BES Performance
Matlab vs. Simulink

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Carnot User Meeting

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Outline

- Introduction
- BES (R-C Networks, system of ODE)
- Numerics PDE / ODE
- ODE Solver in Matlab and Matlab/Simulink
- Performance of the Simulation Modes
- Case Studies
- % Optimization
- Results and Conclusions
- Outlook

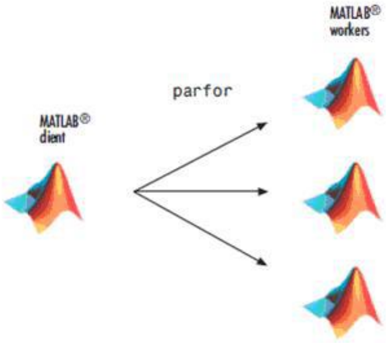
Aspects Influencing Simulation Performance

Bootlenecks

- Number of ODE (PDE -> Large System of ODE)
- Time-constant; Stiff, non-stiff ODE
- Algebraic loops
- „Events“, interpolation, non-linearities, control
- Memory

Simulator‘s choice

- ODE Solver (explicit, implicit, CN)
- Compilation (accelerator, rapid accelerator)
- Model simplification (linearisation, reduced order models, state space)
- parallelisation
- Co-Simulation



No all can be parallelised …

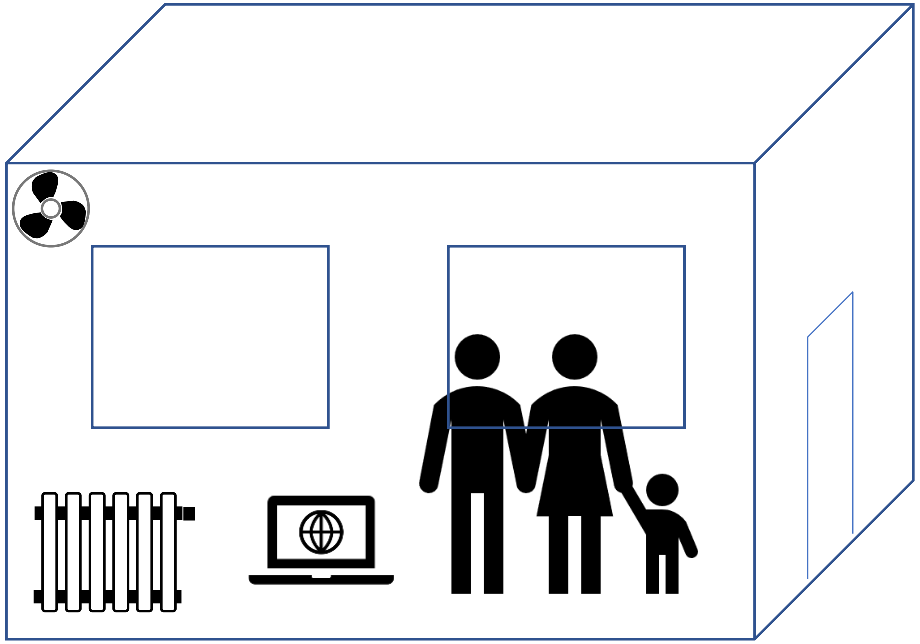
Yes …

Parameter sweep

No …

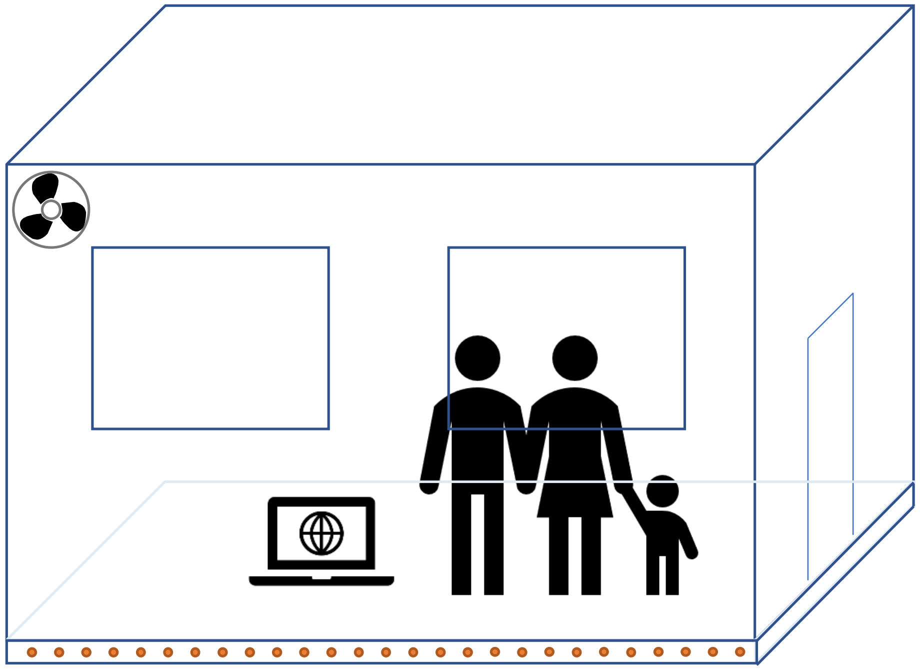
Time

Simple Building (Room) Model - Radiator



- Air Node (thermal Zone)
- Wall (Ceiling, Floor)
- Window
- Ventilation
- Solar Gains (SHGC)
- Internal Gains
- Heating with on/off control (hysteresis)

Simple Building (Room) Model – Floor Heating



» Air Node (thermal Zone)
» Wall (Ceiling, Floor)
» Window
» Ventilation
» Solar Gains (SHGC)
» Internal Gains
» Heating with on/off control (hysteresis)

Gebäudeenergiebilanz instationär

$$\frac{dU}{dt} = \dot{Q}_T + \dot{Q}_V + \dot{Q}_I + \dot{Q}_s + \dot{Q}_{Heat}$$

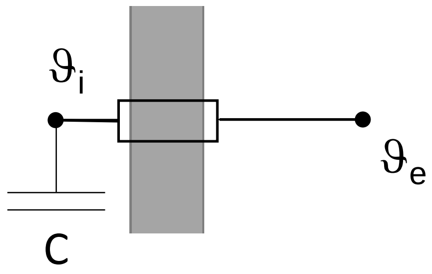
$$(\rho \cdot V \cdot c)_{eff} \frac{d\vartheta}{dt} = \dot{Q}_T + \dot{Q}_V + \dot{Q}_I + \dot{Q}_s + \dot{Q}_{Heat}$$

$$\dot{Q}_T, \dot{Q}_V, \dot{Q}_I, \dot{Q}_S, \dot{Q}_{Heat} = f(t, \vartheta_e, \vartheta_i, \dots)$$

(System of) ODE(s)

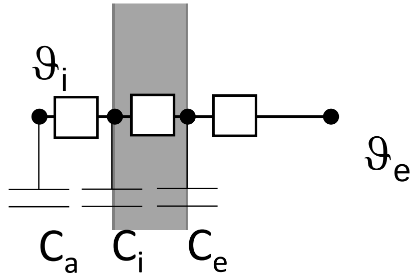
Luftknoten und Wärmekapazität

Lumped Mass, UA (0N)



Resitance Model (lumped capacity)

Wall with Capacity (2N)



R-C Modell (1 … N) Capacitances)

Case Studies

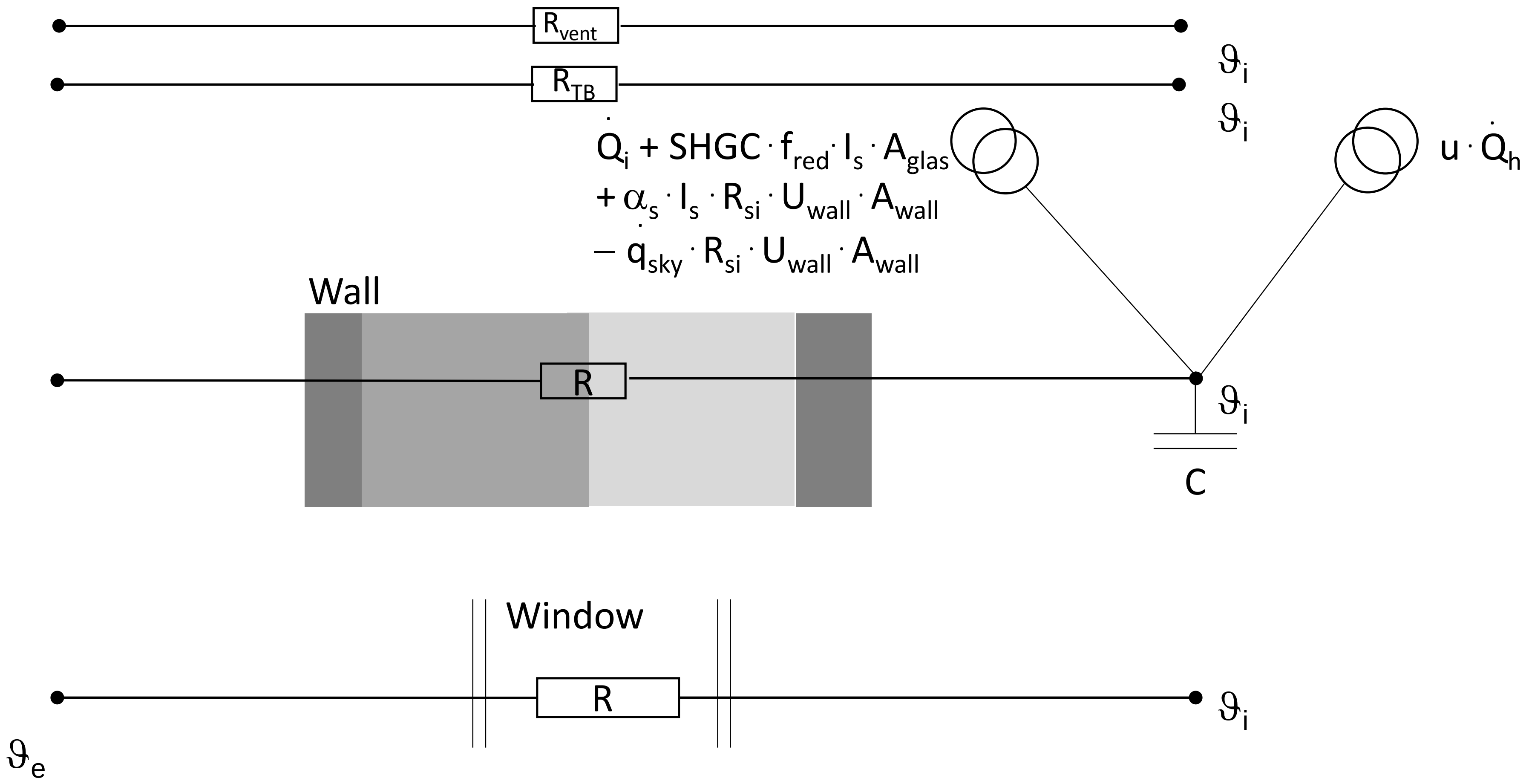
• UA Room Model (simple, lumped mass)	1 ODE
• RC Wall Model (4C)	4 ODE
• 1* thermal zone, RC-Wall Model (4C) window (2C)	7 ODE
• 2* thermal zone, RC-Wall Model (4C) window (2C)	8 ODE
• Floor Heating Model (9C)	9 ODE
• 2* thermal zone RC-Wall (4C) FH (9C) window (2C)	17 ODE

Simple climate (sine, synthetic) … Climate file (interpolation, indexed)

Pre-Processing … Simulation … Post-Processing

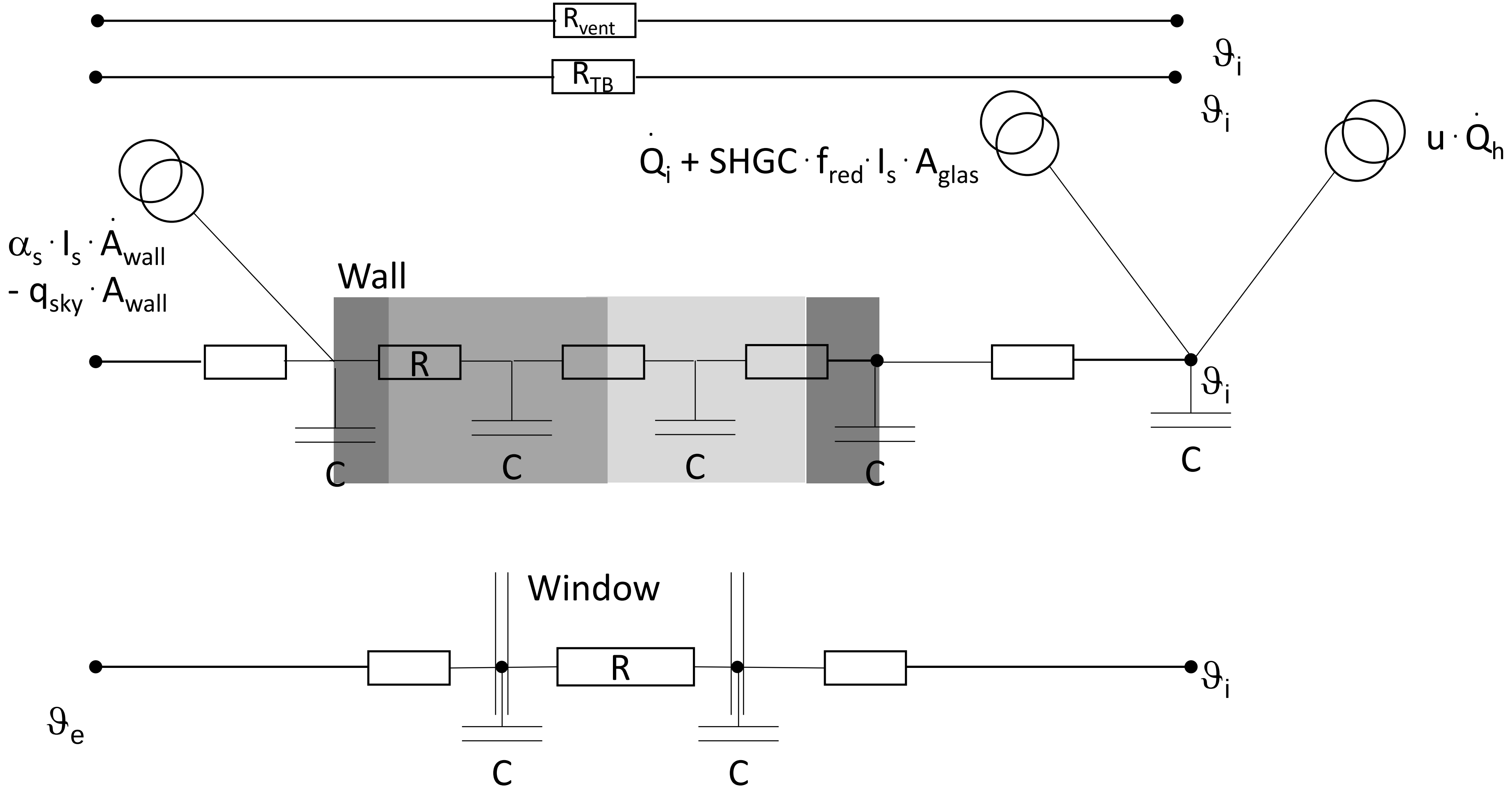
Lumped Mass (0N) model (1 ODE)

$err = \vartheta_{SP} - \vartheta_i$
$u = f(err)$



1star 4 node model (7 ODE)

$err = \vartheta_{SP} - \vartheta_i$
$u = f(err)$

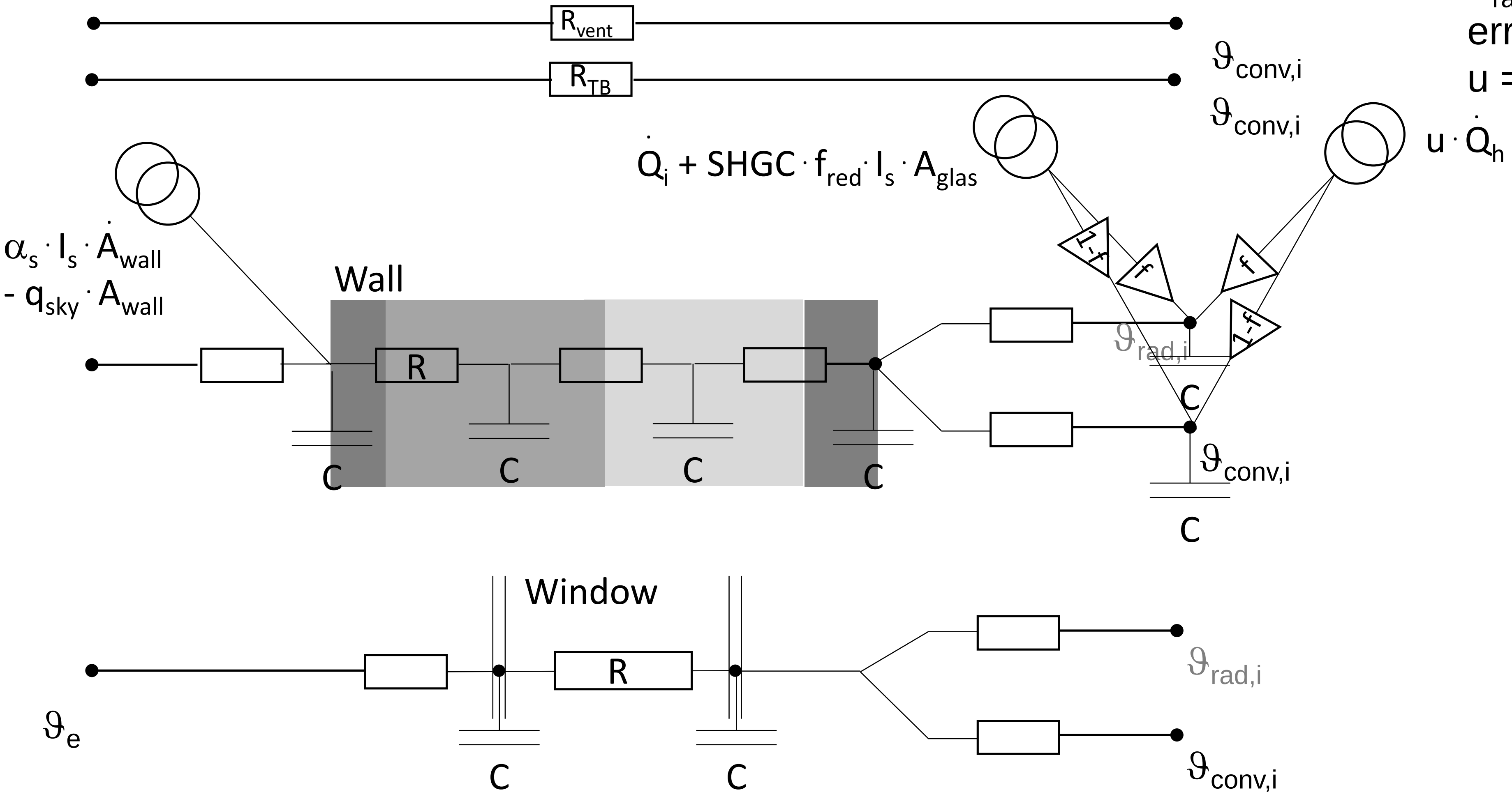


2star 4 node model (8 ODE)

