

# Steady State and Transient Simulation of R744 HVAC- Systems and its Application on Hybrid Vehicles

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# Outline

- Introduction
- Steady State Operation
- Transient Operating Conditions
- Simulation Set Up for Vehicle Air Conditioning
- Hybrid Vehicle Simulation Results
- Summary

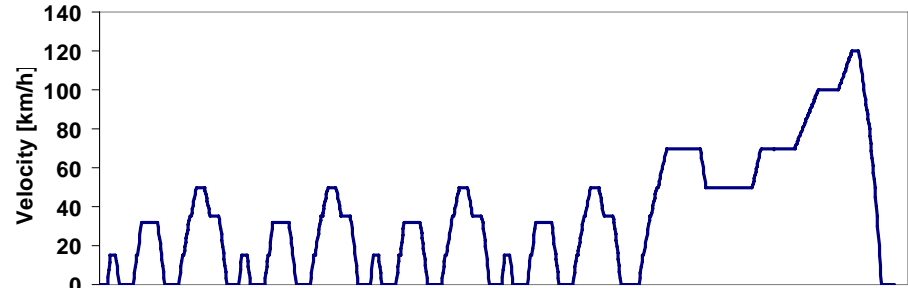
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# Driving Cycles

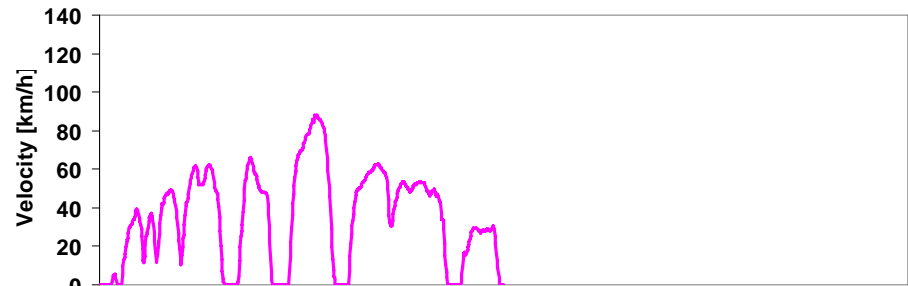
## NEDC

Acceleration  $0,53 \text{ m/s}^2$   
~ 150 RPM/s



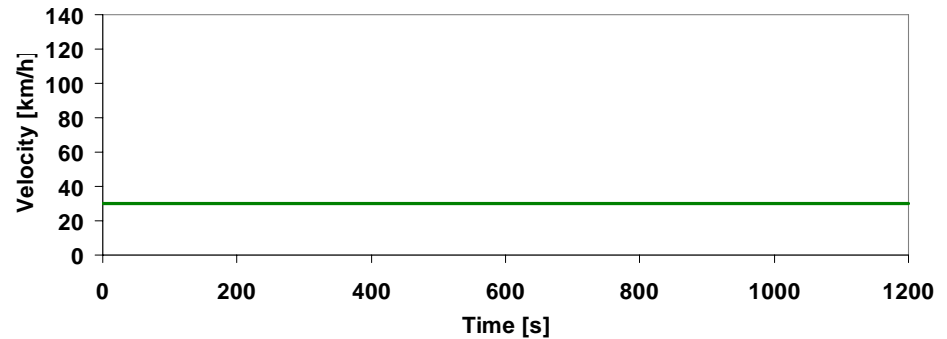
## SC03

Acceleration  $0,50 \text{ m/s}^2$   
~ 140 RPM/s



## Pull Down

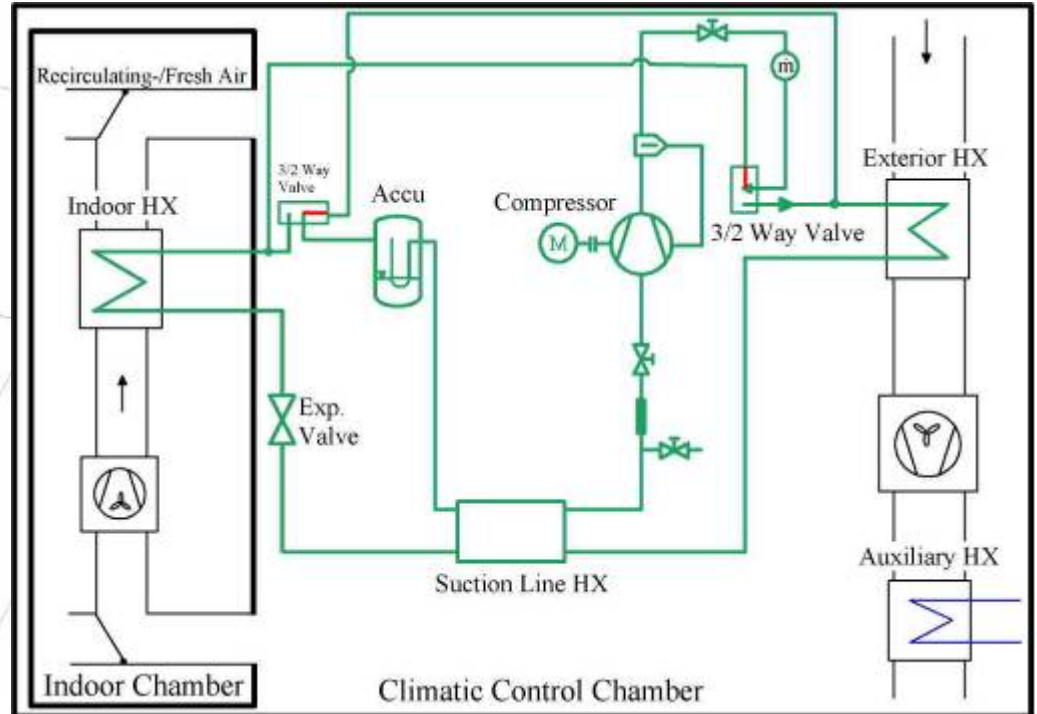
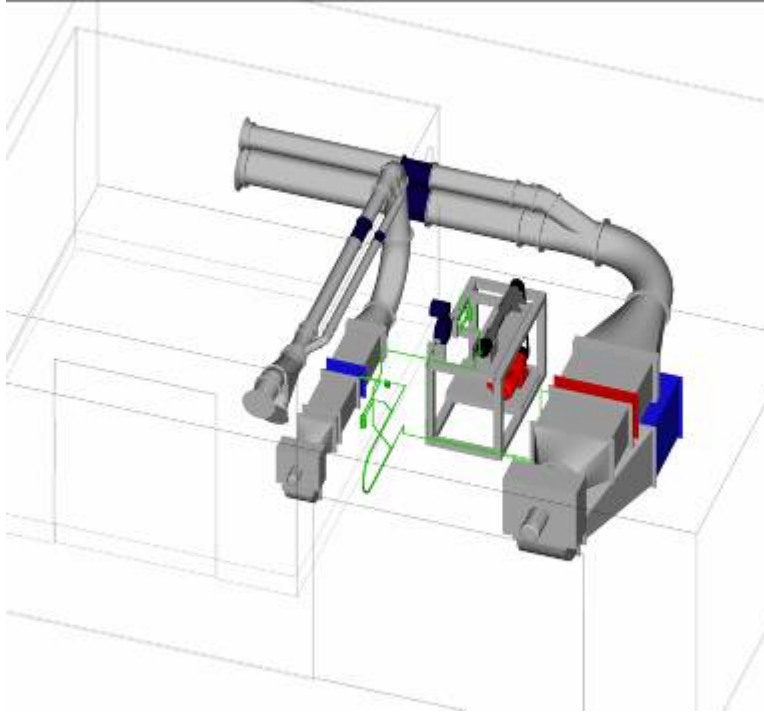
Acceleration  $0 \text{ m/s}^2$   
0 RPM/s



