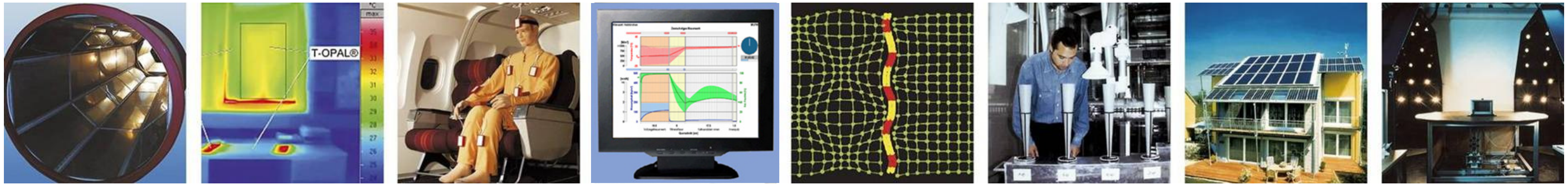

WUFI® Workshop NTNU / SINTEF 2008

Heat and Moisture Sources
Simulation of Ventilation

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Content:

Introduction

Transport Equations in WUFI® Ver. 4.1

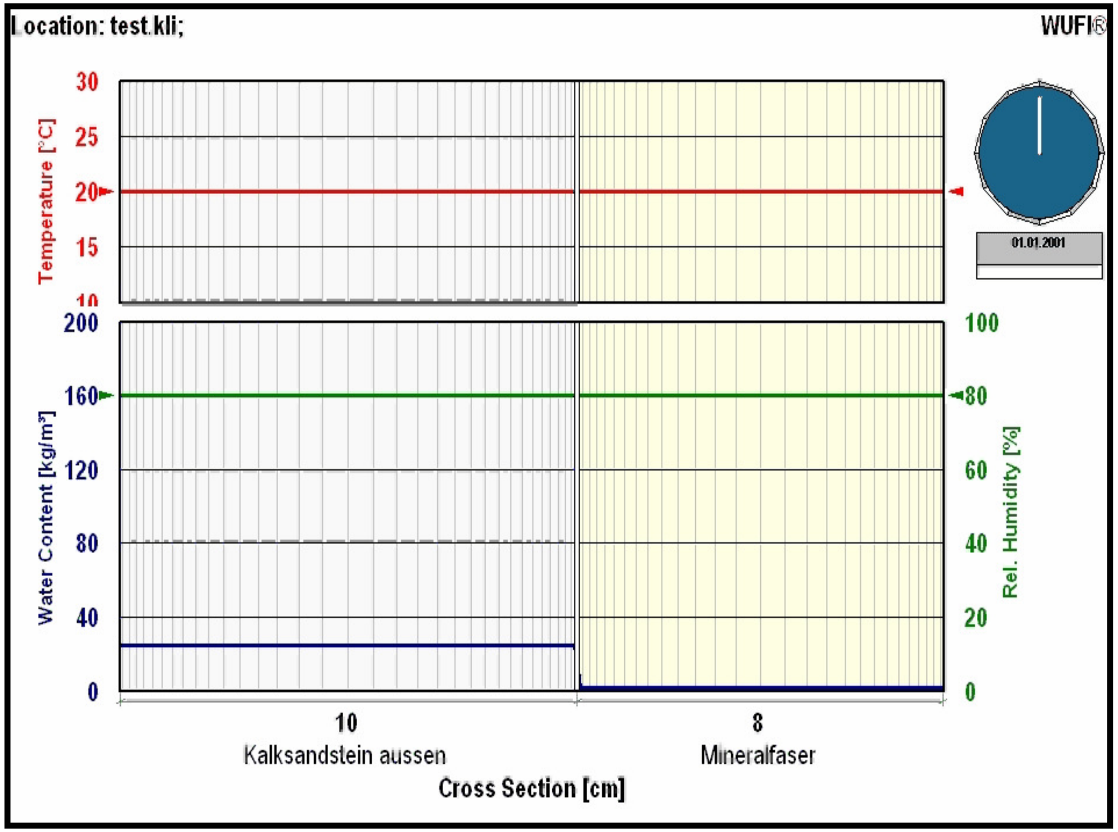
Types of Heat and Moisture Sources

Validation / Examples

Problems

Introduction

Is there really a generation of heat or moisture in terms of a source inside the component?



