HERRICK CONFERENCES

JULY 11 - 14 2022

COMPRESSOR ENGINEERING
REFRIGERATION & AIR CONDITIONING
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Application of Feedforward Neural Networks to Simulate Battery Electric Vehicle Air Conditioning Systems

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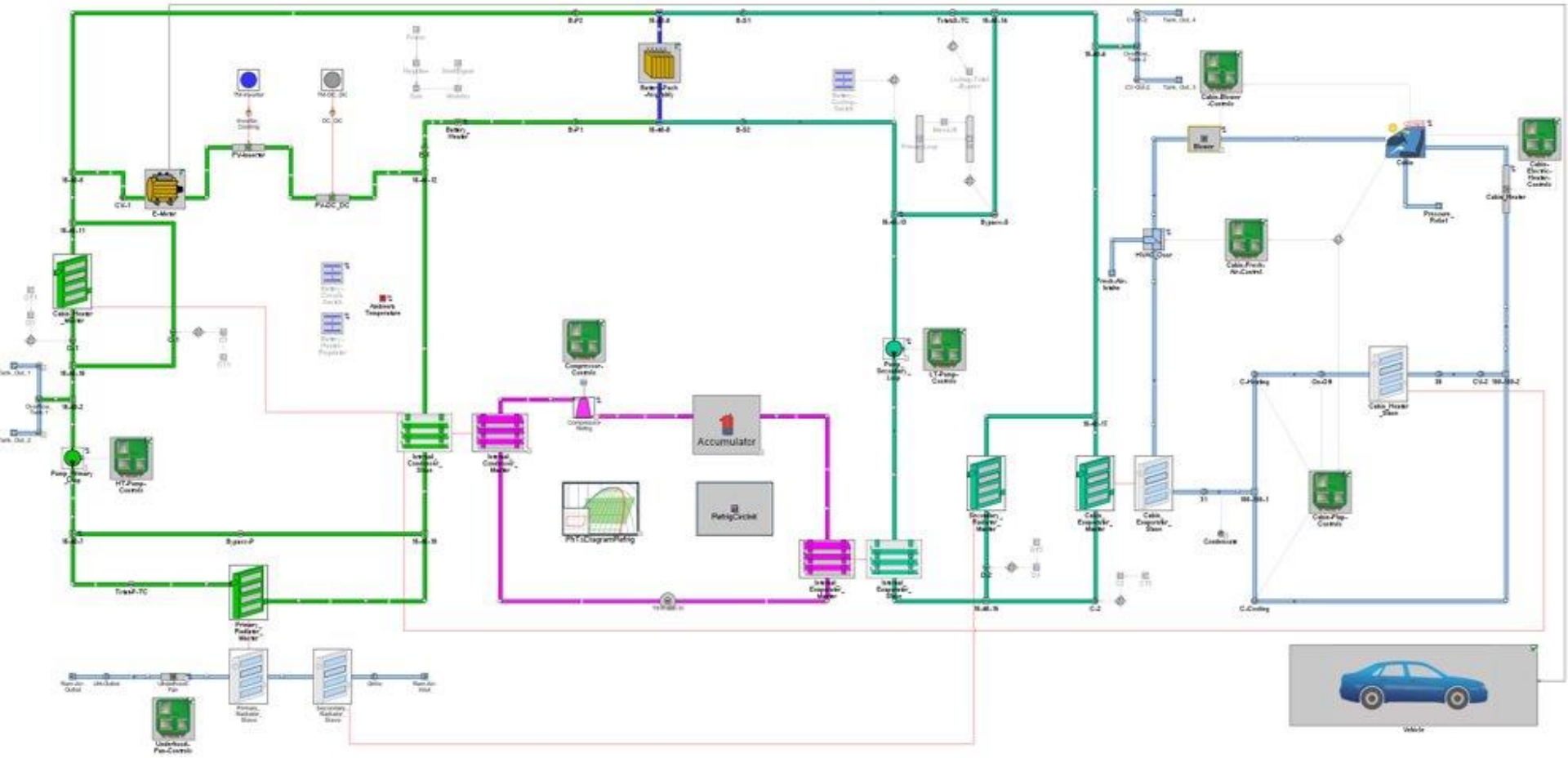
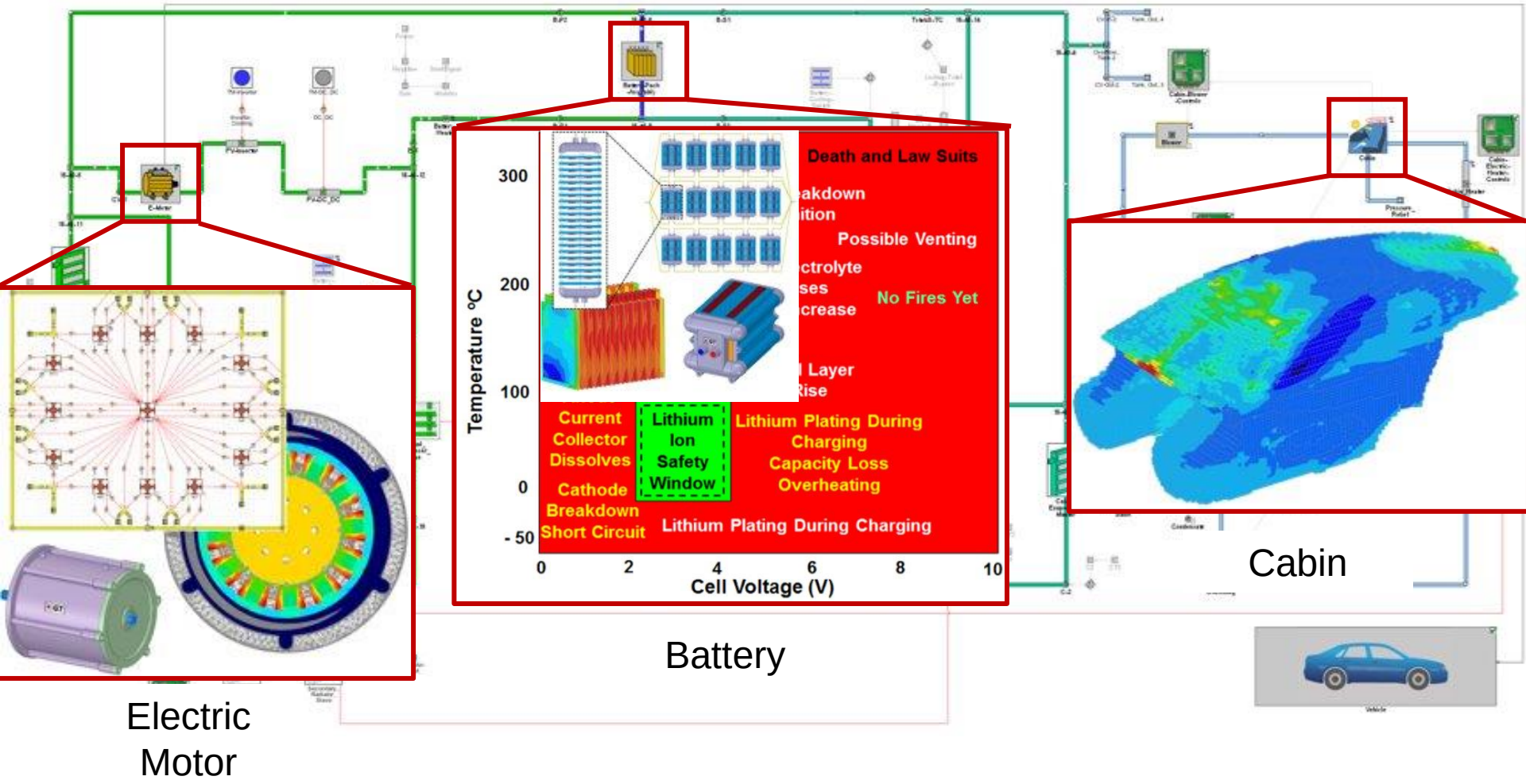
PURDUE UNIVERSITY | Ray W. Herrick Laboratories