$\vartheta_{op,i} = a\,\vartheta_{conv,i} + (1-a)\,\vartheta_{rad,i}$

$err = \vartheta_{SP} - \vartheta_{op,i}$

$u = f(err)$

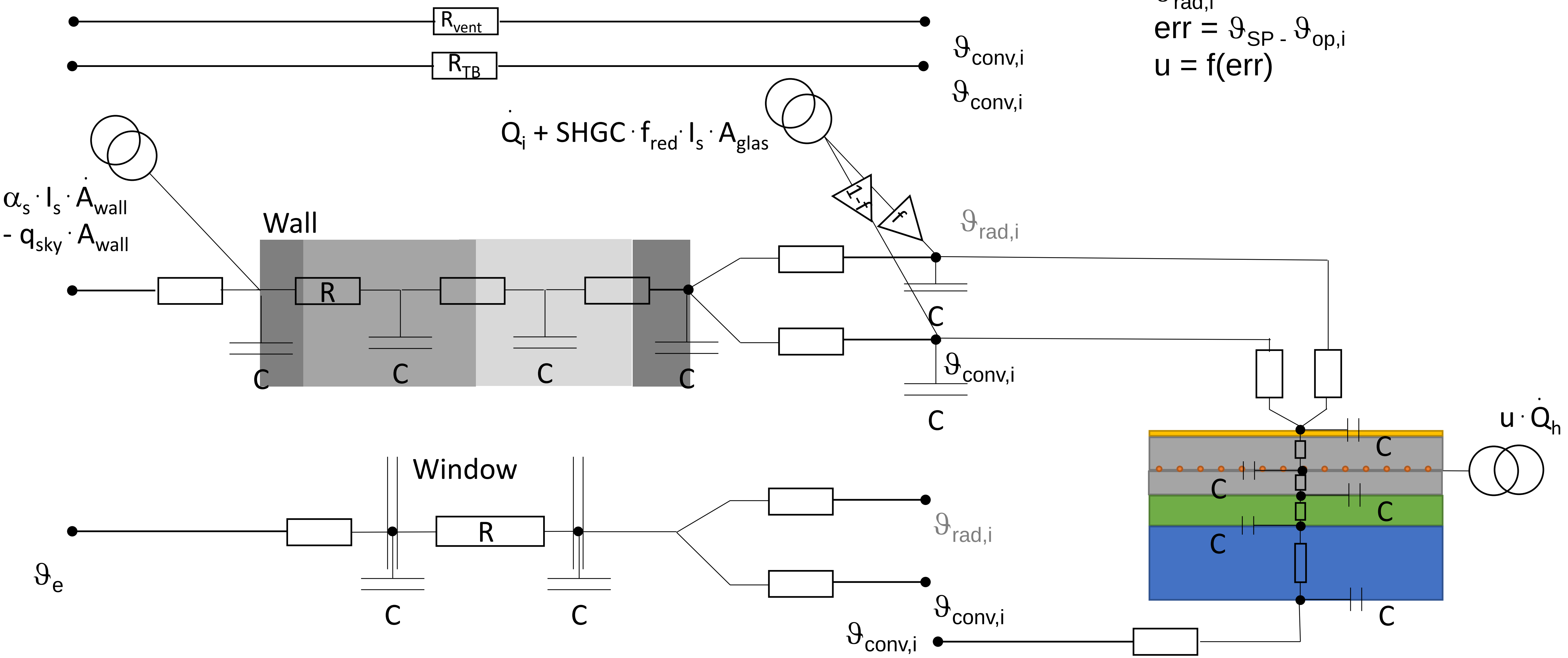


2star 4 node model + UFH (17 ODE)

$\vartheta_{op,i} = a\,\vartheta_{conv,i} + (1-a)\,\vartheta_{rad,i}$

$err = \vartheta_{SP} - \vartheta_{op,i}$

$u = f(err)$



Matlab

```
…
[t_0N,theta_0N] = ode45(@(t,theta) room_wall_0N_ode(t,theta,…),[t0,t1],theta_0,options);


function [t_0N,theta_0N] = ode45(@(t,theta) room_wall_0N_ode(t,theta, …)

…

dthetadt(1) = 1/(mcp_eff)*(Qdot_i_t + Qdot_s_t + Qdot_t_t + Qdot_v_t + Qdot_h_t);
…
end
```

ODE Solver (Matlab/Simulink)

ODE Solver in Matlab (/toolbox/matlab/funfun)

Explizit Methods for non-stiff Problems:

ode45 - Runge-Kutta (Dormand-Prince) *Standard Solver to try first …*

ode23 - Runge-Kutta (Bogacki-Shampine)

ode113 - Adams predictor-corrector (Ordnung 1 bis 13)

ode15i - BDF(Backward Differentiation Formulas)

Implizit Methods for stiff Problems:

ode23s - Runge-Kutta (Rosenbrock)

ode23t - Trapezoidal rule

ode23tb - TR-BDF2 *good choice for building simulation …*

ode15s - NDF (Ordnung 1 bis 5)

built-in local error estimate

Example

» Climate file (hourly)

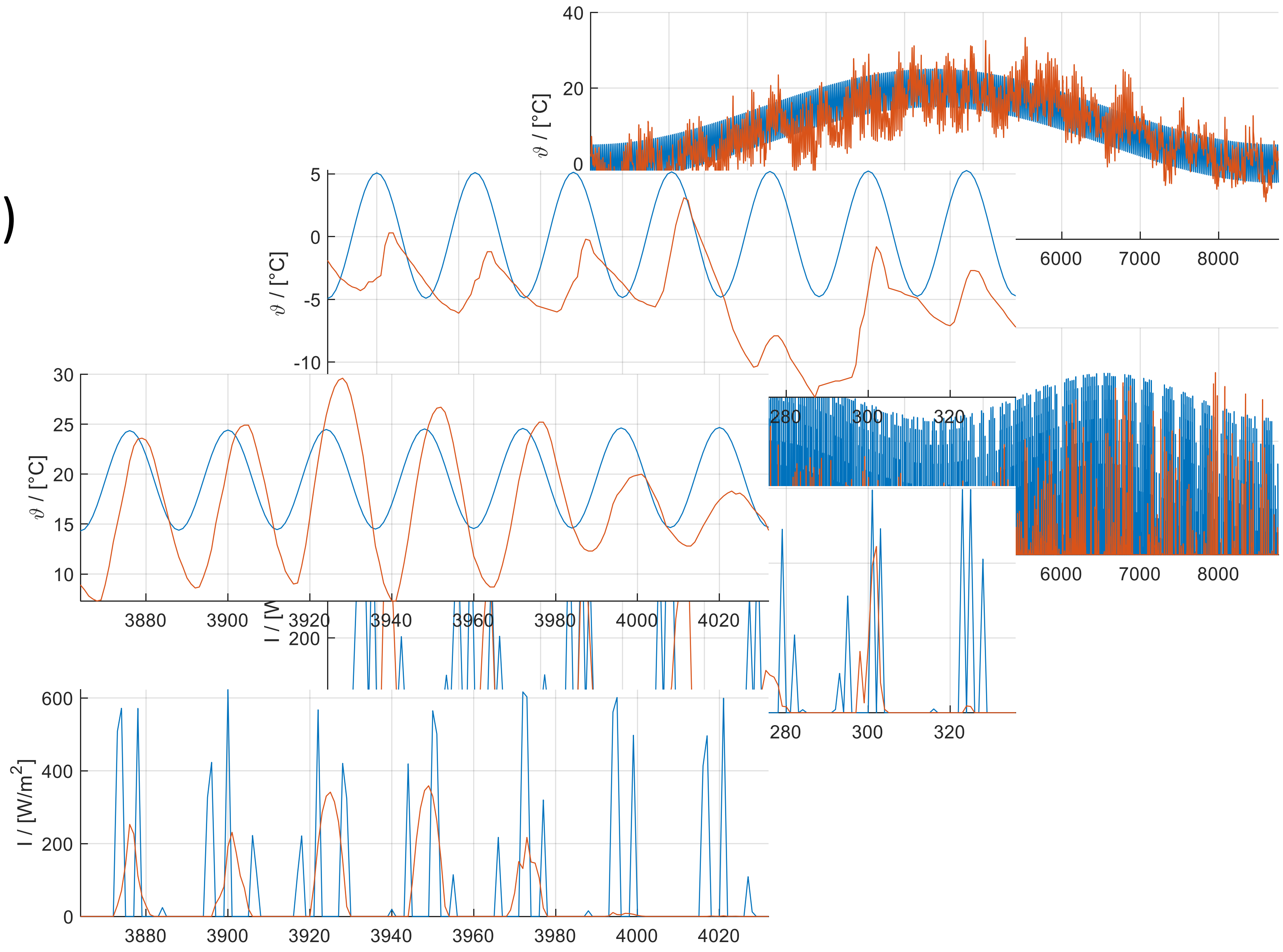
ϑ_m = 8.8°C

885.3 kWh/(m² a)

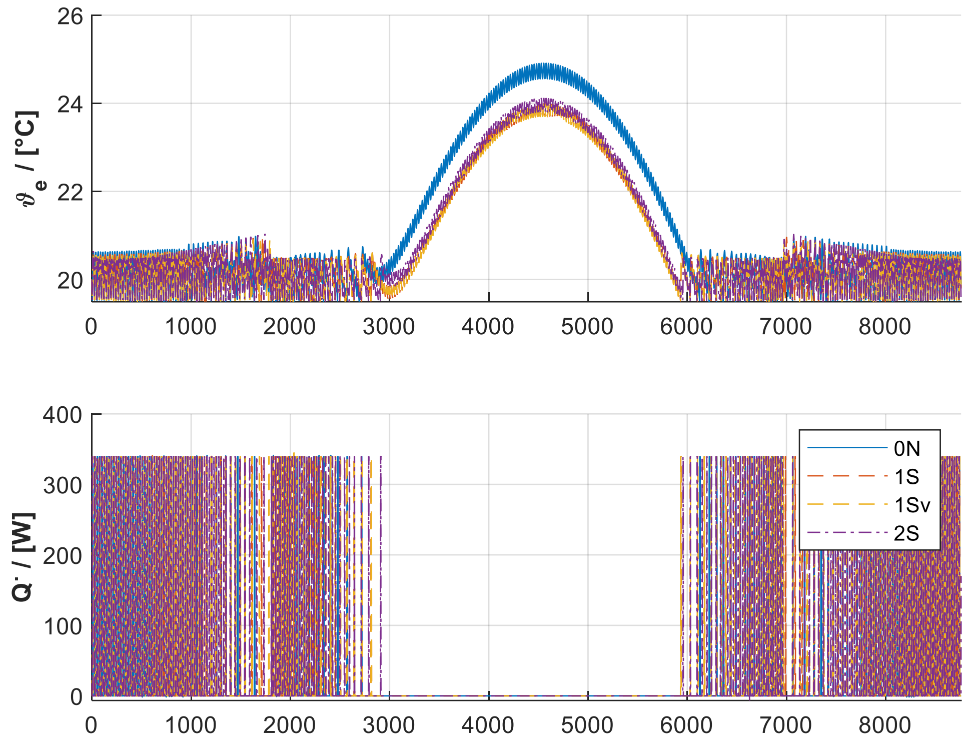
» Synthetic

ϑ_m = 10 °C

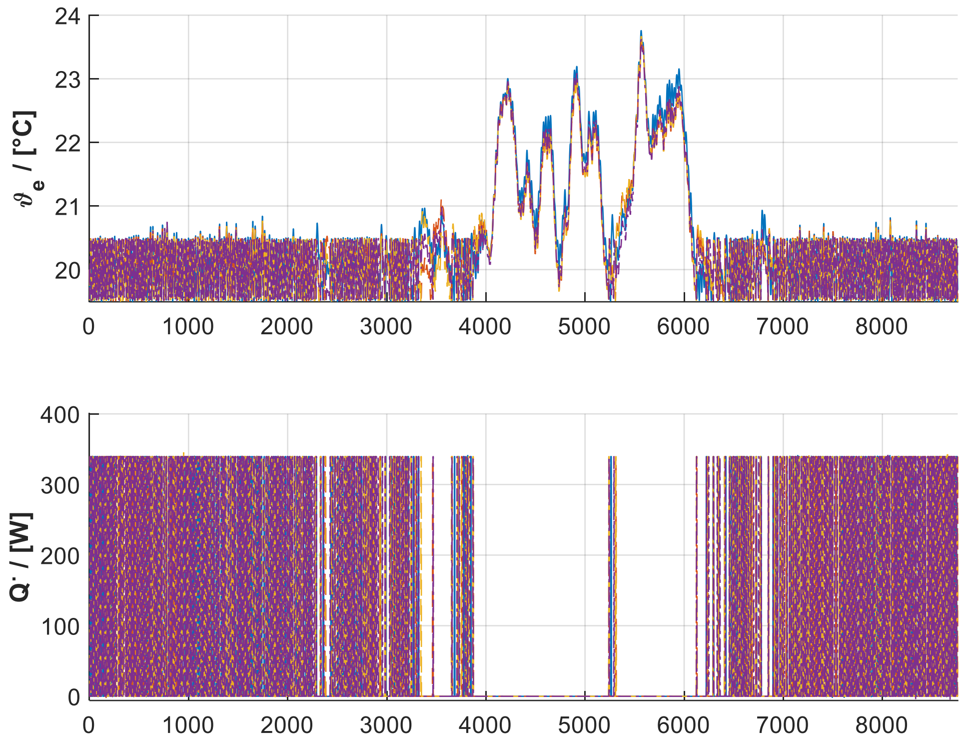
810.4 kWh/(m² a)



Synthetic climate



climate file (meteonorm)

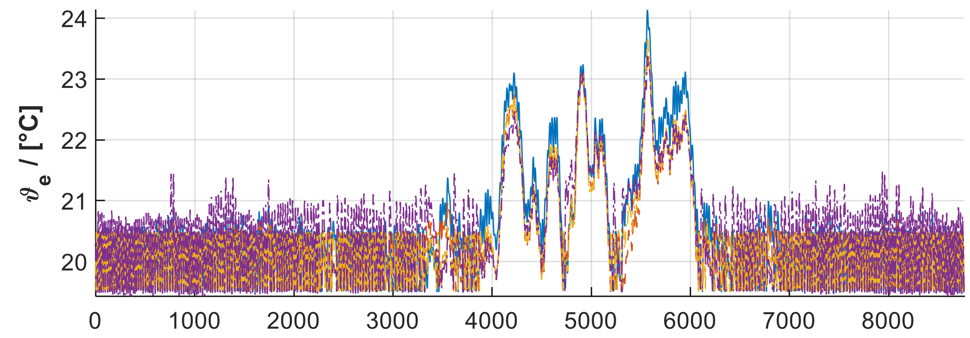


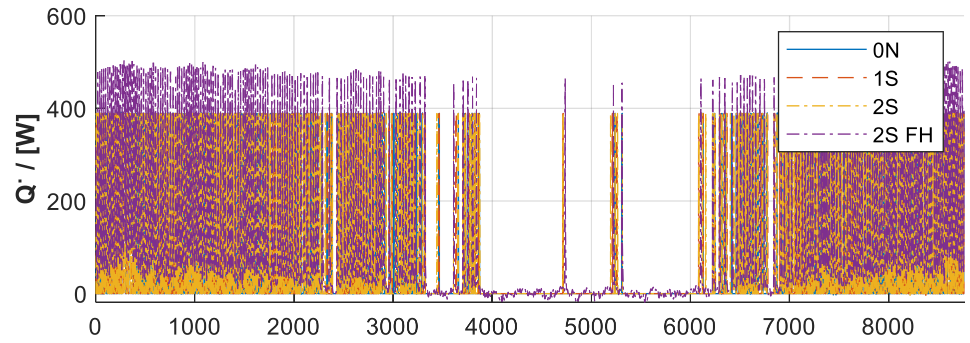
Model Comparison

not calibrated!

