Steady State and Transient Simulation of a Mobile Heating and Cooling System with the Refrigerant R744

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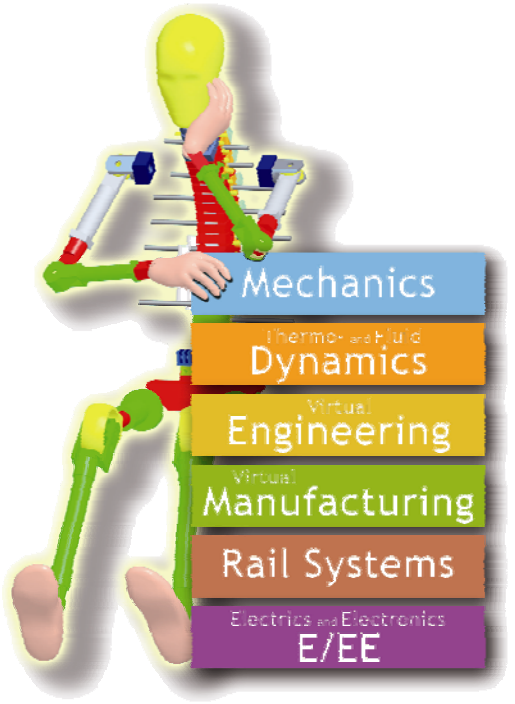

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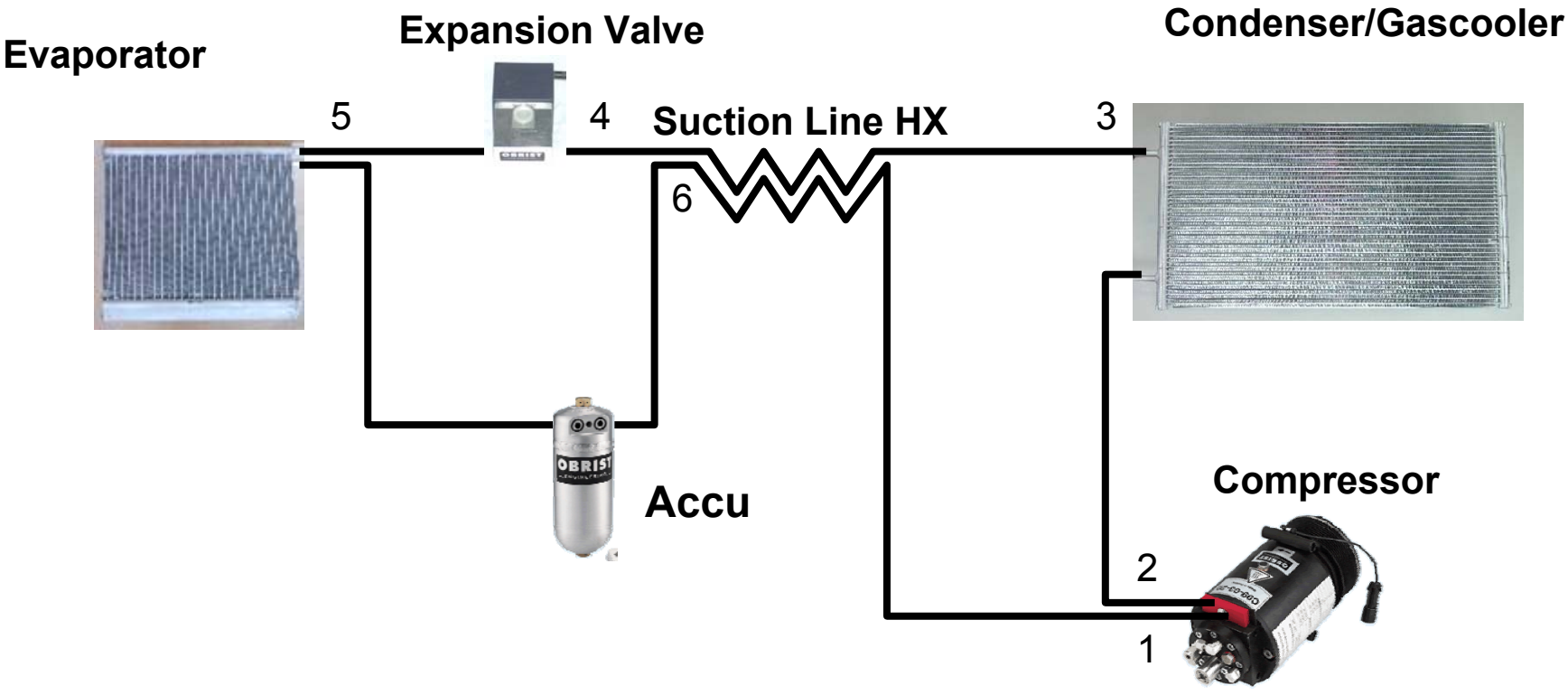
Content

1. **Introduction**
   motivation, CO_2 System
2. **Steady State Simulation vs. Measurement**
   cooling and heating
3. **Transient Simulation vs. Measurement**
   - **quasi steady state**
   - **transient with point masses**
   - **transient with advanced external components**
4. **Summary**

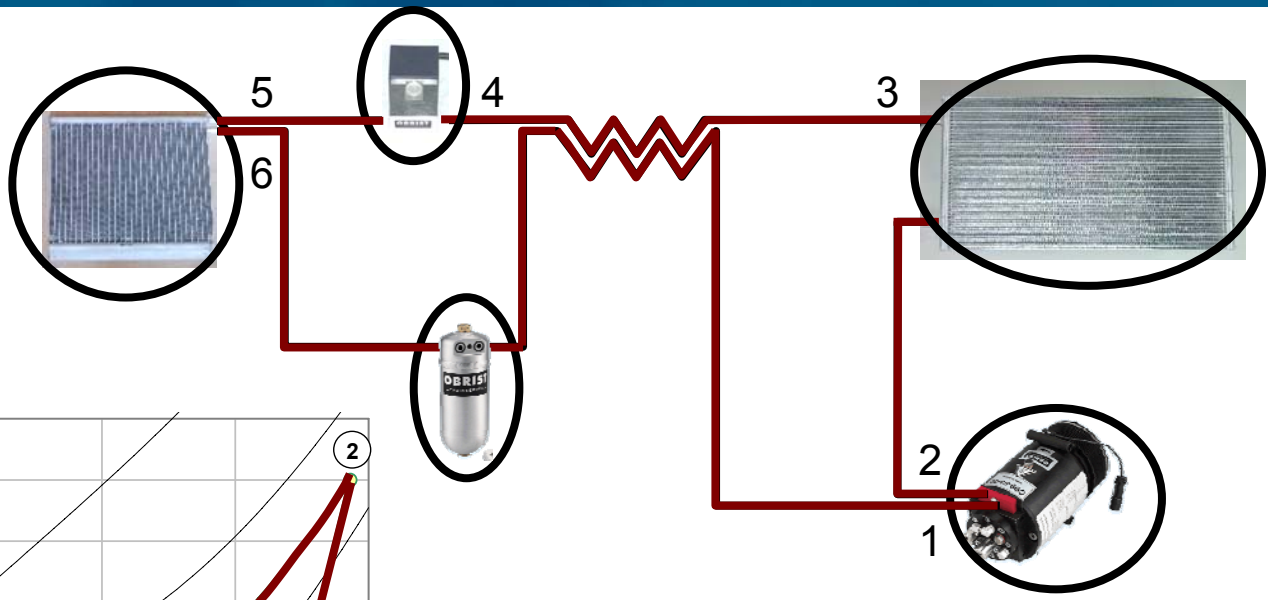
Motivation

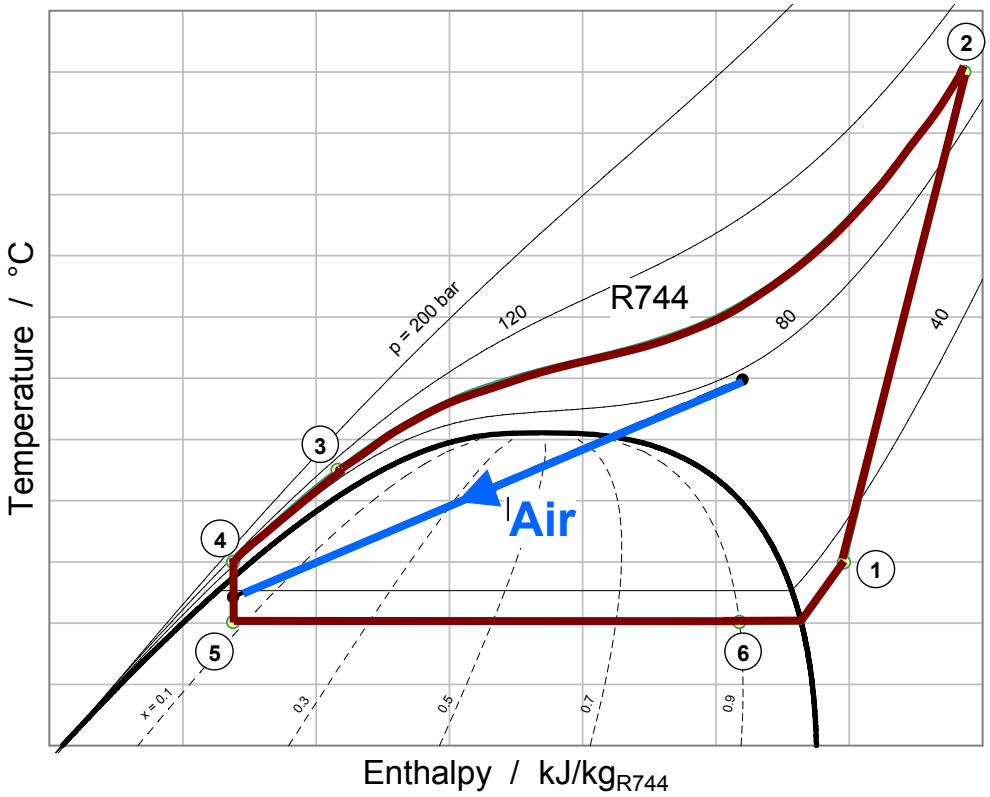
- EU: Directive to phase out R134a from AC systems in new vehicles (beginning from 2011)
  → **CO_2 (R744) as refrigerant**
- High efficient engines often do not offer enough waste heat
  → **supplementary heating**
- Different fluid properties and transcritical process
  → **development of "new" component models**
- AC system is rarely running at steady-state conditions
  → **transient simulation**

AC Mode


Evaporator
Expansion Valve
Condenser/Gascooler
5
4
Suction Line HX
3
6
OBRIST
Accu
Compressor
2
1

