Steady State and Transient Simulation of R744 Refrigerant Cycle

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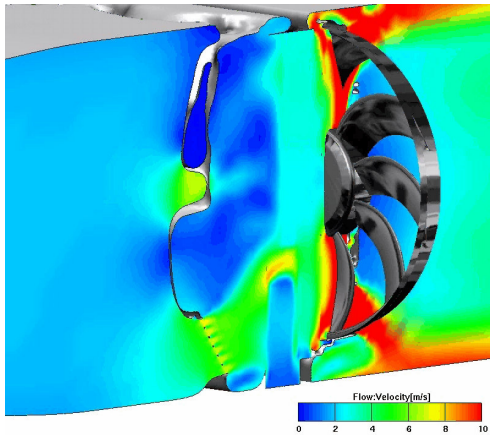
Content

1. **Introduction**
   vif, motivation, CO2 AC System
2. **Advanced component models**
3. **Supplementary heating systems (steady state)**
   Heat Pump & Hot Gas Cycle
4. **Behavior of refrigerant cycle (transient)**
   driving cycle
5. **Summary and Outlook**

Area Thermo- and Fluid Dynamics

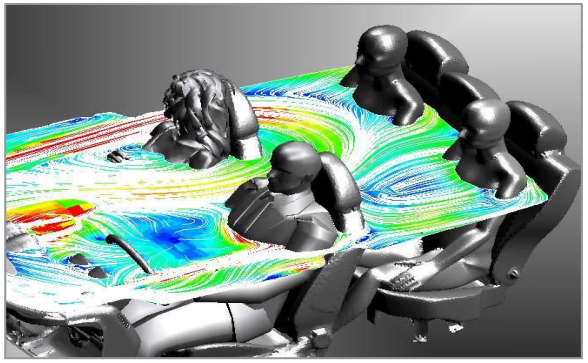
Underhood

- DMU → CFD Workflow
- Fan Modeling
- Radiation Underhood
- Coupling Strategy



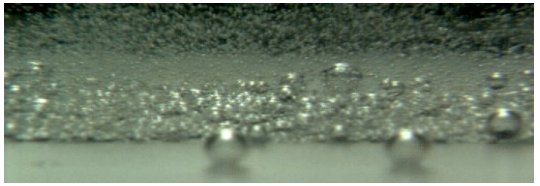
HVAC

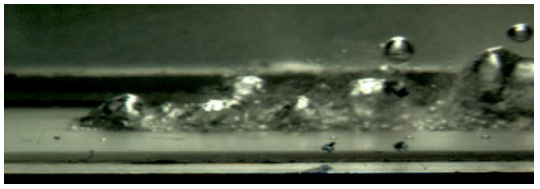
- CO2 (R744) as refrigerant
- Radiation Passenger Cabin
- Thermal Comfort Simulation
- Deicing, Defogging



Cooling System

- Heat Transfer Modelling
- Sub cooled Boiling
- Boundary Layer Simulation
- Additives in the Cooling Media