Answer: No

(Conservation of Energie and Mass)

Introduction

Why do we have and use Sources/Sinks in WUFI® ?

Answer: To apply different effects of a 3-dim. reality in einer 1-dim. simulation.

- **Heat supply due to radiation (partial transparent cladding´s)**
- **Heat supply due to floor or wall heating/cooling systems**
- **Moisture penetration due to driving rain**
- **Moisture and Heat Exchange due to Ventilation**

Content:

- ✓ Introduction
- Transport Equations in WUFI® Ver. 4.1
- Types Heat and Moisure Sources
- Validation / Examples
- Problems

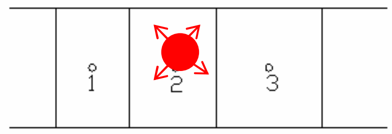
Transport Equations in WUFI® Ver. 4.1

Heat Transport

$[J/m^3K]$ Heat Capacity of the wet material

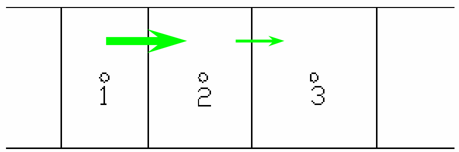
[K/s] Change of Temperature in Time (solution)

[W/m³]
External Heat Source
New in Ver. 4.1



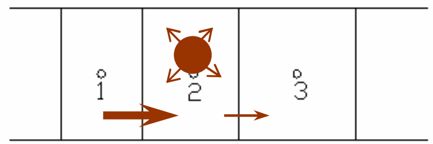
$$\frac{dH}{d\vartheta}\cdot\frac{\delta\vartheta}{\delta t} = \nabla\cdot\underbrace{(\lambda\nabla\vartheta)}_{Heat\ Flux} - \underbrace{h_v\nabla g_v}_{Latent\ Heat\ Source} + s_h$$

Change of the Heat Flux in Depth



$\lambda\ [W/mK]$ Heat Conductivity of the wet material

Change of the Diffusion Flux g_v
In Depth => Heat Source due to sorption

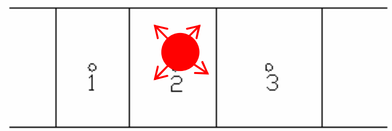


$h_v\ [J/kg]$ Evaporation Enthalpy of water

Transport Equations in WUFI® Ver. 4.1

Moisture Transport

[kg/sm³] external Moisture Source
neu ab Ver. 4.1

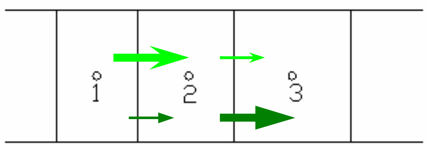


[kg/m³] Moisture Storage Capacity of the material

[1/s] Change of RH in Time (solution)

$$\frac{dw}{d\varphi}\frac{\delta\varphi}{\delta t} = \nabla \cdot \Big(\underbrace{D_\varphi \nabla \varphi}_{Capillary\ Moisture\ Flux} + \underbrace{\frac{\delta_l}{\mu} \nabla (\varphi p_{sat})}_{Vapor\ Diffusion\ Flux} \Big) + s_w$$

Change of he total Moisture Flux in Depth



D_φ $[kgm/s]$	Liquid Transport Coefficient of Water
δ_l $[kg/msPa]$	Vapor Diffusion Transport Coefficent (in Air)
μ $[-]$	Vapor Diffusion Resistance Factor
p_{sat} $[Pa]$	Vapor Saturation Pressure

Transport Equations in WUFI® Ver. 4.1

Coupled Transport Equations

Strong coupling of Heat and Moisture Transport due to

- Vapor Saturation Pressure has an exponentiell dependency of the temperature
- Heat Conductivity depends on Water Content
- Enthalpy Flux due to Vapor Diffusion
- Additional Coupling due to Heat Sources/Sinks (Ver. 4.1)

$$\frac{dH}{d\vartheta} \cdot \frac{\delta\vartheta}{\delta t} = \nabla \cdot \underbrace{(\lambda \nabla \vartheta)}_{Heat\ Flux} - \underbrace{h_v \nabla g_v}_{Latent\ Heat\ Source} + s_h$$

$$\frac{dw}{d\varphi} \cdot \frac{\delta\varphi}{\delta t} = \nabla \cdot (\underbrace{D_\varphi \nabla \varphi}_{Capillary\ Moisture\ Flux} + \underbrace{\frac{\delta_l}{\mu} \nabla (\varphi p_{sat}))}_{Vapor\ Diffusion\ Flux} + s_w$$

Parallel Solution of both equations is a must.

