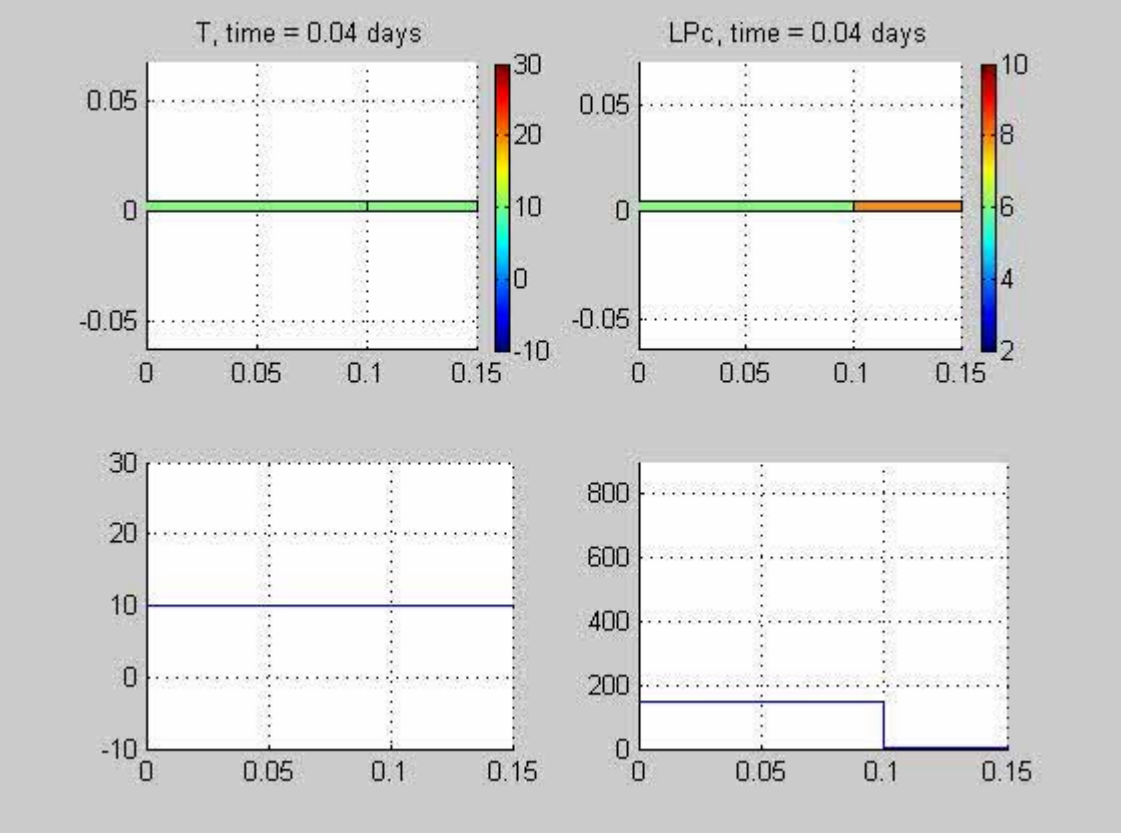
Verification
HAMSTAD Benchmark no 1

$$q = h_e \cdot (T_e - T)$$
$$g = 0$$



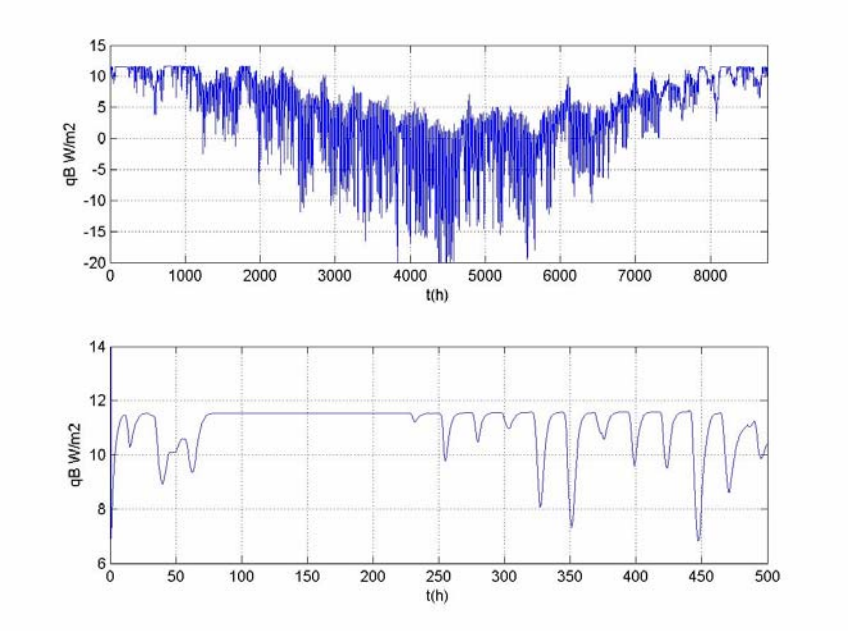
$$q = h_i \cdot (T_i - T) + l_{lv} \cdot \beta \cdot (p_i - p)$$
$$g = \beta \cdot (p_i - p)$$

