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Arbeitsbereich für Energieeffizientes Bauen

Co-Simulation with Matlab and Matlab/Simulink – Example of a Wall Heating System

HP_App&Sim, **Carnot User Meeting 2023**, Bologna

Ochs, Fabian, Assoc. Prof. Dr.-Ing.

(Co-simulation) Approaches for Complex Systems of ODEs and PDEs – Example of a Wall Heating System

Fabian Ochs

Engage all workers …

Parallelisation …

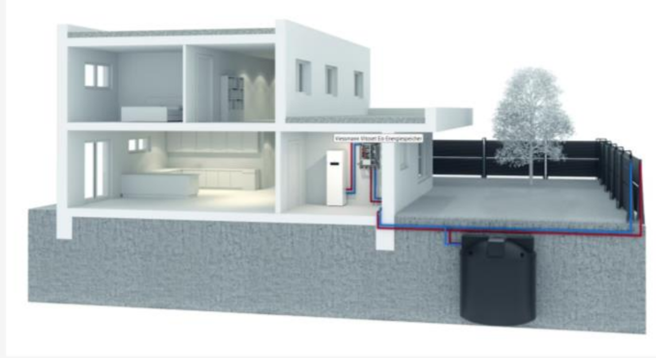
Introduction and Motivation

Examples of 1D, 2D or 3D component models coupled with a thermal building model (thermal zone)

- » Building with thermal activation (floor heating or wall heating)
  (1D, 2D, 3D)
- » Building with heat pump (HP) and ground heat exchanger (GHX), optionally icing/deicing
  (1D, 2D, 3D)
- » Ground coupled ice storage
  (0D, 1D, 2D, 3D)
- » Building with Hygrothermal Wall
  (1D, 2D, 3D)
- » Ground coupled Thermal Energy Storage (TES)
  (2D and 3D)

Einbau des Fassadenprototyps aus „MultiTab" in die Fassadenprüfeinrichtung bei AEE Intec
Foto: AEE Intec

Quelle: A. Drexler

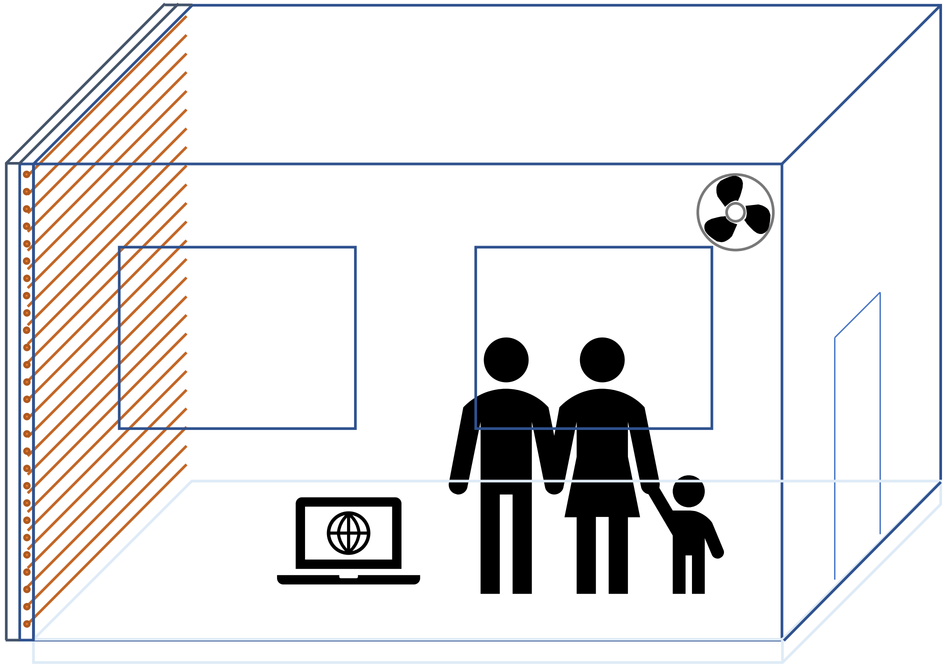


Viessmann Eis-Energiespeicher 2.0: jetzt in Kunststoff

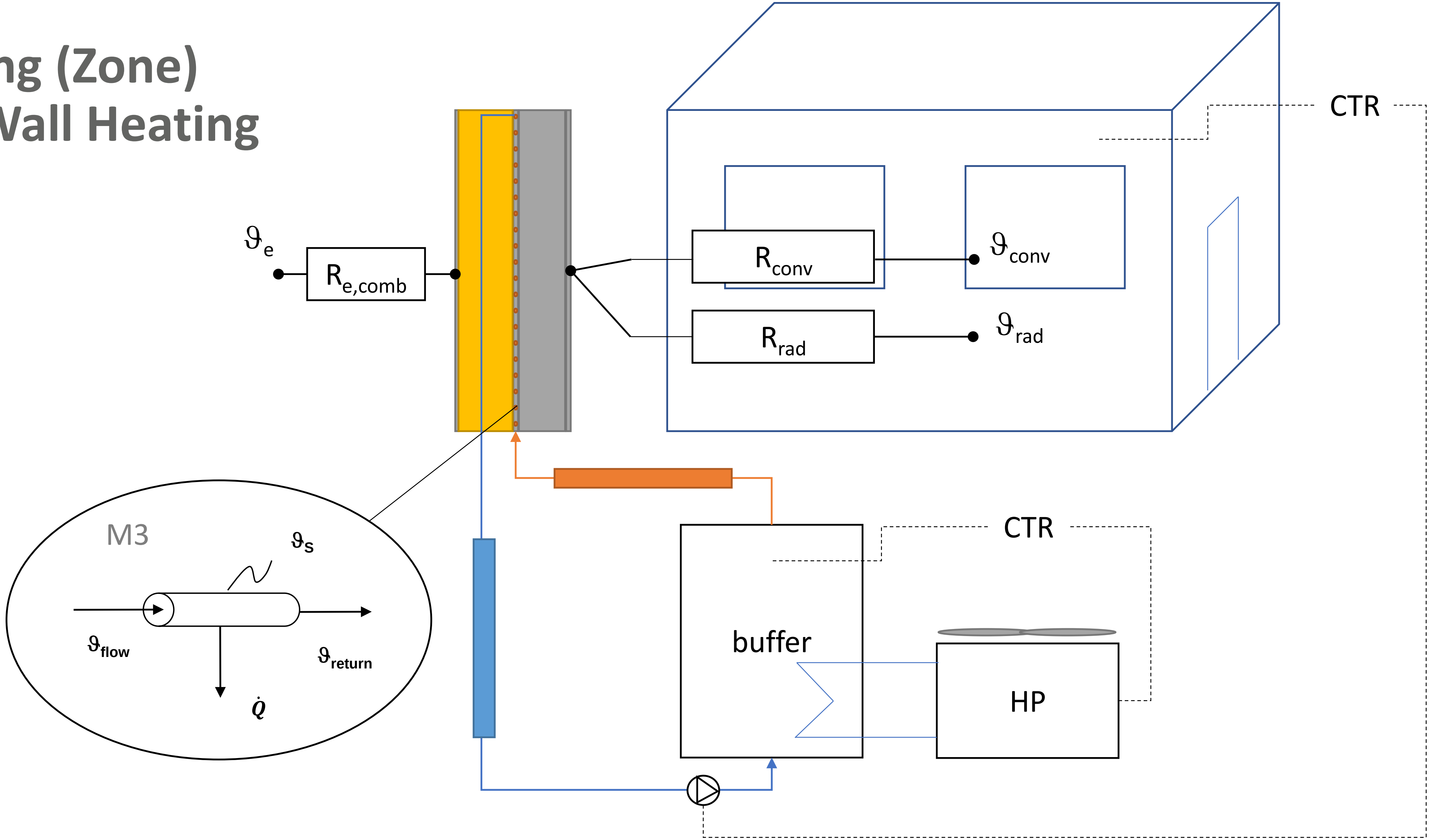
Example - Building with Wall Heating

- Minimal invasive renovation
- Low Temperature Emission
- Thermal mass activation

