MATLAB EXPO

November 13–14, 2024 | Online

Optimizing a Battery Electric Vehicle Thermal Management System

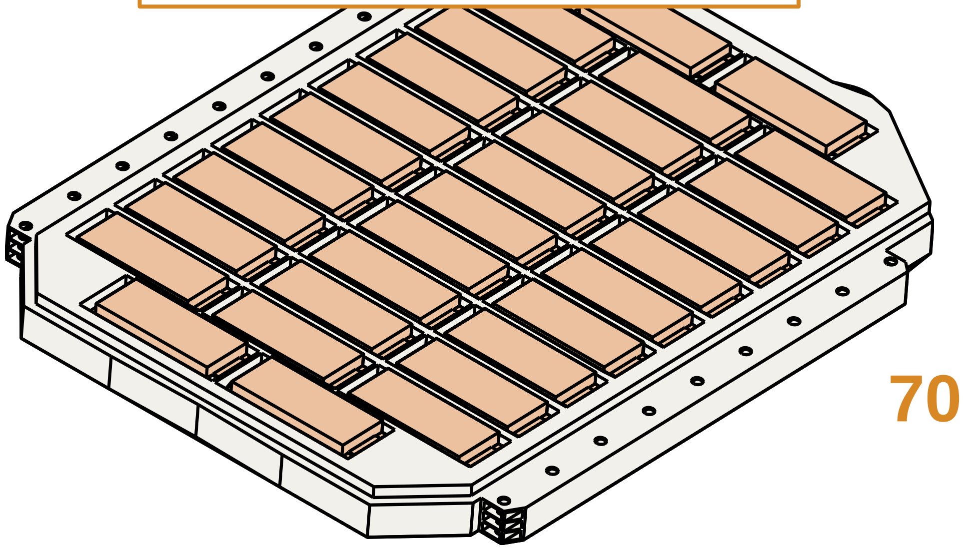
Lorenzo Nicoletti, MathWorks

Steve Miller, MathWorks

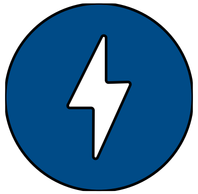
MathWorks®

The achievable range is still a major challenge for Battery Electric Vehicles (BEVs)