Verification
Heat & Moisture

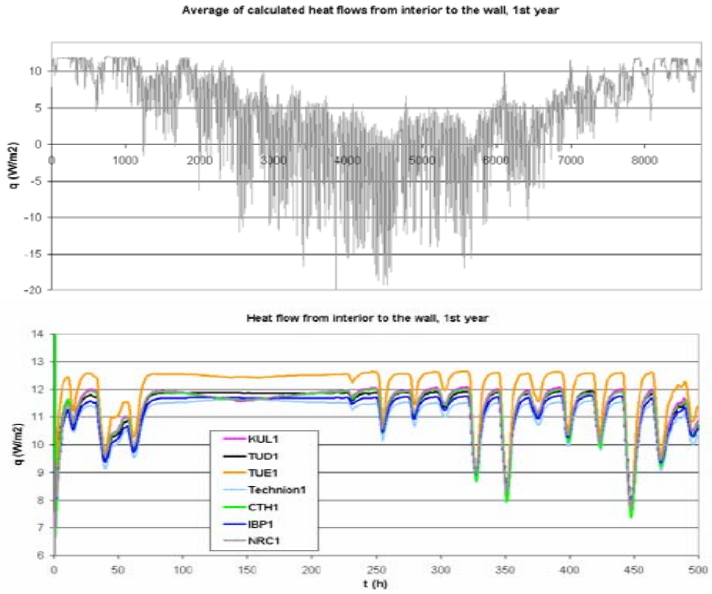


Verification
Heat

COMSOL

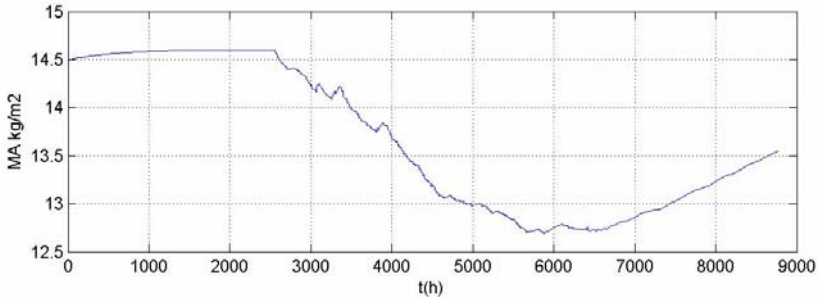


Reference



Verification
Moisture

COMSOL



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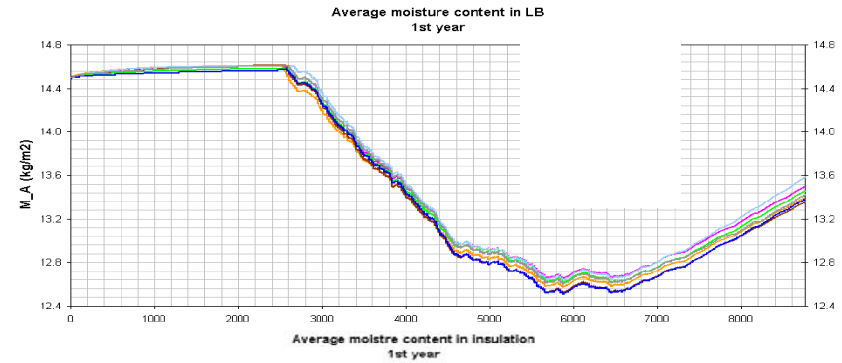
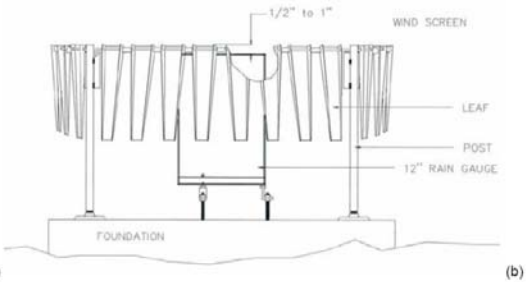