AC Mode


5
4
3
6
2
1

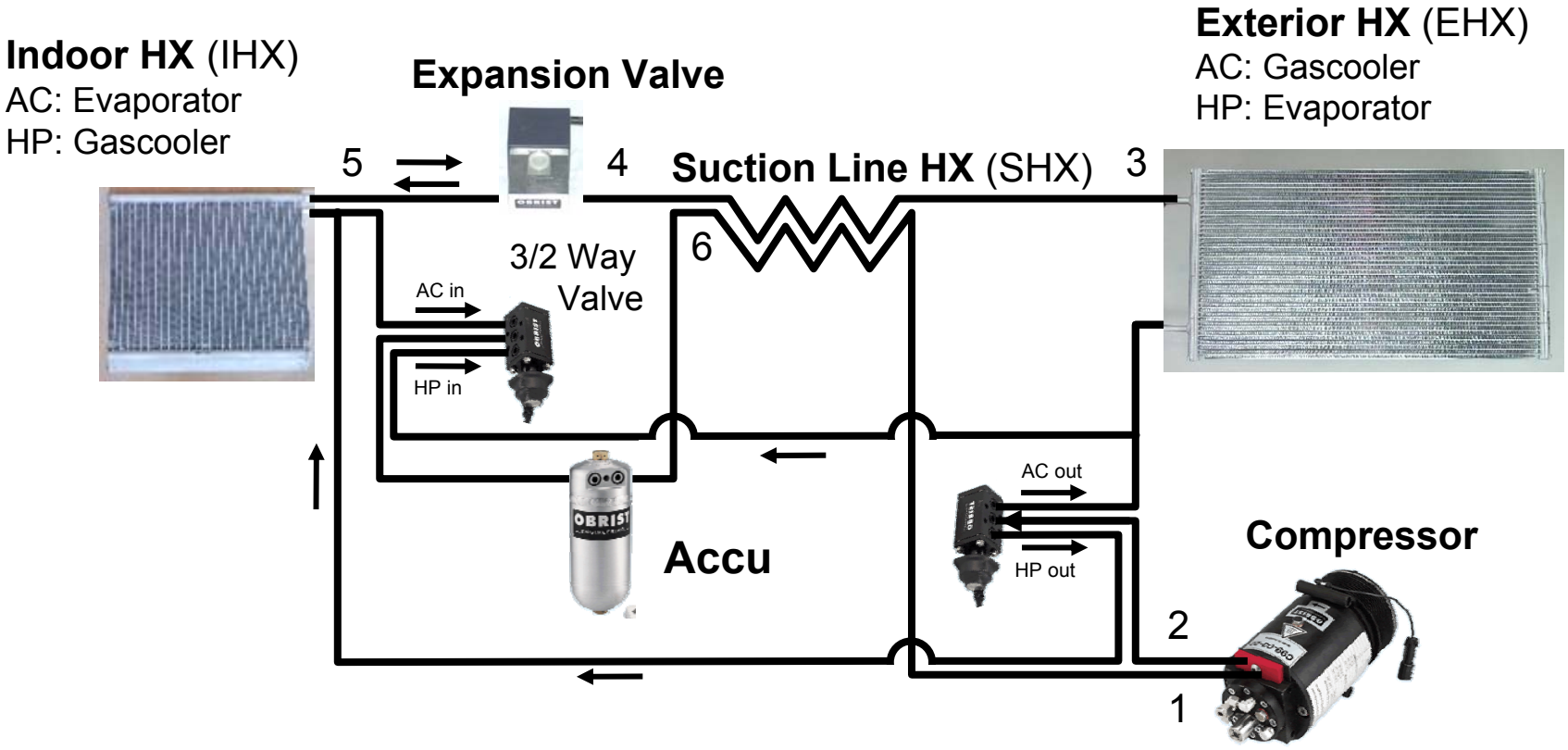

Temperature / °C
Enthalpy / kJ/kg$_{R744}$
p = 200 bar
120
80
40
R744
Air
1
2
3
4
5
6
x = 0,1
0,3
0,5
0,7
0,9

Heating Mode – Several Set-Ups Possible

- **Air/Air Heat Pump**
- Coolant/Air Heat Pump
- Hot Gas Cycle

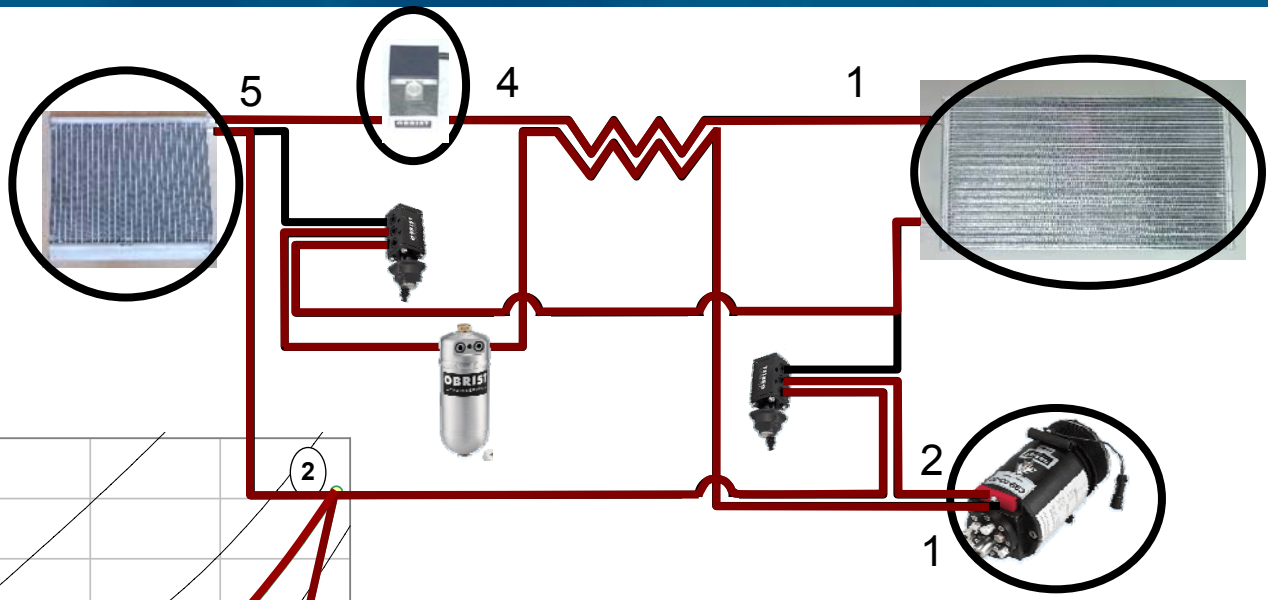
also feasible: coolant as heat sink

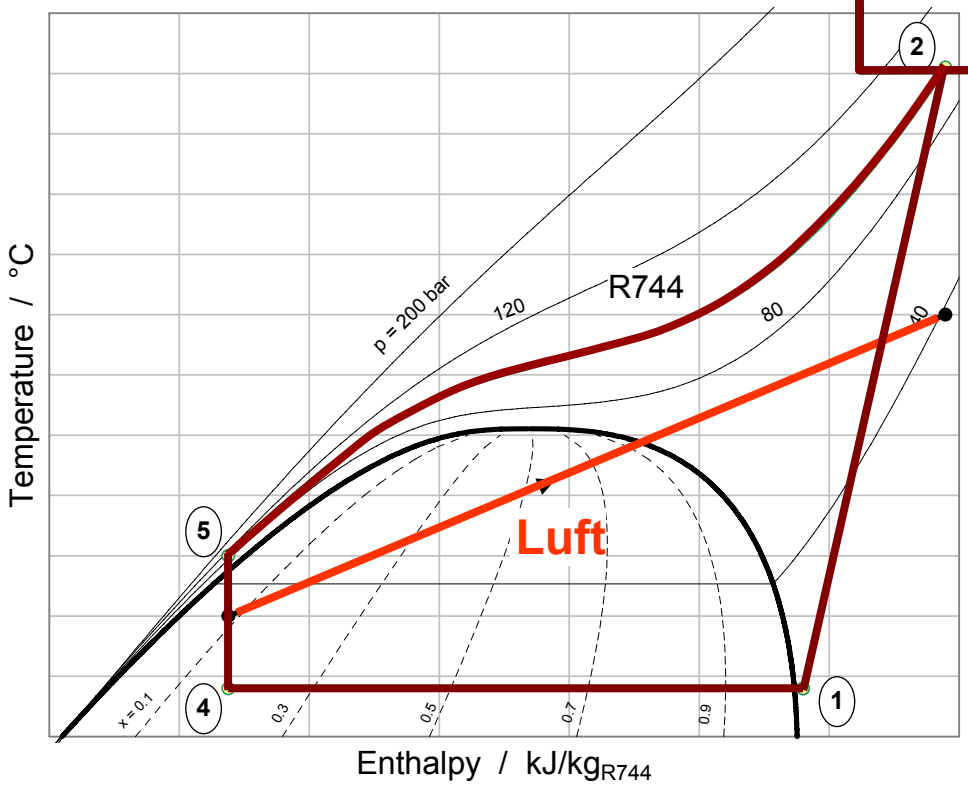
Heating Mode



Air/Air Heat Pump (Heating Mode)

Heating Mode





HVAC Test Rig

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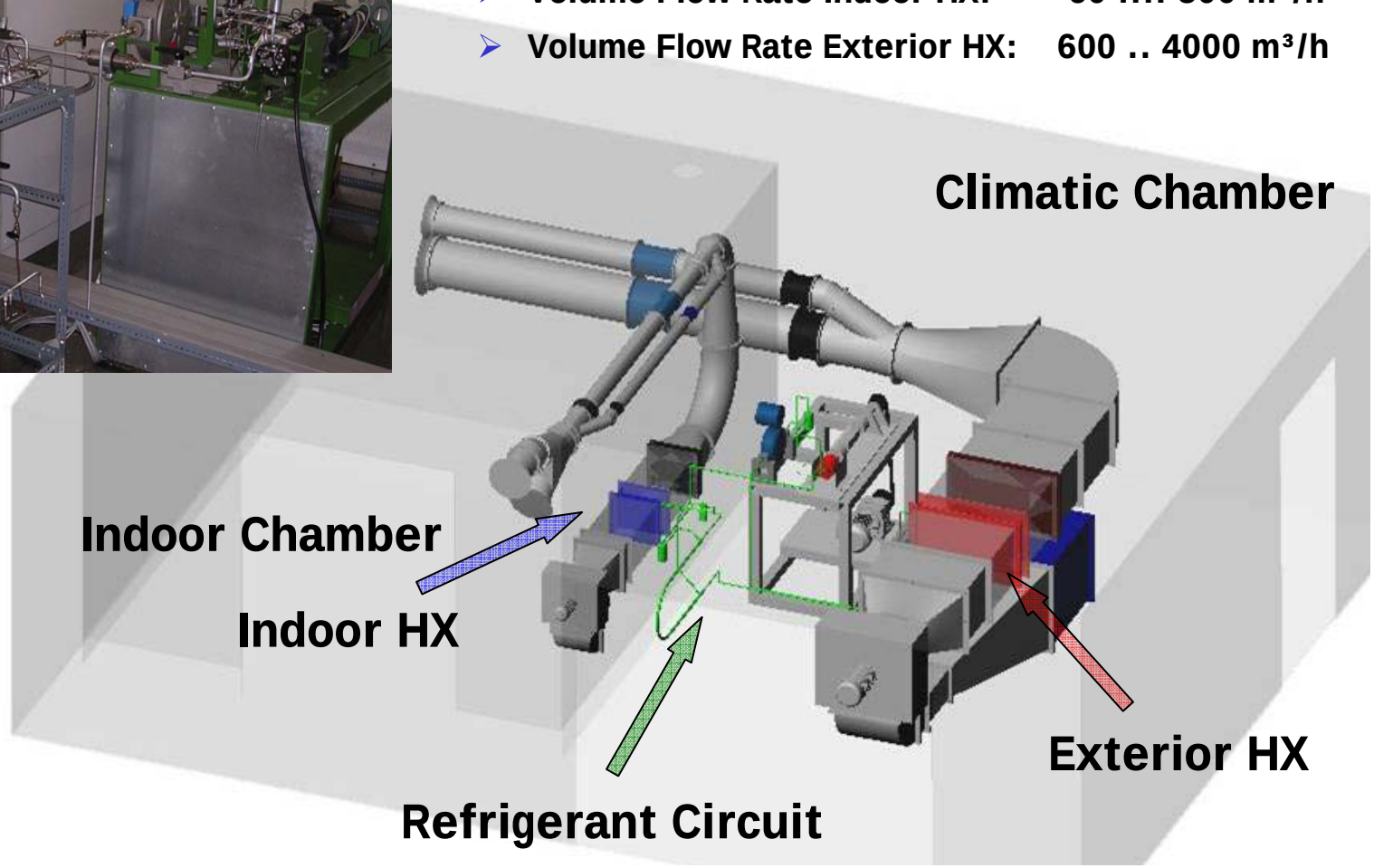
- Ambient Temperature: -20 .. +40 °C
- Ambient Humidity: 20 .... 80 %
- Volume Flow Rate Indoor HX: 60 .... 500 m³/h
- Volume Flow Rate Exterior HX: 600 .. 4000 m³/h