Electric Powertrain

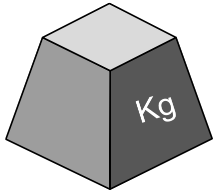


95 kWh

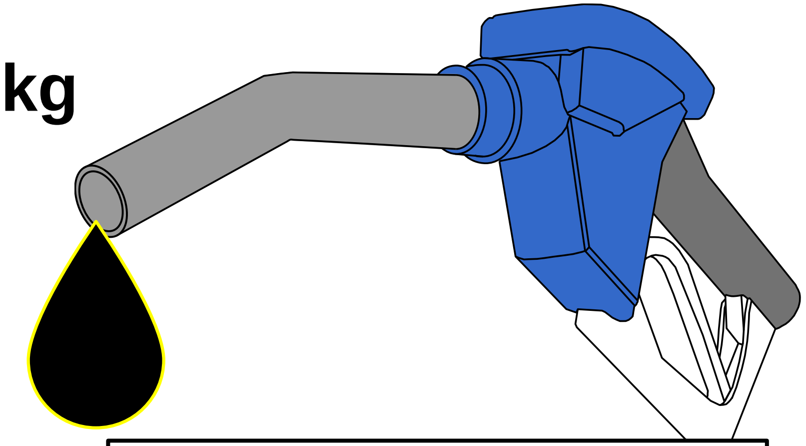


700 kWh

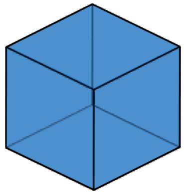
700 kg



95 kg



430 L

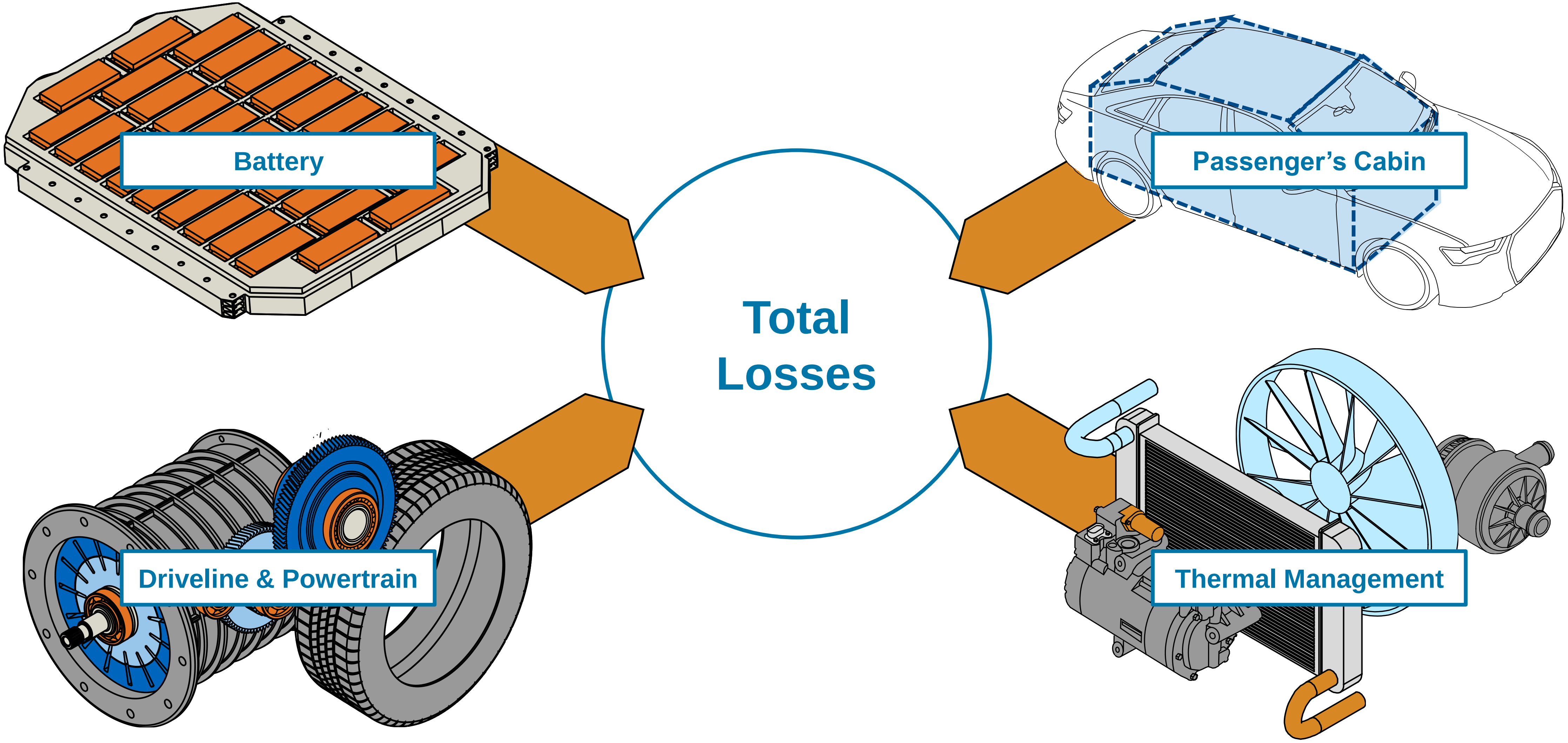


85 L

Diesel Powertrain

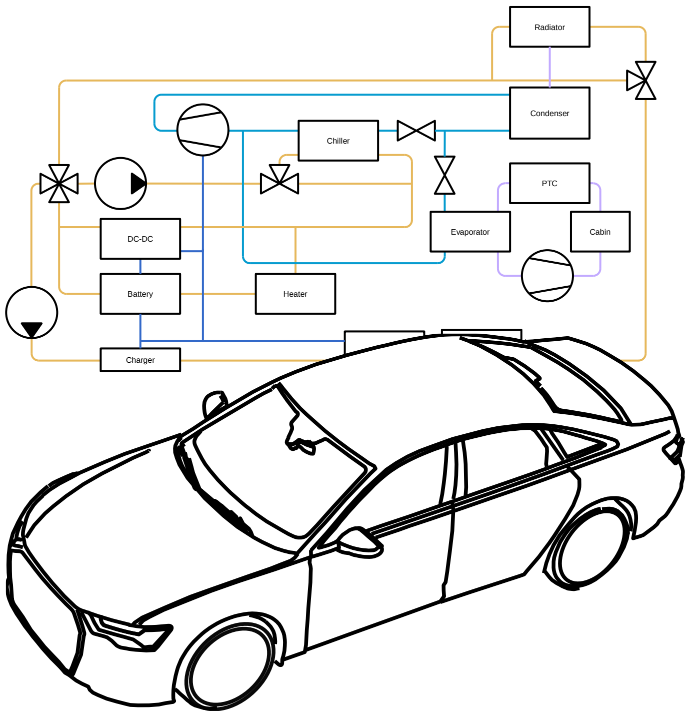
Source: L. Nicoletti, Parametric Modeling of Battery Electric Vehicles in the Early Development Phase. Ph.D. Thesis, 2022

Increasing the range of BEVs requires optimizing all vehicle components following a holistic approach*

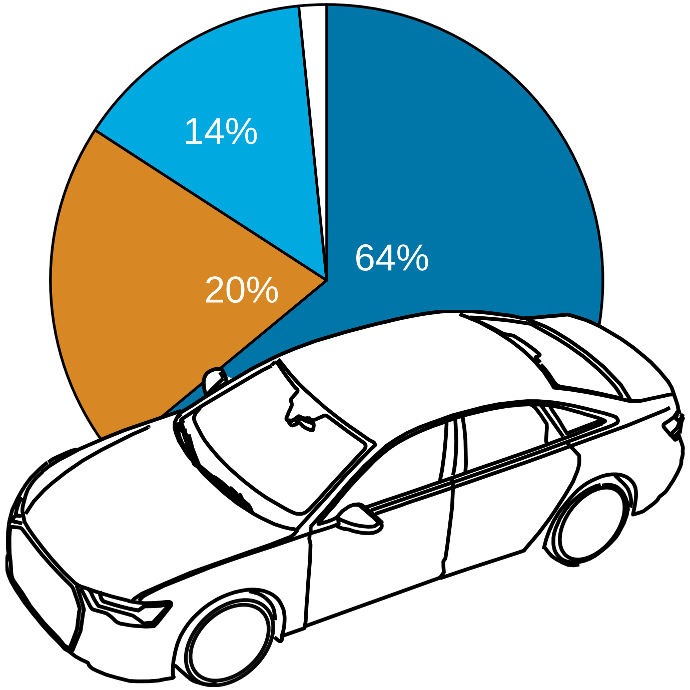


*S. Miller and L. Nicoletti, "A Holistic Approach for Designing a Battery Electric Vehicle Thermal Management System", ELIV, Bonn, 2023

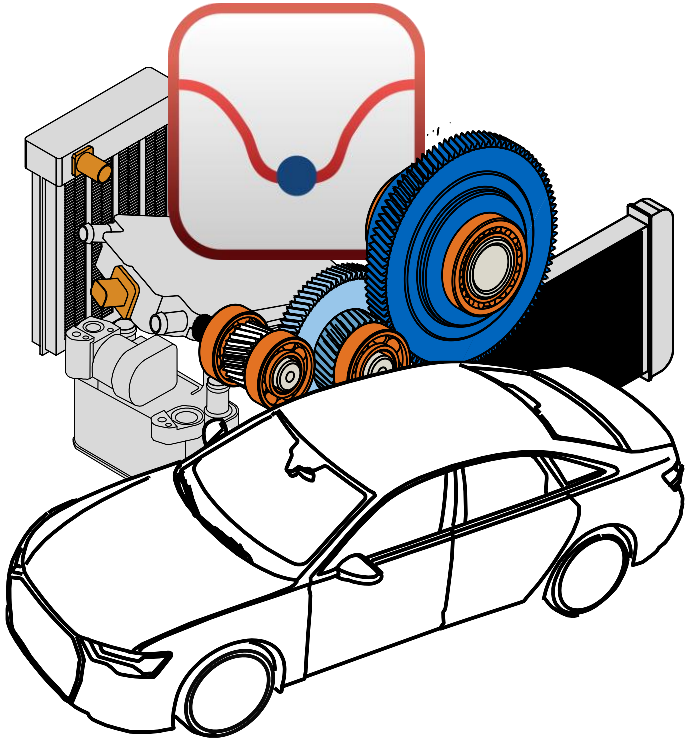
This presentation shows how to build a holistic BEV model and achieve an optimal design