Motivation: EV Thermal Management

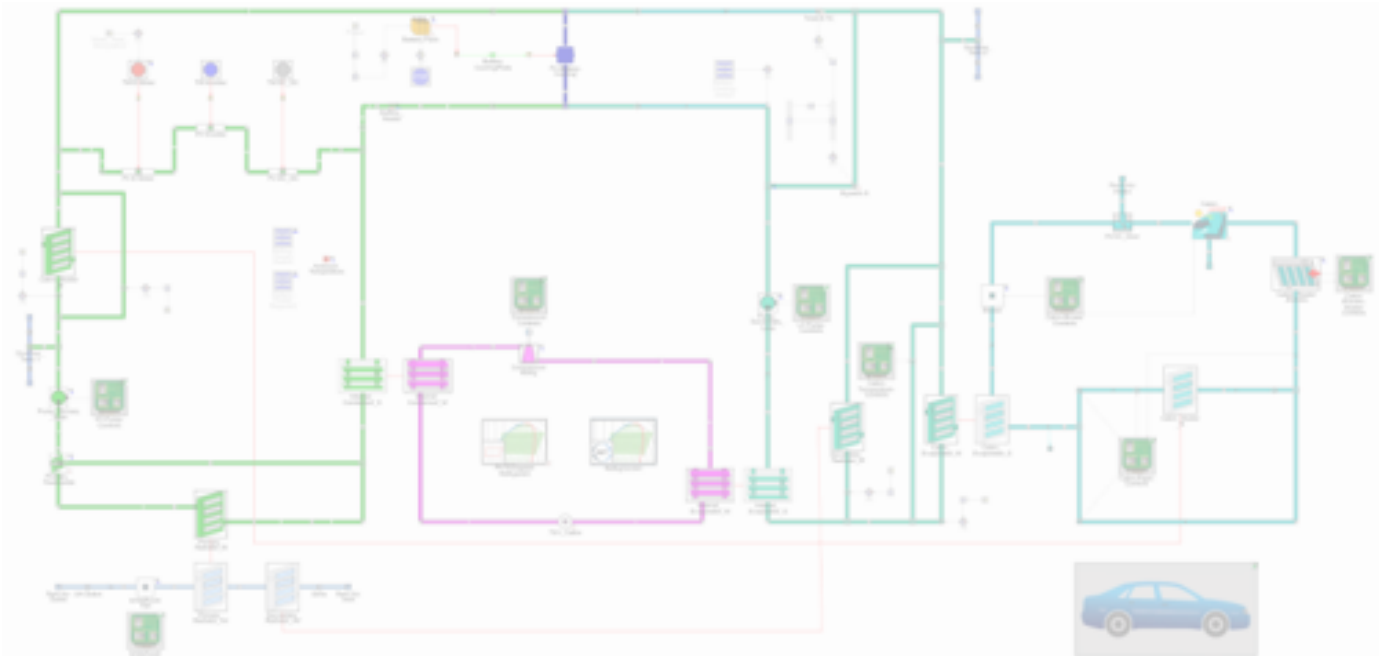


Motivation: EV Thermal Management



Motivation: Make simulations faster

Detailed Model (high # flow volumes)



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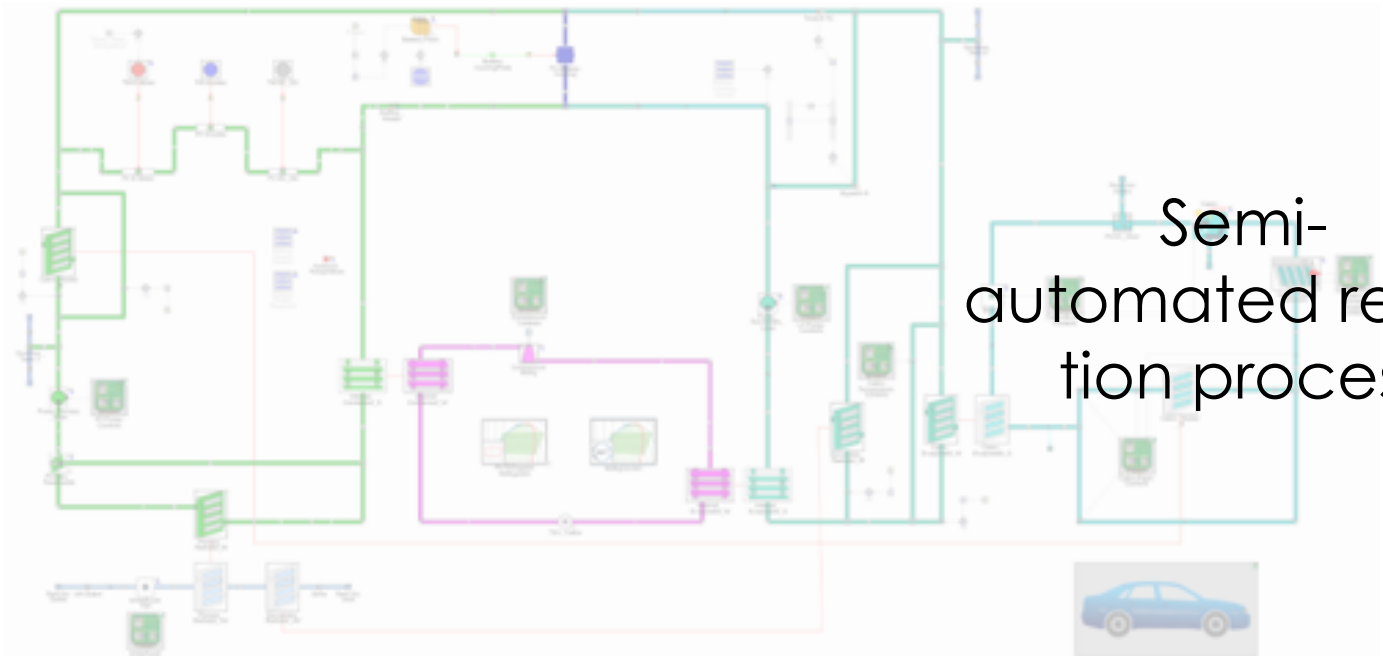
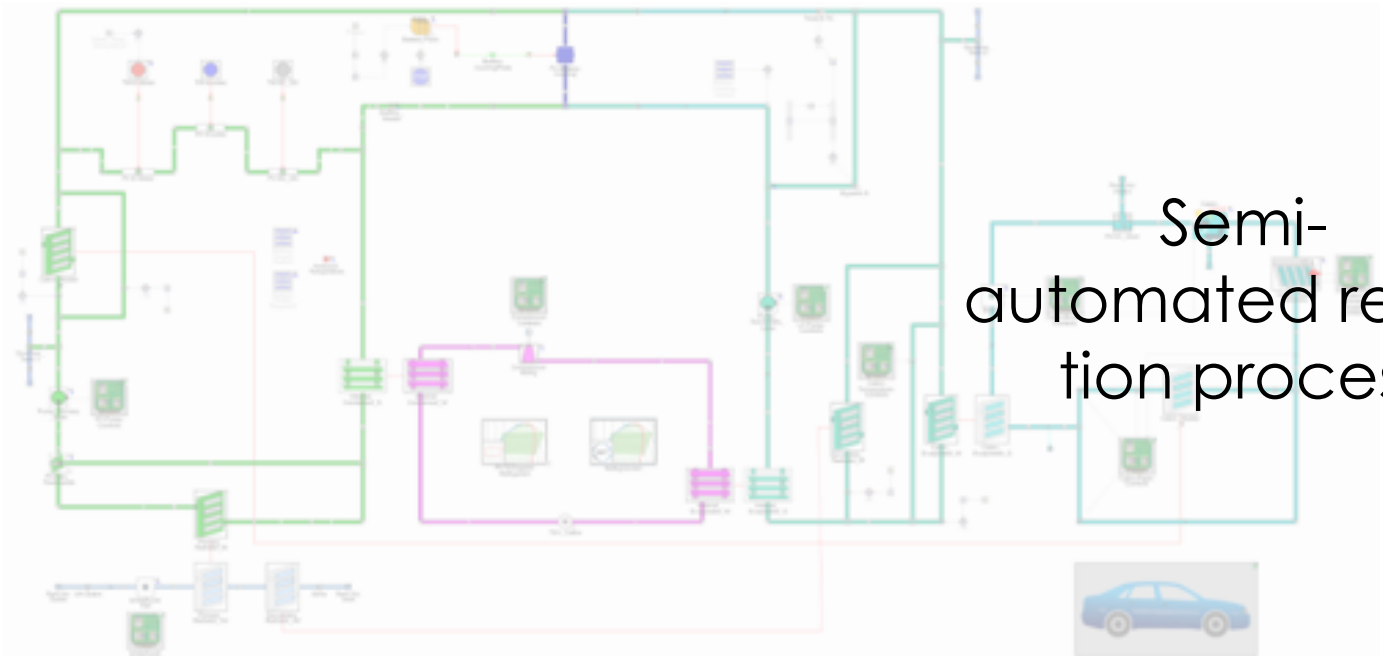
Detailed Model (high # flow volumes)