Transport Equations in WUFI® Ver. 4.1

Effect of Sources and Sinks to the Balances

New !!!

Time Integral of fluxes

Heat Flux, left side [MJ/m²]	-102,03
Heat Flux, right side [MJ/m²]	-105,12
Heat Sources [MJ/m²]	-5,78
Moisture Fluxes, left side [kg/m²]	10,49
Moisture Fluxes, right side [kg/m²]	0,08
Moisture Sources [kg/m²] (1)	-5,31

Status of Calculation

Calculation: Time and Date	06.07.2007 11:24:53
Computing Time	0 min,27 sek
No. of Convergence Failures	2
No. of Rain Absorption Failures	2

Check for numerical quality

Integral of fluxes, left side (kl,dl) [kg/m²] (2)	27,19 -16,72	Σ=10,47
Integral of fluxes, right side (kr,dr) [kg/m²] (3)	0,0 0,08	Σ=0,08
Balance 1 [kg/m²]	5,07	
Balance 2 [kg/m²]	5,08	= (2) - (3) + (1)

Content:

- ✓ Introduction
- ✓ Transport Equations in WUFI® Ver. 4.1
- **Types of Heat and Moisture Sources**
- Validation / Examples
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Types of Heat and Moisture Sources

Heat and Moisture Sources can be defined from the user in the following different ways:

- **Transient (time-dependent) from an external file**
- **Coupled to the exterior boundary condition (Solar Radiation; Driving Rain)**
- **Transient Air Change Rate with the exterior Air (Heat and Moisture Source or Sinks)**

These Sources can be aplied to a single element or to more (side by side) Elements.

Types of Heat and Moisture Sources

Heat Sources

[W/m³] External Heat Source Density

[W/m²] External Heat Source

$$S_h \cdot \Delta x = S_h$$

Fraction of the Solar Radiation

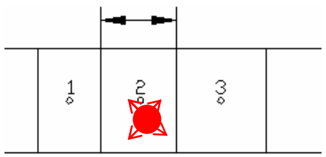
$$S_h = f \cdot I_s$$

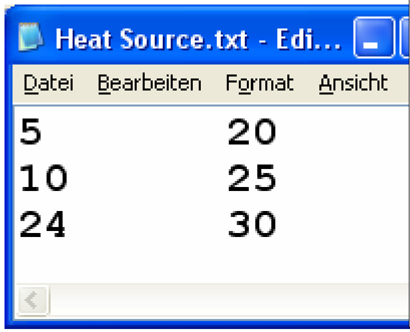
f [-] Fraction

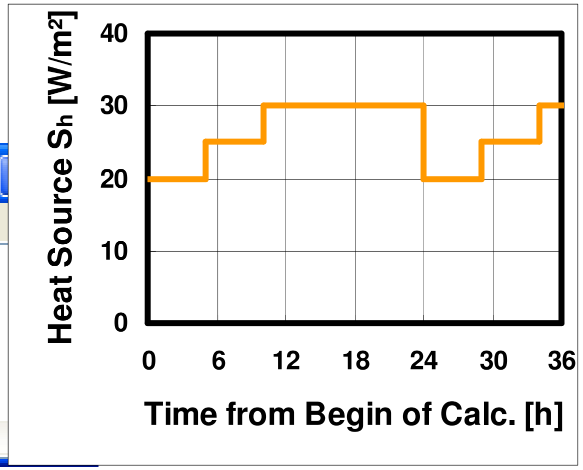
I_s [W/m²] Solar Radiation on the Surface

From File

Δx [m] Element Thickness







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Heat and Moisture Sources / Simulation of Ventilation

Types of Heat and Moisture Sources

Moisture Sources

$$S_w = f \cdot \frac{R}{3600}$$

f [-] Fraction
R [mm/h] Driving Rain on the Surface [l/hm²]; [kg/hm²]