Build Holistic BEV Model

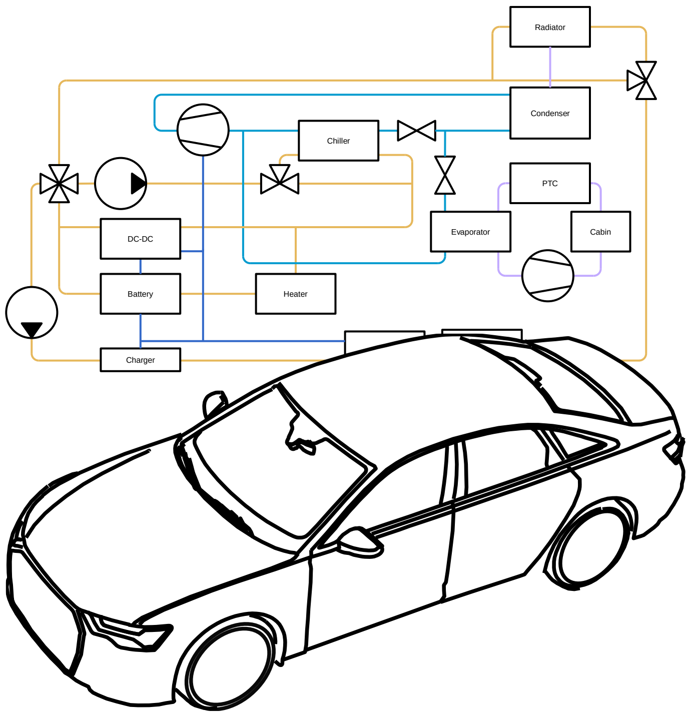


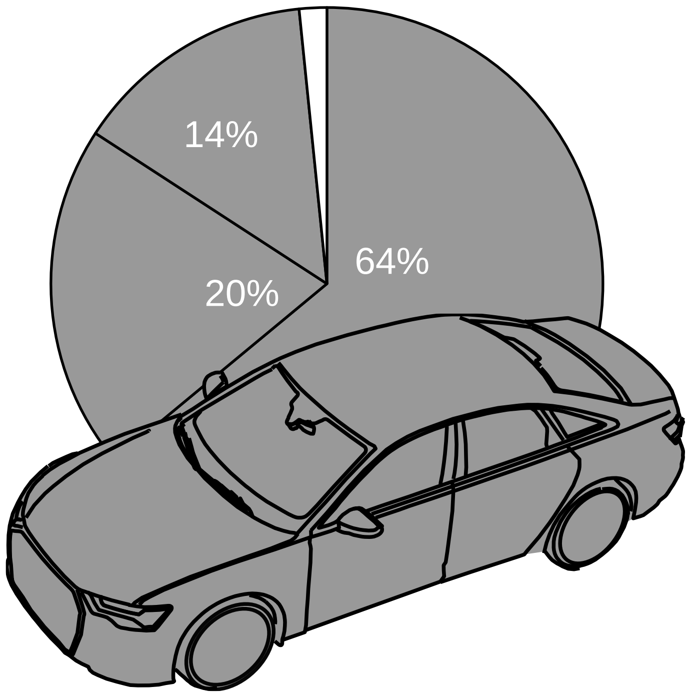
Simulate & Analyze

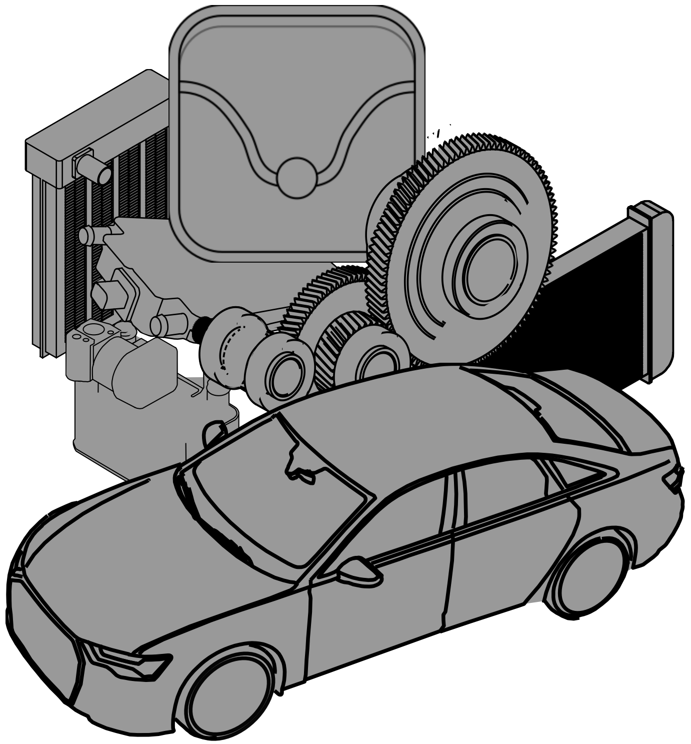


Optimize

Implementing your own BEV model is **fast and intuitive**

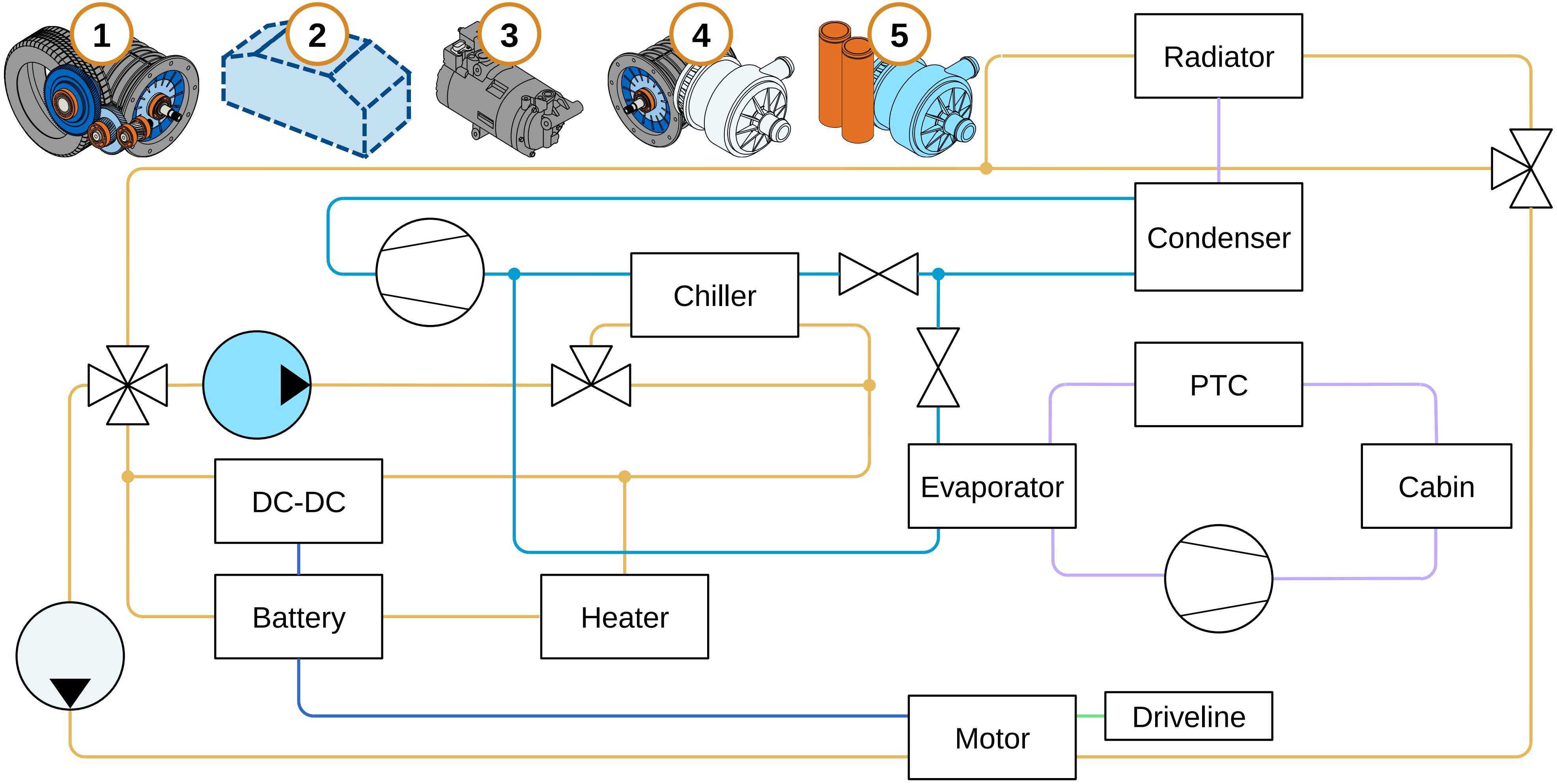