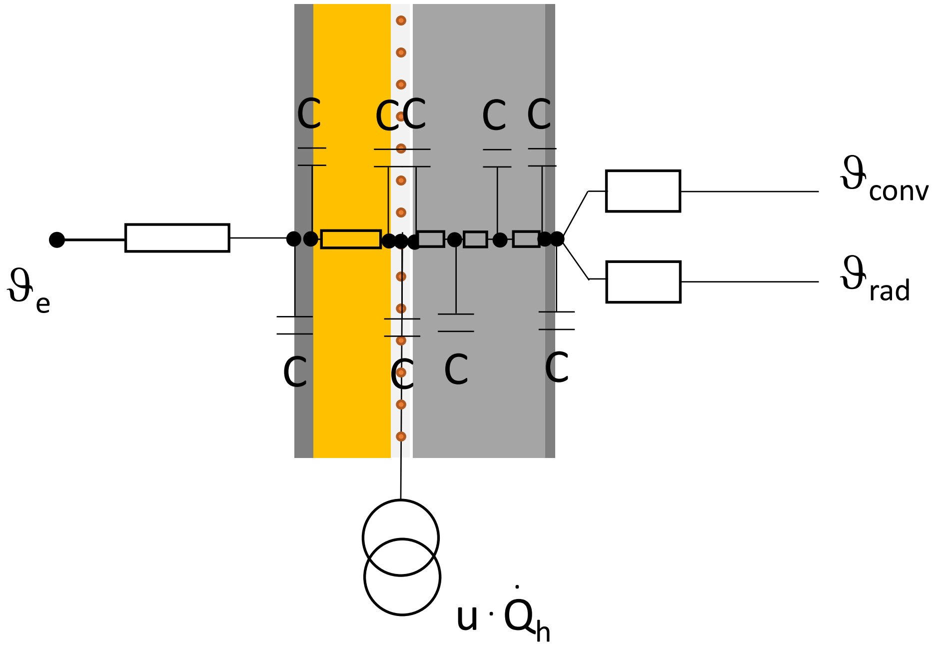
Einbau des Fassadenprototyps aus „MultiTab" in die Fassadenprüfeinrichtung bei AEE Intec
Foto: AEE Intec

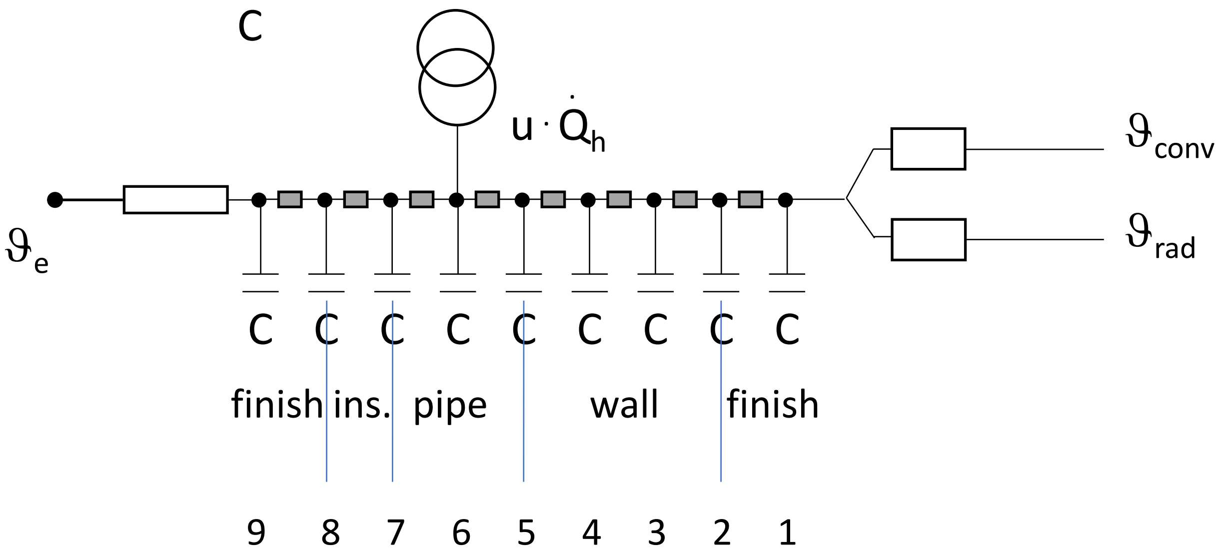


Building (Zone) with Wall Heating



1D Wall Heating 9 Nodes (8R9C)





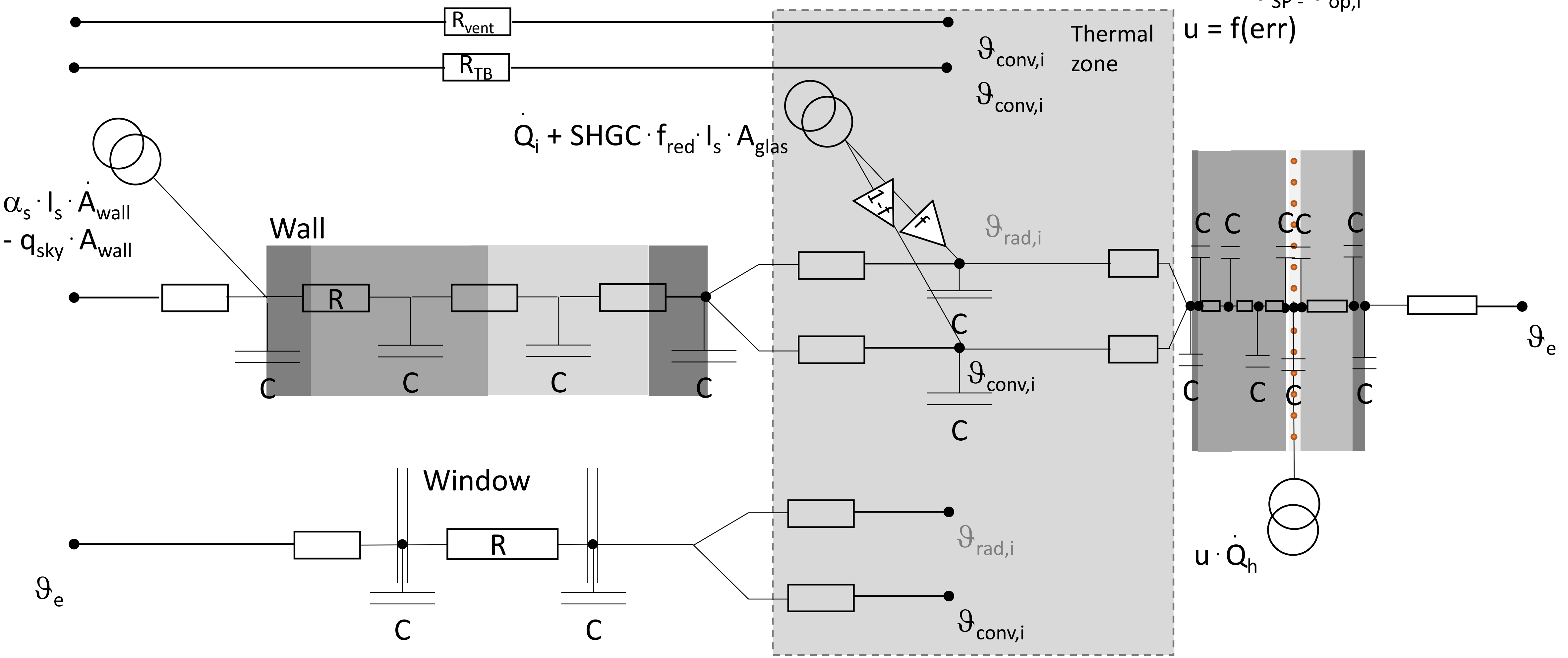
System of ODEs

2star 4 node model + WH (17 ODE)