Semi-automated reduction process

Motivation: Make simulations faster

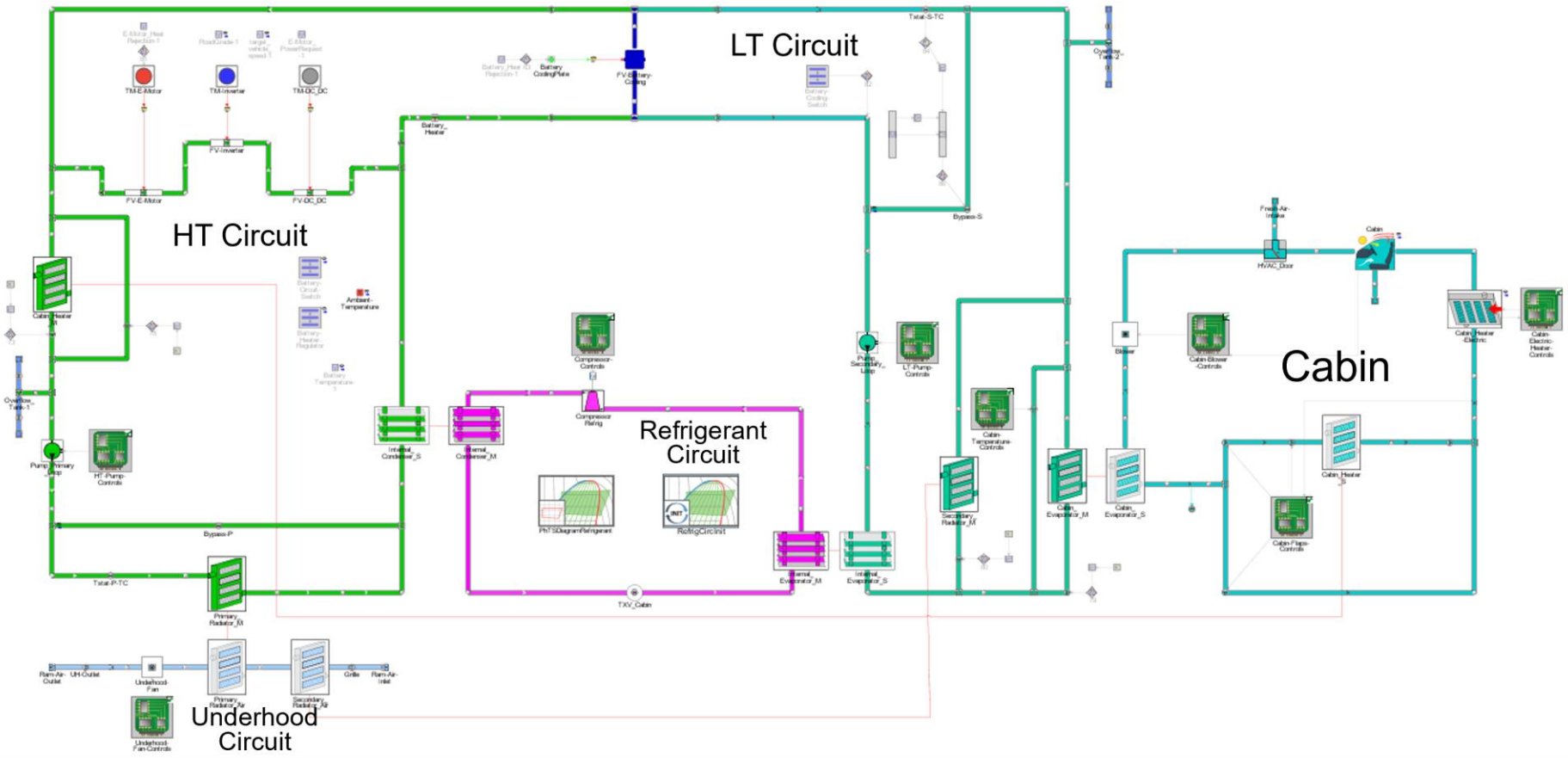
Detailed Model (high # flow volumes)



Semi-automated reduction process

Reduced # Volumes (Faster but similar results)

Motivation: Make simulations faster



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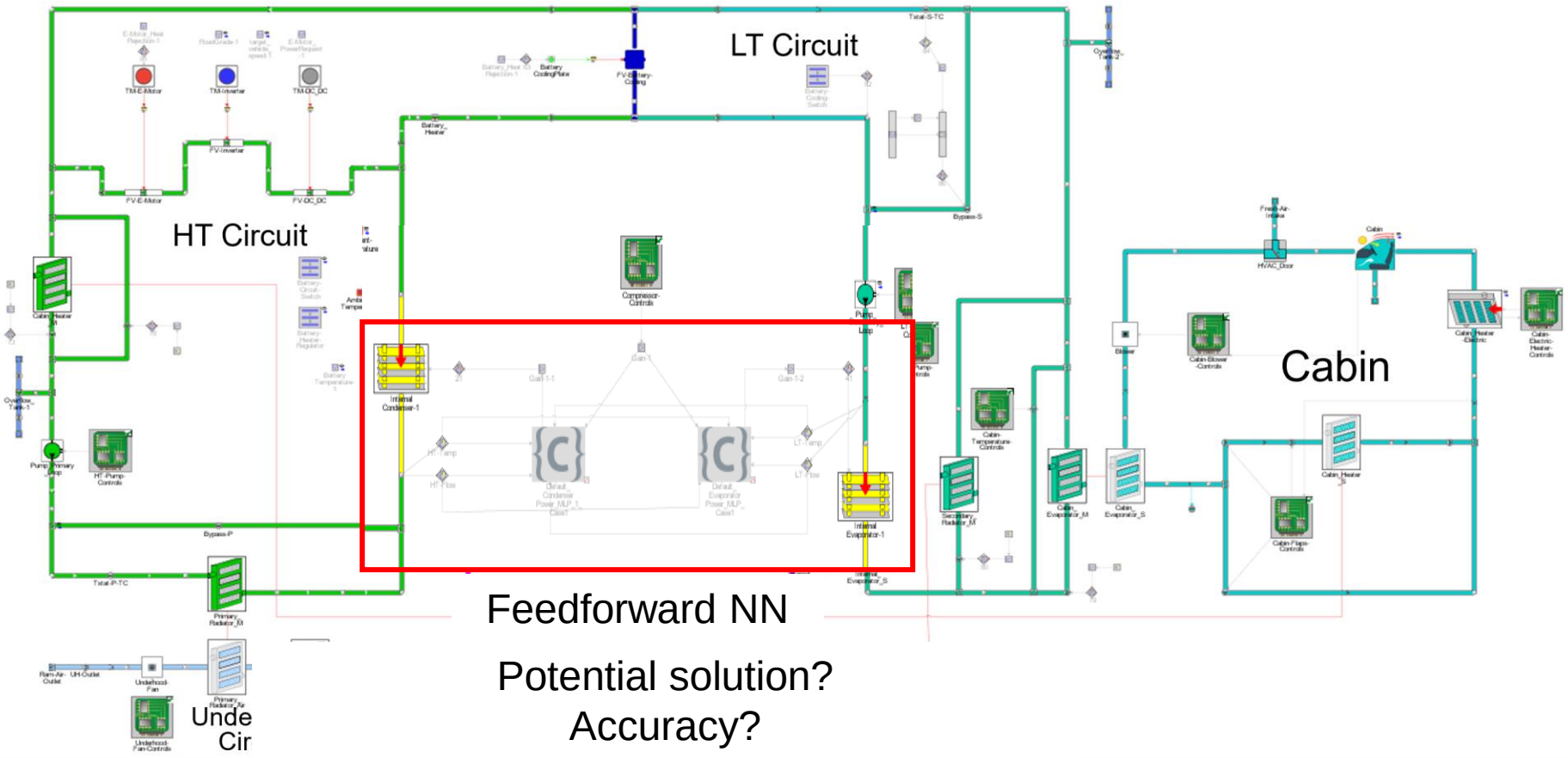


Feedforward NN

Potential solution?
Accuracy?
RT capability?

