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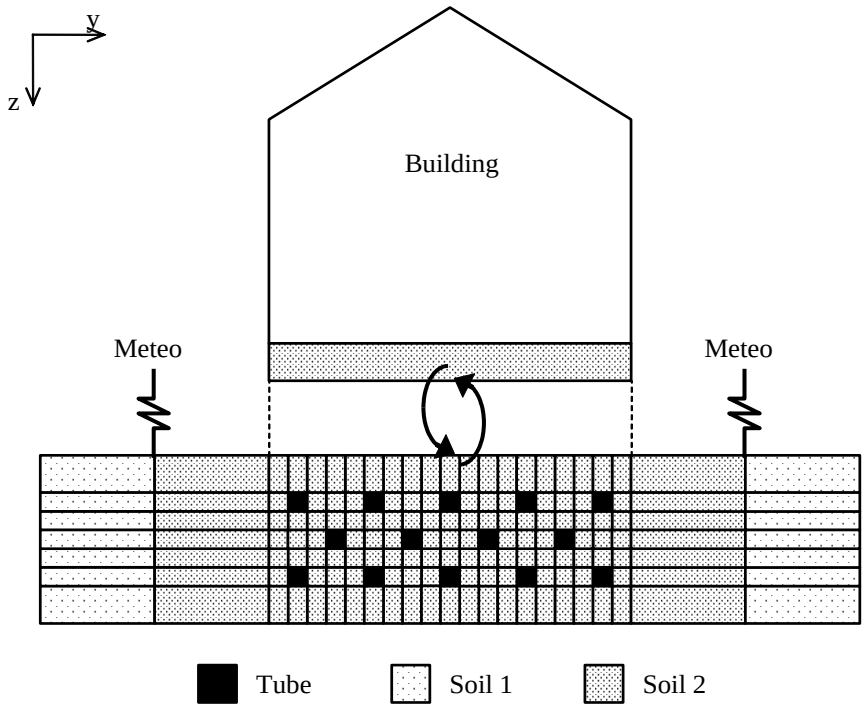
Earth Air Tunnel: Numerical simulation tool

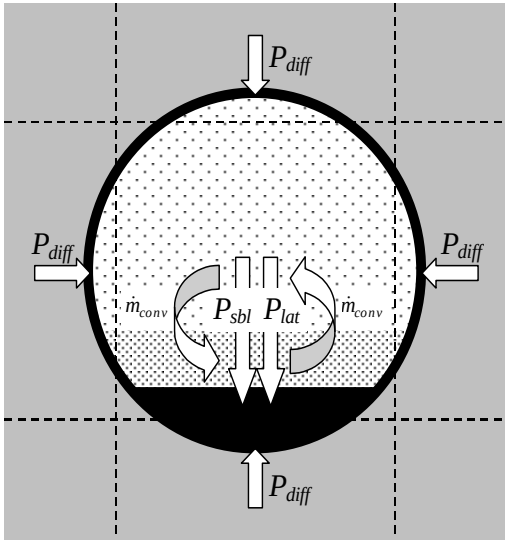
Numerical model



- Flexible geometry (inhomogeneous soils, diverse border conditions)
- 3 dimensional heat diffusion
- Sensible and latent heat exchange (condensation/evaporation)
- Possible water infiltration
- Charge losses
- Variable airflow, variable direction
- Integration in TRNSYS

Numerical model

Algorithm (at pipe node)



- Sensible heat

$$P_{sbl} = S_{tub} \cdot h \cdot \left(T_{air} - T_{tub}\right)$$

$$h = \frac{\lambda_{air}}{2d} Nu$$

$$Nu = 0.0214\left(\mathrm{Re}^{0.8} - 100\right)\mathrm{Pr}^{0.4}\left(1 + \left(\frac{d}{L}\right)^{2/3}\right)\left(\frac{T_a}{T_t}\right)^{0.45}$$

- Latent heat

$$\dot{m}_{conv} = \frac{P_{sbl}}{c_{air} \cdot \left(T_{air} - T_{tub}\right)} = \frac{S_{tub} \cdot h}{c_{air}}$$

$$\dot{m}_{lat} = \left(W_{air} - W_{tub}\right) \cdot \dot{m}_{conv} = \left(W_{air} - W_{tub}\right) \cdot \frac{S_{tub} \cdot h}{c_{air}}$$

$$W_{air} = \frac{H \cdot \mathrm{Pr}_{sat}\left(T_{air}\right) \cdot M_{wat}}{\mathrm{Pr}_{air} \cdot M_{air}}$$