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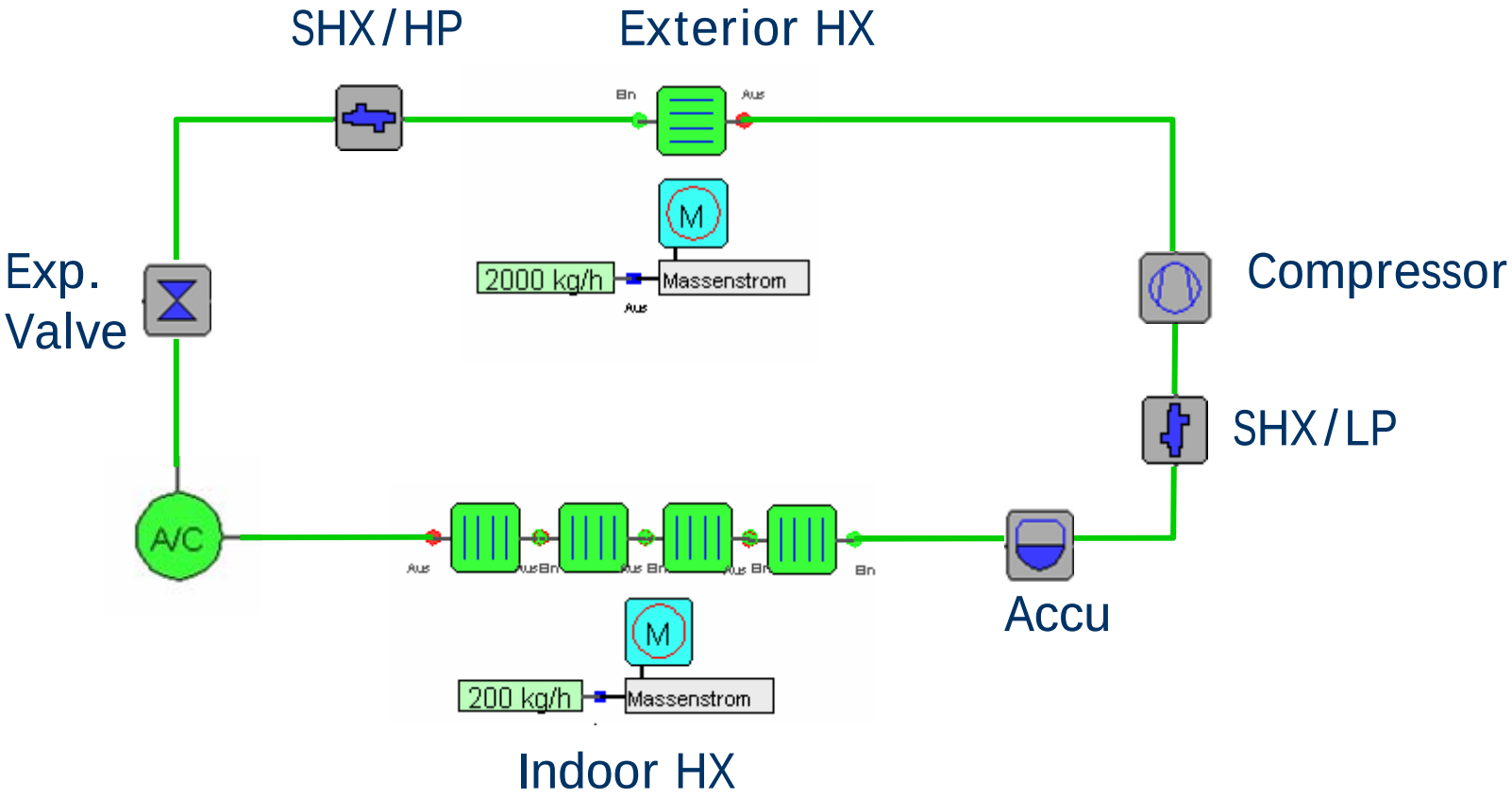
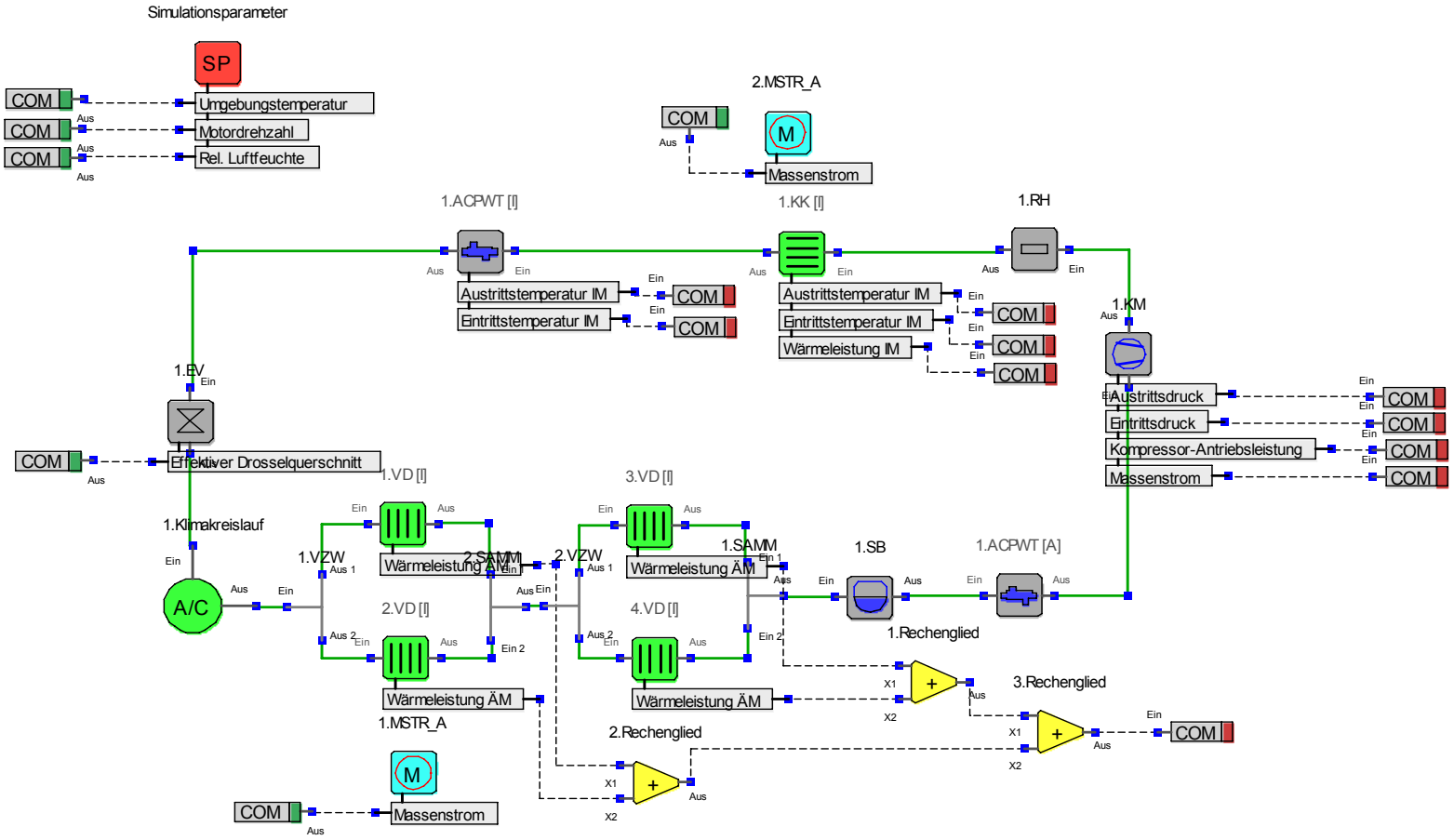
   - transient with point masses
   - transient with advanced external components
4. Summary

Schematic Model for Steady State Simulation (AC Mode)



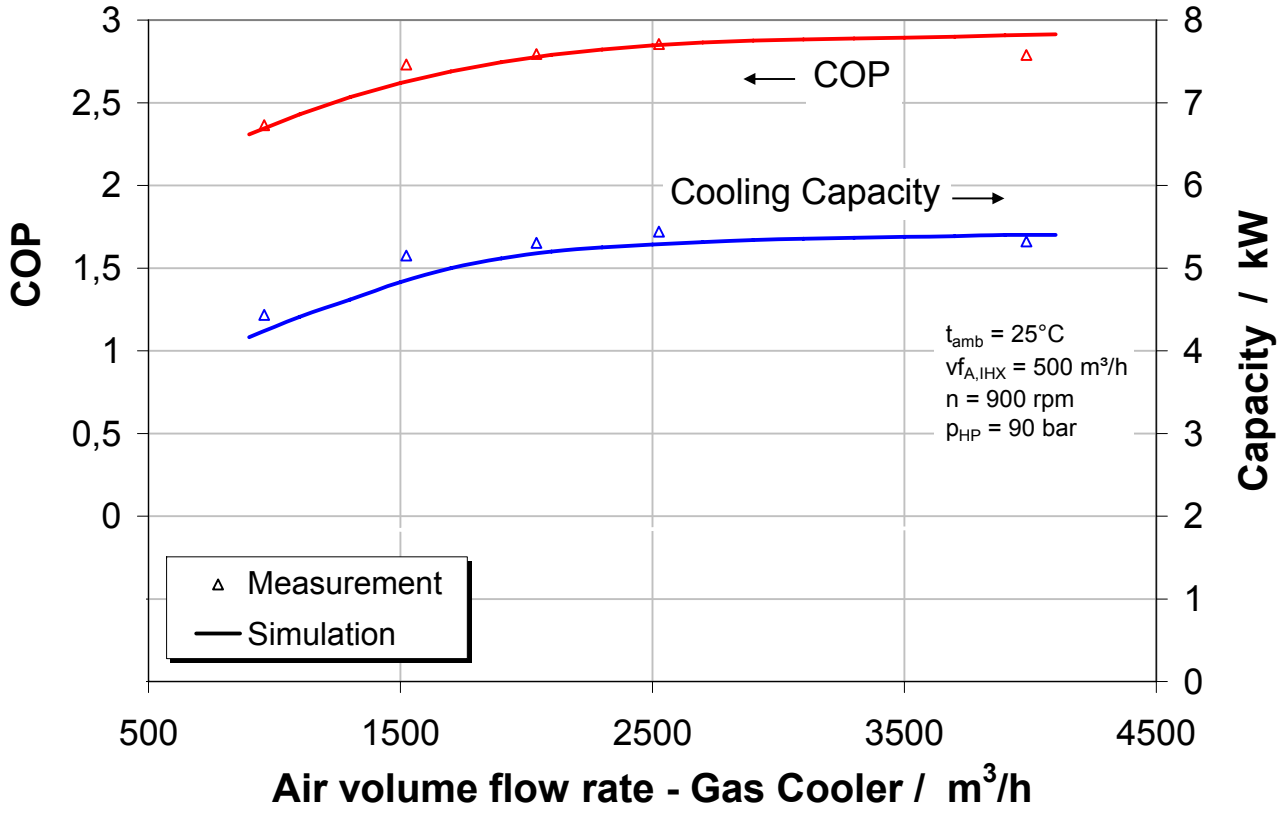
Detailed Model (Example)

- COM controllers for setting parameters according to measurement
- COM controllers for data export → Excel