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

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

$u = f(err)$

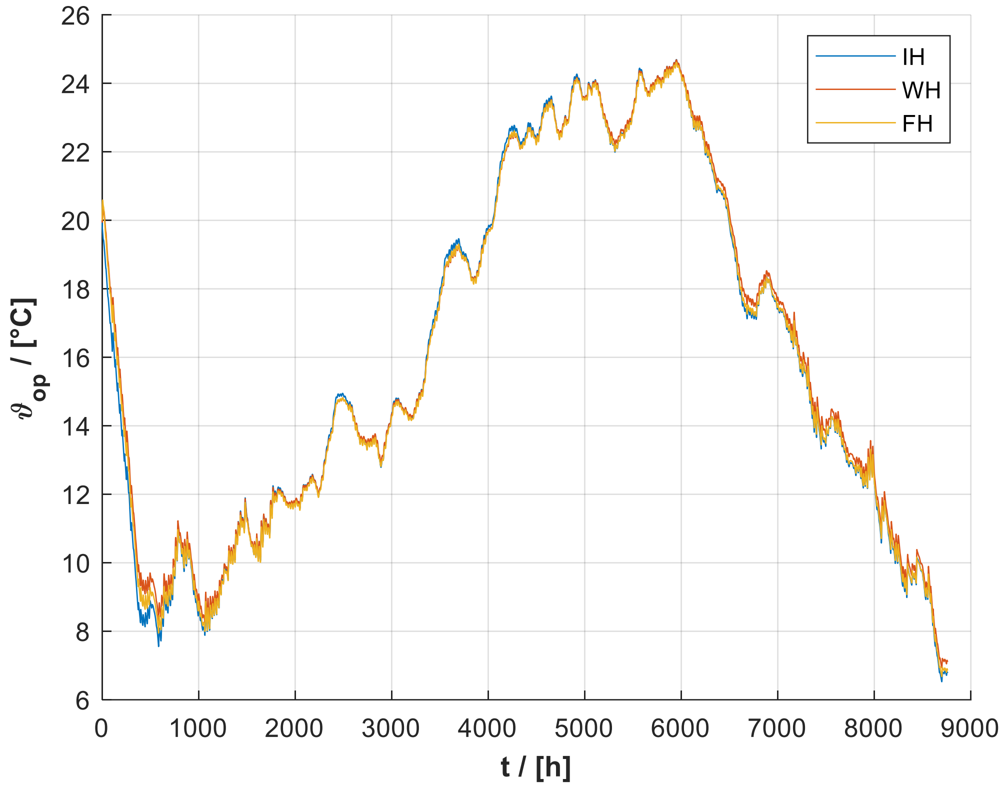


Matlab (Simulink) ODE Solver (mathworks.com)

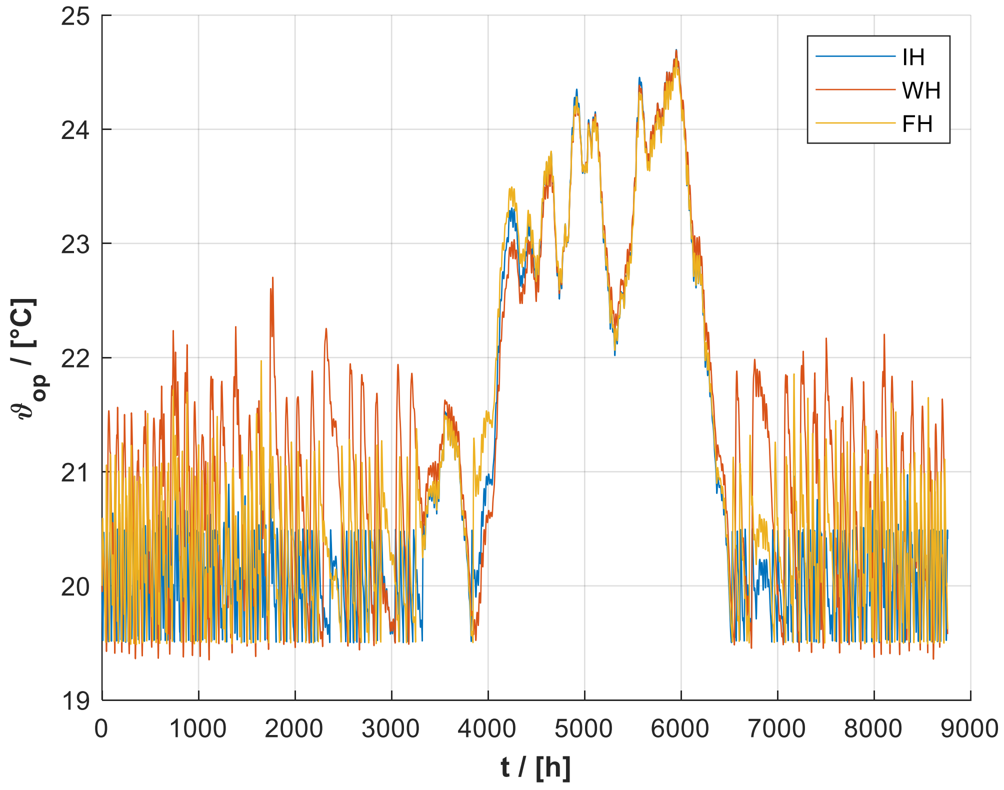
Solver	Problem Type	Accuracy	When to Use
ode45	Nonstiff	Medium	Most of the time. ode45 should be the first solver you try.
ode23		Low	ode23 can be more efficient than ode45 at problems with crude tolerances, or in the presence of moderate stiffness.
ode113		Low to High	ode113 can be more efficient than ode45 at problems with stringent error tolerances, or when the ODE function is expensive to evaluate.
ode78		High	ode78 can be more efficient than ode45 at problems with smooth solutions that have high accuracy requirements.
ode89		High	ode89 can be more efficient than ode78 on very smooth problems, when integrating over long time intervals, or when tolerances are especially tight.
ode15s	Stiff	Low to Medium	Try ode15s when ode45 fails or is inefficient and you suspect that the problem is stiff. Also use ode15s when solving differential algebraic equations (DAEs).
ode23s		Low	ode23s can be more efficient than ode15s at problems with crude error tolerances. It can solve some stiff problems for which ode15s is not effective. ode23s computes the Jacobian in each step, so it is beneficial to provide the Jacobian via odeset to maximize efficiency and accuracy. If there is a mass matrix, it must be constant.
ode23t		Low	Use ode23t if the problem is only moderately stiff and you need a solution without numerical damping. ode23t can solve differential algebraic equations (DAEs).
ode23tb		Low	Like ode23s, the ode23tb solver might be more efficient than ode15s at problems with crude error tolerances.
ode15i	Fully implicit	Low	