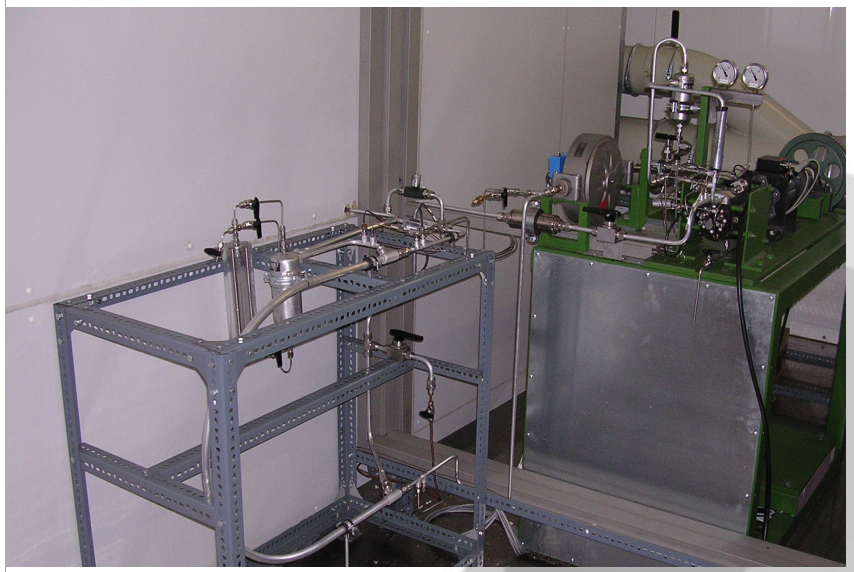




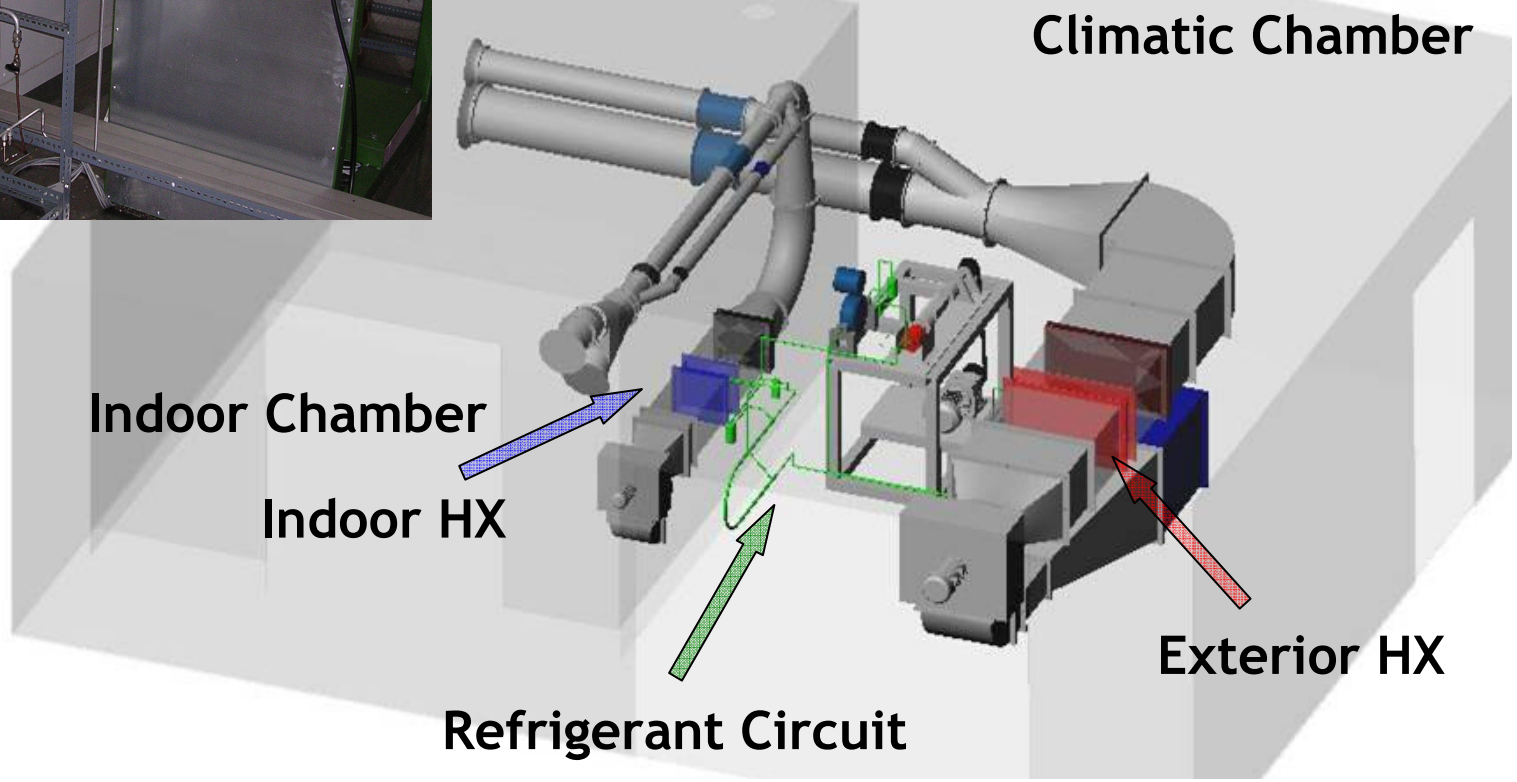
Motivation

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

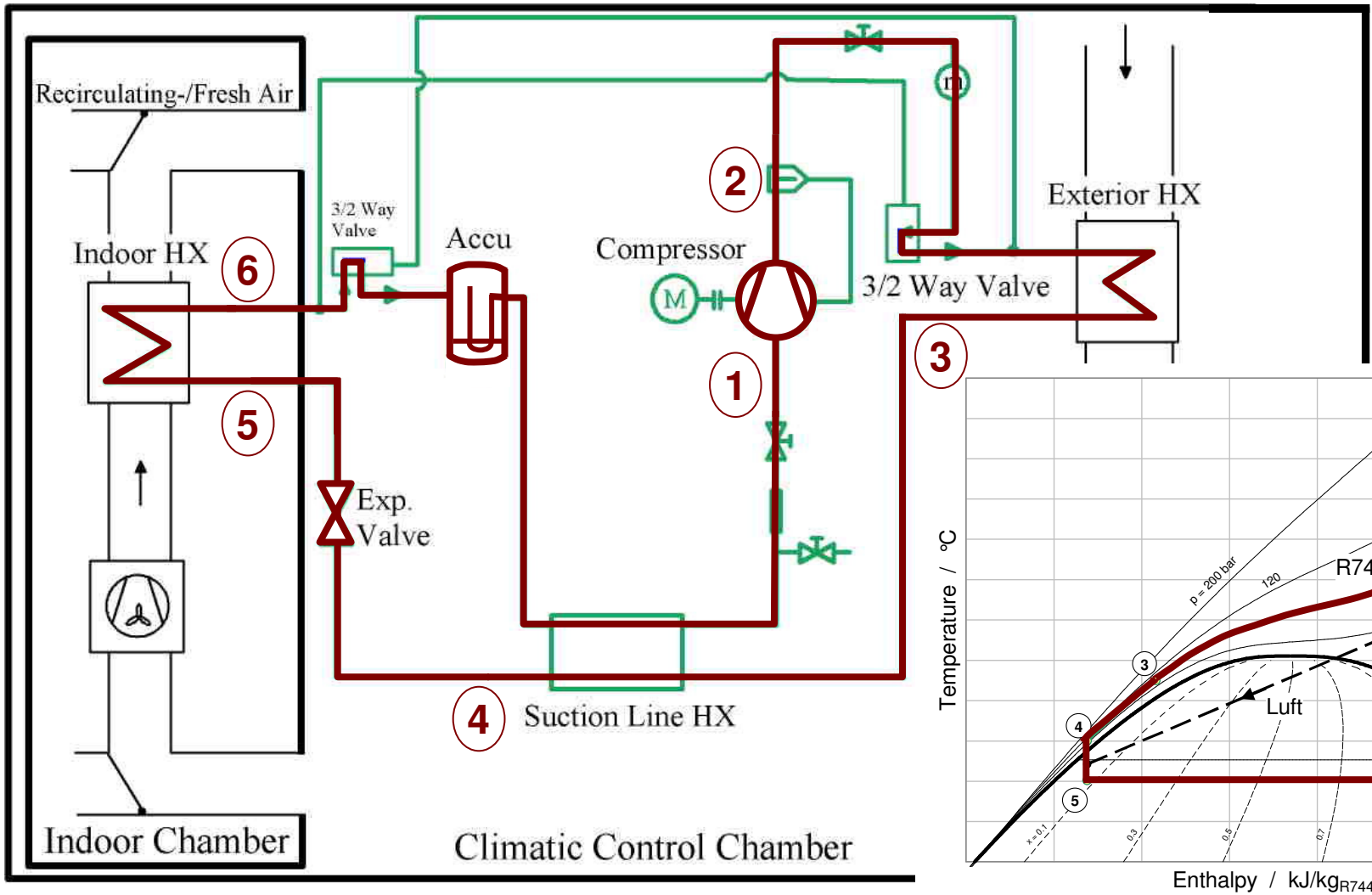
HVAC Test Rig



- 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



AC Mode


Recirculating-/Fresh Air
Indoor HX
6
5
3/2 Way Valve
Accu
Compressor
M
2
1
3/2 Way Valve
Exterior HX
3
Exp. Valve
4
Suction Line HX
Indoor Chamber
Climatic Control Chamber

Temperature / °C
Enthalpy / kJ/kg R744
R744
p = 200 bar
120
80
40
Luft
1
2
3
4
5
6
x = 0.1
0.3
0.5
0.7
0.9

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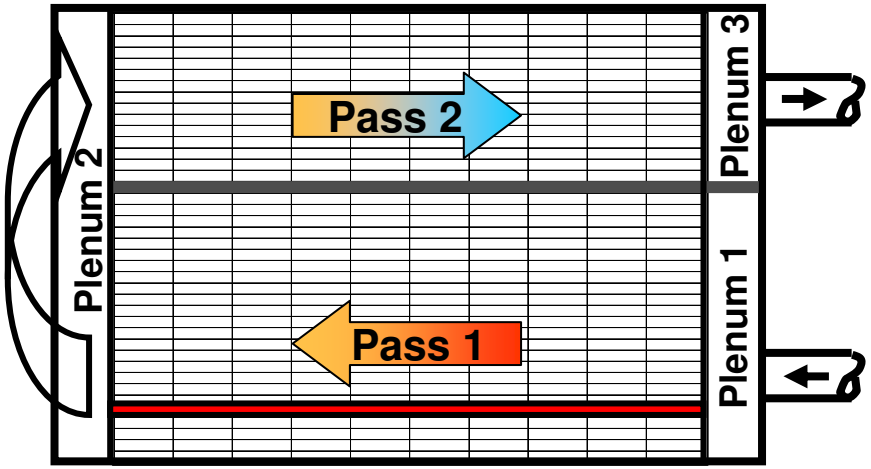
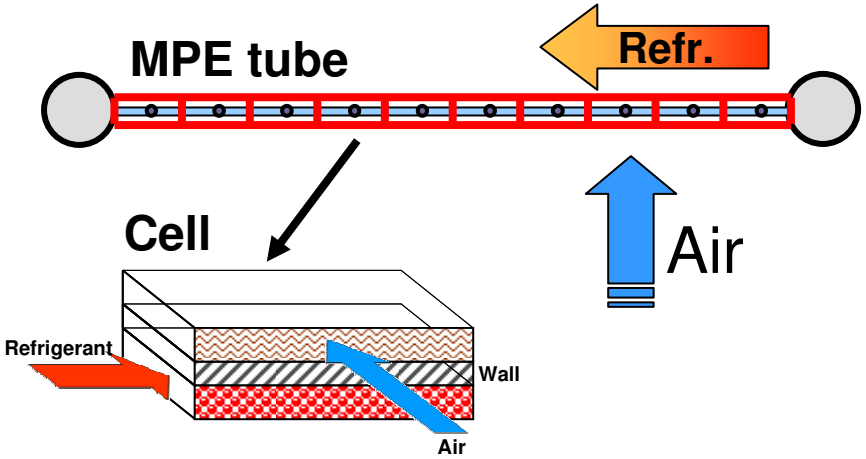
Advanced Models

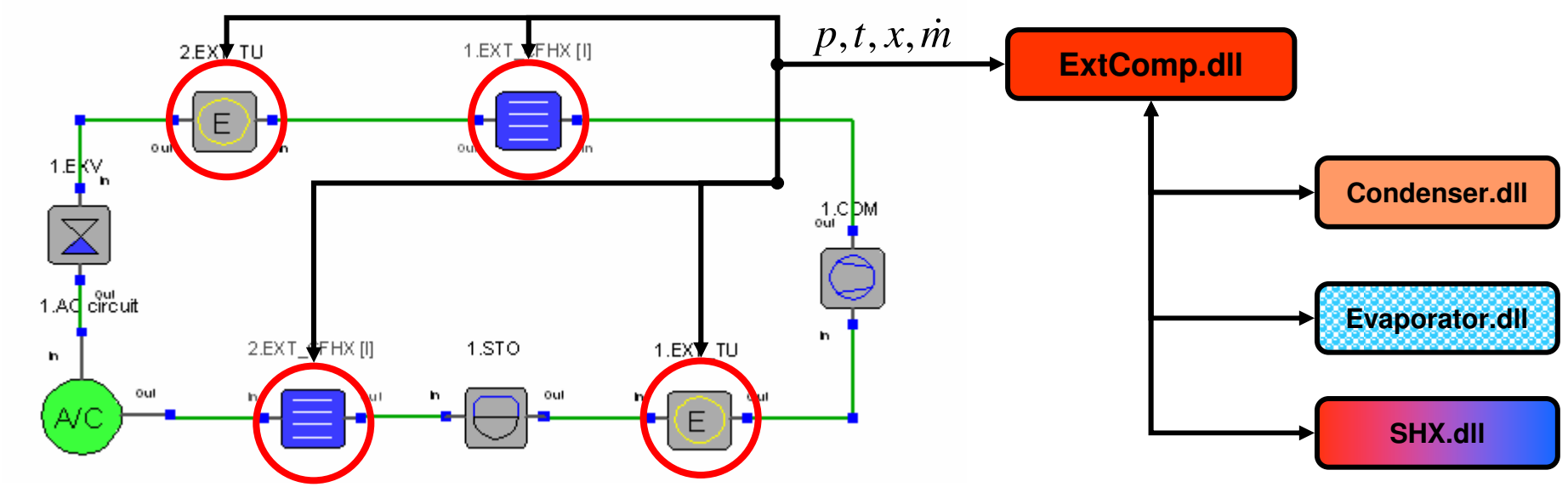
- Applicable for heating and cooling mode
  → **Heat transfer & pressure drop equations for single and 2-phase flow (evaporation & condensation)**
- Transient behavior (structure warm-up)
  → **Transient formulation of mass- and energy conservation for each cell**
- Advanced geometry (modeling of various multi-pass geometry)
  → **Arbitrary cell length for high resolution**



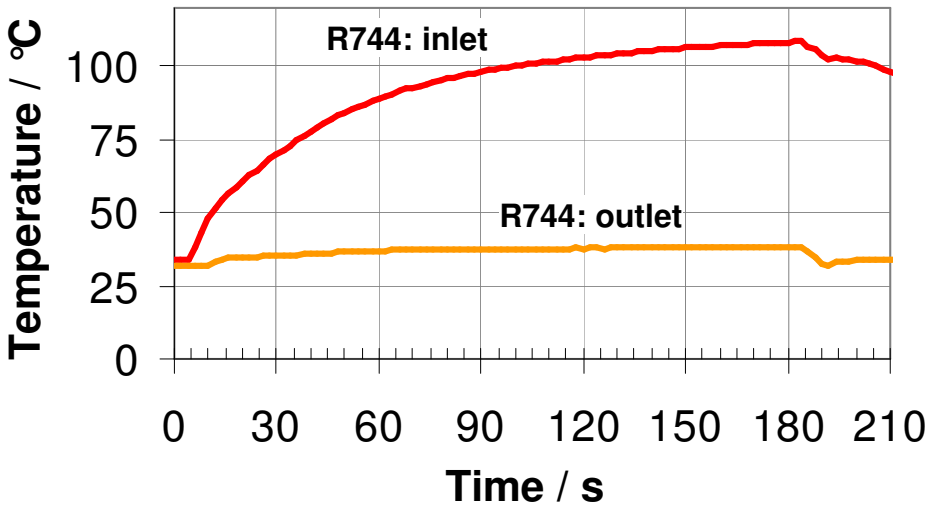


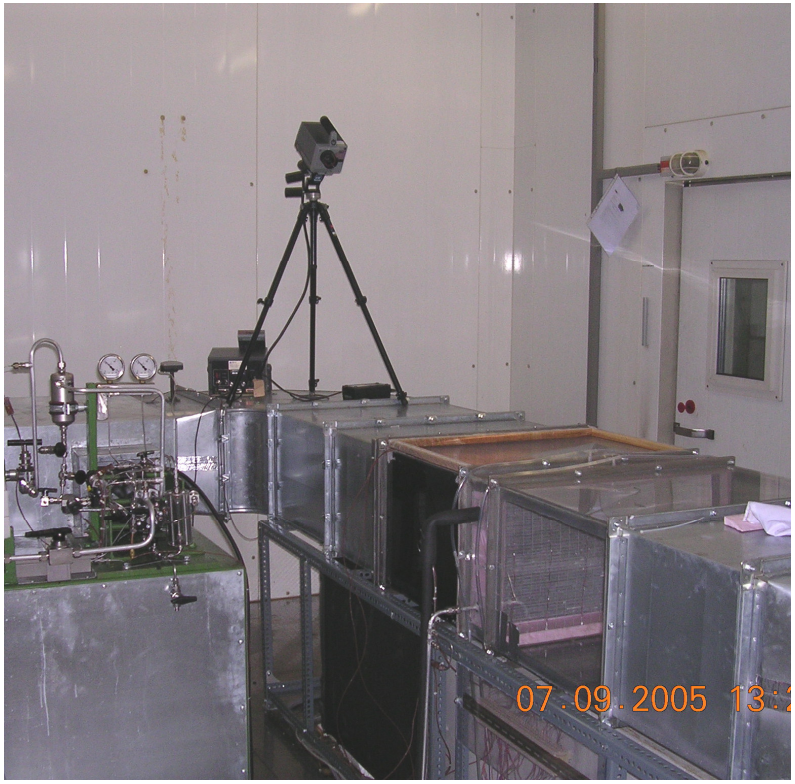
Coupling to KULI

- Geometry data from ASCII-File
- Component results available through KULI-Postprocessor
- Detailed calculation results written to Log-File



