Concordia
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Durability and hygrothermal performance of building envelope

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Building, Civil and Environmental Engineering

November 24, 2006
BCBEC seminar, Vancouver

CEBQ

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Content of presentation

1. Large-scale envelope testing
2. Air movement, air leakage and surface coefficient
3. Wood modeling
4. Whole building performance assessment

1.Full scale testing

Simulated rain infiltration

Summer condensation

Stochastic determination of water leakage risks

Using

- leakage due to defects in rain penetration chamber

Patterns of redistribution of water

depending on material surface properties

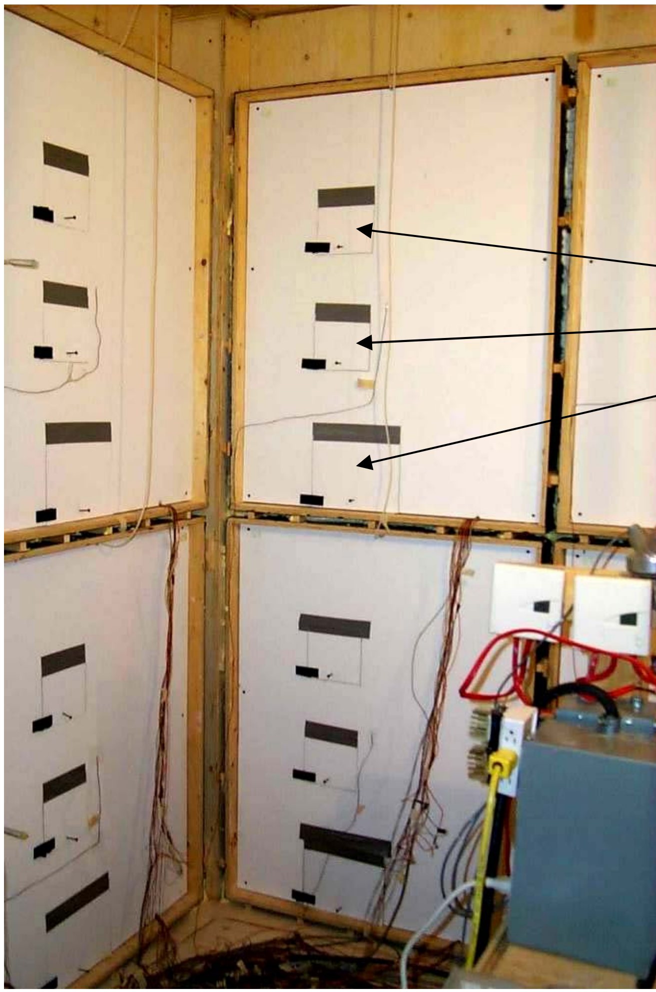
Test 4b wall 3

Large-scale test - Wetting method

Finding ratio of water leakage into windowsill defect

Using weather data to determine
wind-driven rain

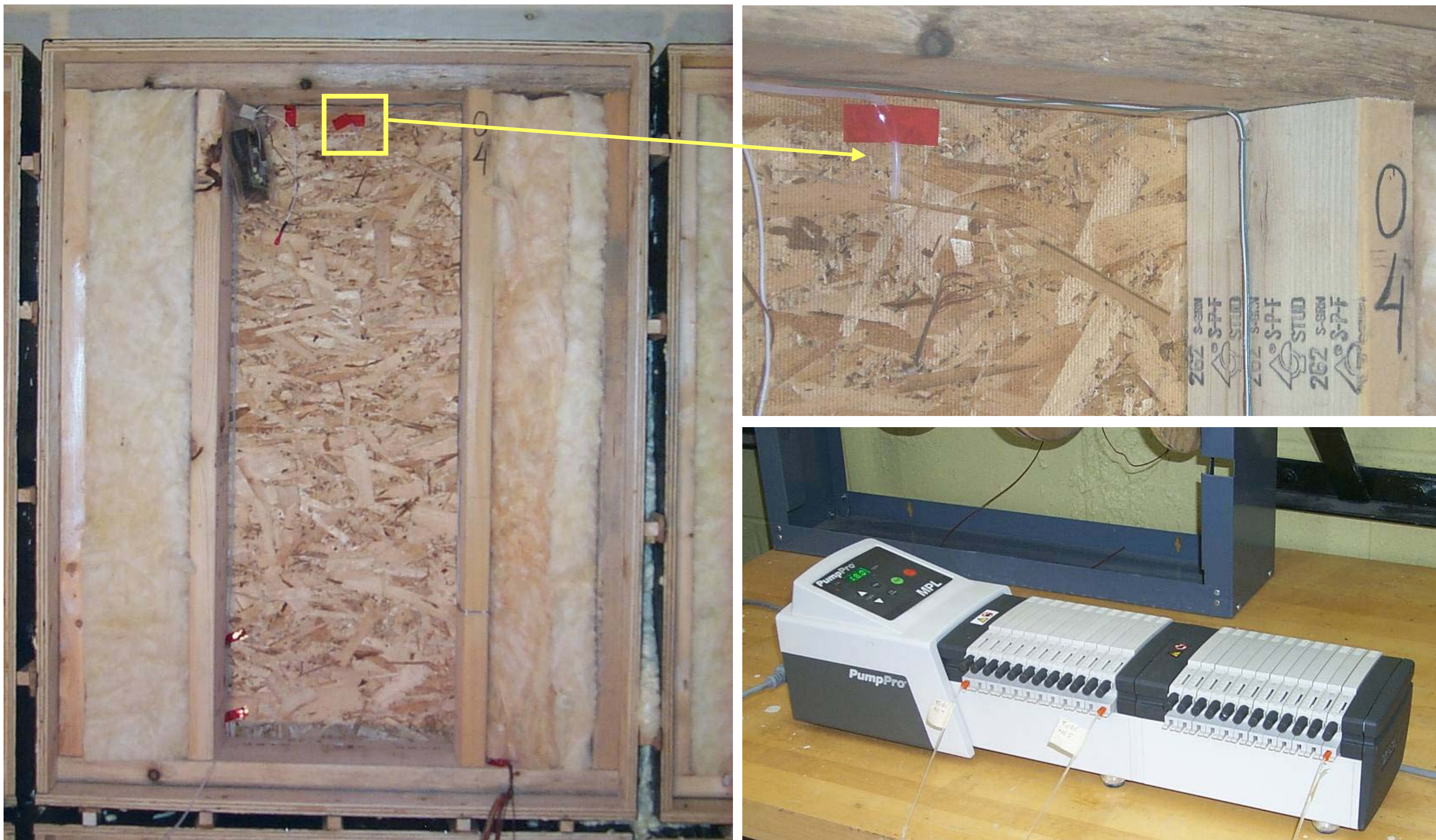
Set up of wall assemblies in the Chamber



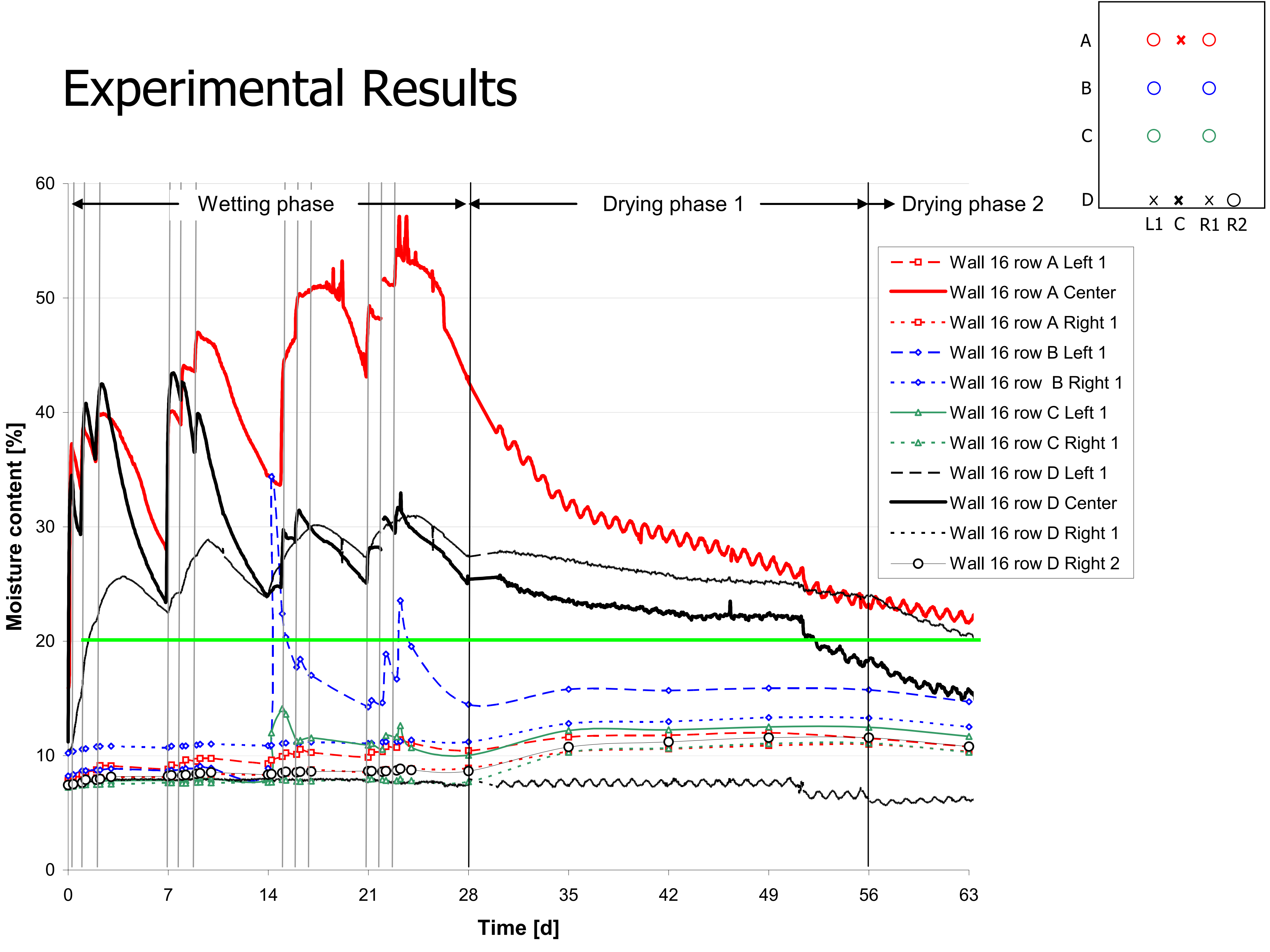
Gypsum access panels
for gravimetry

Wetting

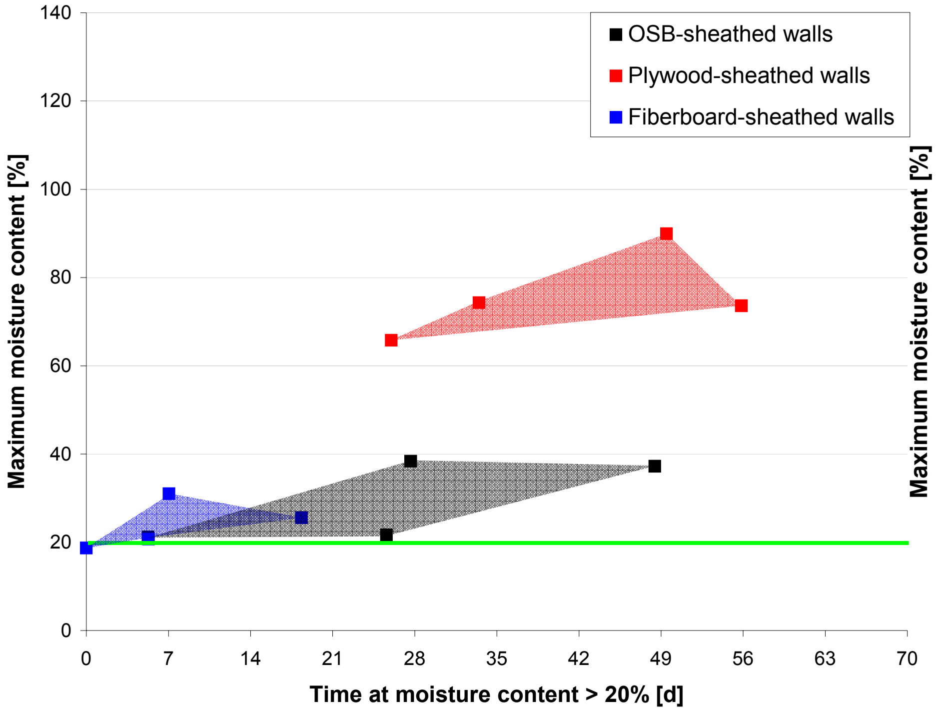
Method of rainwater insertion



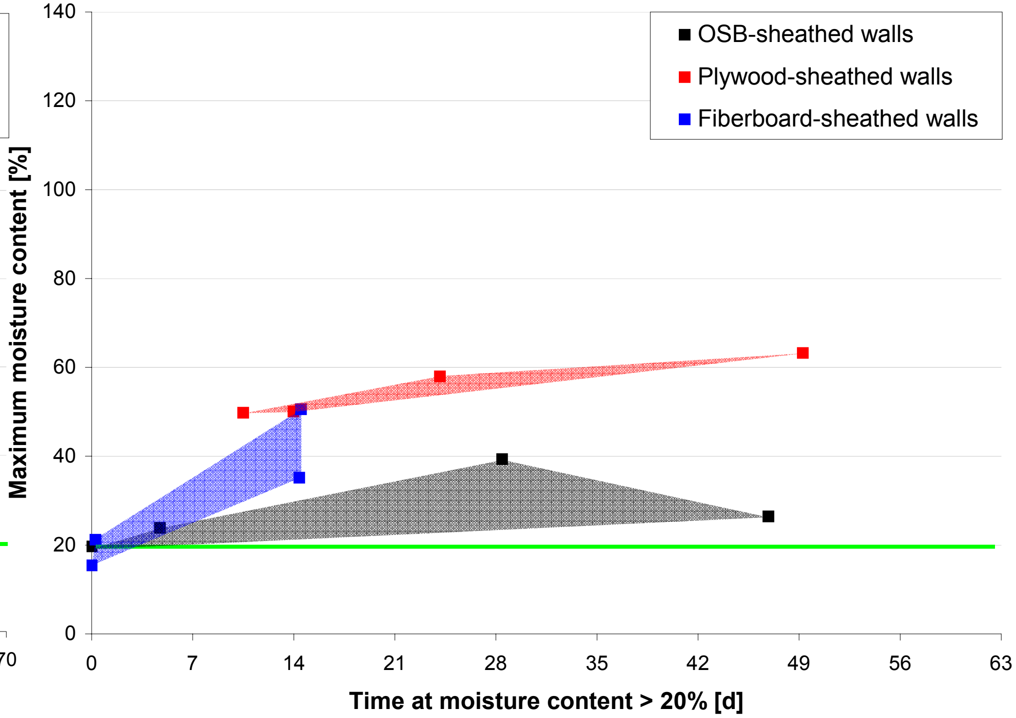
Experimental Results



Experimental Results – Sheathing

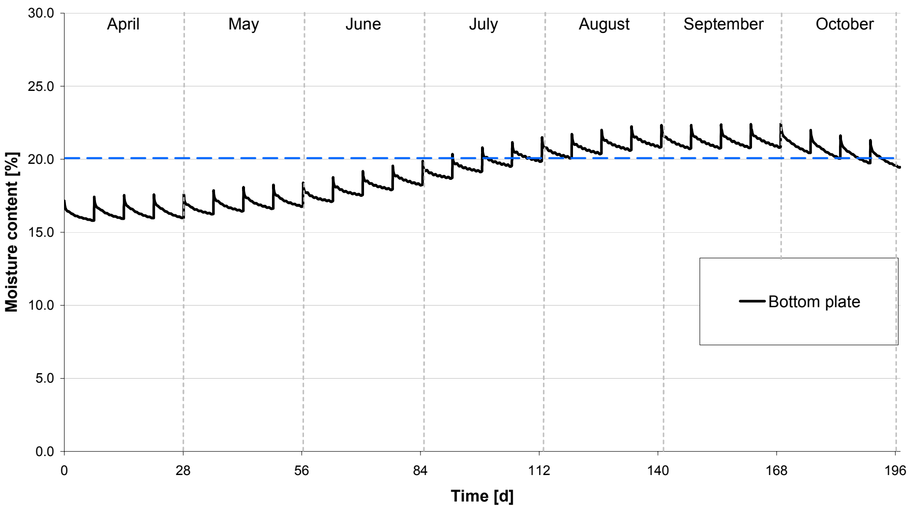


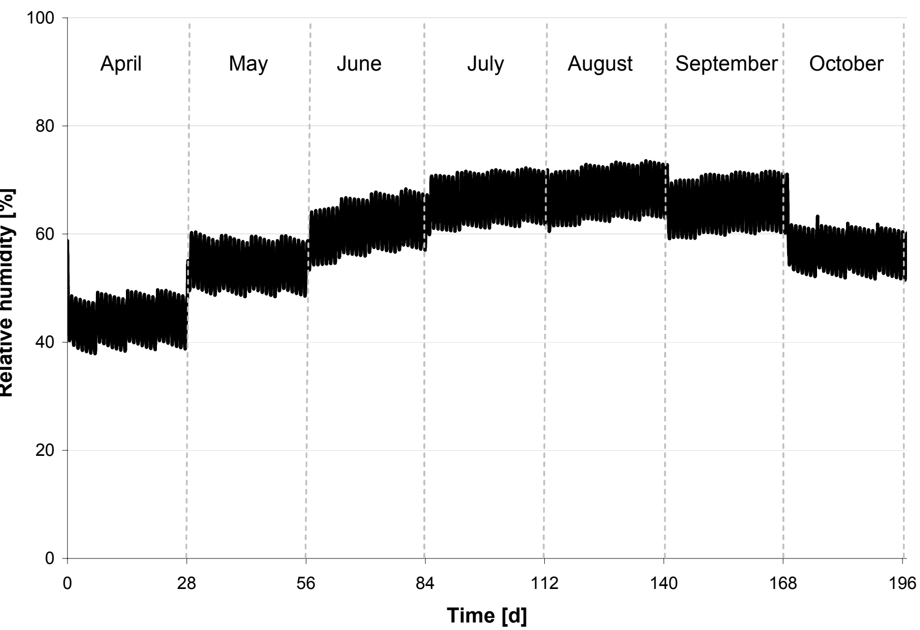
Test 1

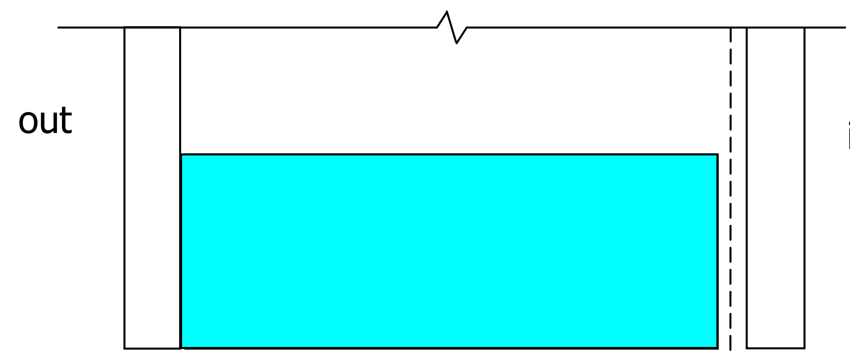


Test 2

Parametric analyses – loading duration







Global M in the bottom plate

Month	Interior p_v [Pa]	Exterior p_v [Pa]
April	995	539-604
May	1070	945-953
June	1461	1391-1463
July	1827	1600-1682
August	1827	1552-1680
September	1070	1142-1333
November	995	794-854

On-going test

Full height walls

Climate of

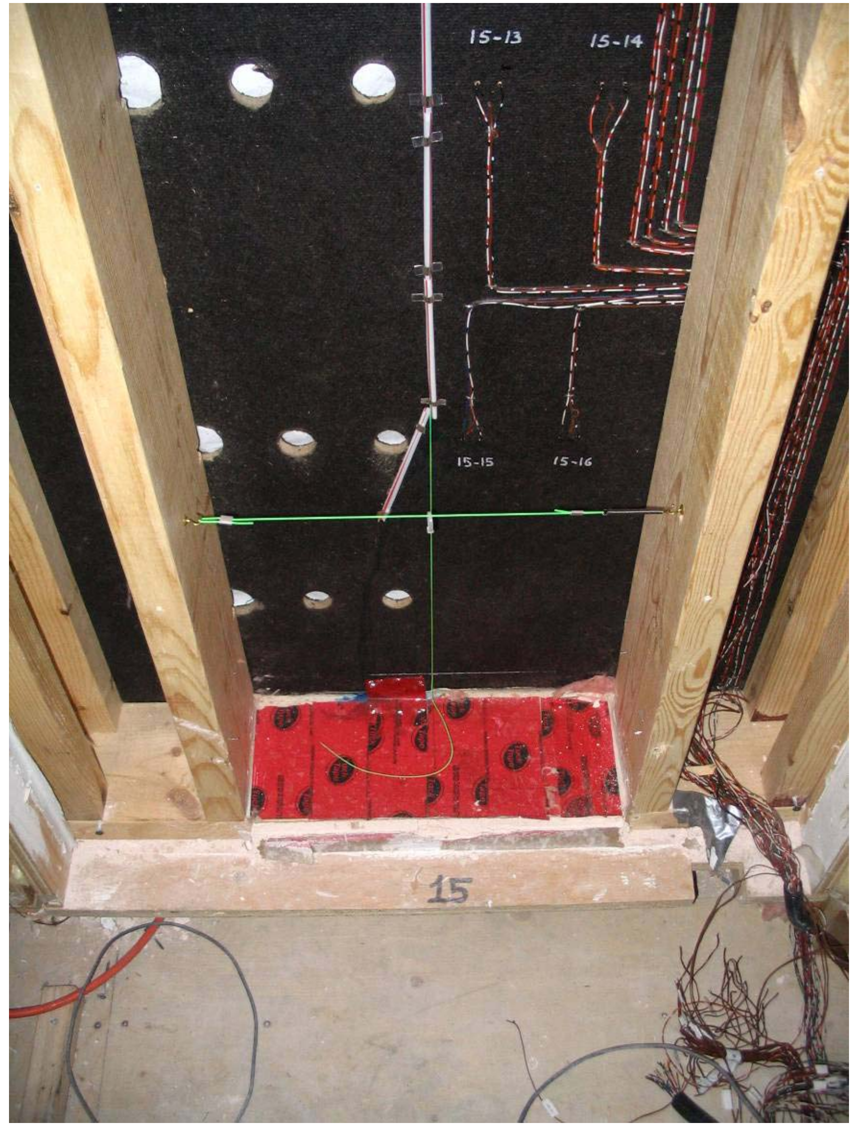
- august
- september
- october
- november