Results 2* Thermal Zone Model with 1D WH - Temperature

w/o Heating



w/ Heating

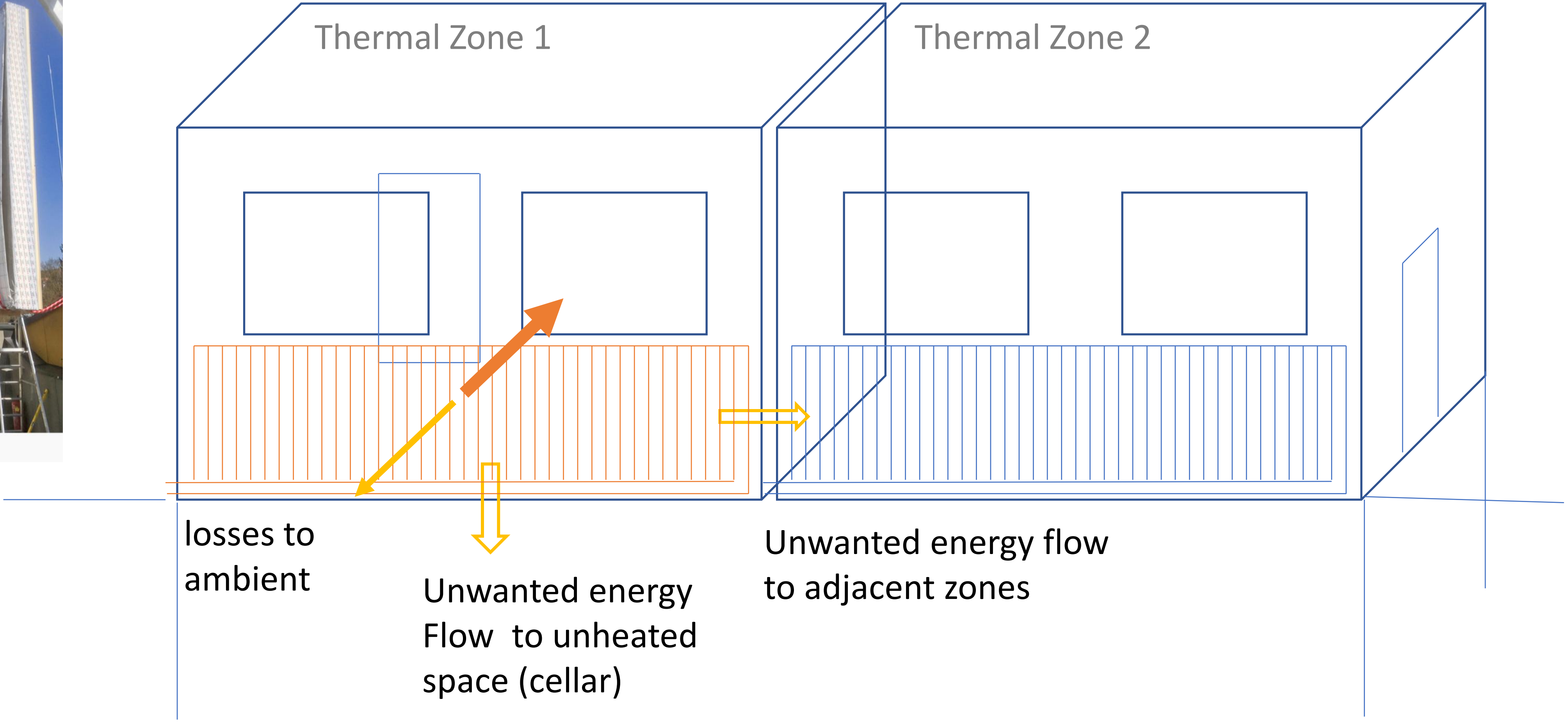


Results 2* Thermal Zone Model with 1D WH – Simulation Time

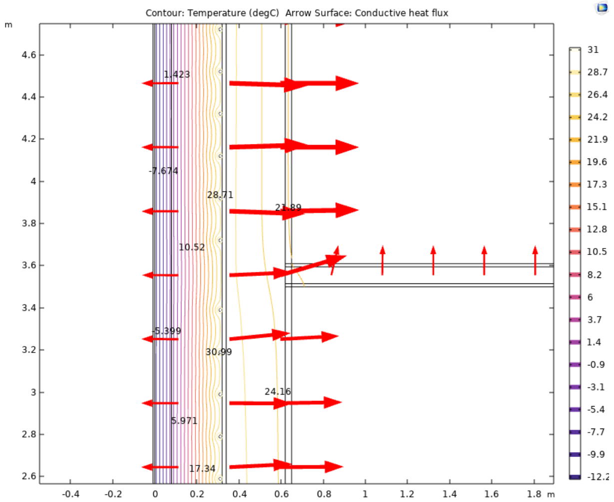
	ODE	Max time step / [s]	Solver	Time / [min]
1D FD WH (stand alone)	9	3600	ode45	4.37
1D FD WH (stand alone)	9	3600	ode15s	.16
1D FD WH (stand alone)	9	600	ode15s	.27
2* Ideal Heating	8	600	ode45	.37
2* 1D Floor Heating	17	600	ode45	.38
2* 1D Wall Heating	17	600	ode45	.51

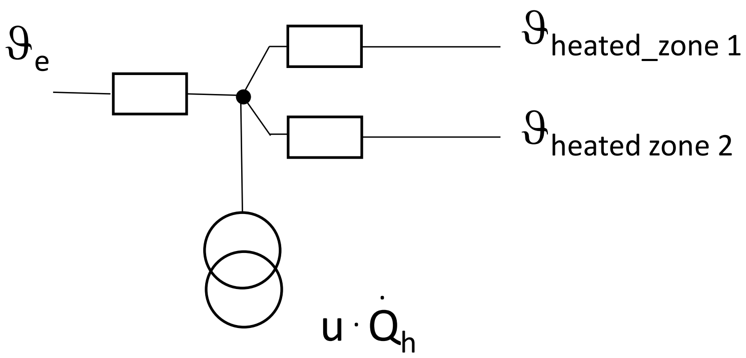
Wall Heating – two thermal zones, 2D and 3D effects

Einbau des Fassadenprototyps aus „MultiTab" in die Fassadenprüfeinrichtung bei AEE Intec
Foto: AEE Intec

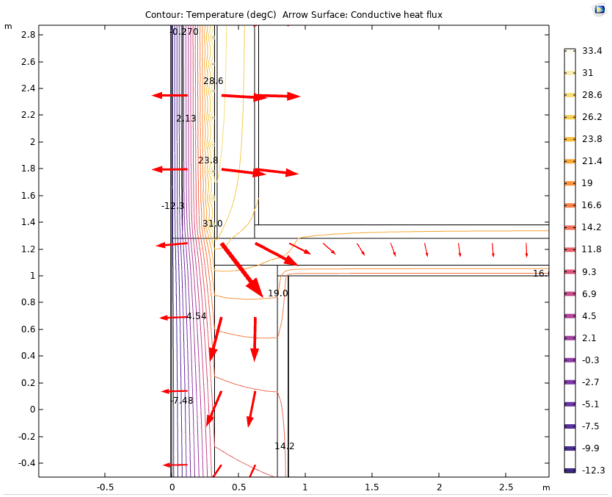


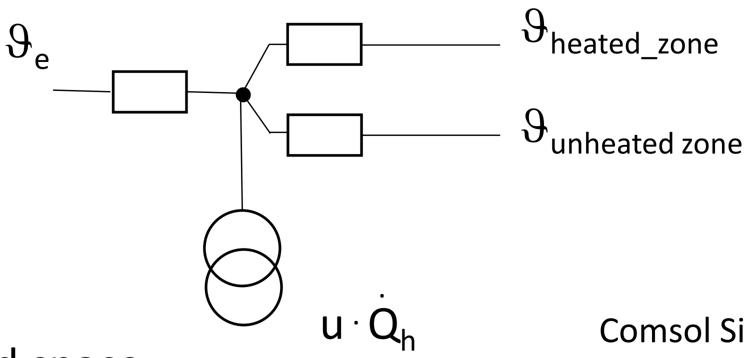
2D (3D) FE Simulation and Resistance Model