Step 1
Measurements, sensors

(a)



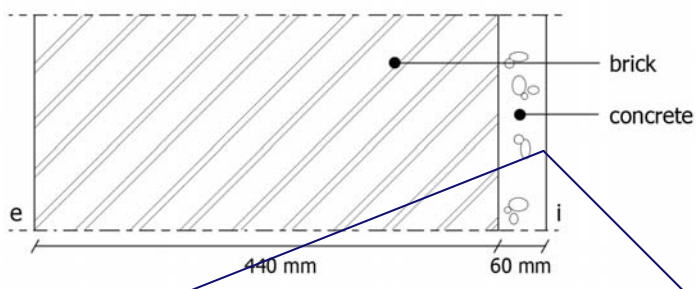
(b)

(a)

(b)

(c)

Step 2: Modeling & Validation
Simulation vs Measurements



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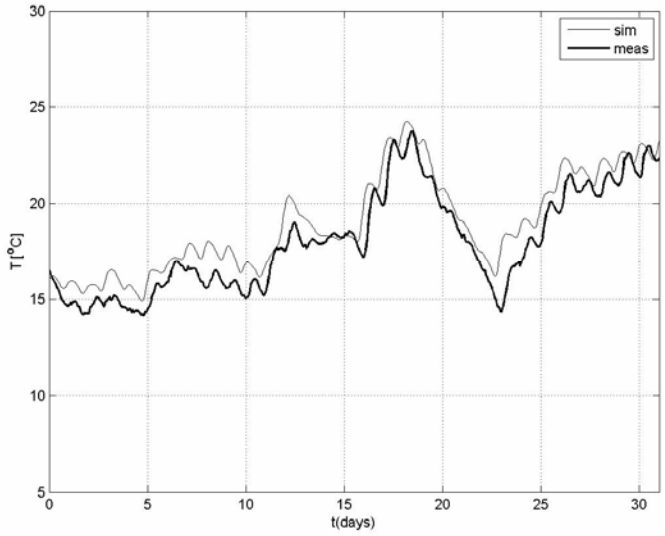
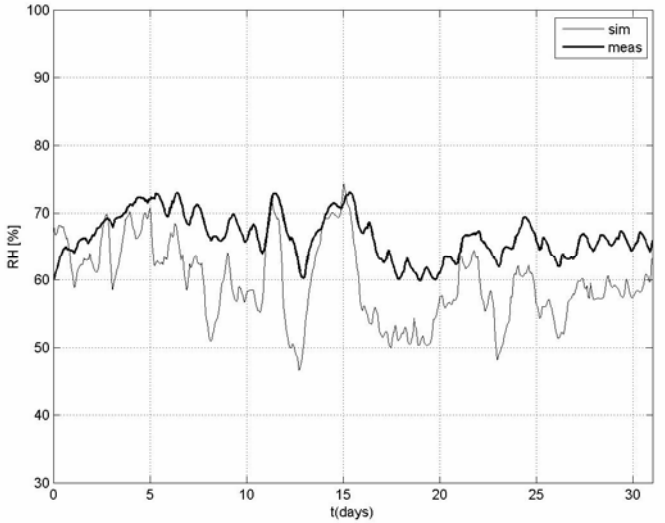


RHi



Step 3: Application of the model

- **Evaluation of the moisture damage**
  - ✓ **Moisture damage not caused by moisture through the construction**
  - ✓ **Moisture damage not caused by condensation at the inside**
  - ✓ **Confirmation of leakages**

- **Evaluation of a new design:**
  - ✓ **Effect of partly removing the concrete**

Conclusion
Multi(building)physics & COMSOL

- COMSOL is a state-of-art Multiphysics modeling tool for doing research in the area of building physics
- High performance on
  - 1,2 & 3D capabilities
  - Grid & solvers techniques
  - Visualisation
  - Flexibility due to PDE abstraction level
- Also a excellent tool for education
- Our models are available at http://sts.bwk.tue.nl/hamlab/

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