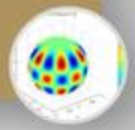
Tool choice: GT-Suite

- any fluid, gas or liquid or mixture

Flow

- both non-linear and linear

Acoustics



- all types of heat transfer

Thermal

- kinematics, multi-body dynamics, frequency domain

Mechanical

- Electric and Electromagnetic circuits, Electromechanical devices

Electric

- chemical kinetics

Chemistry

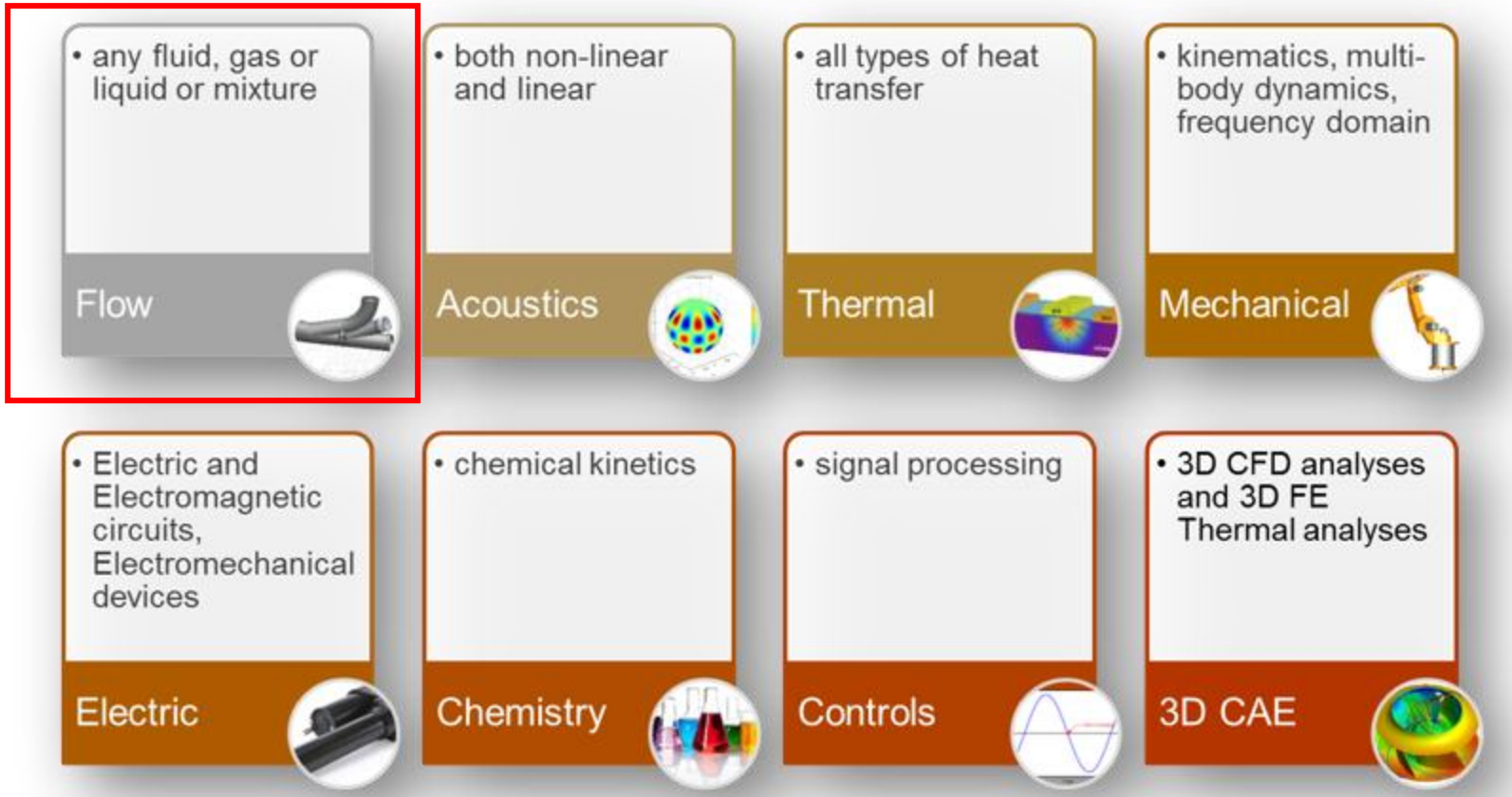
- signal processing

Controls

- 3D CFD analyses and 3D FE Thermal analyses

3D CAE

Tool choice: GT-Suite



Flow solver: GT Suite

- General Flow Solution
  - The basic building block is a flow volume while orifices are modeled as boundaries of the flow volumes.
  - For each flow volume, conservation of mass, momentum and energy equations are solved.
  - Heat exchangers are represented as a collection of flow volumes.

- Fluid Properties
  - Refrigerant properties are calculated from the NIST REFPROP code
  - Pre-tabulated property tables with interpolation to fill in the gaps are used to speed up refrigerant property calculations.

Flow solver: GT Suite

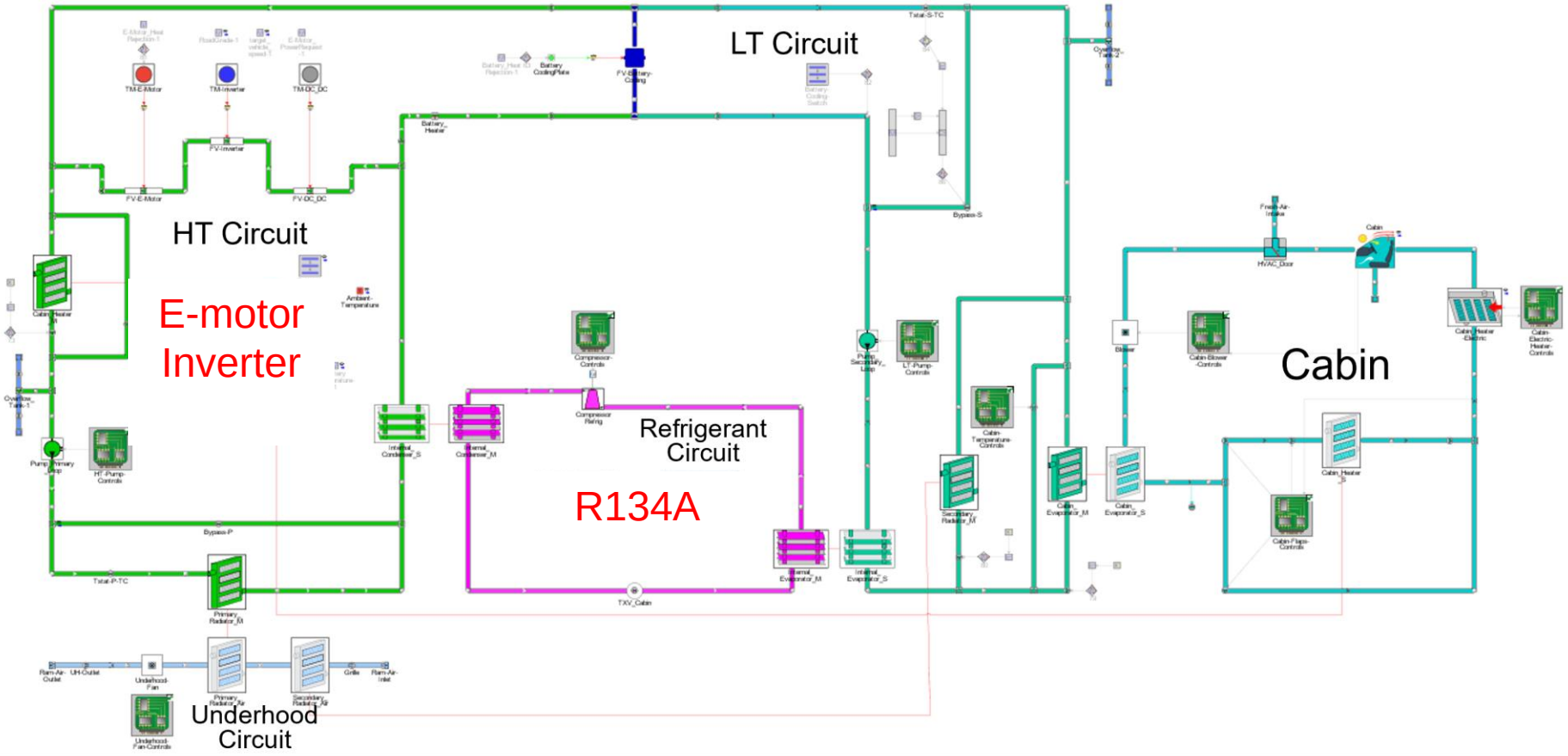
- Compressor Model
  - » A map-based approach, efficiency map and speed map, is used to model the compressor performance.
  - » During the simulation of a transient operation, the pressure ratio is obtained from the flow solution and used to determine the mass flowrate and the isentropic efficiency.

- Expansion Device
  - » The expansion valve is modeled as a round hole with a controllable diameter, i.e. an orifice without volume.
  - » The momentum equation is solved to compute the mass flow rate and the velocity through an orifice.

