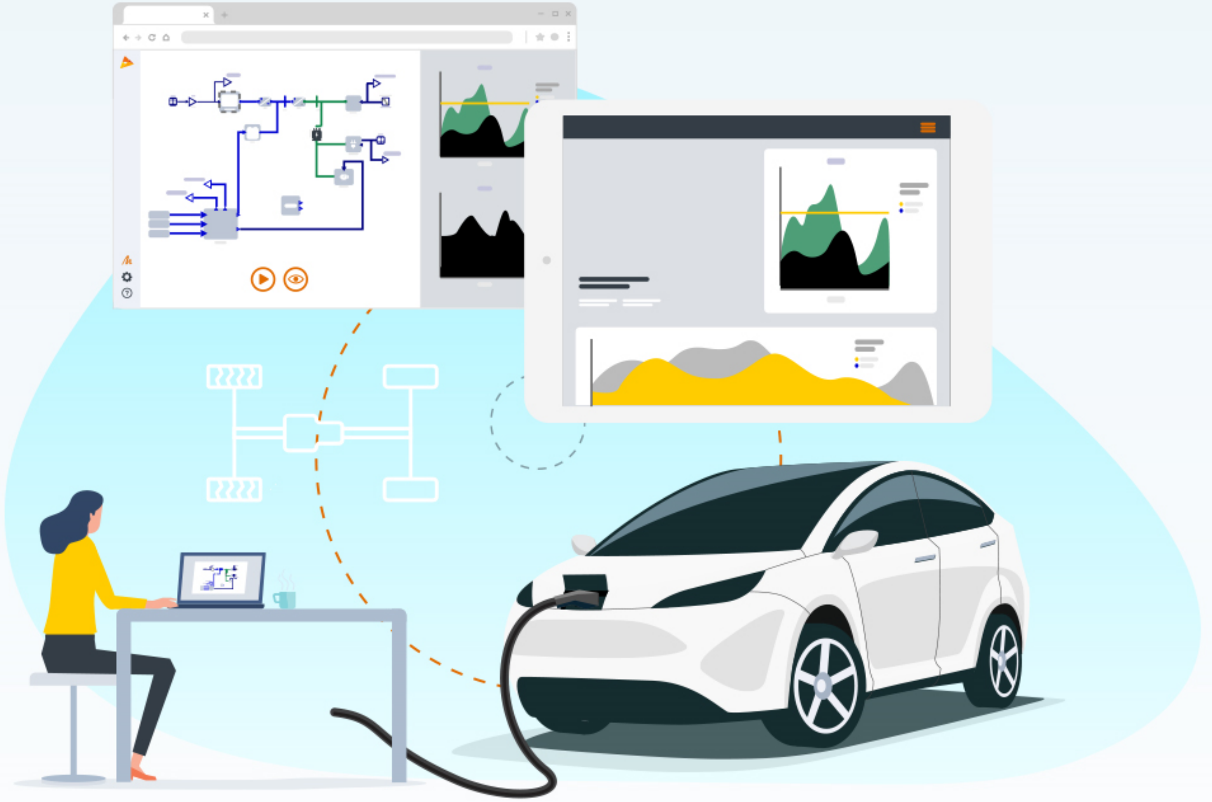
Air Conditioning as a Heat Pump

Matthis Thorade and John Batteh



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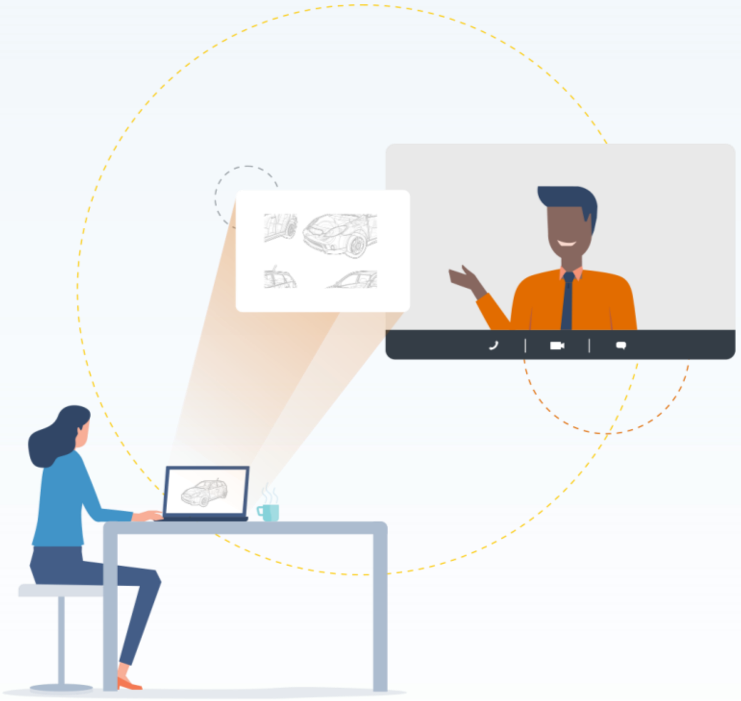
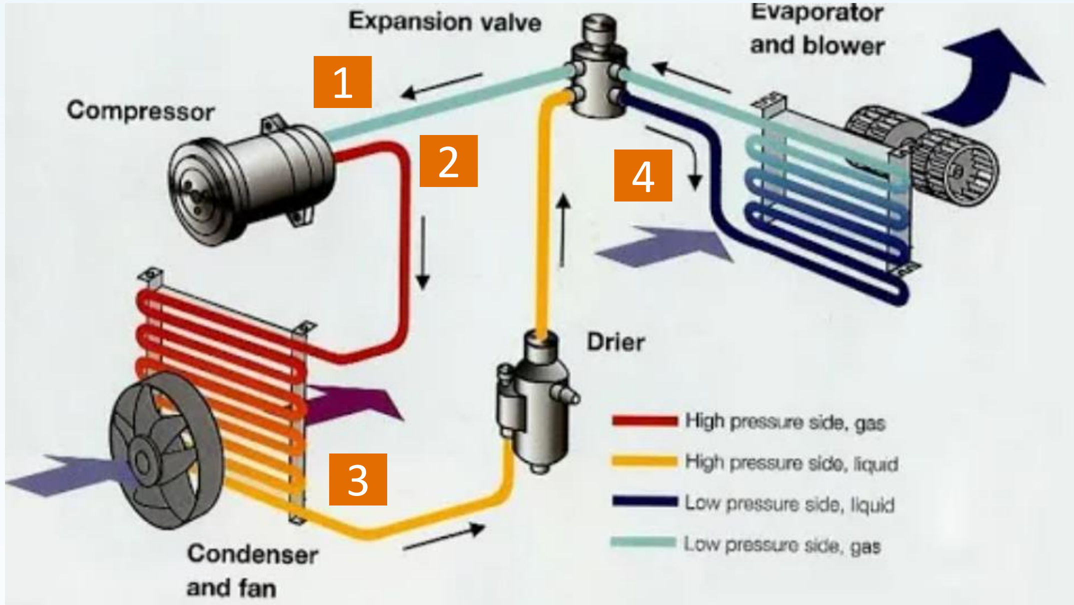
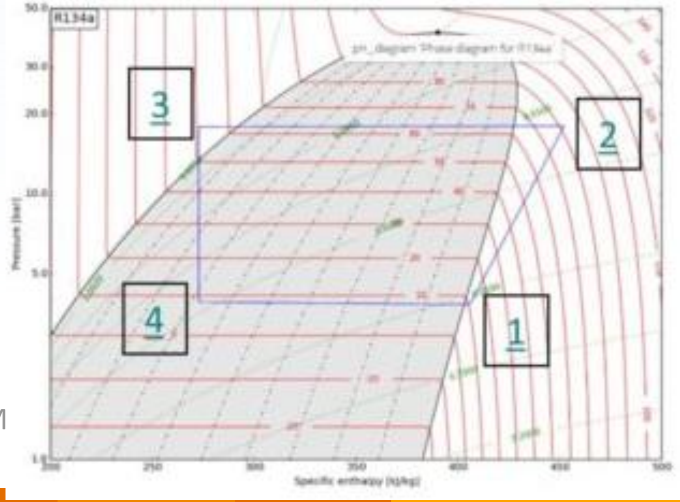
Agenda