More control of water dripping pattern

Monitoring of moisture content gradient

plywood

OSB



fiber board

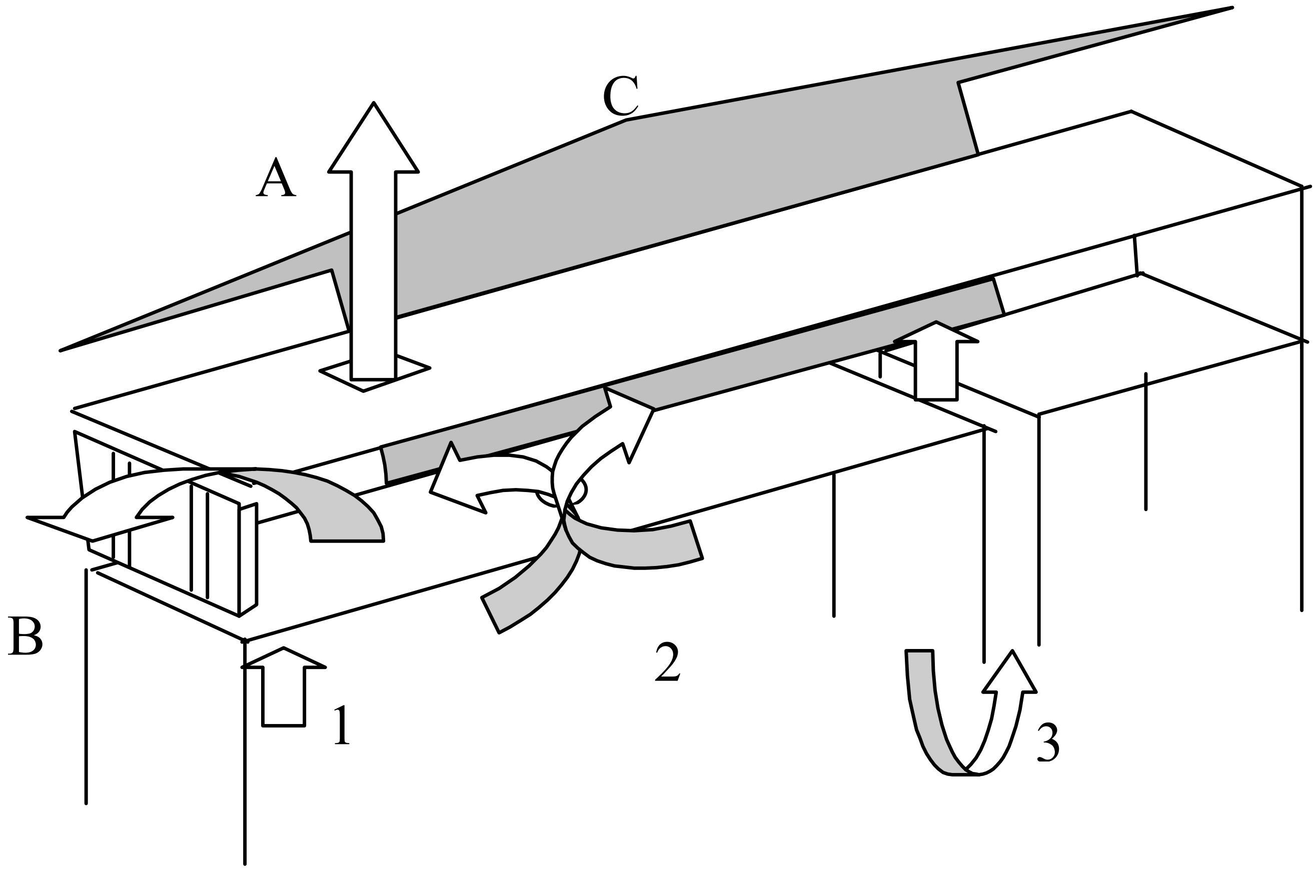
2. Role of air movement

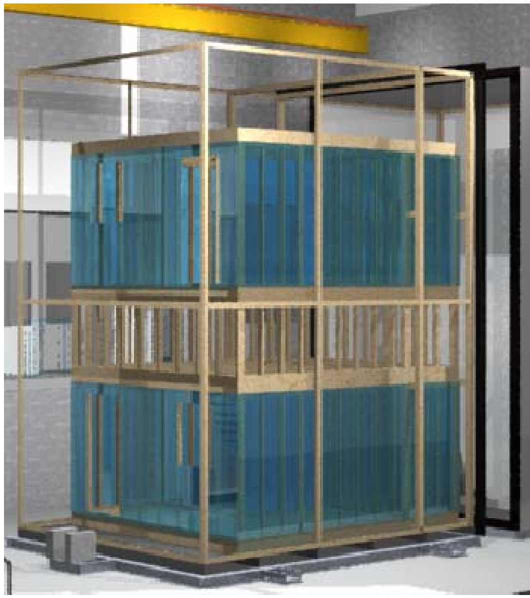
Air movement

Surface coefficients

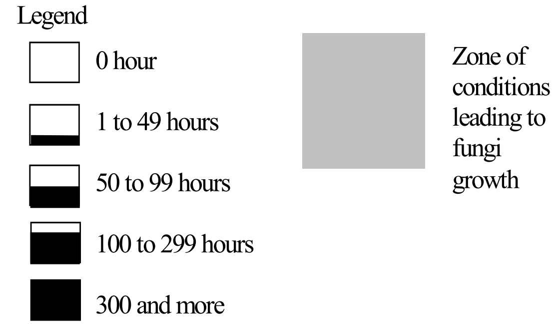
Material-air interaction

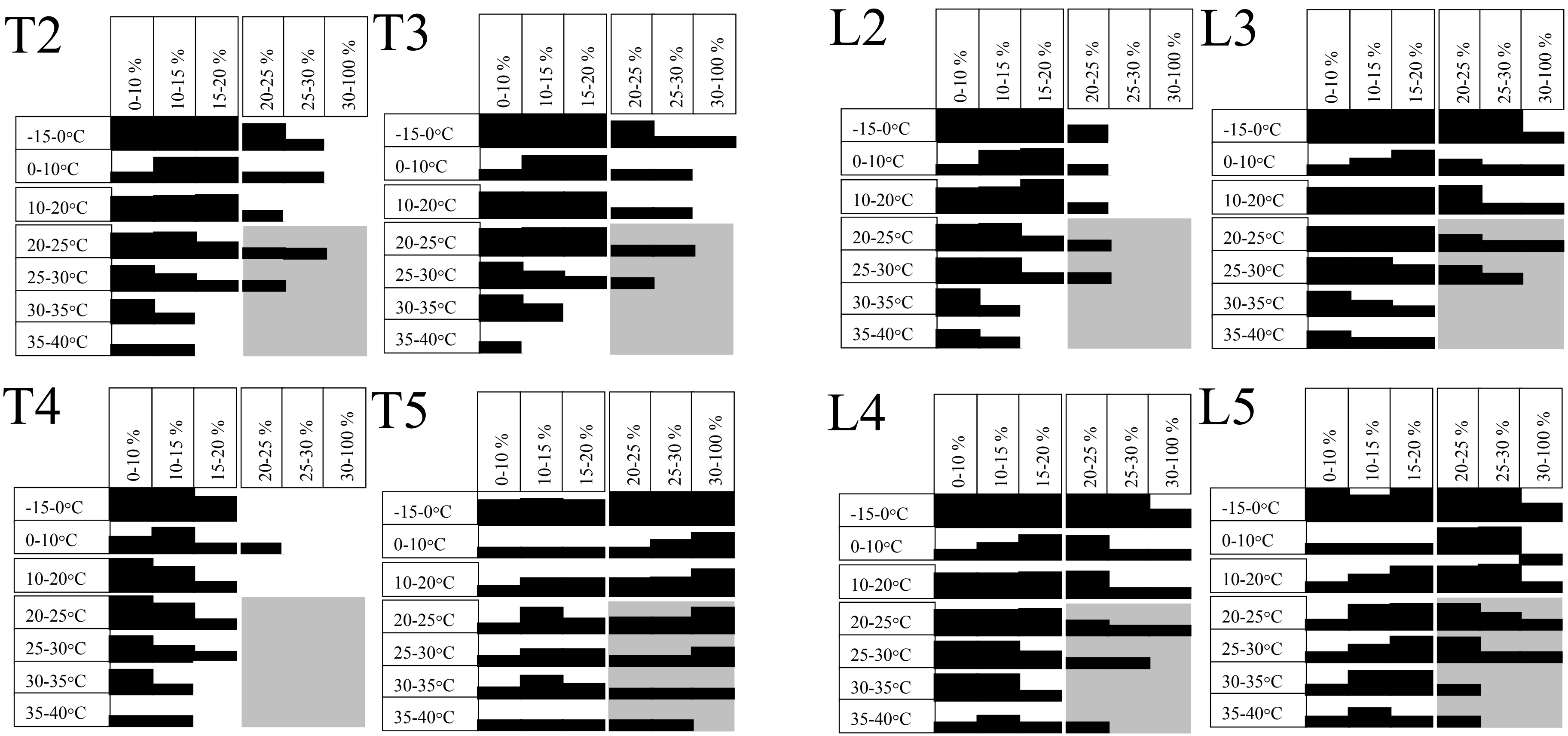
Testing of flat roofs insulated with cellulose fiber with different air leakage paths





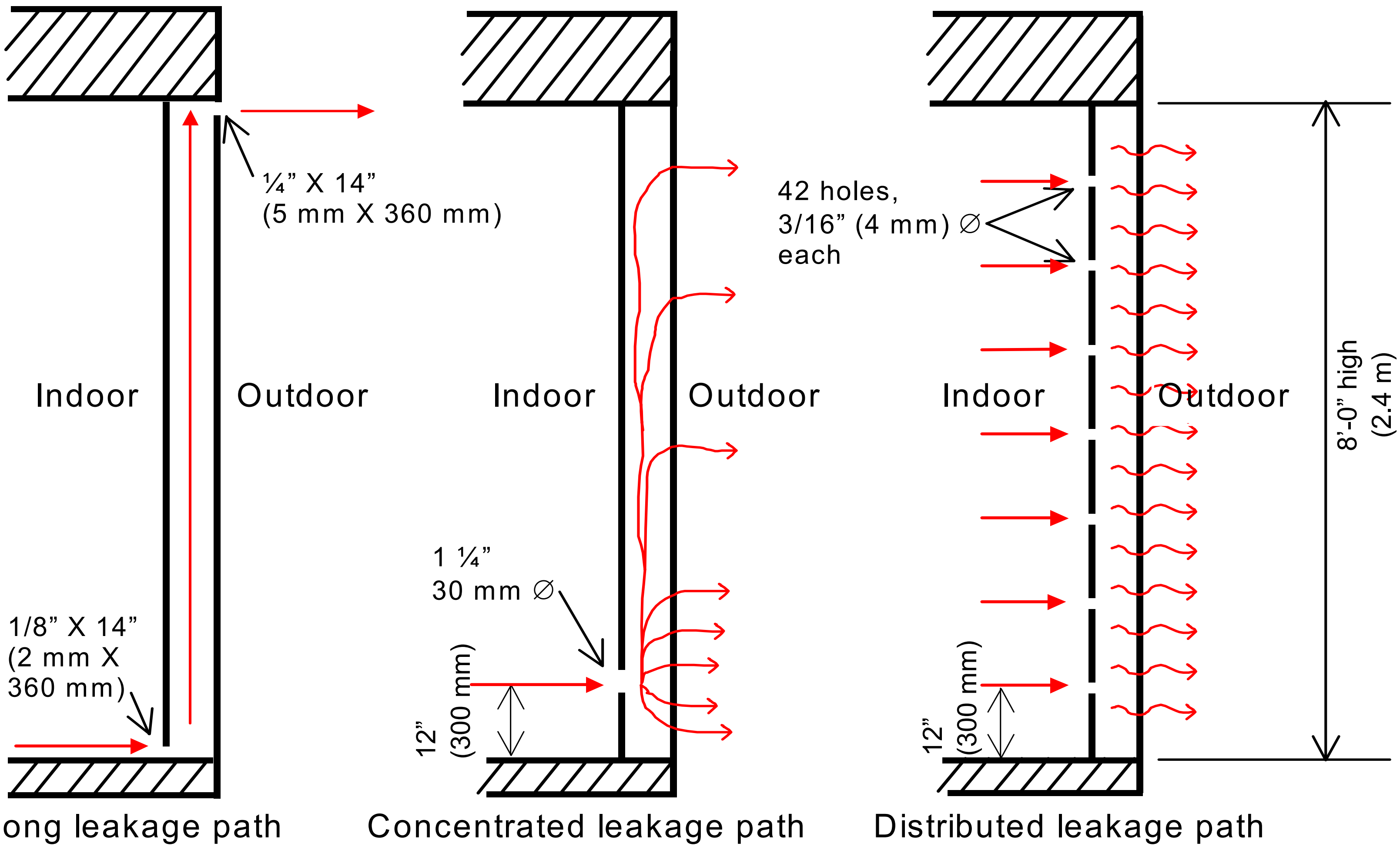
Results



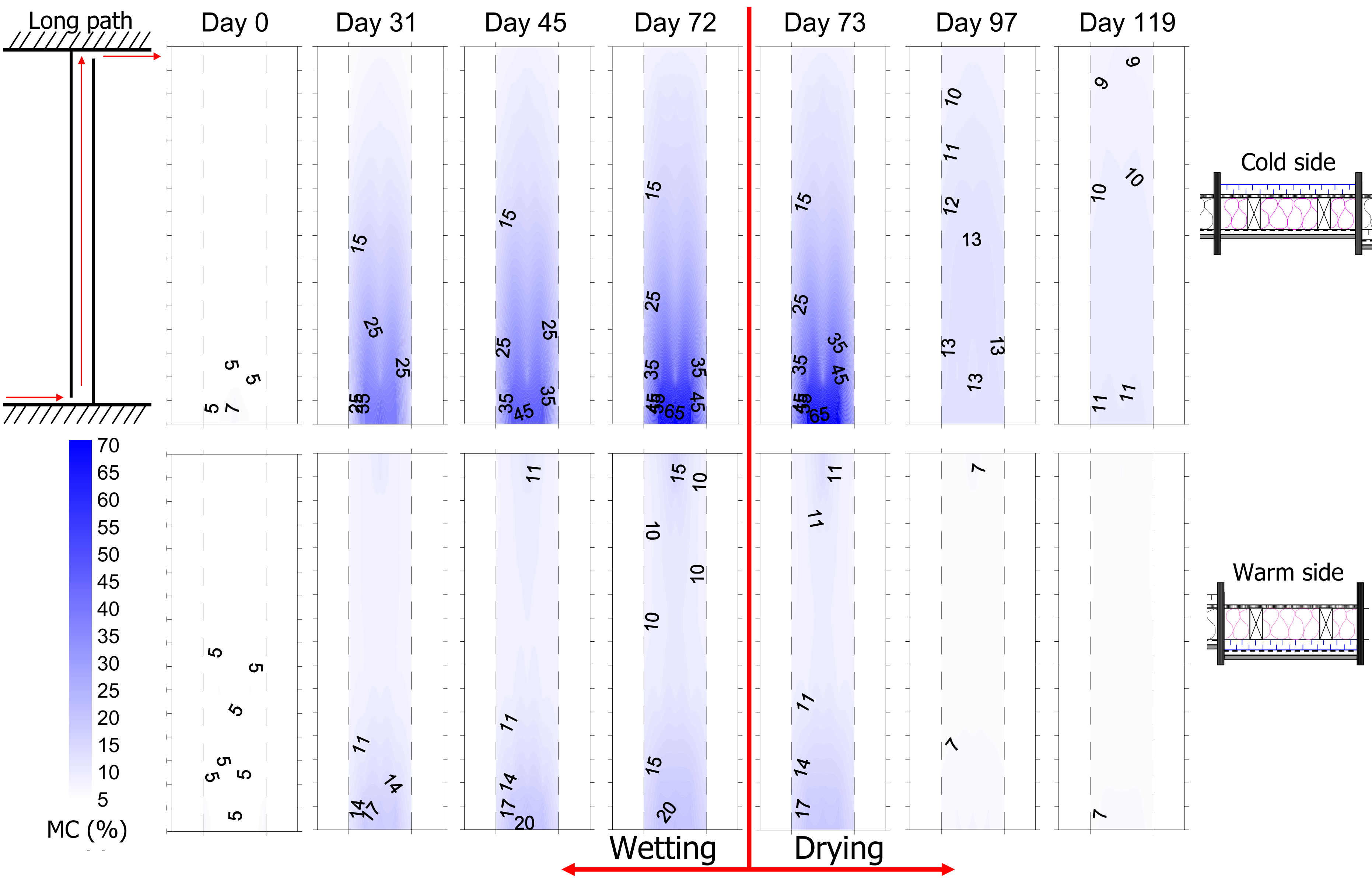


Exposure in hours for all cavities to moisture and temperature

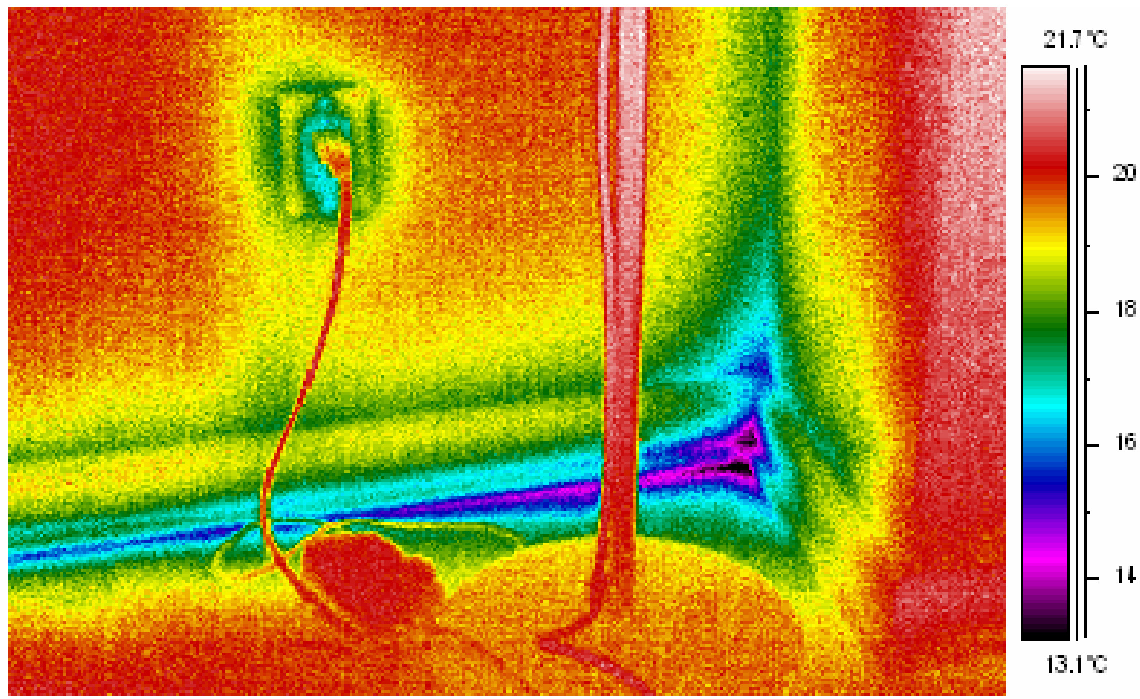
Moisture Performance of Leaky Exterior Walls with Added Insulation
Air leakage configurations



Results - isohygrons

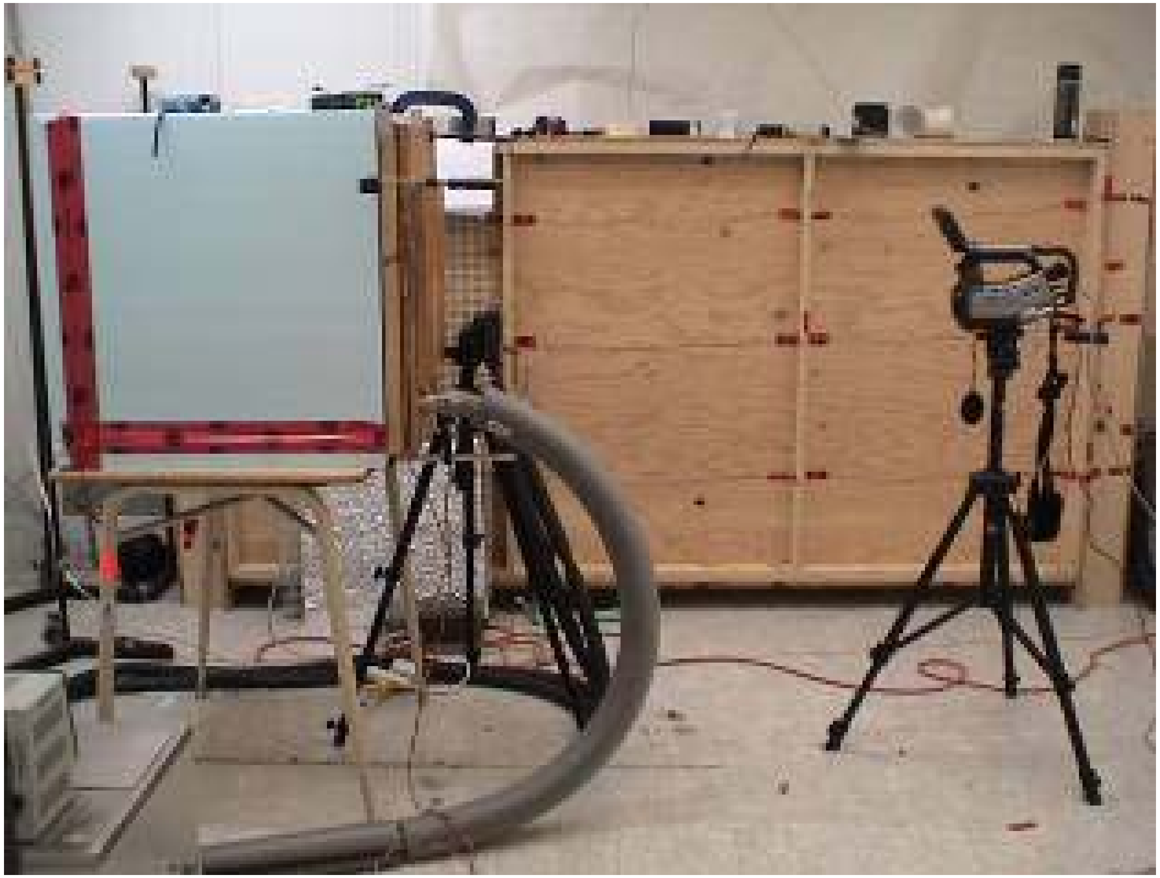


Modeling and experimental work towards quantification of air leaks through the building envelope