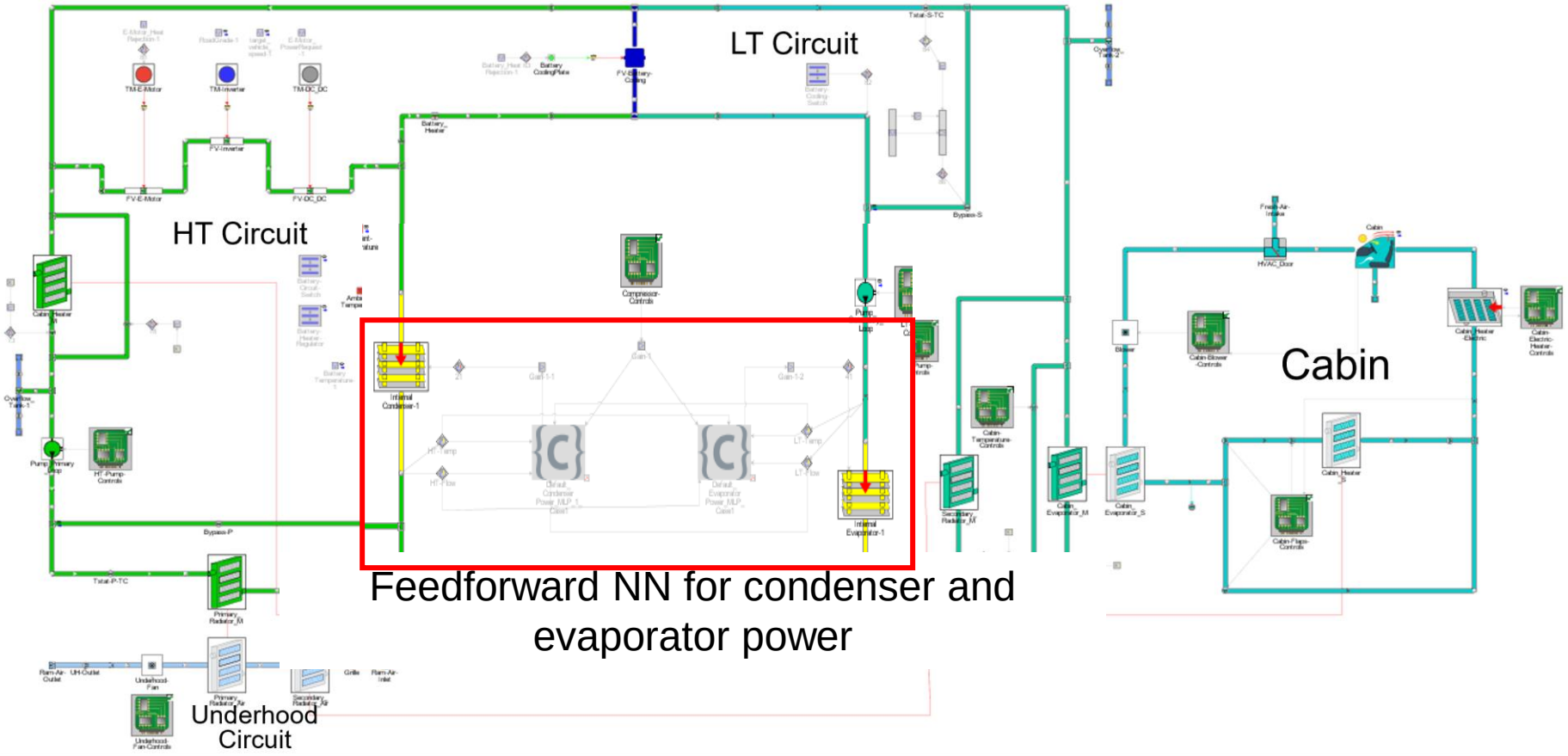
Neural Network

- Neural Network
  - four-layer MLP(Multi layer perceptron) neural network
  - 2 hidden layers consisting of 10 and 5 neurons respectively.
  - sigmoid function is used as a transfer function between hidden layers
  - linear transfer function for the output layer
  - a variant of the Levenberg-Marquardt algorithm the weights of the feed-forward MLP neural network are trained using GT-DOE POST

System Model

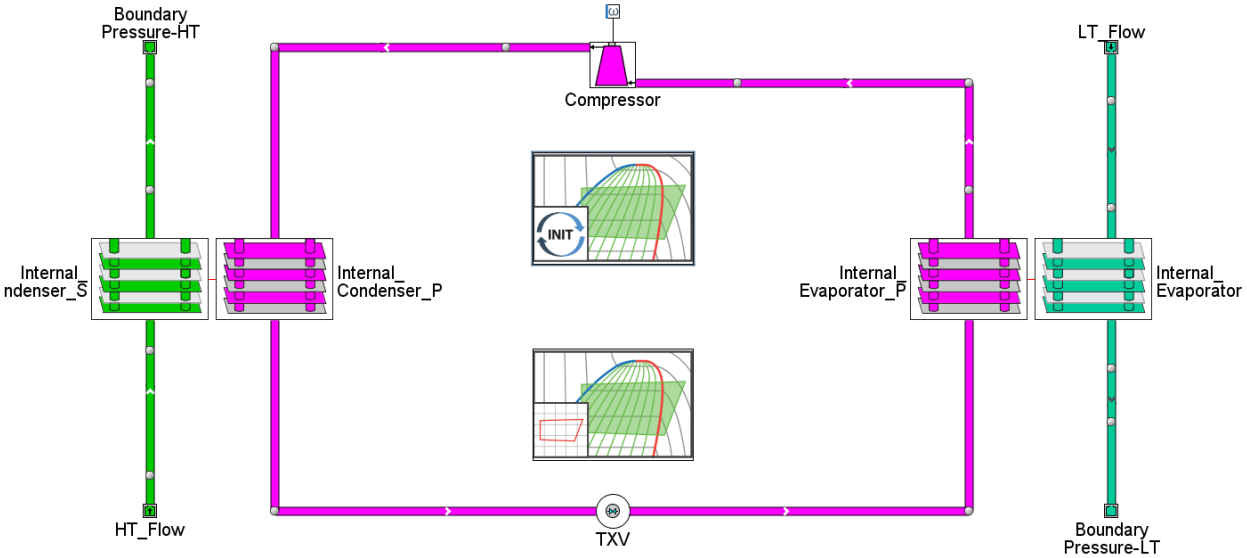


System Model with neural network

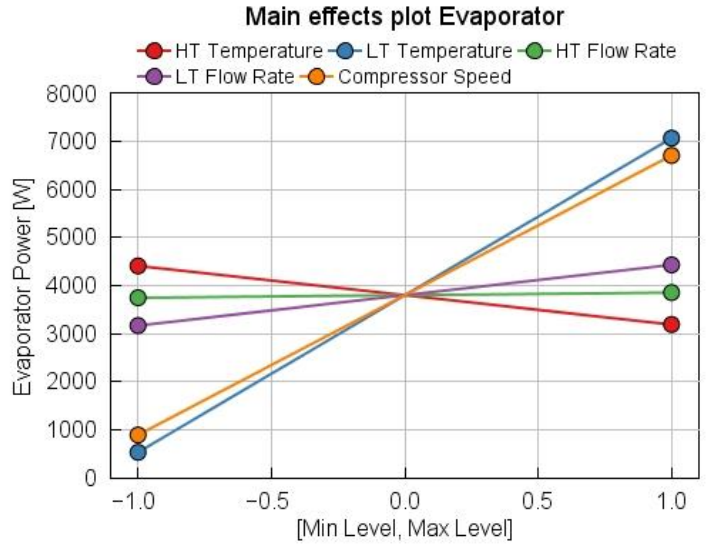


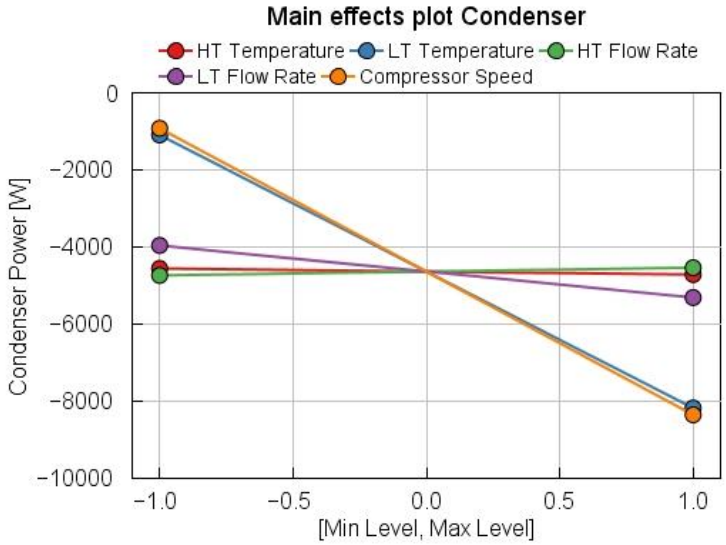
Training Parameters

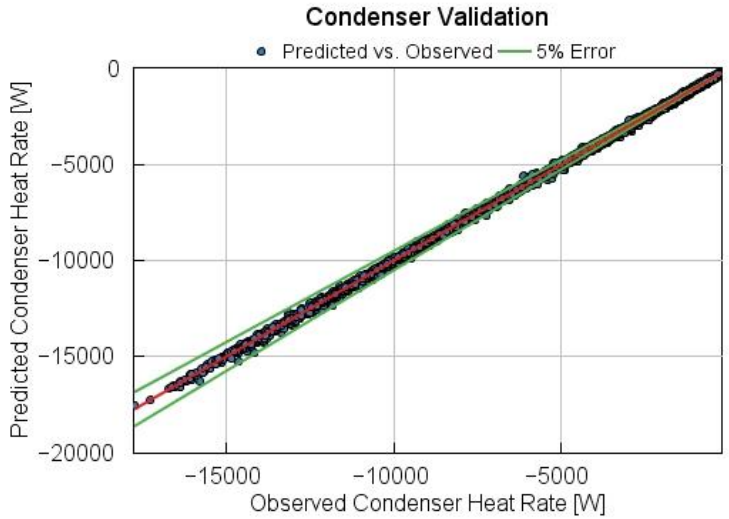
Parameter	Unit	Minimum	Maximum
HT Coolant Temperature	K	253.0	333.0
LT Coolant Temperature	K	253.0	313.0
HT Flow Rate	kg/s	0.0	0.6
LT Flow Rate	kg/s	0.0	0.6
Compressor Speed	RPM	500.0	7000.0