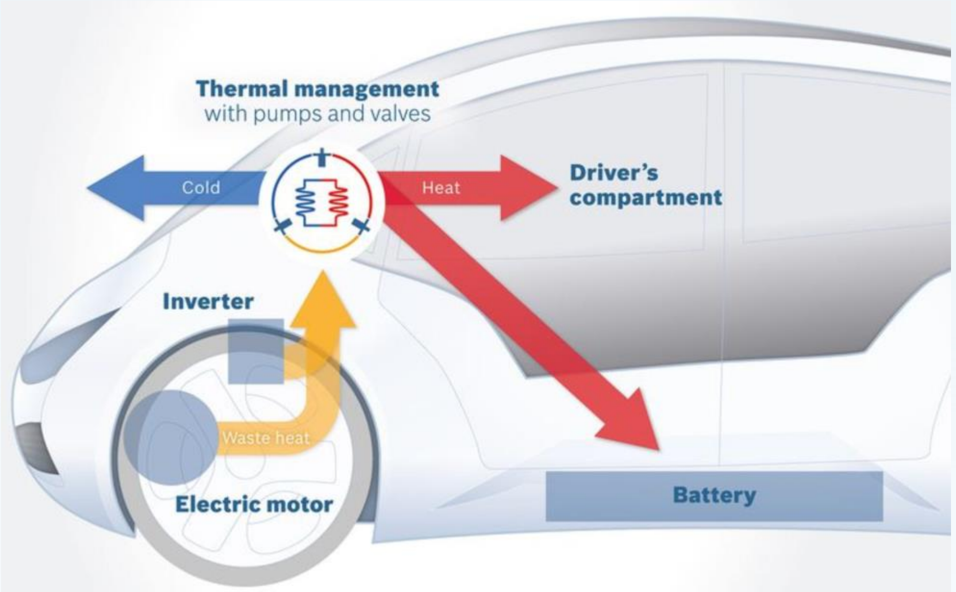
- Trends and challenges
- Library advancements and future development
- Demo applications
- Discussion

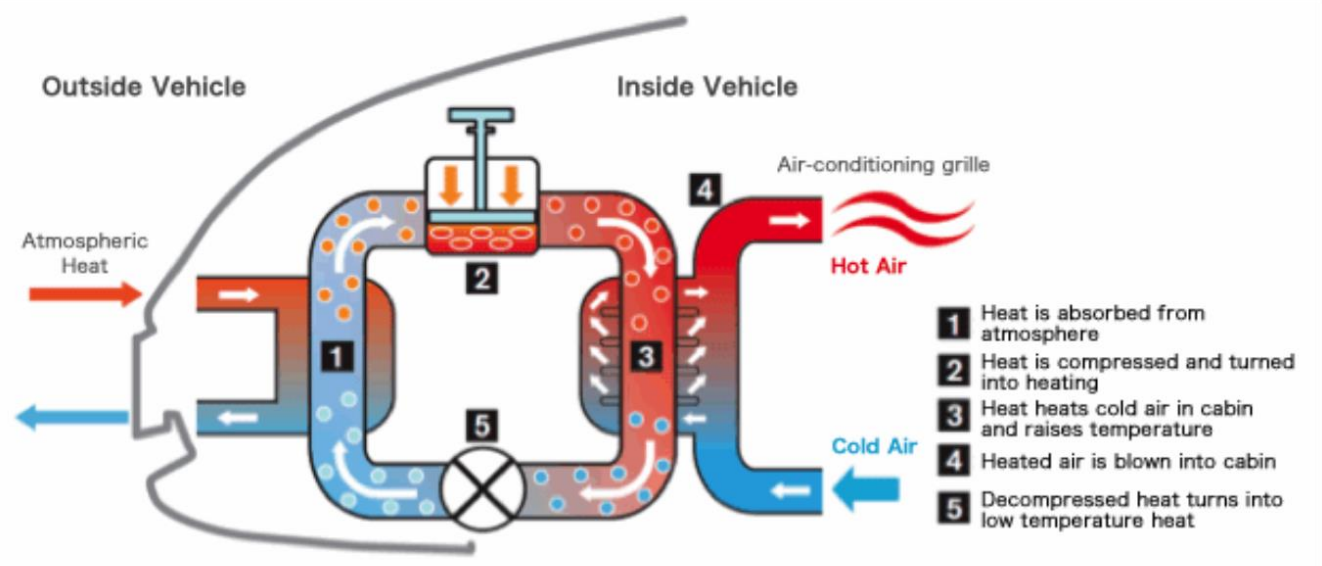


Thermal Management 101



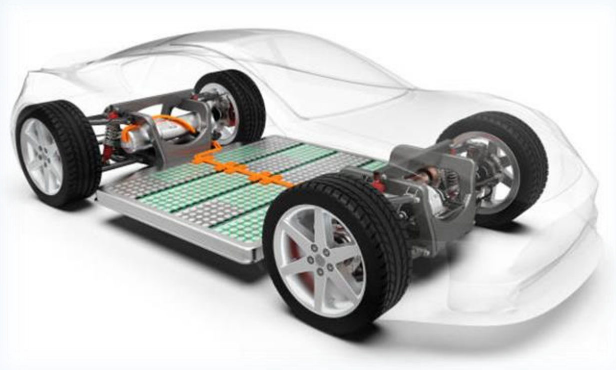






Nissan heat pump cabin heater. (Image courtesy of Nissan.)

Industry Trends



- Battery electric vehicle
  - No waste heat available for heating, use AC as heat pump
  - Thermal management for batteries, motor, inverter

- Increasing complexity and reduced time to market
  - Distribute refrigerant instead of air, use multiple evaporators
  - Distribute coolant and refrigerant, use multiple valves and multiple HXs for different modes of operation
  - Multiple refrigerant loops
  - Investigate new refrigerants

Challenges

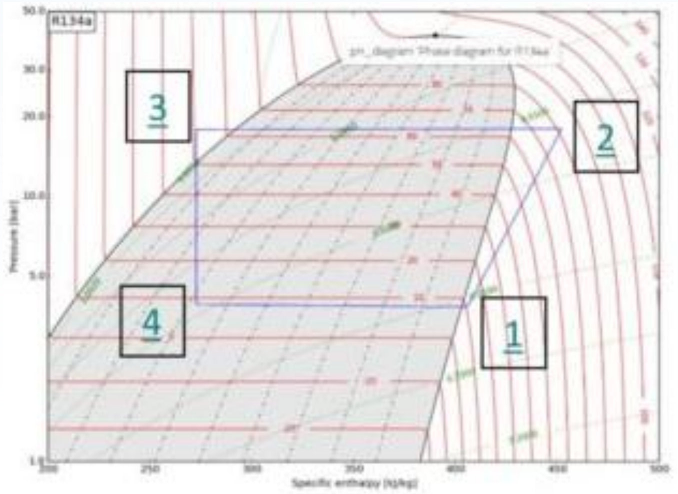
- Ambient operating range
  - Many systems can only operate in a limited range or may require external heating
- System architecture, sizing, and attribute tradeoffs
- Controls challenges
  - Many operating modes
  - Compressor, valve, air flow, secondary fluid flow, secondary fluid routing, external heaters all require coordinated control
  - Electronic expansion valves with advanced operation
- Multiple branches, shutting off branches, zero mass flow
  - Numeric challenges if mass flow is same order of magnitude as numerical noise
  - Possibly large number of structural variants