$$W_{tub} = \frac{100\% \cdot \mathrm{Pr}_{sat}\left(T_{tub}\right) \cdot M_{wat}}{\mathrm{Pr}_{air} \cdot M_{air}}$$

$$P_{lat} = c_{lat} \cdot \dot{m}_{lat}$$

Numerical model

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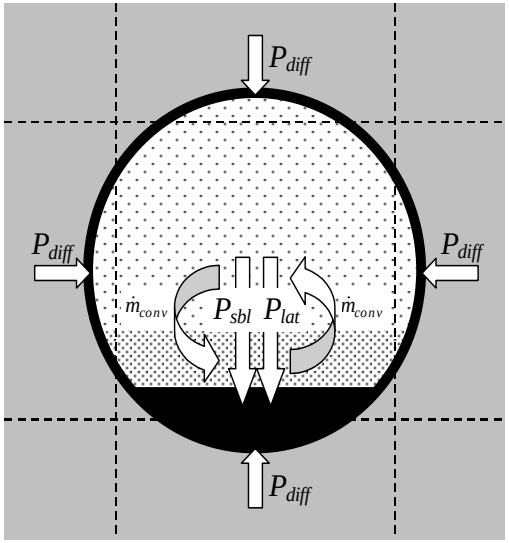
Algorithm (at pipe node)



- Heat diffusion

$$P_{diff} = \sum_{i \in soil} S_i \cdot k_i \cdot \left(T_{soil,i,t-1} - T_{tub}\right) + \sum_{i \in tube} S_i \cdot k_i \cdot \left(T_{tub,i,t-1} - T_{tub}\right)$$

- Internal gains

$$P_{int} = \frac{\left(c_{tub} \cdot \rho_{tub} \cdot V_{tub} + c_{wat} \cdot m_{wat,t-1}\right) \cdot \left(T_{tub} - T_{tub,t-1}\right)}{\Delta t}$$

- Energy balance on pipe node

$$P_{int} - \left(P_{sbl} + P_{lat} + P_{diff}\right) = 0$$

- Charge losses

$$P_{fric} = \dot{m}_{air} \cdot f \cdot \frac{l}{d} \cdot \frac{v_{air}^2}{2}$$

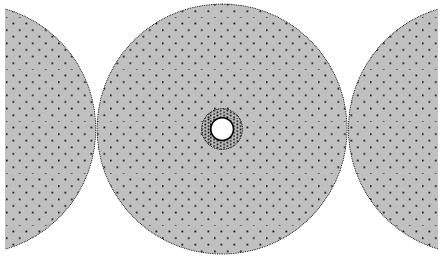
- Energy balance on airflow

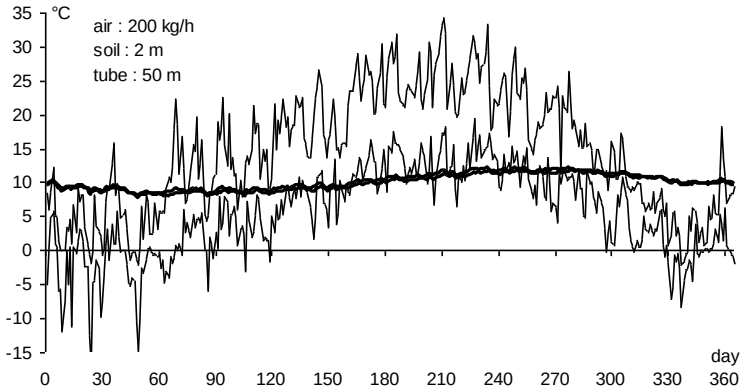
$$T_{air,i} = T_{air} + \frac{P_{fric} - P_{sbl}}{\left(c_{air} + c_{vap} \cdot W_{air}\right) \cdot \dot{m}_{air}}$$