[kg/sm³] External Moisture Source Density

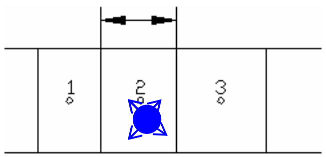
[kg/sm²] Ext. Moisture Source

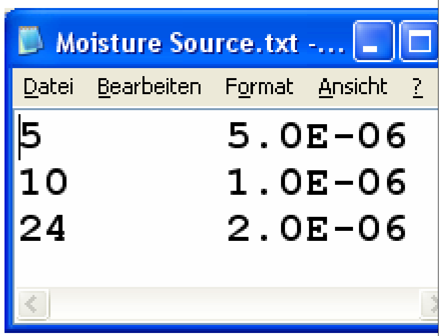
$$S_w \, \Delta x = S_w$$

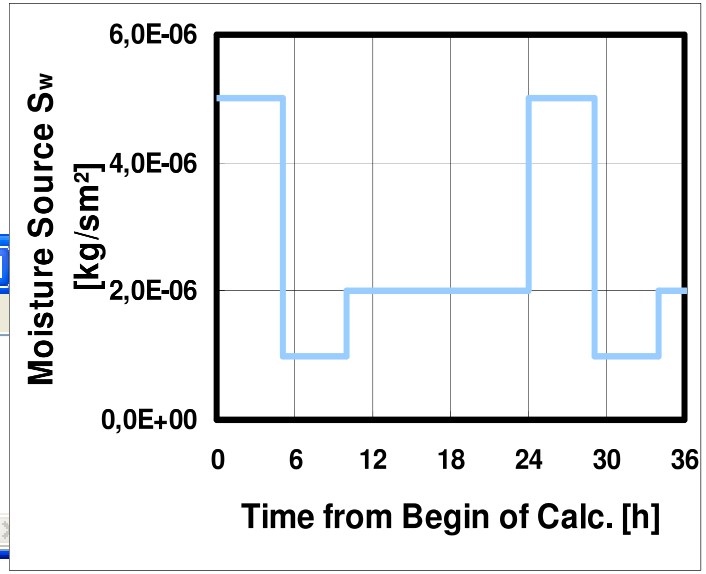
Fraction of driving Rain

From File

Δx [m] Element Thickness

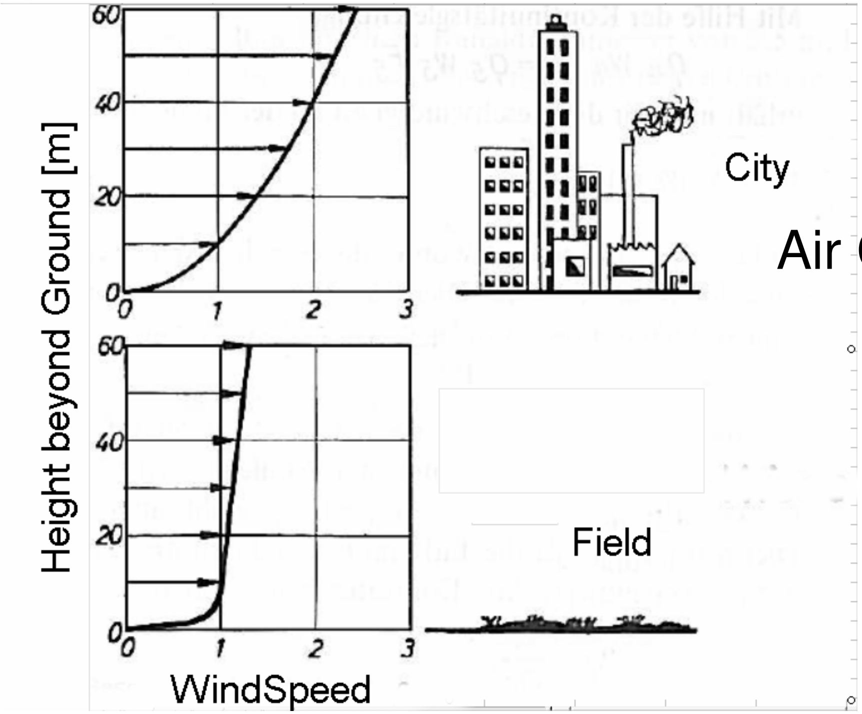






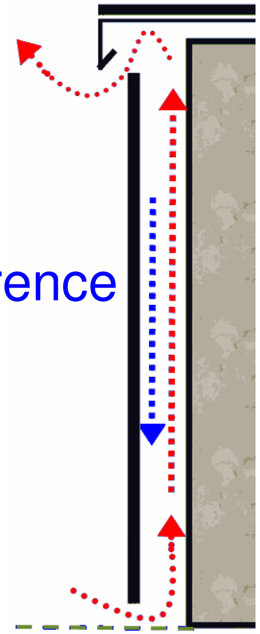
Types of Heat and Moisture Sources

Air Change in Ventilated Cavities



Air Change due to:

- Wind Pressure Difference
- Thermal Buoyancy

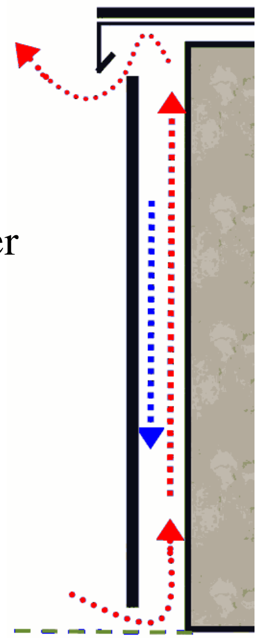


But: Generally accepted models do not exist at the time!!!

Types of Heat and Moisture Sources

Heat and Moisture Source due to Ventilation

Wind Pressure Difference und Thermal Buoyancy result in an Air Change between Cavity and the exterior Air. This can be describied with the Air Change Rate [1/h].