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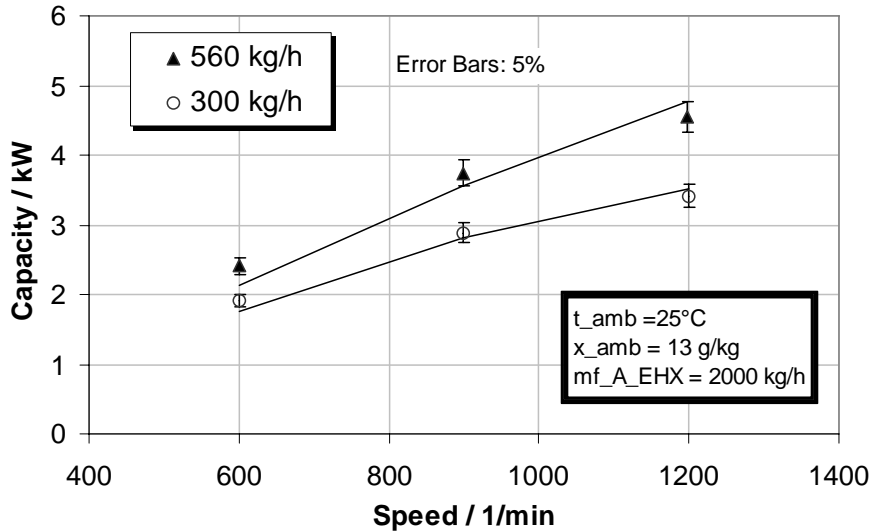
# Climatic Chamber Test Stand



Air temperature range -20 ... +40 °C  
Relative humidity 20 ... 80 %

Flow wind tunnel 1: 60 ... 500 m<sup>3</sup>/h  
Flow wind tunnel 2: 600 ... 4000 m<sup>3</sup>/h

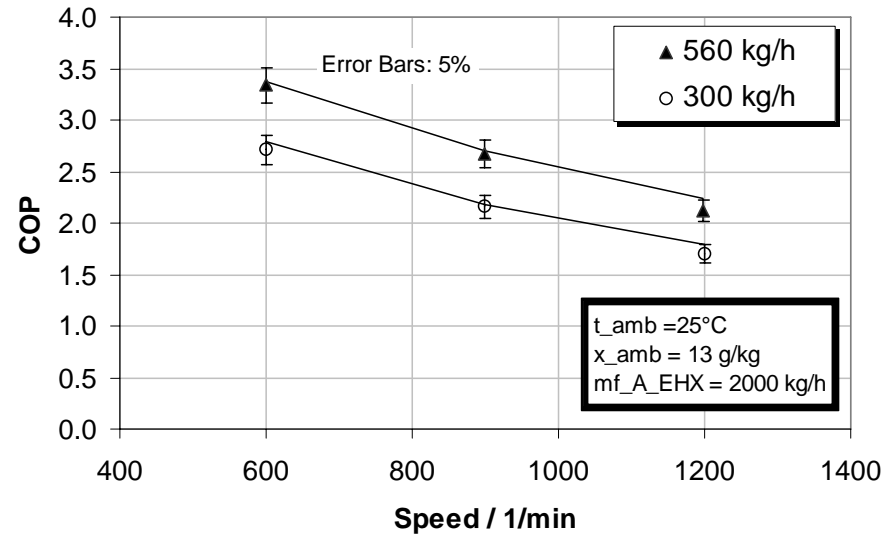
# Evaporator Capacity and COP



Steady state  
evaporator capacity  
measured and simulated

Steady state  
COP

measured and simulated

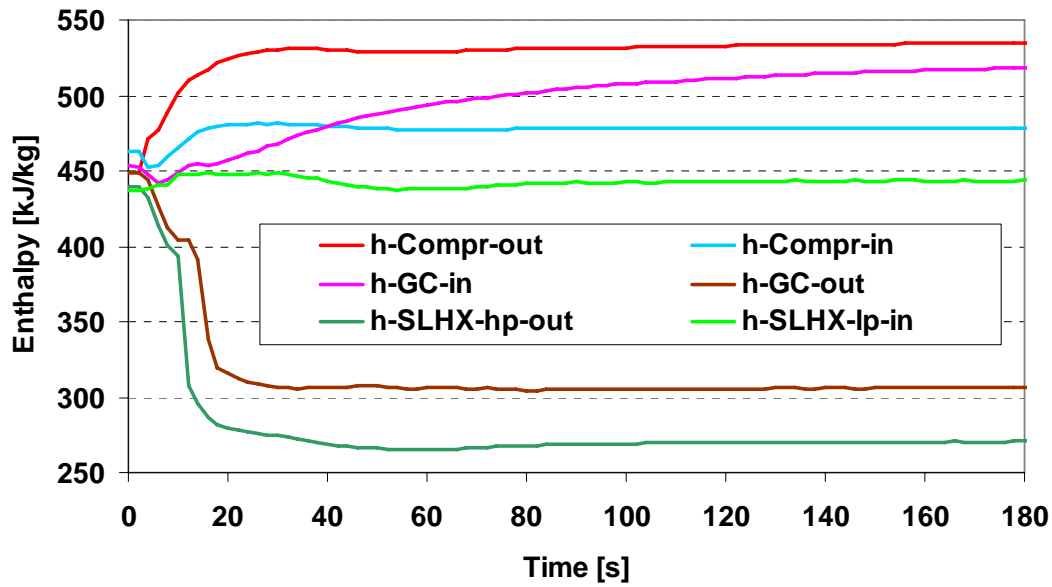
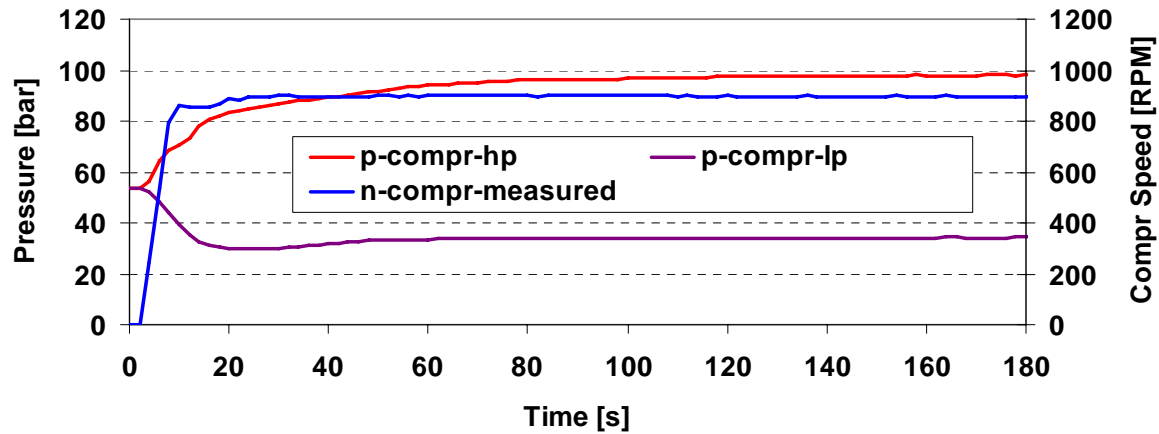