ODE45 dt_{min} = 600 s

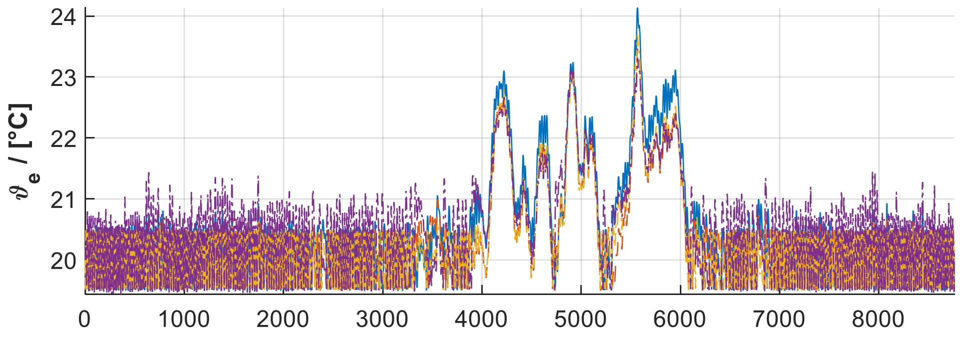
UA Room Model (simple, lumped mass)	1 ODE
1* thermal zone, RC-Wall Model (4C) window (2C)	7 ODE
2* thermal zone, RC-Wall Model (4C) window (2C)	8 ODE
2* thermal zone RC-Wall (4C) FH (9C) window (2C)	17 ODE

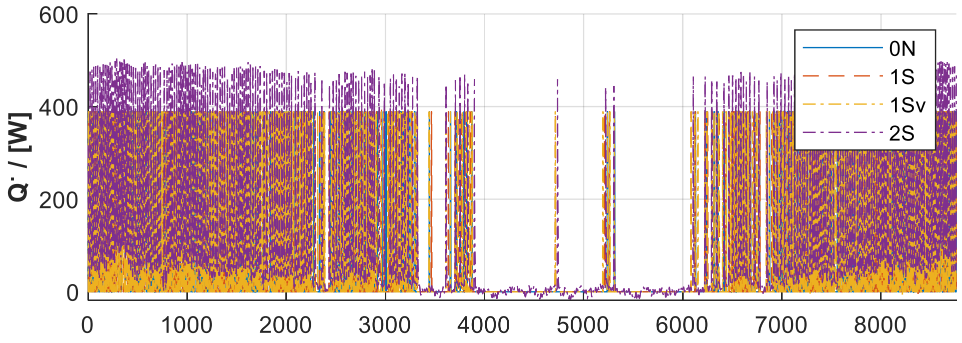


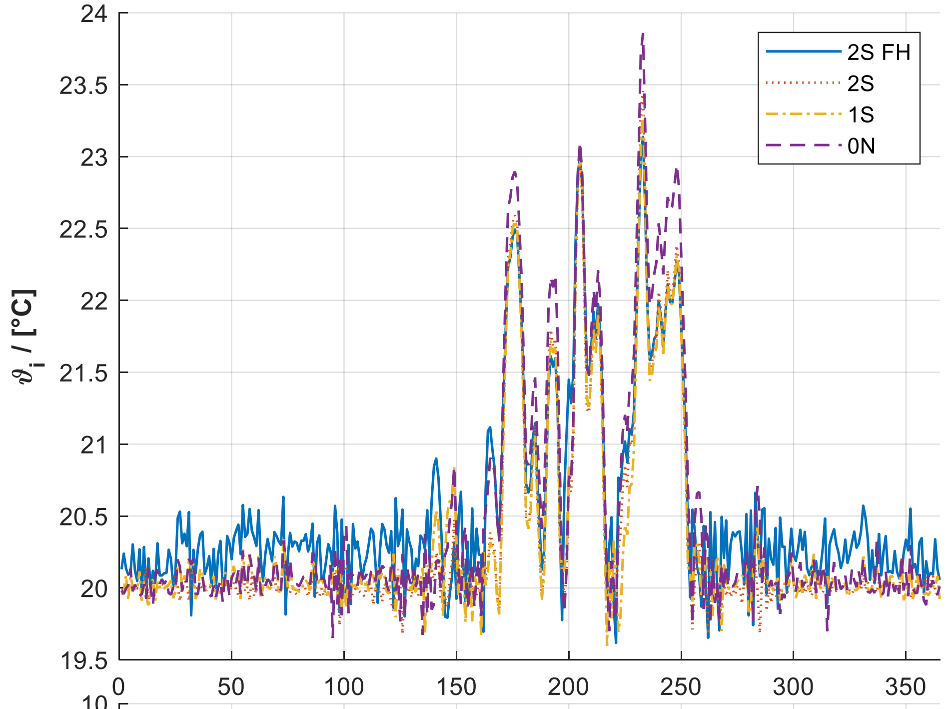


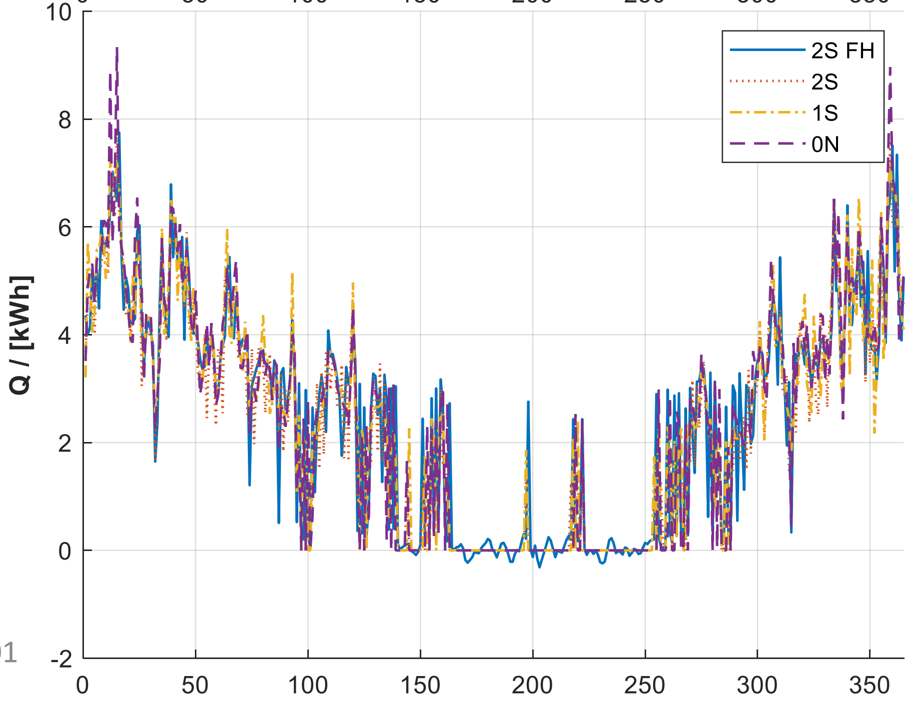
	kWh	-
Q_h_0N_h	896.4	-0.0116
Q_h_4N_h	887	-0.0005
Q_h_2S4N_h	862.2	0.0275
Q_h_2S4N_FH9C_h	886.6	0.0000