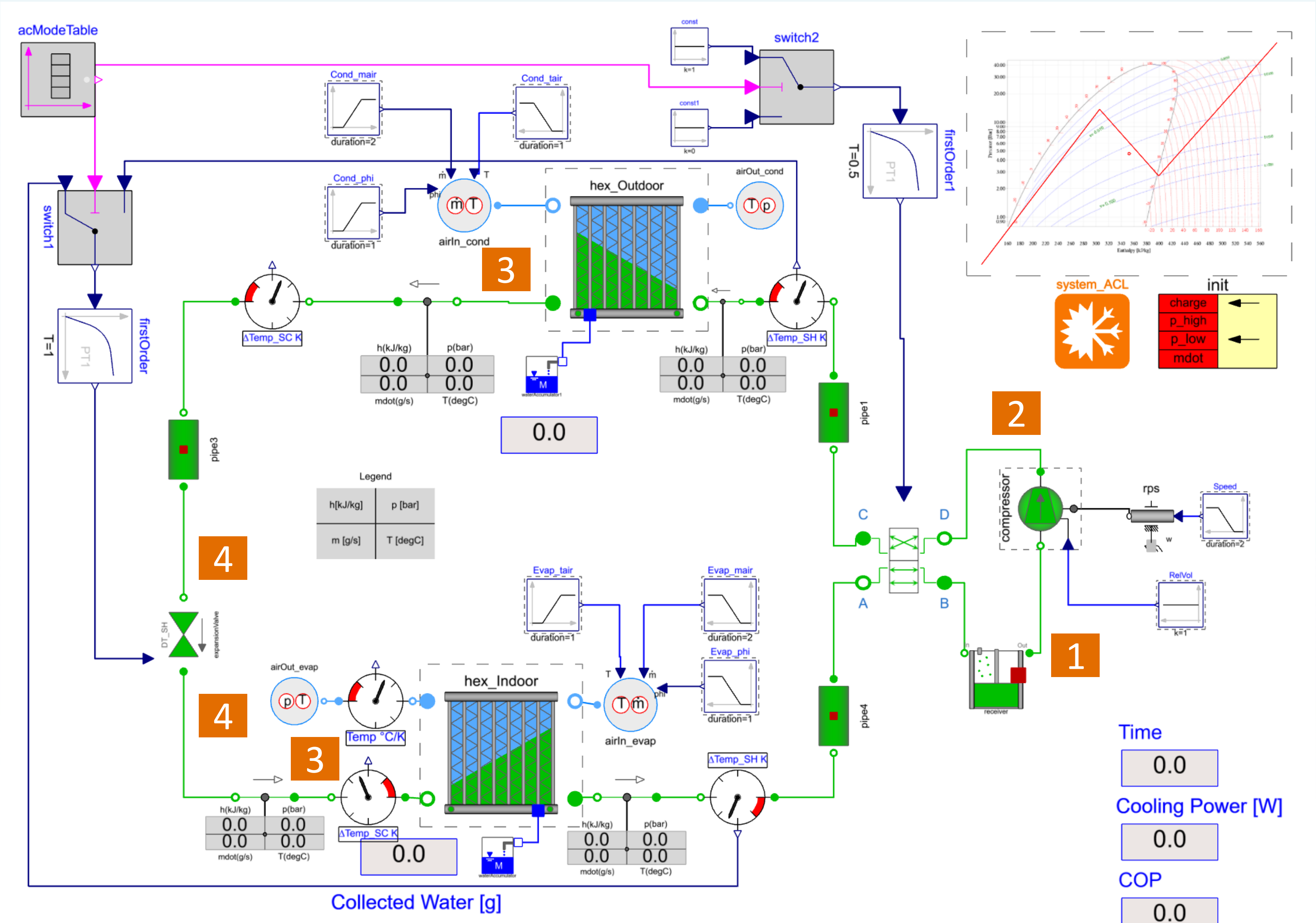
Library Coverage

- Air Conditioning Library (Vapor Cycle Library)
- Heat Exchanger Library
- Liquid Cooling Library
- Electrification Library

Heat Pump Systems: Air

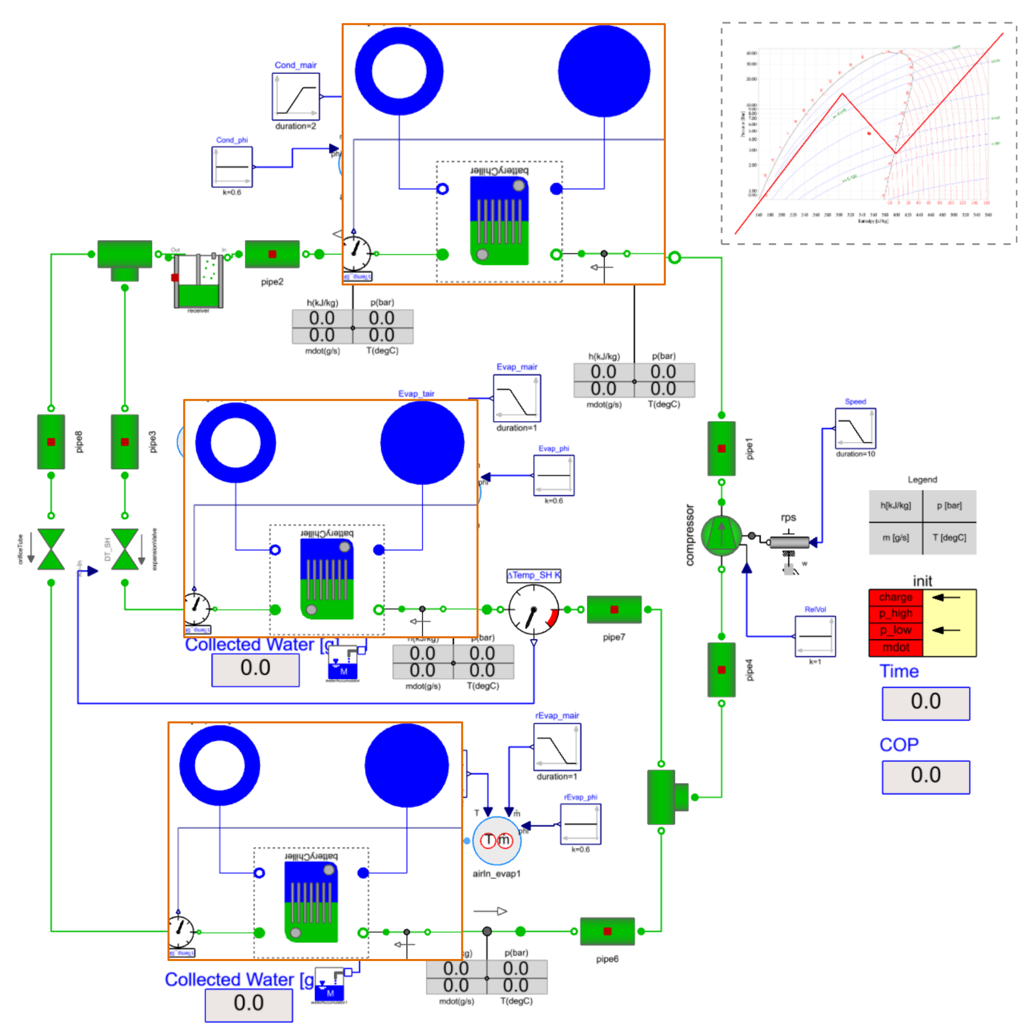
- Air-based system
- Refrigerant flow reverses





Heat Pump Systems: Secondary Loop

- Secondary loop system(s)
- Refrigerant flow does not reverse
- Air-based HXs replaced by refrigerant-secondary HXs
- Coolant flow routed appropriately in different modes to heaters, coolers, battery, motor/inverter, outside HX, etc.