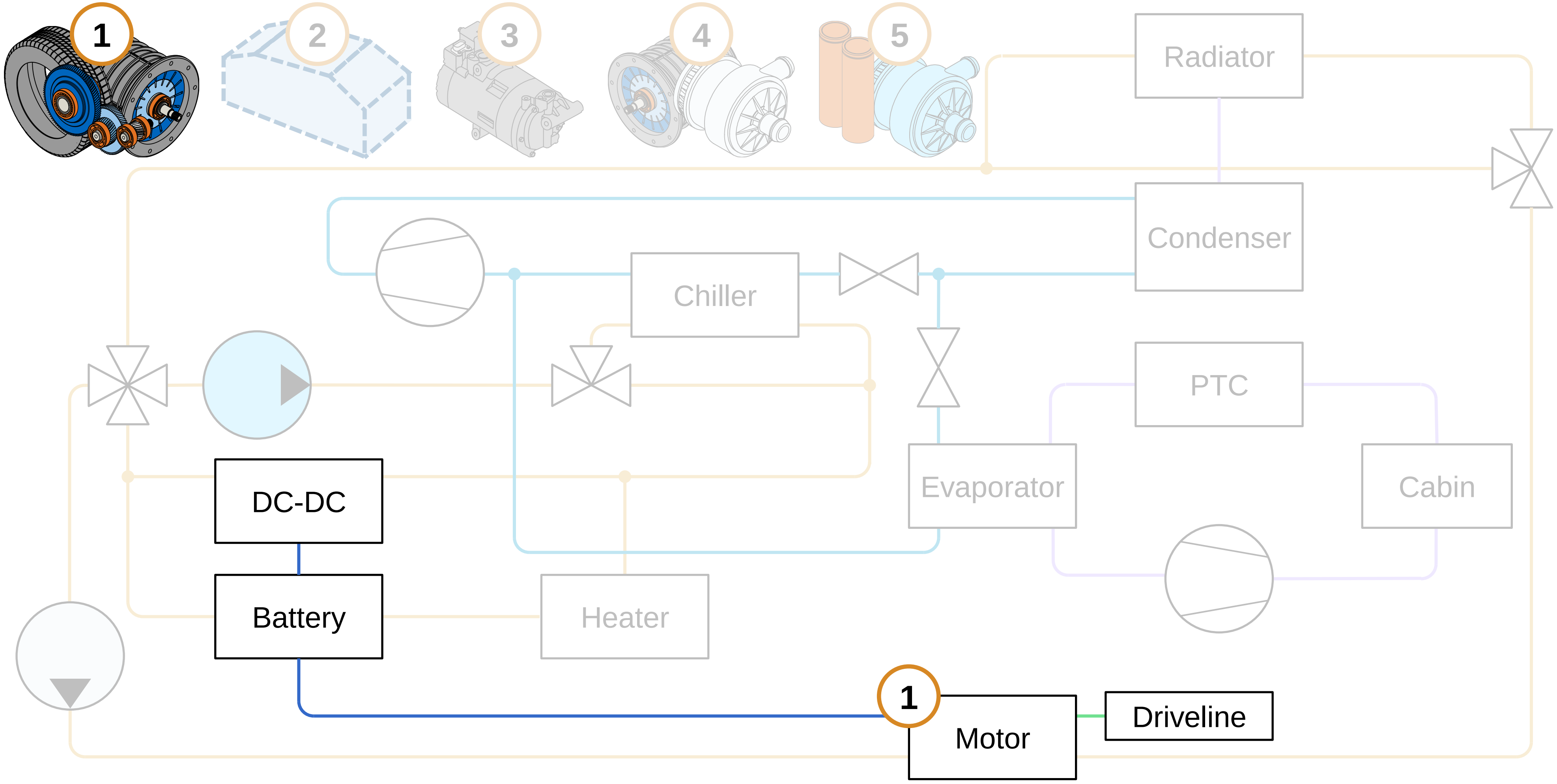
Build Holistic BEV Model Simulate & Analyze Optimize

The BEV model allows for a **full vehicle simulation***



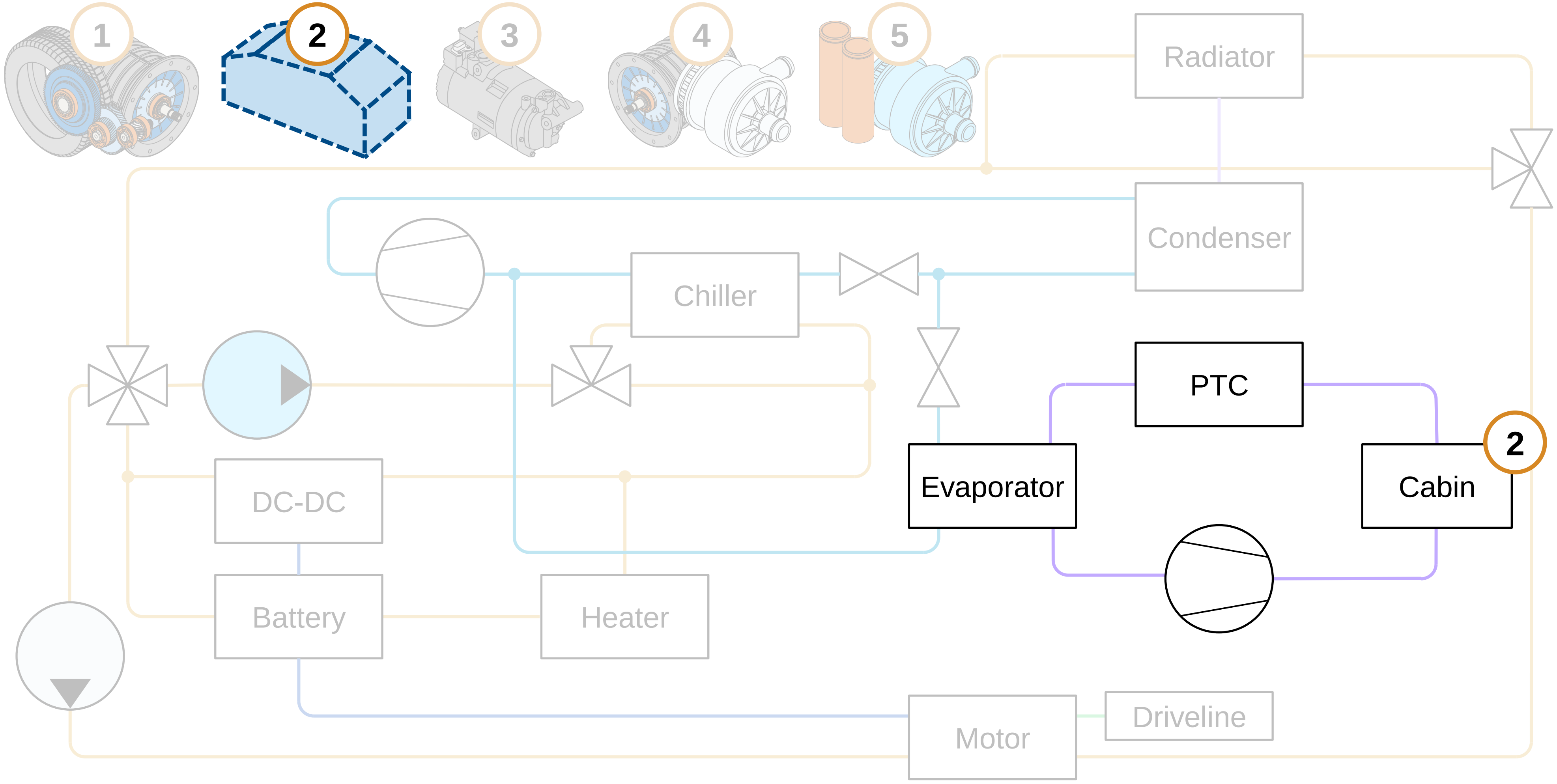
*A version of this model is available on GitHub: https://github.com/simscape/EV-Thermal-Management-Simscape-ELIV-2023