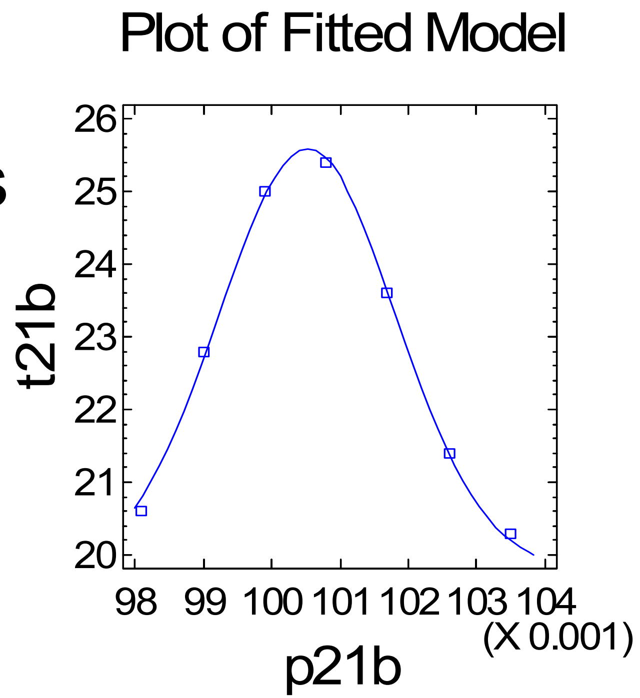
mbd5 Standards methods have been developed to find the precise locations of air leakage using infrared thermography.
marianne bérubé, 9/26/2006

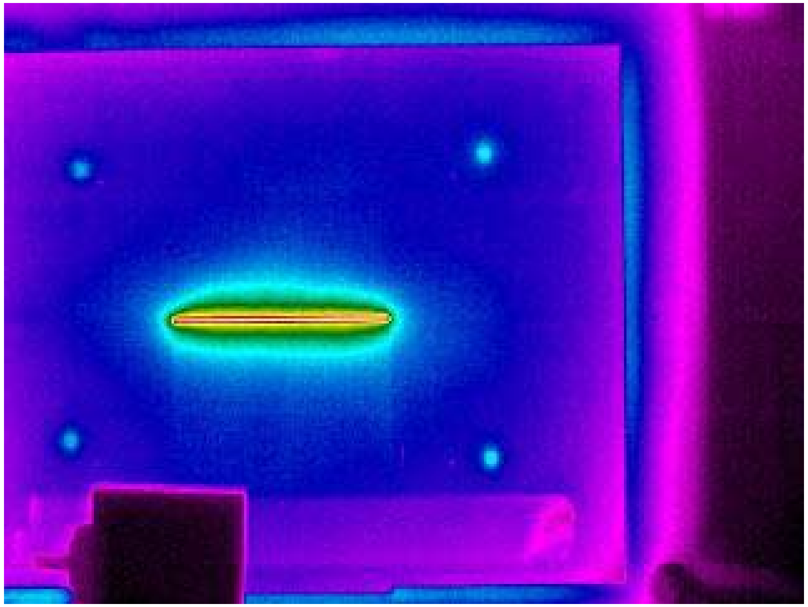
Modeling and experimental work towards quantification of air leaks through the building envelope

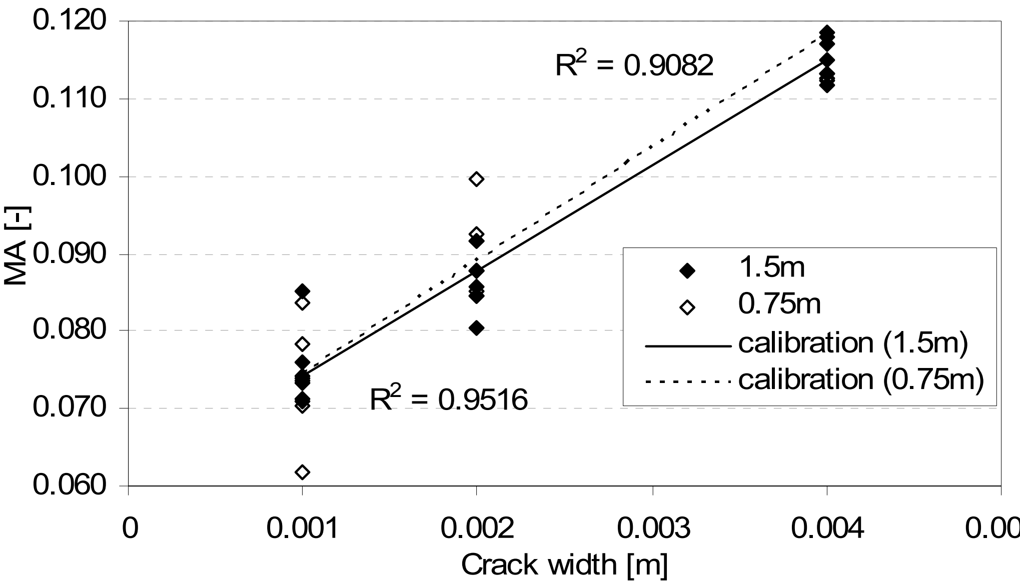


mbd6 Standards methods have been developed to find the precise locations of air leakage using infrared thermography.
marianne bérubé, 9/26/2006

Modeling and experimental work towards quantification of air leaks through the building envelope







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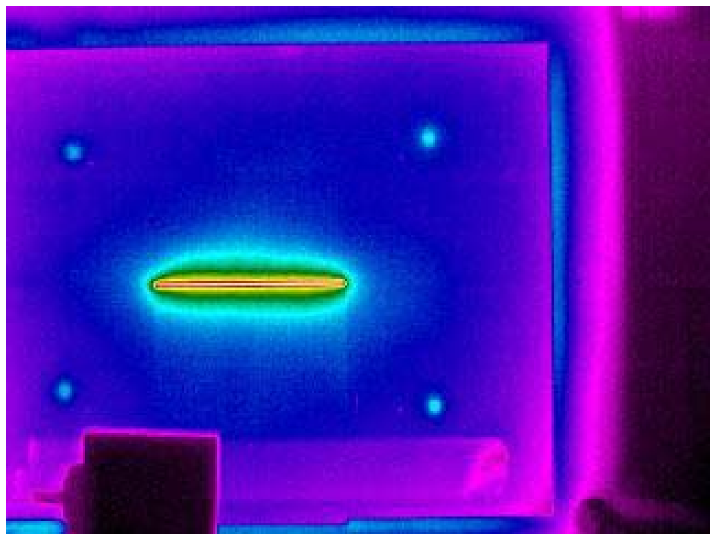
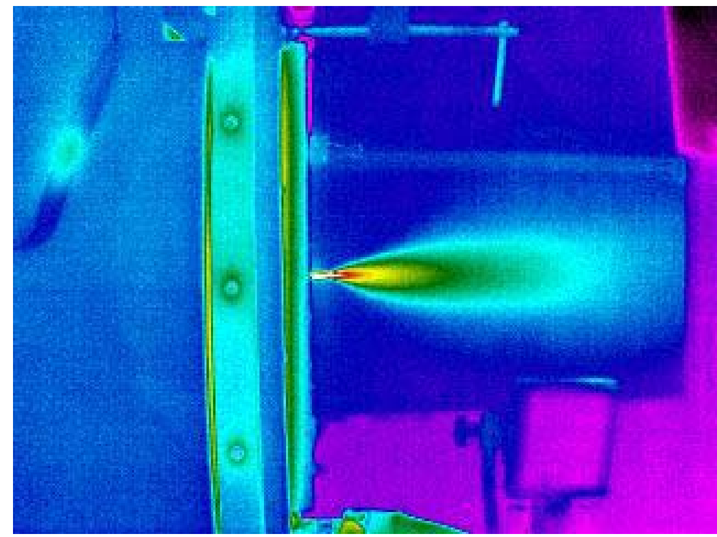
mbd7 Standards methods have been developed to find the precise locations of air leakage using infrared thermography.
marianne bérubé, 9/26/2006

Stochastic determination of air leakage paths and related risks

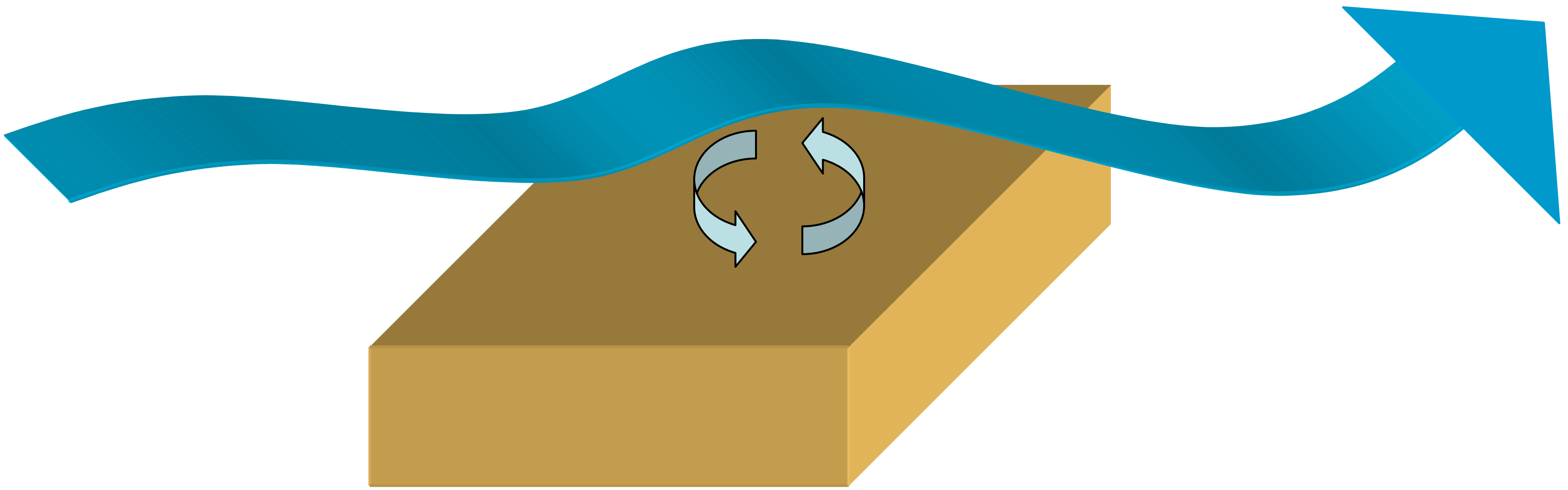
Using

- Infrared thermography
- PIV
- CFD





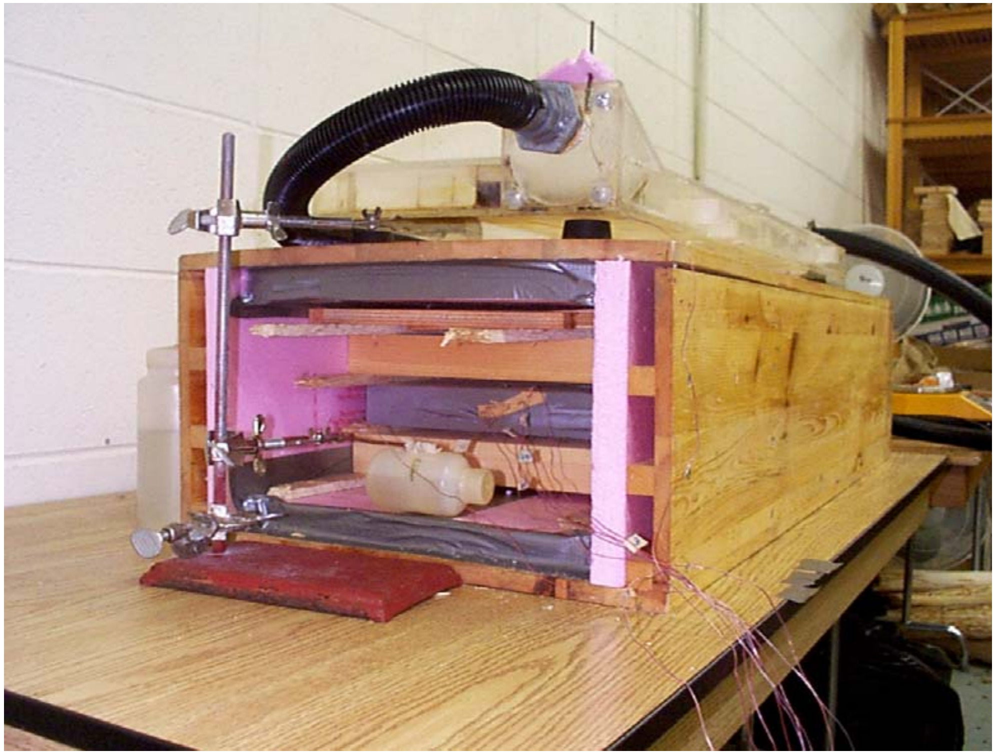
Required for modeling,
determination of surface coefficients
for heat and mass transport



Determination of surface coefficients for heat and mass transport

Using

- laminar flow tunnel measurements
- microtome

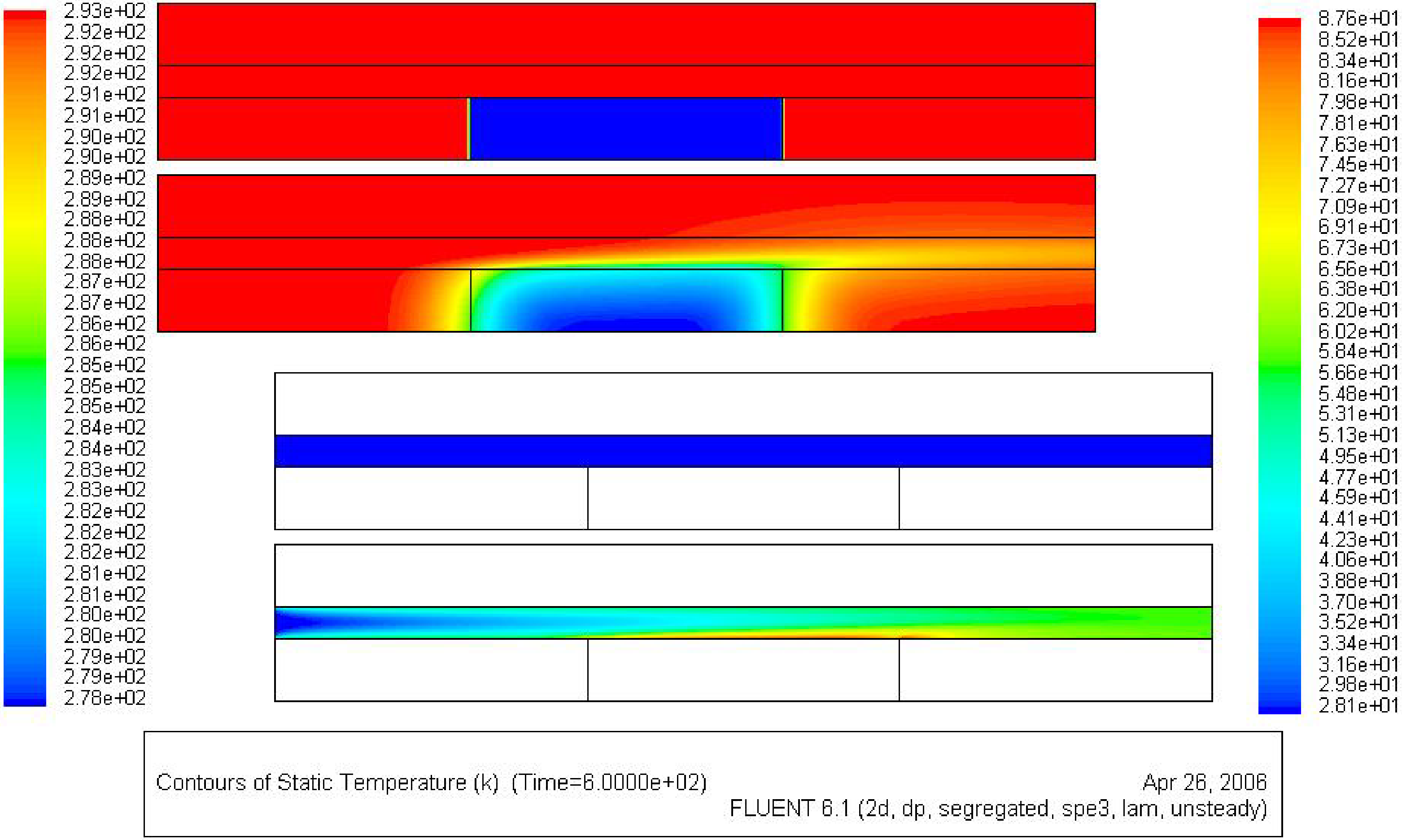


Determination of convective transfer coefficients as a function of moisture content, surface roughness, air velocity

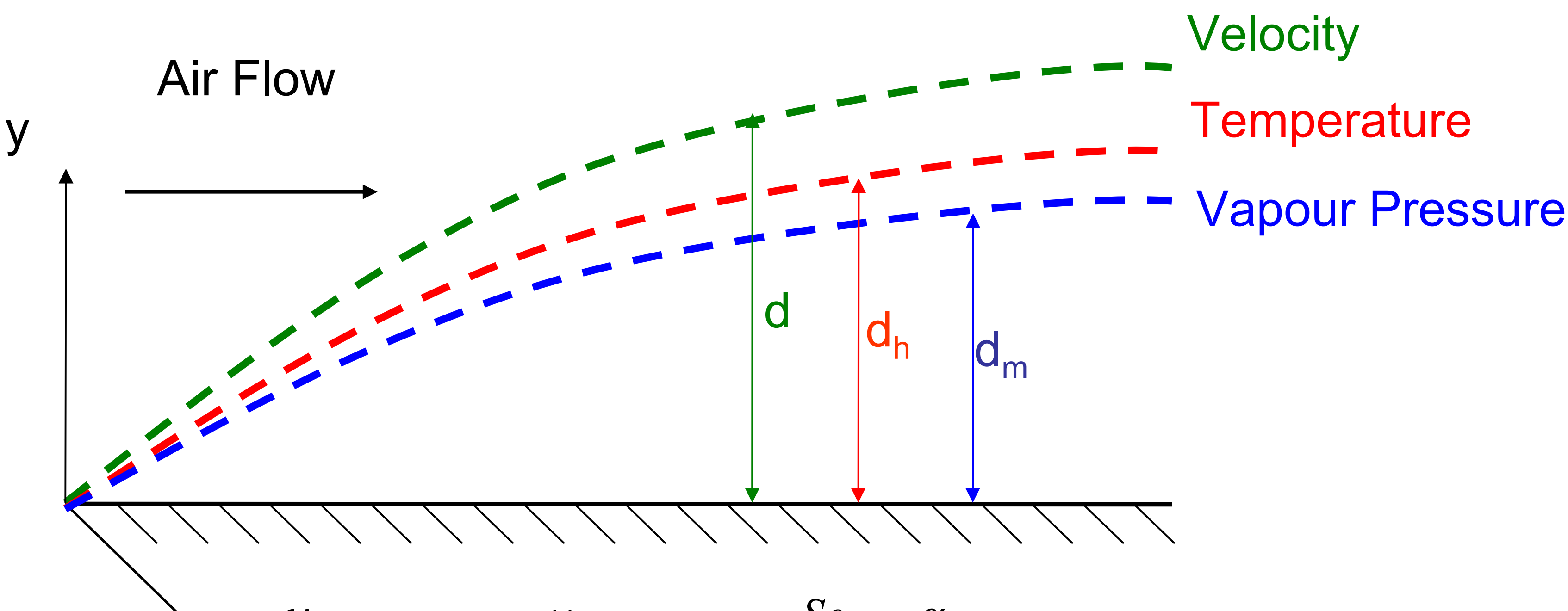
Determination of surface coefficients for heat and mass transport

Using

- CFD



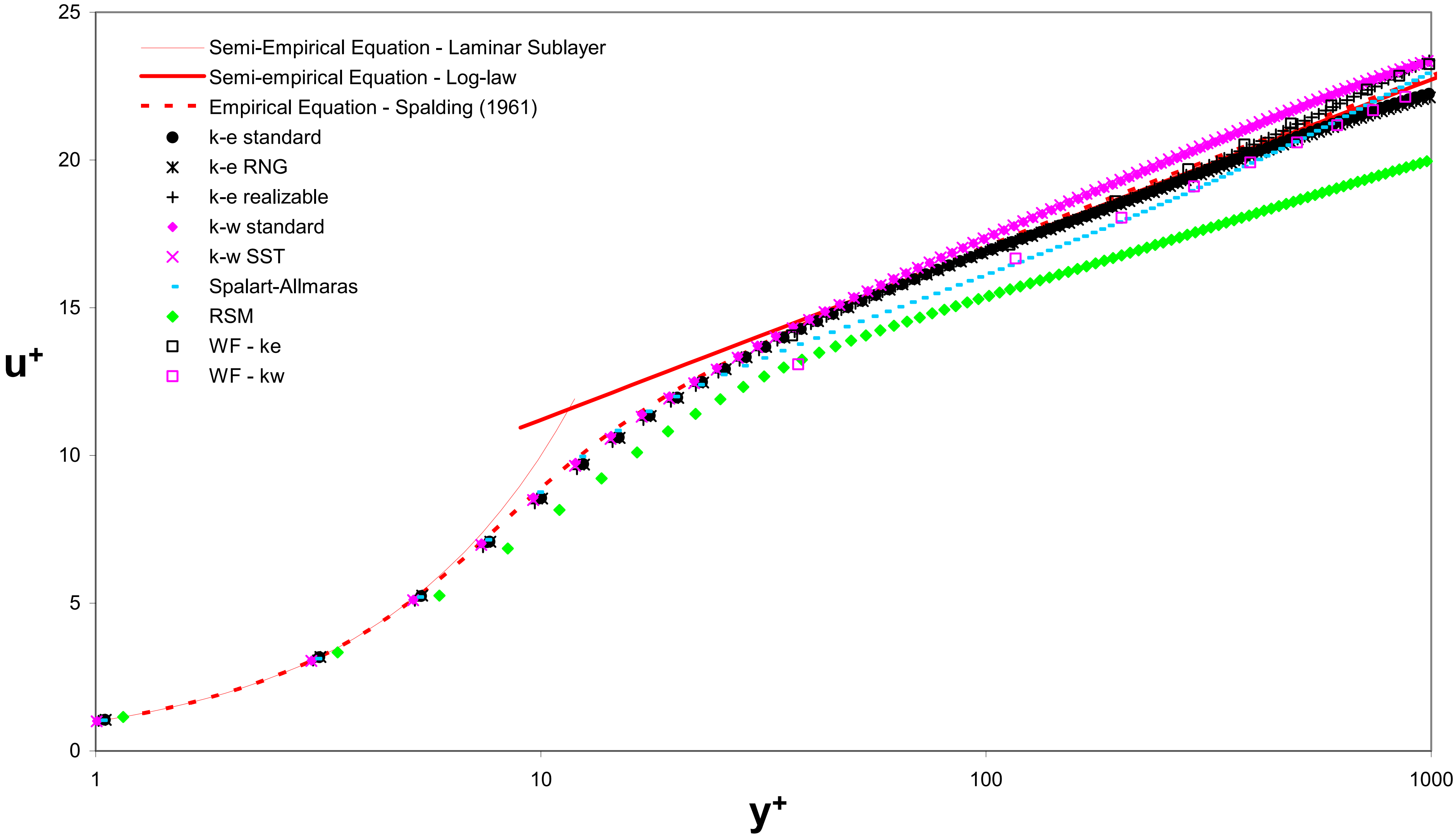
Determination of Surface Coefficients with CFD