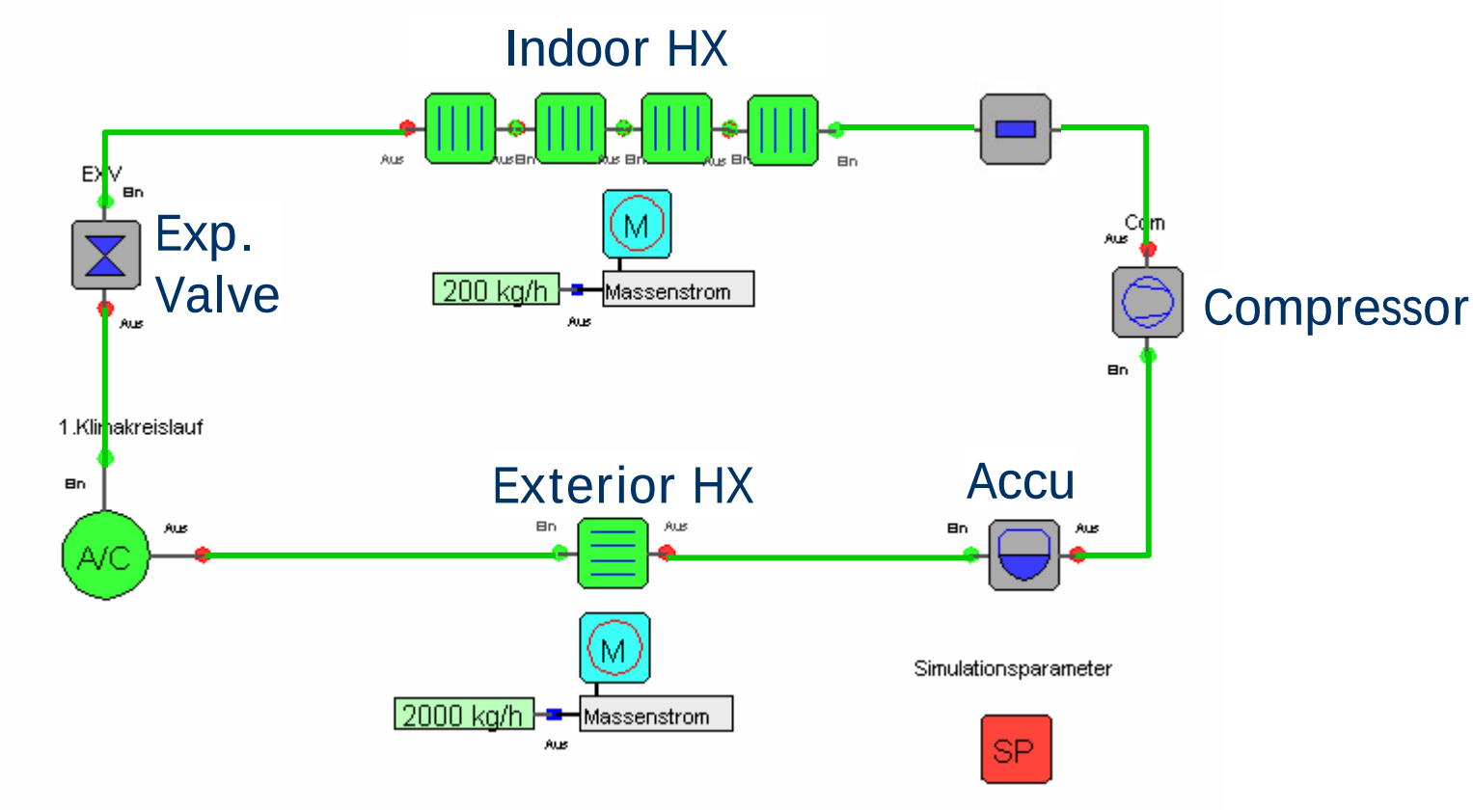


COP, Cooling Capacity and Driving Power vs. Gas Cooler Air Flow Rate

Simulation vs. Measurement



Schematic Model for Steady State Simulation (Air/Air-Heat Pump)



Steady State Simulation (HP)

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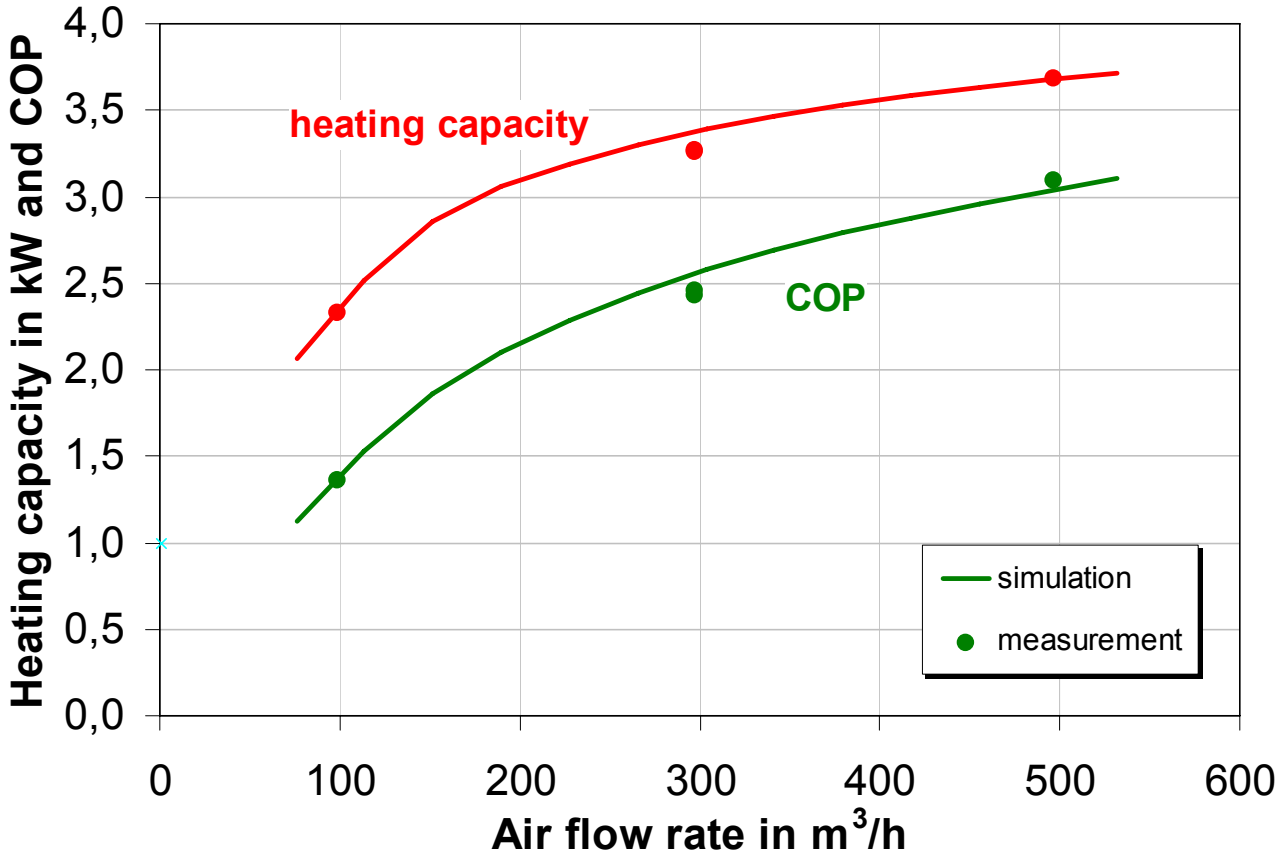
Simulation vs. Measurement



t_amb = -5 °C, n_Com = 900 rpm, A_EXV = const

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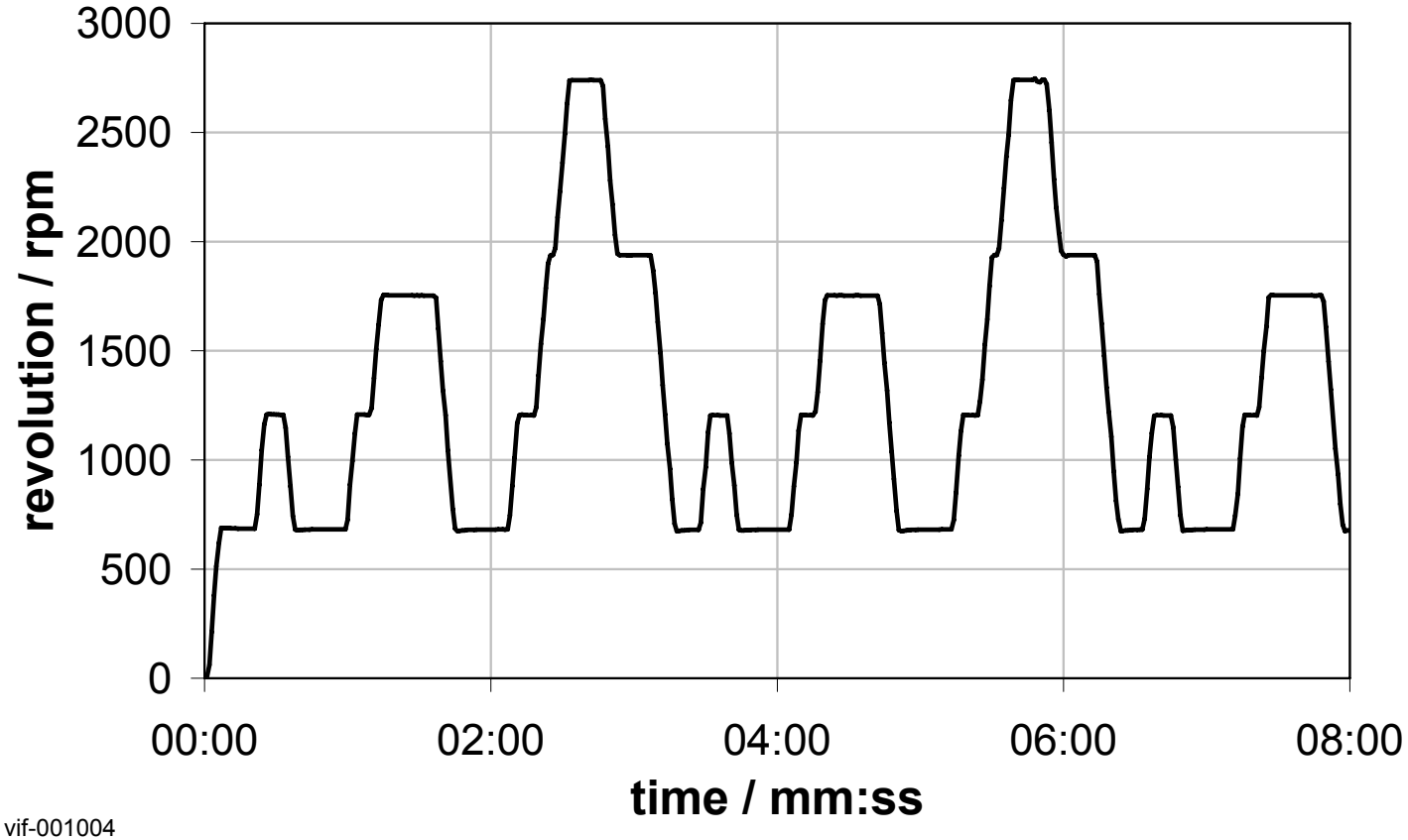
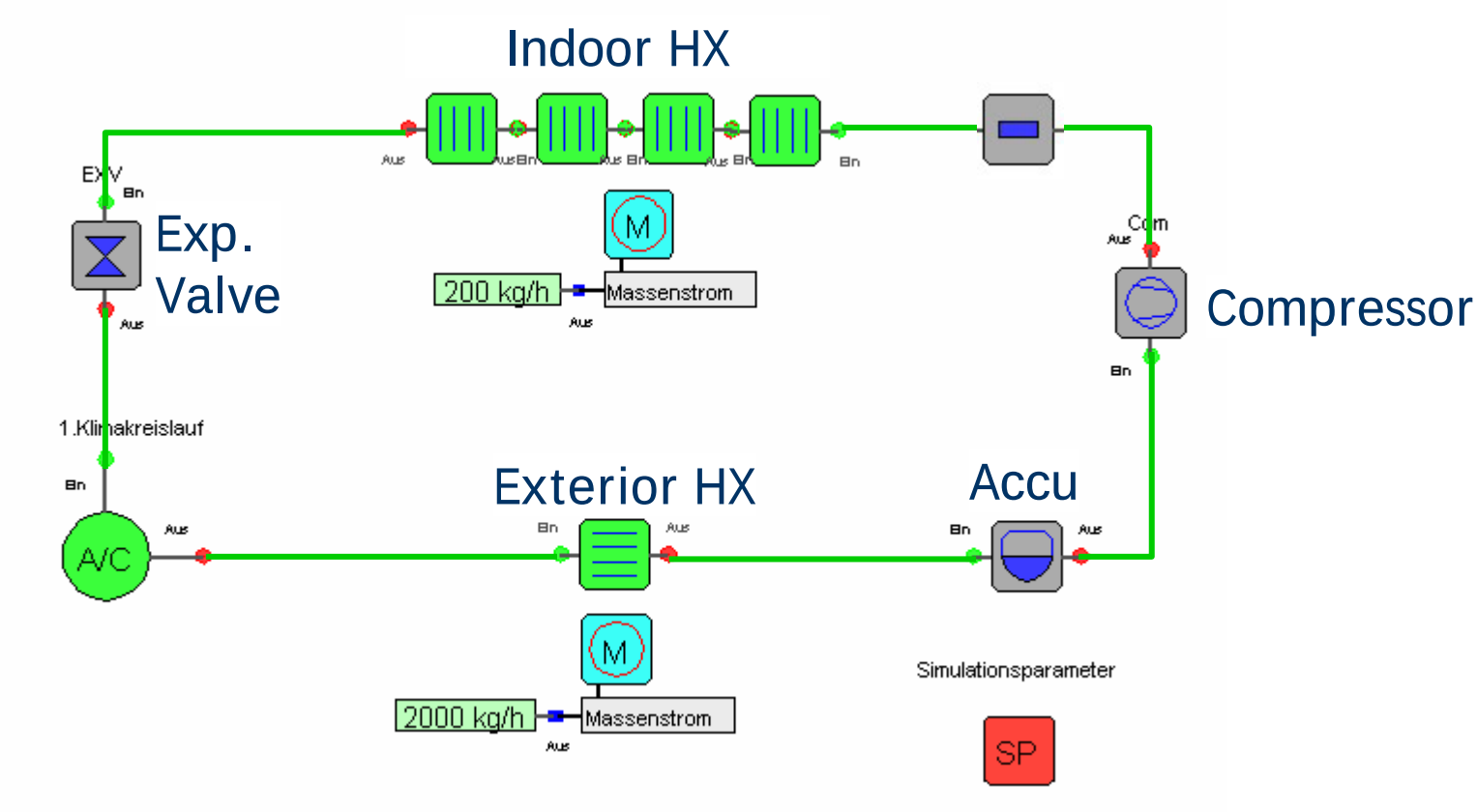
Driving Cycle – Boundary Conditions