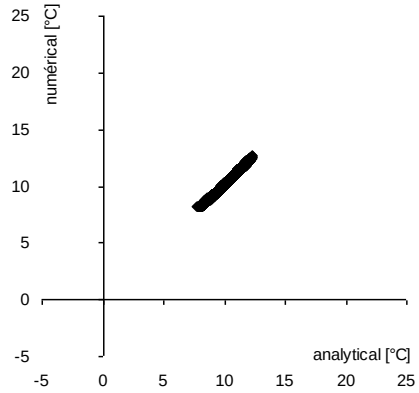
Model validation

Numerical versus analytical model

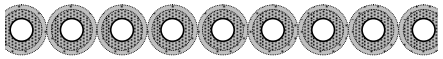
Dampening of annual oscillation

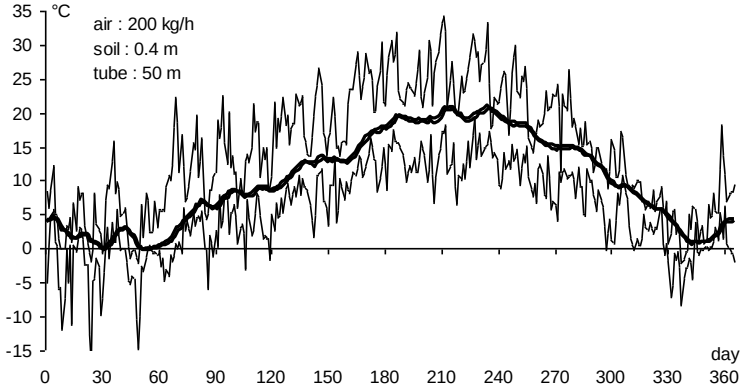


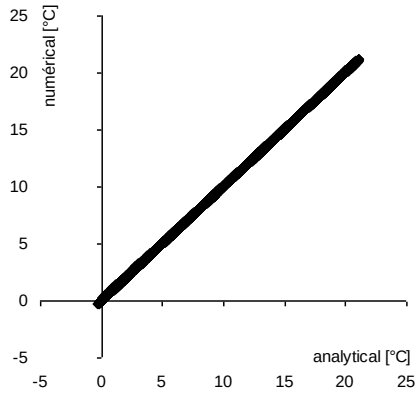




Dampening of daily oscillation

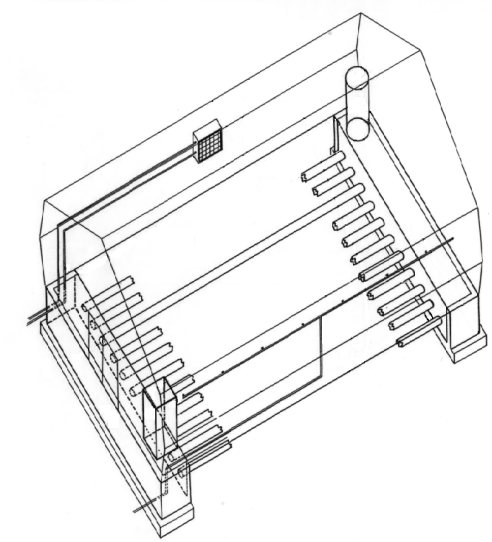


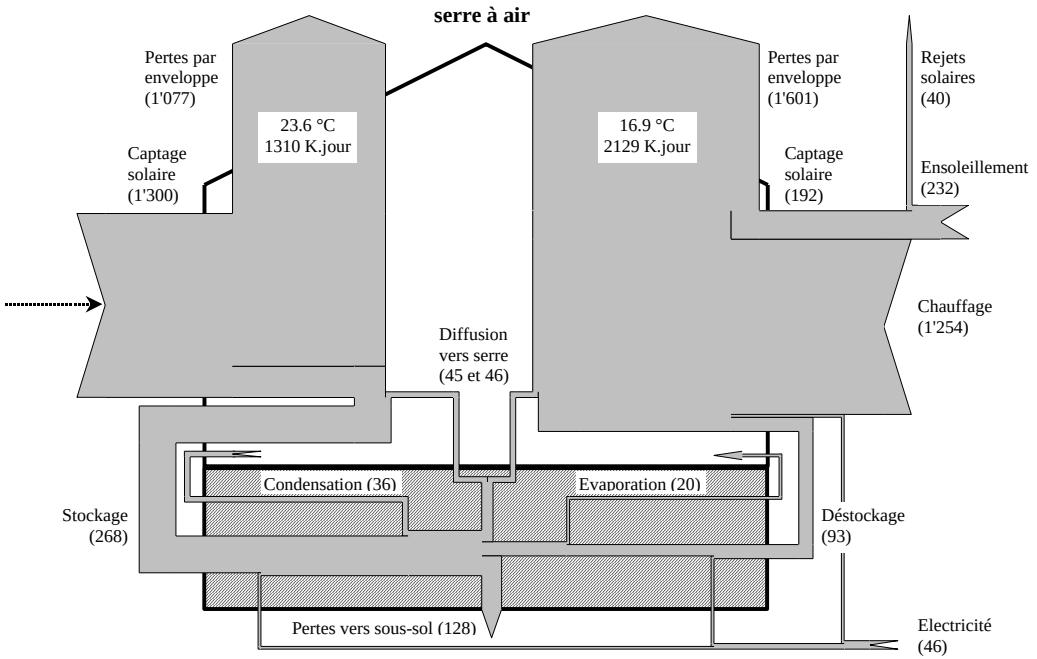




Model validation

Numerical simulation versus monitoring (Geoser)