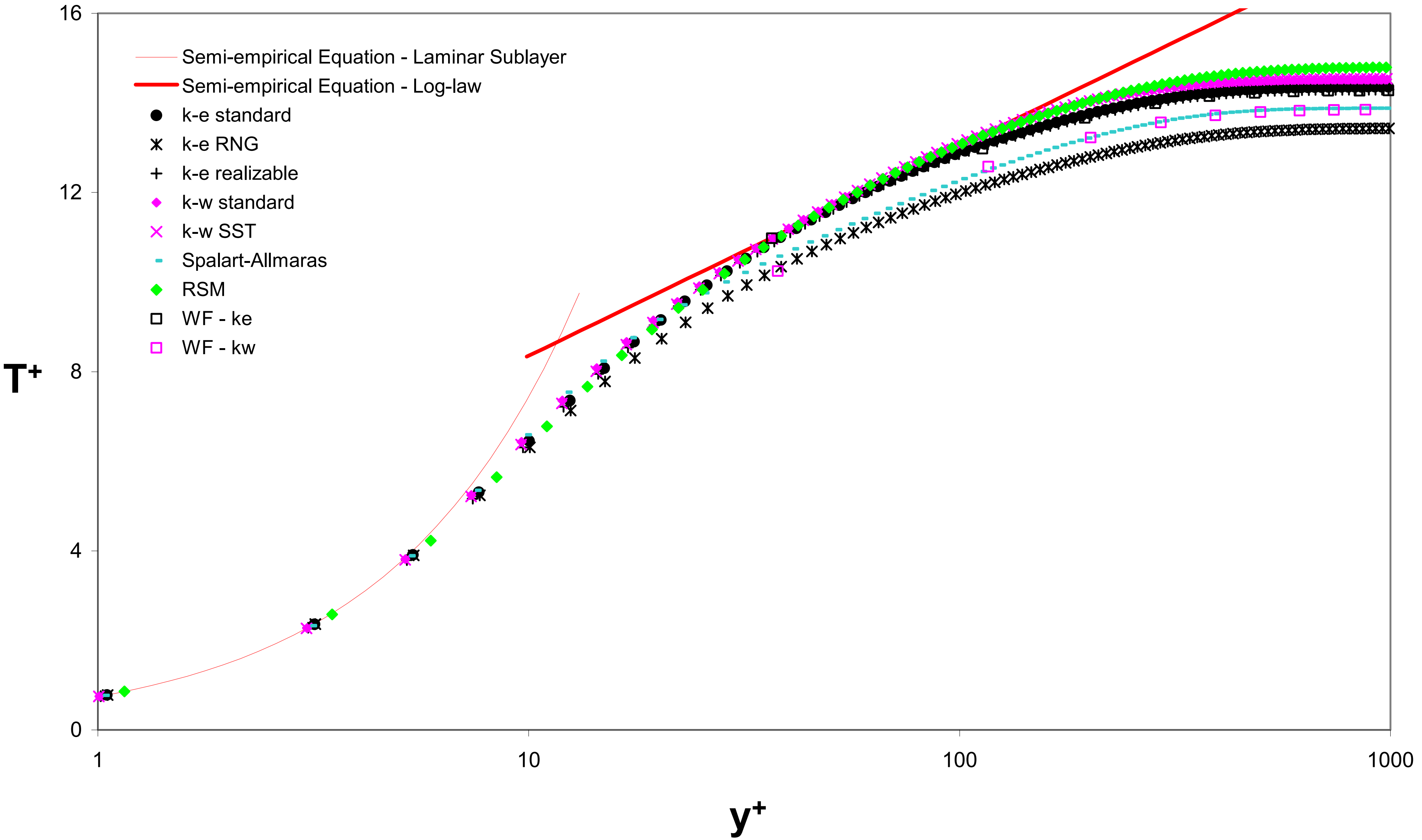
$$Pr \equiv \frac{\nu}{\alpha} \qquad Sc \equiv \frac{\nu}{D_{eff}} \qquad Le \equiv \frac{Sc}{Pr} \equiv \frac{\alpha}{D_{eff}}$$

Chilton-Colburn Analogy: $$h_m = \frac{h_c}{\rho c_p Le^{2/3}}$$

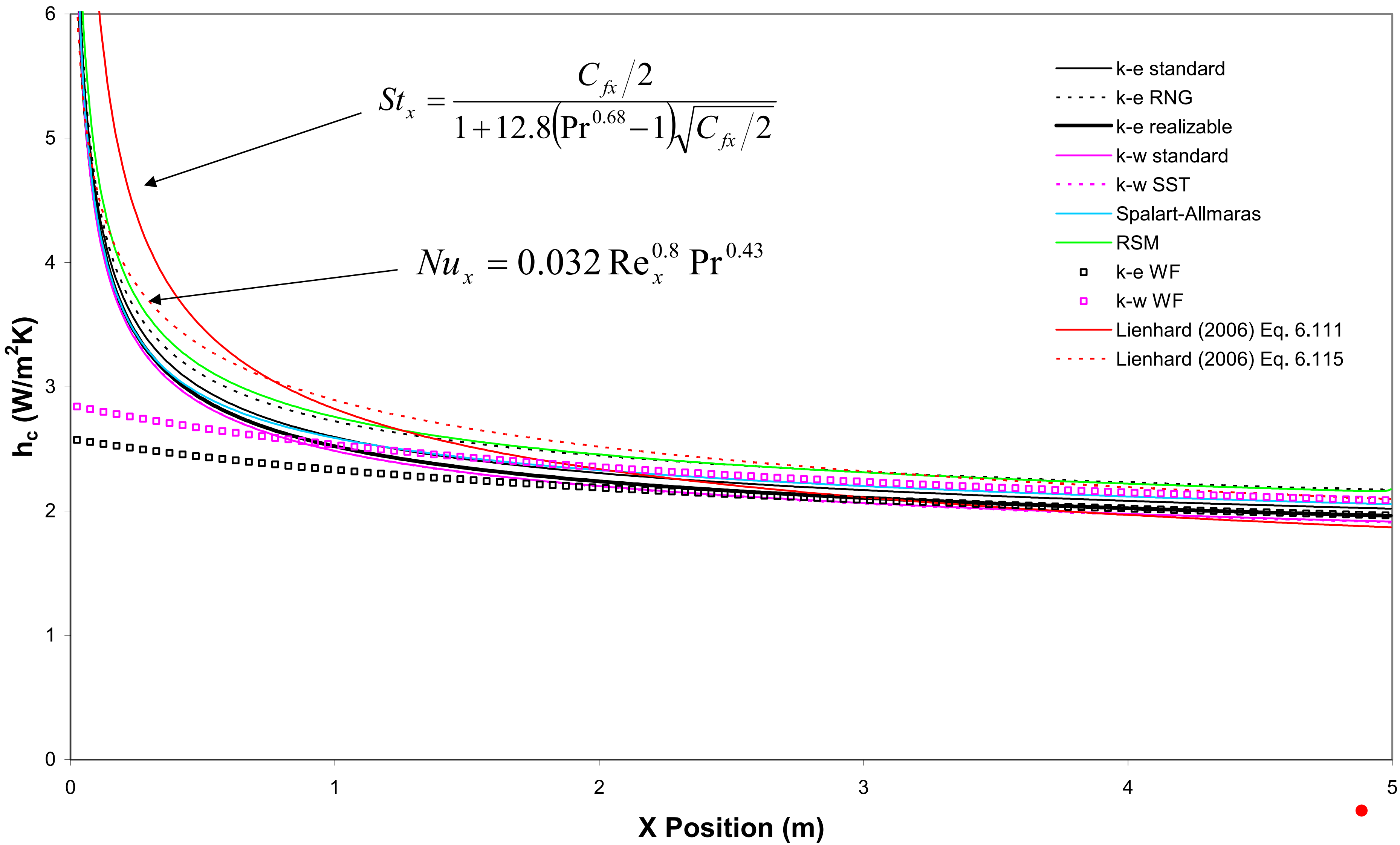
Velocity Boundary Layer Results



Temperature Boundary Layer Results



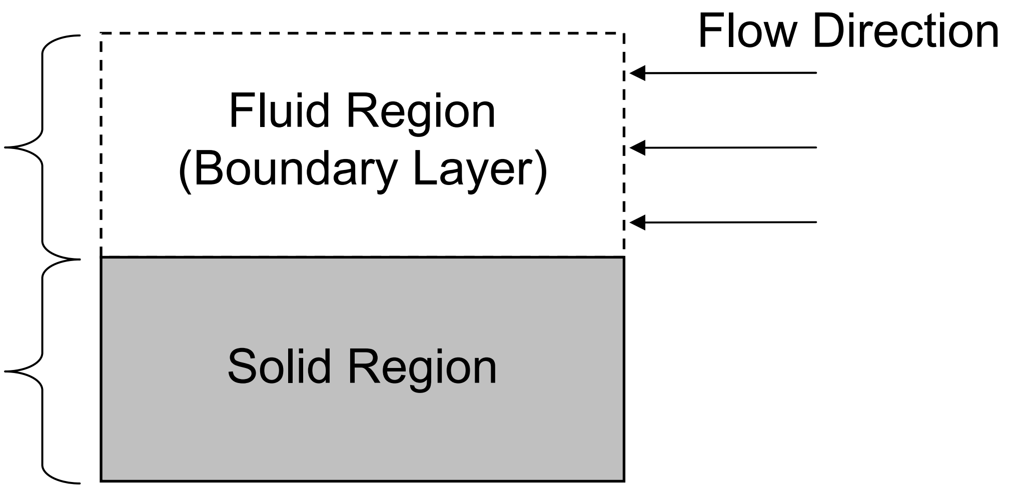
Convective Heat Transfer Coefficient Results



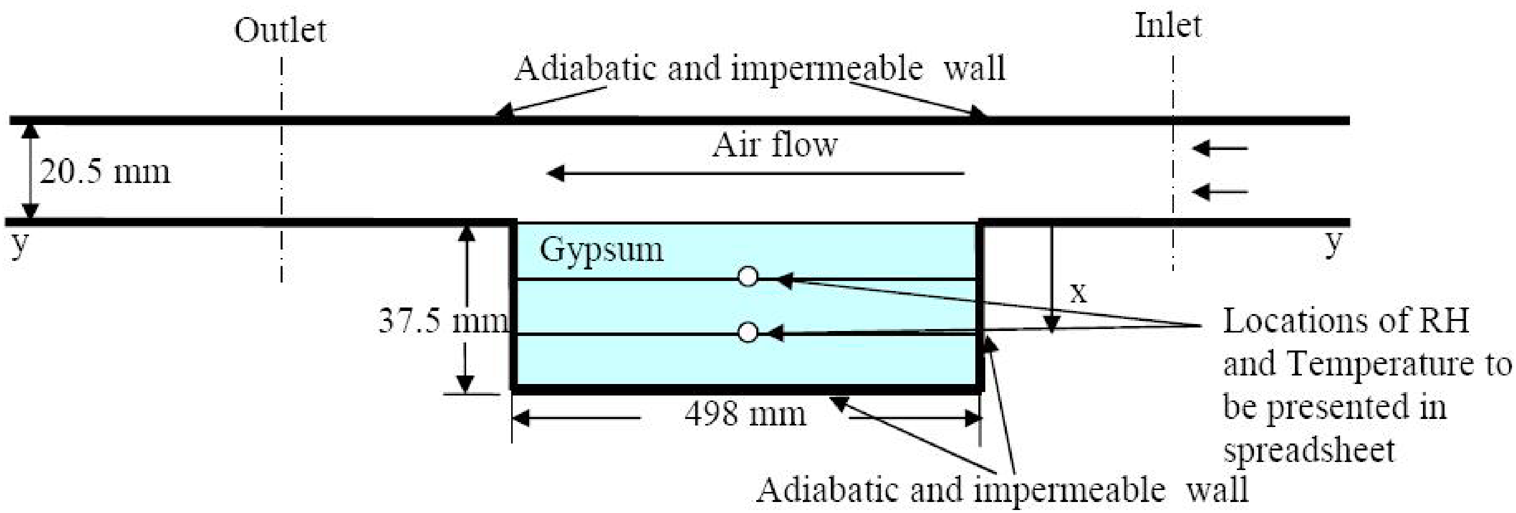
Combined heat and vapour transfer

1) Air flow
2) Convective heat transfer
3) Convective vapour transfer
4) Radiation

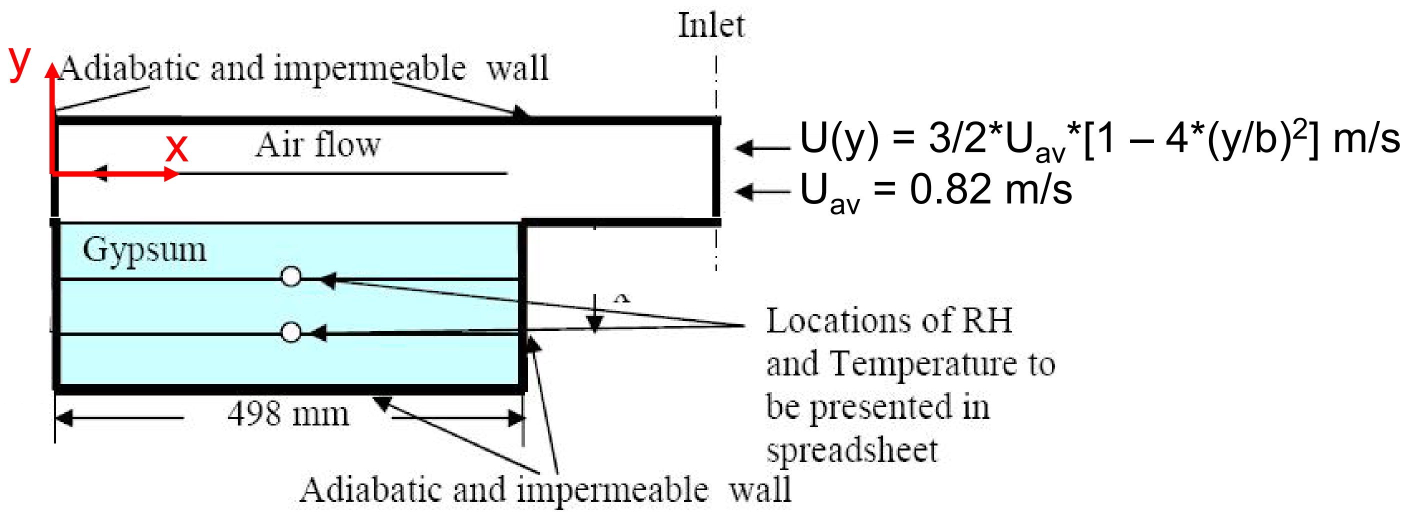
5) Thermal Diffusion
6) Vapour Diffusion

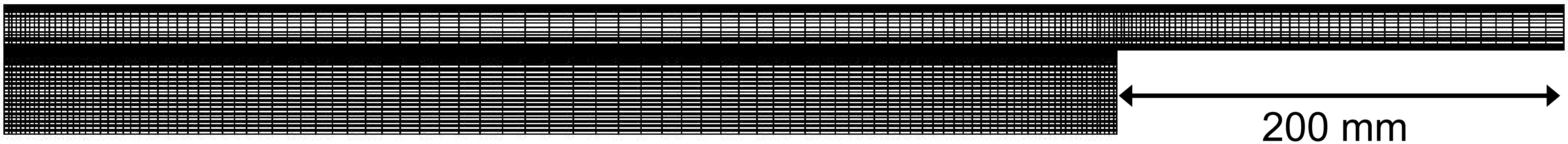


Modeling Exercise



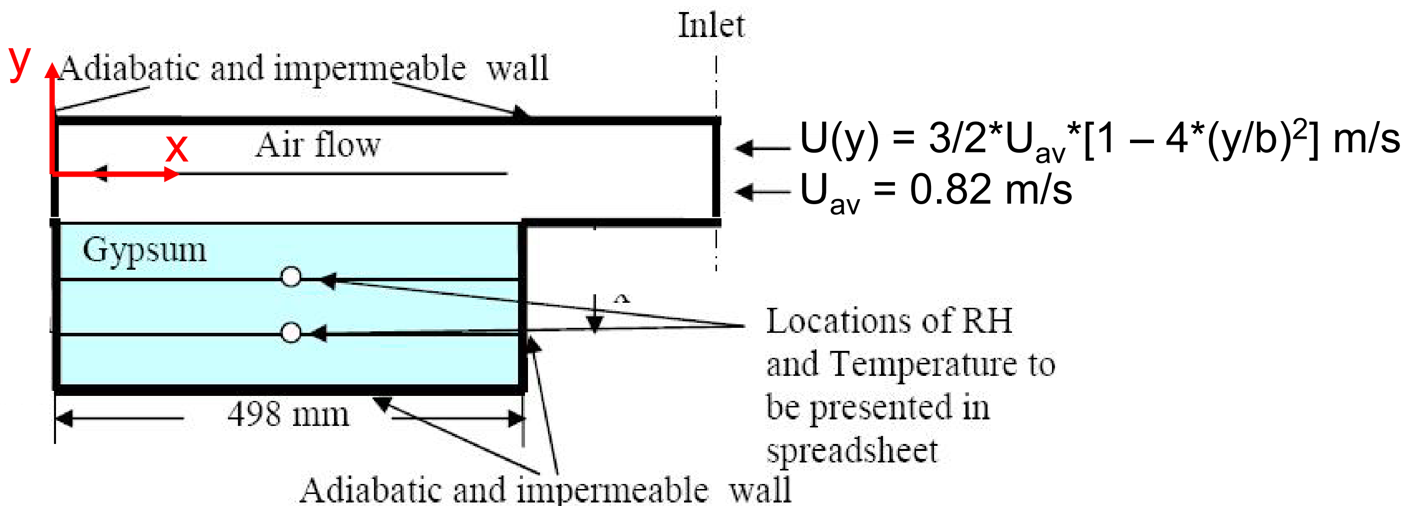
Modeling Exercise





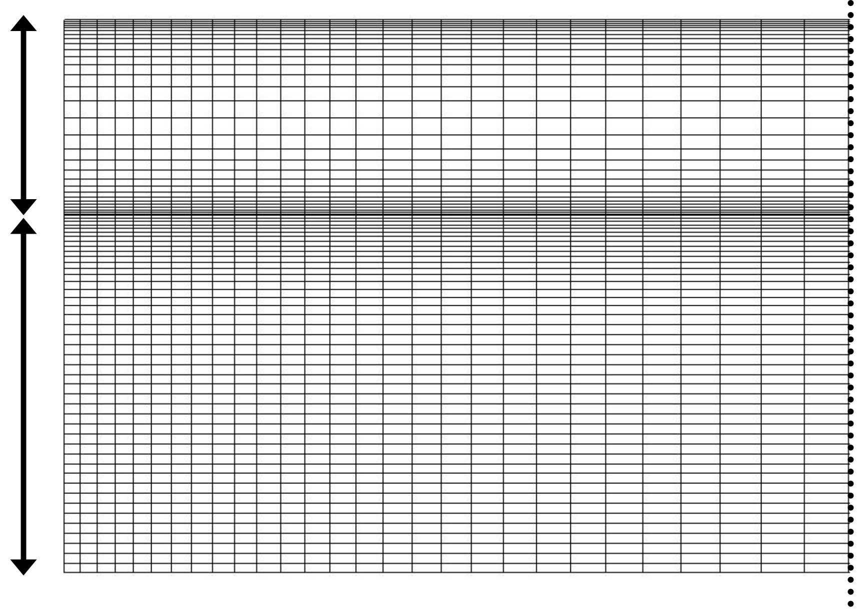
Note: Not to scale

Modeling Exercise



Smallest Cell Heights:

30 elements



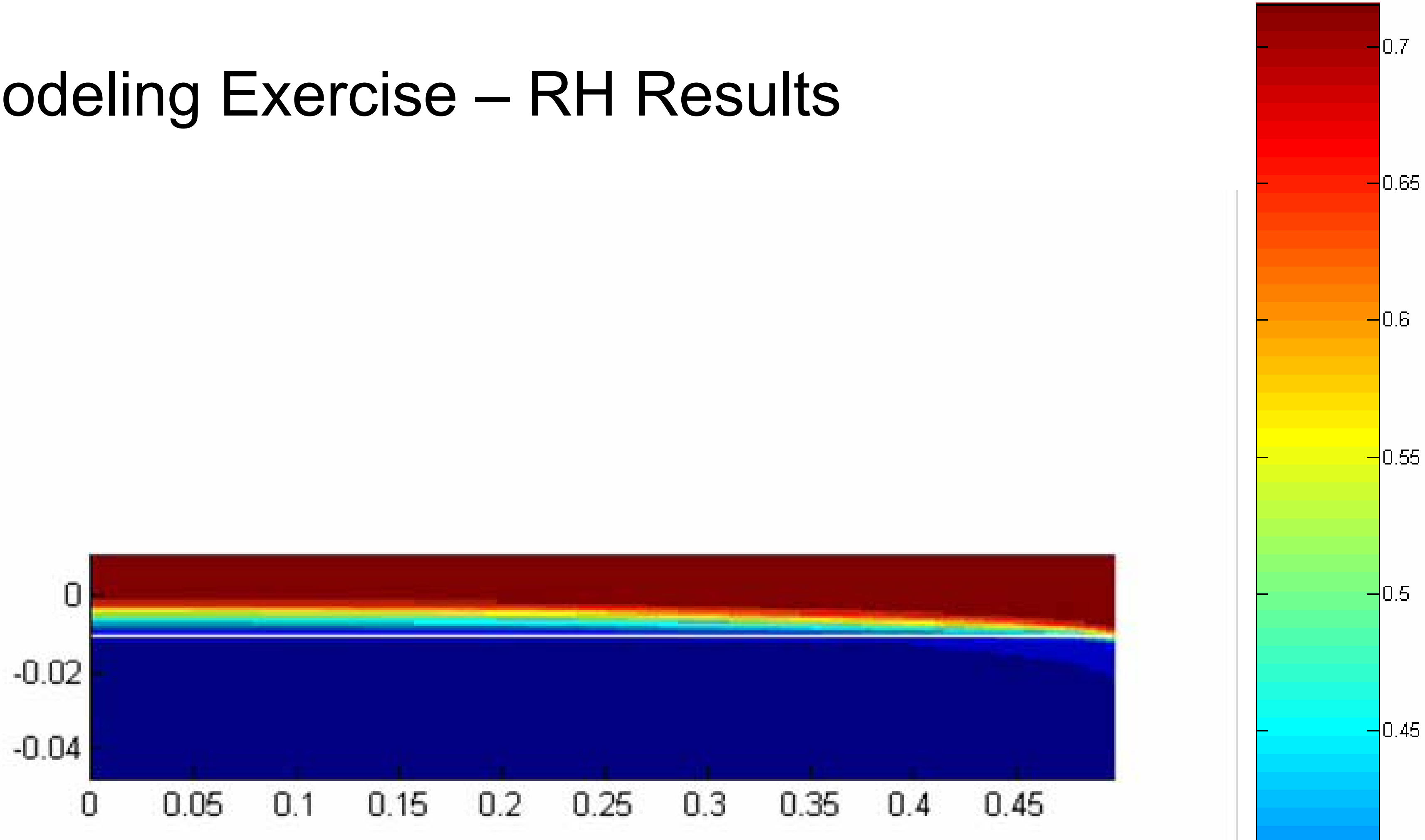
dy = 0.0001556 m

dy = 0.0003145 m

44 elements

Note: Not to scale

Modeling Exercise – RH Results

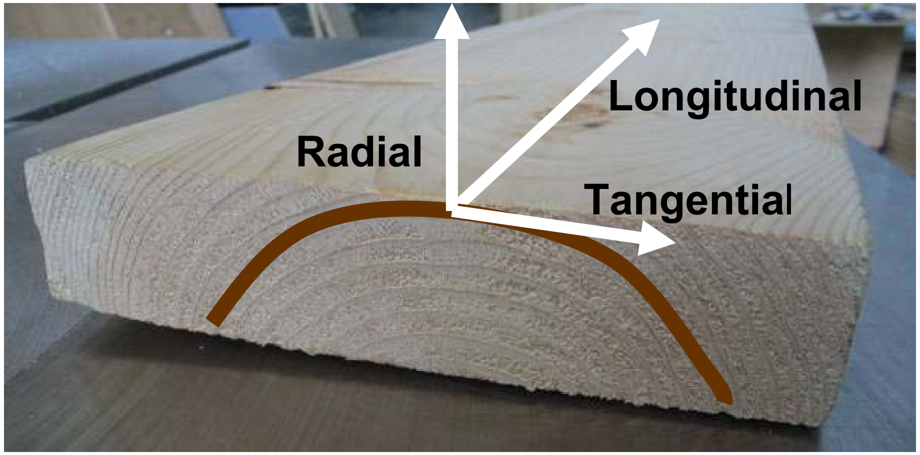


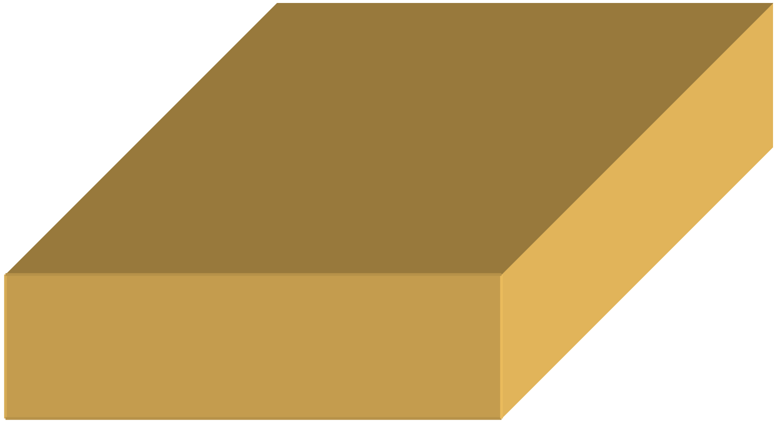
3. Wood modeling

Moisture movement in wood

Multi-scale approach

Required for modeling, orthotropic numerical model of the material wood

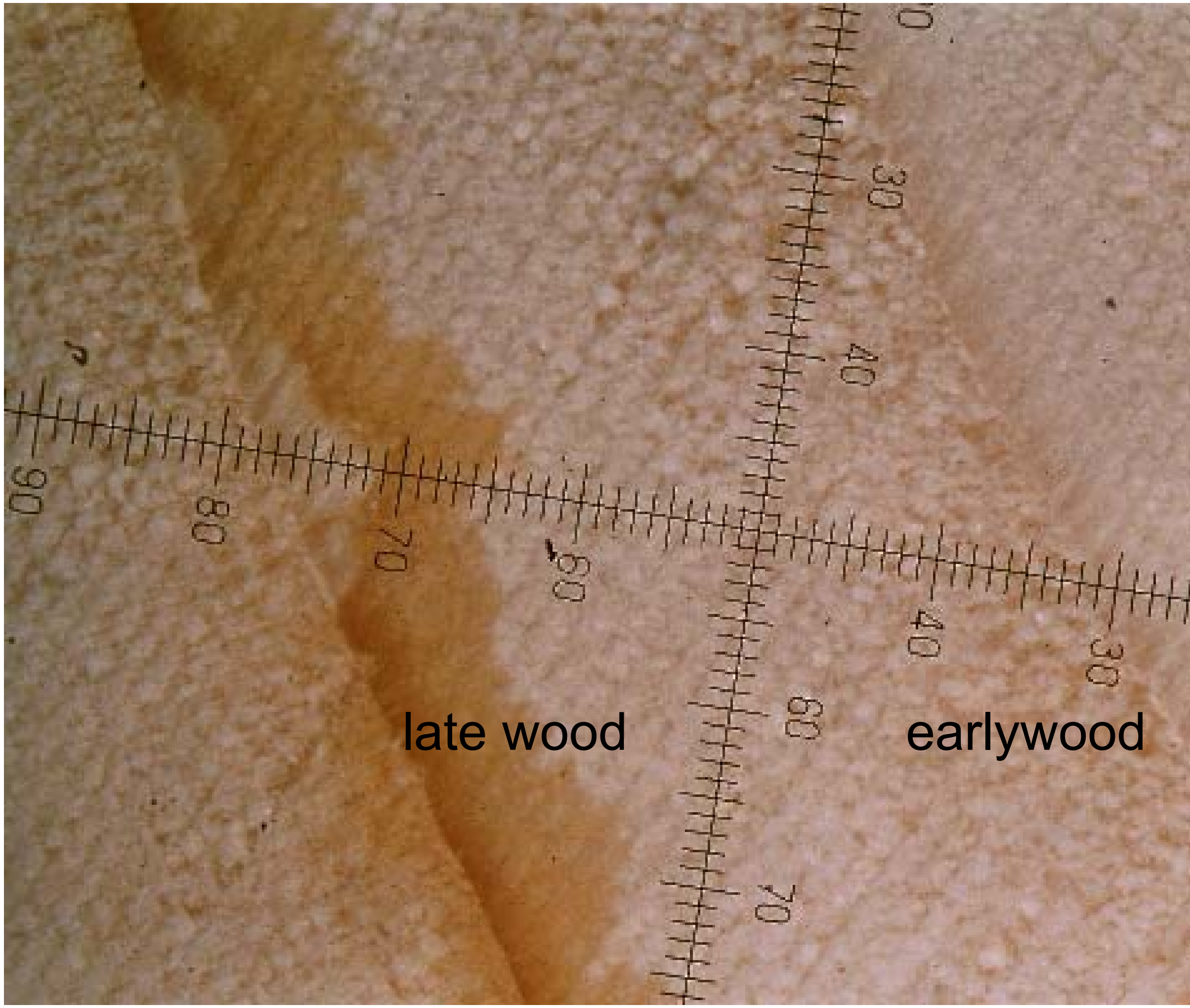




Currently modeled as homogeneous isotropic material

Water distribution

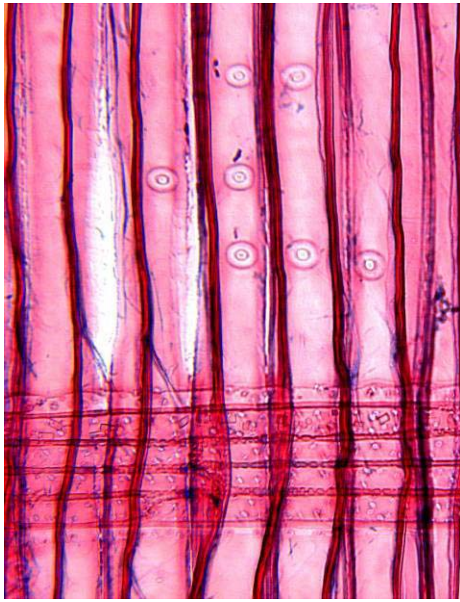
Microscopic view of wet wood



Orthotropic numerical model of the material wood

Using

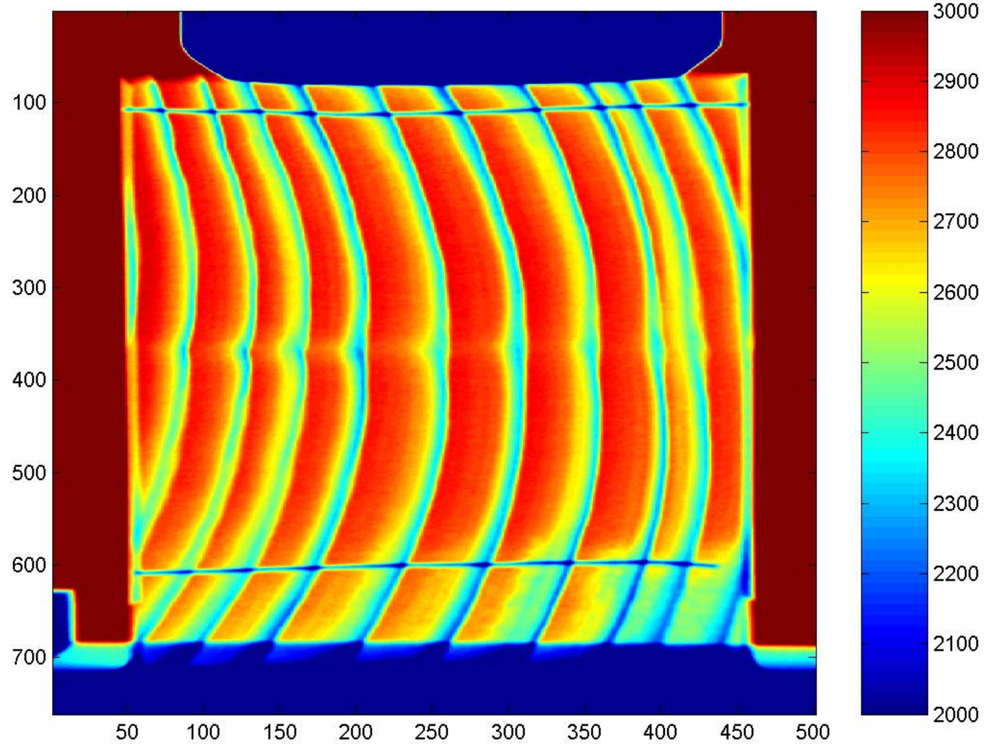
- scanning electronic microscopy
- light microscopy
- mercury porosimetry
- helium pictometer
- pressure plates
- permeance tests
- sorption curves

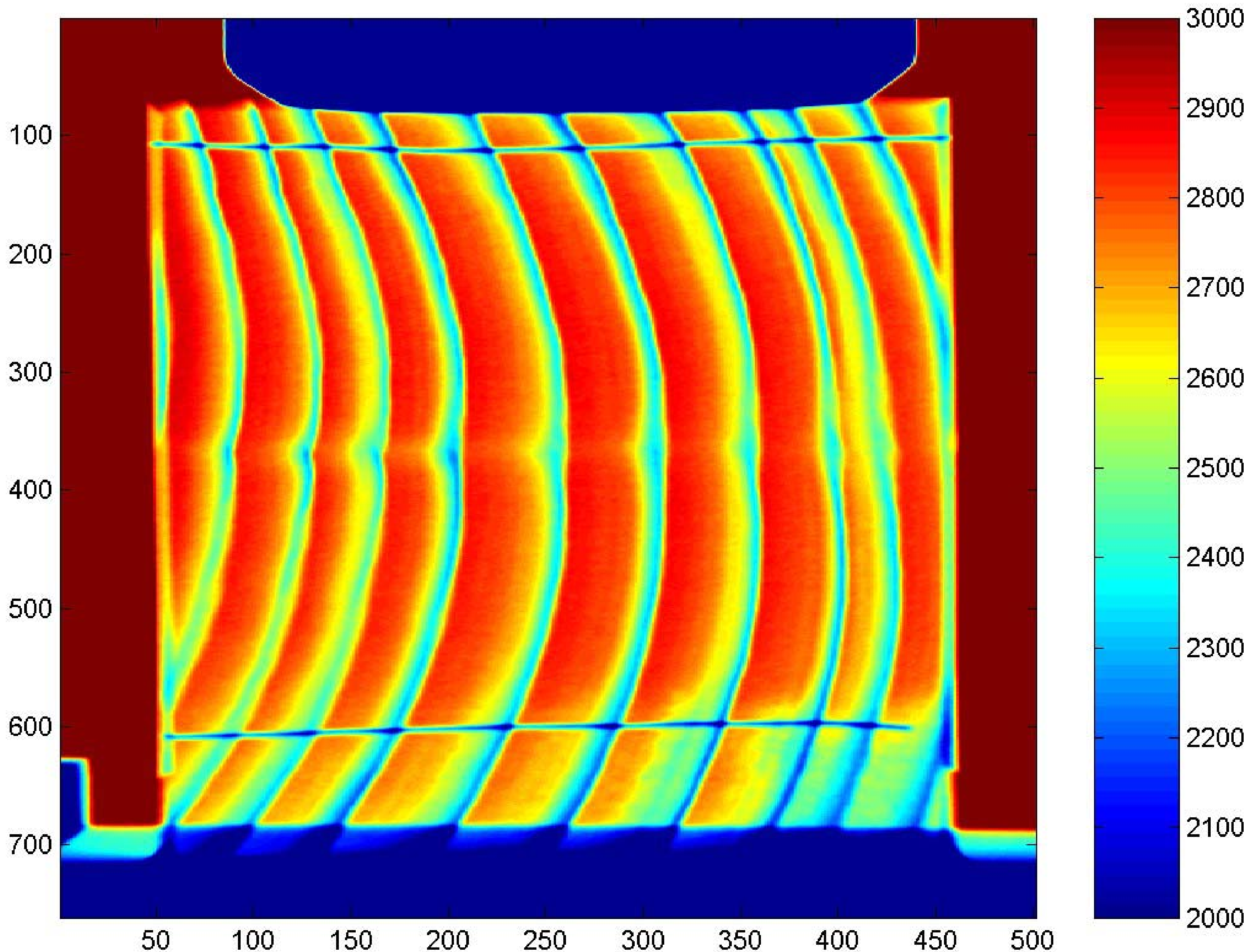


Orthotropic numerical model of the material wood

Using

- Micro-focus X-ray





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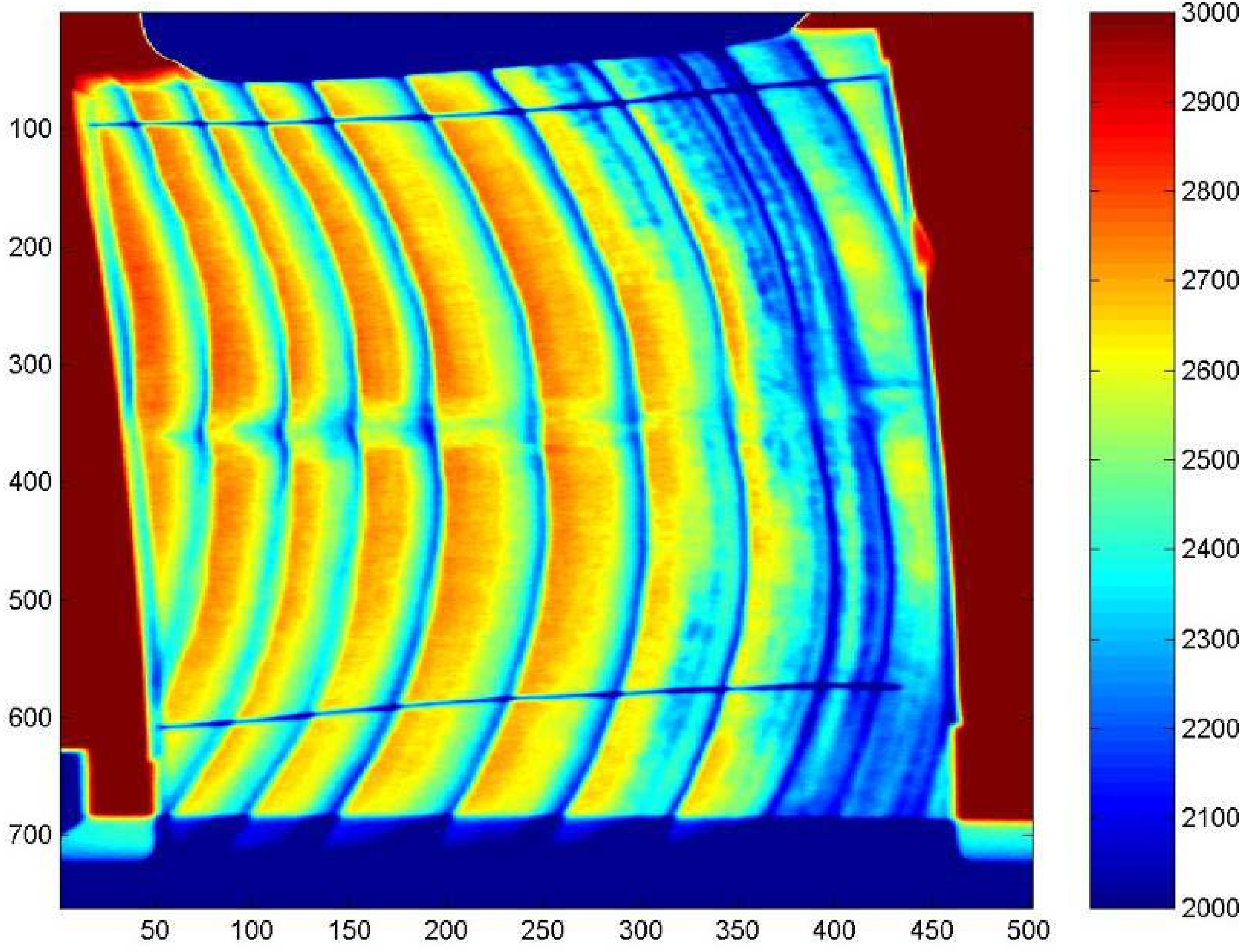
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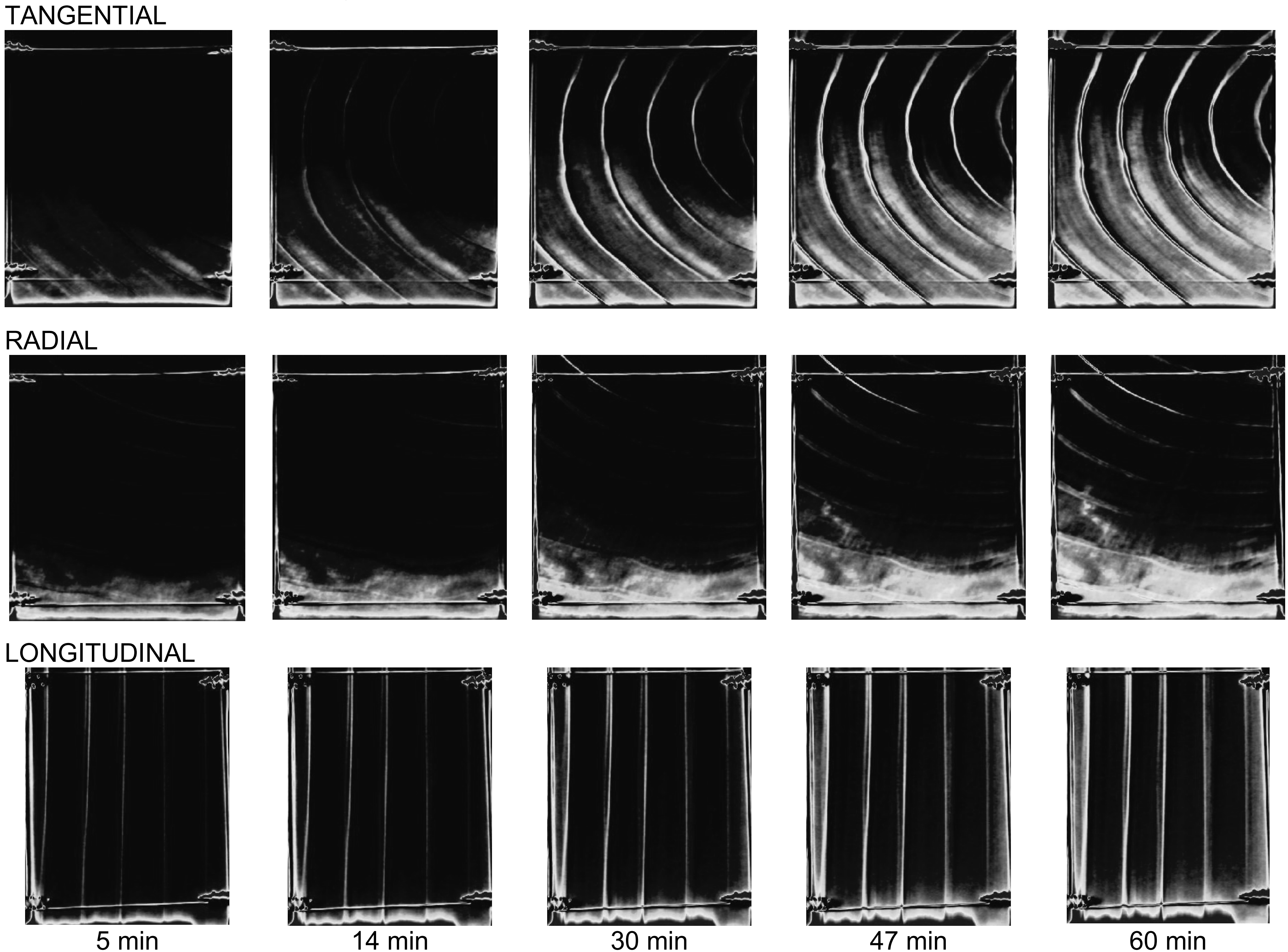
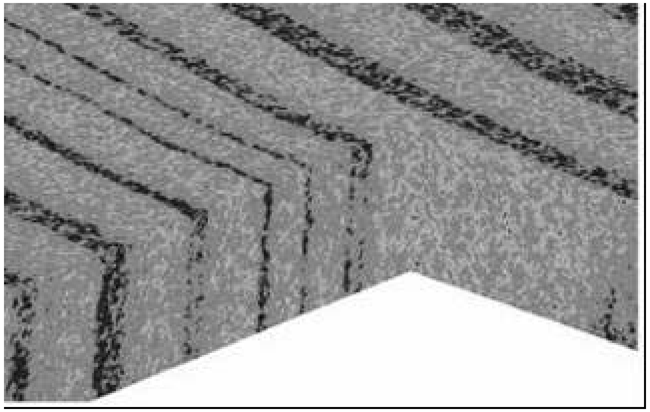
X-ray measurements of free water uptake in spruce