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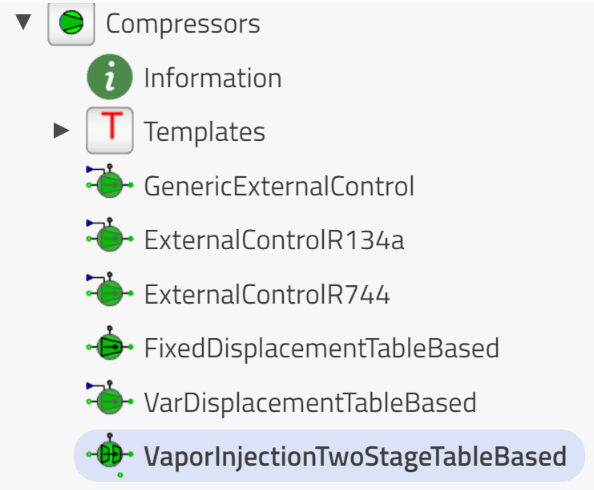
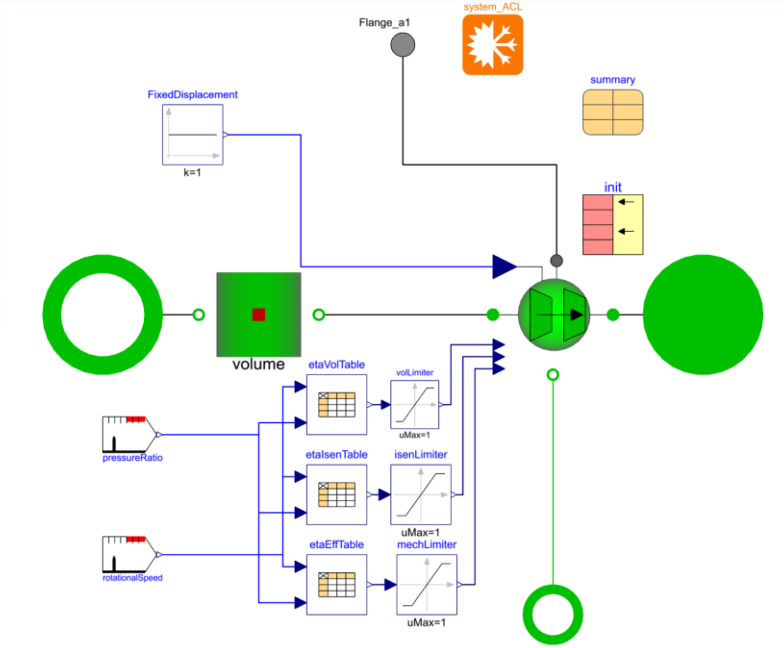
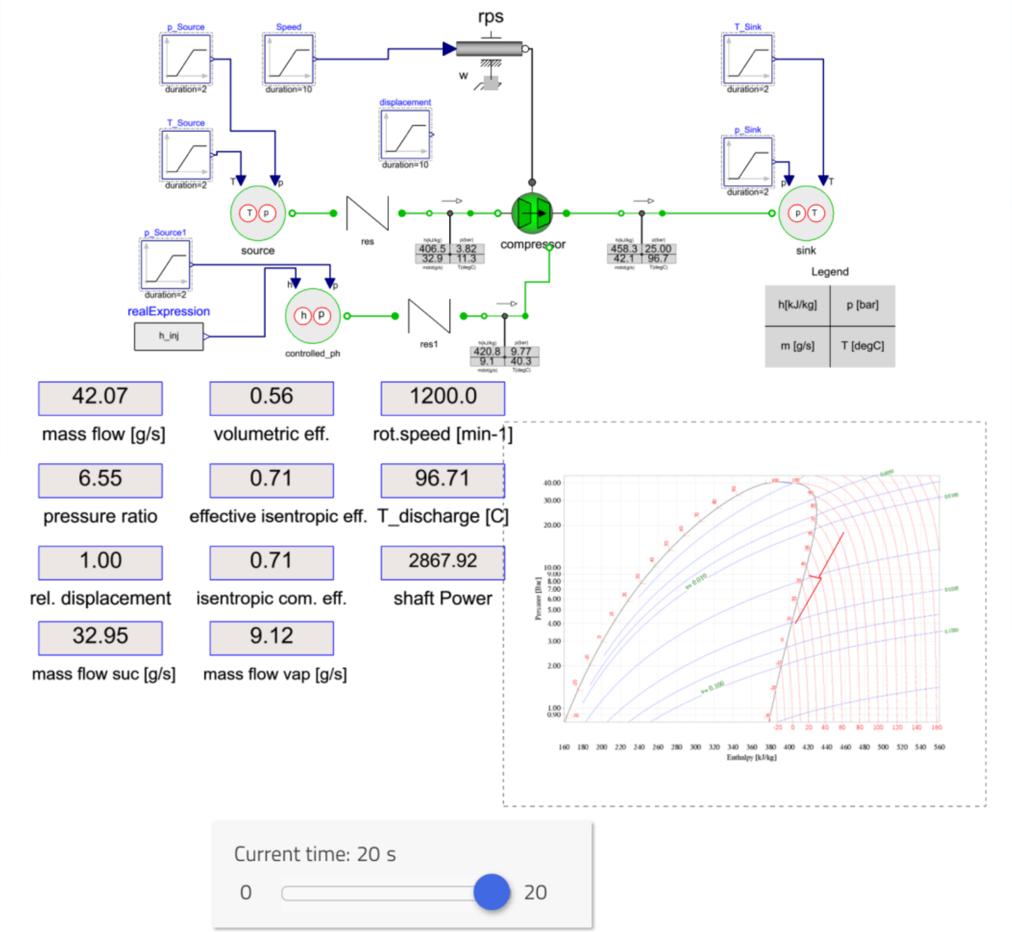
Vapor Injection

- Table-based compressor with VI port
- Intermediate pressure via table
- Starting point for custom models

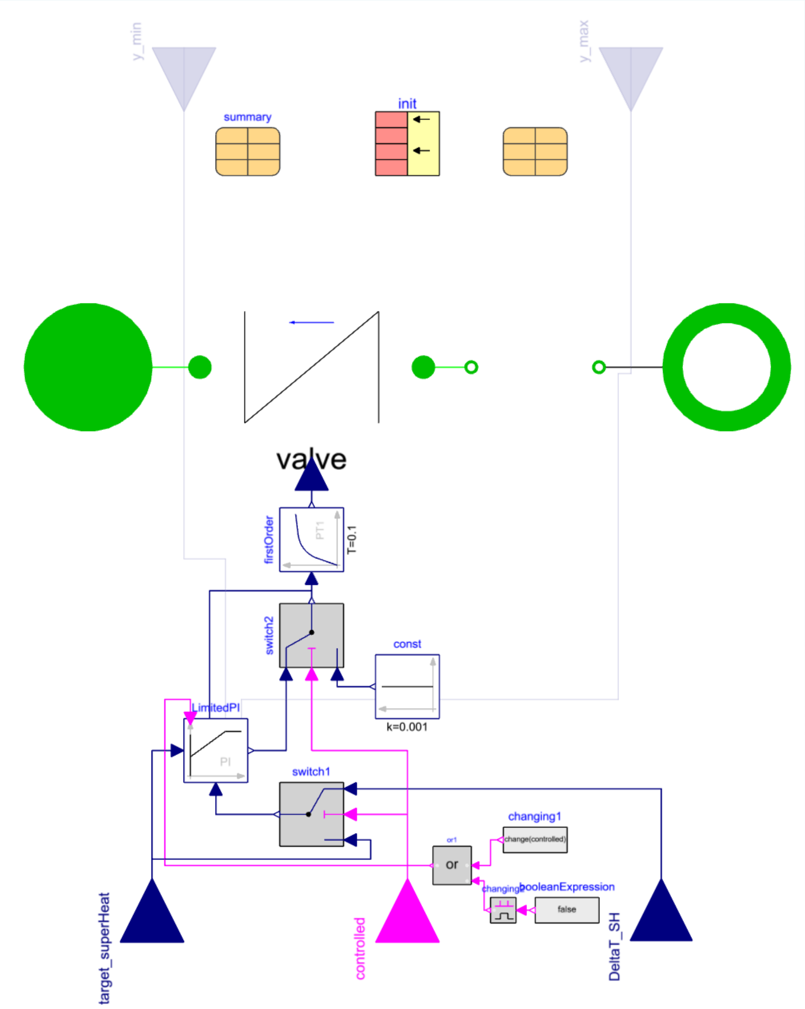




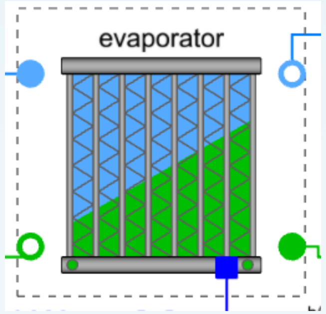


Control Valves

- Advanced control valves to mimic behavior of electronic expansion valves and control strategy
  - "Normal" controlled operation (PID)
  - Variable max and min settings
  - Reset capability
  - Valve off response
  - Transient dynamics