Powertrain & driveline models capture vehicle behavior



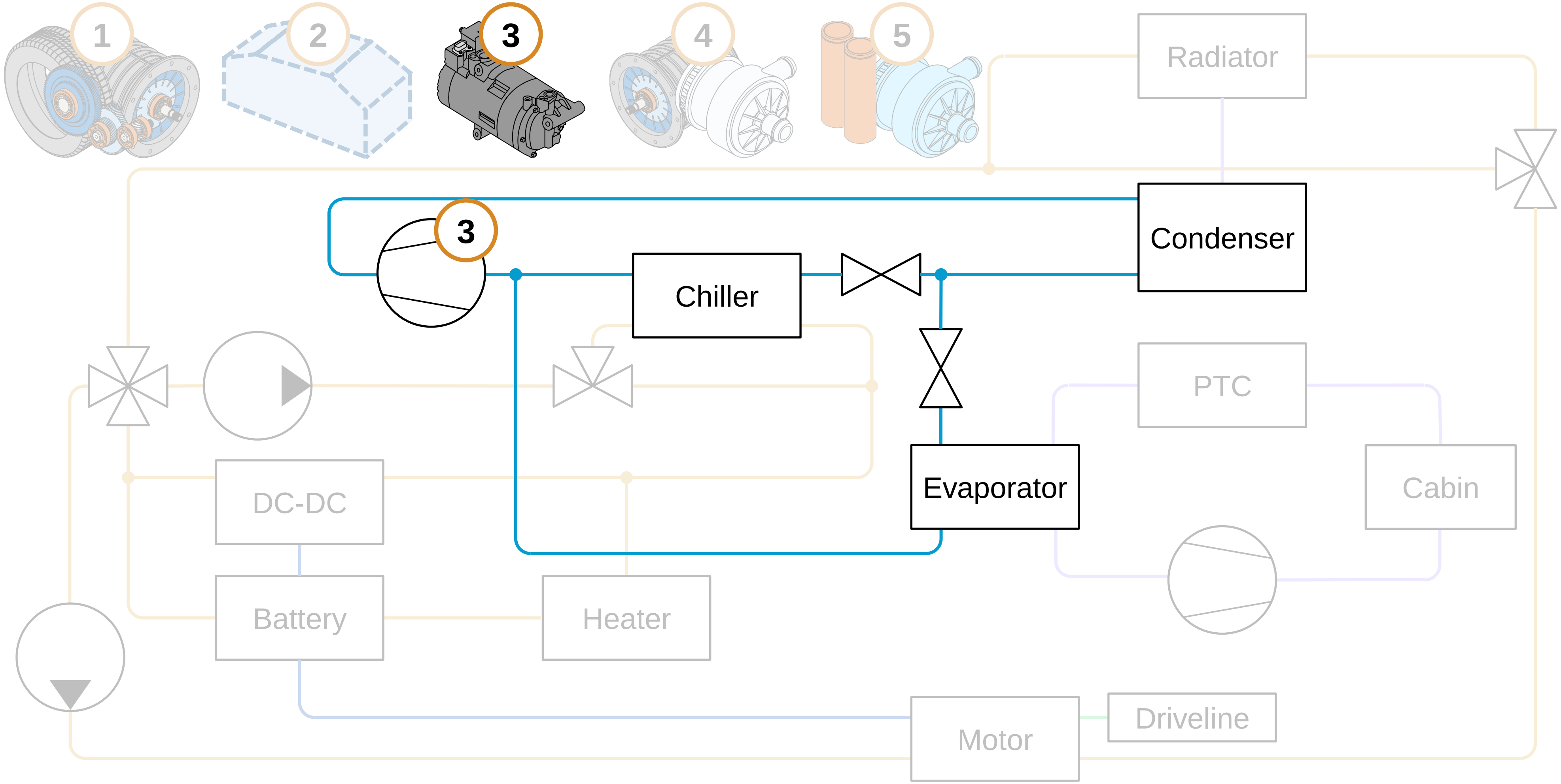
MATLAB EXPO

Cabin loop controls the cabin's temperature



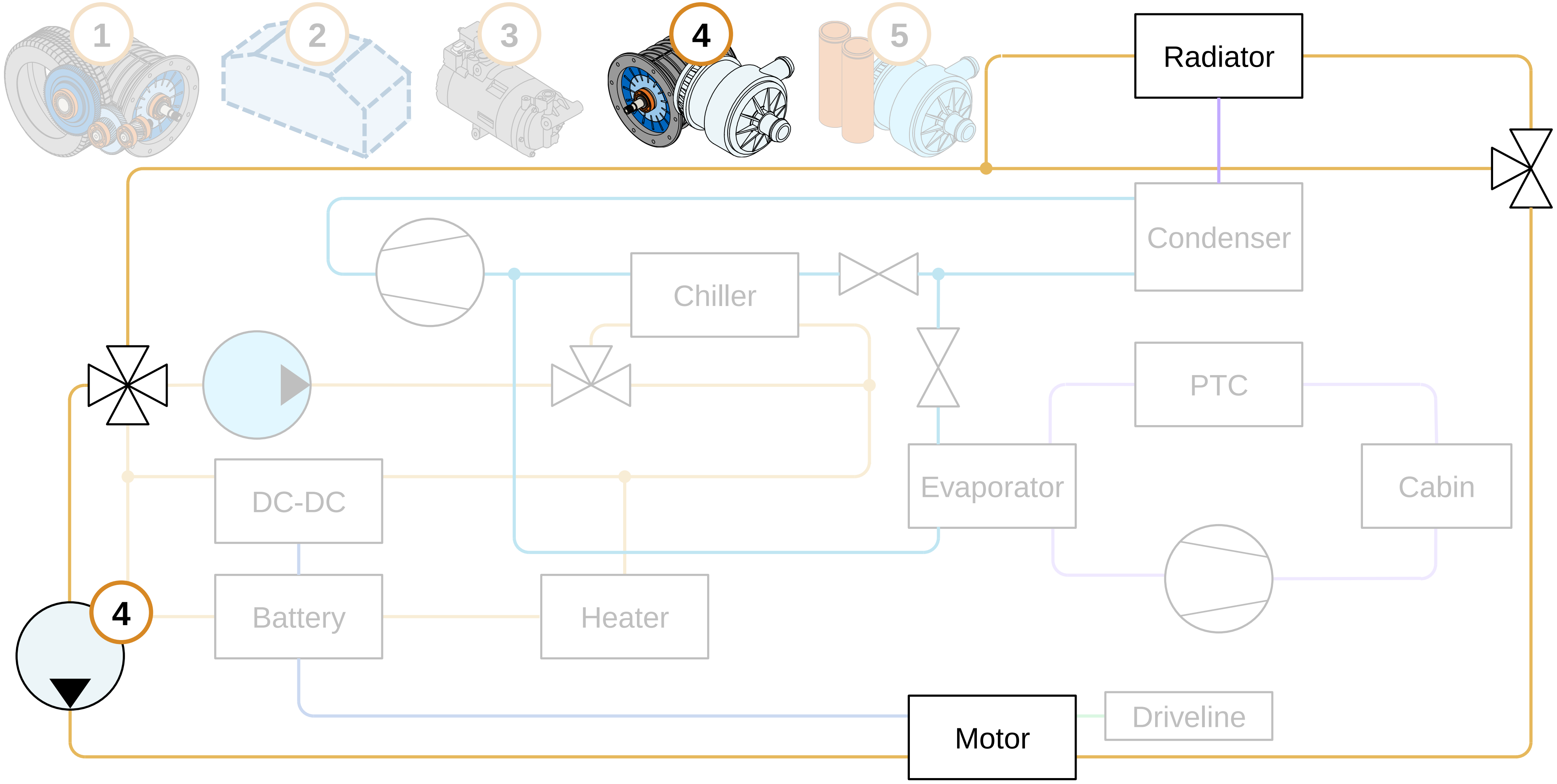
MATLAB EXPO