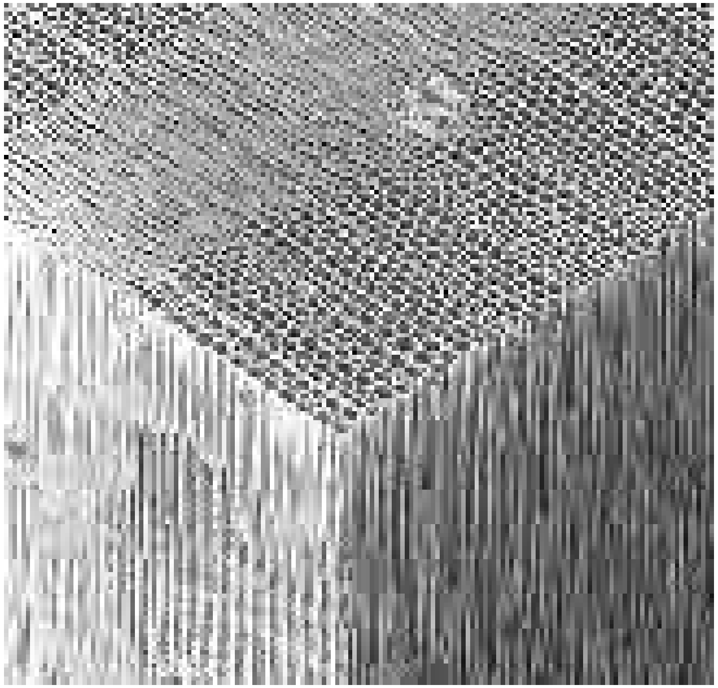


Orthotropic numerical model of the material wood

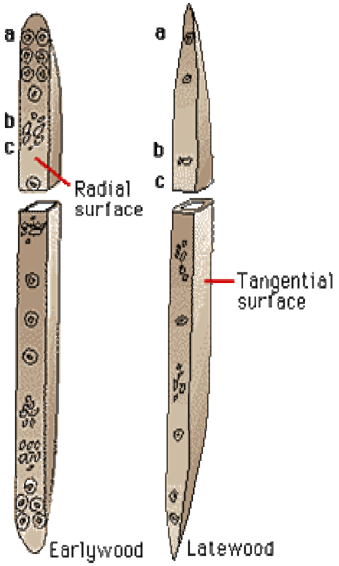
Using multi-scale approach



Macroscale

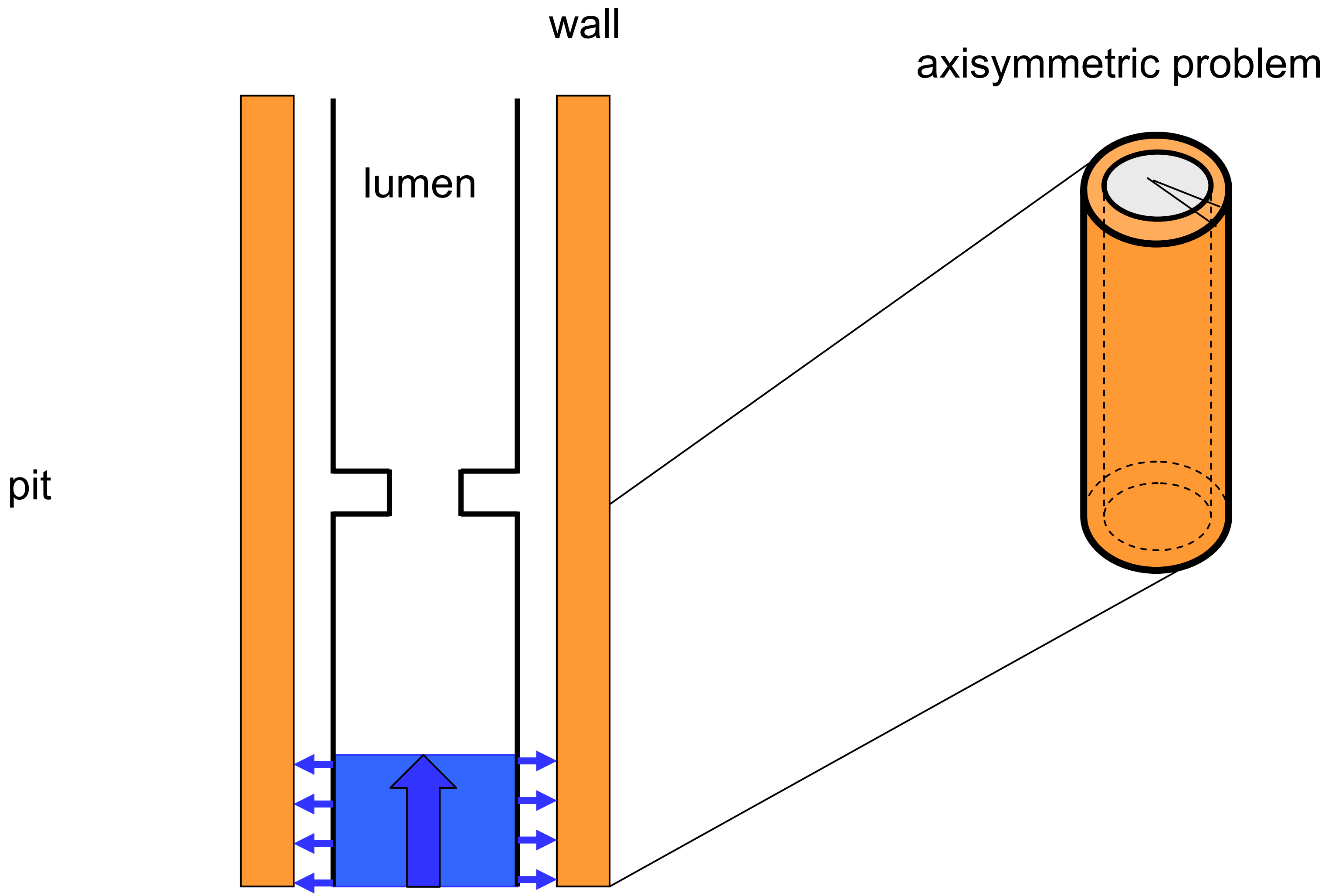


Mesoscale

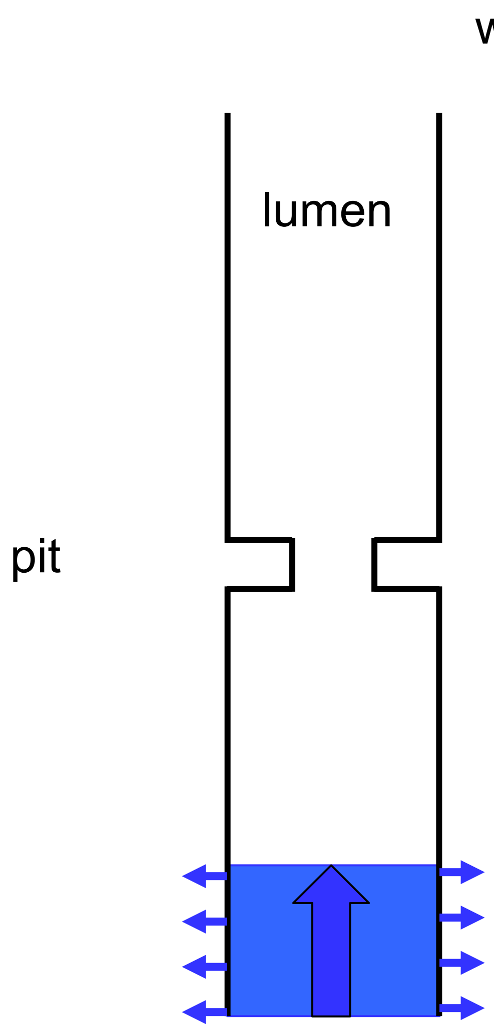


Cellular scale

MODELLING ON THE CELLULAR SCALE



flow in lumen/pit solved by front-tracking method

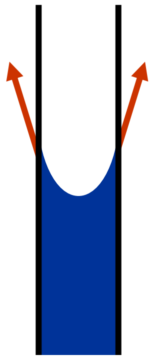


Quasi static pressure equation

$$\nabla\left(K\left(\nabla P_l + \rho_l g \cos\phi\right)\right) - S = 0$$

Darcian flux equation

$$u = \frac{\partial z}{\partial t} = -\frac{K}{\rho_l}\left(\nabla P_l + \rho_l g \cos\phi\right)$$



$$p_c = \frac{4\sigma\cos\theta}{b}$$

SUBCELLULAR SCALE

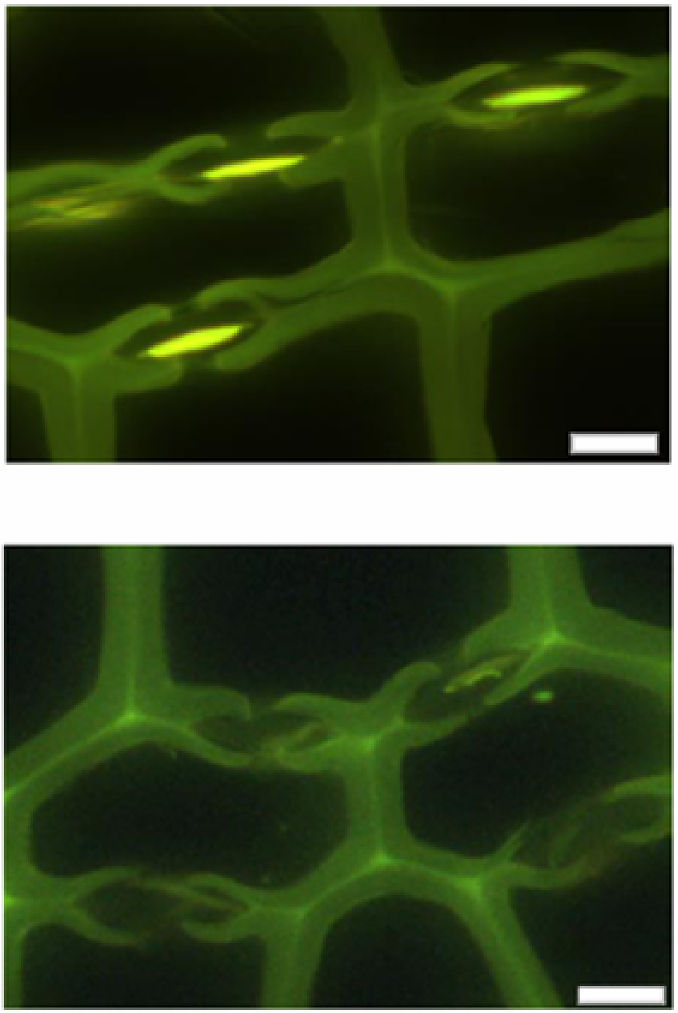
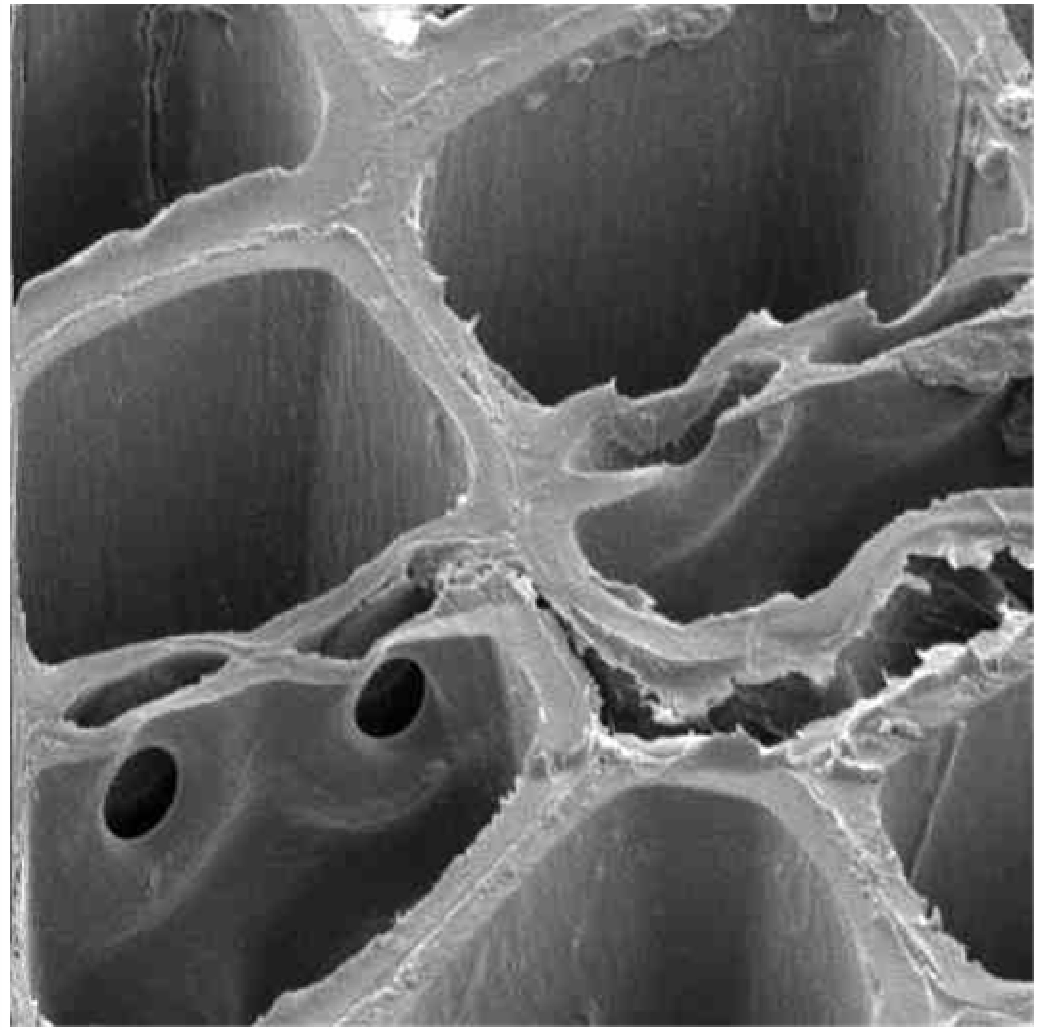


Figure 19. Fluorescent tori in water-sprinkled spruce (above) and tori in fresh spruce (below). Scale bar is 10 μm.



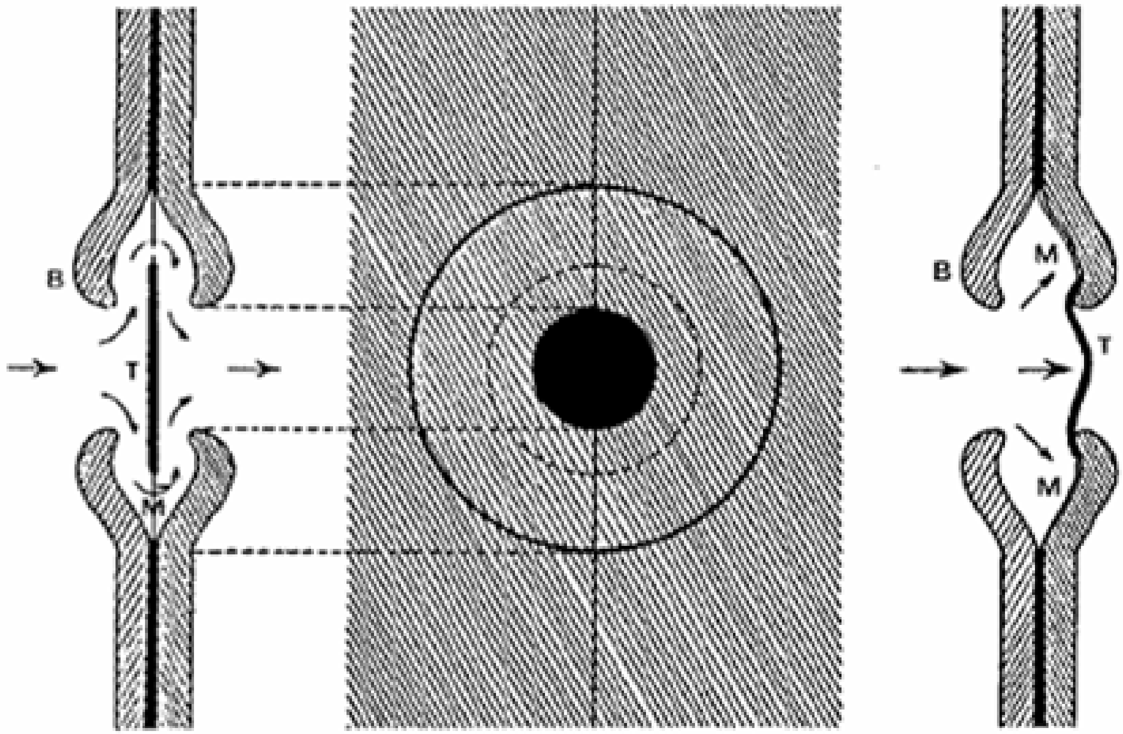


Fig. 3.12. *Center* Surface view of the radial wall of a coniferous tracheid, showing a bordered pit. *Left* The same pit in section, *arrows* indicating the path of water from one tracheid into the next. *Right* Section showing the valve-like action of the torus. *T* torus; *M* pit membrane; *B* pit border. (Bailey 1913)

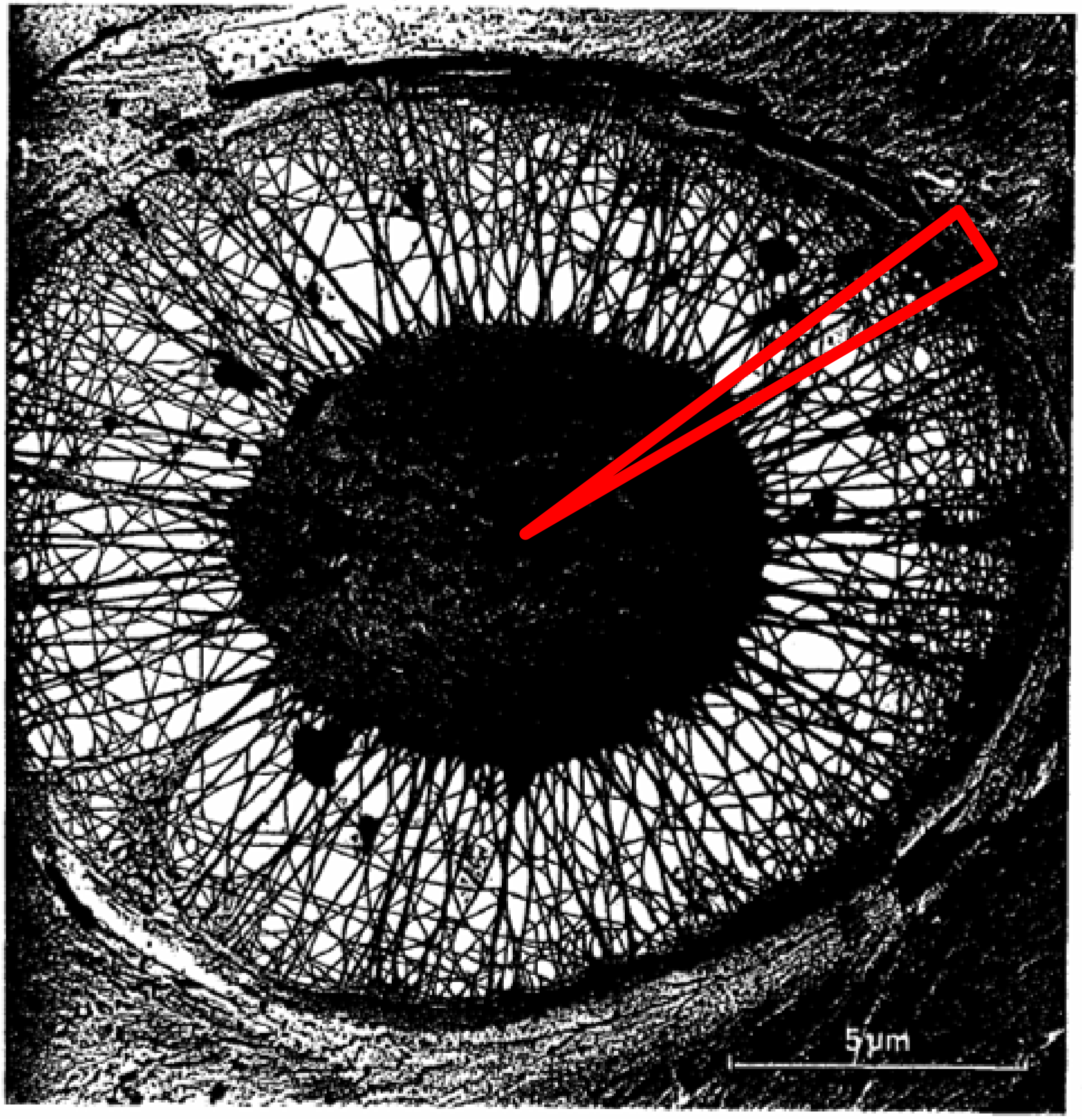
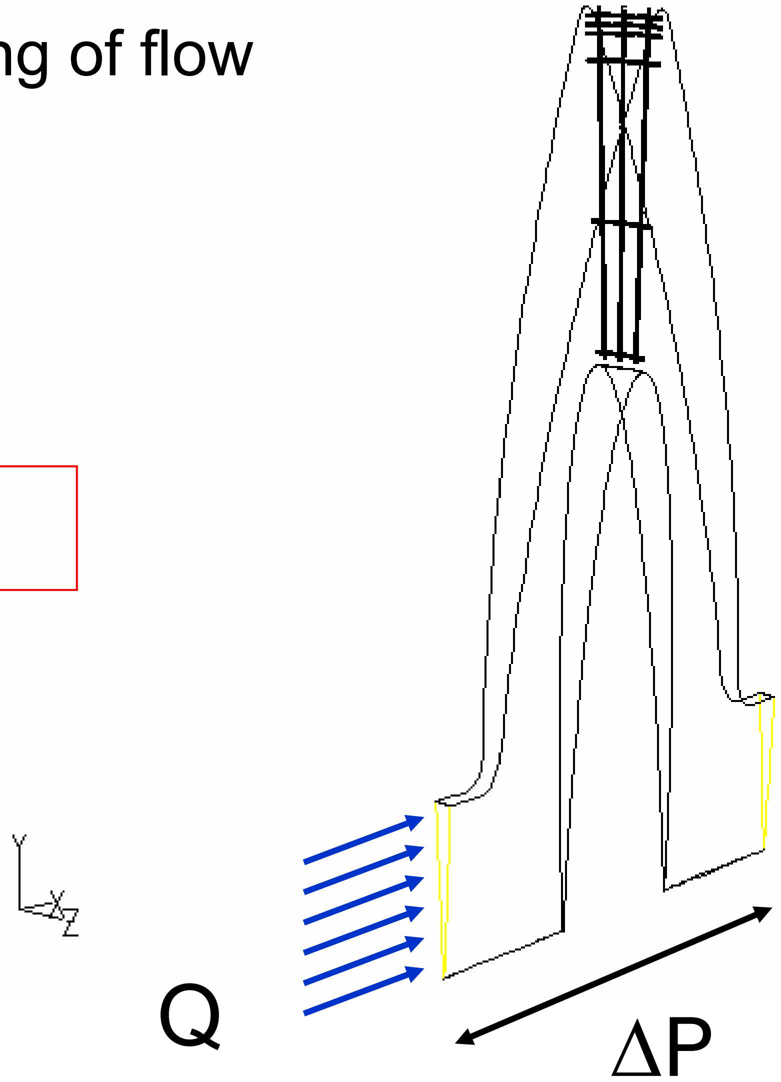