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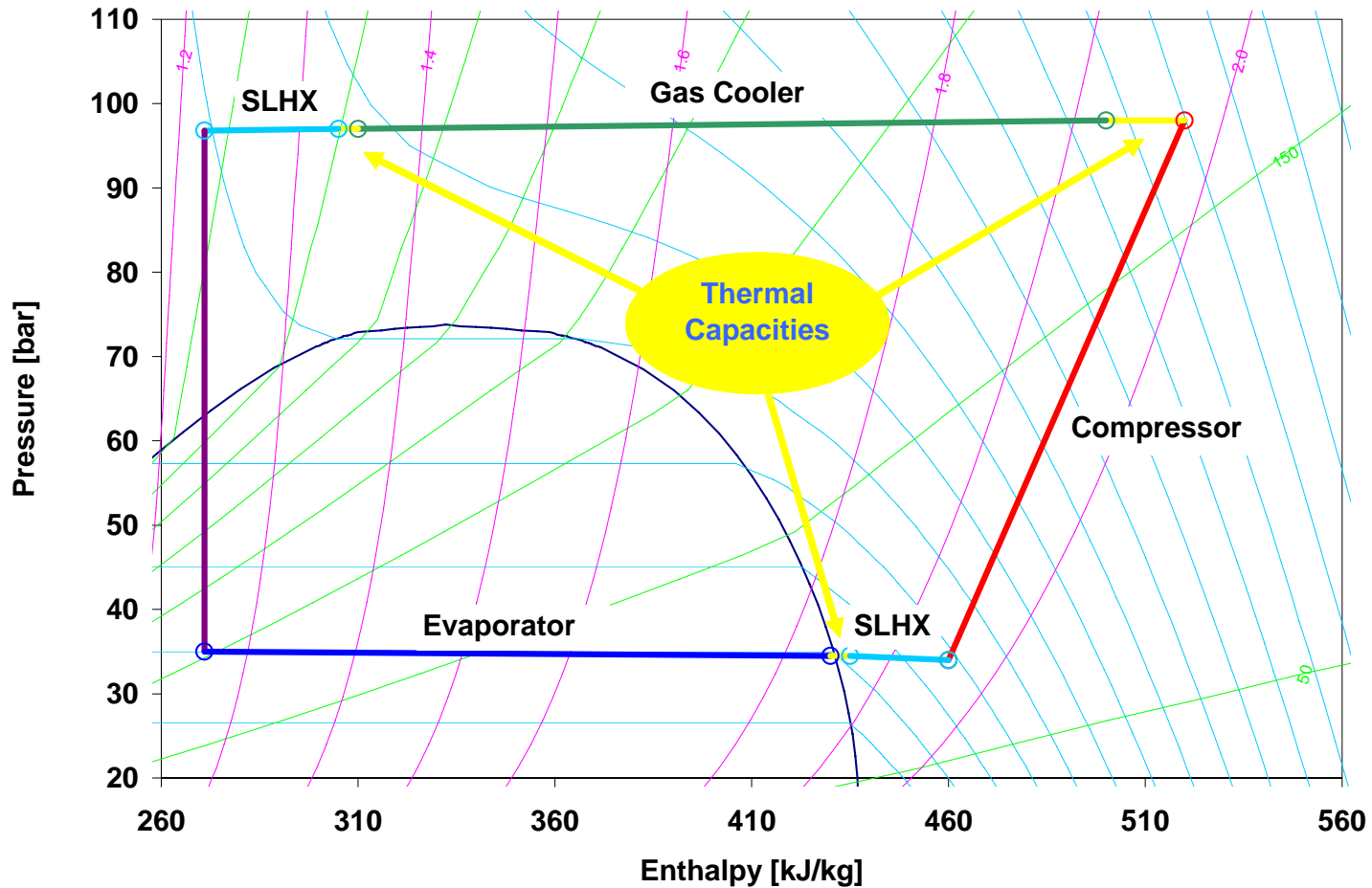
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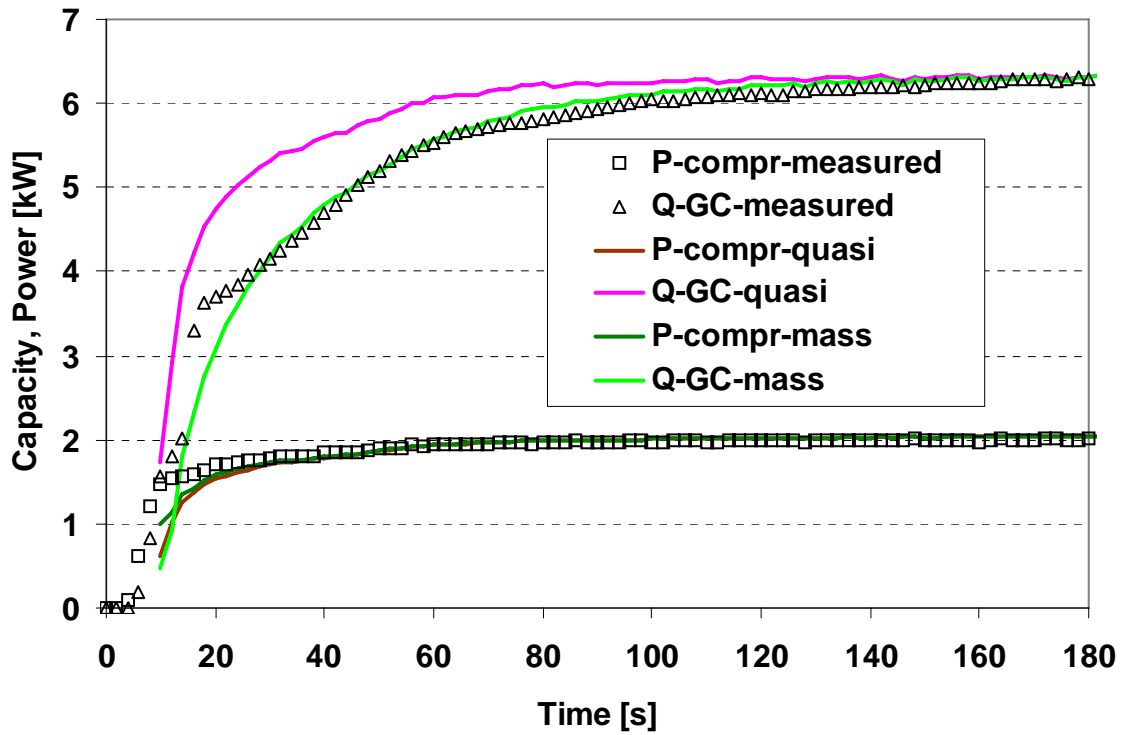
# Start-up Measurement