Refrigerant loop dissipates heat from cabin & powertrain



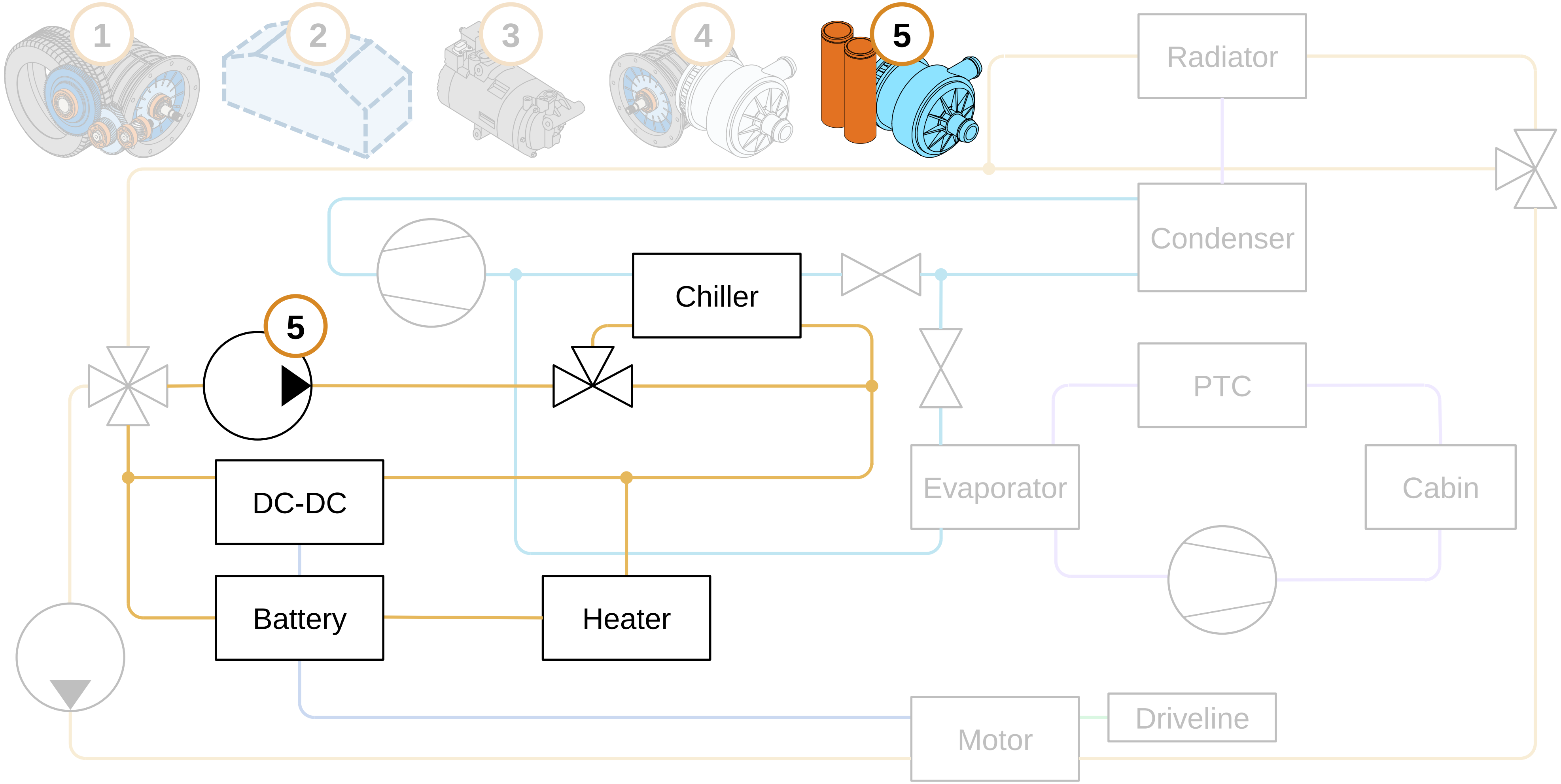
MATLAB EXPO

Outer coolant loop controls motor temperature

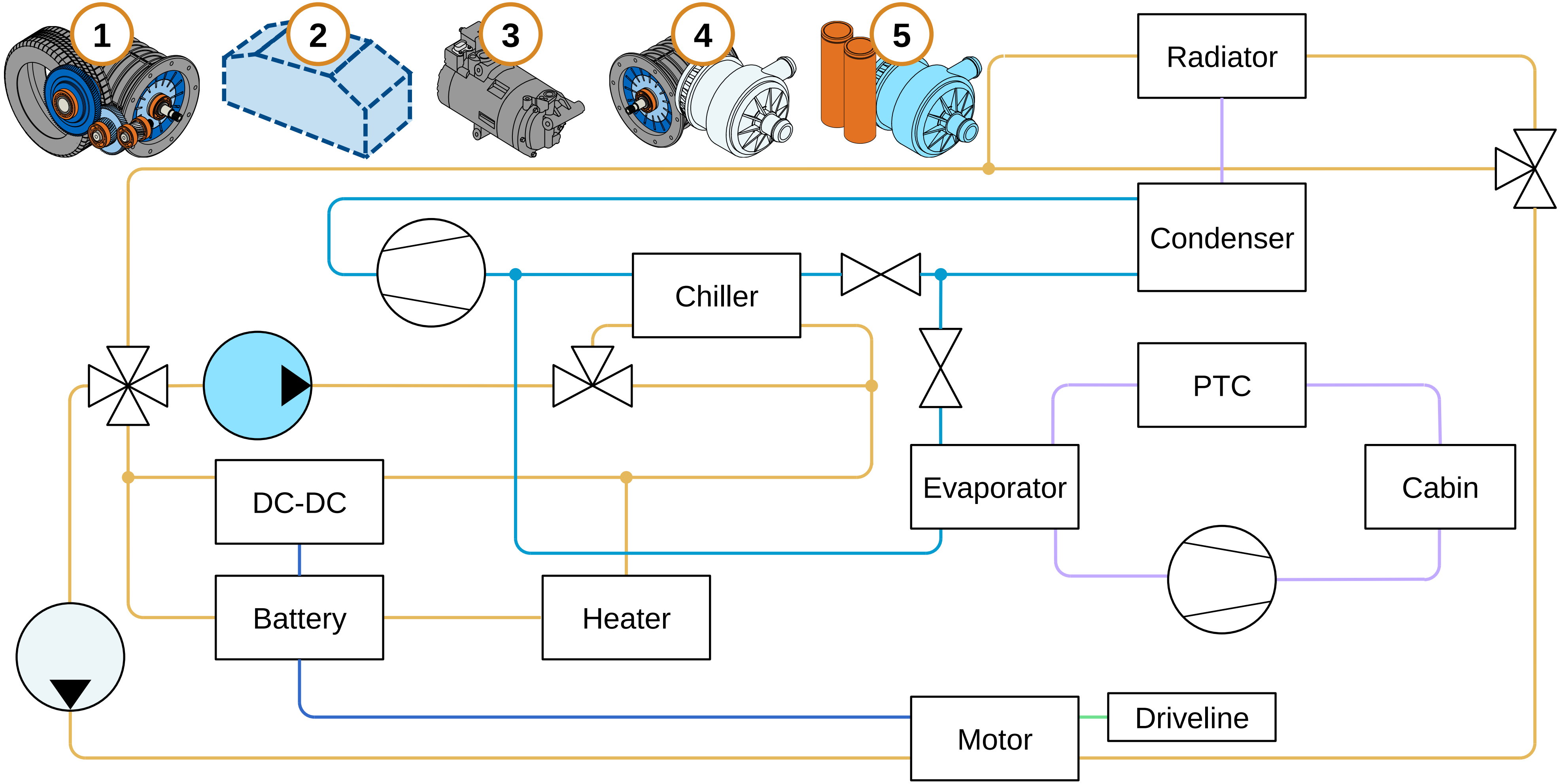