Fig. 1.11. Bordered pit of eastern hemlock (*Tsuga canadensis*), solvent-dried from green condition. The pit membrane consists of the net-like margo and the central torus. (Transmission electron micrograph courtesy W.A. Côté)

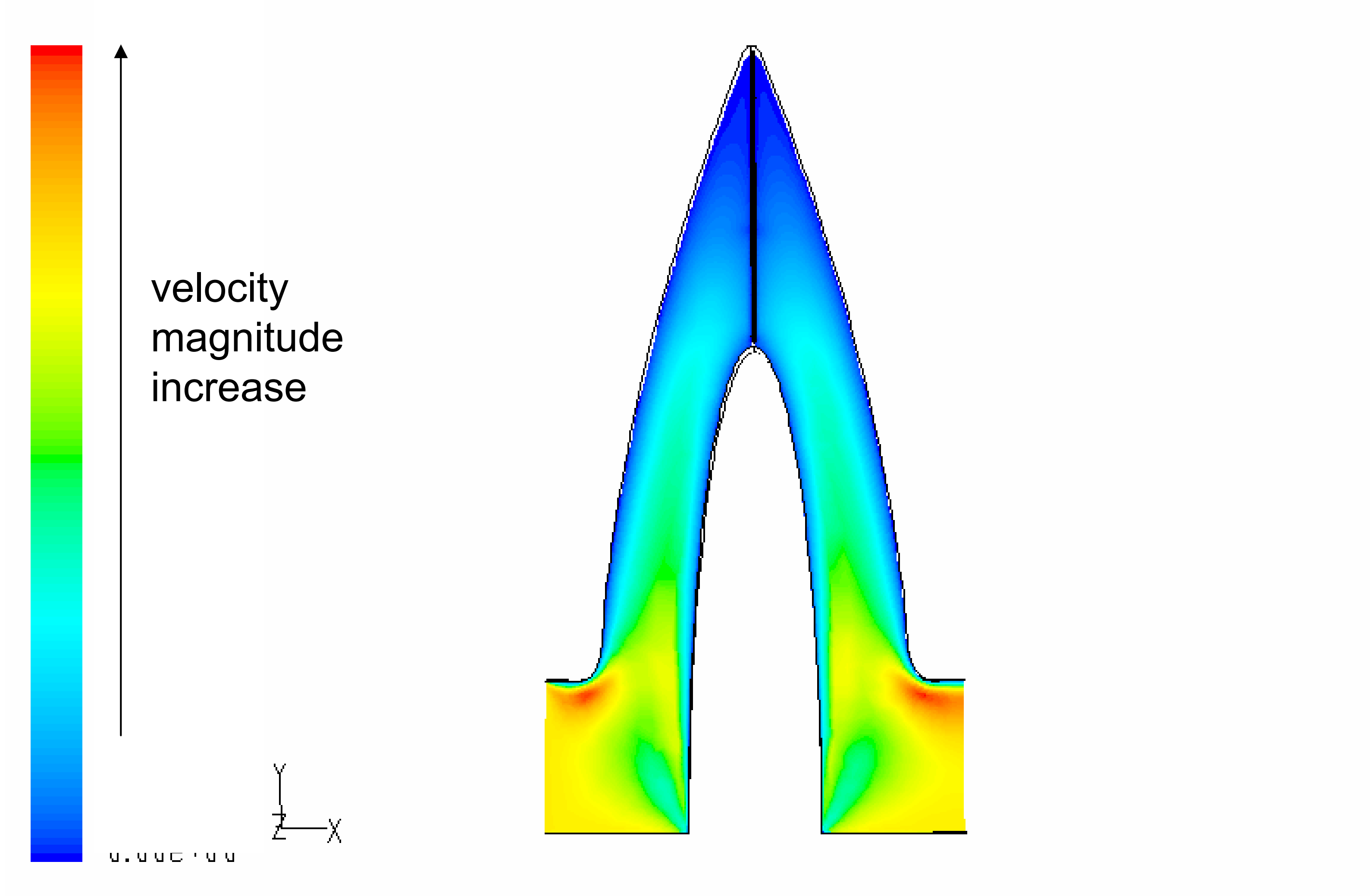
MODELLING ON THE SUB-CELLULAR SCALE

CFD modelling of flow

$$Q = \xi \, \Delta P$$

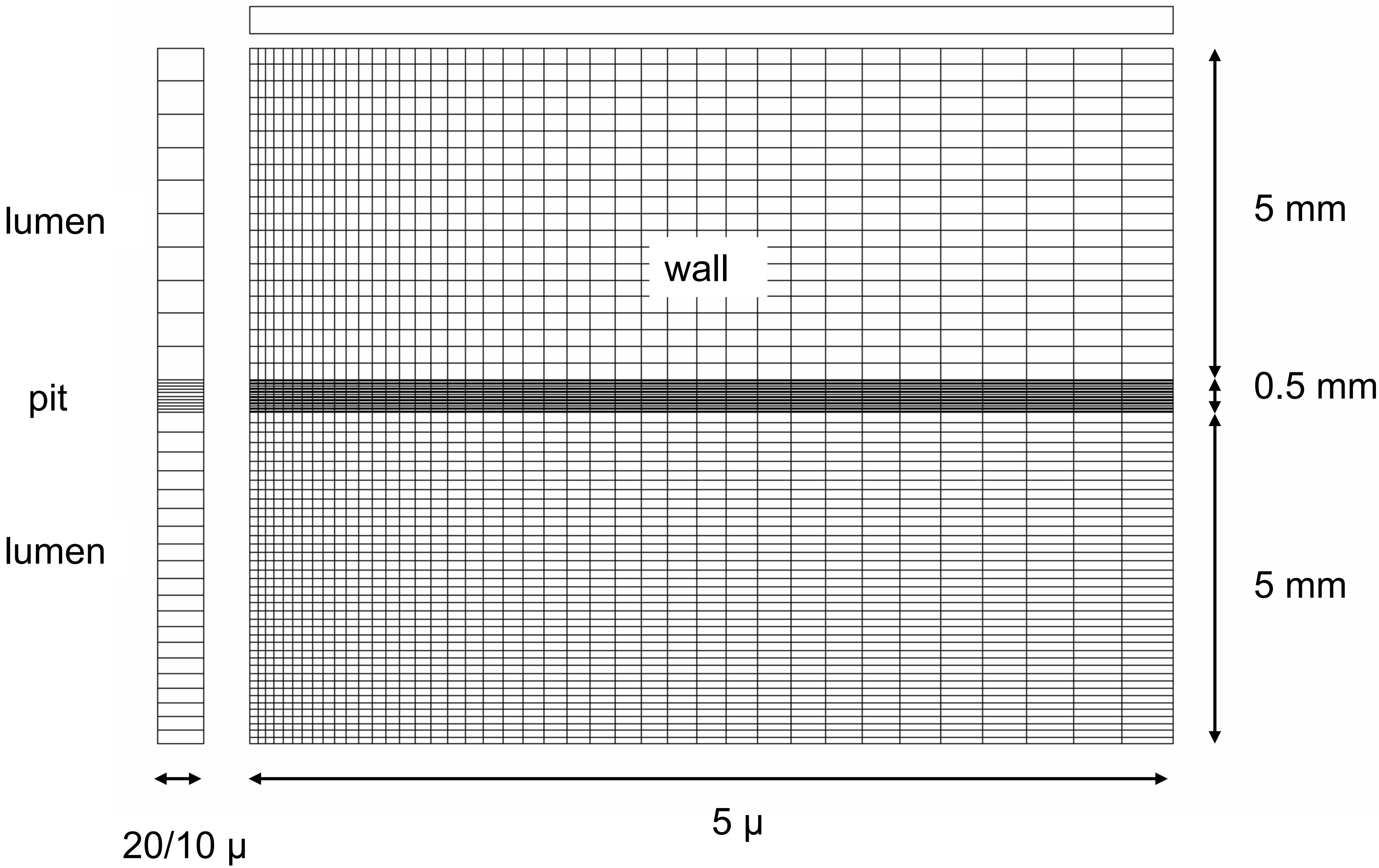


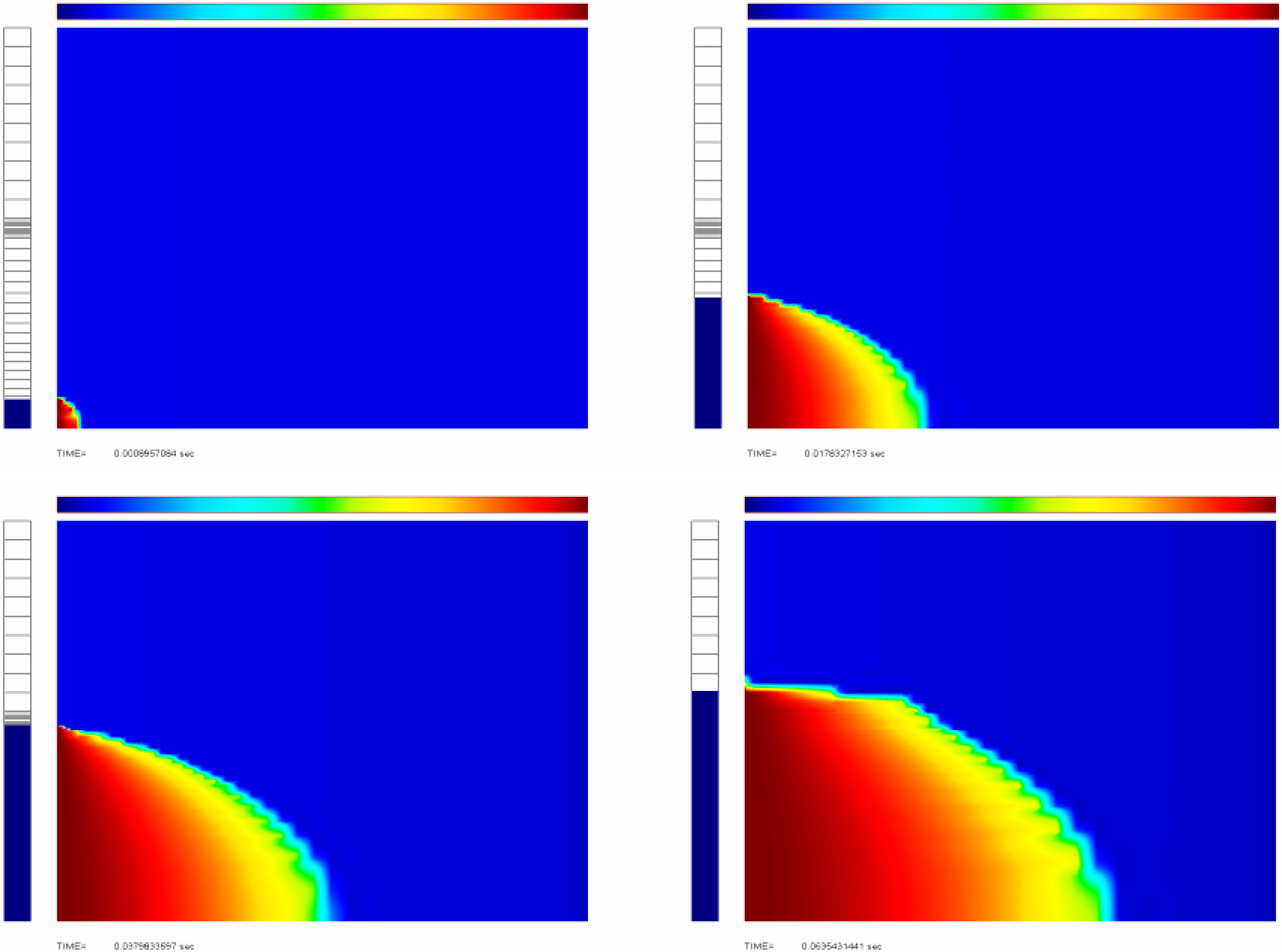
MODELLING ON THE SUB-CELLULAR SCALE



Contours of velocity magnitude in a pit centerplane (half of pit cross-section)

MODELLING ON THE CELLULAR SCALE

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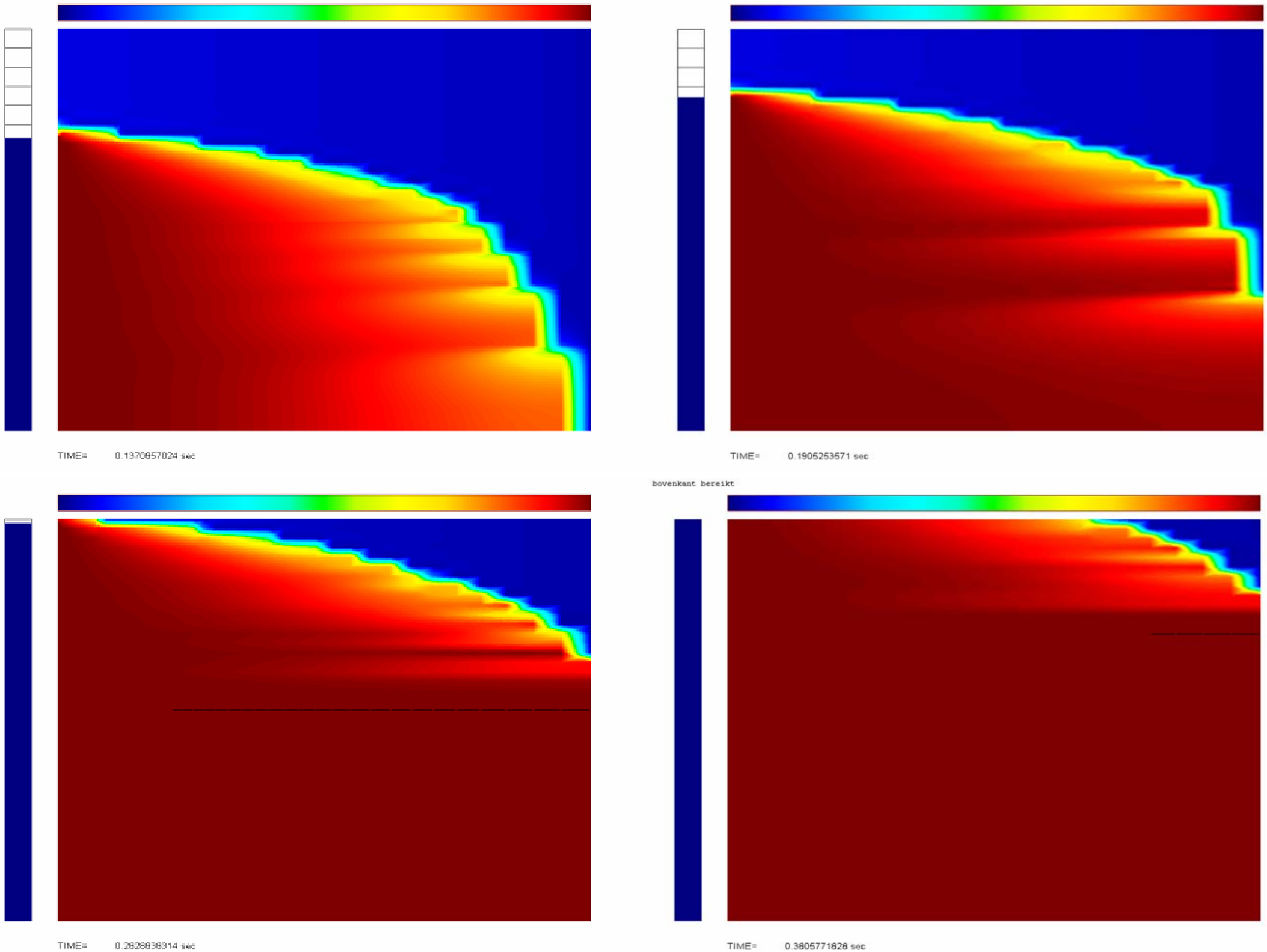

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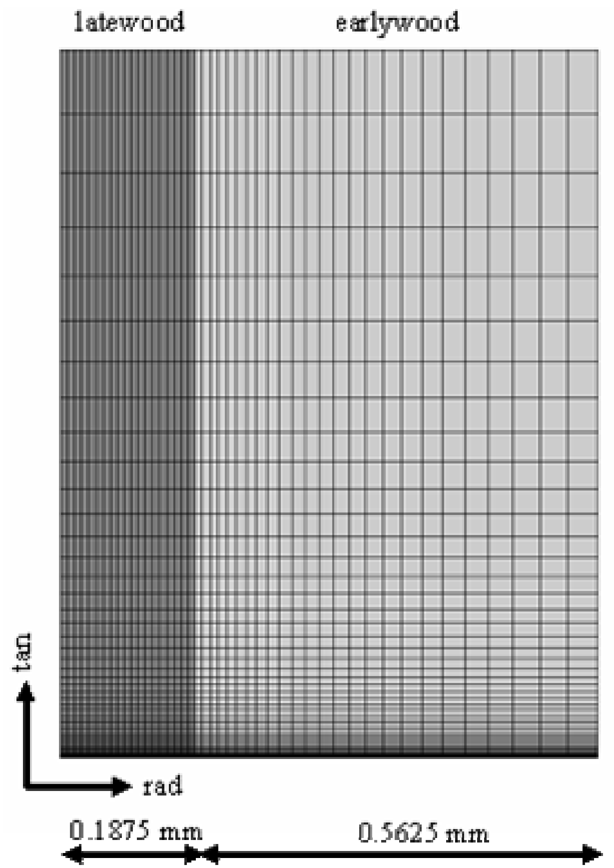
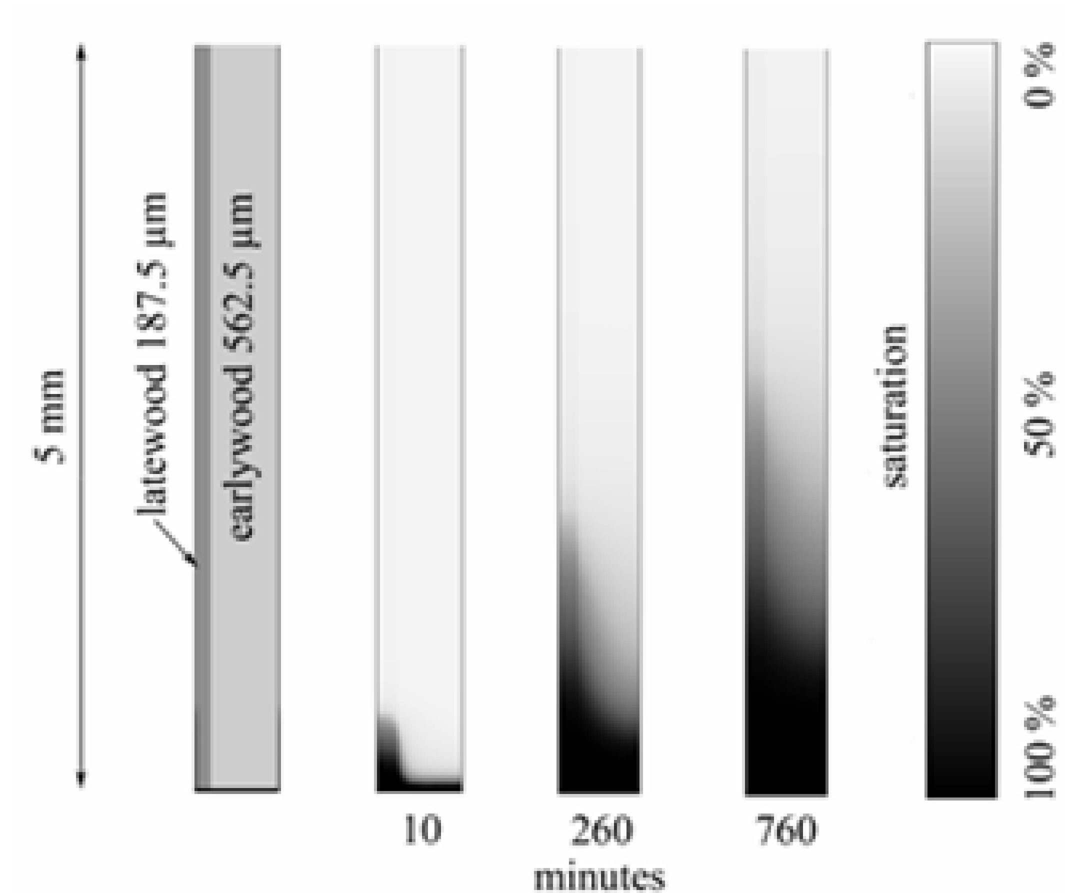
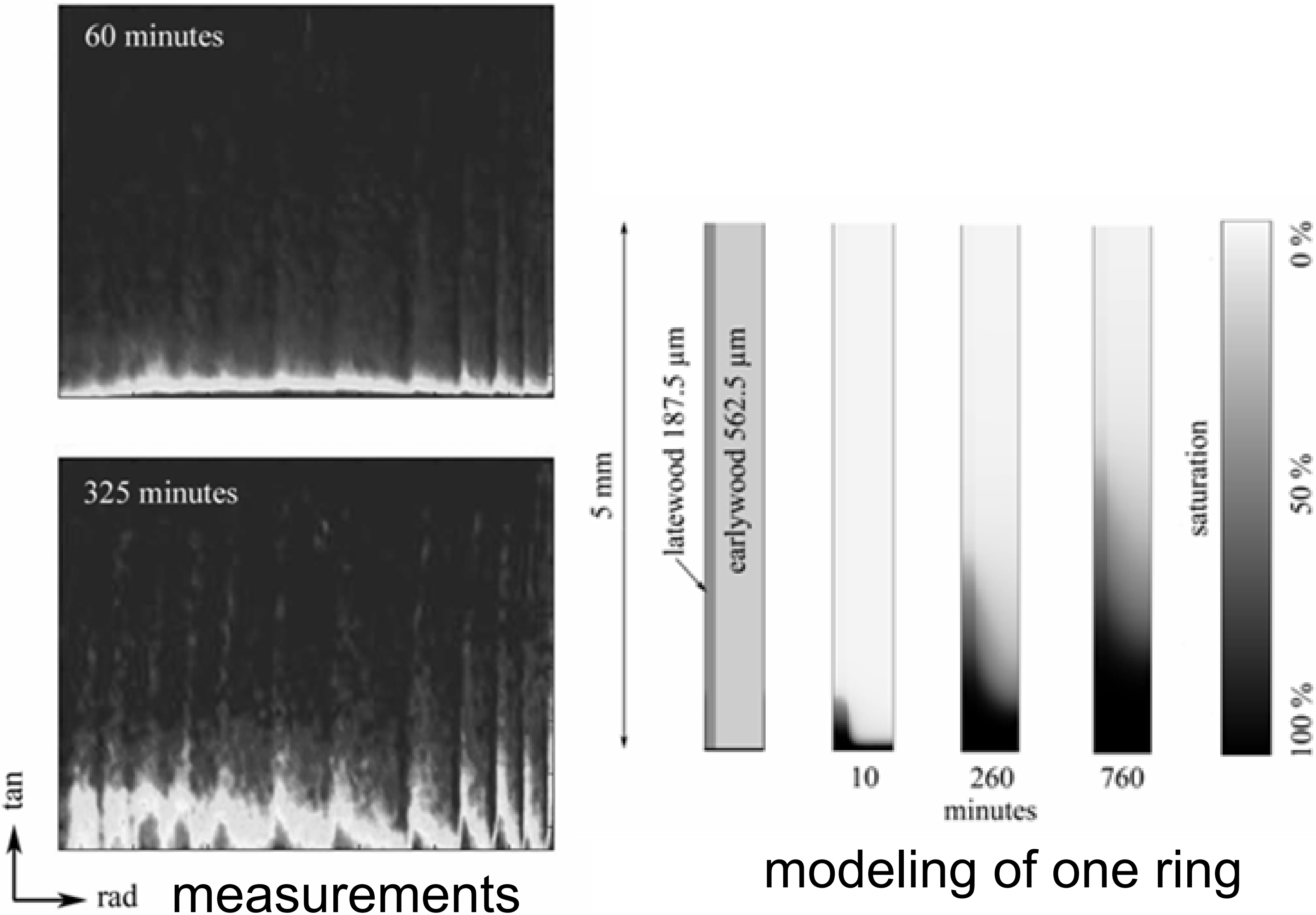
MODELLING ON THE MESOSCALE