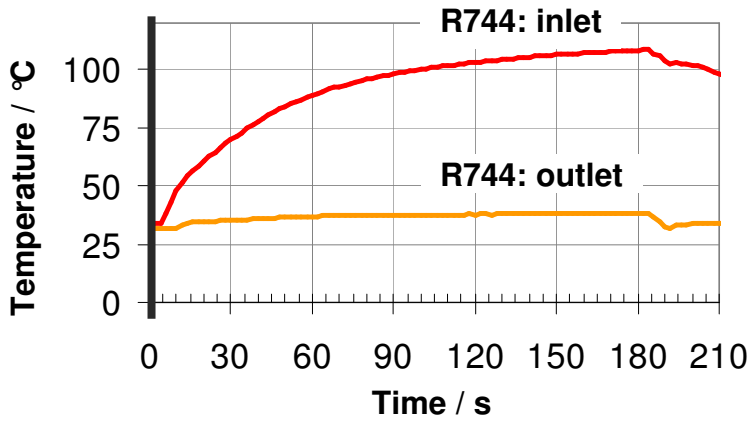
Gas Cooler (AC mode) - warm-up behavior
measurement (thermography) vs. simulation

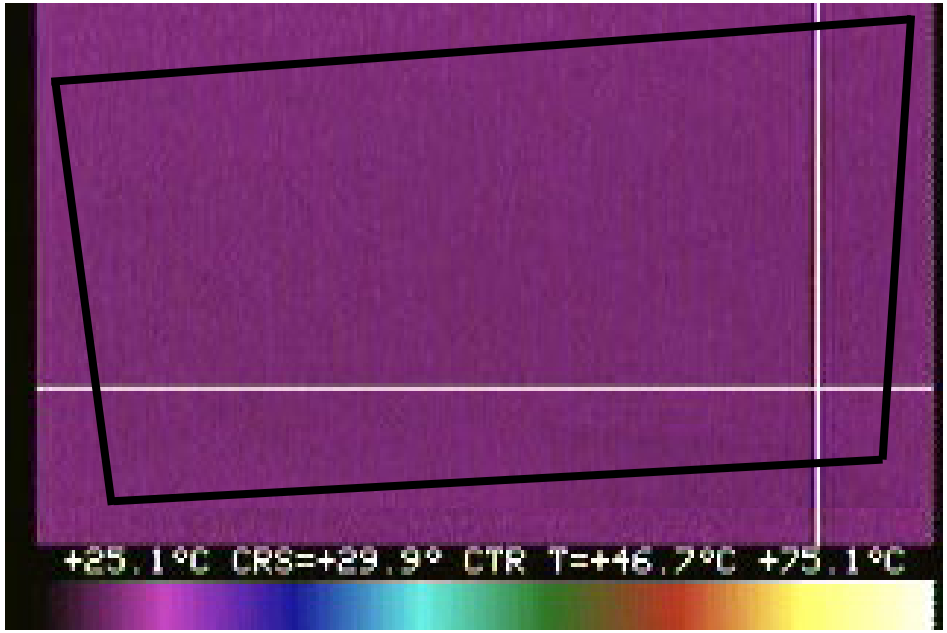


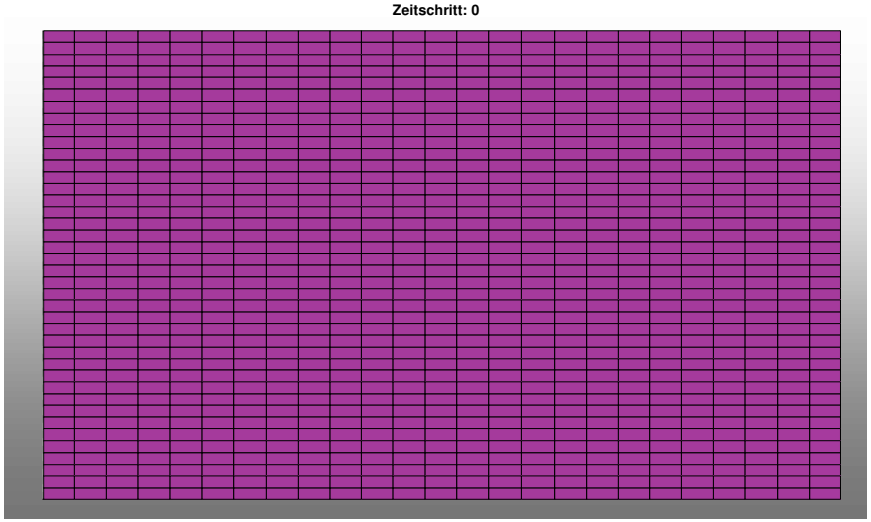


Advanced Models

Compressor Start **time: 0s**

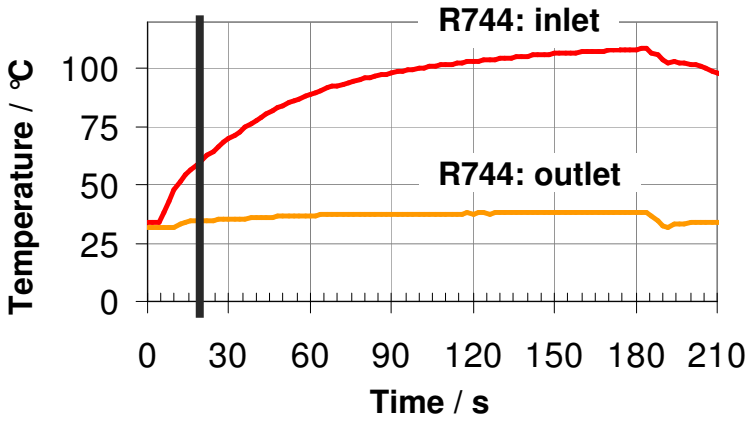