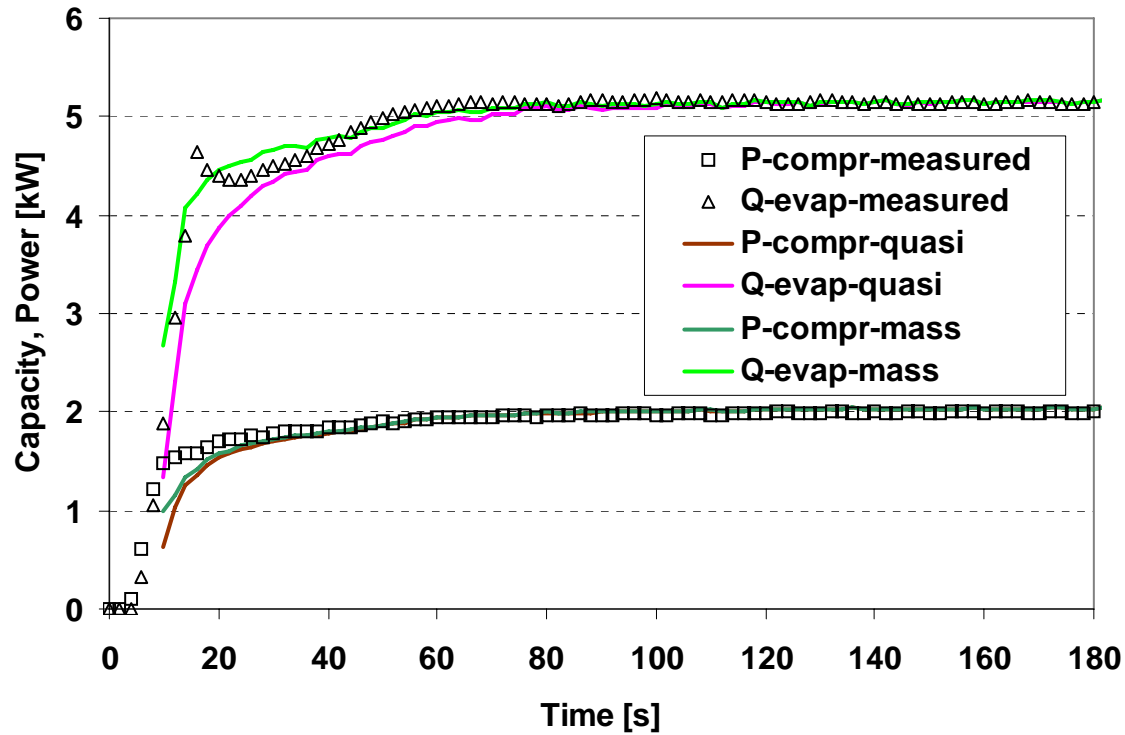
# Influence of Thermal Capacities



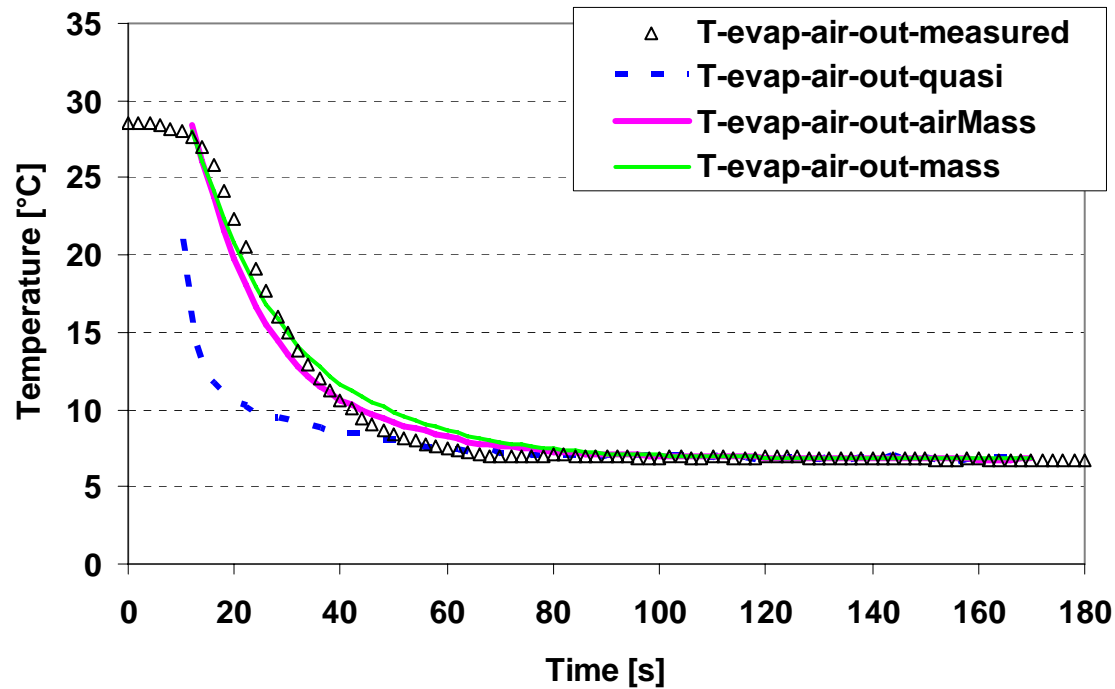
# Start-up Simulation of Gas Cooler



# Start-up Simulation of Evaporator

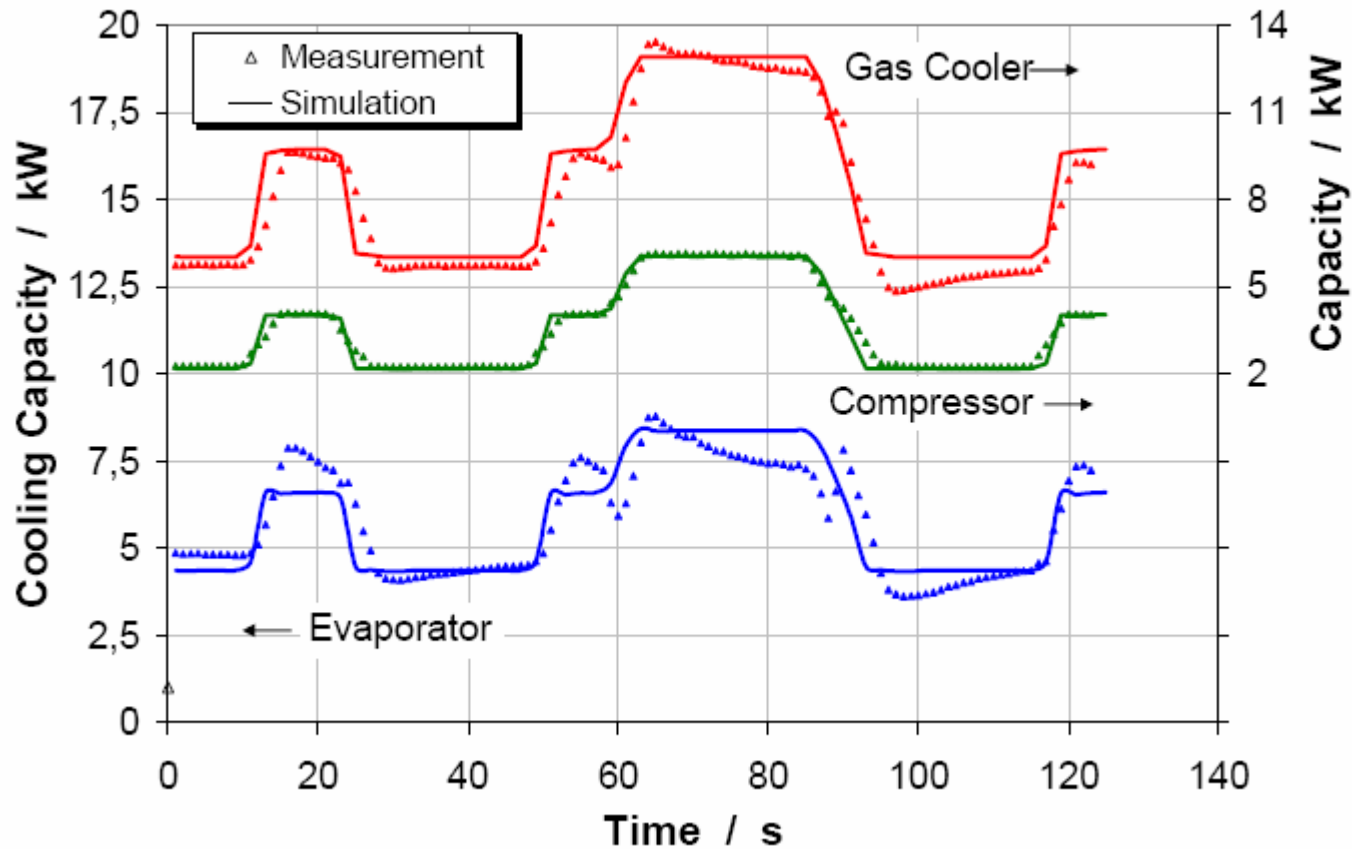


# Start-up – Simulation Evaporator Air Out Temperature

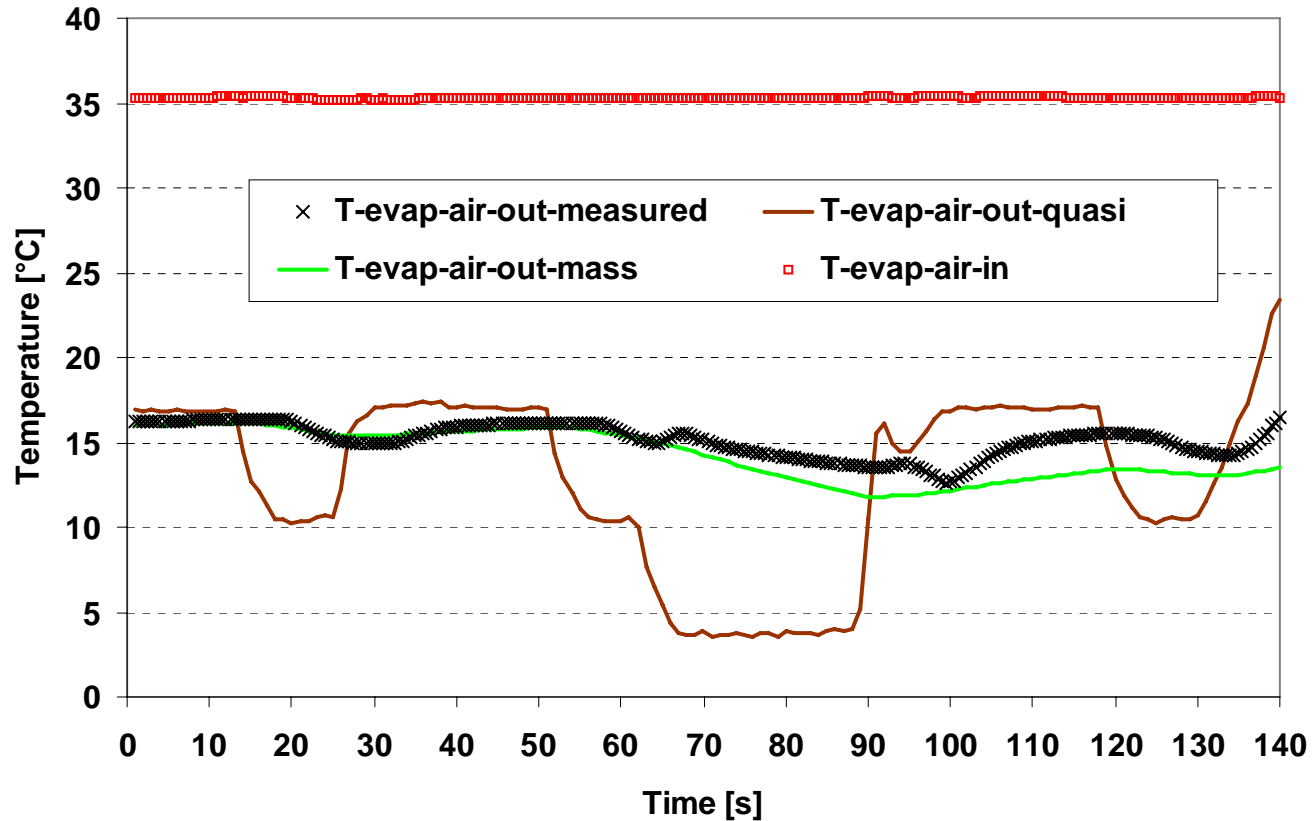