Model Comparison

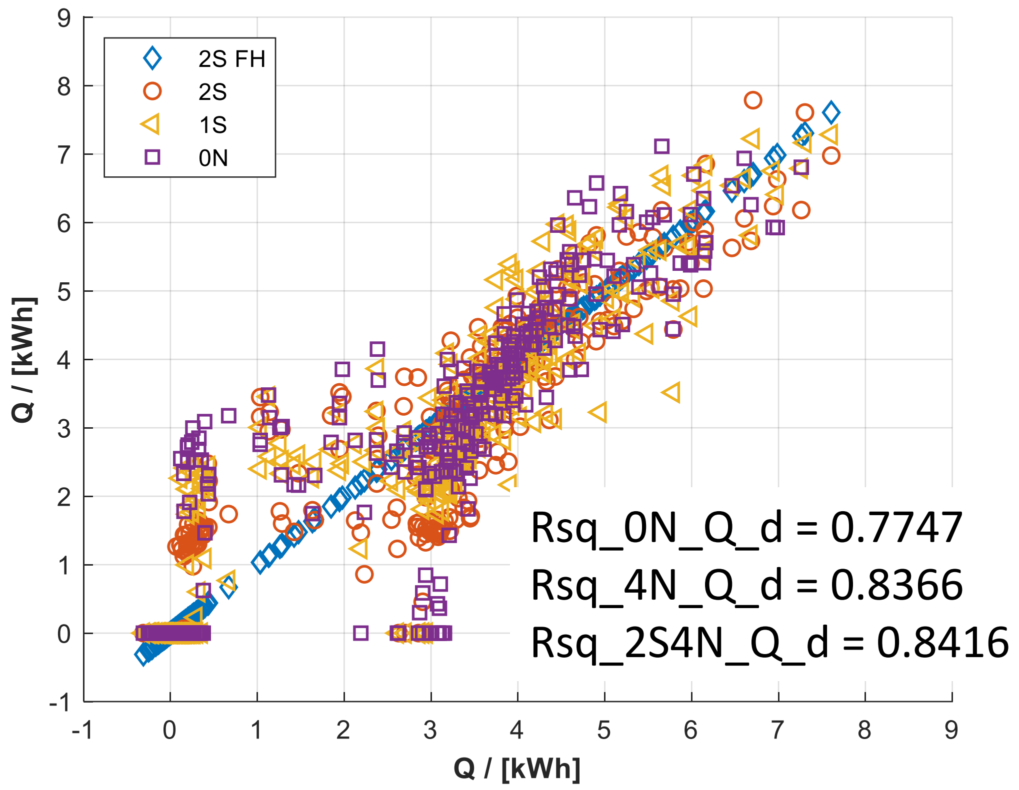


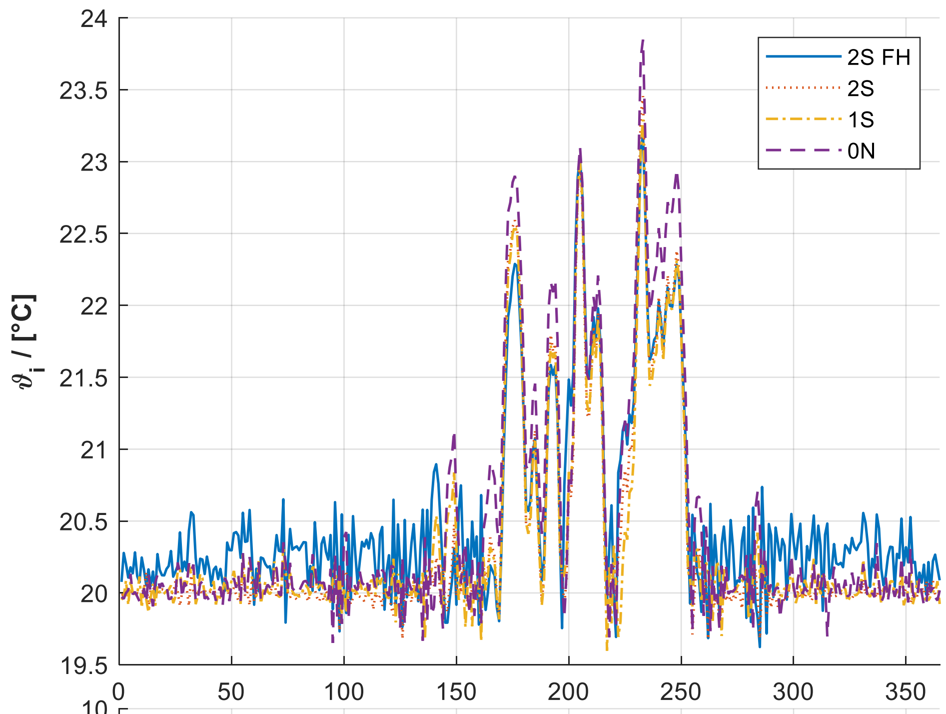


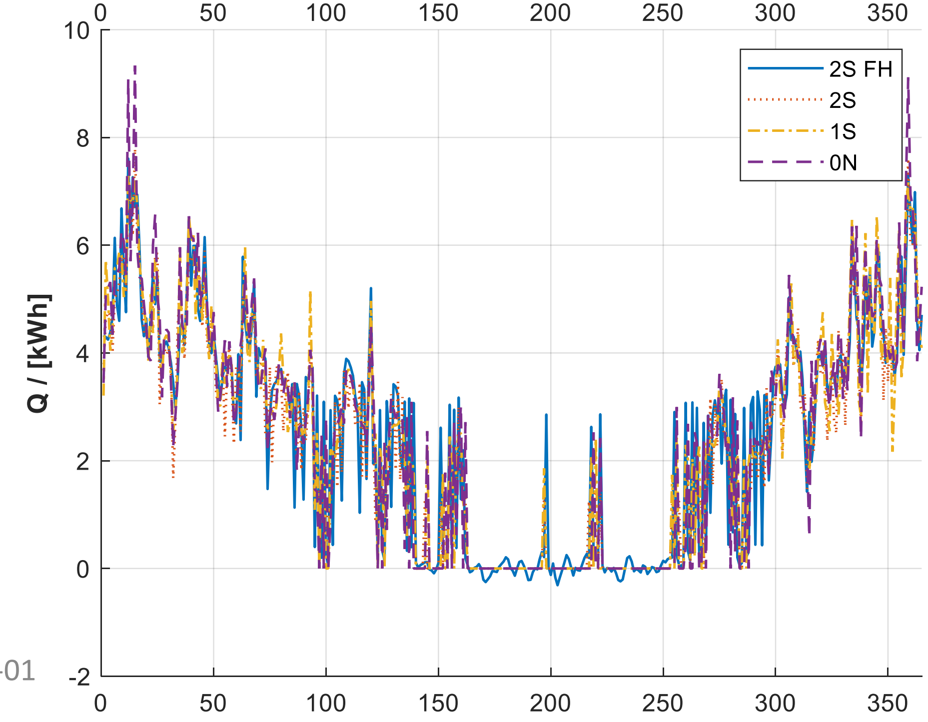




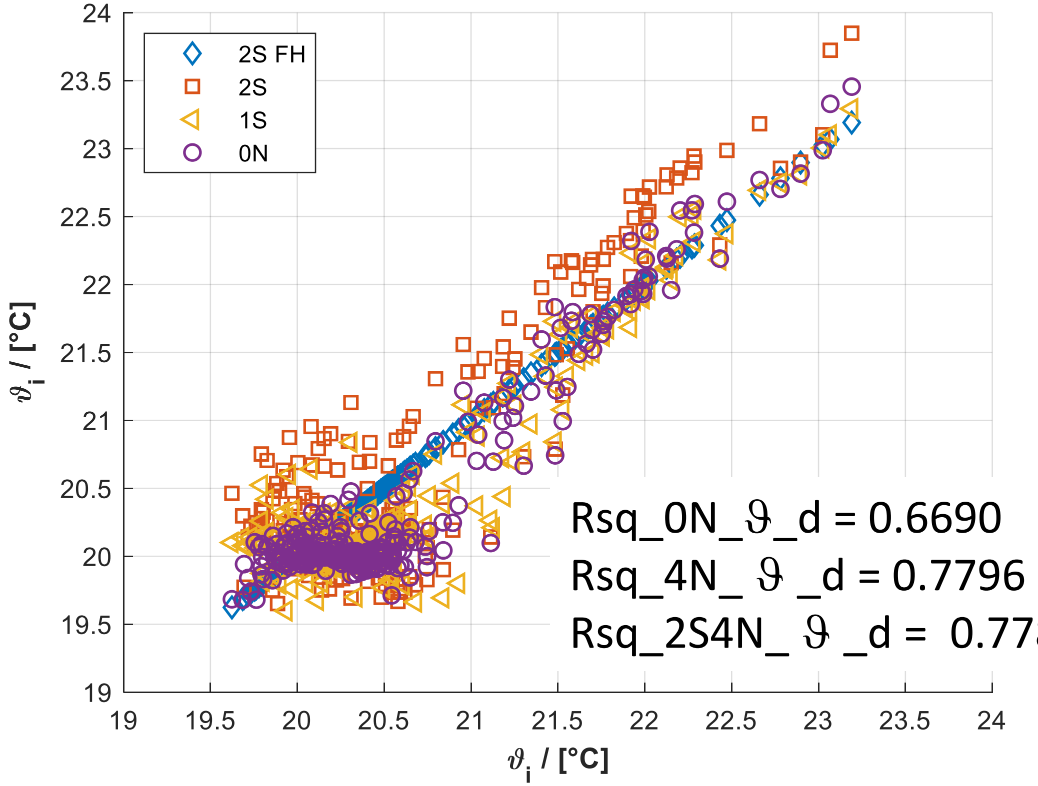
Model Comparison



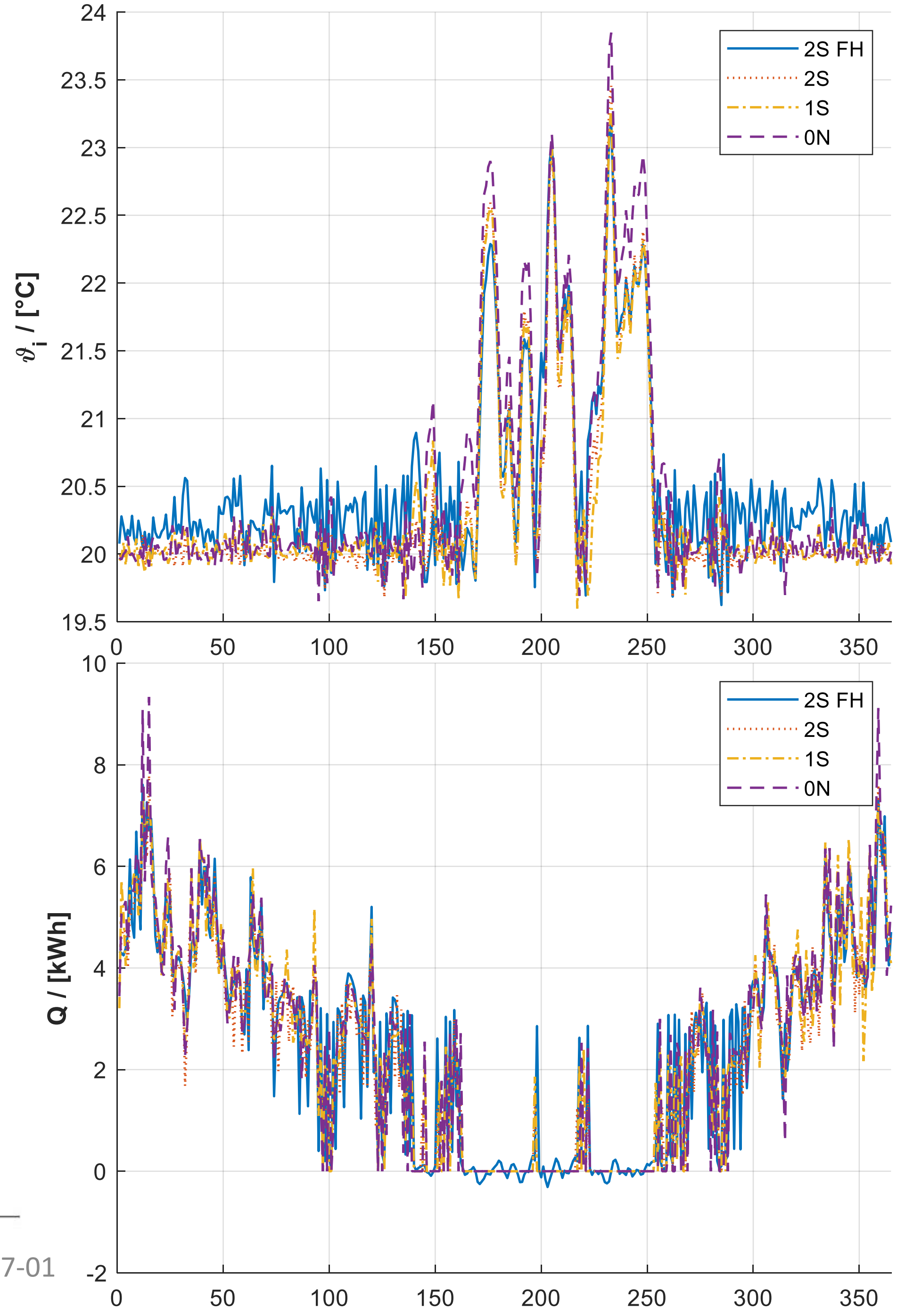




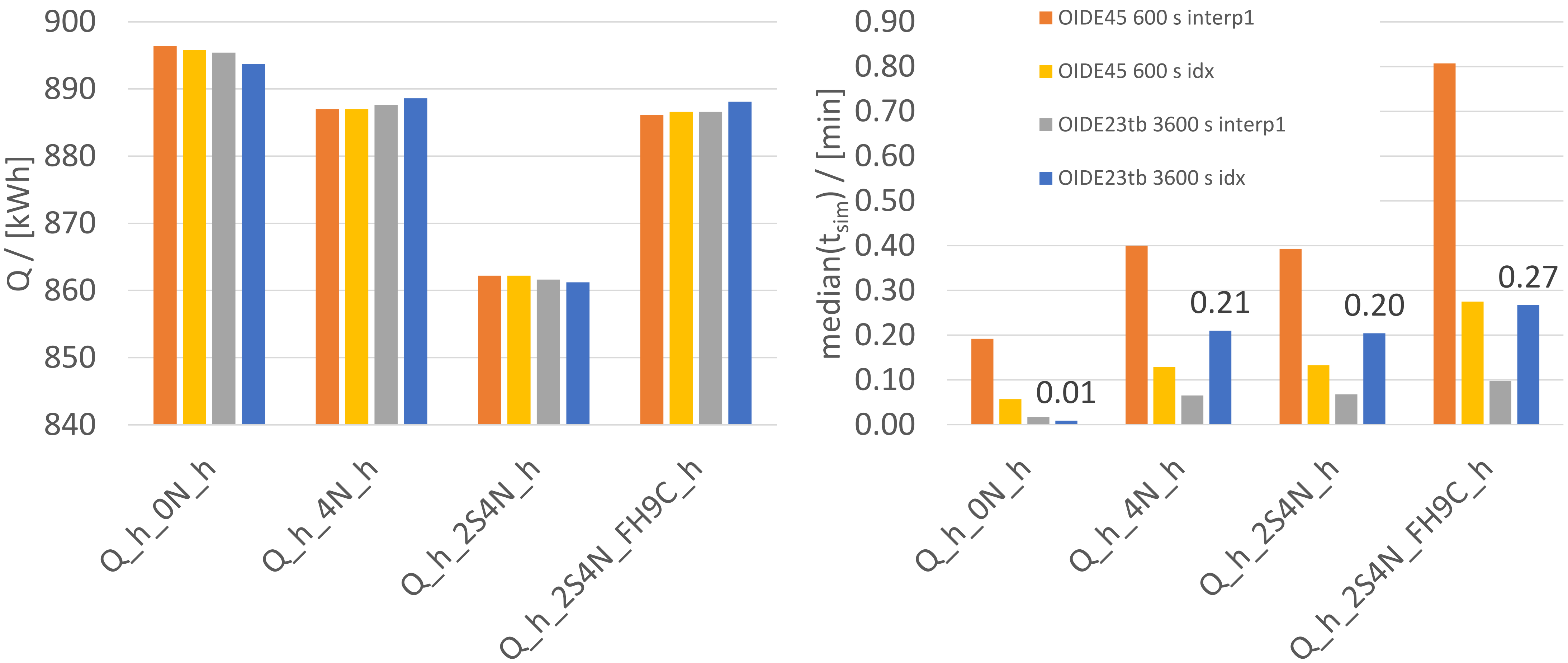
Model Comparison



Rsq_0N_ϑ_d = 0.6690
Rsq_4N_ ϑ _d = 0.7796
Rsq_2S4N_ ϑ _d = 0.7783

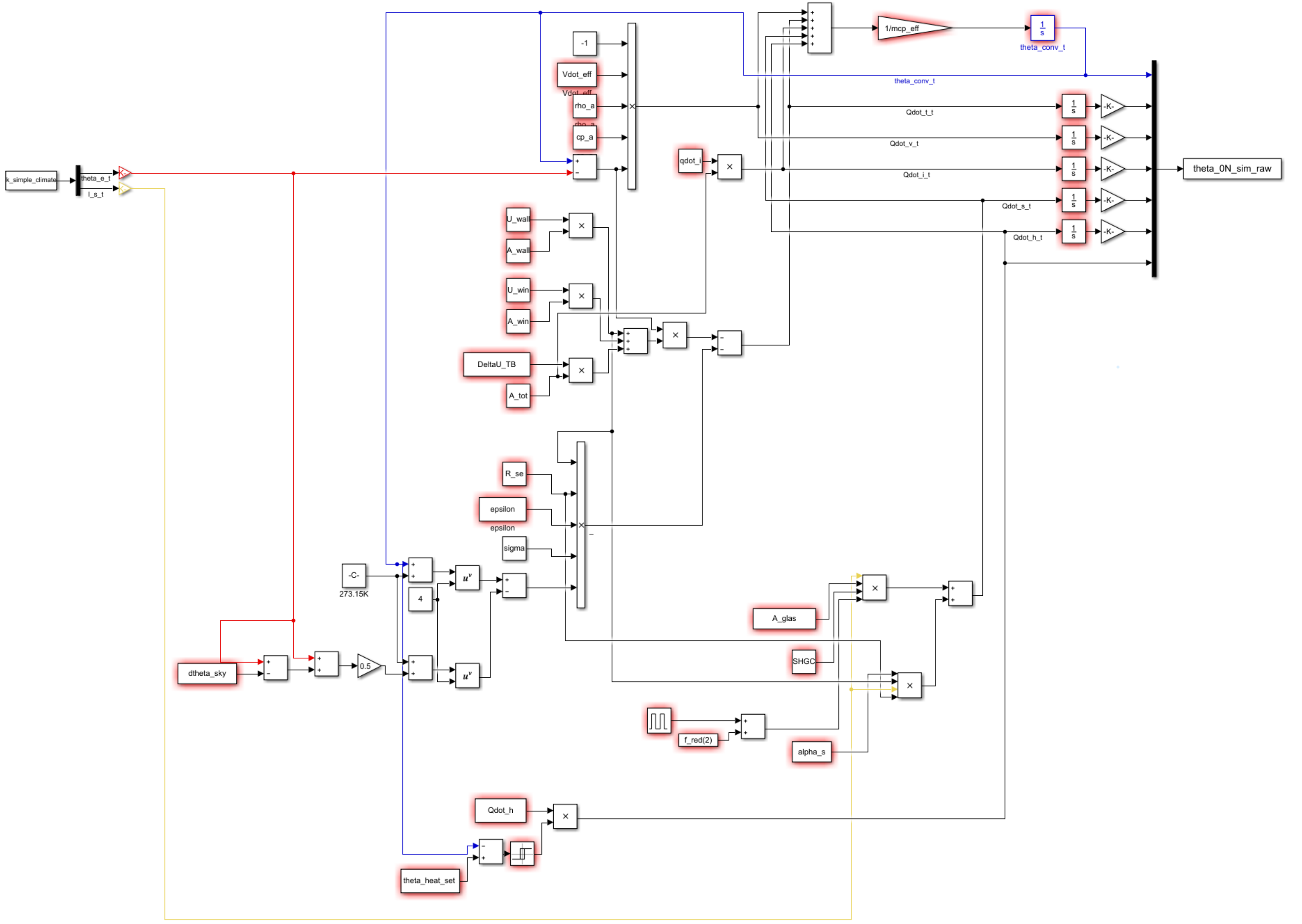


Accuracy and Performance



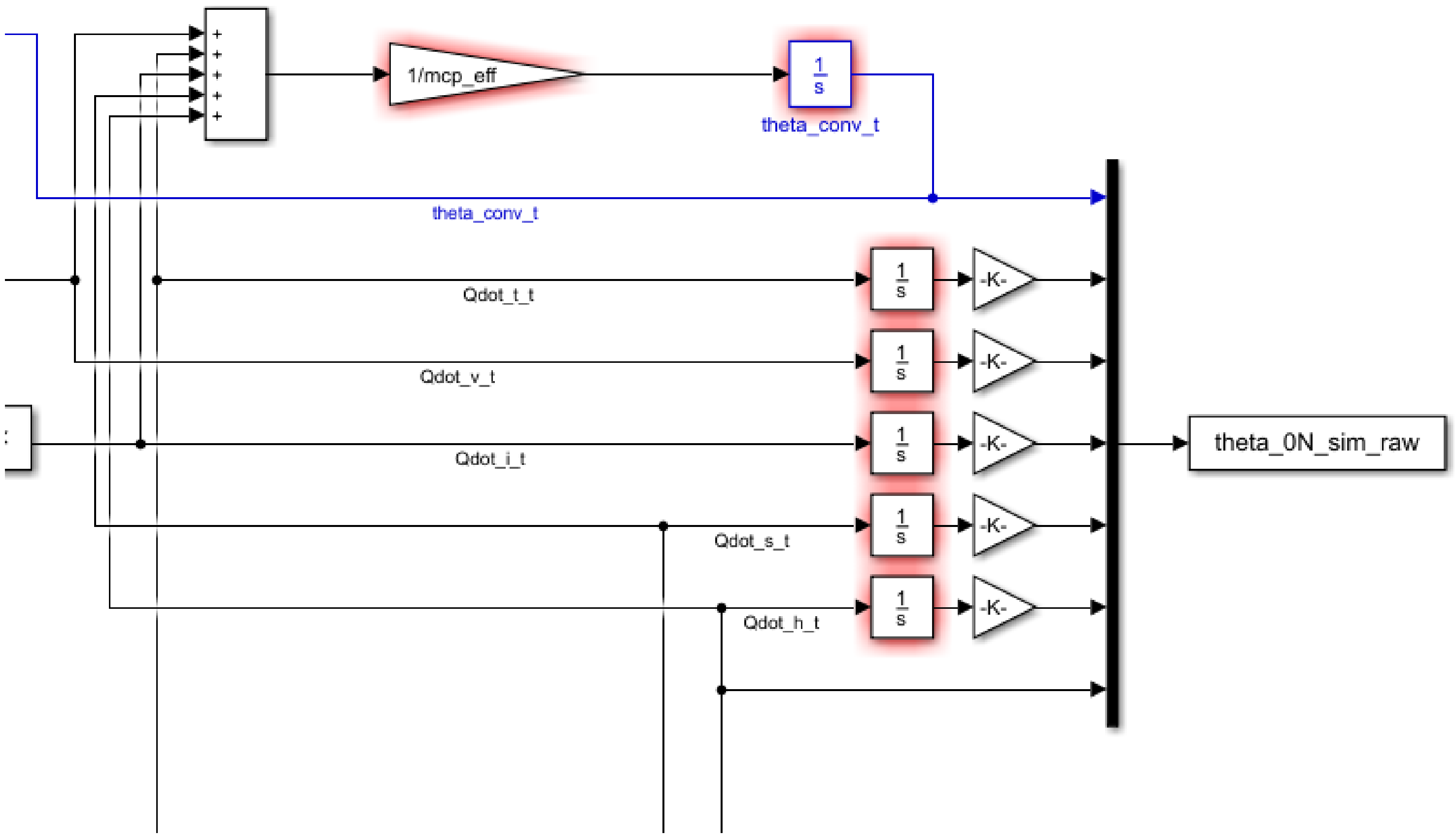
Simulink

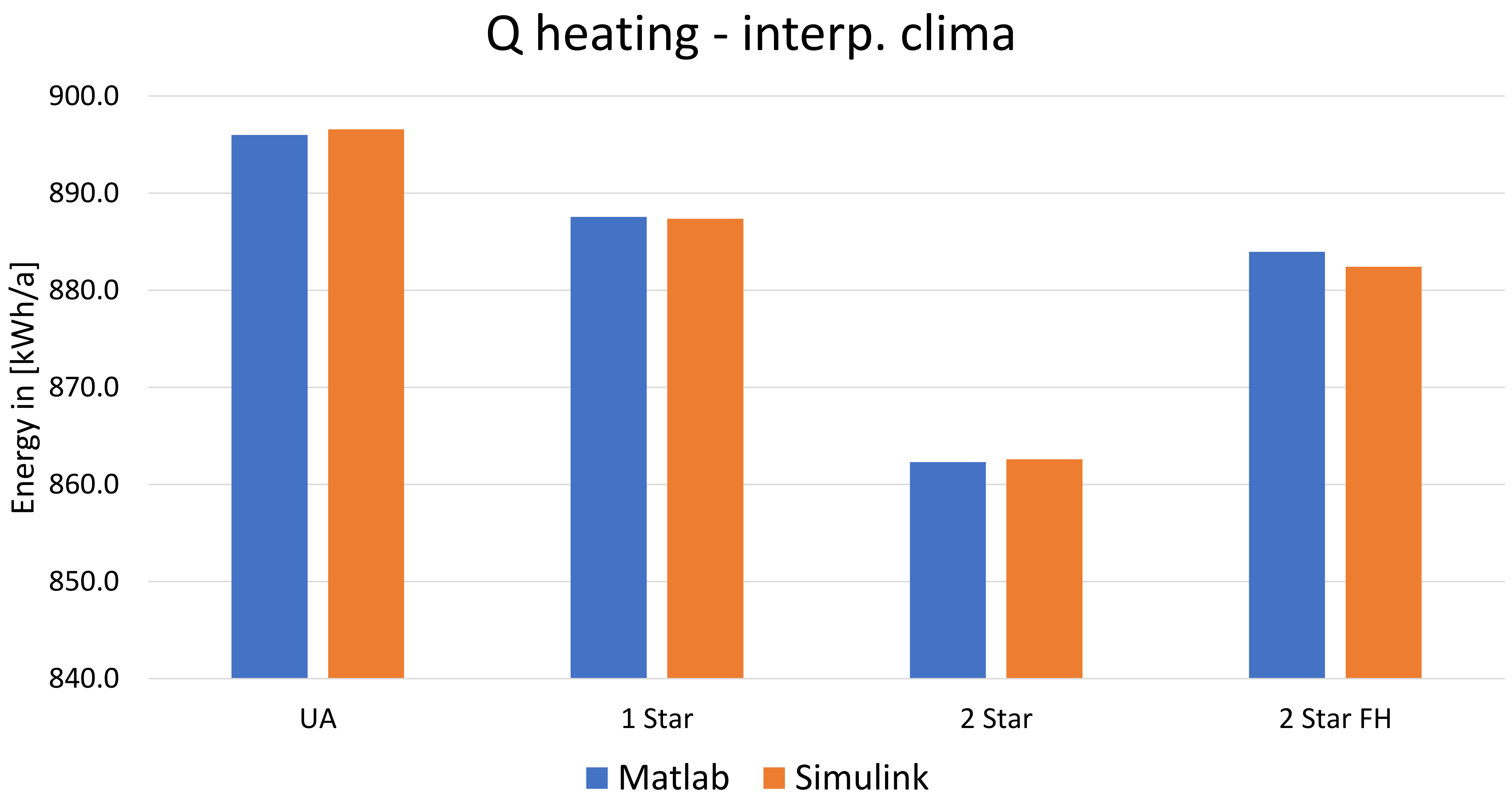
Lumped Mass (0N) Model (1 ODE)