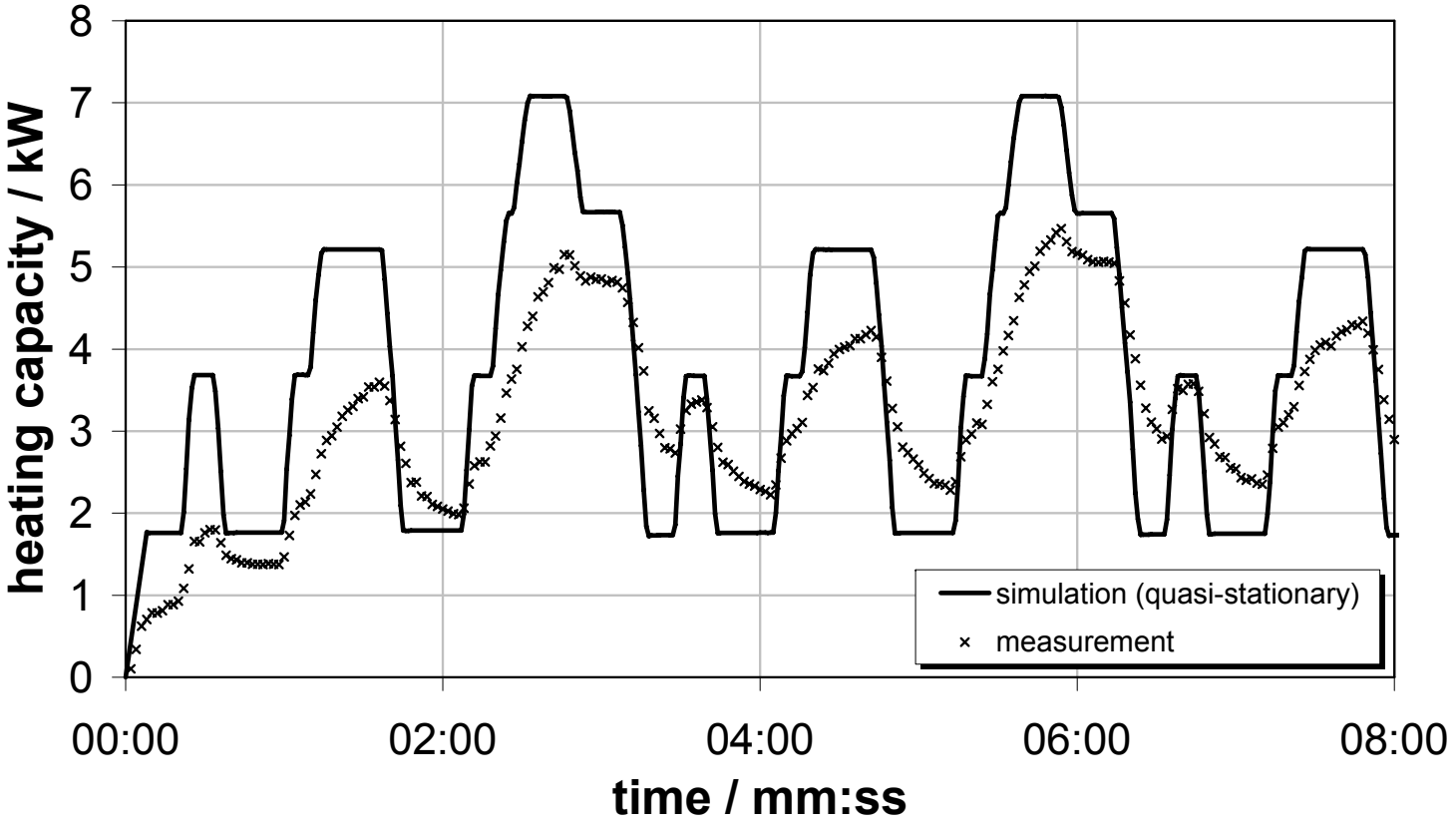
vif-001004

t_amb = -5 °C, vf_A_EHX = 1500 m³/h, vf_A_IHX = 300 m³/h

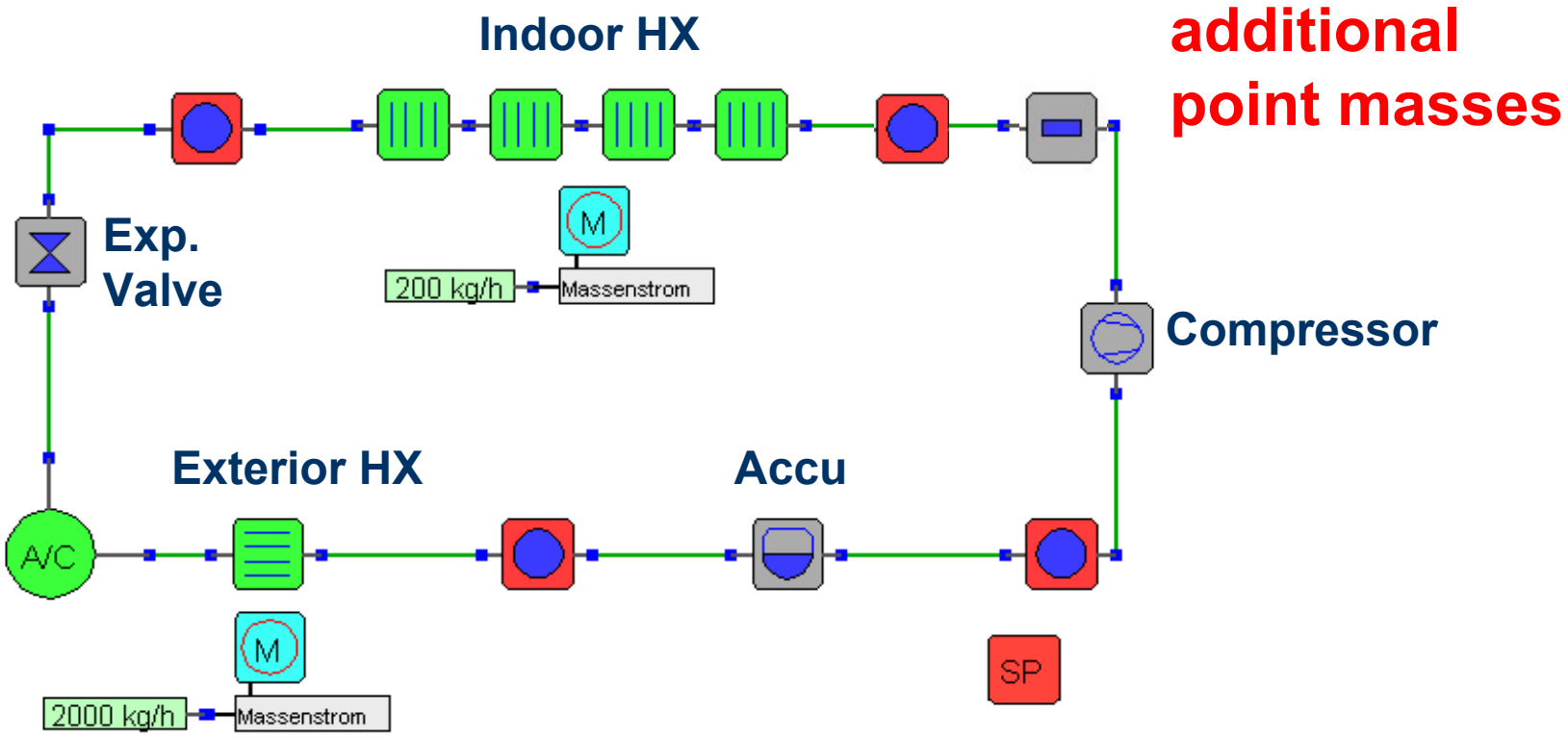
Schematic Model for Quasi Steady State Simulation (Air/Air-Heat Pump)



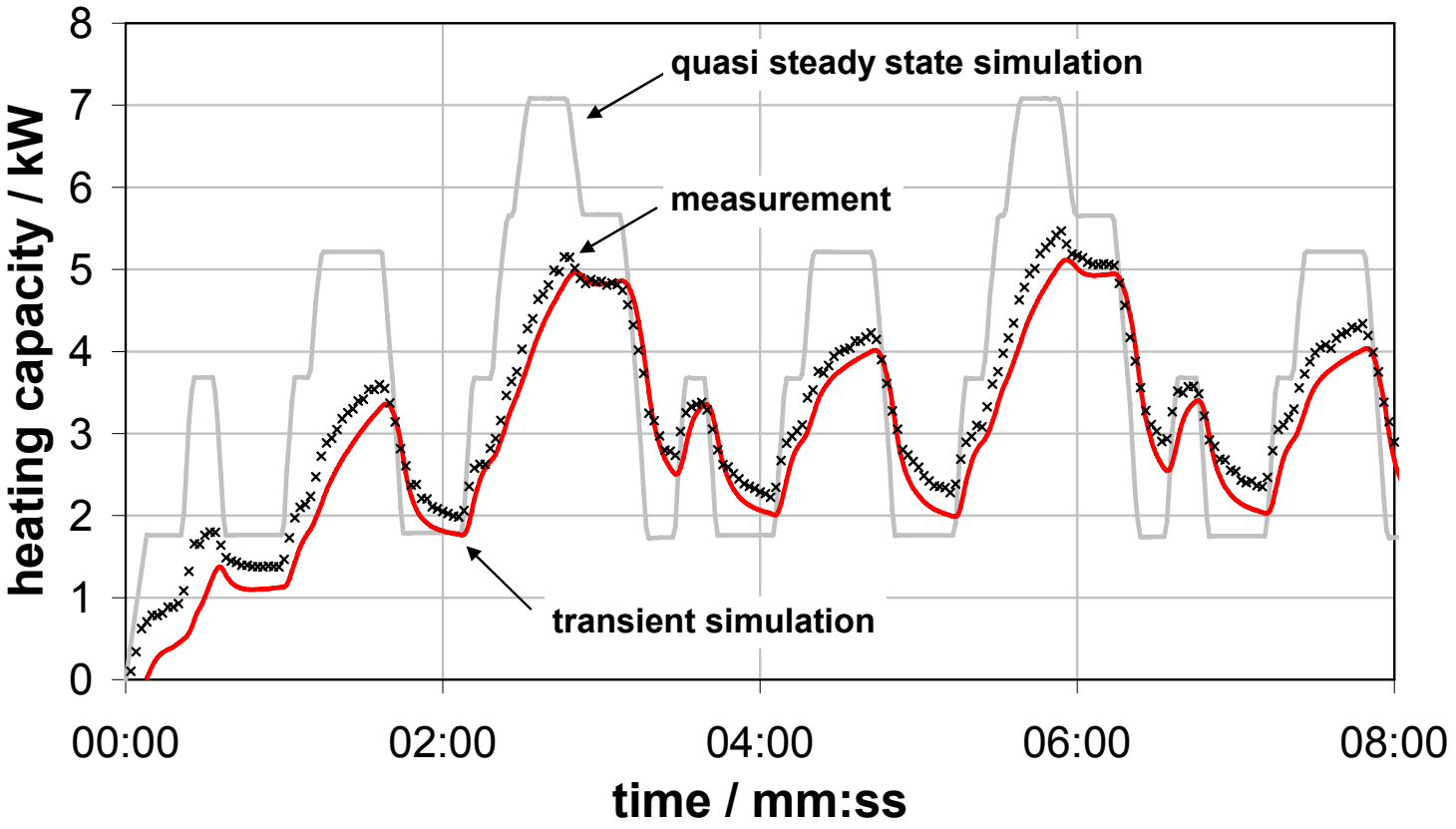
Quasi Steady State Simulation vs. Measurement