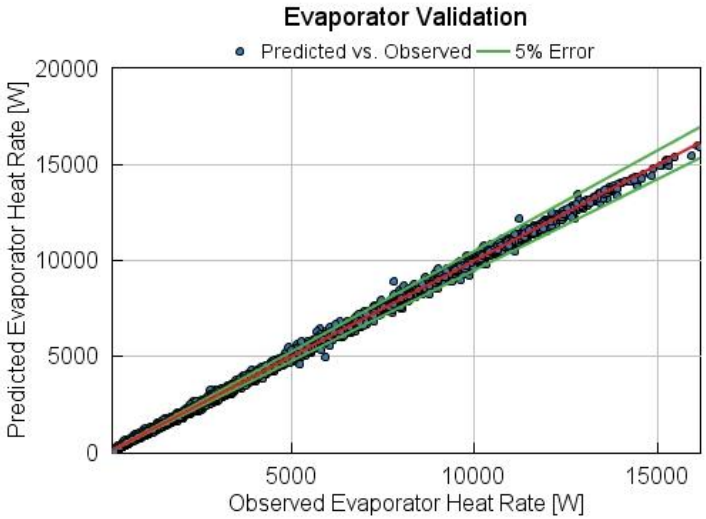


Neural Net Validation

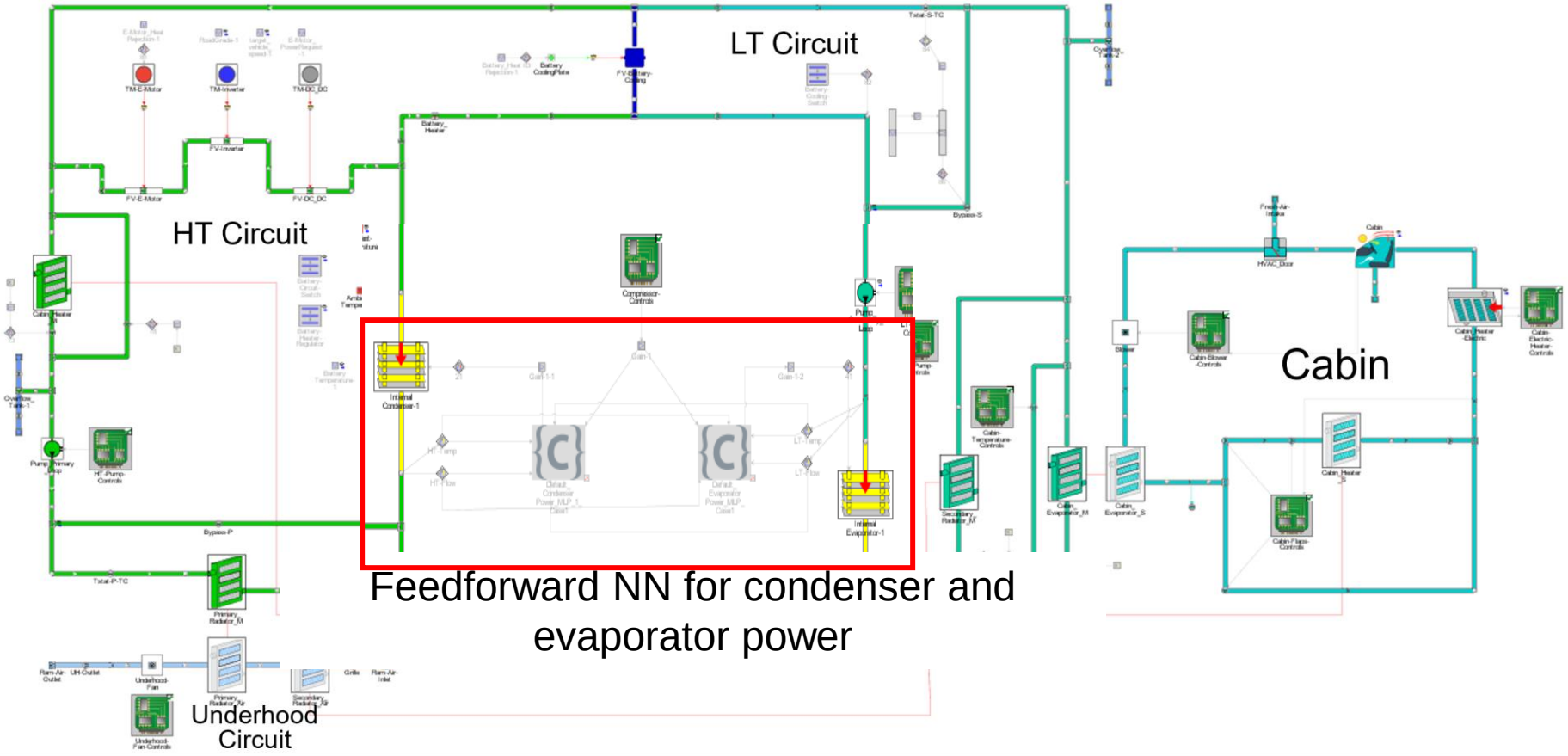




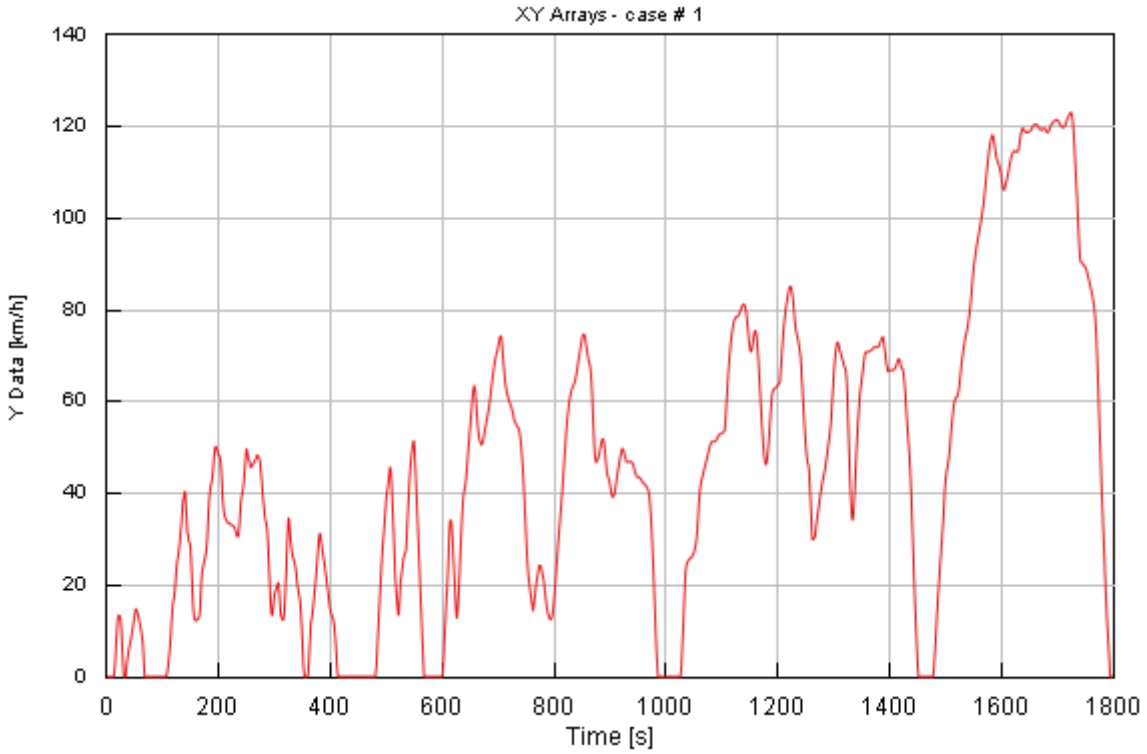




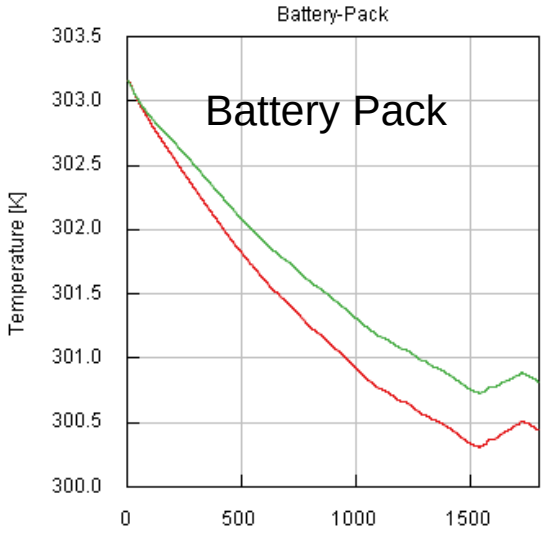
System Model with Neural Network

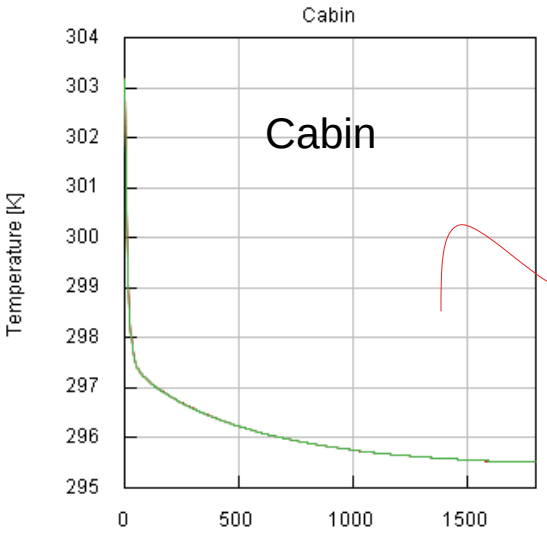


WLPT Drive Cycle – Target Speeds

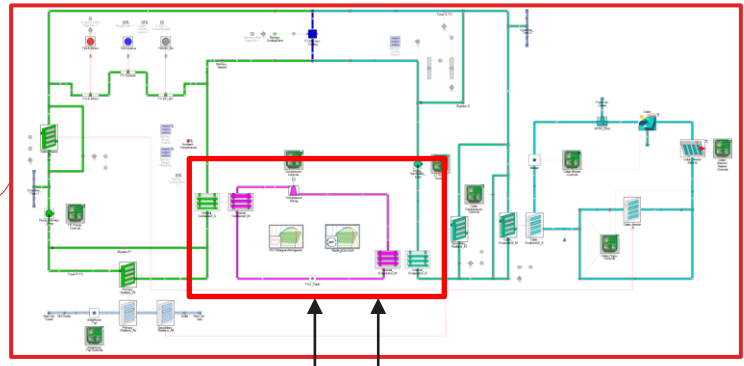


WLPT drive cycle: Cooldown