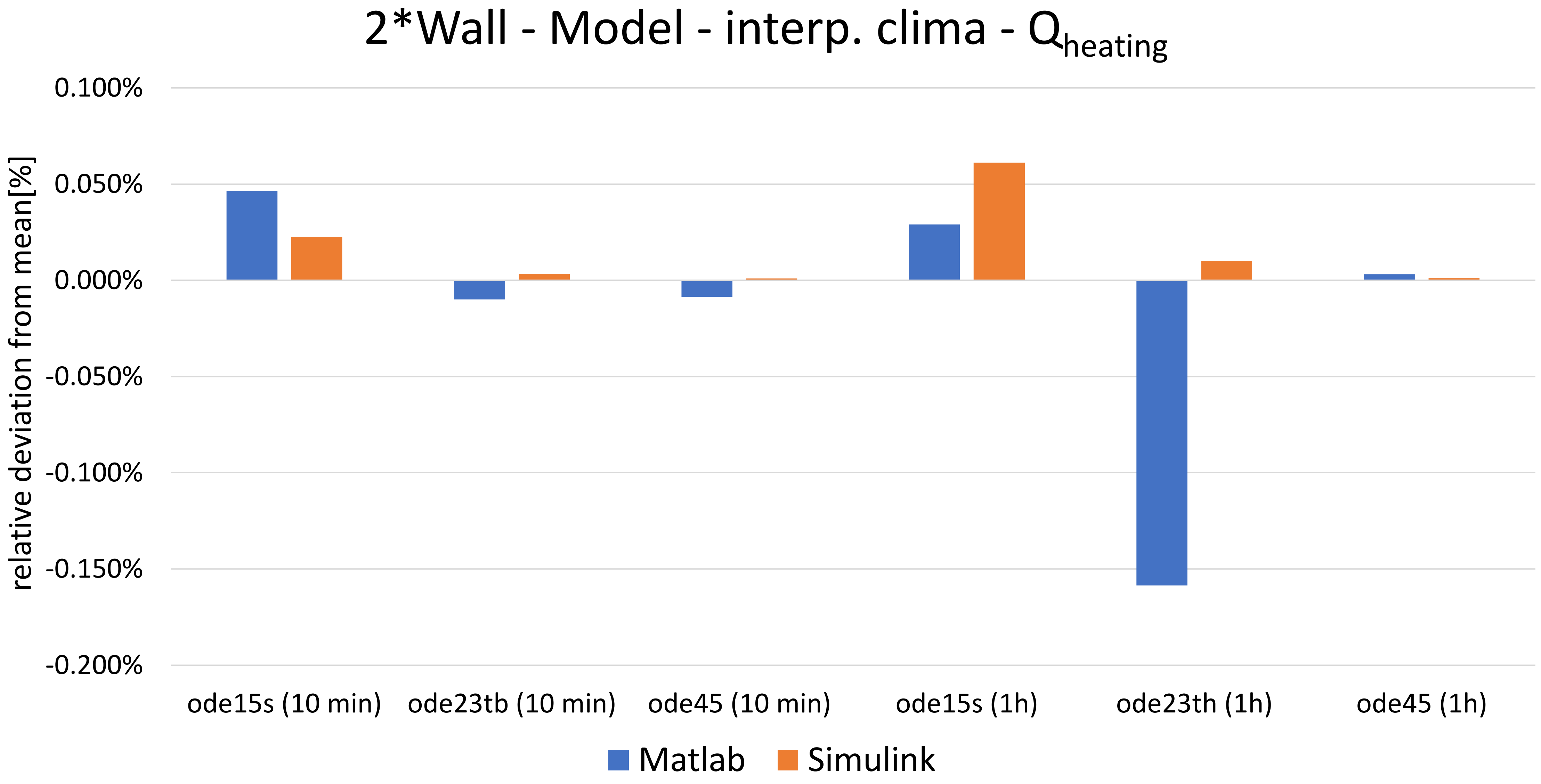


Simulink

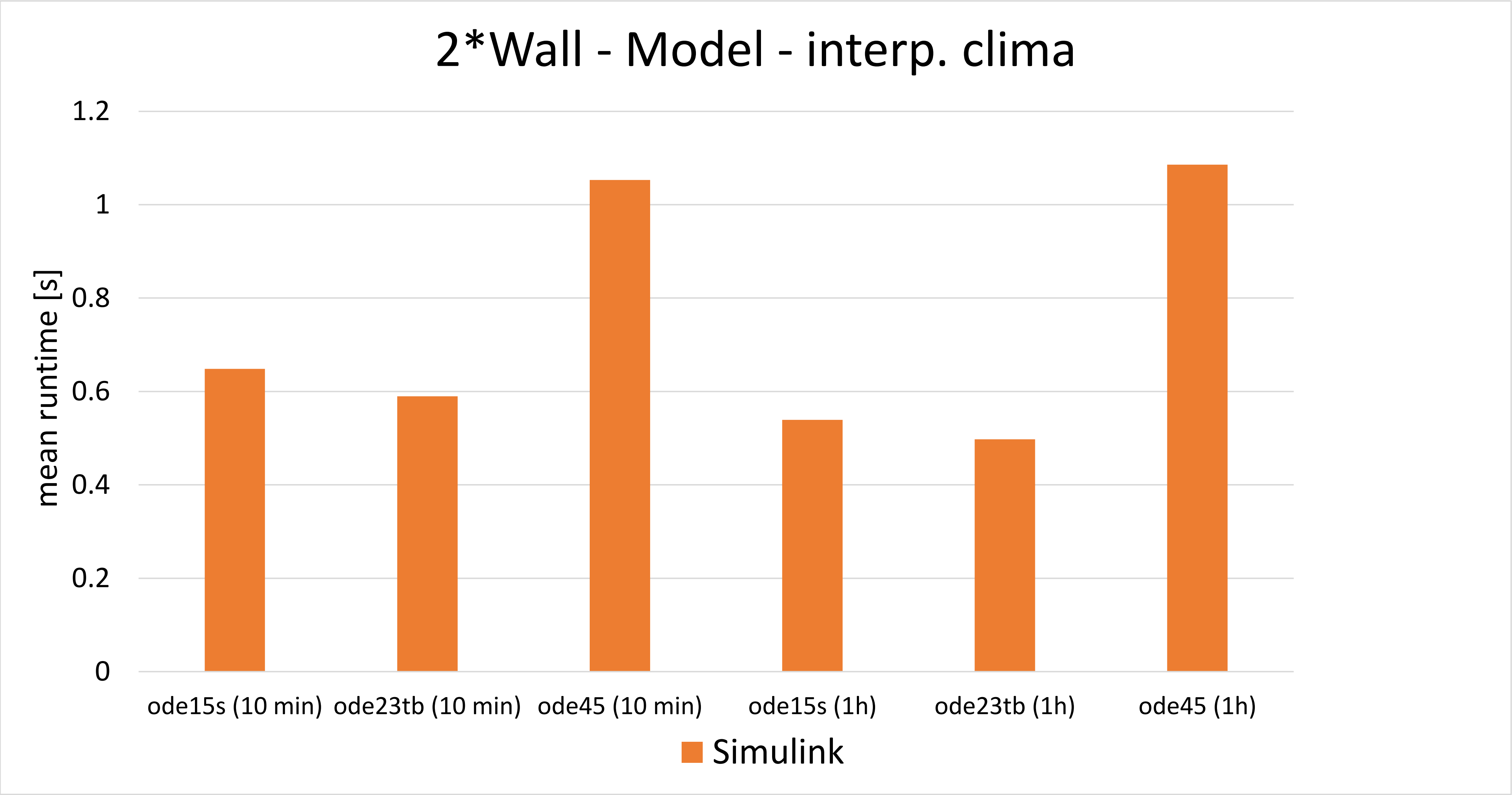
Lumped Mass (0N) Model (1 ODE)




Q heating - interp. clima
Energy in [kWh/a]
900.0
890.0
880.0
870.0
860.0
850.0
840.0
UA
1 Star
2 Star
2 Star FH
Matlab
Simulink



2*Wall - Model - interp. clima - $Q_{heating}$
0.100%
0.050%
0.000%
-0.050%
-0.100%
-0.150%
-0.200%
relative deviation from mean[%]
ode15s (10 min)
ode23tb (10 min)
ode45 (10 min)
ode15s (1h)
ode23th (1h)
ode45 (1h)
Matlab
Simulink



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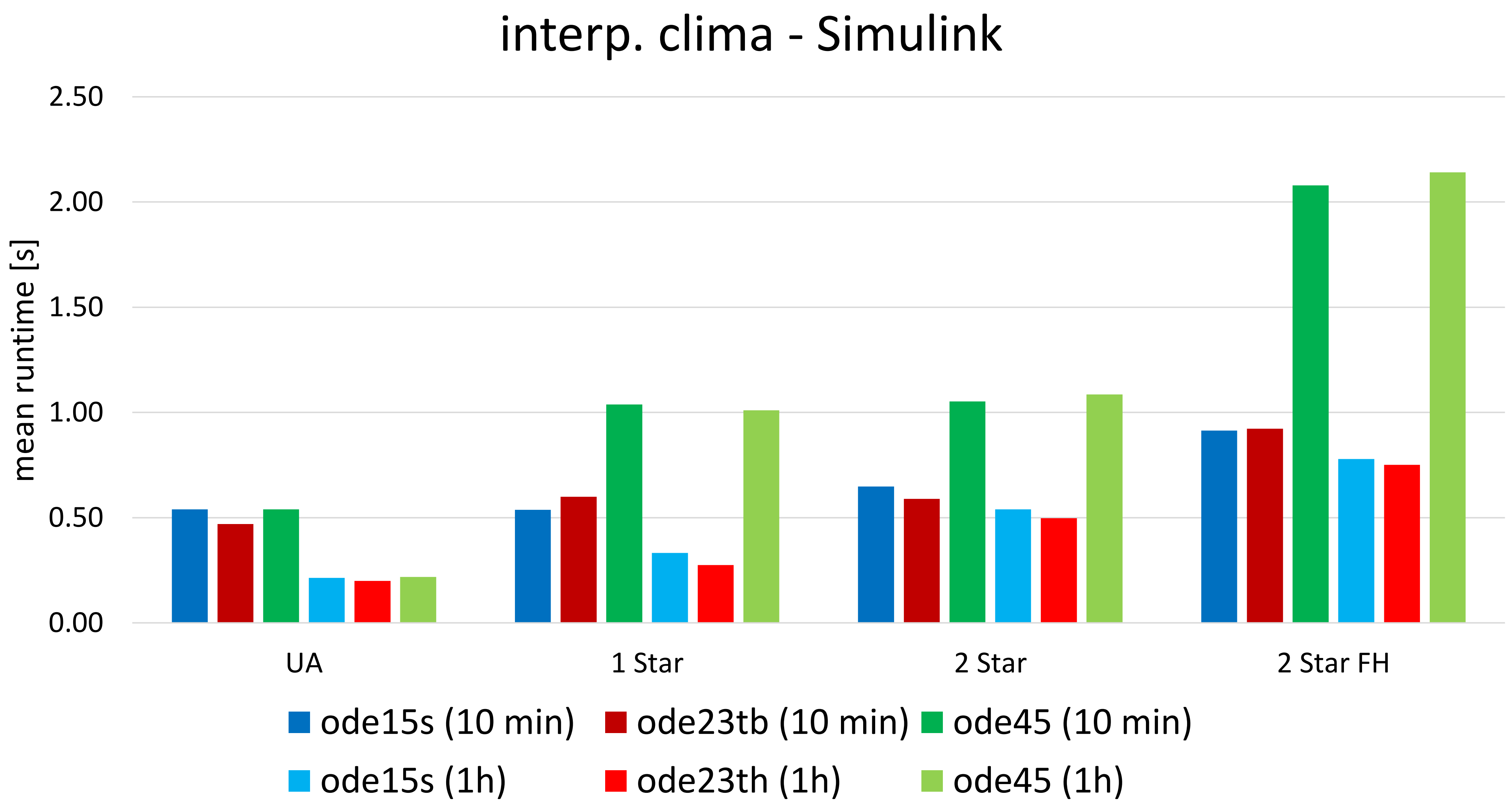
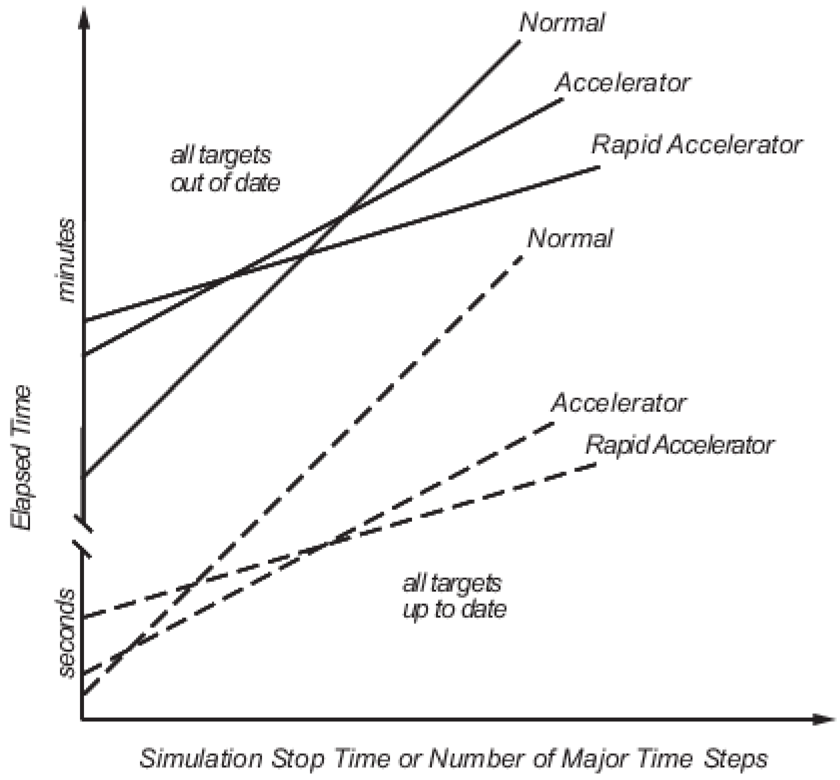
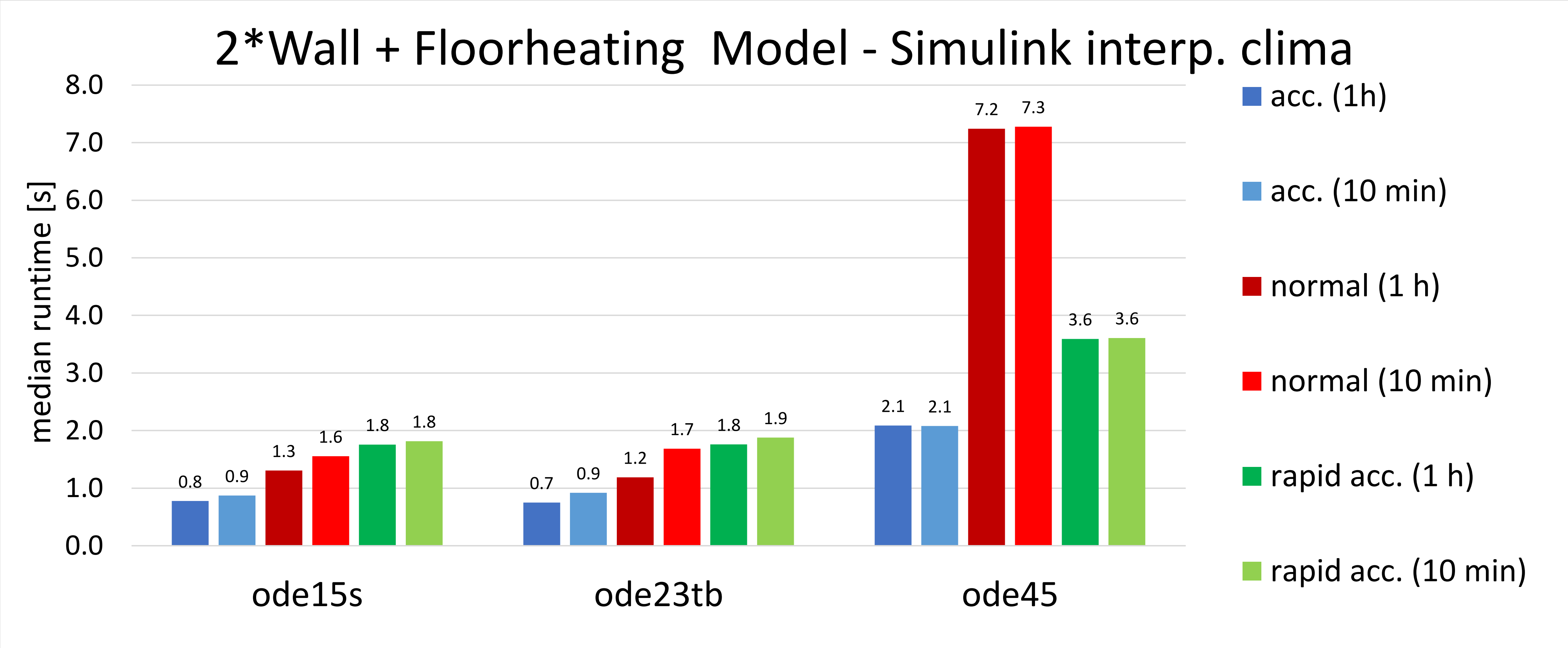

interp. clima - Simulink
mean runtime [s]
2.50
2.00
1.50
1.00
0.50
0.00
UA
1 Star
2 Star
2 Star FH
ode15s (10 min)
ode23tb (10 min)
ode45 (10 min)
ode15s (1h)
ode23th (1h)
ode45 (1h)