Schematic Model for Transient Simulation (Air/Air-Heat Pump)

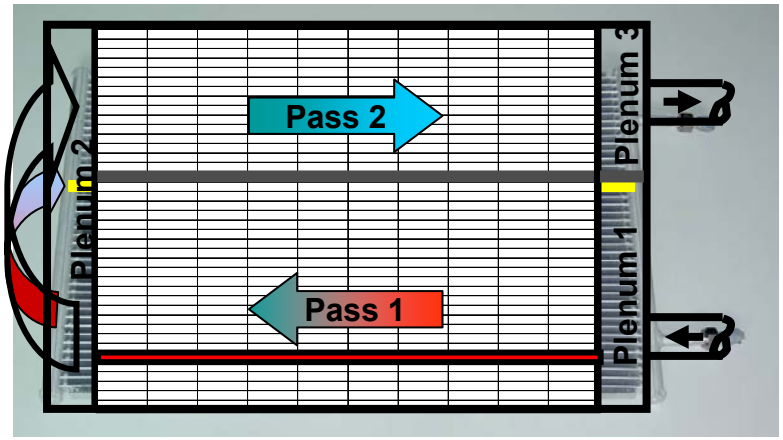


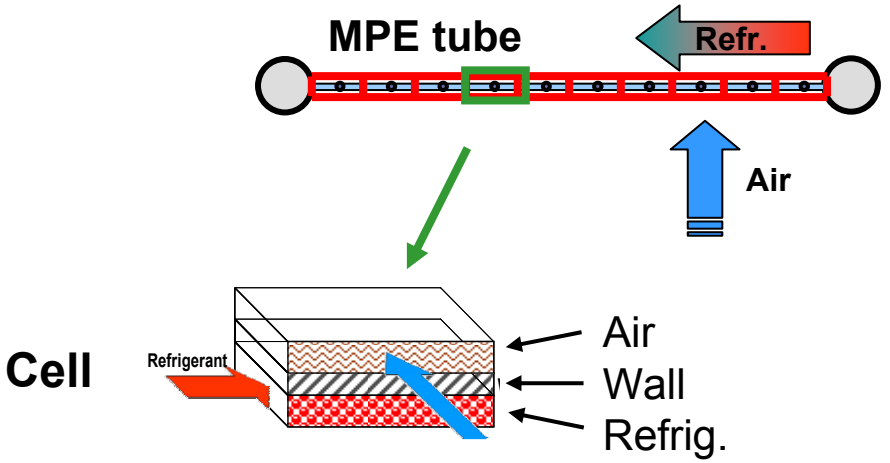
Transient Simulation vs. Measurement



Advanced External Components

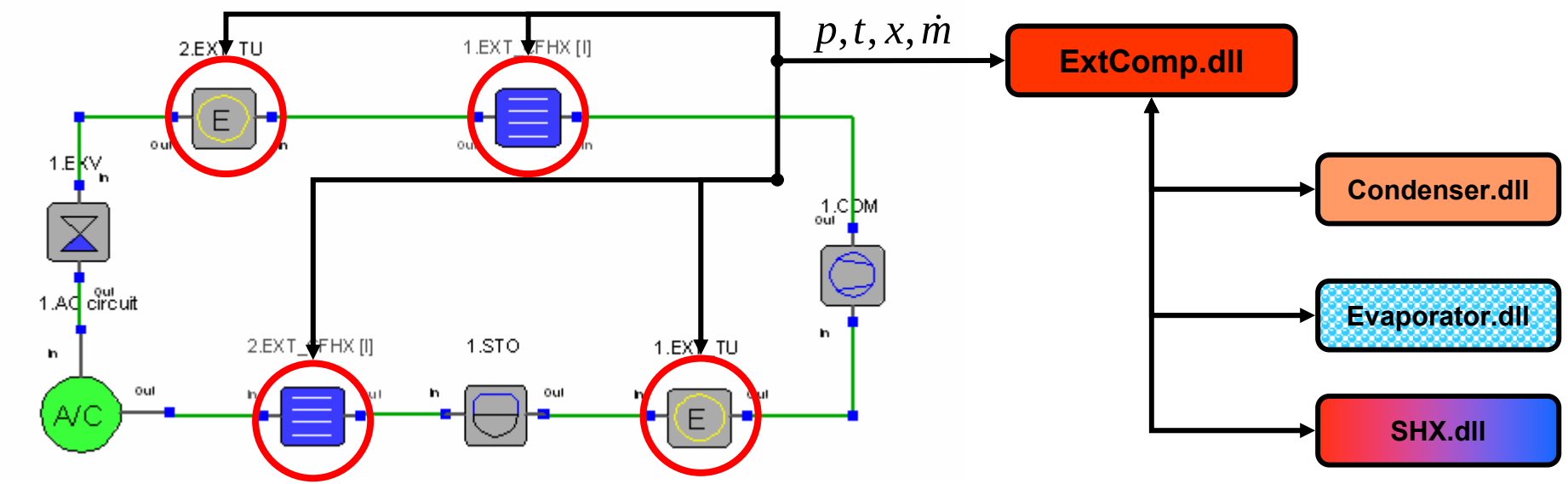
- Applicable for heating and cooling mode
- Several correlations for heat transfer & pressure drop
- Transient behavior (structure warm-up)
  → Transient formulation of mass- and energy conservation for each cell





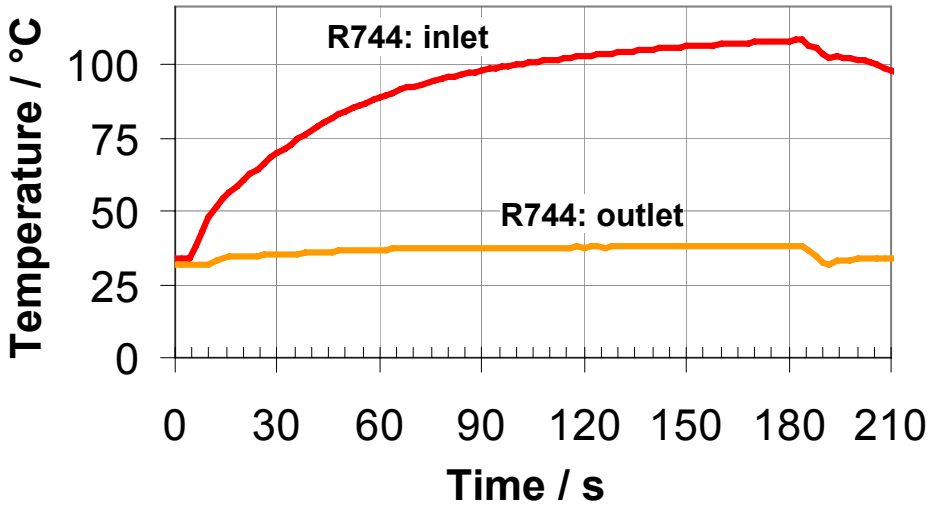
Advanced External Components

- Coupled to KULI via dll
- Component results available through KULI-Postprocessor