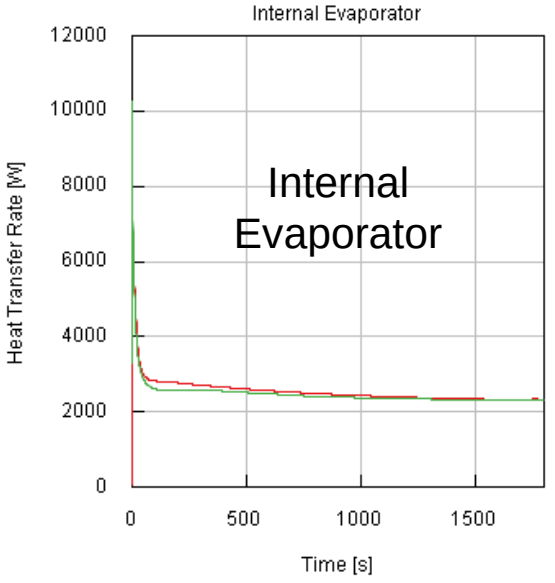


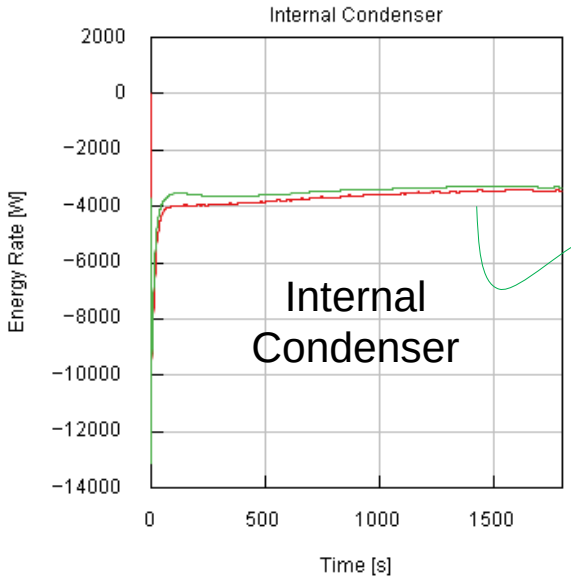


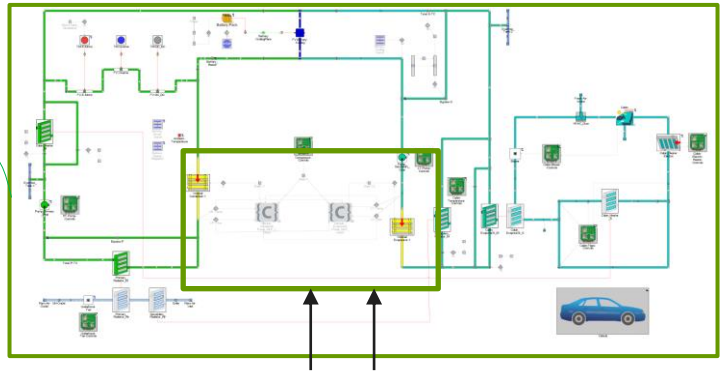
Ambient temperature: 30 °C



Physics-based model

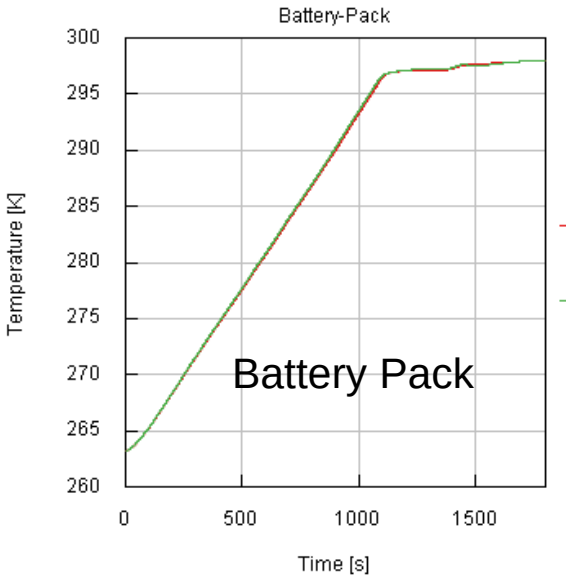


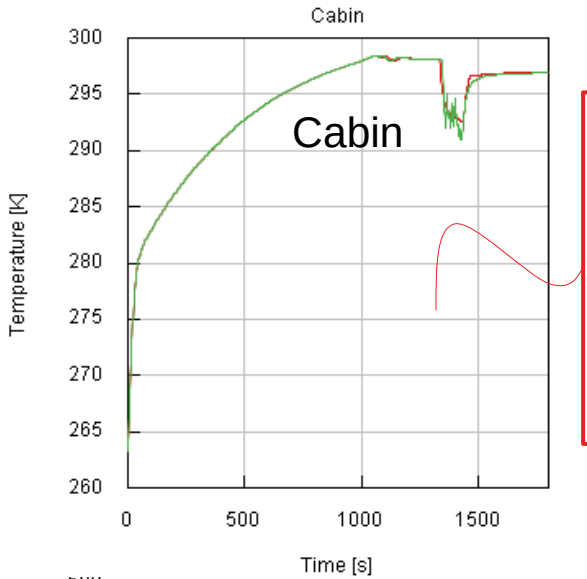




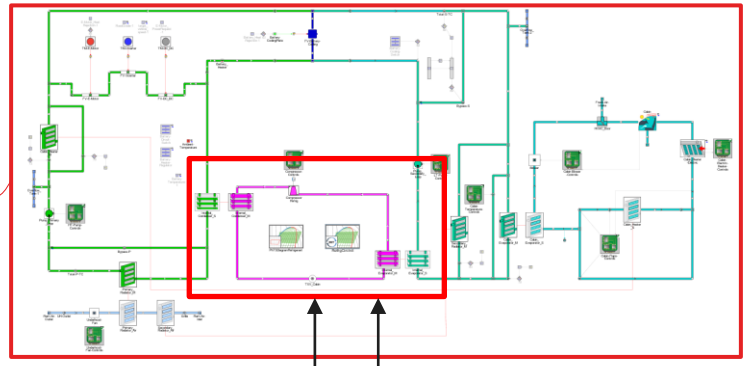
Feedforward NN for condenser and evaporator power