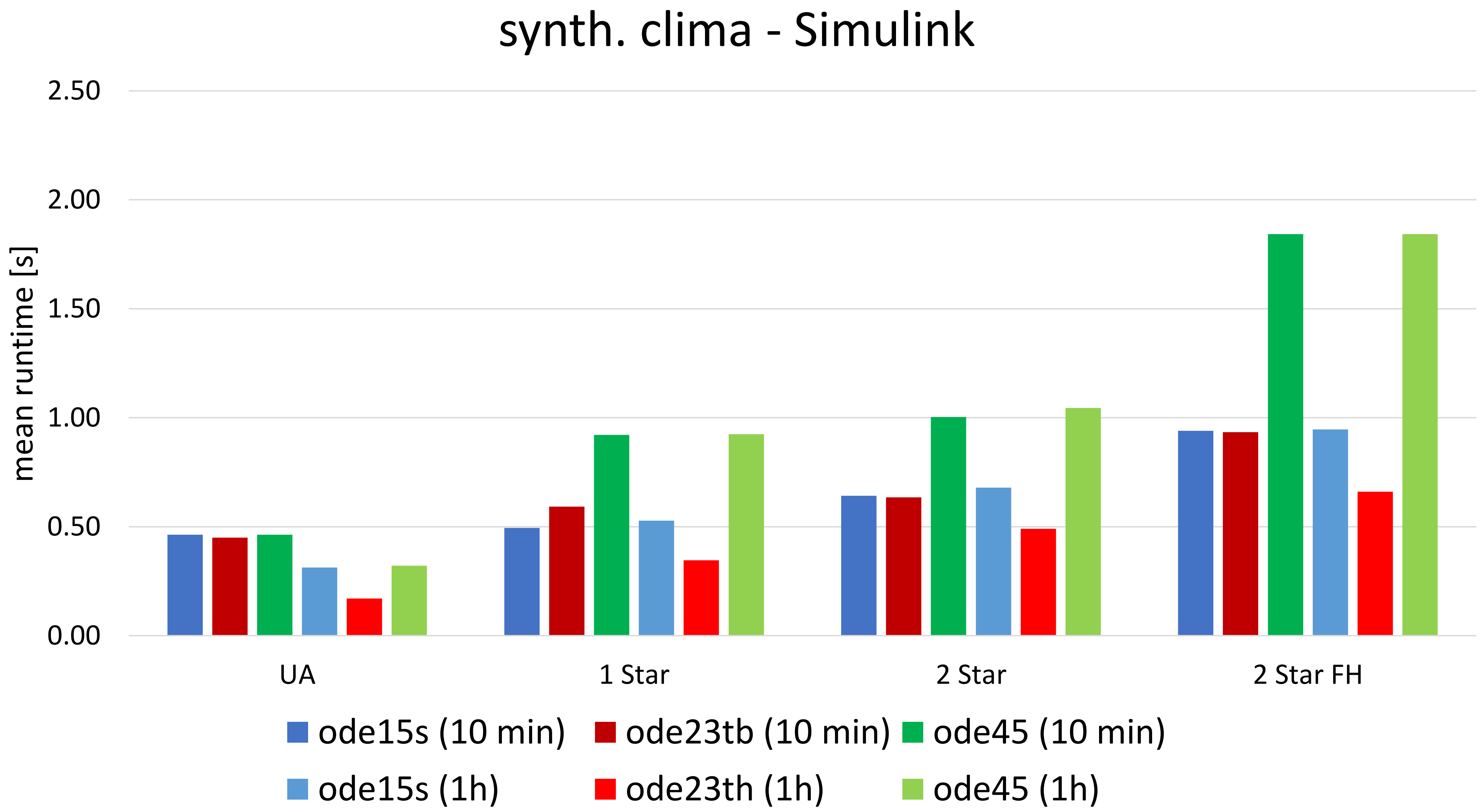
Performance of the Simulation Modes



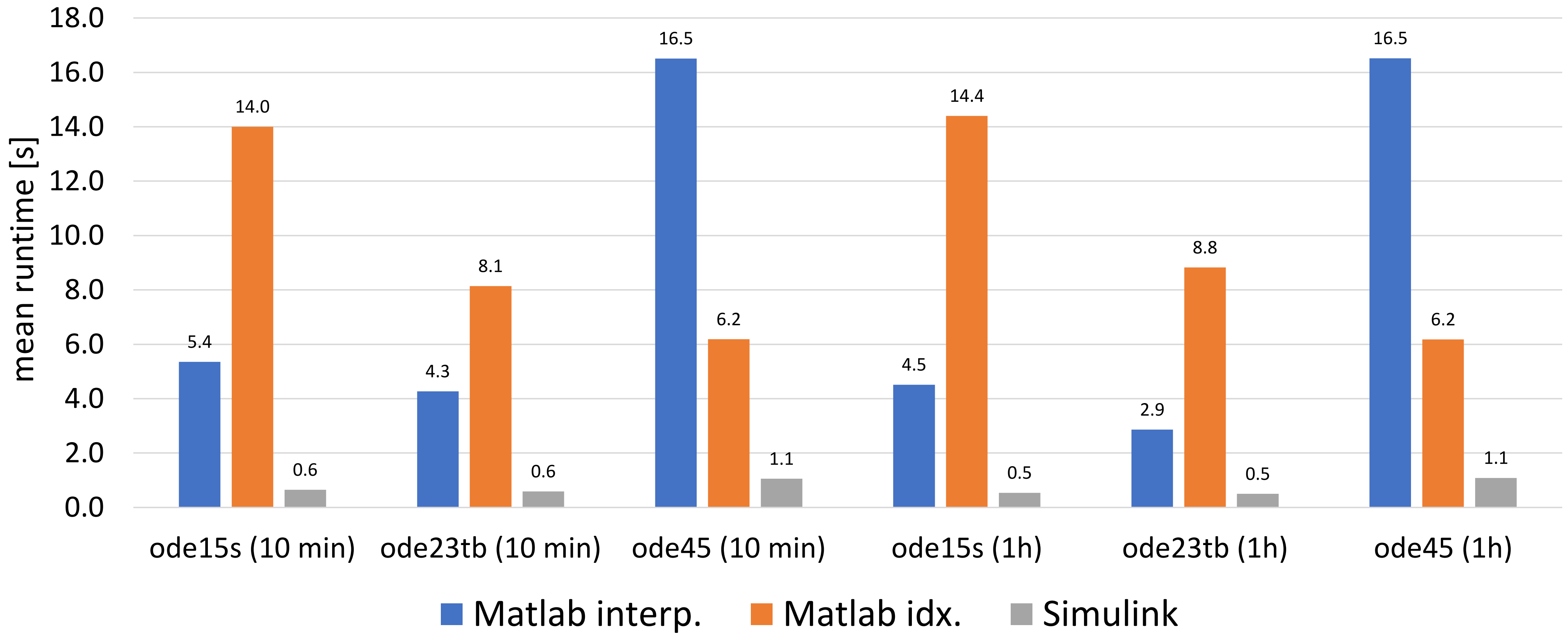
www.mathworks.com

(rapid) Accelerator Mode



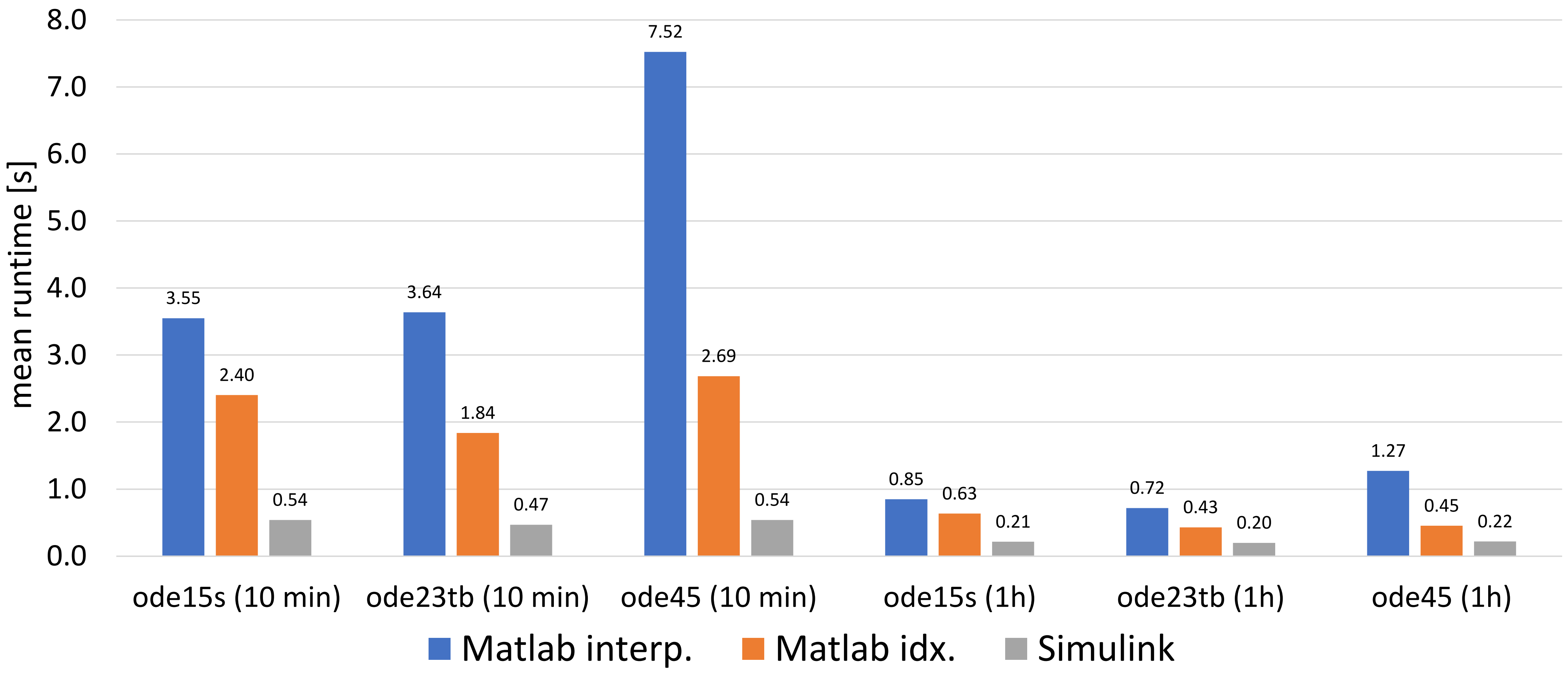

synth. clima - Simulink
mean runtime [s]
2.50
2.00
1.50
1.00
0.50
0.00
UA
1 Star
2 Star
2 Star FH
ode15s (10 min)
ode23tb (10 min)
ode45 (10 min)
ode15s (1h)
ode23th (1h)
ode45 (1h)

2*Wall - Model



mean runtime [s]
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
5.4
14.0
0.6
4.3
8.1
0.6
16.5
6.2
1.1
4.5
14.4
0.5
2.9
8.8
0.5
16.5
6.2
1.1
ode15s (10 min)
ode23tb (10 min)
ode45 (10 min)
ode15s (1h)
ode23tb (1h)
ode45 (1h)
Matlab interp.
Matlab idx.
Simulink

UA Model



8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
mean runtime [s]
3.55
2.40
0.54
3.64
1.84
0.47
7.52
2.69
0.54
0.85
0.63
0.21
0.72
0.43
0.20
1.27
0.45
0.22
ode15s (10 min)
ode23tb (10 min)
ode45 (10 min)
ode15s (1h)
ode23tb (1h)
ode45 (1h)
Matlab interp.
Matlab idx.
Simulink

Conclusions

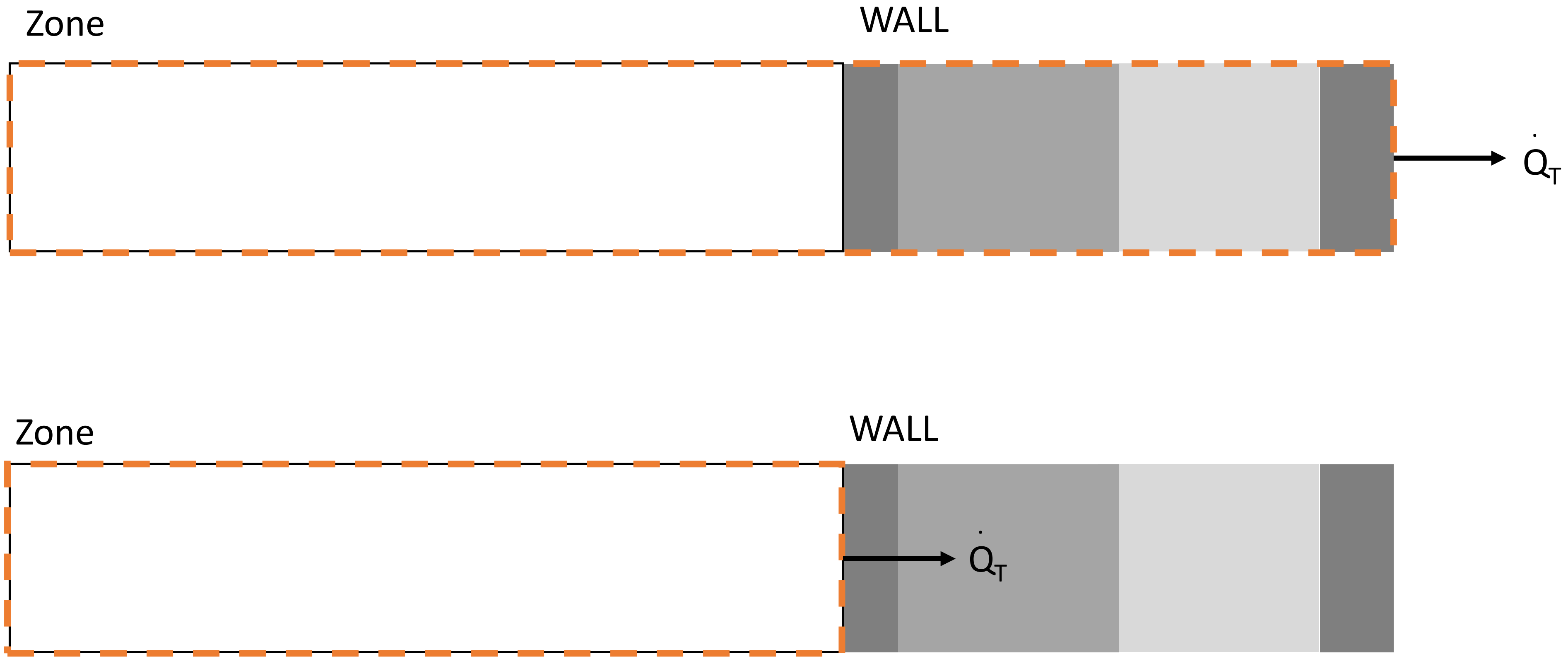
- » Strong influence of model complexity (no of ODEs) on simulation performance
- » Rel. small influence on results (in terms of heating demand)
- » Dynamics can be approximated with simplified models
- » Strong influence of solver and settings (depending on model complexity)
- » Simulink outperforms Matlab
  (different internal solver settings, pre-compilation ???)

- » Many thing still to be improved (and need for better understanding …)
- » Parallelisation and co-simulation options to be explored …
  (e.g. fast: control, tapping, (elec.) peaks vs. slow: inertia in walls, ground …)