$$ACH = \frac{Q}{V}$$

ACH	[1/h]	Air Change Rate
Q	[m³/h]	Volume Flow Rate in the ventilated Layer
V	[m³]	Volume of ventilated Layer

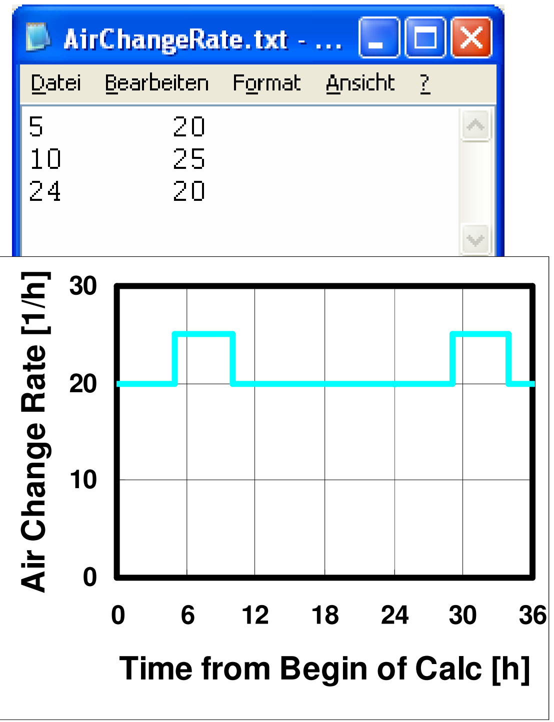
$$ACH = \frac{v \cdot 3600 \frac{s}{h}}{H}$$

v	[m/s]	Wind Speed in the ventilated Layer
H	[m]	Height of the ventilated Layer

Types of Heat and Moisture Sources

Calculation of the Source Term due to Ventilation

Heat Source: $$S_h = \rho_{out} \cdot \frac{ACH}{3600} \cdot d_{Vent} \cdot C_{p,Air} \cdot (T_{Out} - T_{Vent})$$



S_h: Heat Source [W/m²]
ρ_{out}: Density of the exterior Air [kg/m³]
ACH: Air Change Rate in the ventilated Layer [1/h]
d_{Vent}: Thickness of the ventilated Layer [m]
$C_{p,Air}$: Spec. Heat Capacity of Air [J/kg K]
T_{out}: Temperature; Outdoor [K]
T_{Vent}: Temperature in the ventilated Layer [K] (mean value of all Elements)