# Comparison Measurement Quasi Steady State Simulation

## Driving cycle - Simulation vs. Measurement



# Air Side Temperatures Evaporator

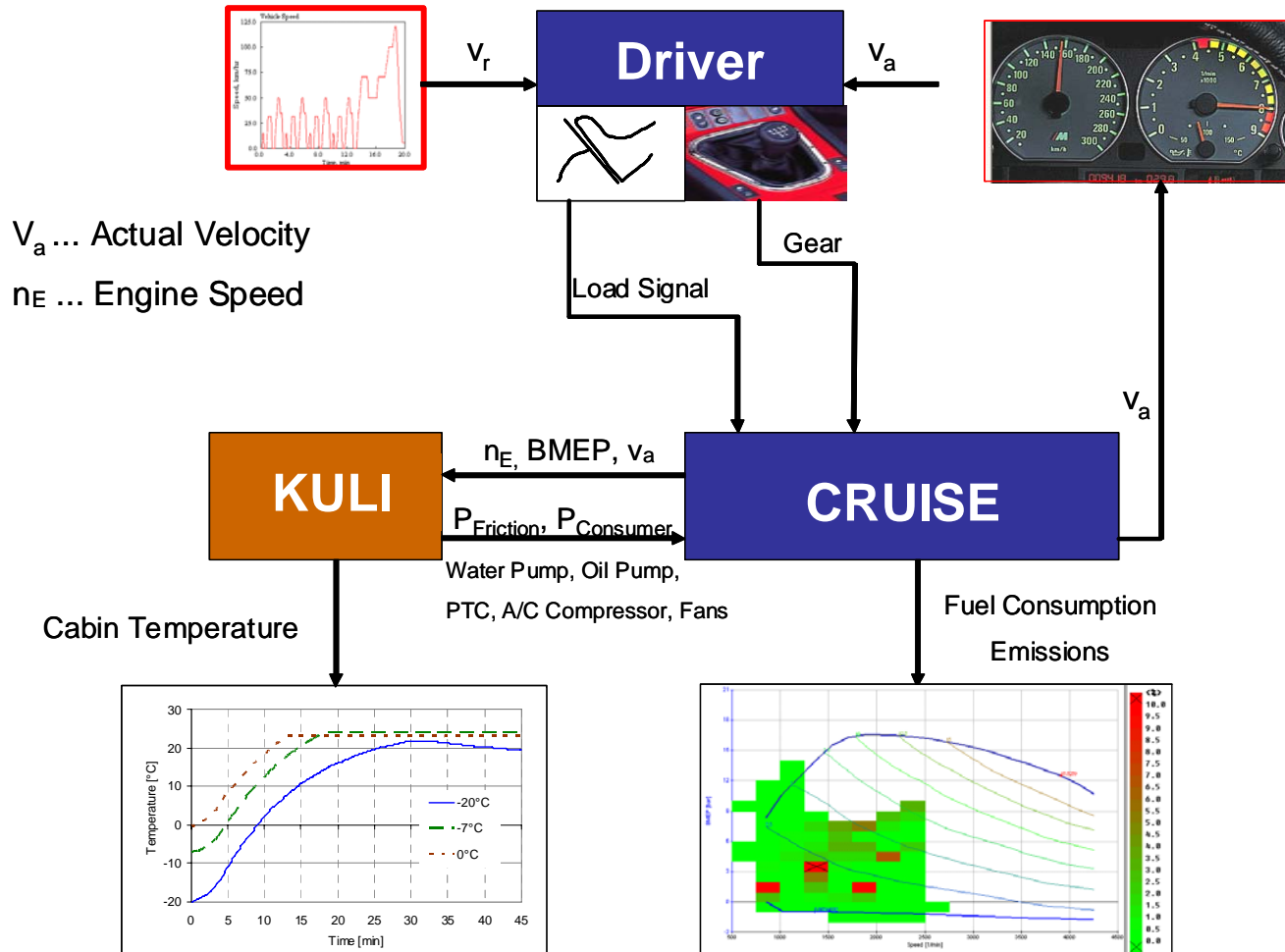


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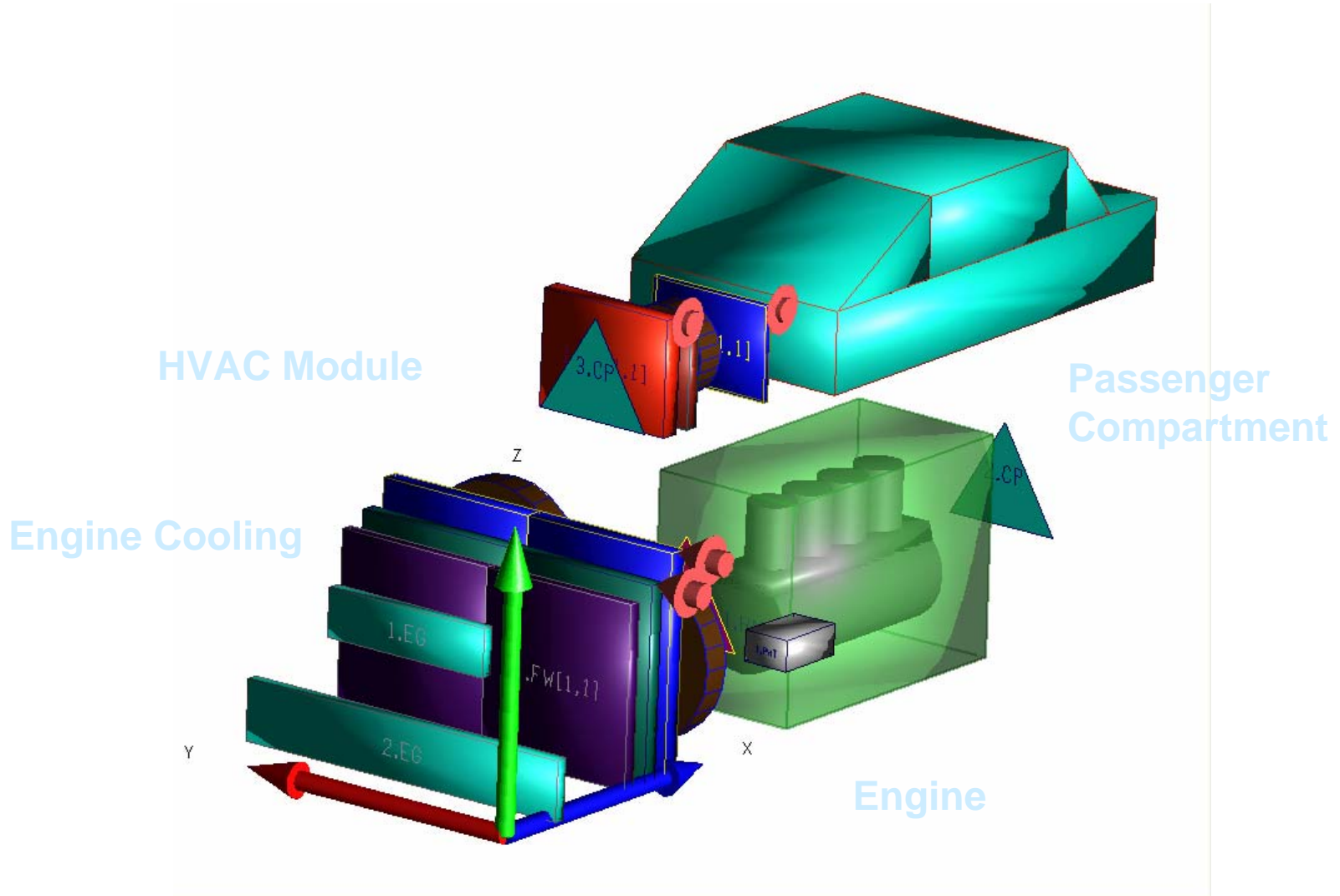
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# Simulation Environment Hybrid Vehicle