Two thermal zones

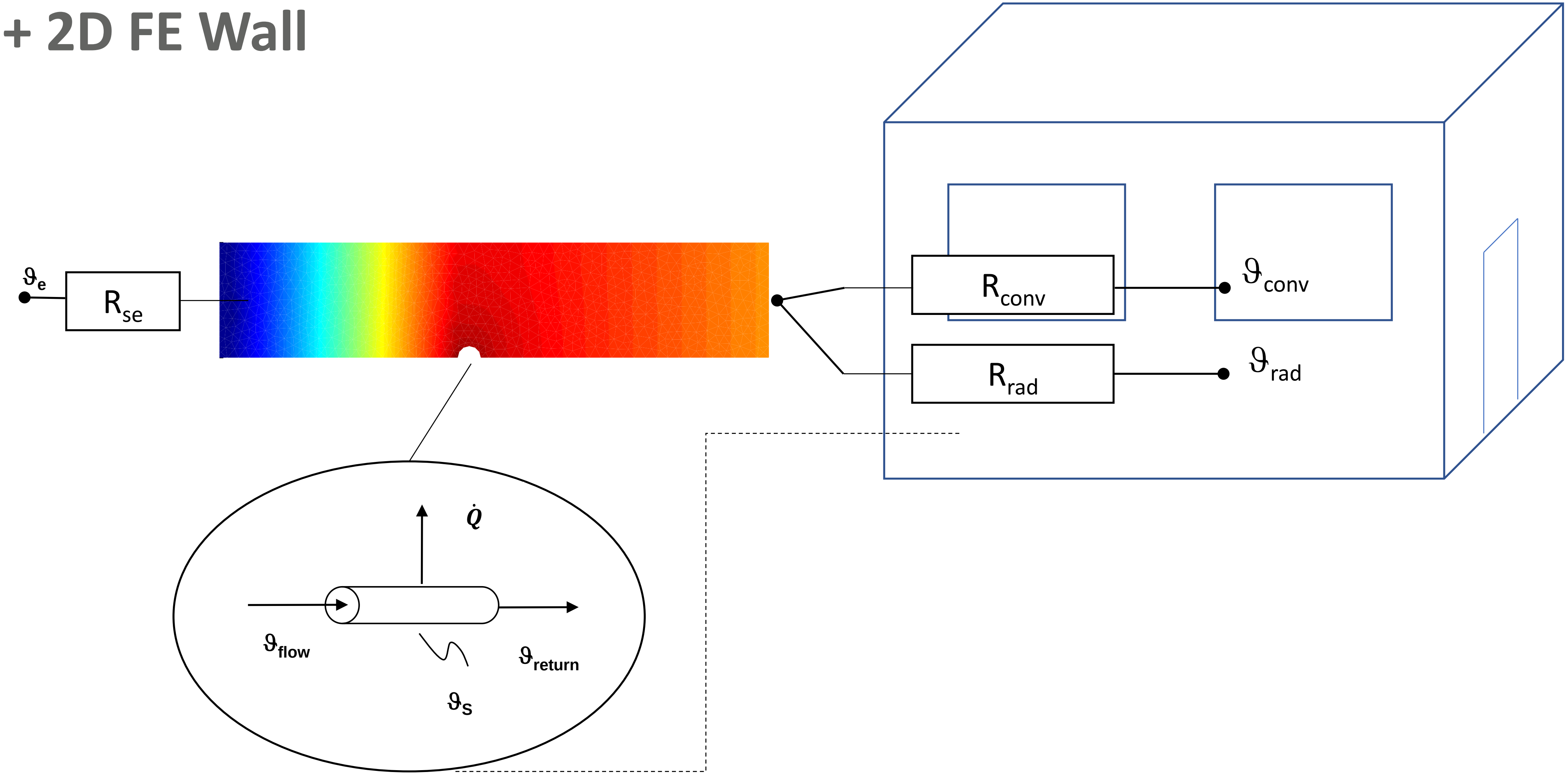




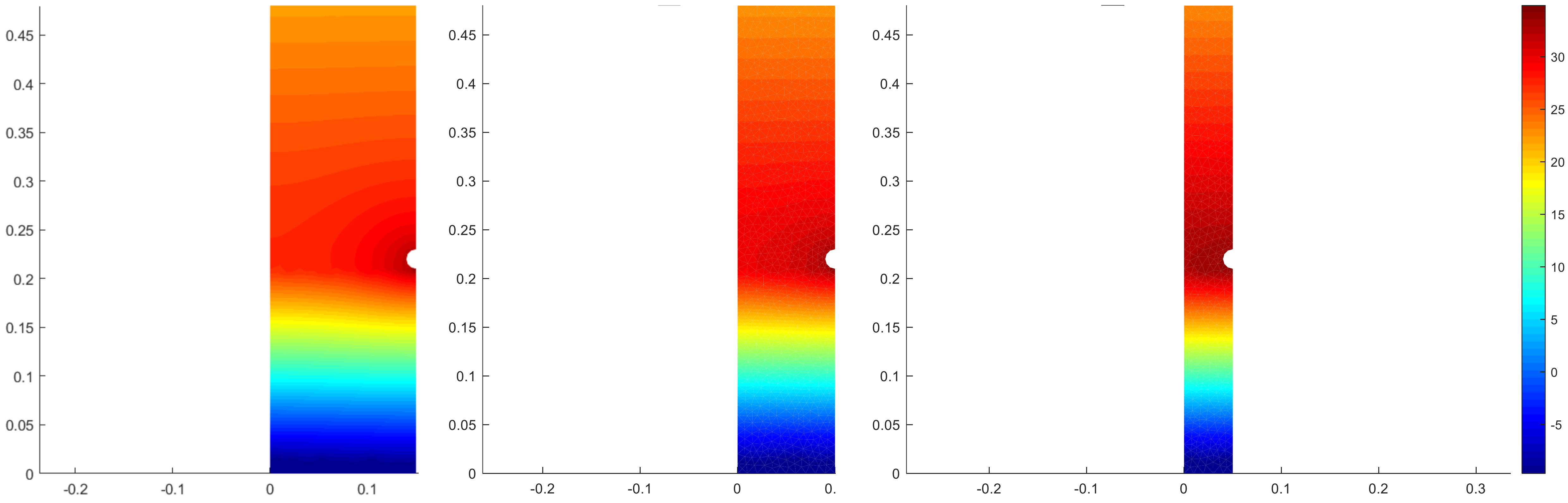
Thermal zone and unheated space

Comsol Simulation Results
FFG Project SüdSan (Tosatto, Ochs)

Test Case – 2* Thermal Zone + 2D FE Wall



2D Wall Heating - Pipe Distance (30 cm, 20 cm, 10 cm)



FEM - Method of Lines

Parabolic PDE (coefficient form)

$$d\frac{\partial u}{dt} - \nabla \cdot (c\nabla u) + au = f$$

Generation of System of ODE with „Method of Lines“

Matrix Form (Integrated Equation)

$$\frac{d}{dt}U = M^{-1}(F + G + R + KU + QU + HU)$$

Update of PDE parameter with each time step
Integration by Matlab, Matlab/Simulink

PDE Problem ⇨ Matlab or Simulink Block

States	*One for each node*
Input	*Time dependent: BC, source, control*
Output	*Temperature of Nodes, heat flux, etc.*

$$K_{i,j} = \int_{\Omega} (c\nabla\phi_j) \cdot \nabla\phi_i dx$$ K stiffness matrix

$$M_{i,j} = \int_{\Omega} a\phi_j\phi_i dx$$ M mass matrix

$$Q_{i,j} = \int_{\partial\Omega} q\phi_j\phi_i ds$$ Q boundary matrix (Neumann)

$$F_i = \int_{\Omega} f\phi_i dx$$ F load (right side) vector

$$G_i = \int_{\partial\Omega} g\phi_i ds$$ G boundary vector (Neumann)