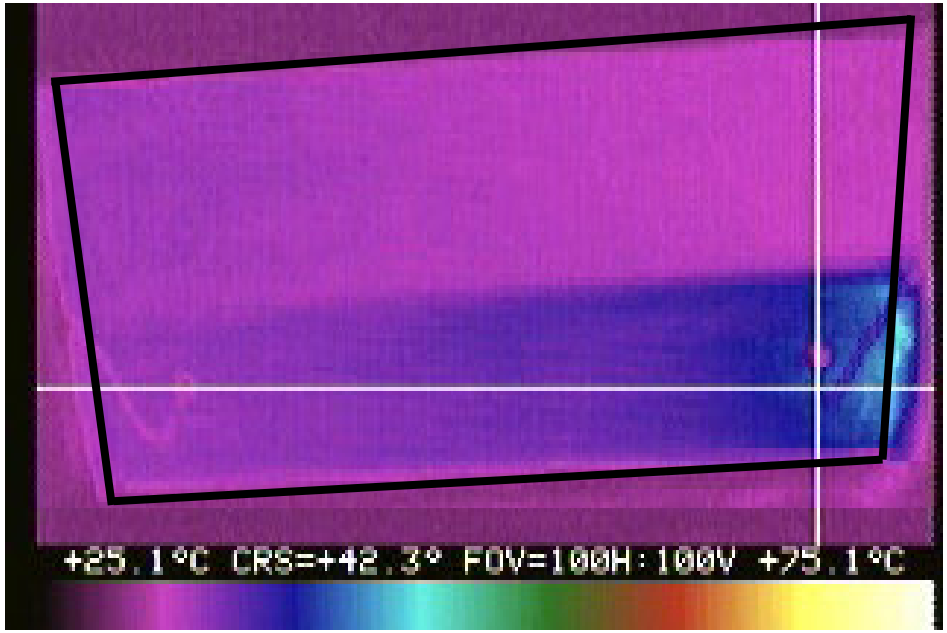


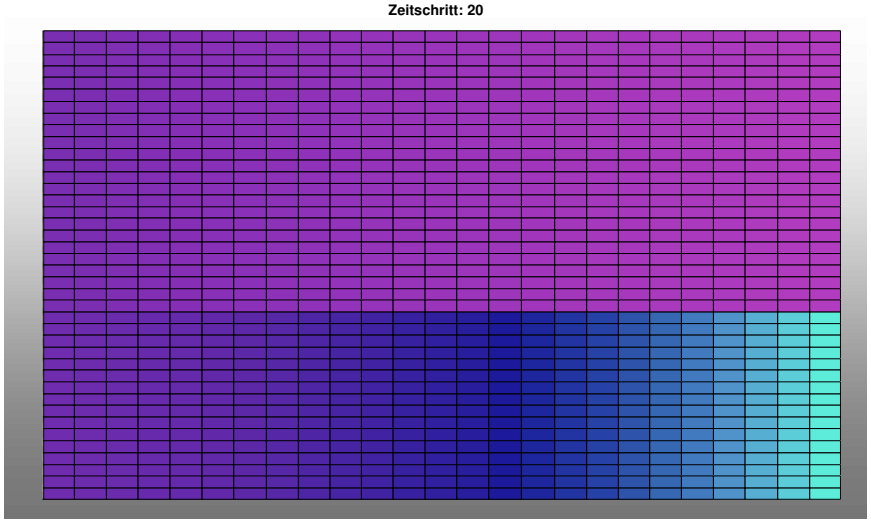


Advanced Models

time: 20s

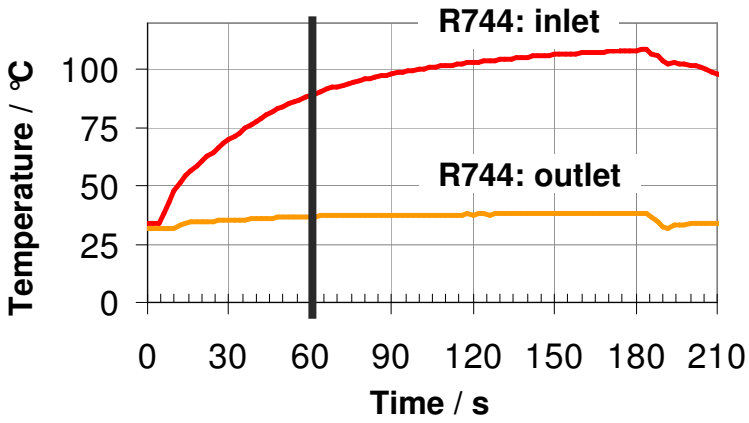


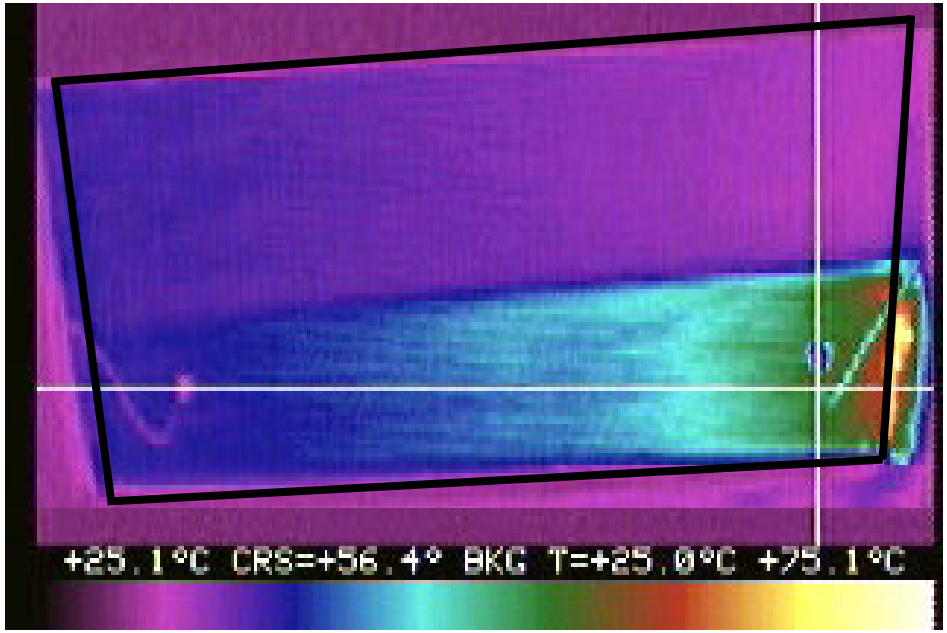


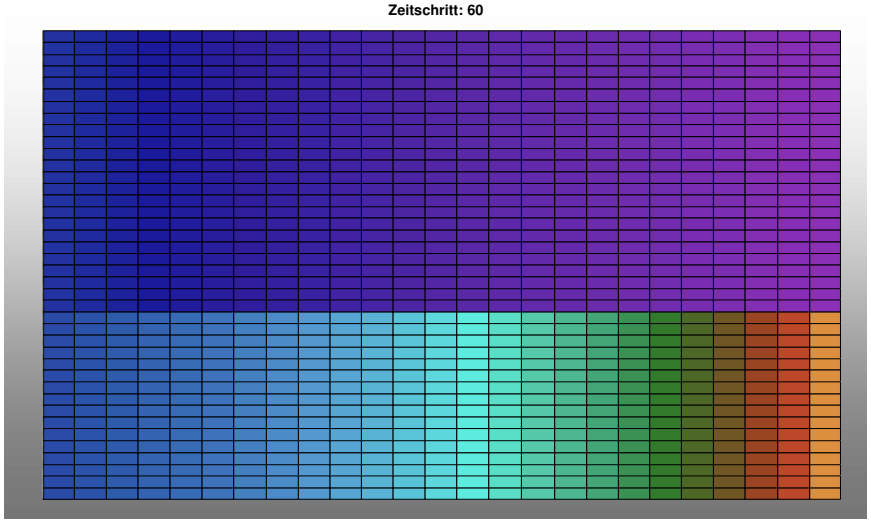


Advanced Models

time: 60s

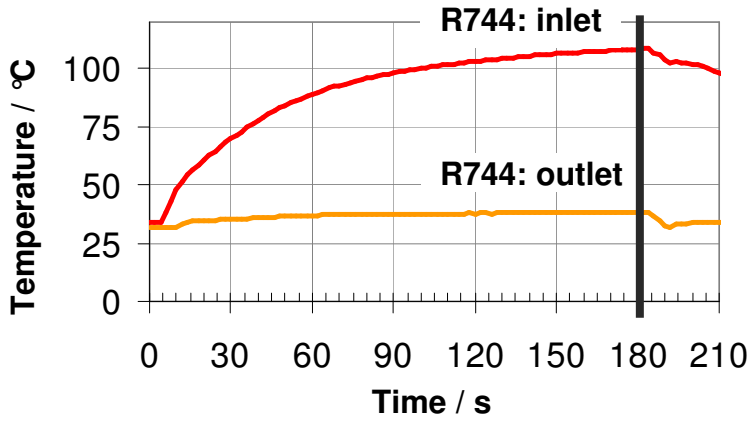