Monitoring data:

- 1 hour time step
- 18 months

Model validation

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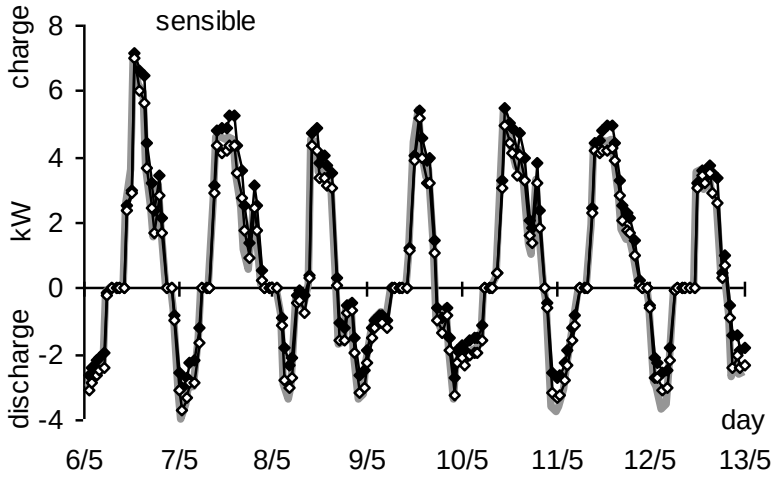
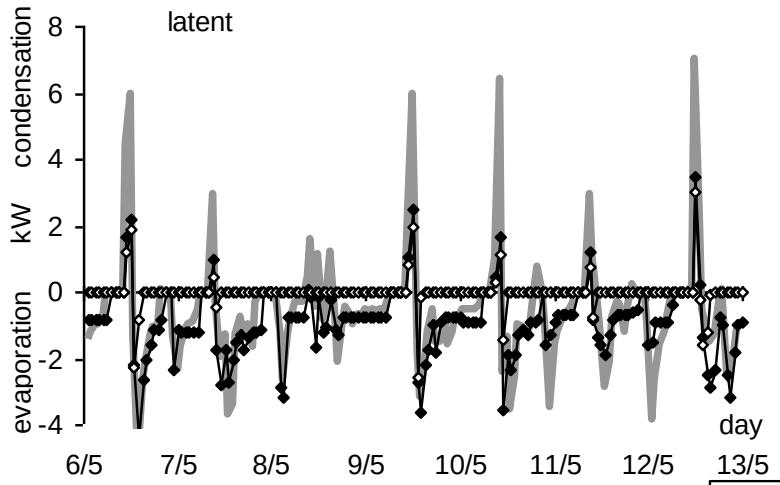
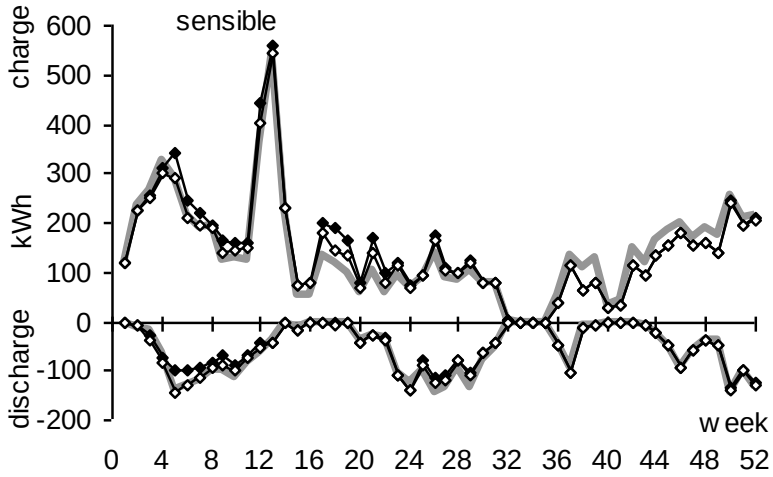
Numerical simulation versus monitoring (Schwerzenbacherhof)