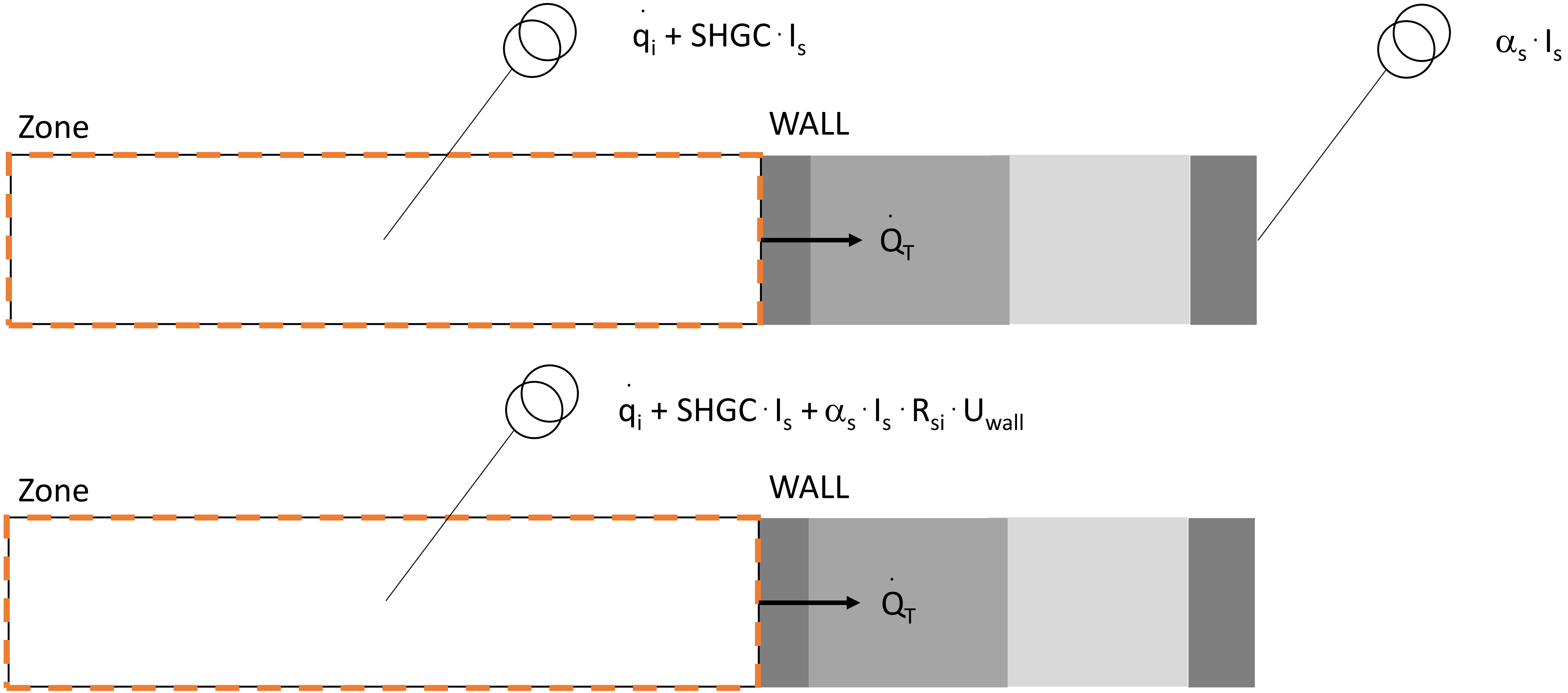
Parallelisation …

DiePresse.com

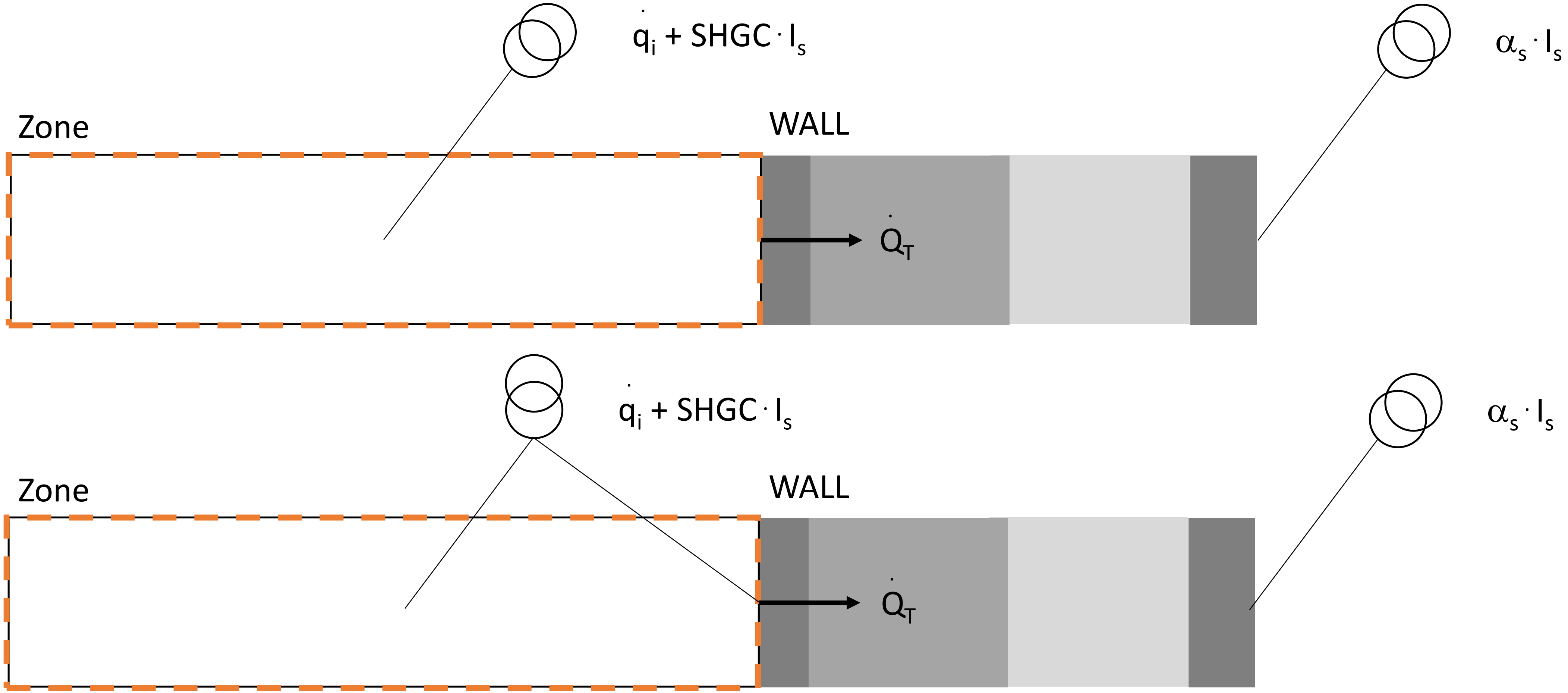
Balancing – post-processing



Balancing – post-processing



Balancing – post-processing



Weather (Climate) …

» from Climate File
» OIB 2019: Site Climate (IBK) -> Meteonorm –> Hourly Data

» „synthetic“

sin wave

climate file

Matlab

- Sin wave
- interp1
- qinterp1

Simulink

- Sin wave
- From file
- Simin (from workspace)

Climate

timeseries (t: ϑ_e, ϑ_{sky}, rH, I_{dir}, I_{dif}, v_{wind})

e.g. $\vartheta_e(t)$

function (approx.)	theta_e_t = theta_0 + theta_amp*sin(2*pi*(t-t_0)t/tau)	
Indexing	theta_e_t = theta_e(floor(t/3600))	(round/ceil)
Interpolation	theta_e_t = interp1(time,theta_e,t)	
fast interpolation	theta_e_t = qinterp1(time,theta_e,t)	

Simulink (simin, from file)

Solver, Solver Settings

- Solver

- Solver Settings

	ode45	ode15s	ode23tb	Remark

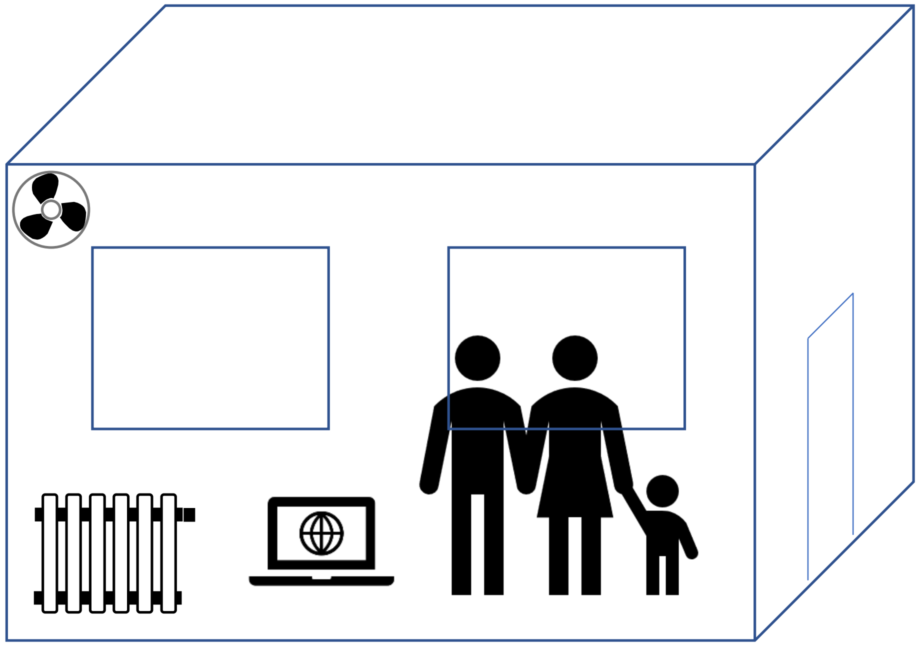
Room Model (simple, lumped mass)

Room Model (2*)

Room Model (2* + FH)

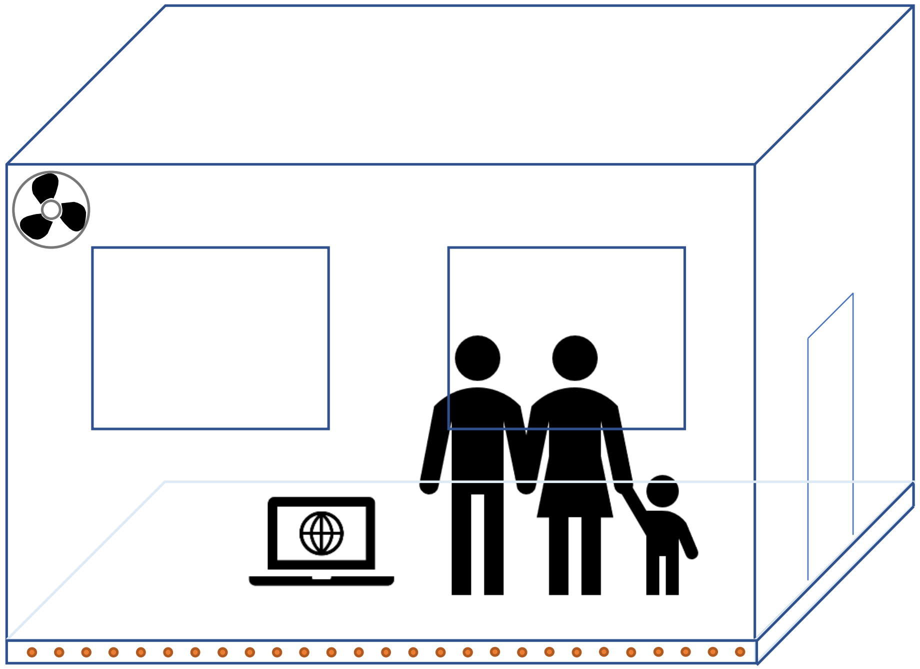
„Simple“: 1 fluid Node

Gebäudemodell - Radiator



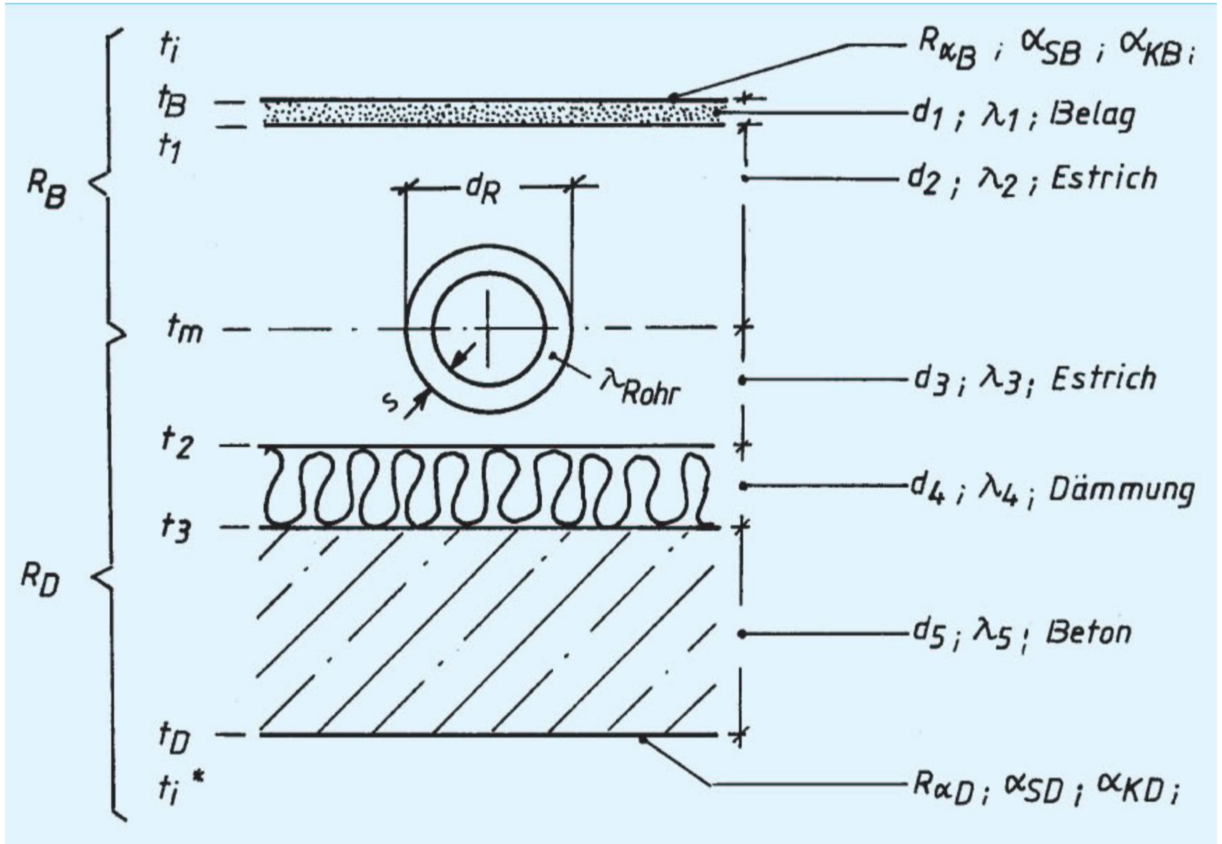
» Luftknoten (thermische Zone)
» Wände/Decken/Böden
» Fenster
» Lüftung
» Solare Gewinne
» Interne Gewinne
» Heizung

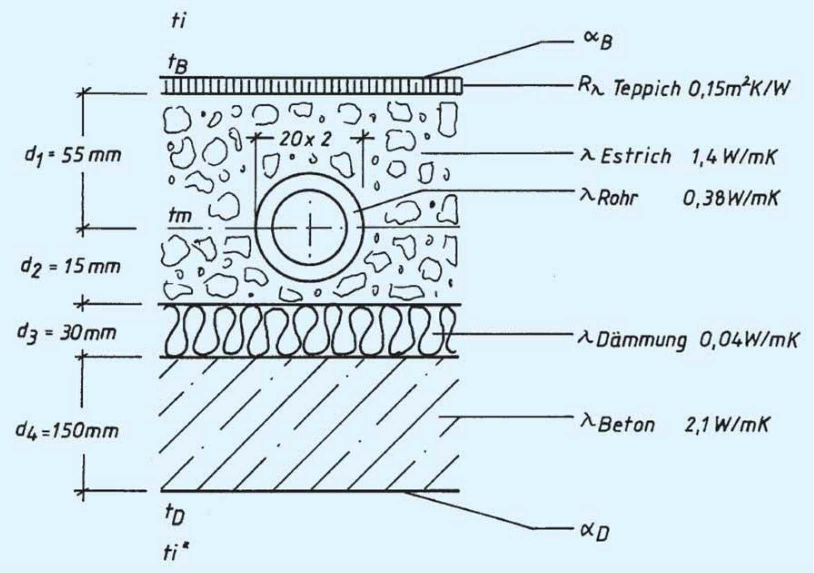
Gebäudemodell - FBH



- » Luftknoten (thermische Zone)
- » Wände/Decken/Böden
- » Fenster
- » Lüftung
- » Solare Gewinne
- » Interne Gewinne
- » Heizung

Beispiel Fussbodenheizung





tm mittlere Temperatur der Heizrohrebene
to mittlere Temperatur der Heizrohroberfläche
αB Wärmeübergangskoeffizient Fußboden
qsp spezifischer Wärmebedarf des Raumes
αS Wärmeübergangskoeffizient Strahlung
αK Wärmeübergangskoeffizient Konvektion
qK Wärmestrom Konvektion
qS Wärmestrom, Strahlung
q Gesamtwärmestrom
Δta Übertemperatur des Fußbodens
tB Oberflächentemperatur des Fußbodens

Radtke, Das ABC der Flächenheizung und Flächenkühlung, Heizungs-Journal Verlags-GmbH, ISBN 3-924788-16-2

Auslegung

$$\vartheta_{flow} = 35°C$$

$$\vartheta_{return} = 30°C$$

$$\vartheta_m = 32.5°C$$

$$R_t = R_{si} + R(1) + R(2)$$

$$R_b = R(3) + R(4) + R(5) + R_{se}$$

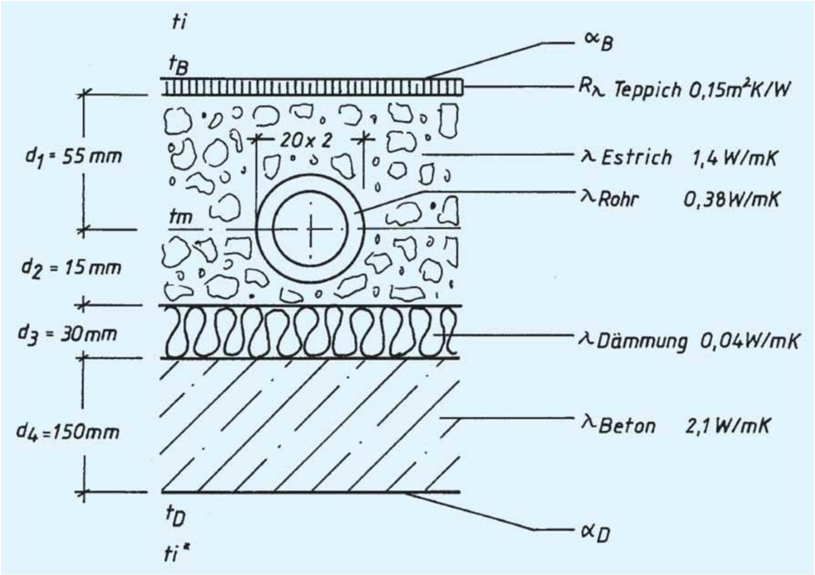
$$\dot{q}_t = \frac{1}{R_t} \cdot (\vartheta_m - \vartheta_i)$$

$$\dot{q}_b = \frac{1}{R_b} \cdot (\vartheta_m - \vartheta_e)$$

$$\dot{q}_{FH} = \dot{q}_t + \dot{q}_b$$

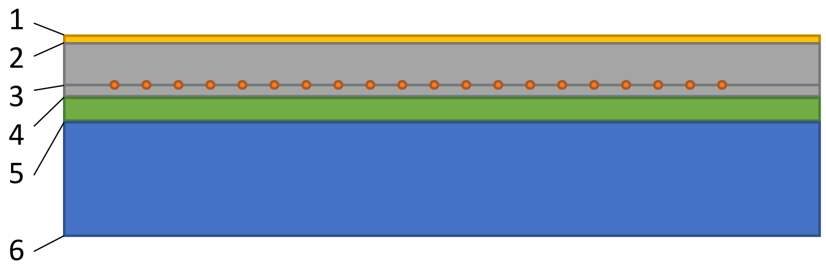
$$\dot{Q}_{FH} = A \cdot \dot{q}_{FH}$$

$$m_{FH} = \dot{Q}_{FH} / (c_{p,w} \cdot (\vartheta_{flow} \text{-} \vartheta_{return}))$$