R Dirichlet vector

H Dirichlet matrix

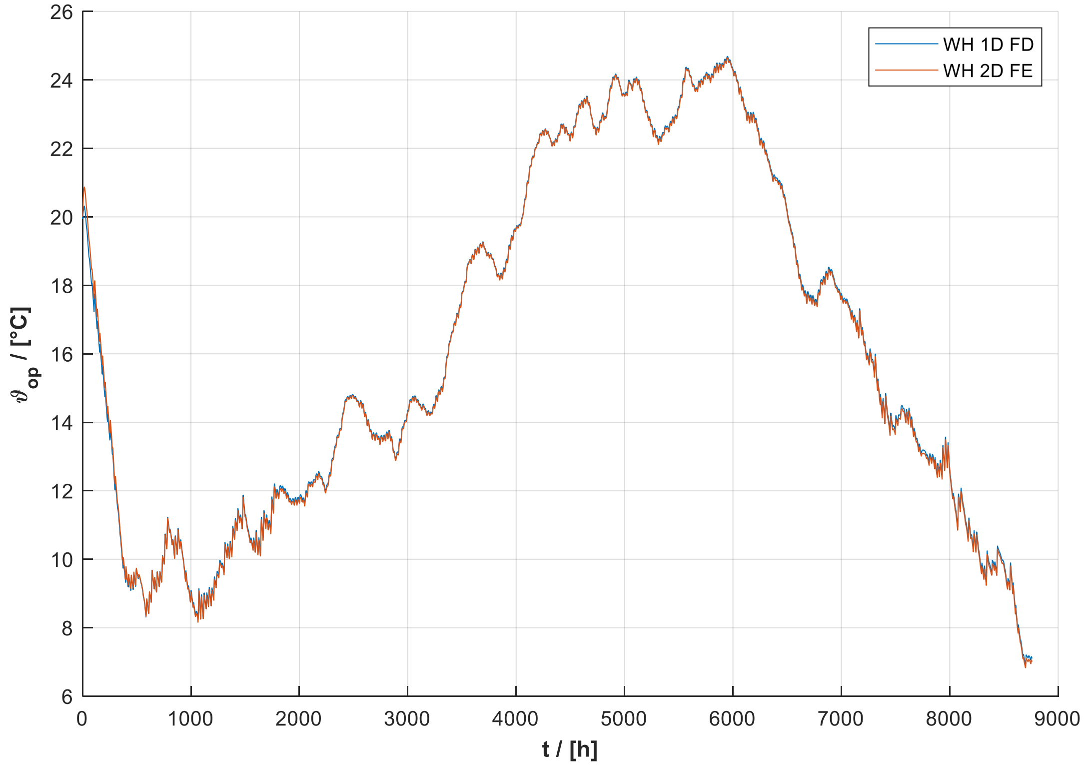
Ochs, F. Feist W., FE Erdreich-Wärmeübertrager Model für dynamische Gebäude- und Anlagensimulation mit Matlab/Simulink, Fourth German-Austrian IBPSA Conference, Berlin University of the Arts, Bausim 2012

(Co-)Simulation Options

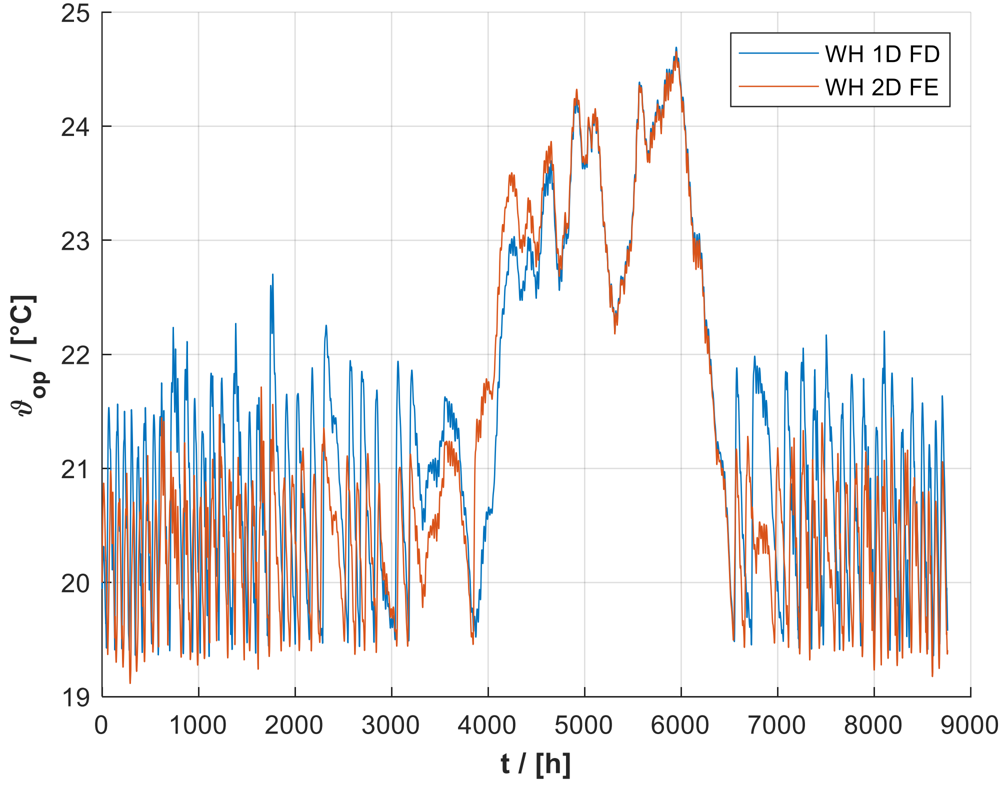
- Approach 1: fully coupled system of ODEs, 1 solver, variable time step
- Approach 2: decoupled systems of ODEs, 2 or more solvers,
  - ping-pong fixed time steps
  - event controlled