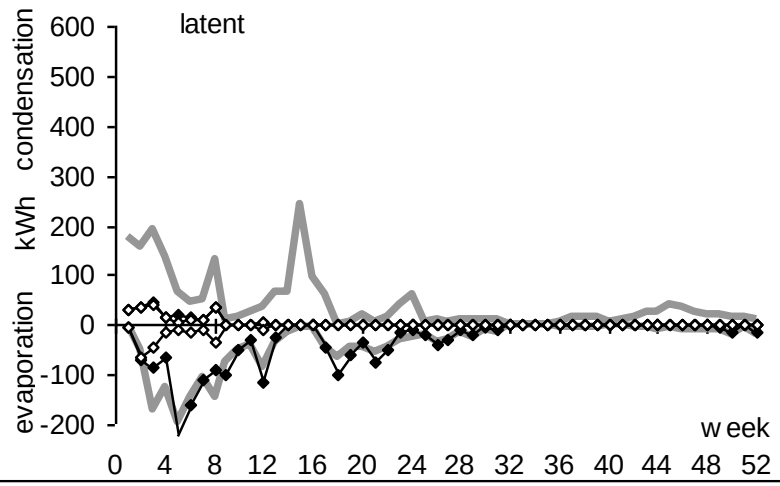
Hourly dynamic over one week





Weekly dynamic over one year





monitoring — simulation with infiltration — simulation without infiltration

Model validation

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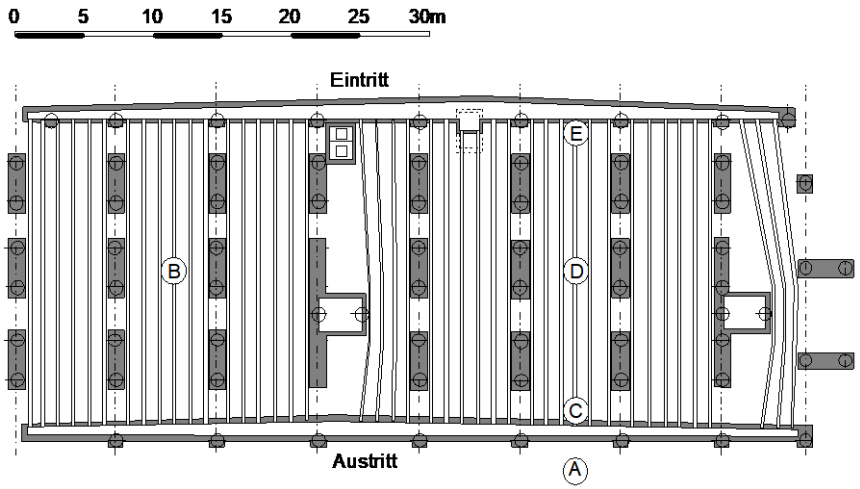
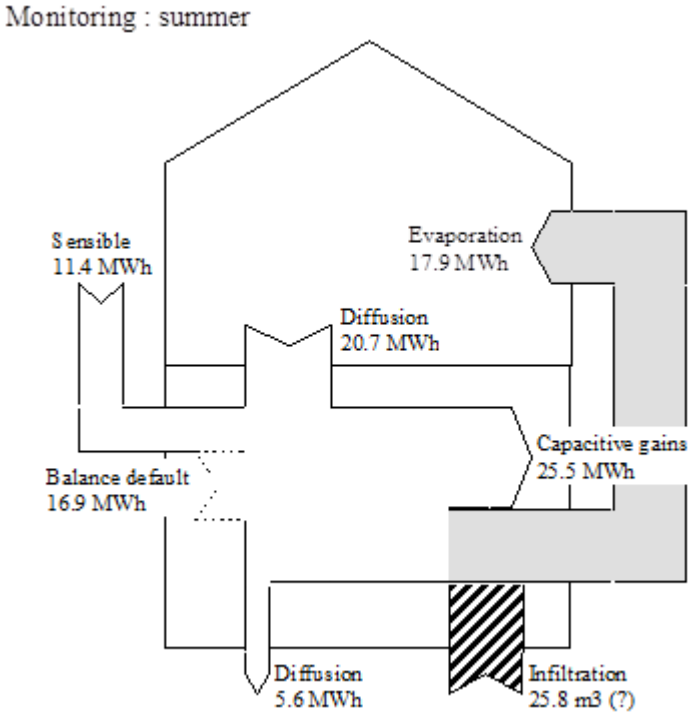
Numerical simulation versus monitoring (Schwerzenbacherhof)





Monitoring data:

- Airflow, temperature, humidity
- 1 hour time step over 1 year

Model validation

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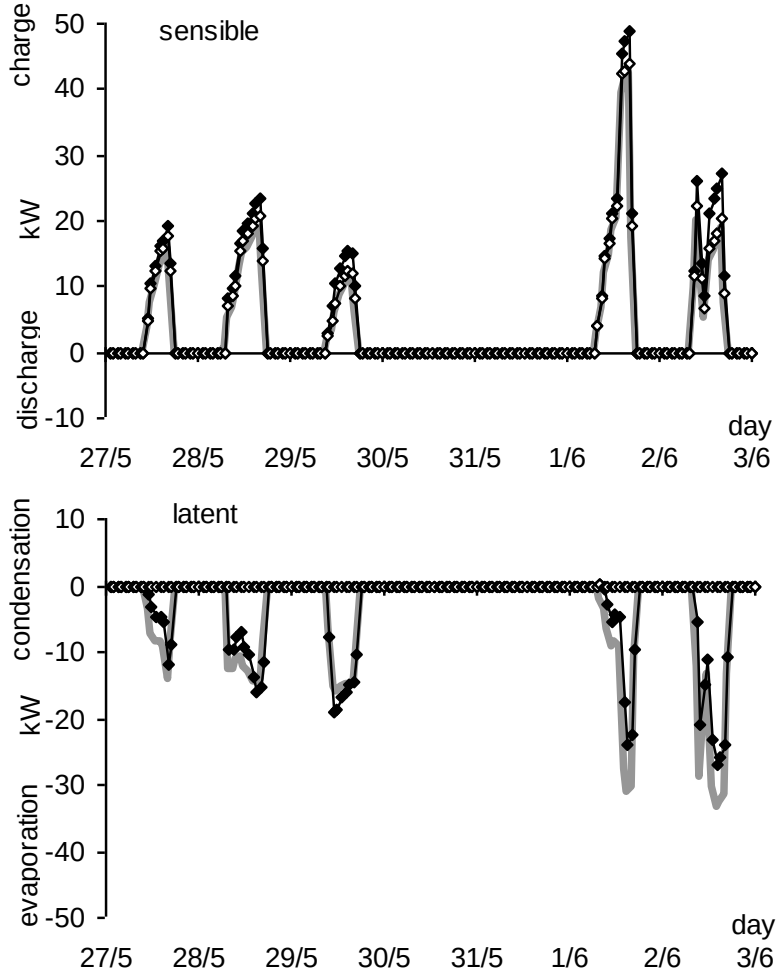
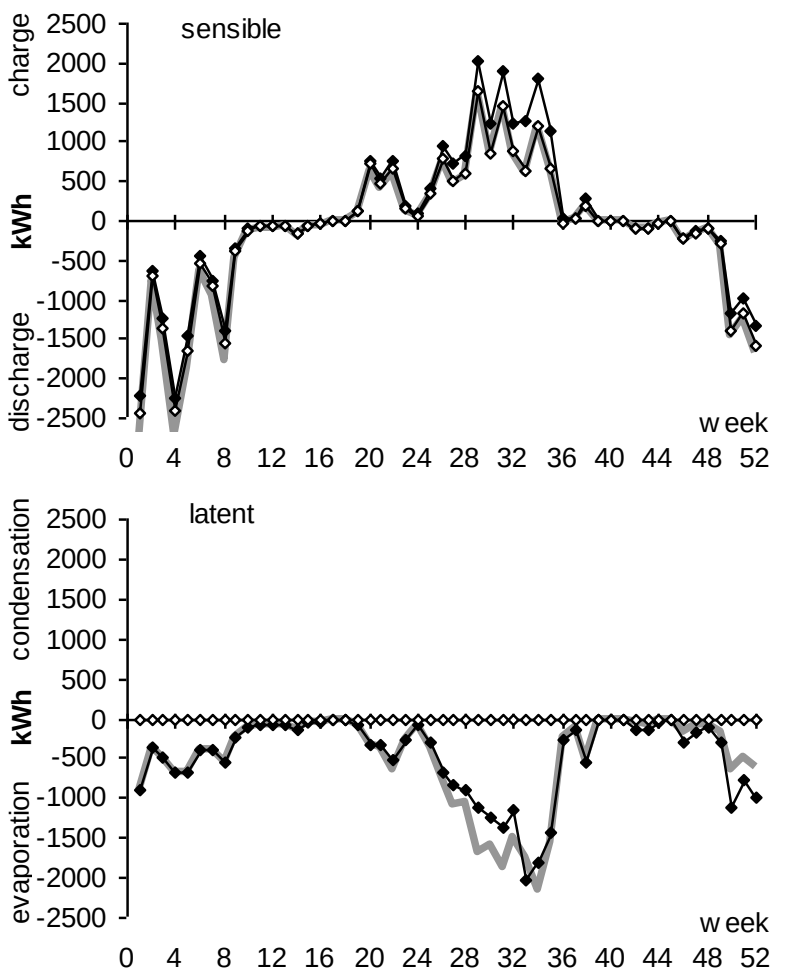
Numerical simulation versus monitoring (Geoser)