Reduced-Order Heat Exchanger



- Discretized, finite volume heat exchangers are most complex component in the system, slowing down simulation (~50-70% of CPU time)
- Control design does not need full predictive capability, instead needs fast and robust models that represent dynamics correctly
- Approaches to simplify :
  - Remove discretization for pressure, use lumped pressure or pressure profile
  - Simplified closure relations (DP, HT)
  - Workflow to calibrate reduced-order model to high-accuracy model

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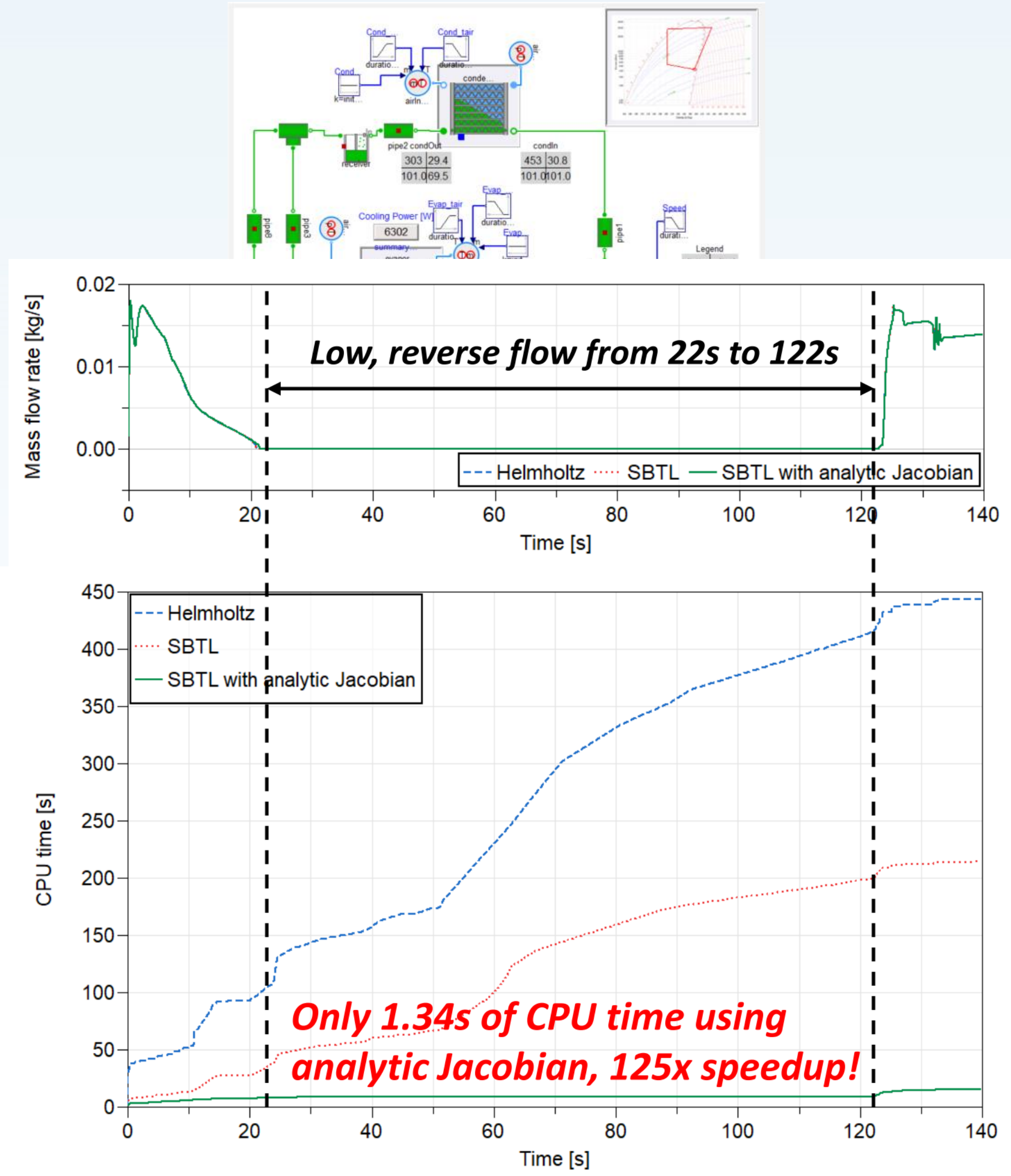
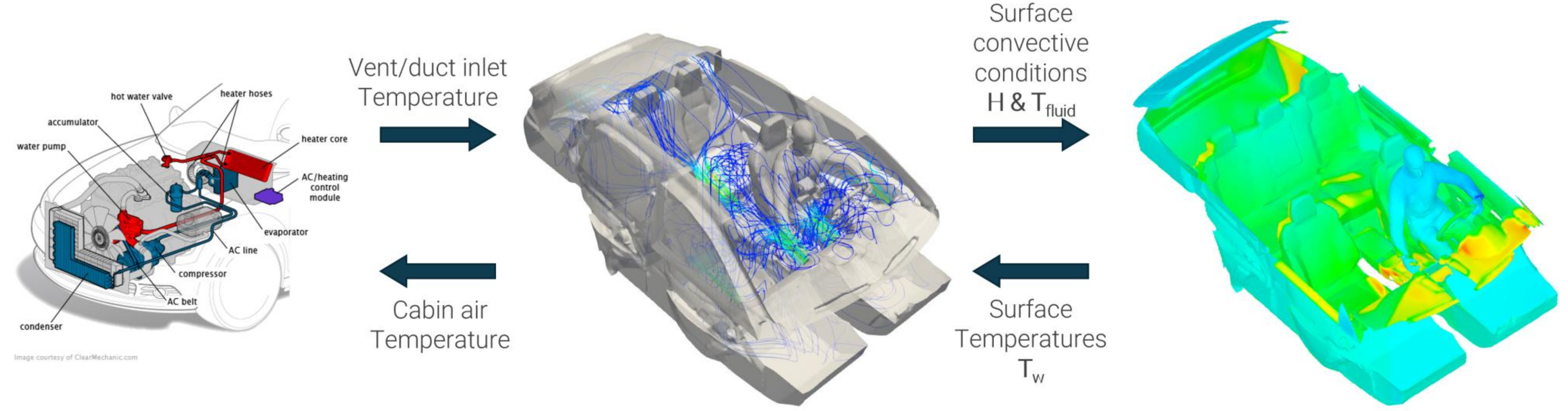
SBTL Mixtures

- SBTL refrigerant properties for pseudo pure refrigerants enable significant computational efficiency improvements, especially when coupled with analytic Jacobians
- Optimized refrigerant mixtures (temperature glide) for heat pumps currently being considered
- Modelon is working to expand SBTL capability to refrigerant mixtures



https://2020.american.conference.modelica.org/proceedings/papers/Modelica2020US_presentation_18.pdf