MATLAB EXPO

Inner coolant loop controls battery temperature

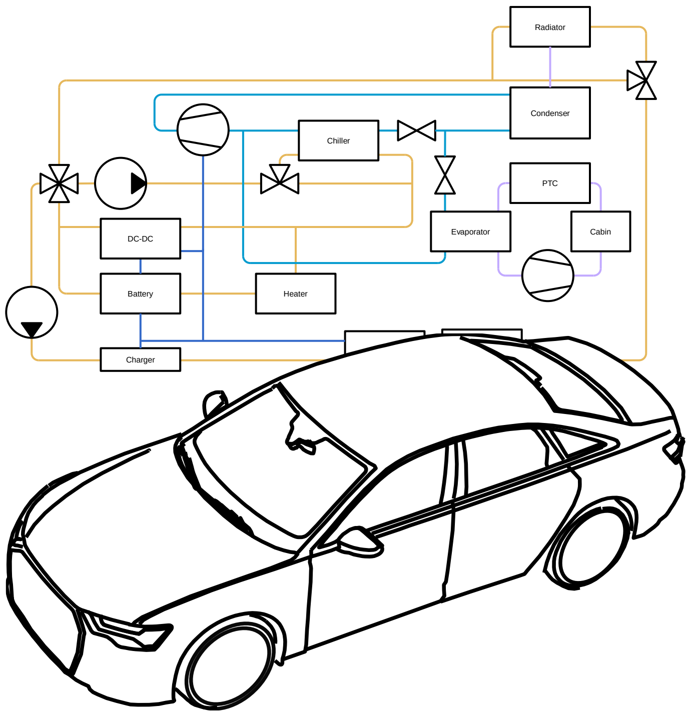


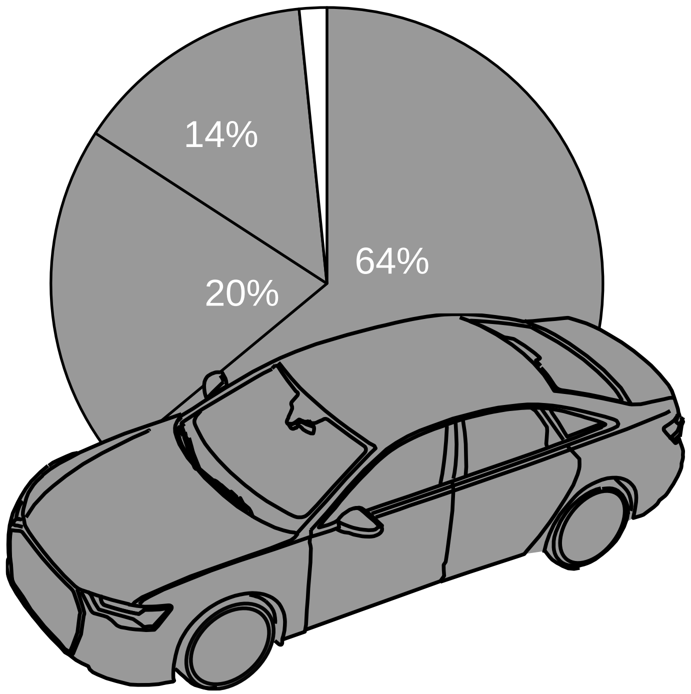
The BEV model allows for a **full vehicle simulation***