Hourly dynamic over one week



Weekly dynamic over one year



monitoring — simulation with infiltration — simulation without infiltration

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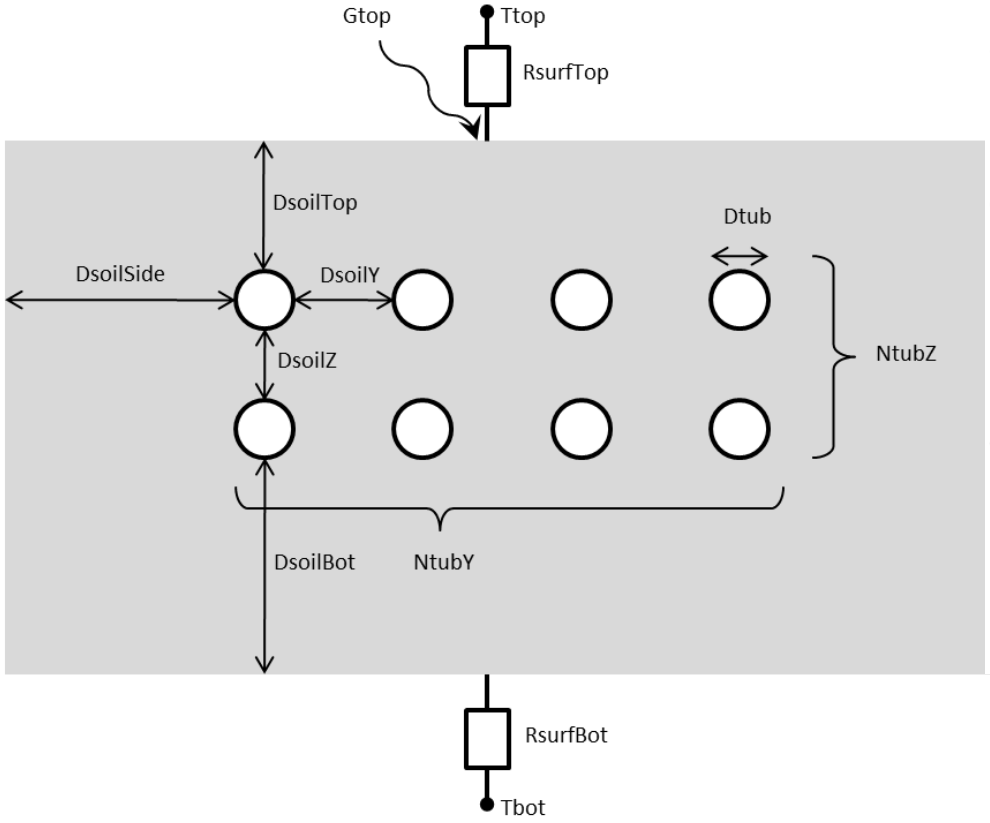
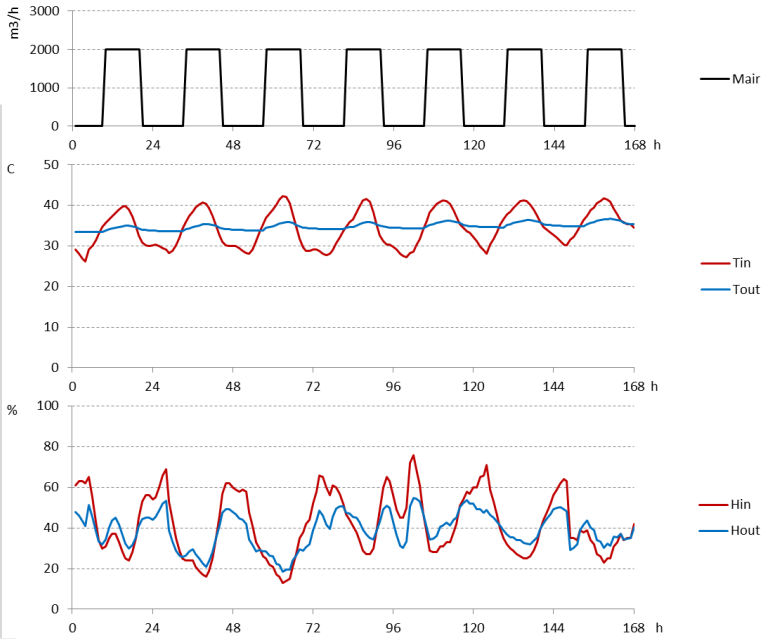
Excel interface to Trnsys simulation environment