Moisture Source: $$S_w = \frac{ACH}{3600} \cdot d_{Vent} (c_{Out} - c_{Vent})$$

S_w: Moisture Source [kg/m²s]
c_{out}: Water Vapor Concentration in the Air; Outdoor [kg/m³]
c_{Vent}: Water Vapor Concentration in ventilated Layer [kg/m³] (mean value of all Elements)

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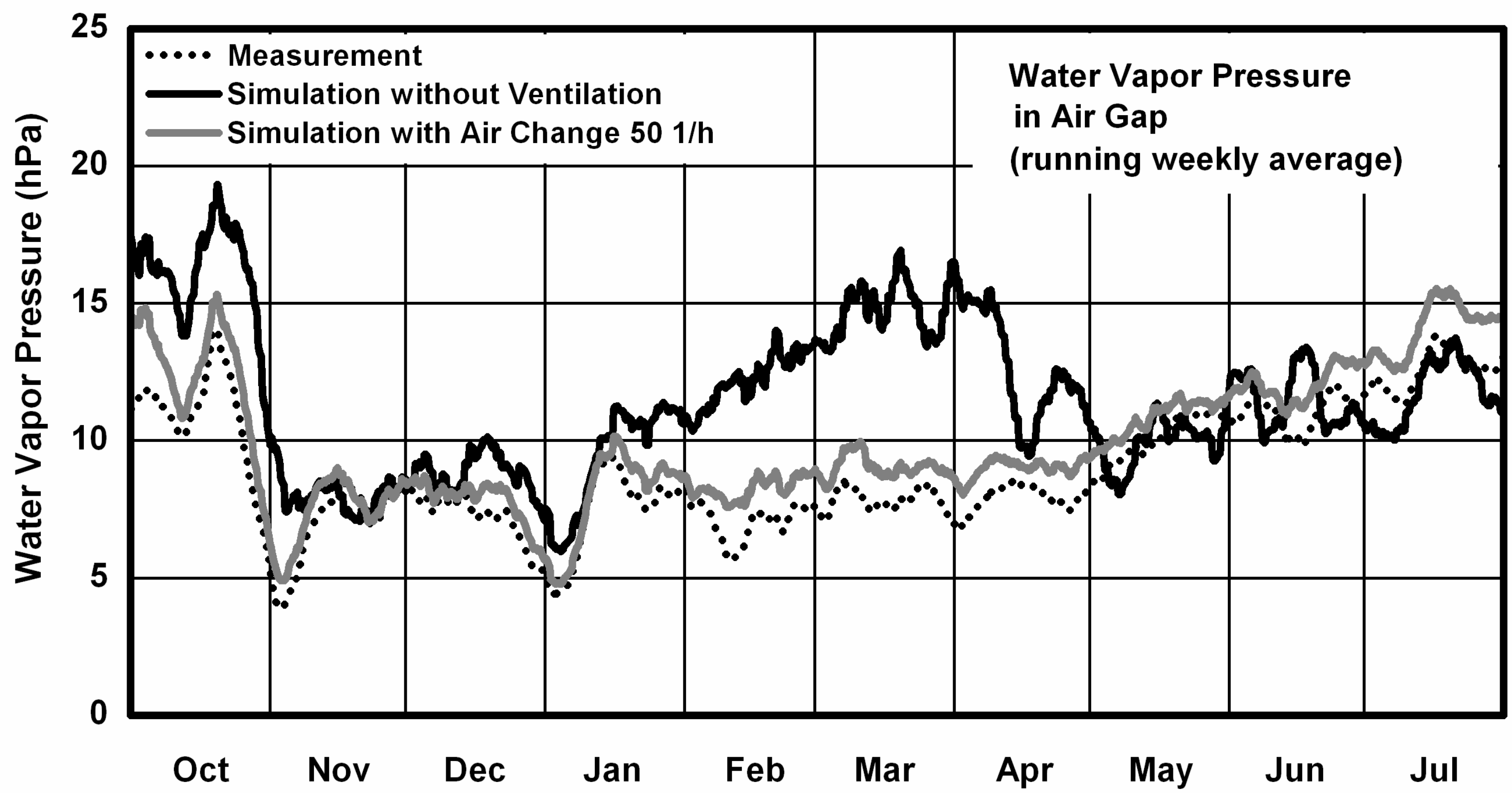
Validation / Examples

Test Building in Seattle

- Wooden Construction with ventilated plaster cladding
- Measurements of Outdoor/Indoor Climate for about 1 year
- Measurements of the climate conditions in the Cavity