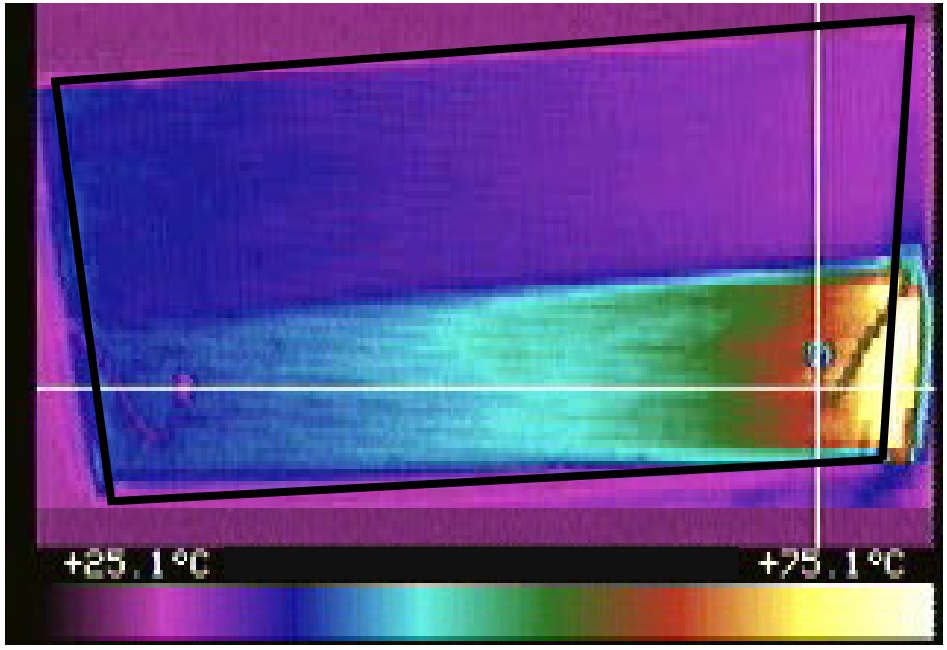


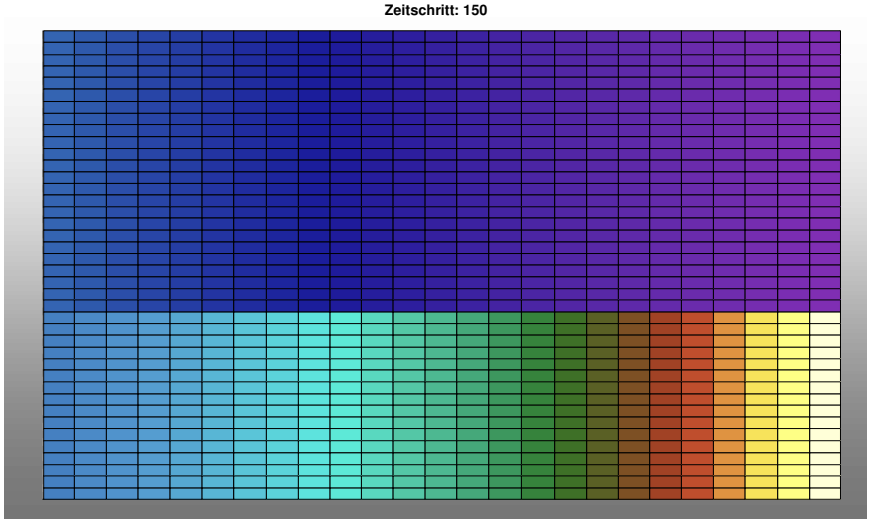


Advanced Models

time: 180s







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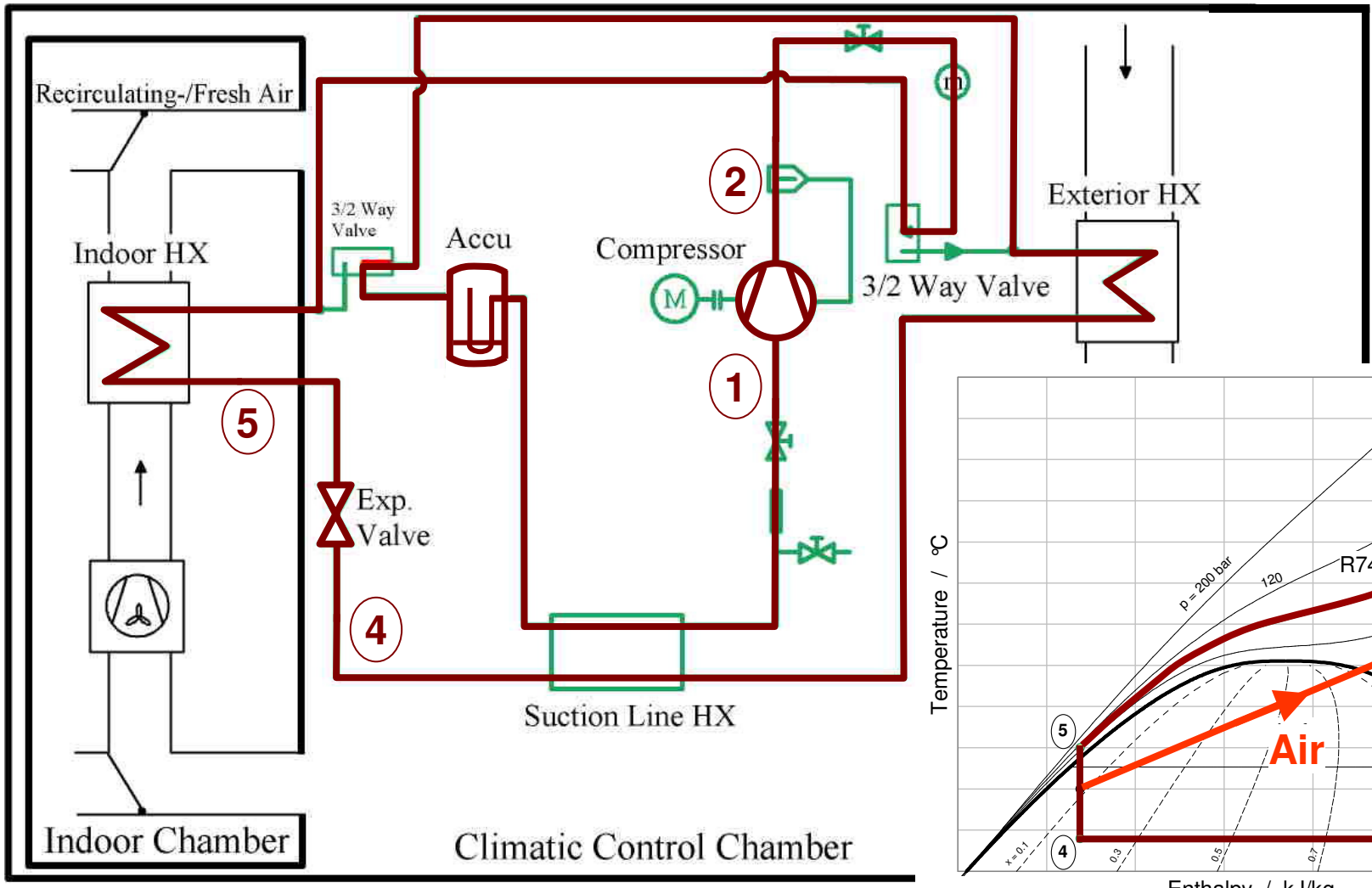
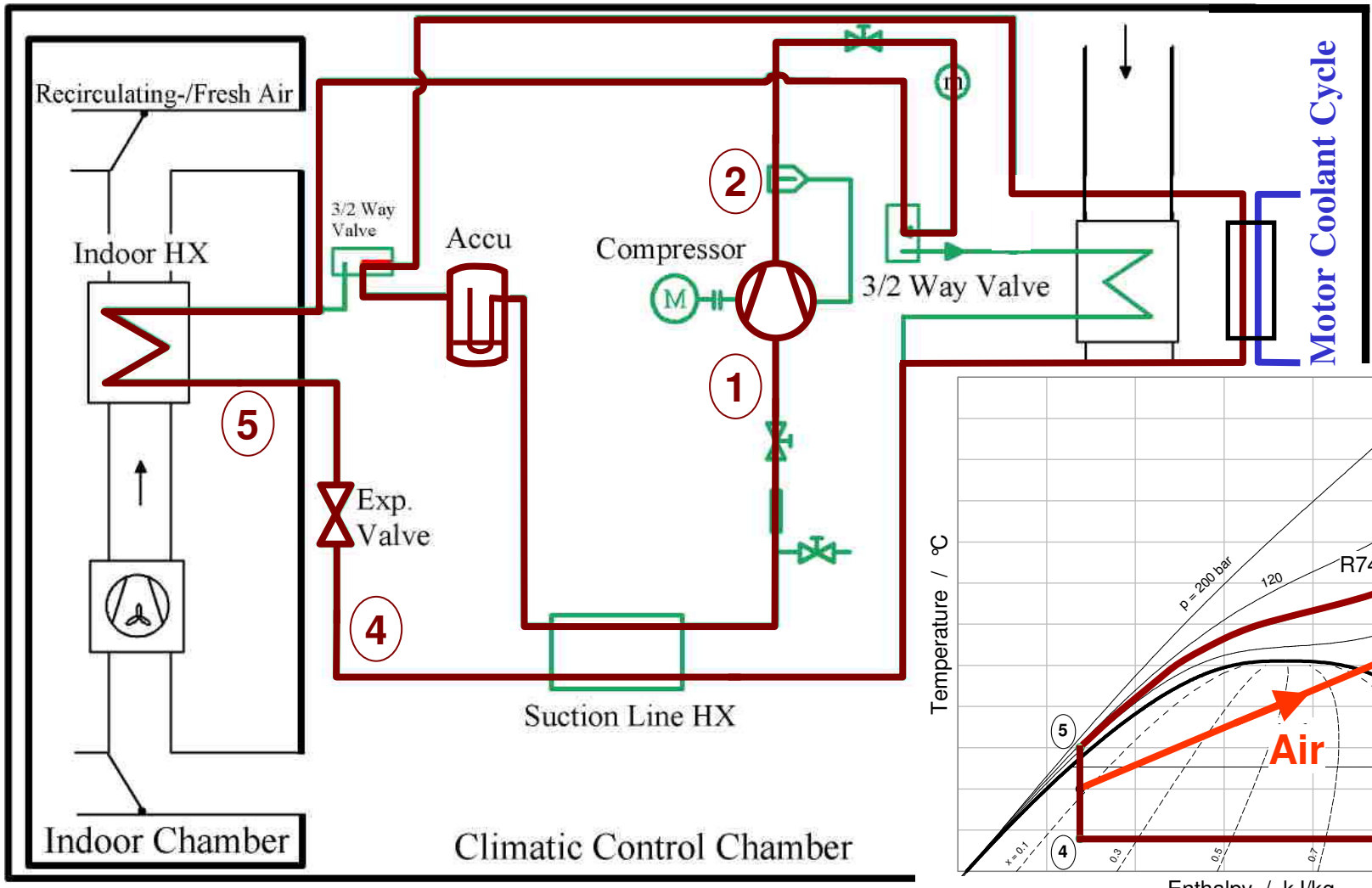
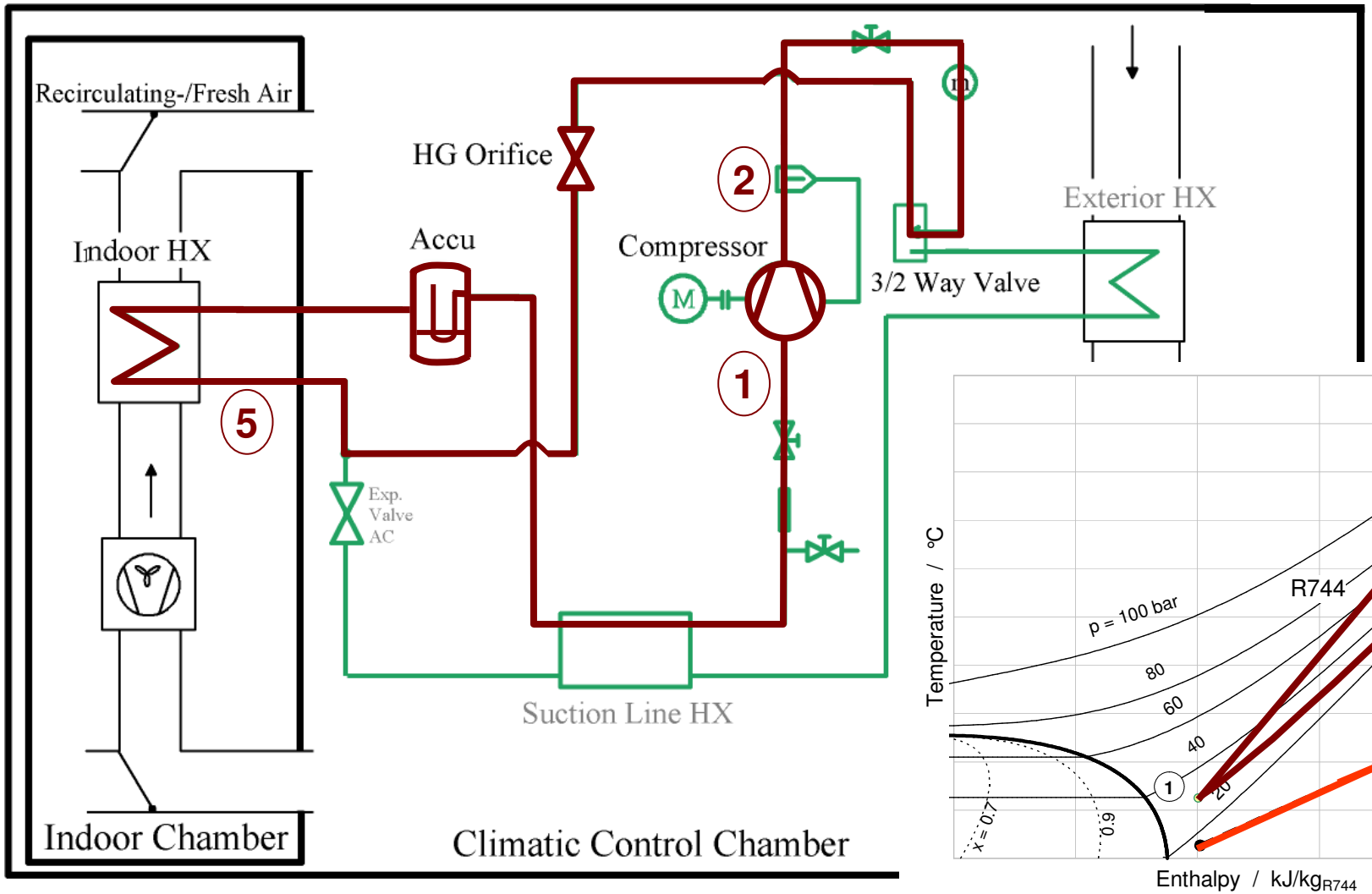
Air/Air-Heat Pump