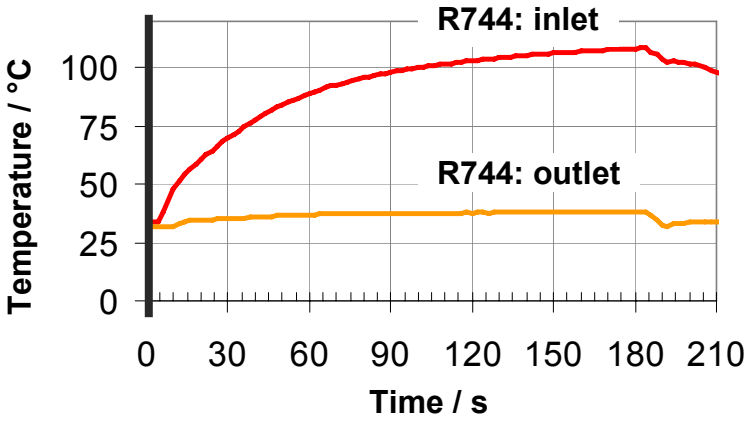


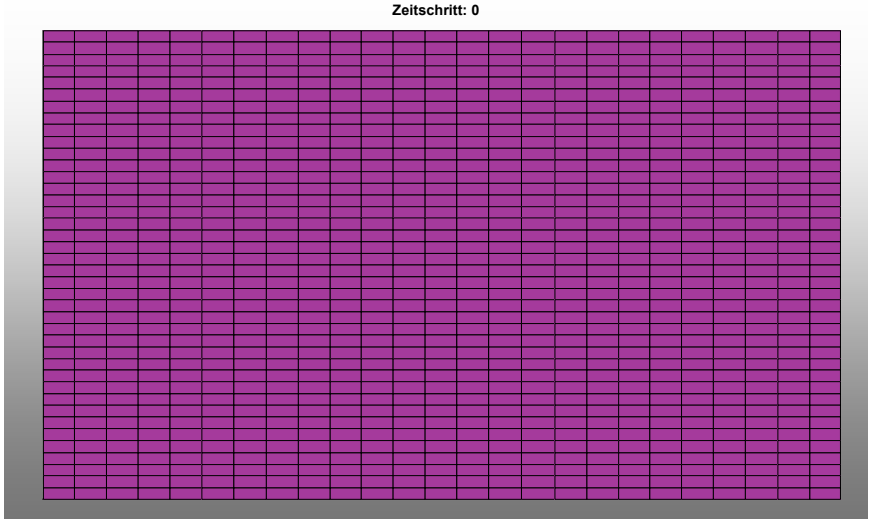
Gas Cooler (AC Mode) – Warm-Up Behavior

Measurement (Thermography) vs. Simulation



Compressor Start **time: 0s**





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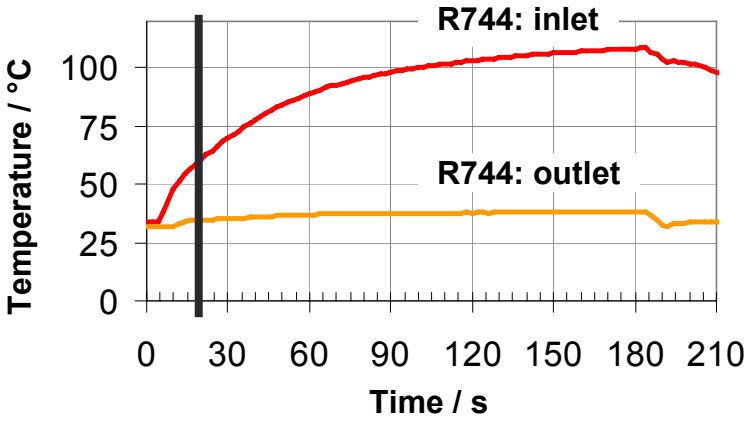
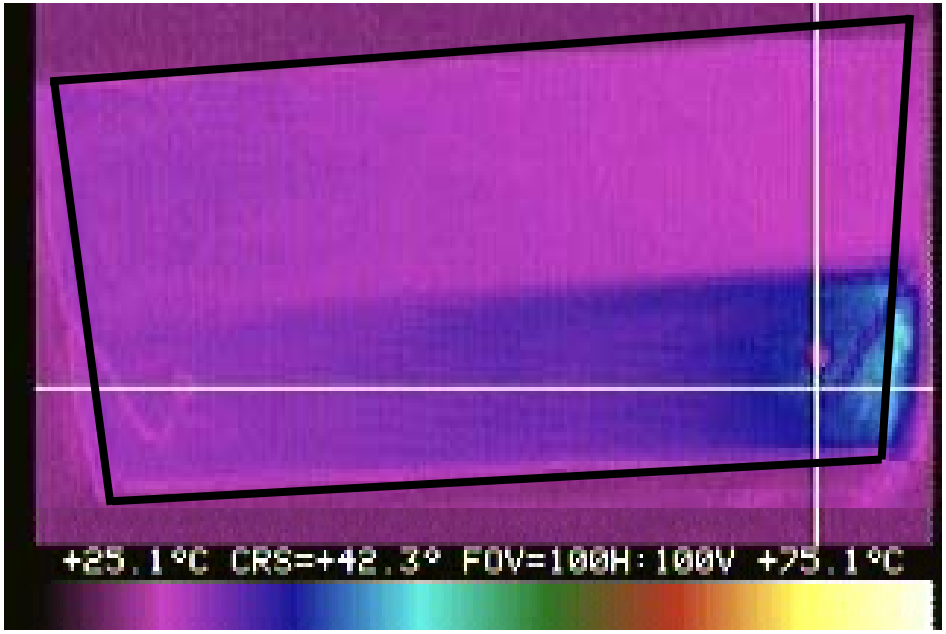
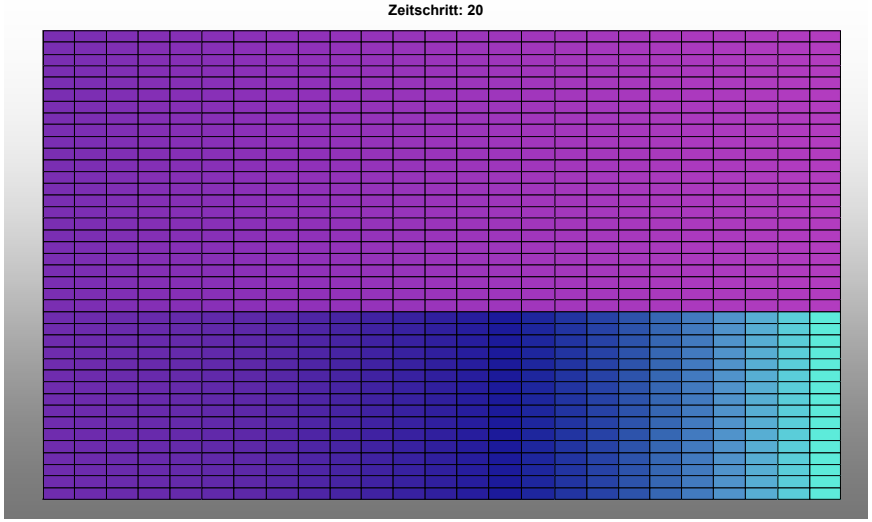
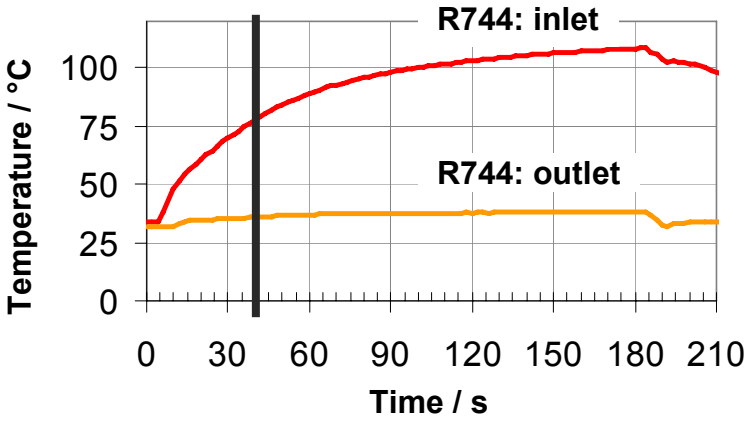
time: 20s

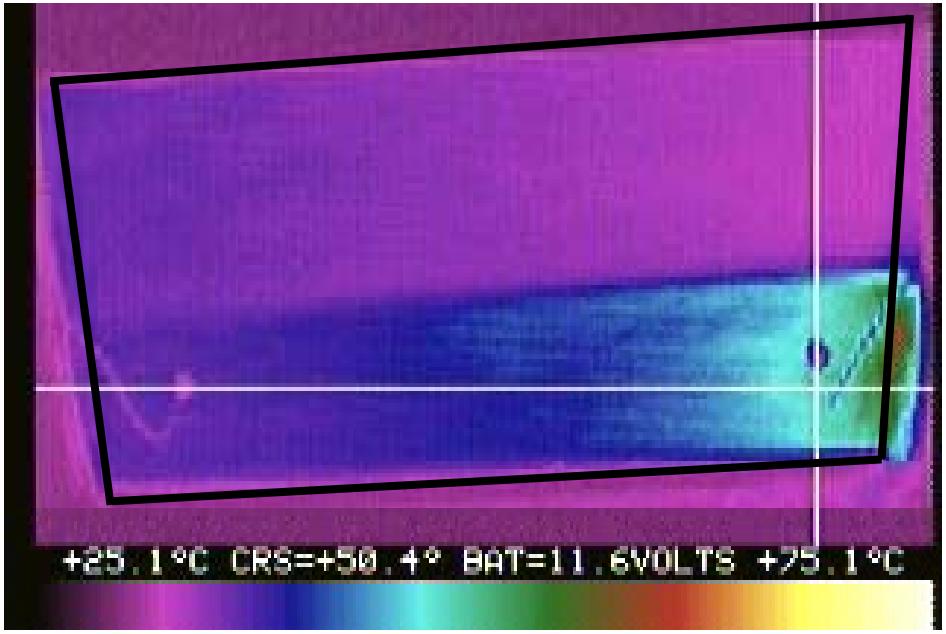


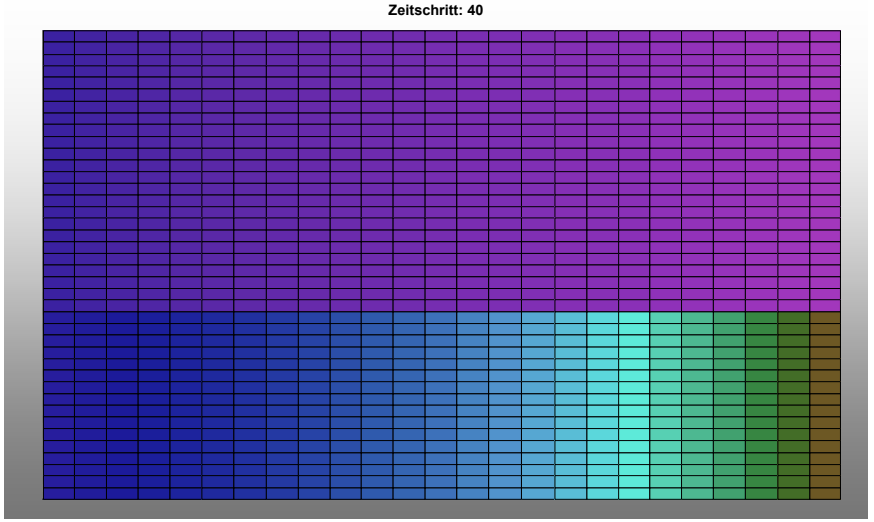




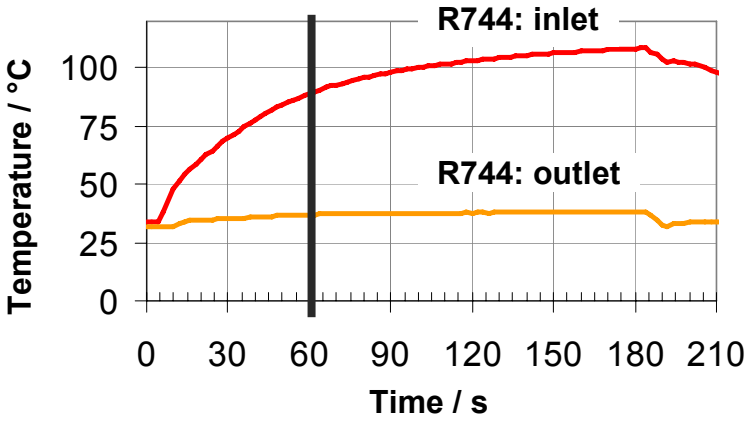
time: 40s

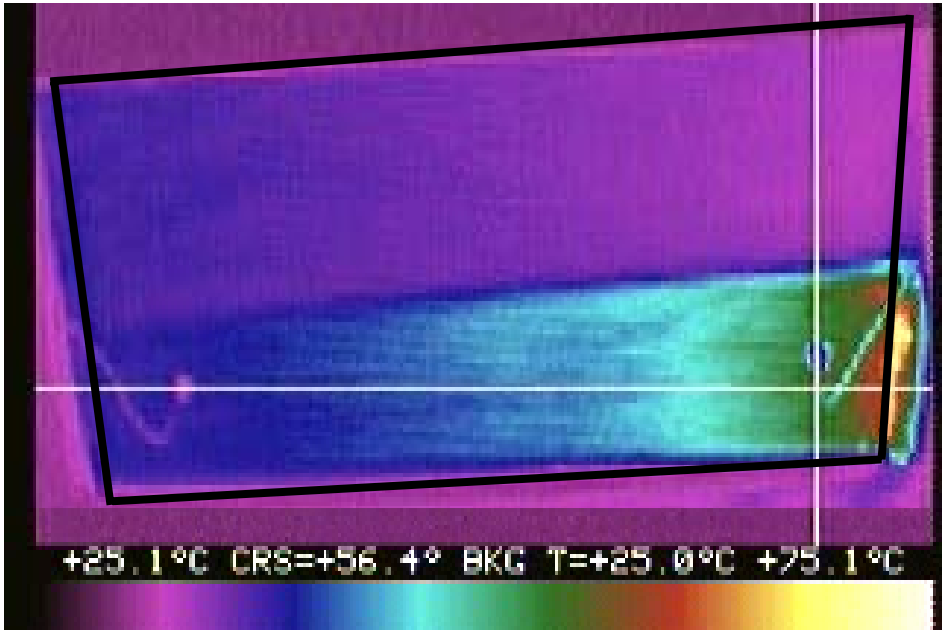

R744: inlet
R744: outlet
Temperature / °C
100
75
50
25
0
0
30
60
90
120
150
180
210
Time / s

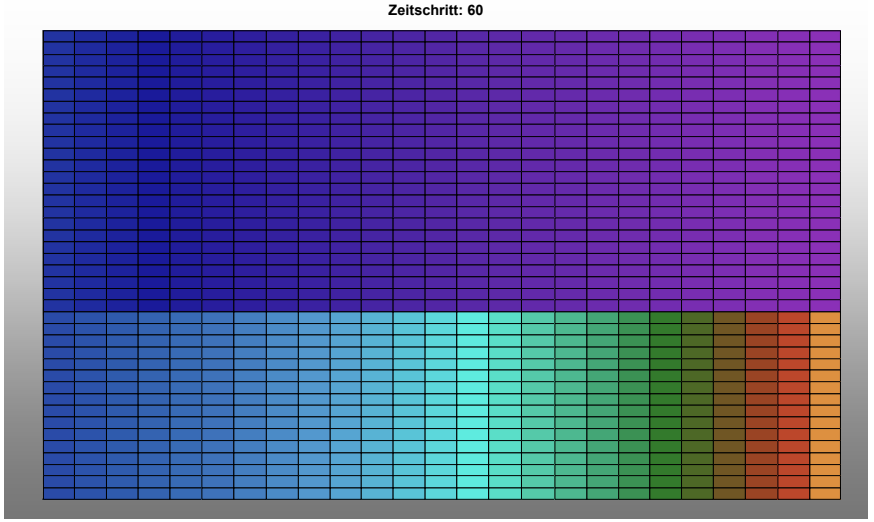

+25.1°C CRS=+50.4° BAT=11.6VOLTS +75.1°C


Zeitschritt: 40

time: 60s


R744: inlet
R744: outlet
Temperature / °C
100
75
50
25
0
0
30
60
90
120
150
180
210
Time / s