1D-3D Coupling

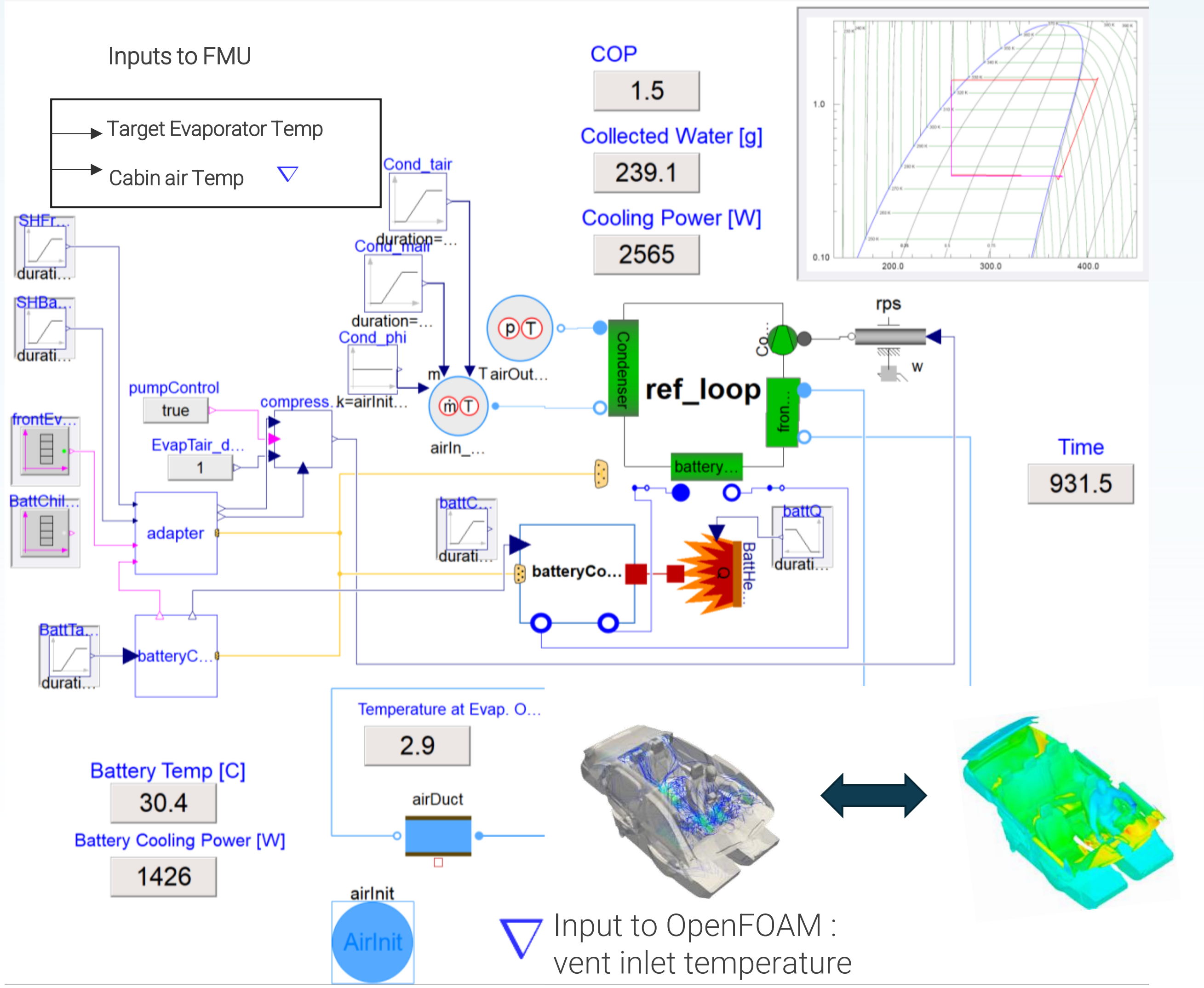


1D HVAC model (FMU)
- Heating/AC component modeling
- Heating/cooling output & power consumption
- Fresh air / recirculation mix

CFD (OpenFOAM)
- Cabin interior flow/temperature
- Convection to internal surfaces

TAITherm
- Heat transfer to/from/within cabin
- Human physiology & comfort
- Environment/solar load

TAITherm Integration



- Detailed CFD provides higher resolution insights into cabin flow and occupant comfort
- Detailed, geometric model for solar influx and influence of materials
- Human comfort model allows assessment of overall comfort based on geometric details (breath temperature, skin temperatures, etc.)