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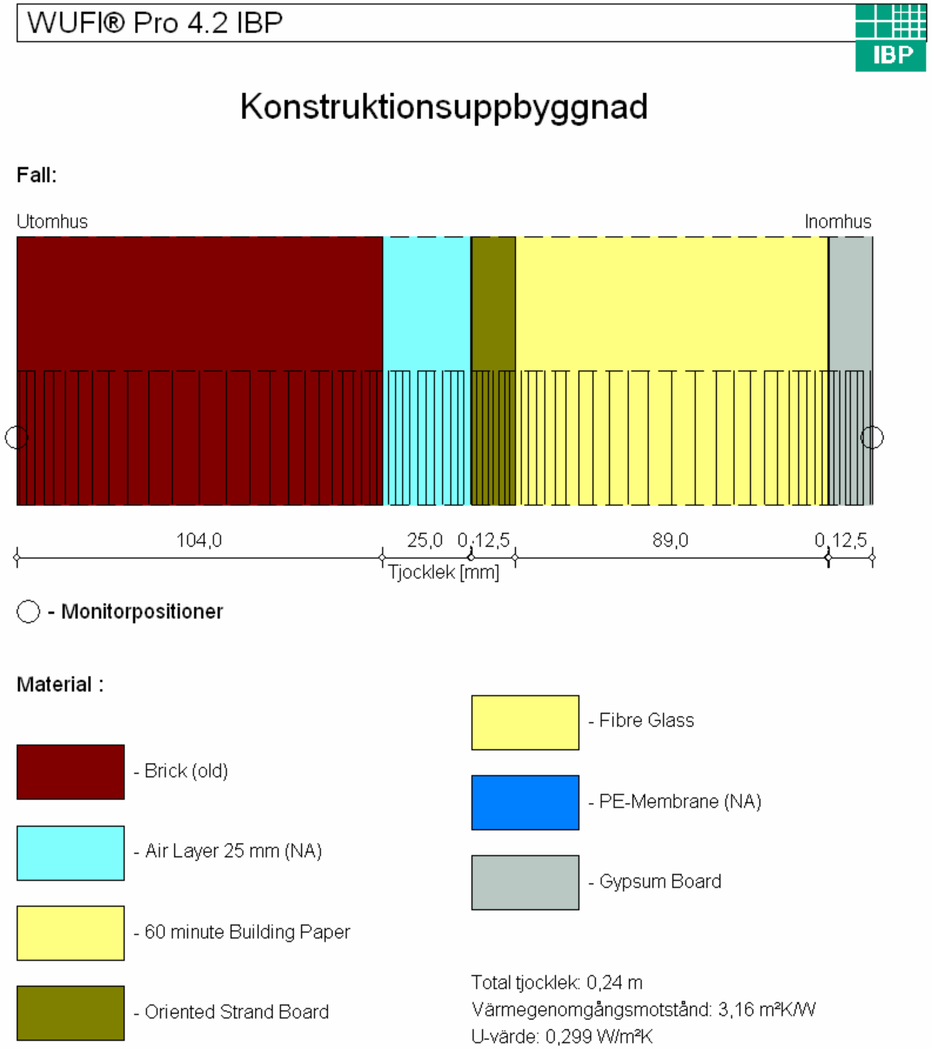
Heat and Moisture Sources / Simulation of Ventilation



Comparison:

Air Gap ventilated

versus

Air Gap not ventilated

Start Animation 1D

Content:

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- **Problems**

Problems

Sources/Sinks are additional requirements for the numerical solution

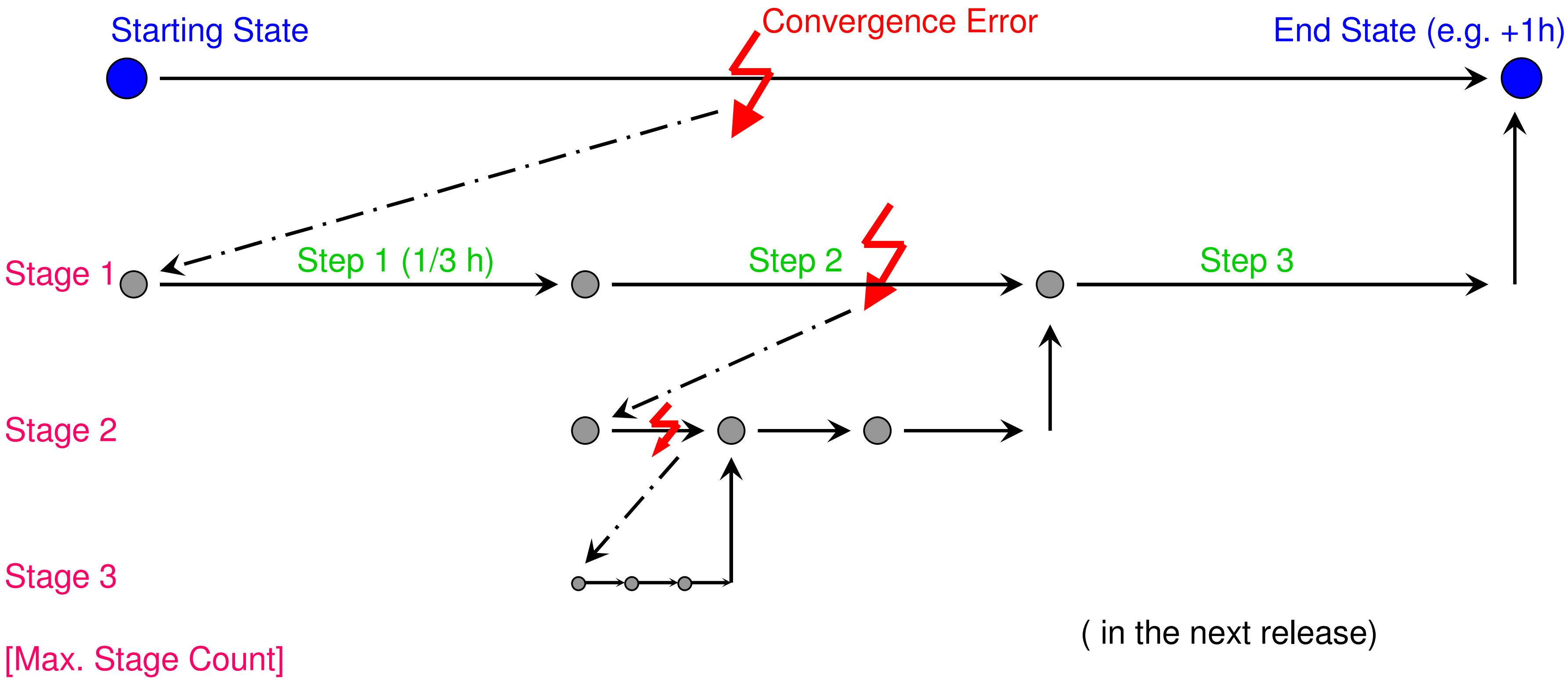
- Additional Coupling of the Heat and Moisture Equation
- High Amounts of Moisture can not be absorped
- Sources due to Air Change Rate yields implcit Source Terms (means they must be recalculated at every iteration step)

Consequence:

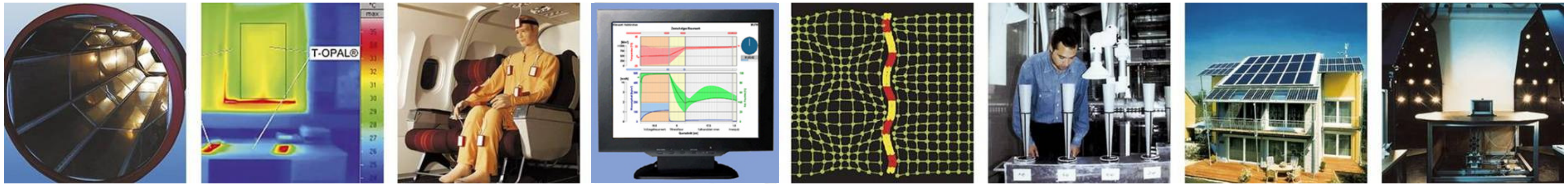
- Count of Convergence Error can increase
- The both Equations can diverge
- Numerical Crashes (Zero Division; Floating-Point Overflow)

Problems/Solution

ATSC: Adaptive Time Step Control



(in the next release)



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