Coolant/Air-Heat Pump

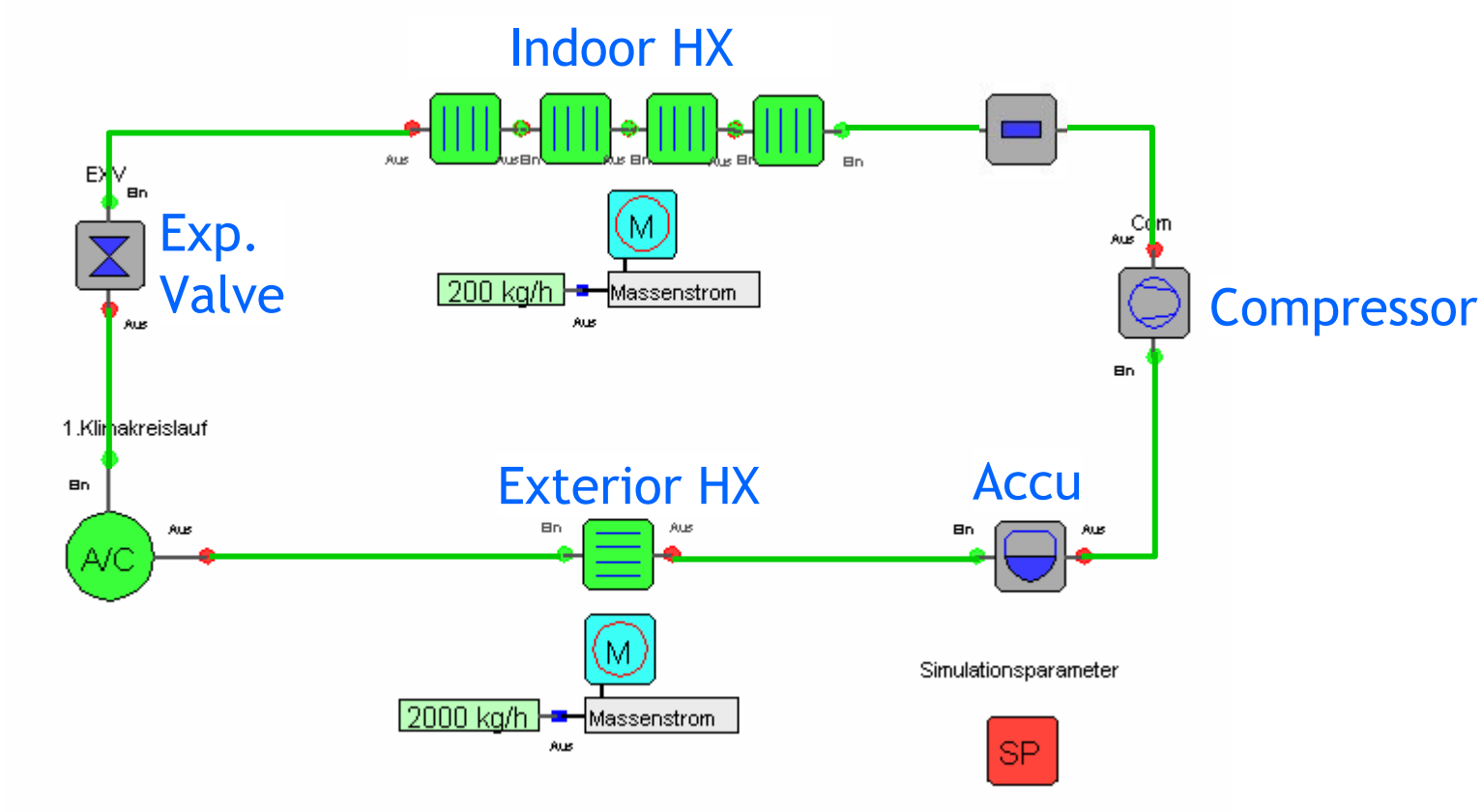


Hot Gas Cycle (HGC)



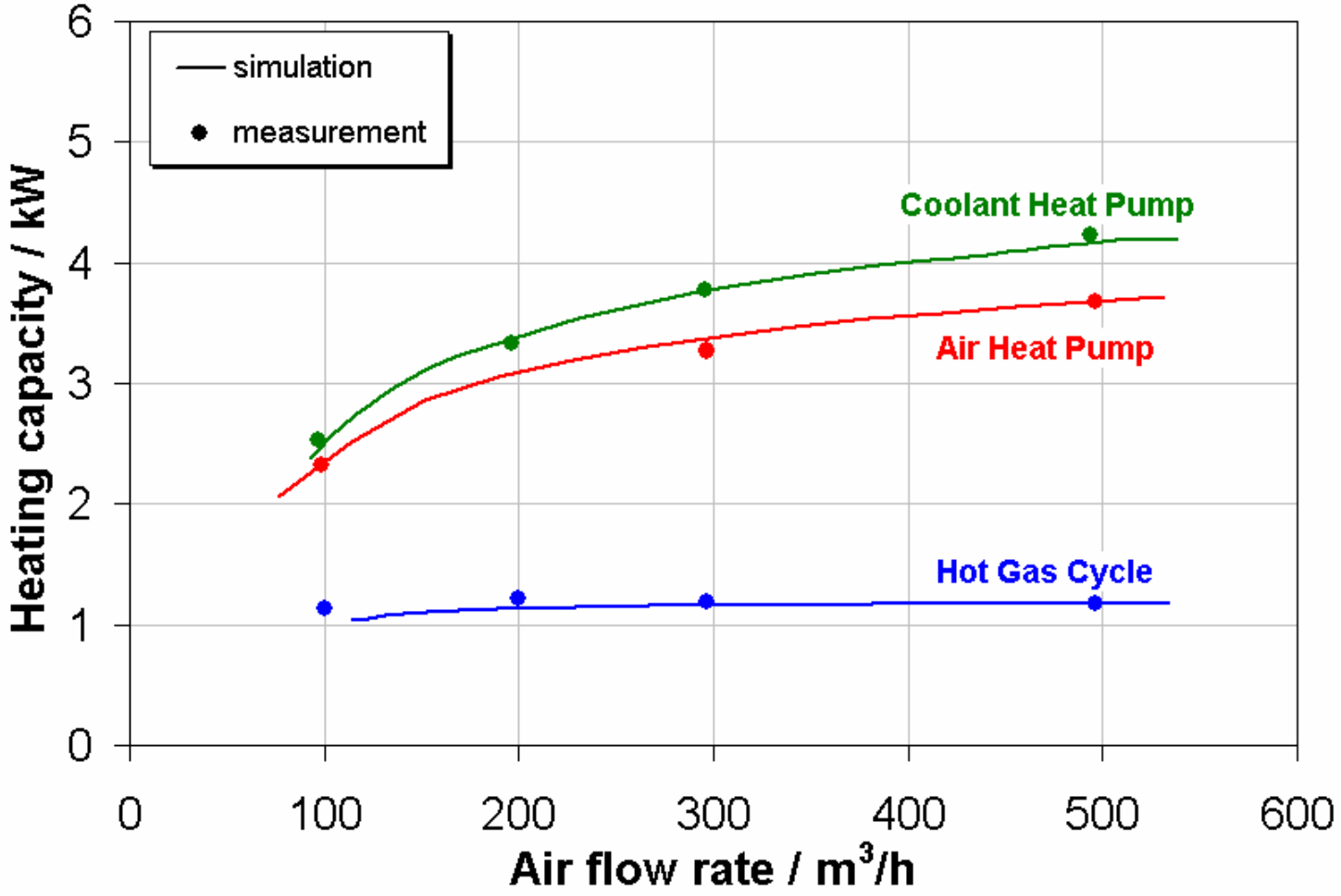
Steady State Simulation

schematic model for steady state simulation (Air/Air-Heat Pump)