THERMO ANALYTICS

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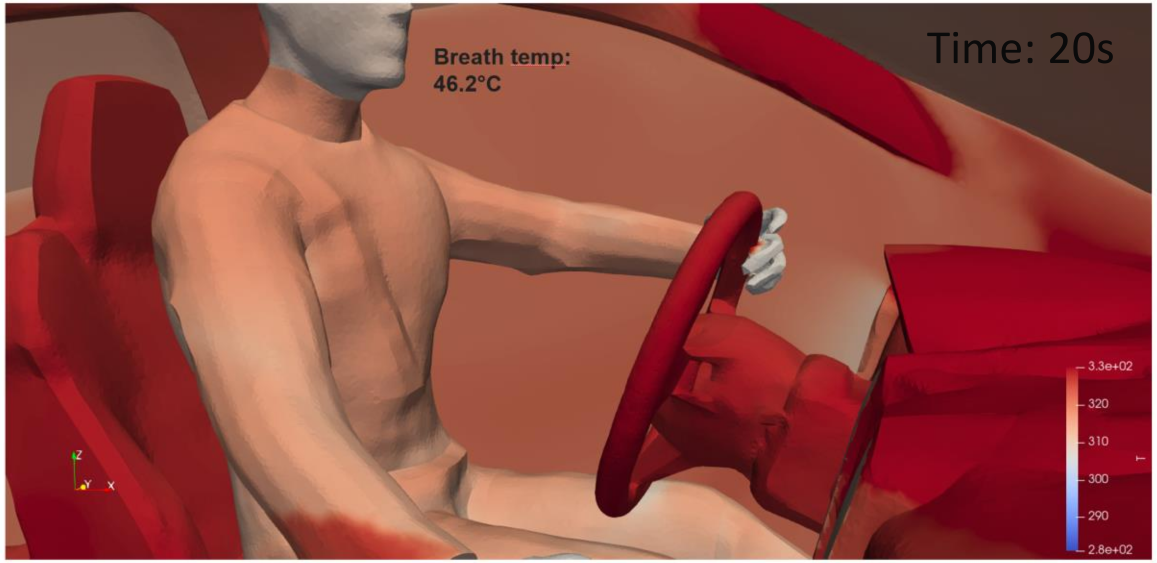
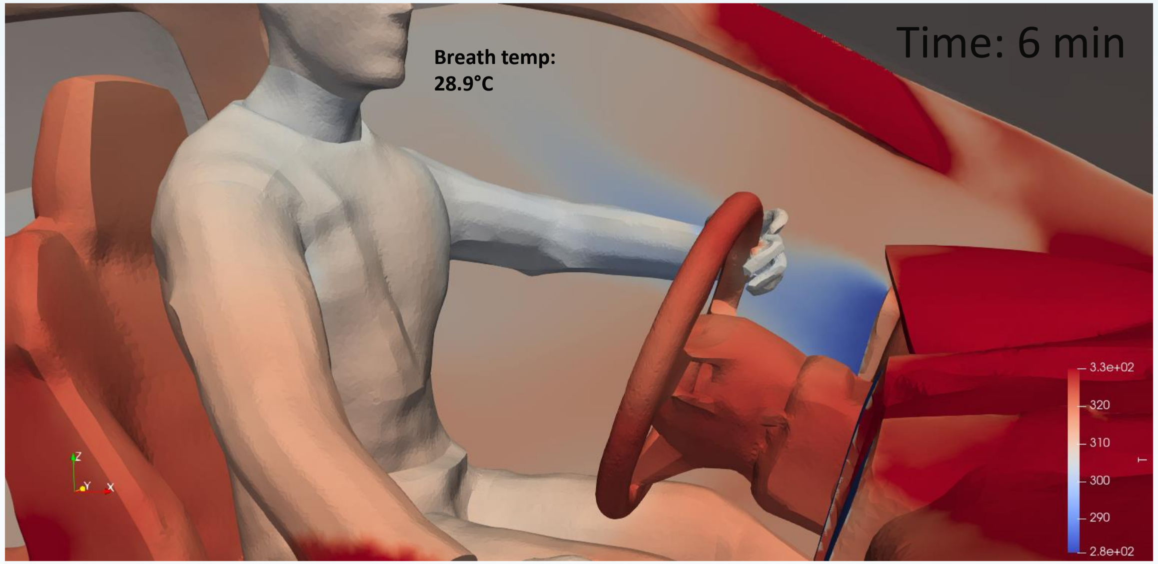
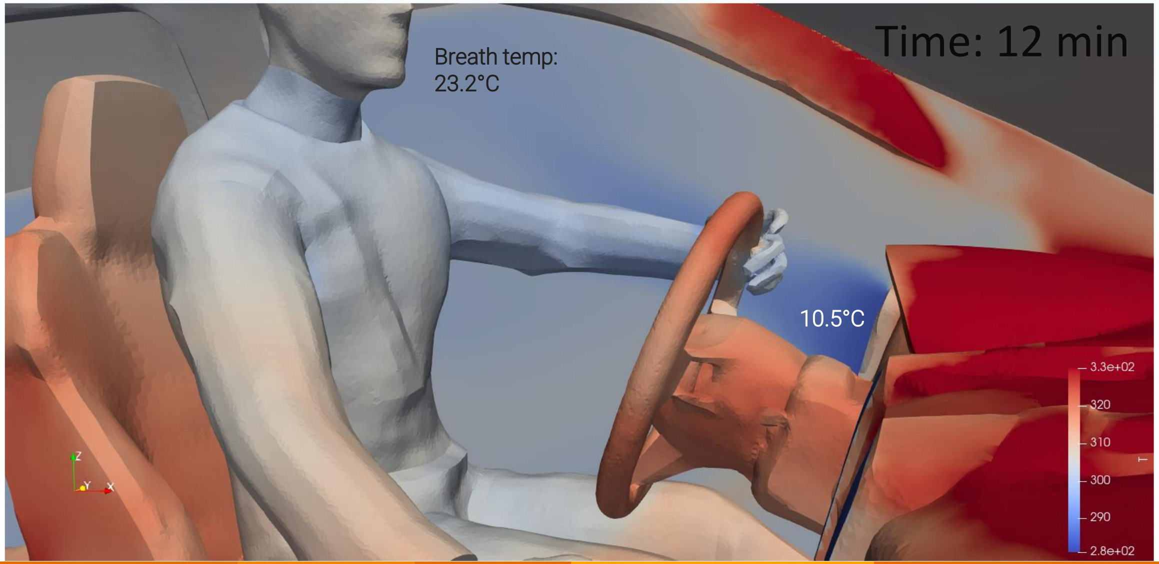
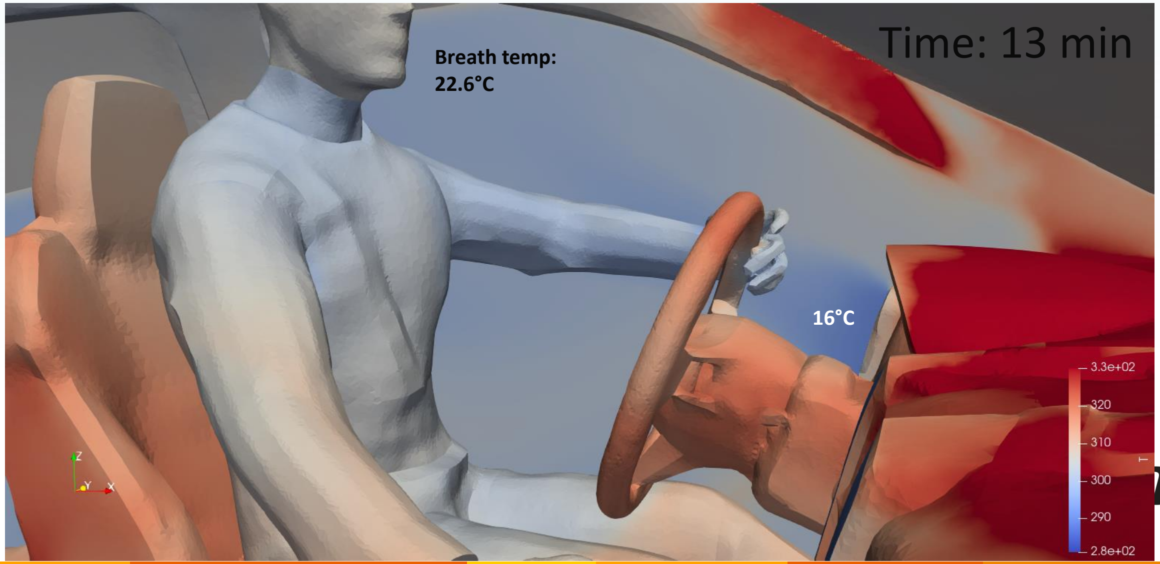
Max AC Pulldown