Simulation Results 2* FE WH

» w/o Heating

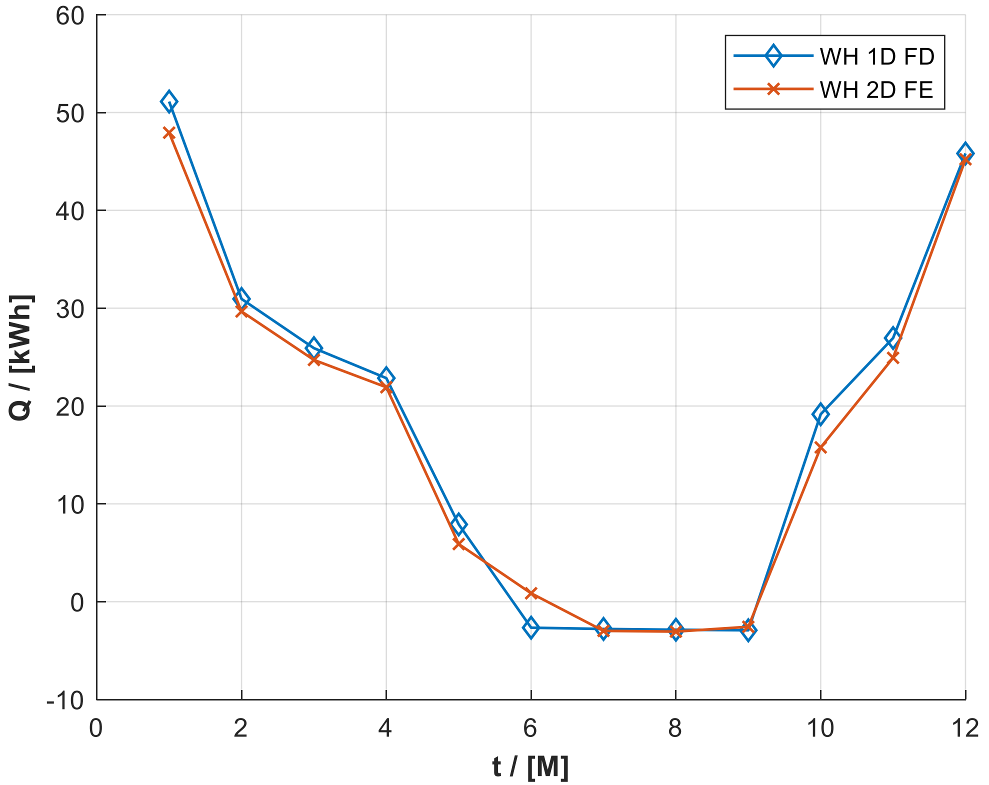


w/ Heating

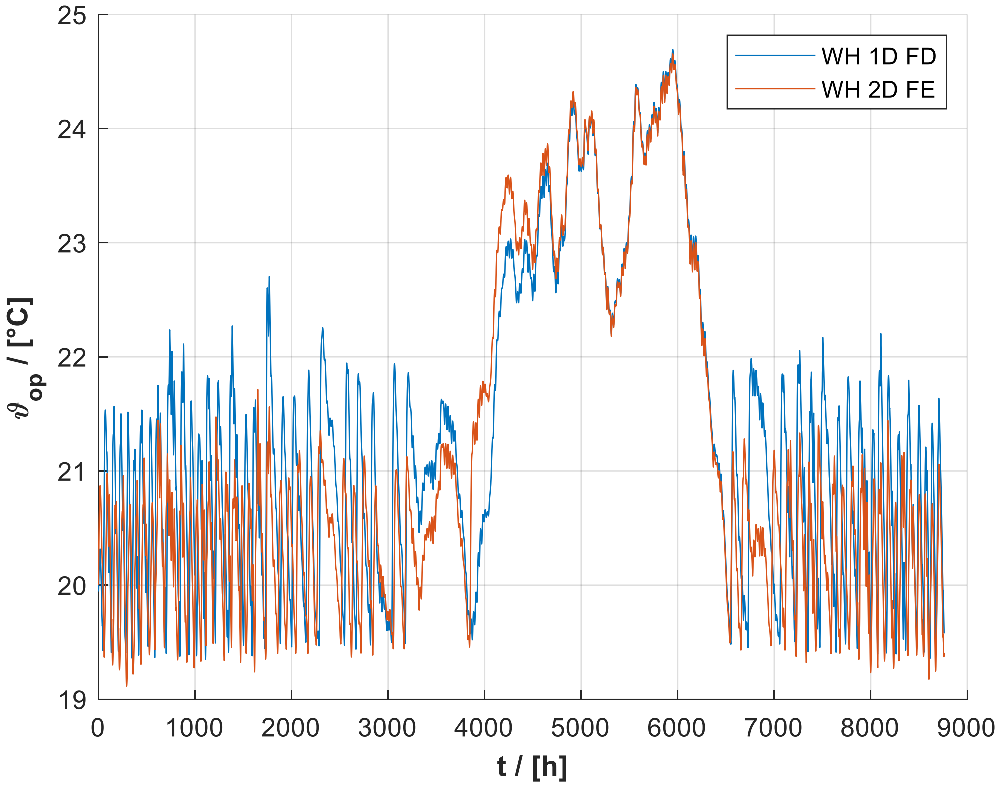


Simulation Results 2* FE WH

» Heating Demand



Temperature



Simulation Results 2* FE WH – Simulation Time

	ODE	Max time step / [s]	Solver	Time / [min]
1D FD WH (stand alone)	9	3600	ode15s	.16
2D FE WH (stand alone)	130	3600	ode45	OoRo(m)P
2D FE WH (stand alone)	130	3600	ode15s	.08
2D FE WH (stand alone)	130	600	Ode15s	.47
2D FE WH (stand alone)	1276	600	ode15s	4.9

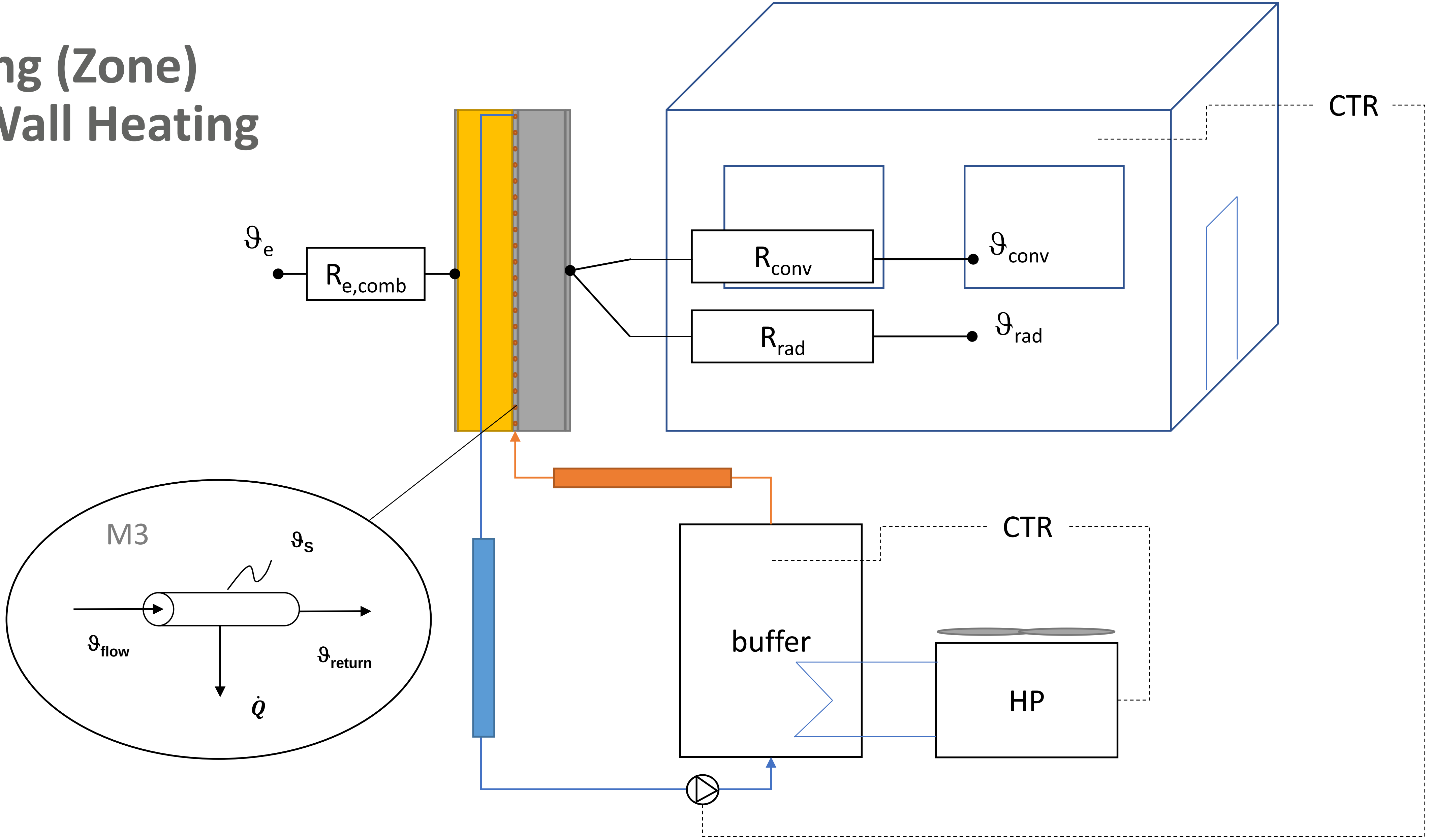
OoRo(m)P: Out of Range of (my) Patiance

Simulation Results 2* FE WH – Simulation Time

	ODE	Max time step / [s]	Solver	Time / [min]
1D FD WH (stand alone)	9	3600	ode15s	.16
2D FE WH (stand alone)	130	3600	ode45	OoRo(m)P
2D FE WH (stand alone)	130	3600	ode15s	.08
2D FE WH (stand alone)	130	600	Ode15s	.47
2D FE WH (stand alone)	1276	600	ode15s	4.9
2* 2D FE Wall Heating	130	600 / 3600	ode15s	2.1
2* 2D FE Wall Heating	1276	3600	ode15s	still running