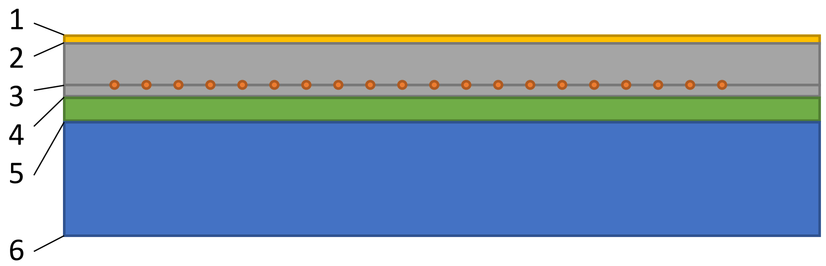
tm mittlere Temperatur der Heizrohrebene
to mittlere Temperatur der Heizrohroberfläche
αB Wärmeübergangskoeffizient Fußboden
qsp spezifischer Wärmebedarf des Raumes
αS Wärmeübergangskoeffizient Strahlung
αK Wärmeübergangskoeffizient Konvektion
qK Wärmestrom Konvektion
qS Wärmestrom, Strahlung
q Gesamtwärmestrom
Δta Übertemperatur des Fußbodens
tB Oberflächentemperatur des Fußbodens

Floor Heating (steady state)



$$R_t = R_{si} + R(1) + R(2)$$
$$R_b = R(3) + R(4) + R(5) + R_{se}$$

Floor Heating (steady state)

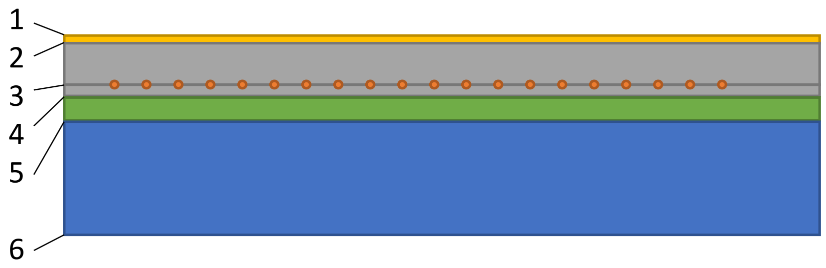


$$R_t = R_{si} + R(1) + R(2)$$
$$R_b = R(3) + R(4) + R(5) + R_{se}$$

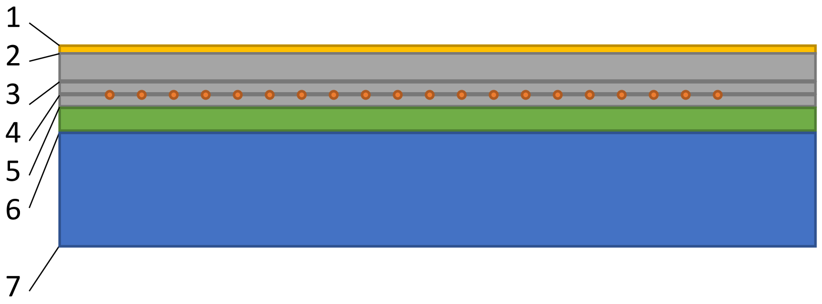
U_floor = 0.82078 W/(m^2 K)
R_t = 0.21621 (m^2 K)/W
R_b = 1.0021 (m^2 K)/W
qdot_t = 57.8 W/m^2
qdot_b = 12.5 W/m^2
qdot_FH = 70.3 W/m^2
mdot_FH = 0.0033582 kg/s/m^2
theta_se = 22.1 °C
theta_si = 25.8 °C

Floor Heating with …

6 Nodes



7 Nodes

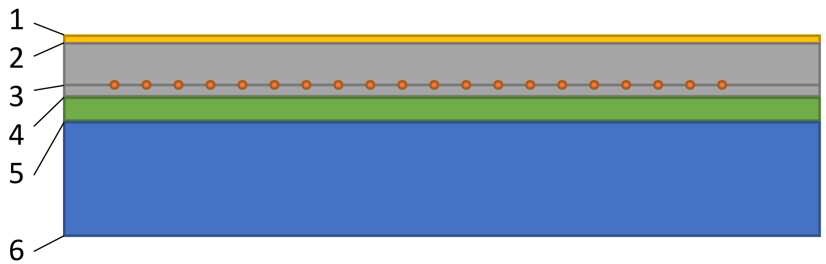


$$R_t = R_{si} + R(1) + R(2)$$
$$R_b = R(3) + R(4) + R(5) + R_{se}$$

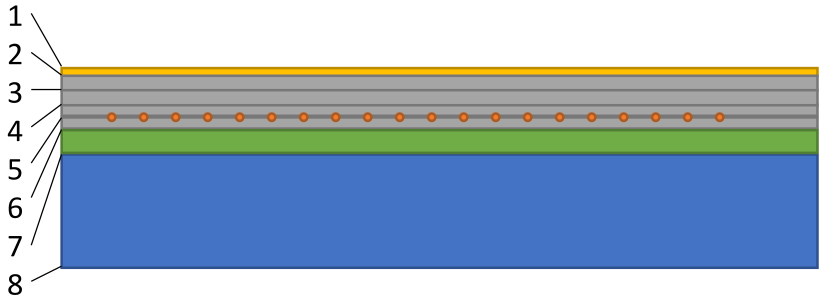
$$R_t = R_{si} + R(1) + R(2) + R(3)$$
$$R_b = R(4) + R(5) + R(6) + R_{se}$$

Floor Heating with …

6 Nodes



8 Nodes



$$R_t = R_{si} + R(1) + R(2)$$
$$R_b = R(3) + R(4) + R(5) + R_{se}$$

$$R_t = R_{si} + R(1) + R(2) + R(3) + R(4)$$
$$R_b = R(5) + R(6) + R(7) + R_{se}$$

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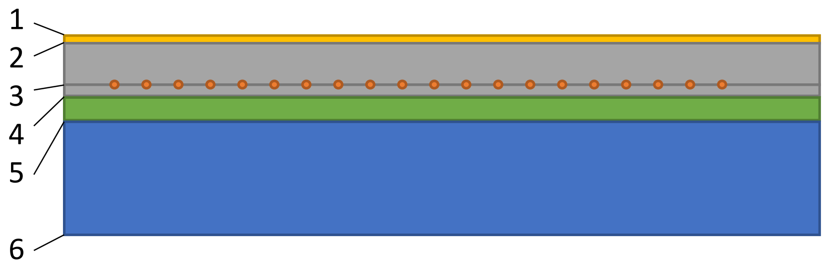
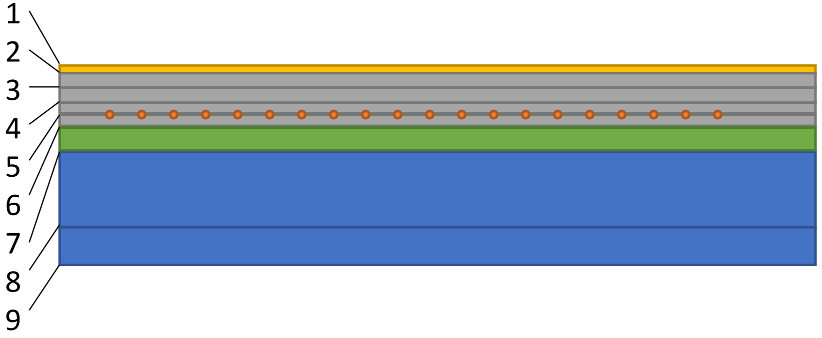
Floor Heating with …

6 Nodes



9 Nodes

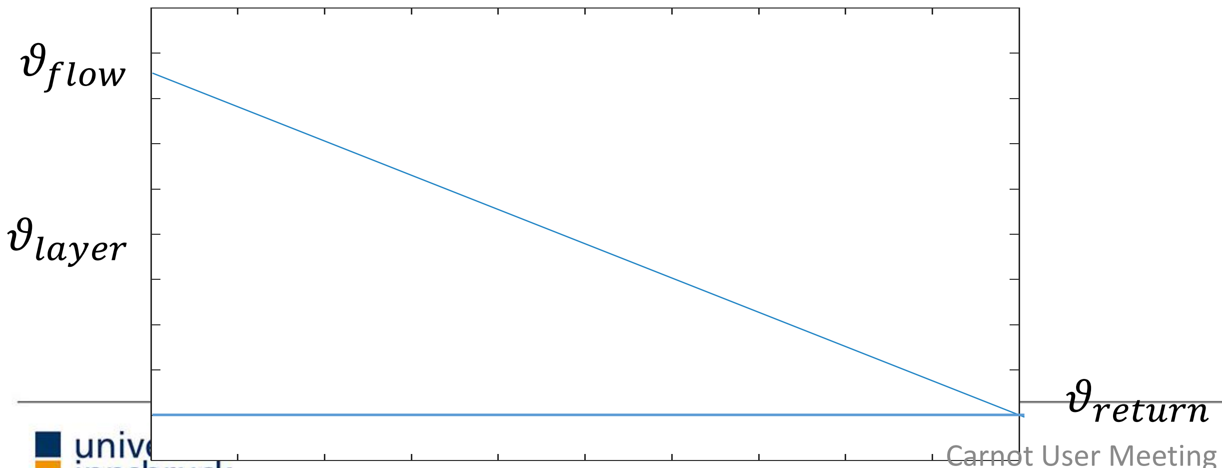


$$R_t = R_{si} + R(1) + R(2)$$
$$R_b = R(3) + R(4) + R(5) + R_{se}$$

$$R_t = R_{si} + R(1) + R(2) + R(3) + R(4)$$
$$R_b = R(5) + R(6) + R(7) + R(8) + R_{se}$$

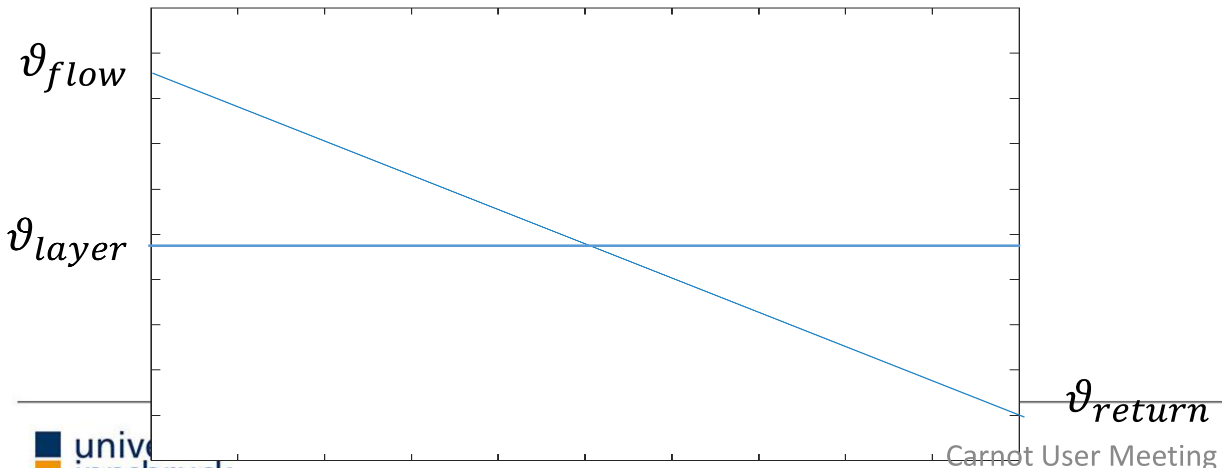
Simple – 1 Node

$$\vartheta_{return} = \vartheta_{layer}$$
$$\dot{Q}_{FH} = \dot{m} \cdot c_p \cdot \left(\vartheta_{flow} - \vartheta_{return}\right)$$



Improved“ mean temperature (ϑ_m)

$$\vartheta_{return} = 2 \cdot \vartheta_{layer} - \vartheta_{flow}$$
$$\dot{Q}_{FH} = \dot{m} \cdot c_p \cdot \left(\vartheta_{flow} - \vartheta_{return}\right)$$



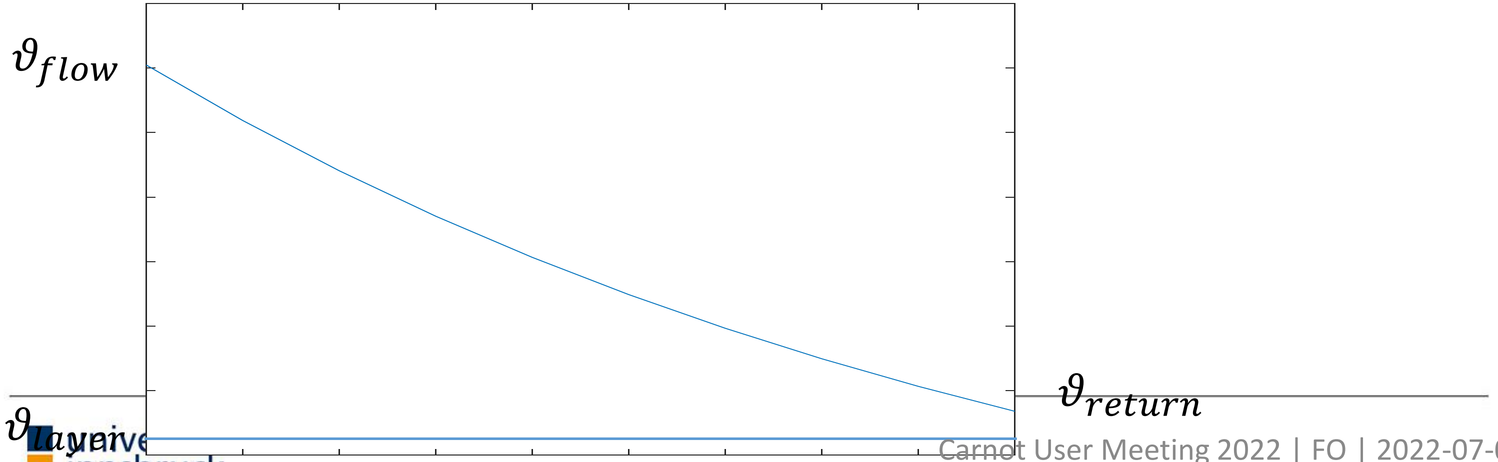
„Physical“ LMTD

- logarithmic mean temperature difference LMTD

$$\Delta\vartheta_{log} = \frac{\vartheta_{flow} - \vartheta_{return}}{\ln\left(\frac{\vartheta_{flow} - \vartheta_{layer}}{\vartheta_{retrun} - \vartheta_{layer}}\right)}$$

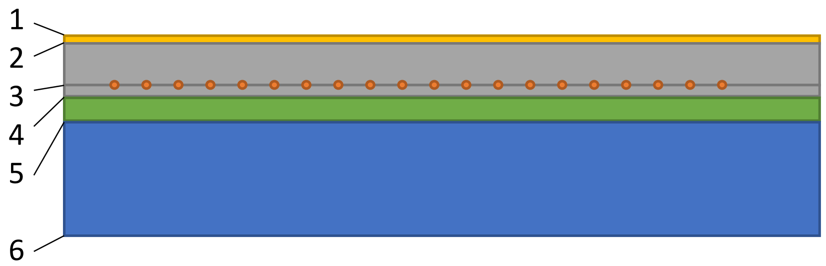
$$\dot{Q}_{FH} = UA \cdot \Delta\vartheta_{log}$$

$$\vartheta_{return} = \vartheta_{flow} - \frac{\dot{Q}_{FH}}{\dot{m} \cdot c_p}$$



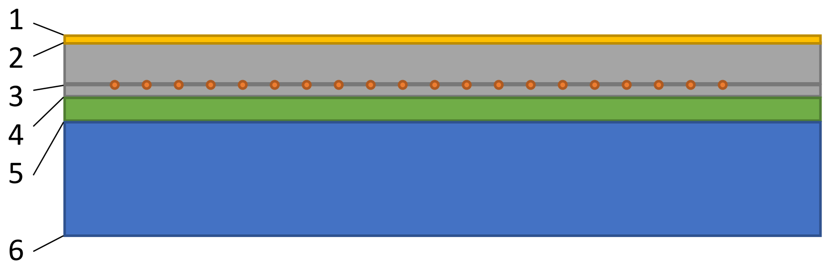
Floor Heating with …

6 Nodes (simple)



$$\vartheta_{return} = \vartheta_3$$
$$\dot{Q}_{FH} = \dot{m} \cdot c_p \cdot (\vartheta_{flow} - \vartheta_{return})$$

6 Nodes (UA)



$$\vartheta_{return} = \vartheta_{flow} - \frac{\dot{Q}_{FH}}{\dot{m} \cdot c_p}$$
$$\dot{Q}_{FH} = \dot{m} \cdot c_p \cdot \left(\vartheta_{flow} - \vartheta_{return}\right)$$
$$\dot{Q}_{FH} = UA \cdot \Delta\vartheta_{log}$$
$$\Delta\vartheta_{log} = \frac{\vartheta_{flow} - \vartheta_{return}}{\ln\left(\frac{\vartheta_{flow} - \vartheta_3}{\vartheta_{retrun} - \vartheta_3}\right)}$$

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PDEPE