WLPT drive cycle: Heatup

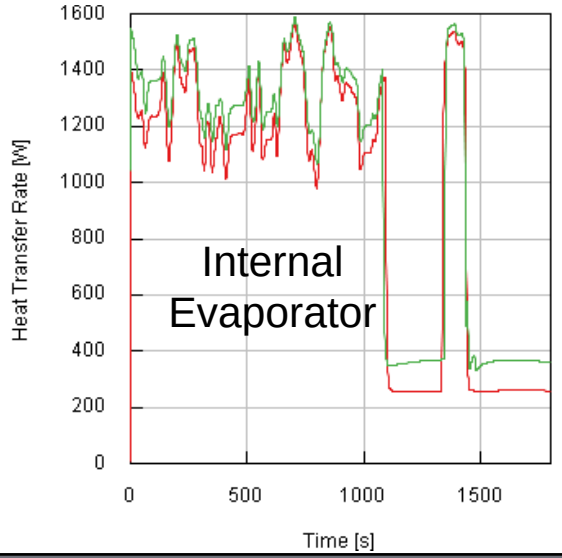


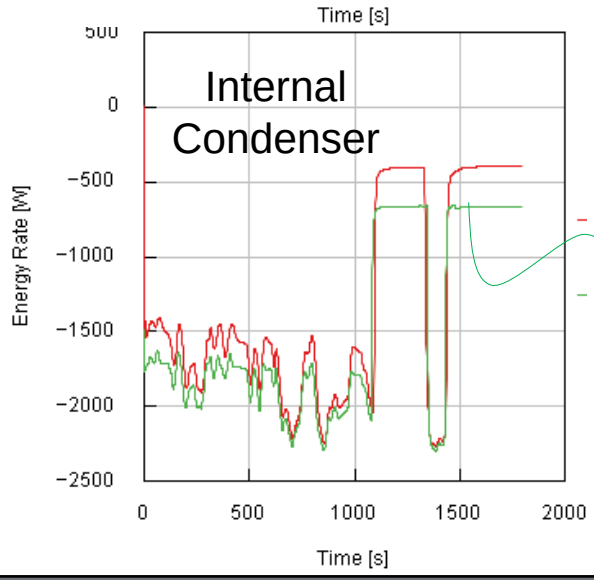


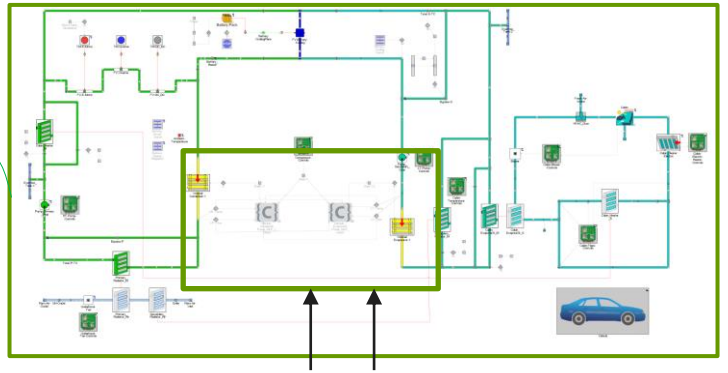
Ambient temperature: -10 °C



Physics-based model

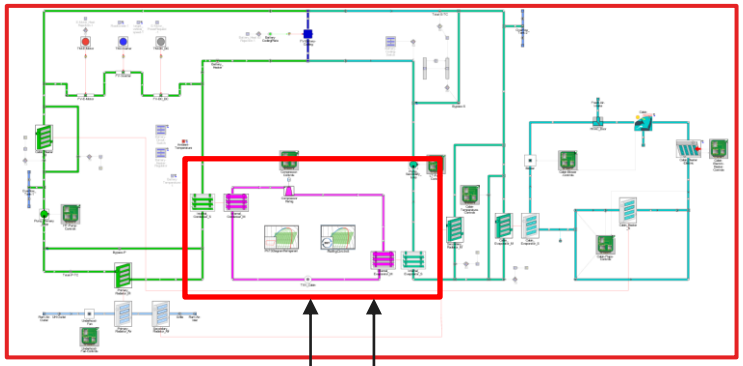






Feedforward NN for condenser and evaporator power

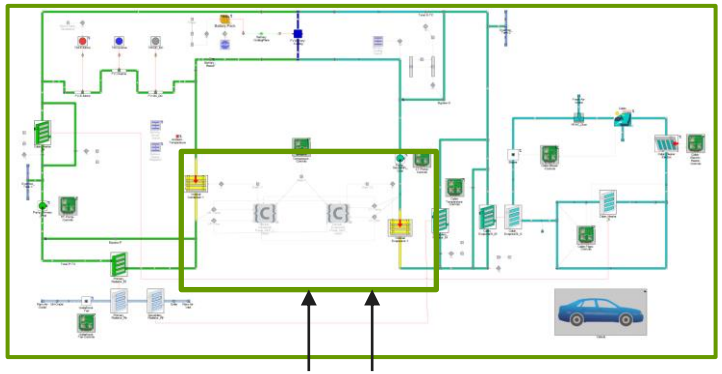
Speed comparisons



Physics-based model

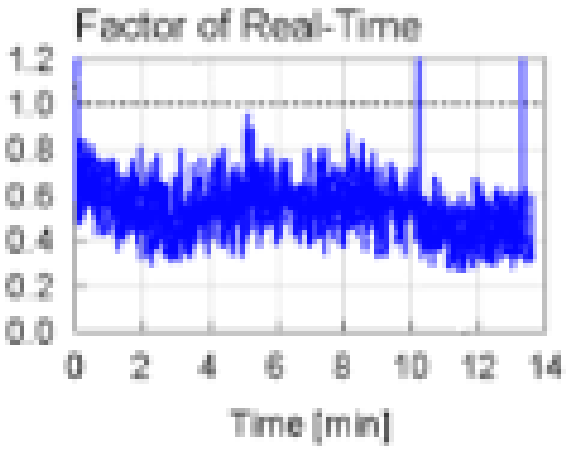
0.27 RT

~ 37 % speedup

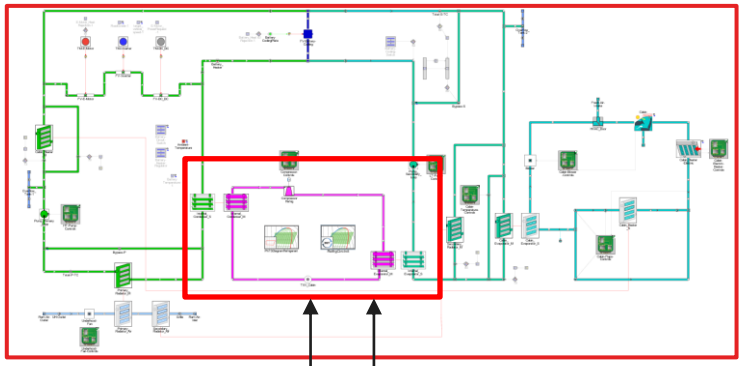


Feedforward NN for condenser and evaporator power

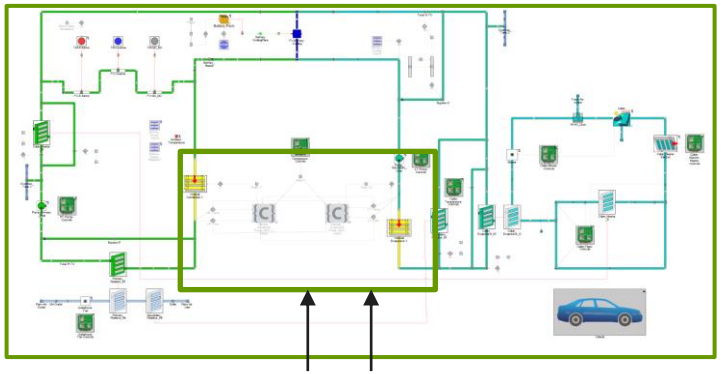
0.17 RT



Conclusions



Physics-based model



Feedforward NN for condenser and evaporator power

- Successfully implemented a replacement feedforward neural network for the refrigerant circuit and ran a transient drive-cycle simulation
- The replacement NN can reproduce the Battery Temperature and Cabin Temperature during WLPT heatup and cooldown
- Not fully able to reproduce the transient heat transfer rate in the heat exchangers