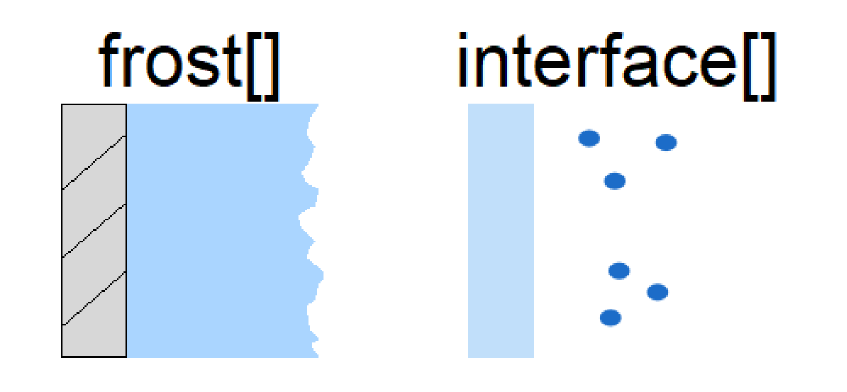


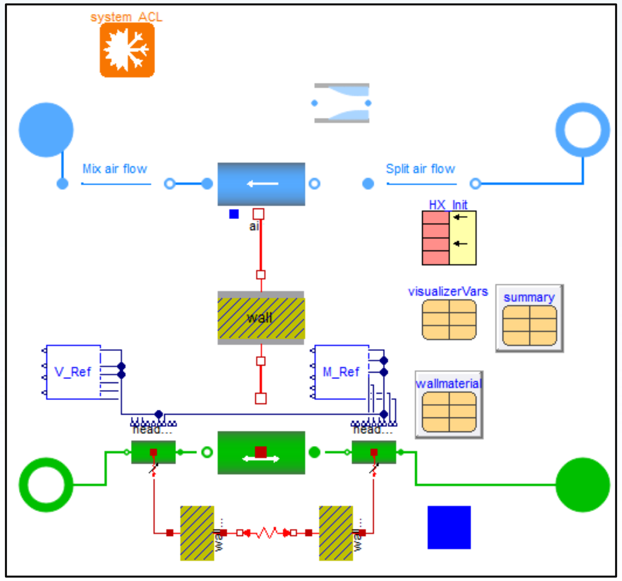




Heat Exchanger Frost

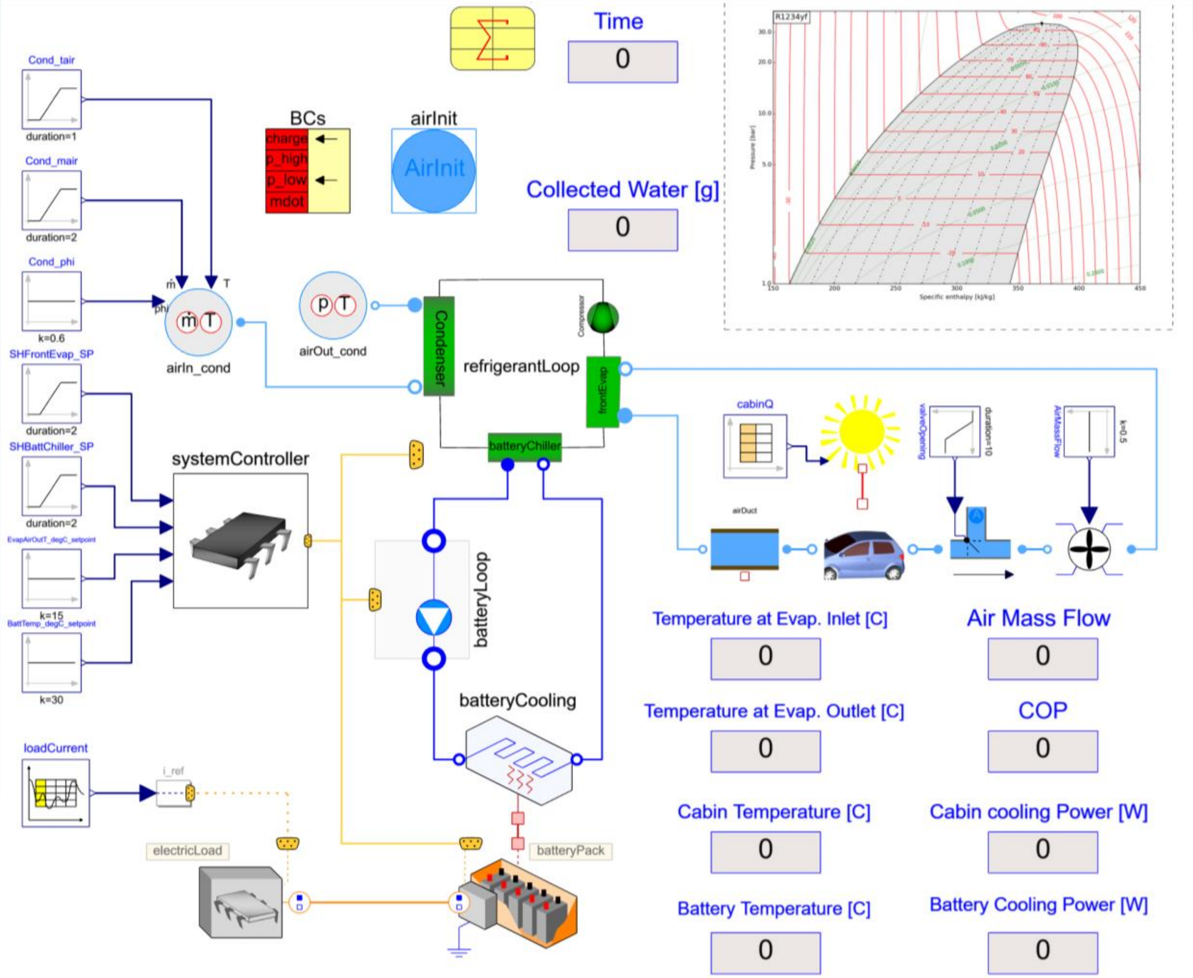
- During heat pump operations, air moisture may condense and freeze
- Frost layer
  - Growth and shrinkage of the frost, density/densification of frost
- Interface
  - Mass and heat transfer between frost and moist air
- Flow distribution
  - Clogging of channel

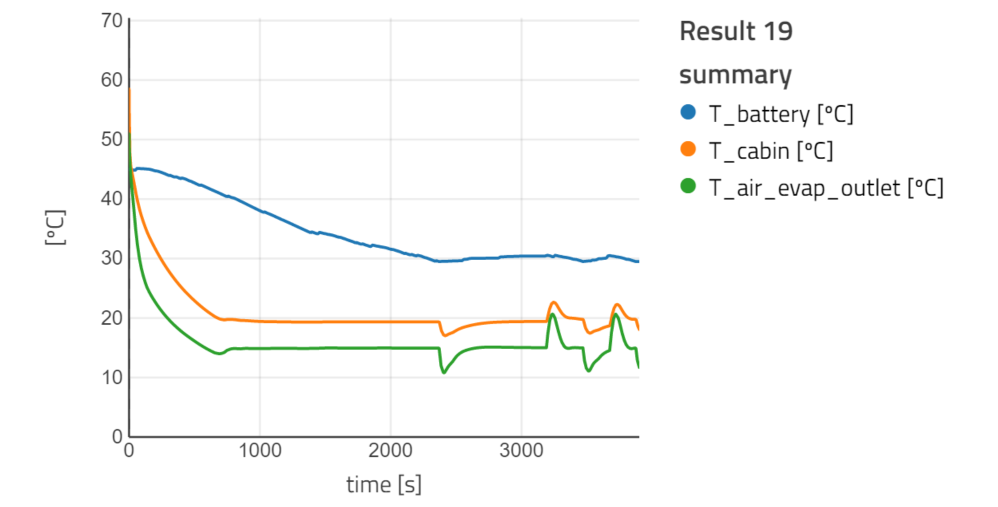


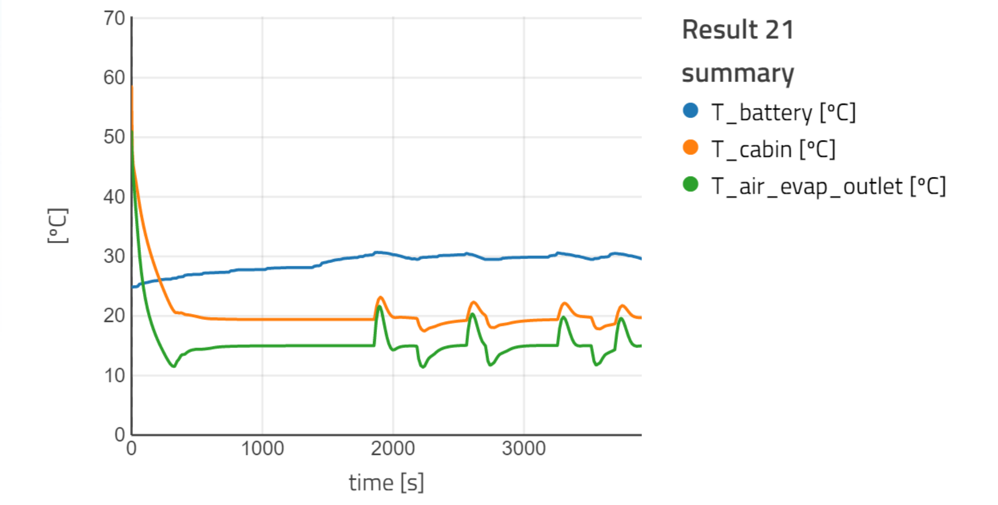


Demo Applications

Demo Application: Attribute Tradeoffs







Best Practice Demo

- Duplicate AirConditioning.Examples.TwinEvaporatorCycleDistributingValve
- Initial value propagation
- Switch to SBTL R134a extended range
- Add SystemACL, switch to pdh states, loosen tolerance x10
- Distributing valve sine signal: offset=0.5, amplitude=0.48, f=1/180
- AJ: generate_ode_jacobian, generate_block_jacobian

Modelon Impact

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