# Simulation Model





# Air Conditioning of Hybrid Vehicle

- Start / stop driving conditions
- Electrical driven compressor
- Air conditioning comfort equal or better compared to conventional vehicle
- R744 circuit with cooling and heating mode (heat pump)
- Optimization of fuel consumption for air conditioning

# Vehicle Data

Front wheel driven passenger car

Vehicle mass = 1467 kg

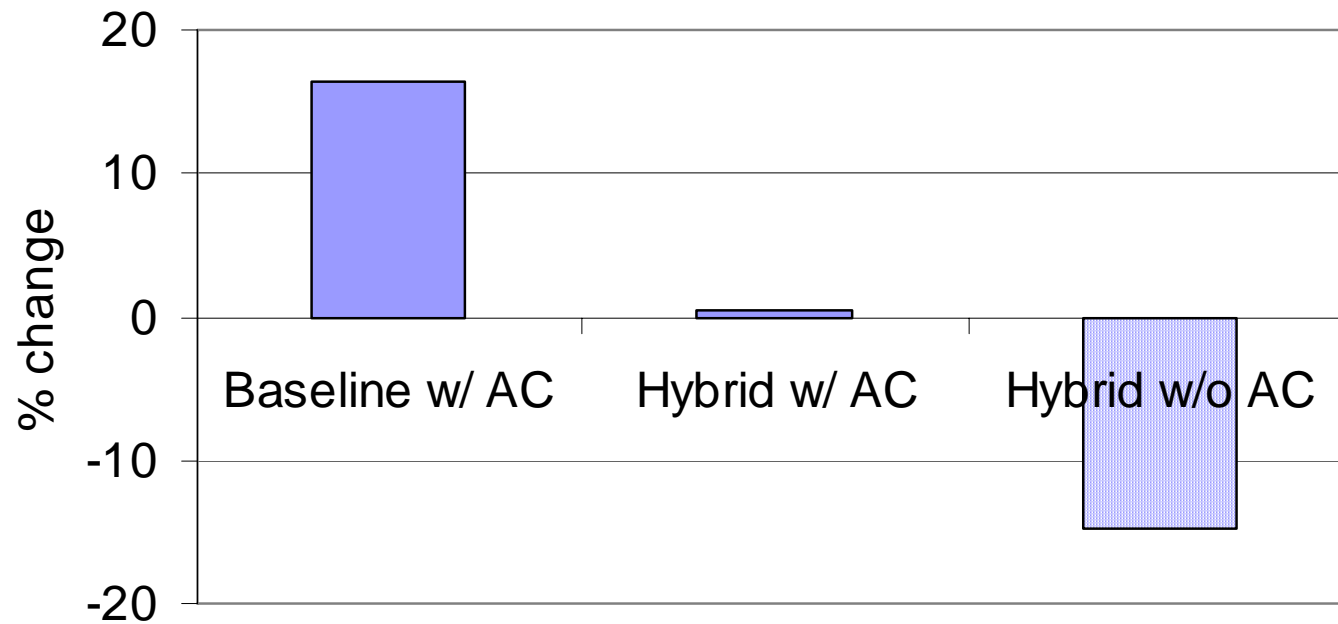
	Conventional	Hybrid
Combustion engine	4 cylinder diesel supercharged	3 cylinder diesel supercharged
Displacement [l]	2	1.2
Power ICE [kW]	80	57
Electric motor [kW]	-	10
Generator [kW]	-	10
Storage capacity [kWh]	-	3.36