Steady State

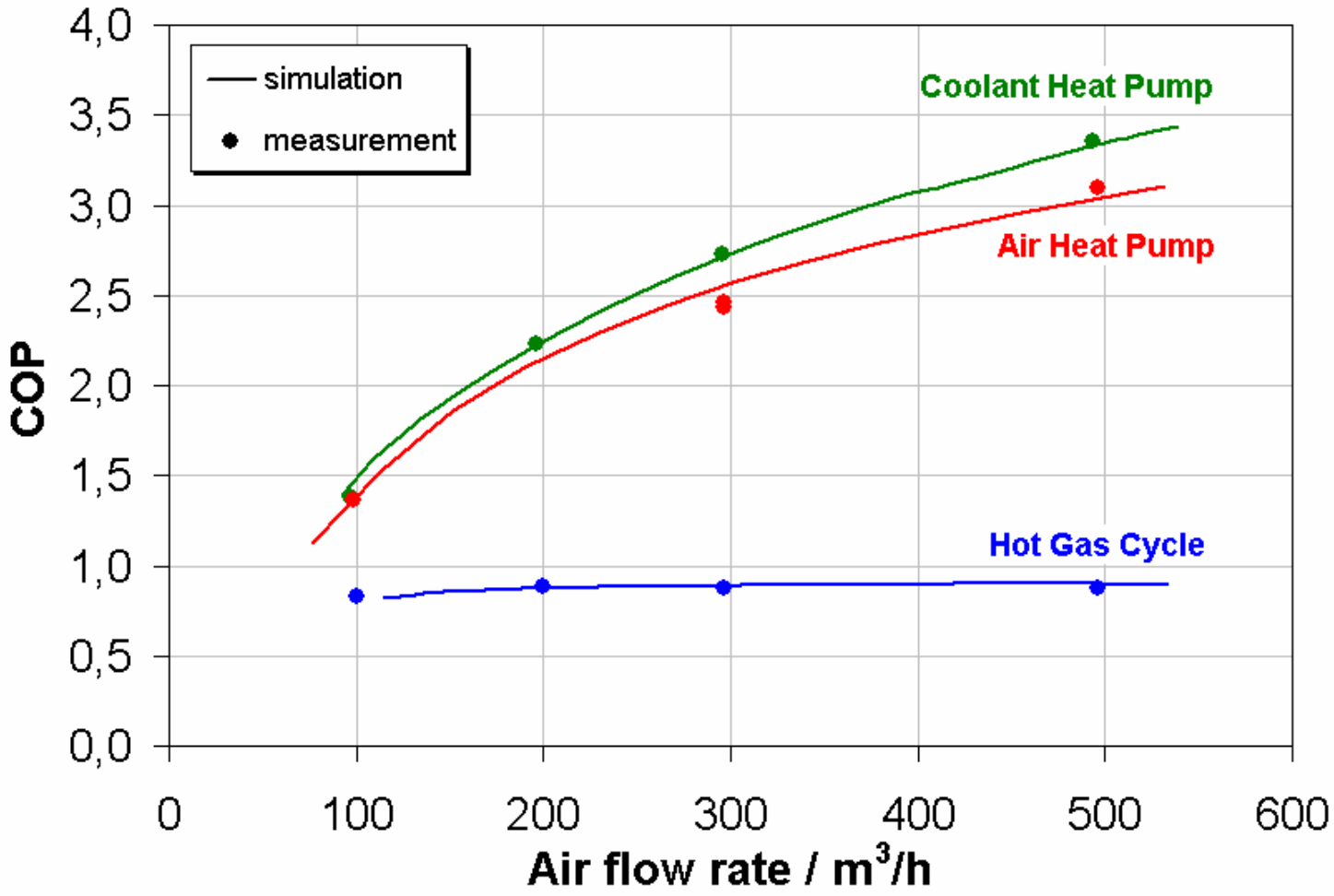
Simulation vs. Measurement



t_amb = - 5 °C, n_Com = 900 rpm

Steady State

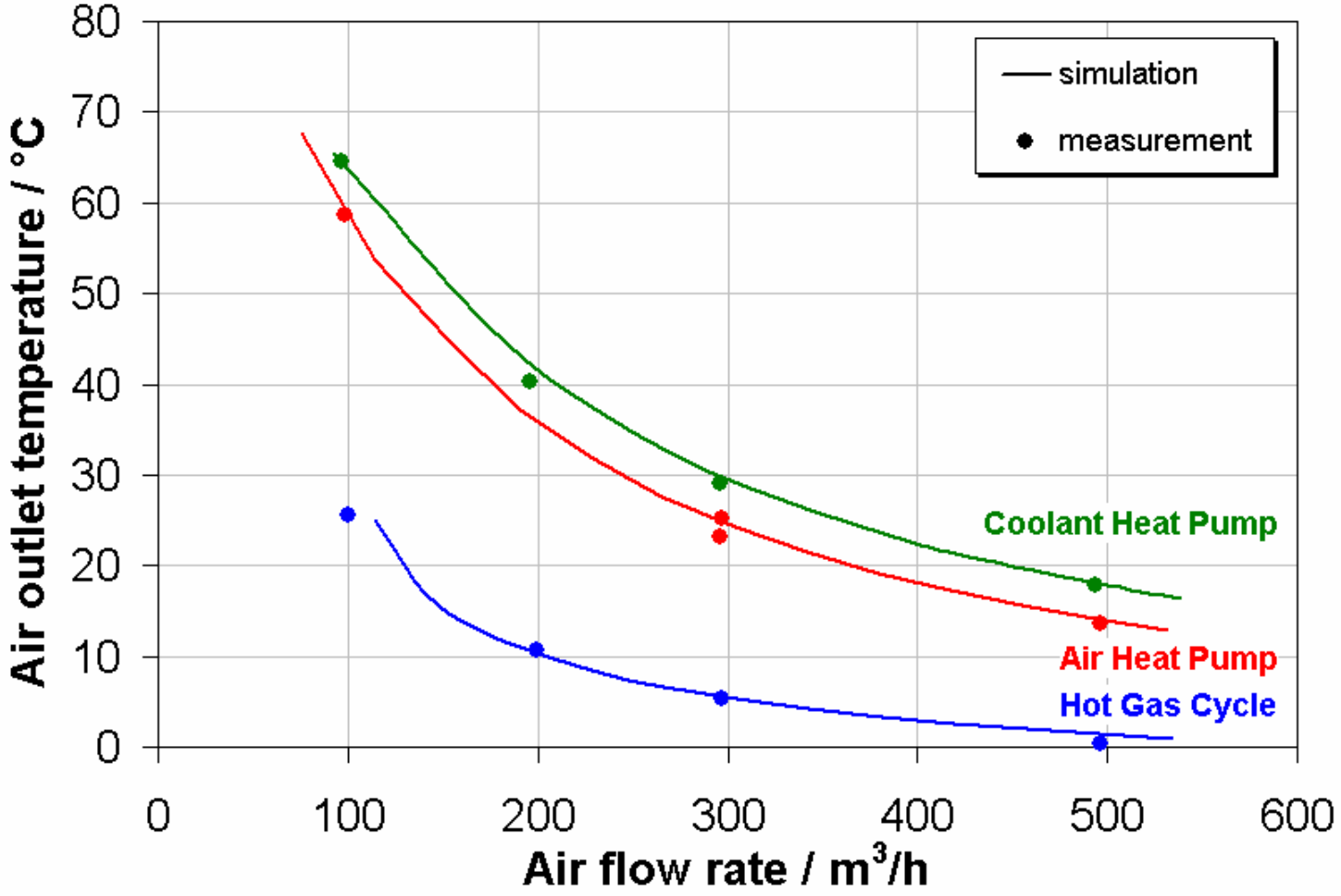
Simulation vs. Measurement



t_amb = - 5 °C, n_Com = 900 rpm

Steady State

Simulation vs. Measurement

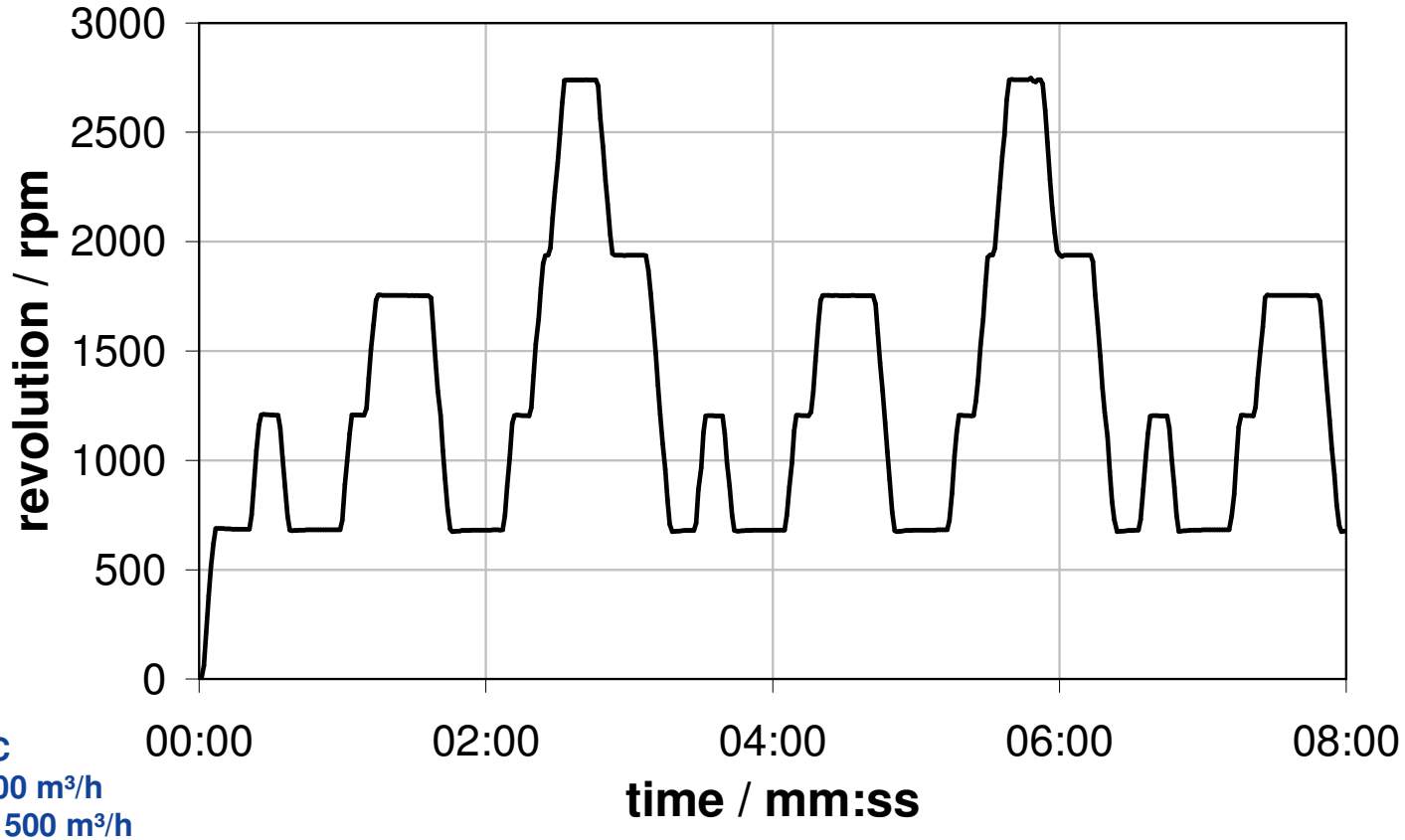


t_amb = - 5 °C, n_Com = 900 rpm

Content

Air/Air Heat pump - Driving Cycle

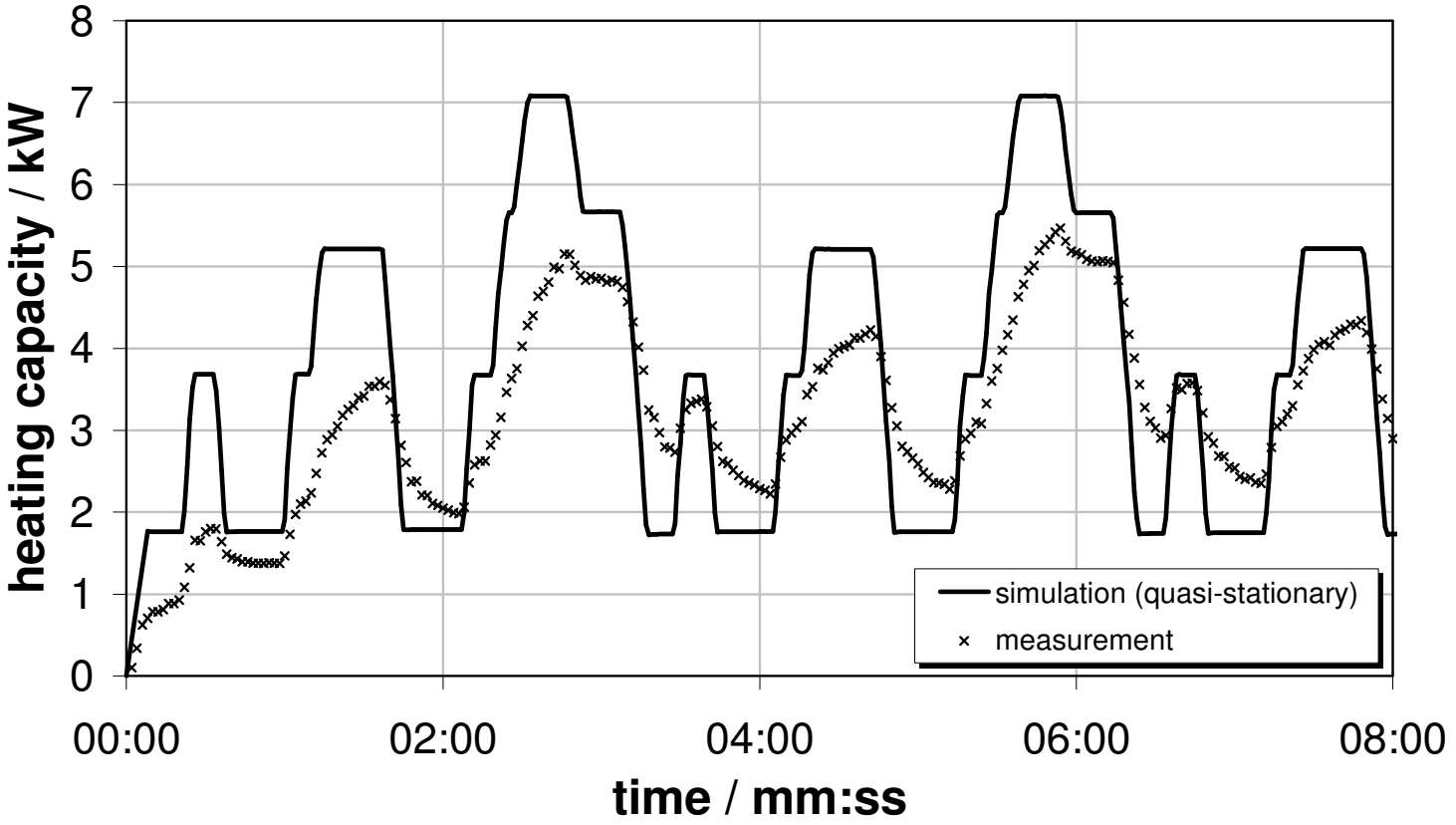
boundary conditions



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

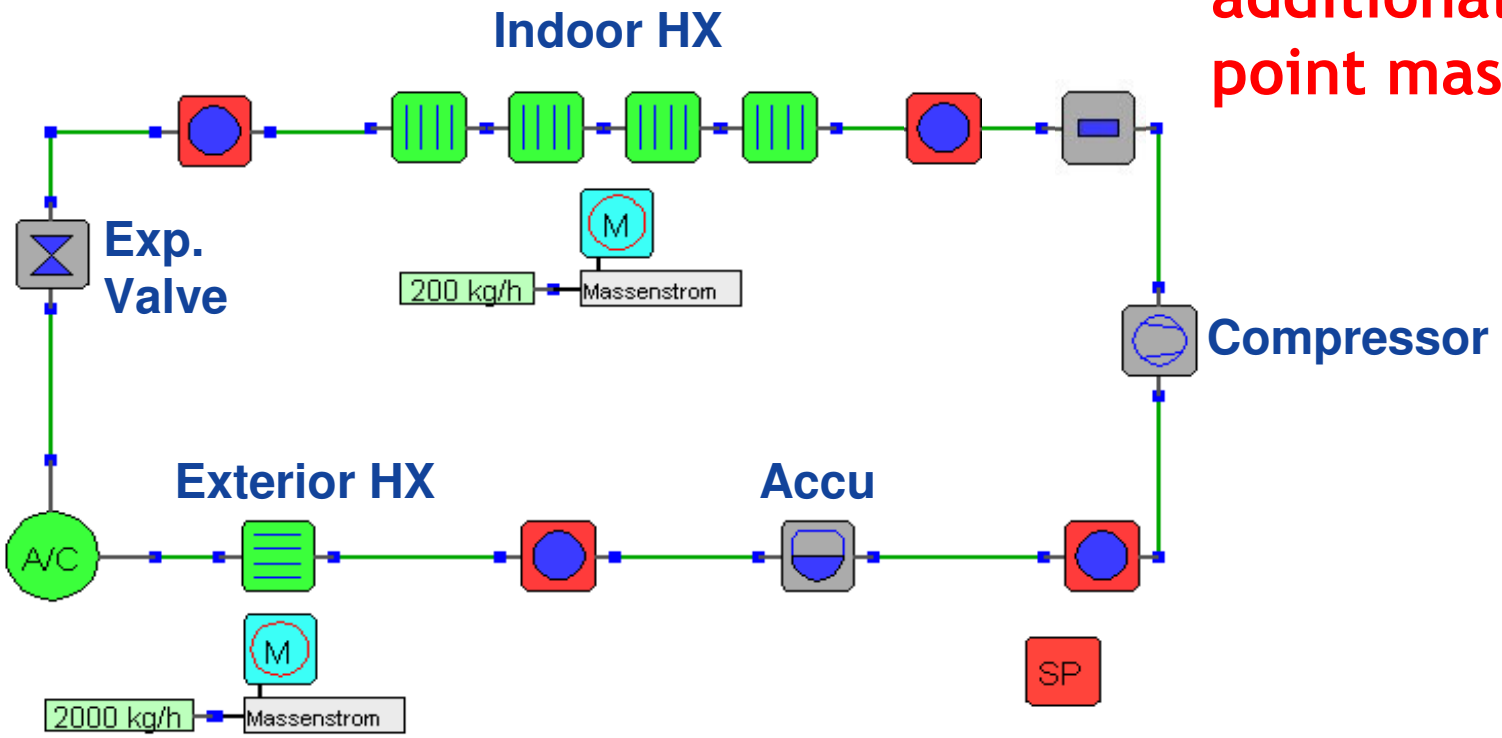
Air/Air Heat pump - Driving Cycle

quasi steady state simulation vs. measurement



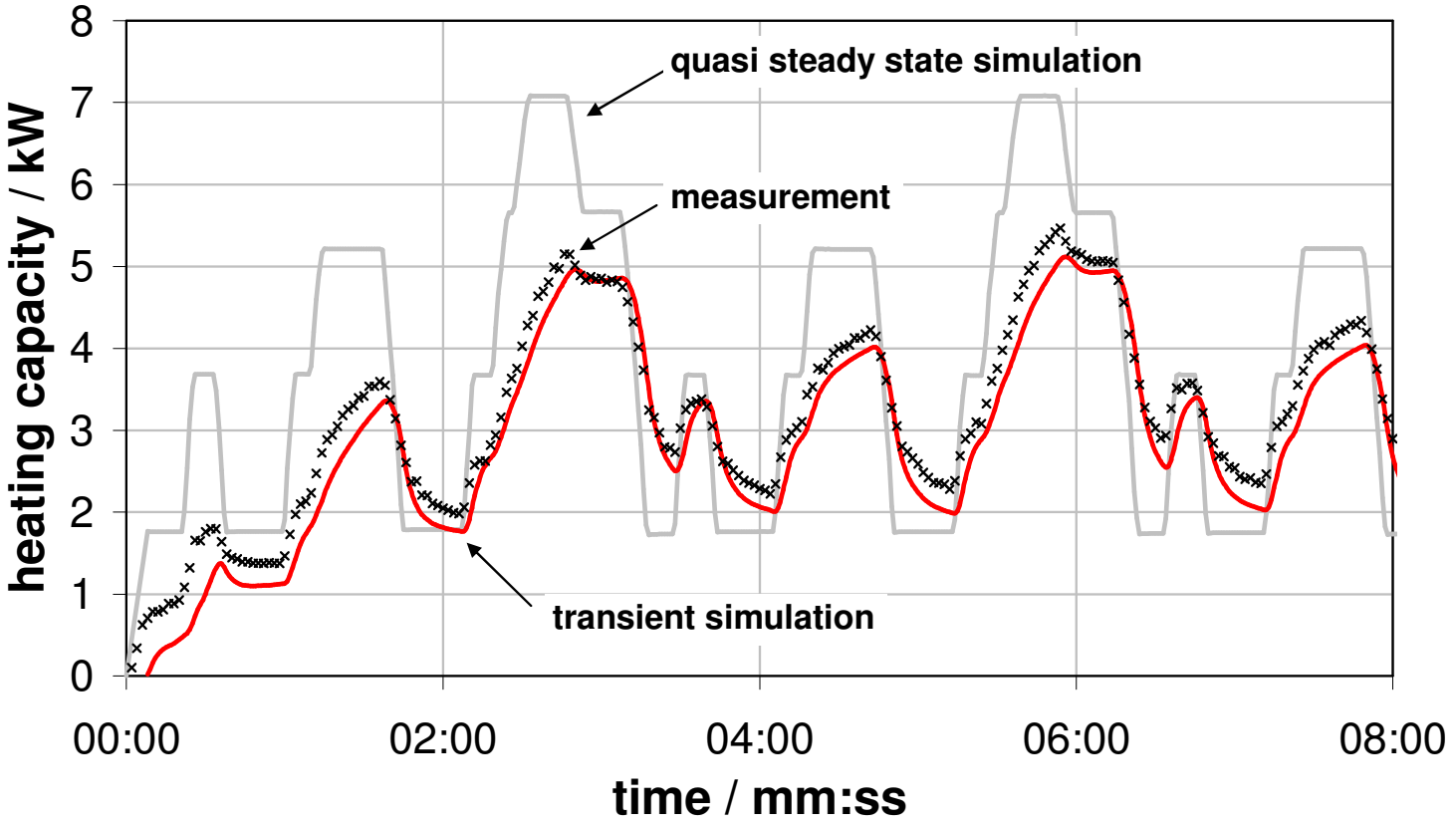
Transient Simulation

schematic model for transient simulation (Air/Air-Heat Pump)



Air/Air Heat pump - Driving Cycle

transient simulation vs. measurement

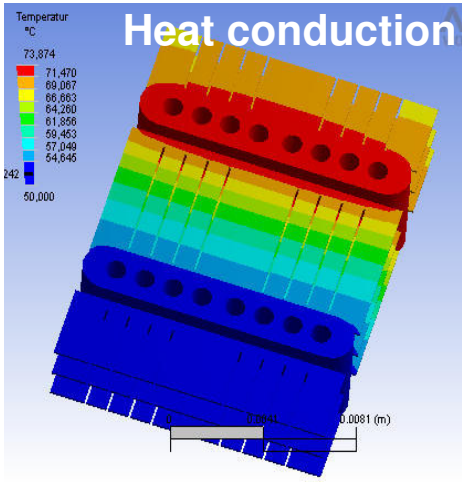


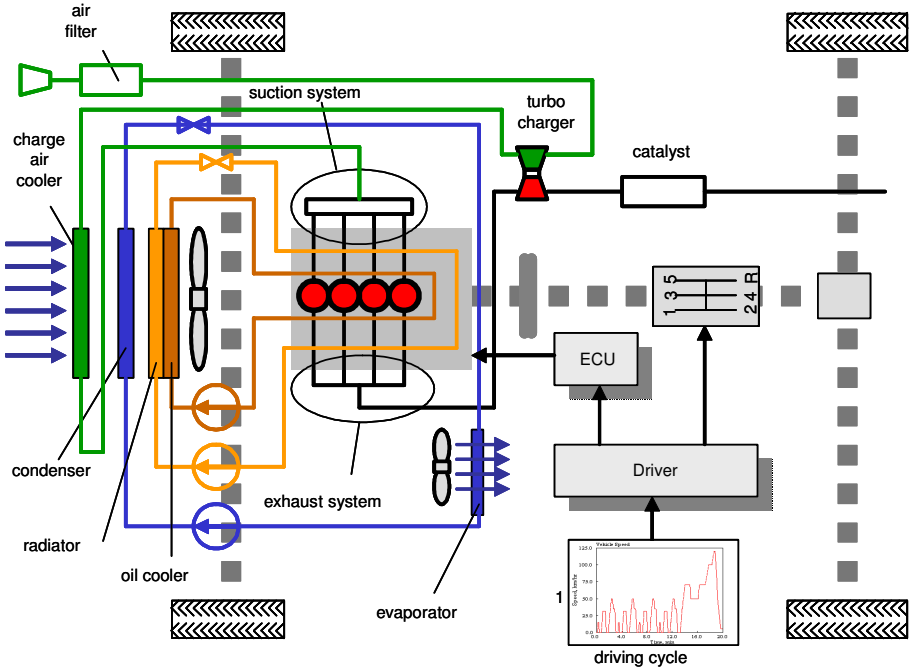
Summary

- advanced (external) components available
- heat pump systems offer efficient and powerful possibility for supplementary heating
- performance of air/air- and coolant/air heat pump is similar at steady state conditions
- heat pump is far superior to hot gas cycle
- acceptable air temperatures only at low air flow rates
- quasi steady state simulation does not deliver sufficient results → transient simulation much better
- thermal masses play important role for transient behavior of entire cycle

Outlook

- further improvement of HX models
  (heat conduction, frosting, oil, refrig. distribution, …)
- simulation of entire vehicle
  and verification with vehicle tests
- system optimization





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Kplus
Kompetenzzentren-Programm

Das Land Steiermark

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SFG
FAST FORWARD COMMUNITY

Stadt GRAZ Wissenschaft

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