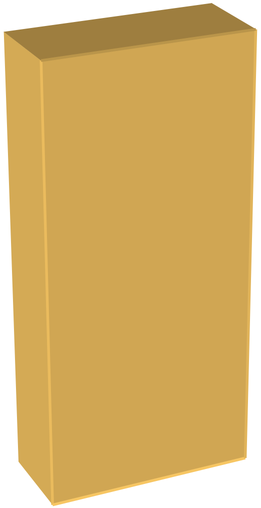
measurements

modeling of one ring

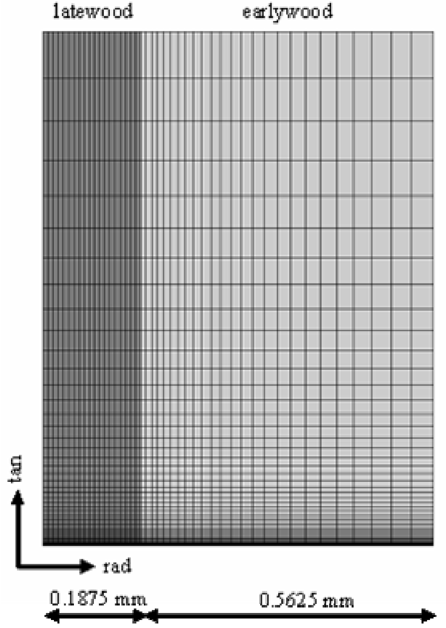
Orthotropic numerical model of the material wood

multi-scale modeling

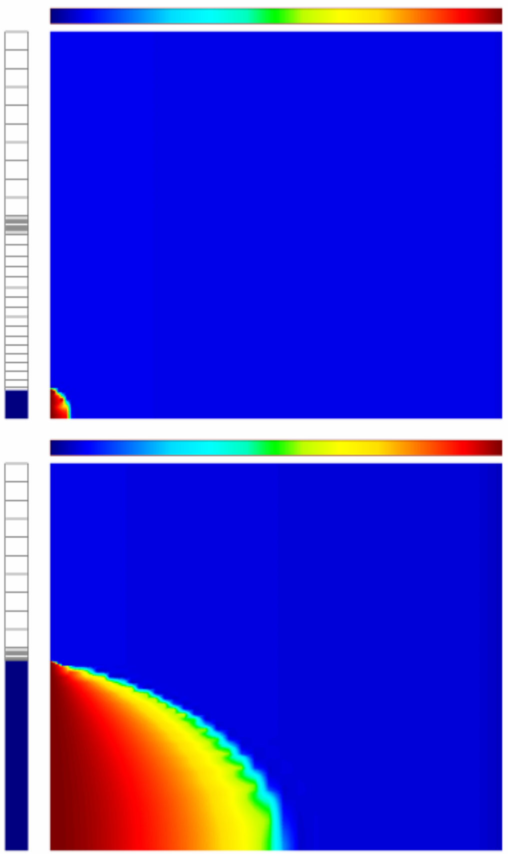
Macroscale
orthotropic
homogenized



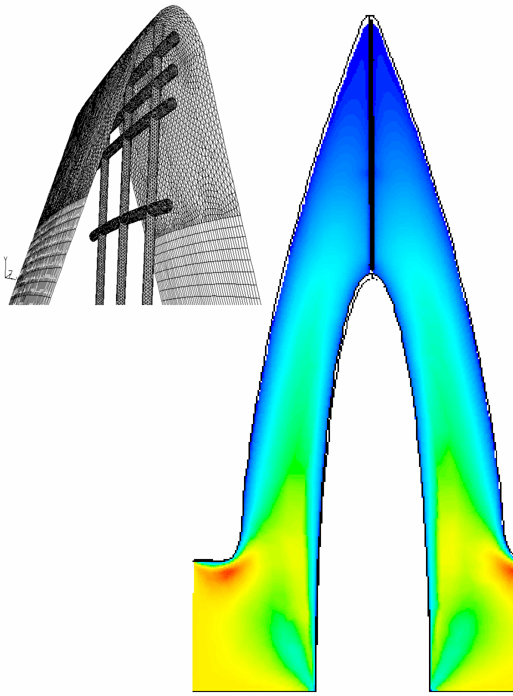
Mesoscale
continuum model



Cellular scale
mixed model

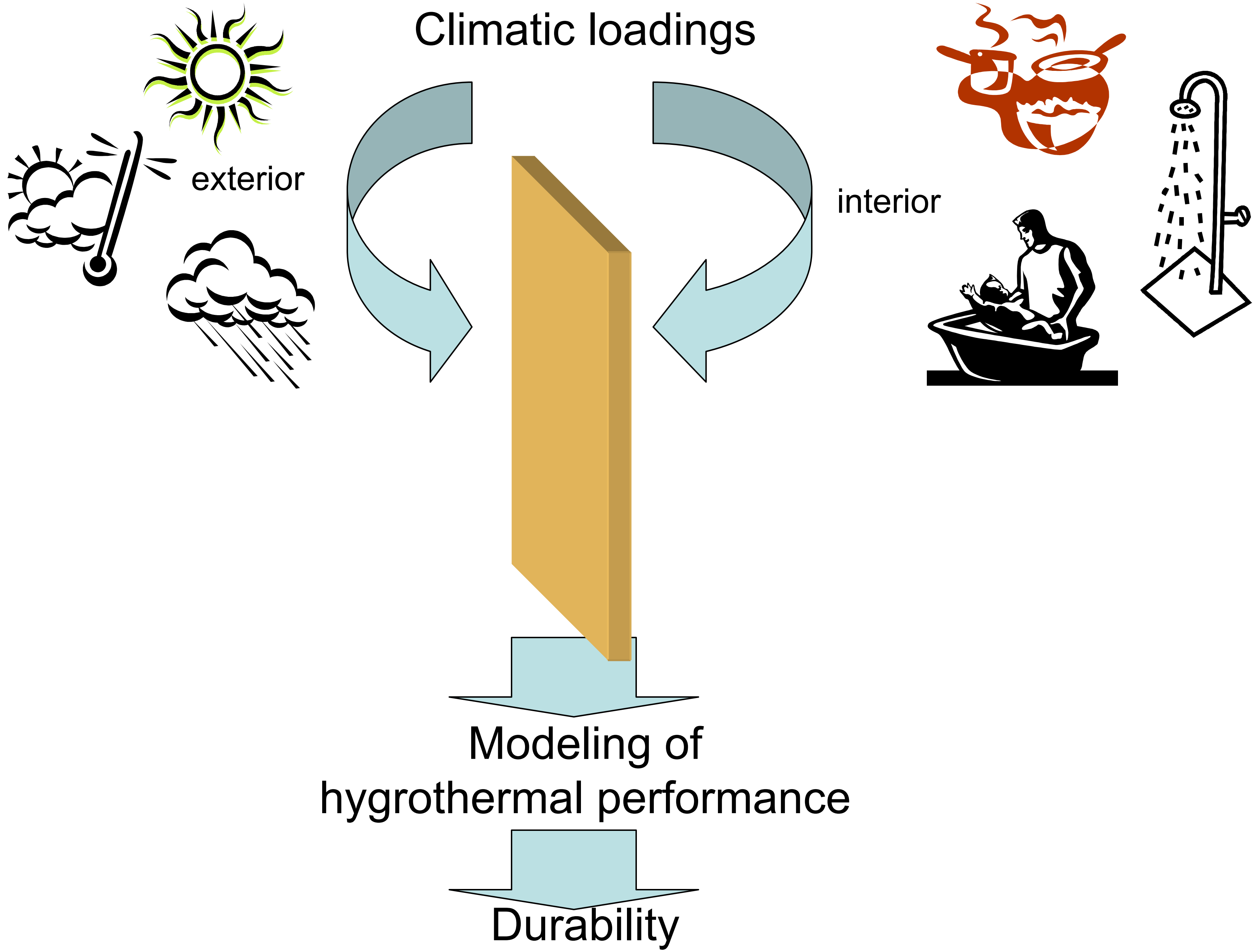


Micro scale
CFD

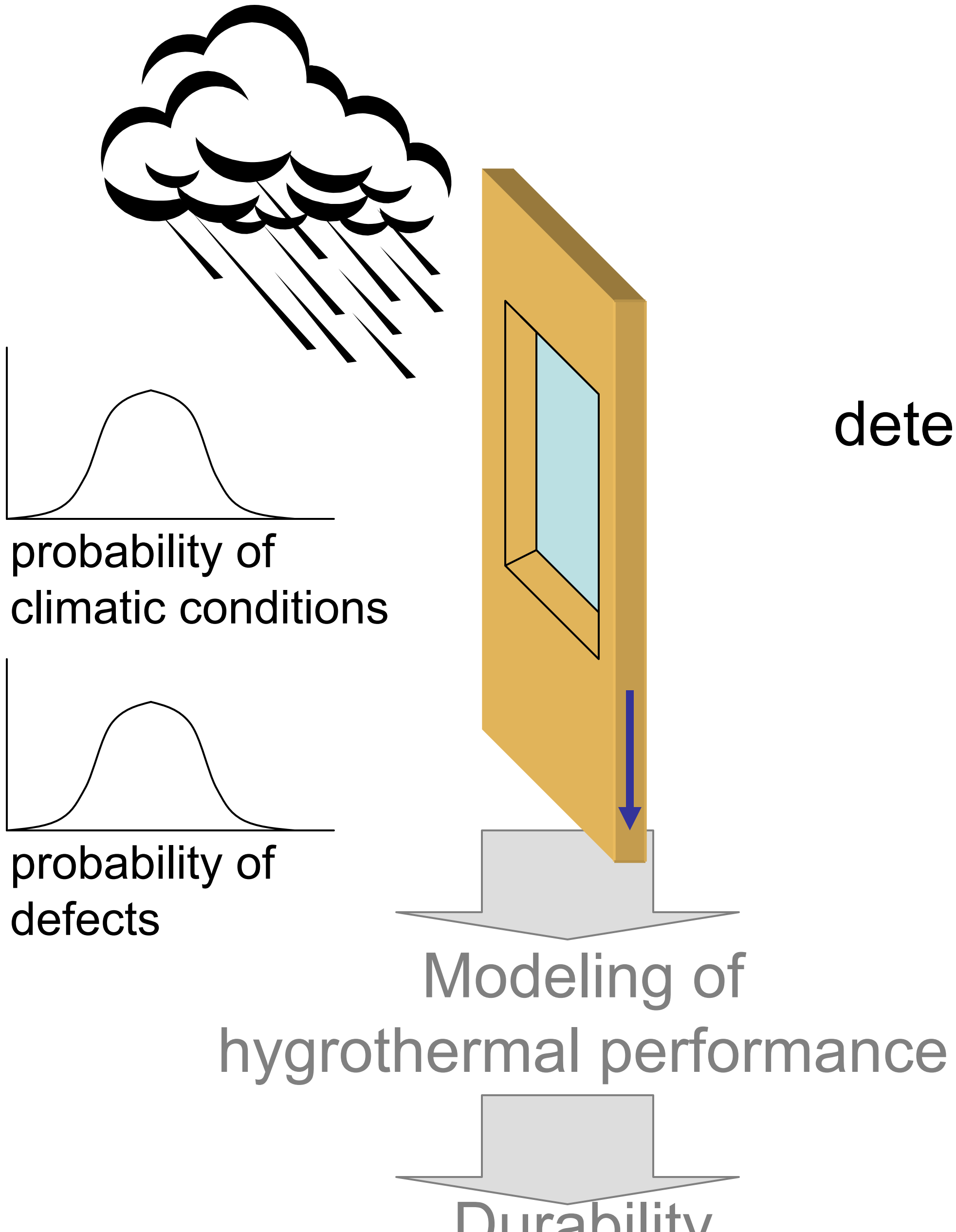


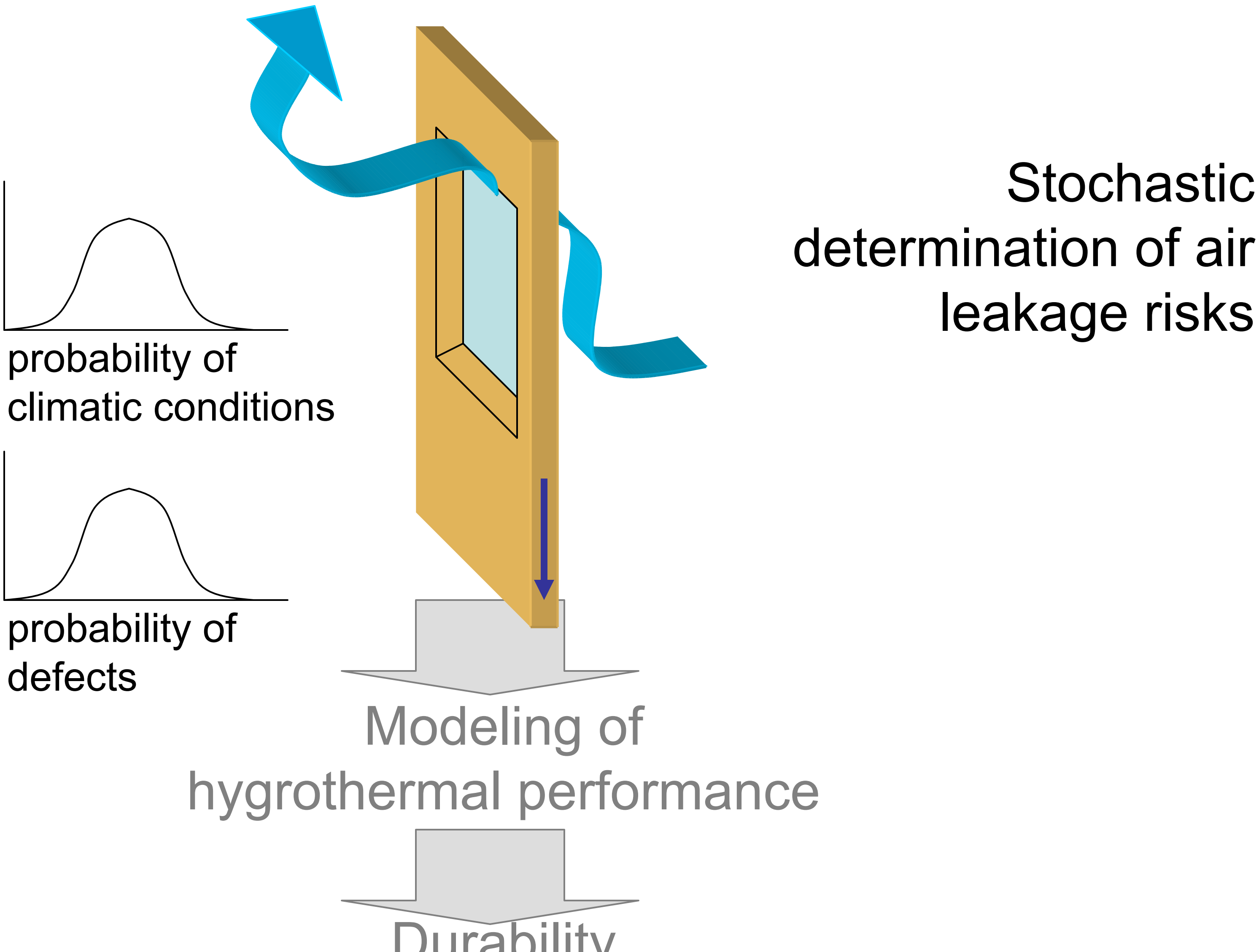
Conclusion

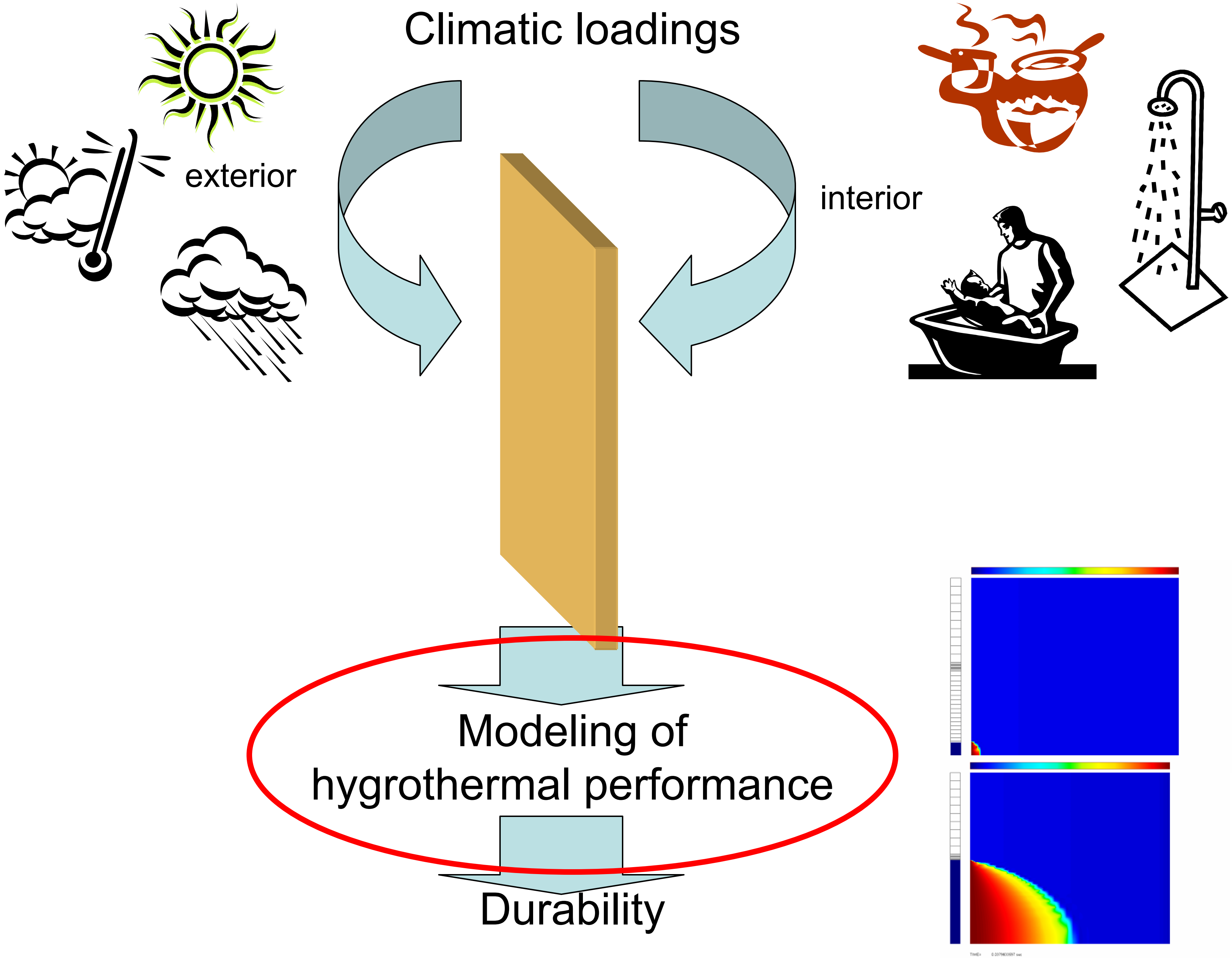
a global picture of our research program


Climatic loadings
exterior
interior
Modeling of
hygrothermal performance
Durability

Stochastic determination of water leakage risks




Stochastic determination of air leakage risks
probability of climatic conditions
probability of defects
Modeling of hygrothermal performance
Durability


Climatic loadings
exterior
interior
Modeling of
hygrothermal performance
Durability