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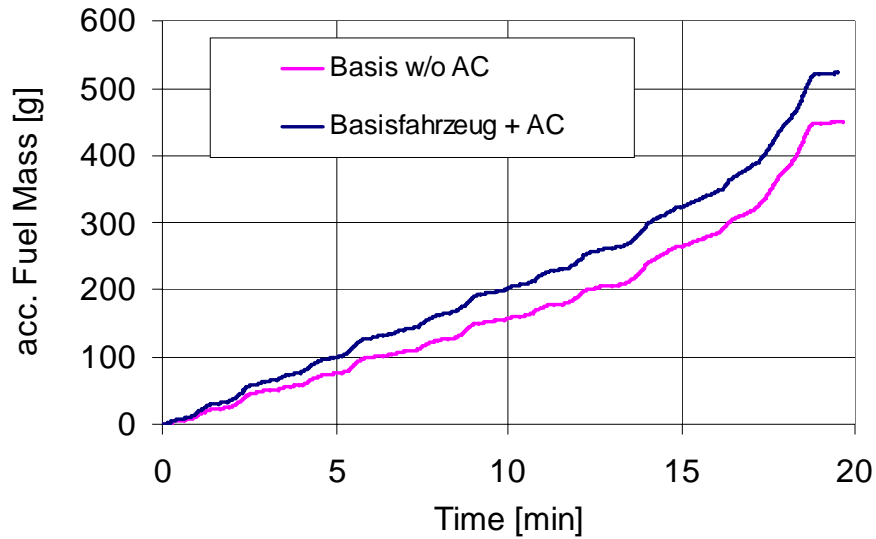
# Fuel Consumption

Fuel Consumption / NEDC (26°C)  
compared to Baseline Vehicle w/o AC

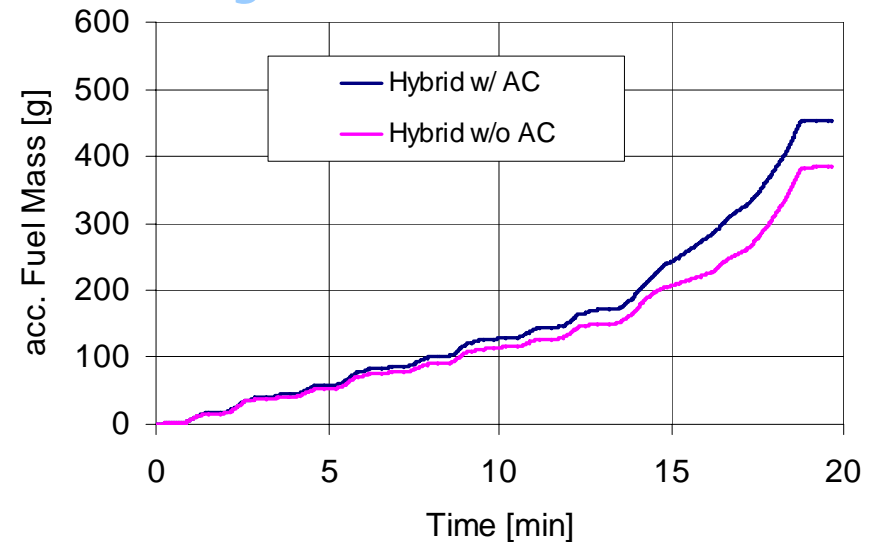


# Accumulated Fuel Consumption NEDC

## ICE Vehicle

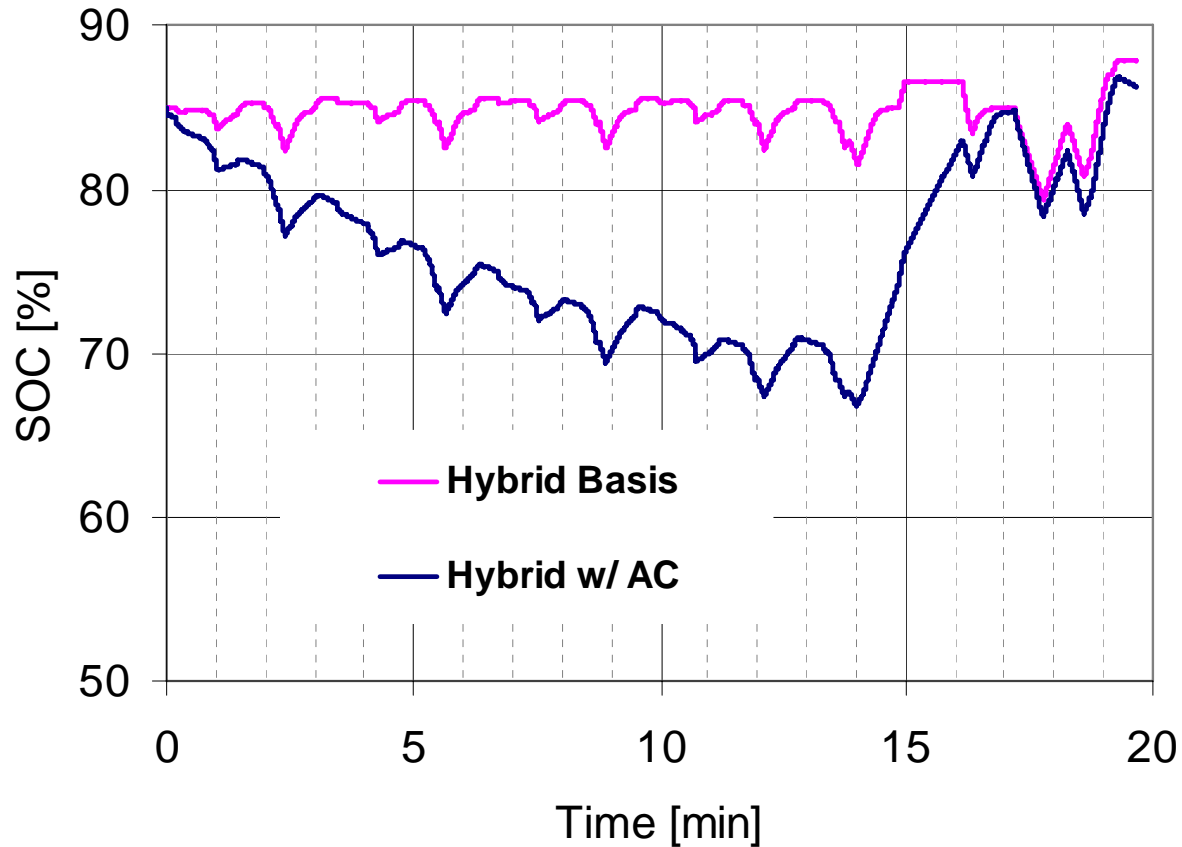


## Hybrid Vehicle





# Hybrid – State of Charge



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# Summary

- Steady state and transient operating conditions were studied on an AC test stand
- Test results were used to verify numerical simulation methods
- Full transient simulation means a high effort for numerical simulation
- For many operating conditions it is sufficient to consider thermal capacities
- A co-simulation method was used to optimize the fuel consumption of the AC of a hybrid vehicle