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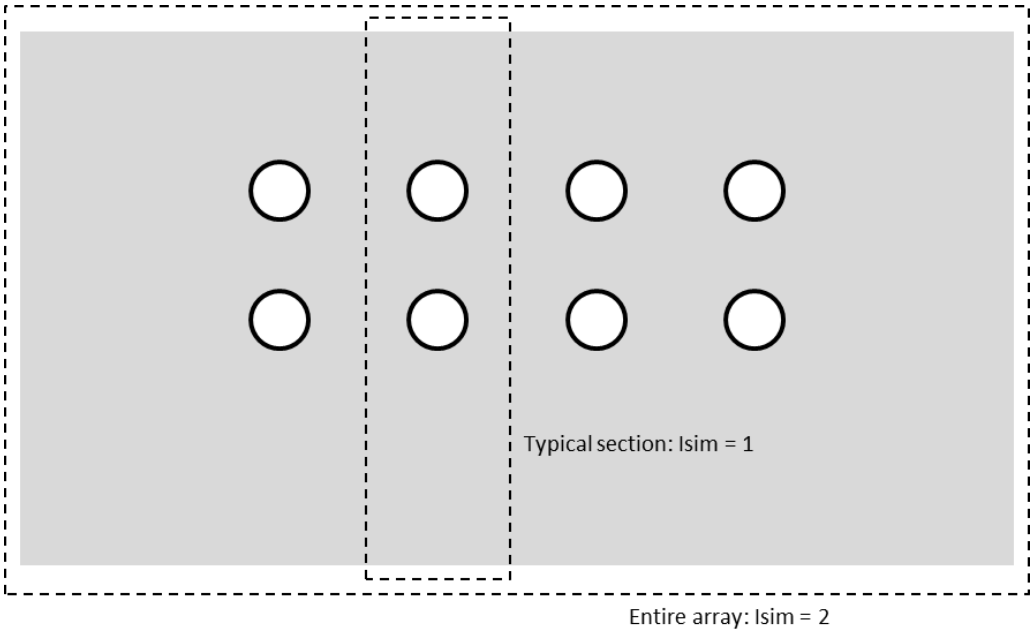
Optimization of simulation time



- Possibility to simulate only one typical section

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Parameters

Symbol	Unit	Description
Geometry		
Ltub	m	pipe length (per pipe)
Dtub	m	pipe diameter
ThTub	m	pipe thickness
NtubY	-	number of pipes y axis
NtubZ	-	number of pipes z axis
DsoilY	m	pipe - pipe distance y axis
DsoilZ	m	pipe - pipe distance z axis
DsoilTop	m	pipe - top surface distance
DsoilBot	m	pipe - bottom surface distance
DsoilSide	m	pipe - lateral surface distance
Node size		
DxIni	m	node initial size, x axis
DxExp	-	node expansion factor, x axis
DyzIni	m	node initial size, y and z axis
DyzExp	-	node expansion factor, y and z axis
Physical properties		
LamSoil	W/K.m	soil conductivity
CvSoil	kJ/K.m3	soil heat capacity
LamTub	W/K.m	pipe conductivity
CvTub	kJ/K.m3	pipe heat capacity
CtubFric	-	pipe friction coefficient
PrAir	Pa	air pressure

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Parameters

Symbol	Unit	Description
Border & initial conditions		
IsurfTop	-	border condition, top (0: adiabatic, 1: active)
RsurfTop	K.m2/W	resistance, top
AsurfTop	-	solar absorptivity
IsurfBot	-	border condition, bottom (0: adiabatic, 1: active)
RsurfBot	K.m2/W	resistance, bottom
TsurfBot	C	temperature, bottom
TiniSoil	C	initial soil temperature
Simulation		
Isim	-	type of simulation (1: typical section, 2: entire array)
Nyear	-	number of years to be simulated

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Inputs

Variable	Unit	Description
Tin	C	inlet temperature
Hin	pcent	inlet relative humidity
Ttop	C	air temperature, top surface
Gtop	W/m2	solar radiation, top surface
Mair	m3/h	air flow (total over all pipe, even for Isim = 1)

Outputs

Variable	Unit	Description
Tout	C	outlet temperature
Hout	pcent	outlet relative humidity
Psbl	kW	sensible heat rate
Plat	kW	latent heat rate
Ptop	kW	diffusive heat rate, top surface