+25.1°C CRS=+56.4° BKG T=+25.0°C +75.1°C


Zeitschritt: 60

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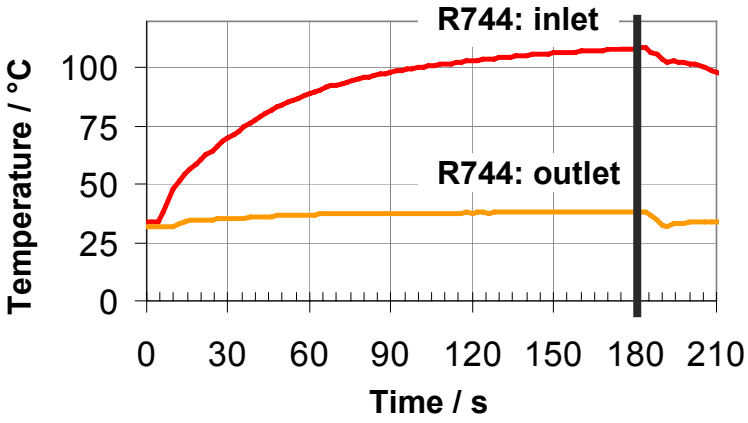
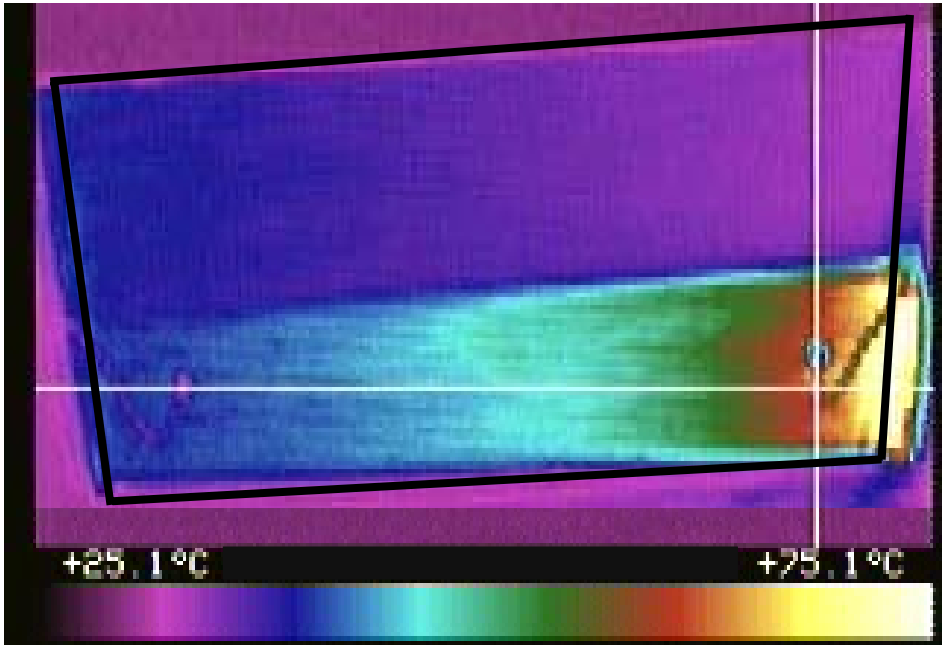
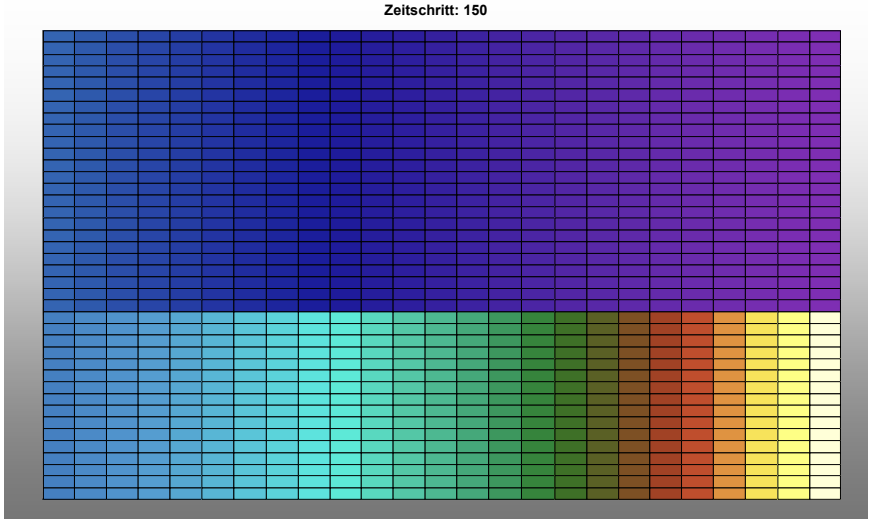
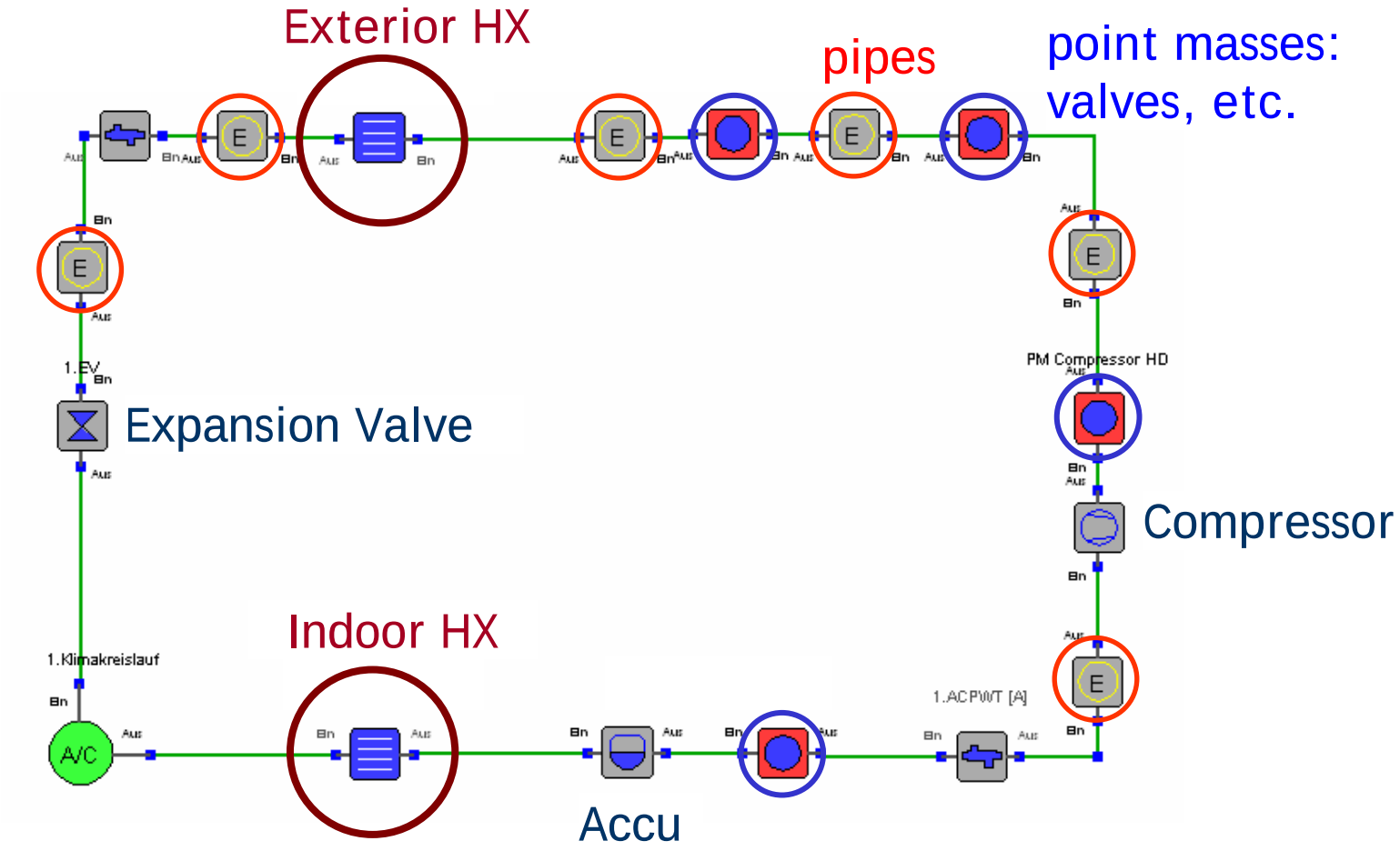
time: 180s







Schematic Model for Transient Simulation with External Components (AC Mode)



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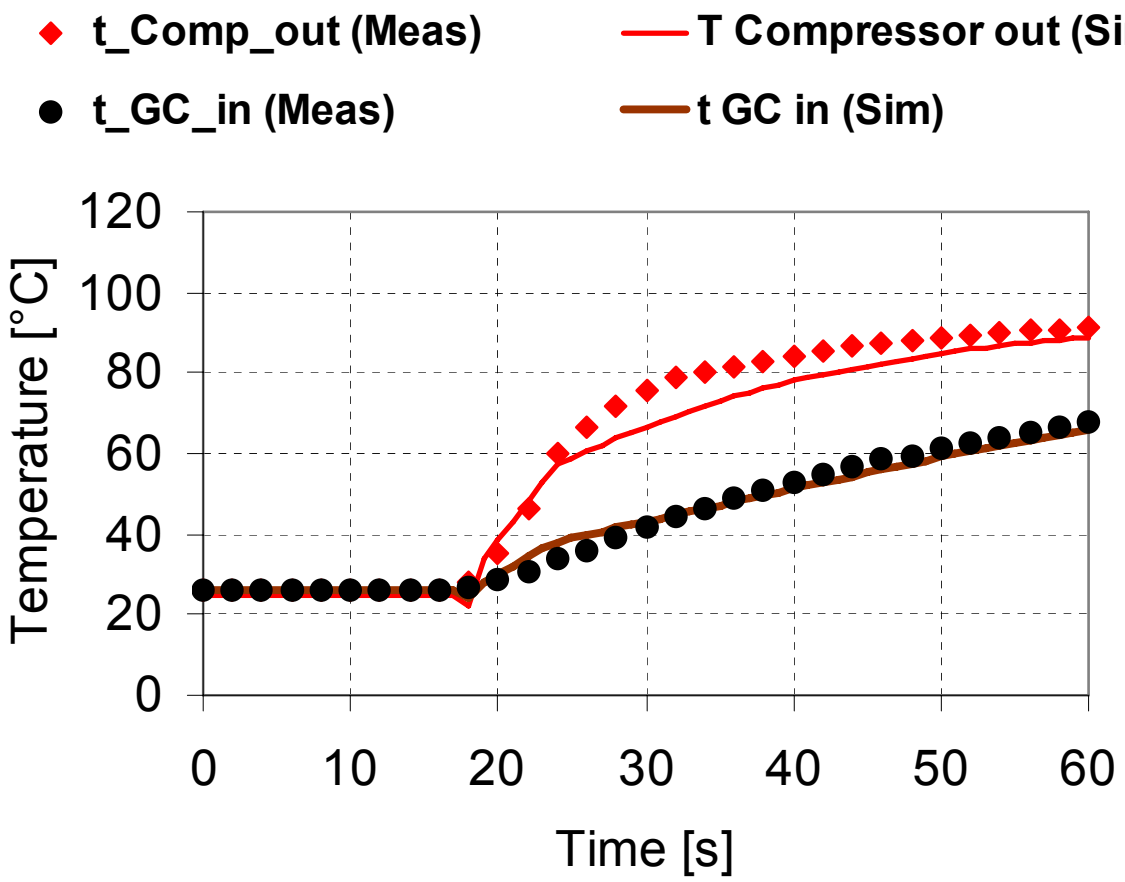
Temperatures at Compressor Outlet and Gas Cooler Inlet

Simulation vs. Measurement



Summary

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- Kuli offers the possibility to simulate reversible systems for cooling and heating (simulation results verified by means of experiments)
- heat pump systems offer efficient and powerful possibility for supplementary heating
- thermal masses play an important role for transient behavior of entire cycle
- quasi steady state simulation does not deliver sufficient results for transient conditions
- principal transient behavior of entire cycle can be described with point masses
- for detailed investigations advanced external components can be used

Acknowledgements

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TU Graz Graz University of Technology

SFG Steirische Wirtschaftsförderung Fast Forward Community

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