OoRo(m)P: Out of Range of (my) Patiance

Building (Zone) with Wall Heating



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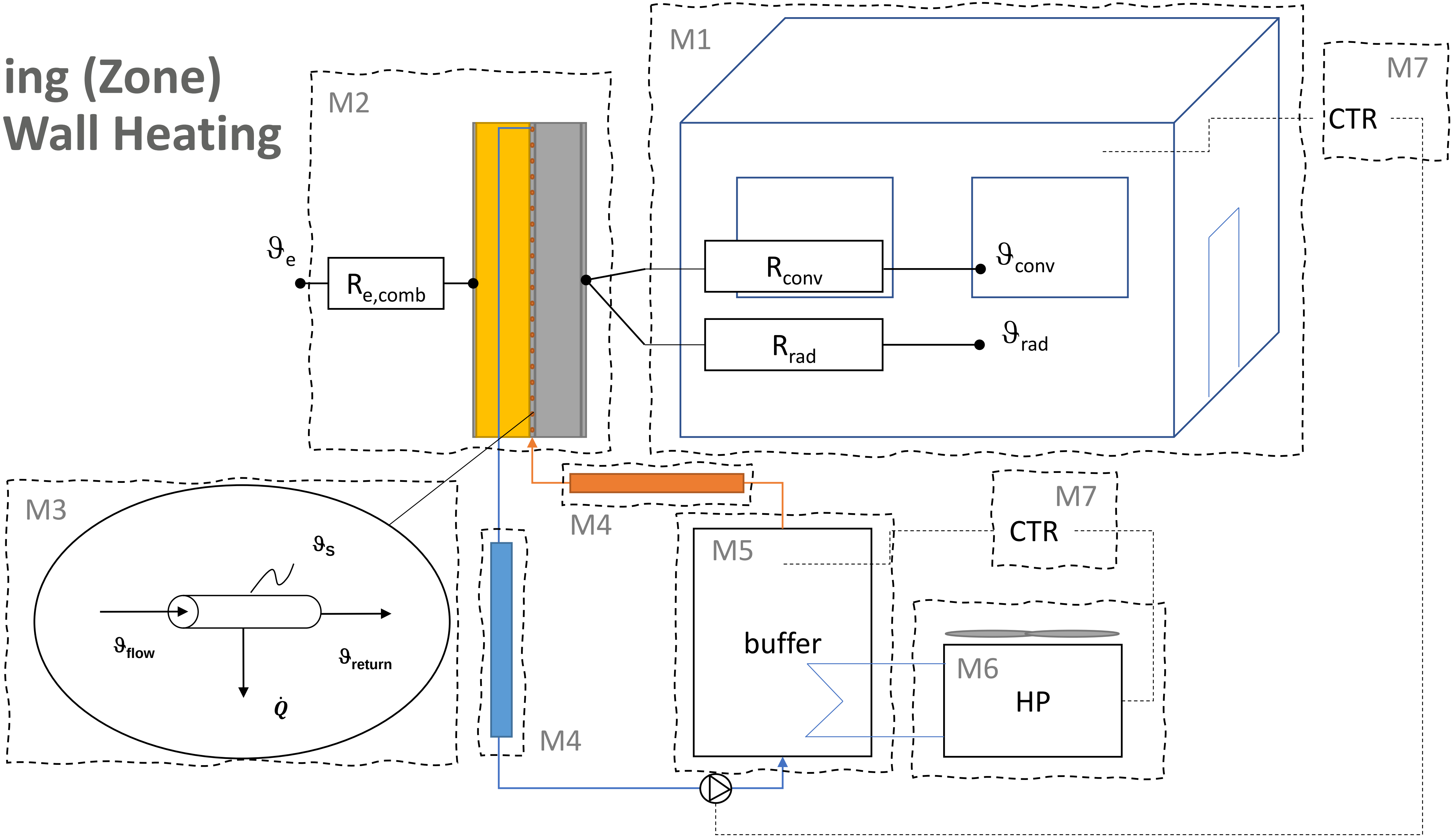
Building (Zone) with Wall Heating



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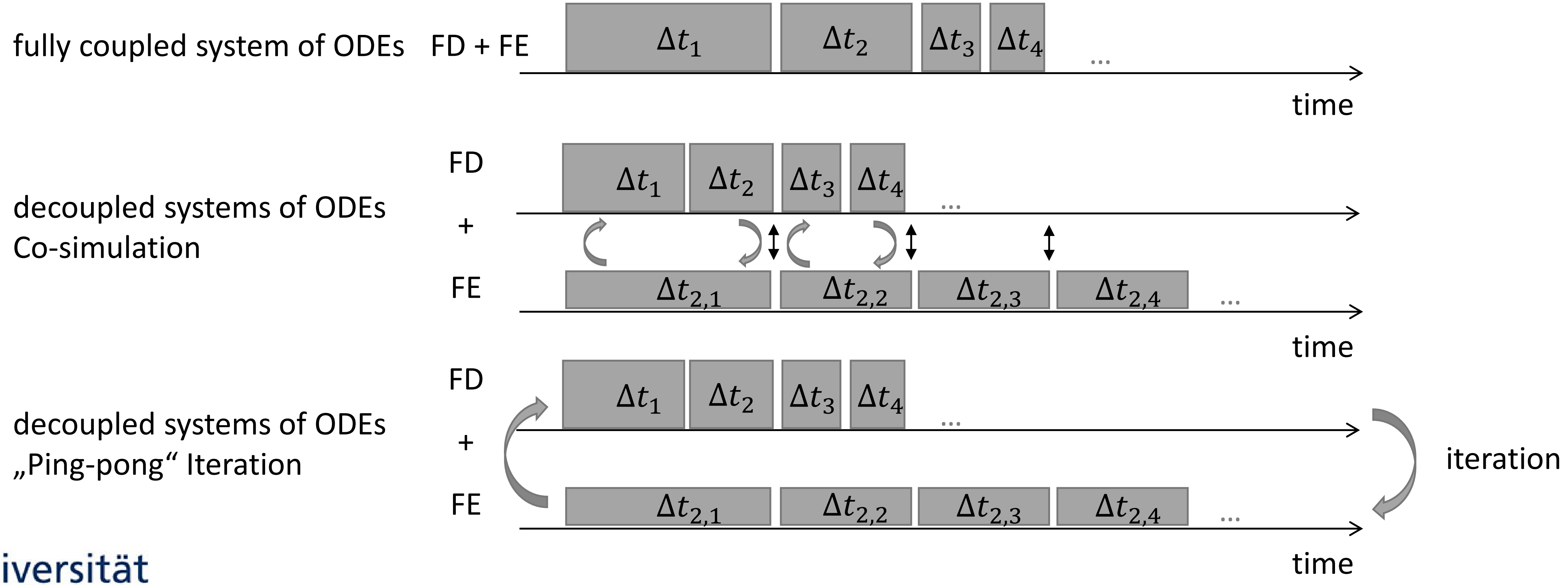
Model Structure (Modules)

- Module 1: Building Model (thermal zone)
  - Submodule 1.1 2* Model
  - Submodule 1.2 Wall
  - Submodule 1.3 Window
  - Submodule 1.4 (Mechanical) Ventilation (with HR)
  - Submodule 1.5 Solar Gains
  - Submodule 1.6 Internal Gains
- Module 2: Wall with Heating Loop (solid domain)
- Module 3: Heating Loop (fluid domain)
- Module 4: Pipes (fluid domain)
- Module 5: Buffer Storage (fluid domain)
- Module 6: Heat Pump (refrigerant cycle / PM)
- Module 7: Controller
  - Submodule 7.1 Heating Loop (on/off, PID)
  - Submodule 7.2 HP Loop (on/off, PID)

Coupled Model with 1 Solver vs.
Decoupled Modules with dedicated solvers?

(Co-)Simulation Options

Fixed time step vs. Variable time step
Master time step and Sub-time step



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Open questions …

For what kind of problems which (variable) master and (variable) sub-time step?

Which (required) accuracy with which (accetable) computational performance?

Coupling of (complex) FE or calibration of simplified models …

(Conclusions)

- Coupled ODE System R-C model (FD) with FEM to simulated complex building systems (wall heating, ground heat exchanger, etx.)
- FEM, Method of Lines leads to large systems of ODEs
- Numerically challenging (long simulation times), solver choice and settings
- Decoupled system components significantly faster than coupled large ODE systsem
- Co-simulation of systems with dedicated solvers could be a promising solution
- Further work required …

Thank you …

Acknowledgement:

This work is possible through the funding within the FFG Project SüdSan.