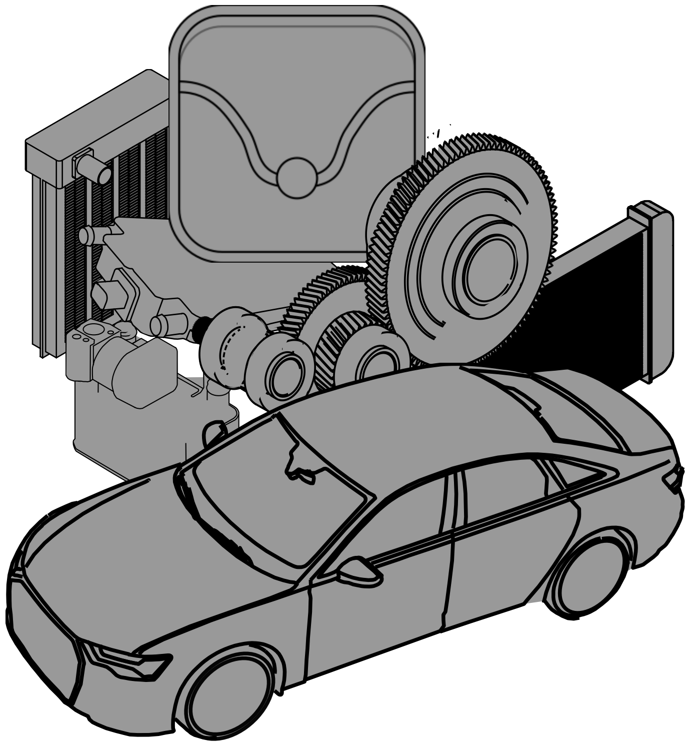


*A version of this model is available on GitHub: https://github.com/simscape/EV-Thermal-Management-Simscape-ELIV-2023

Implementing your own BEV model is **fast and intuitive**

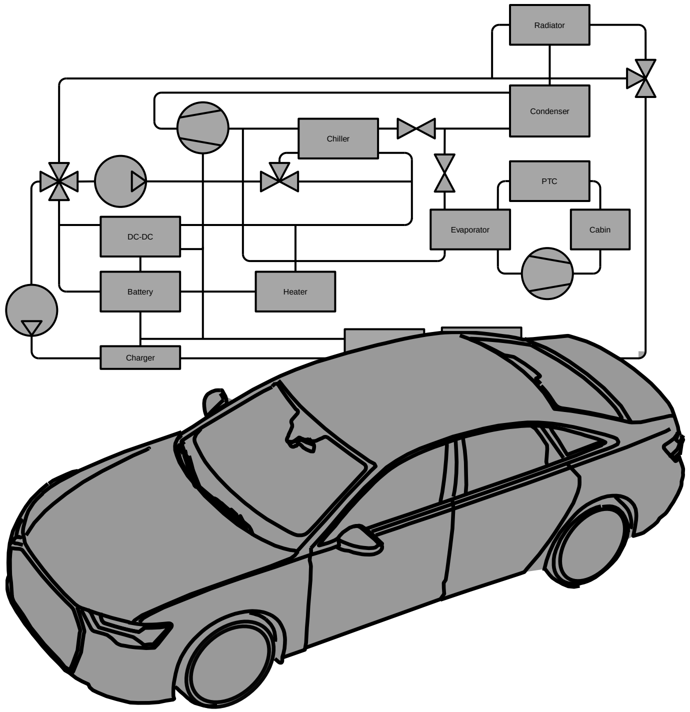




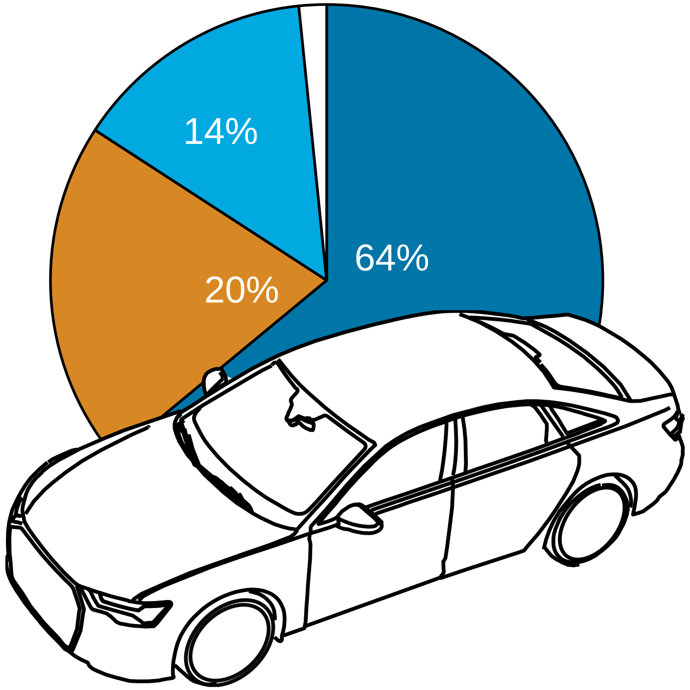


Build Holistic BEV Model **Simulate & Analyze** **Optimize**

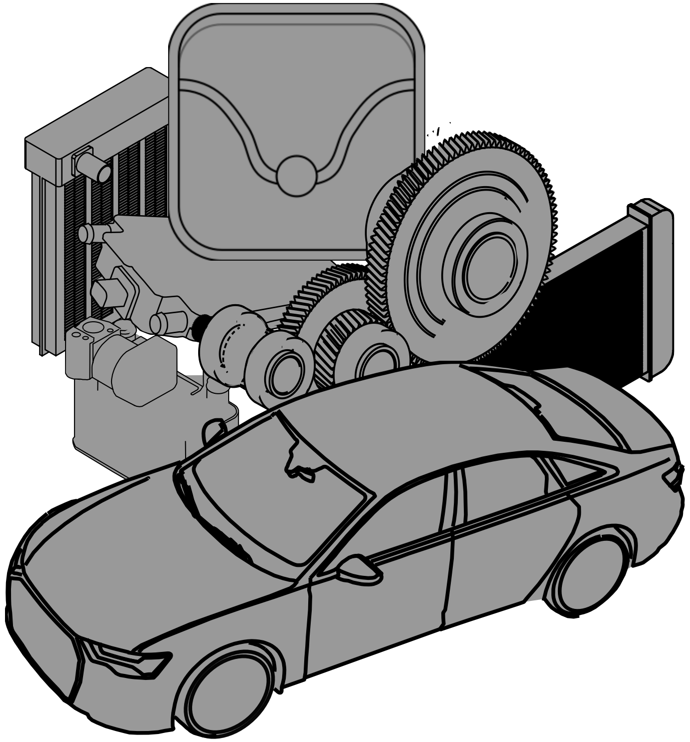
Use the BEV model to **understand your design**



Build Holistic BEV Model

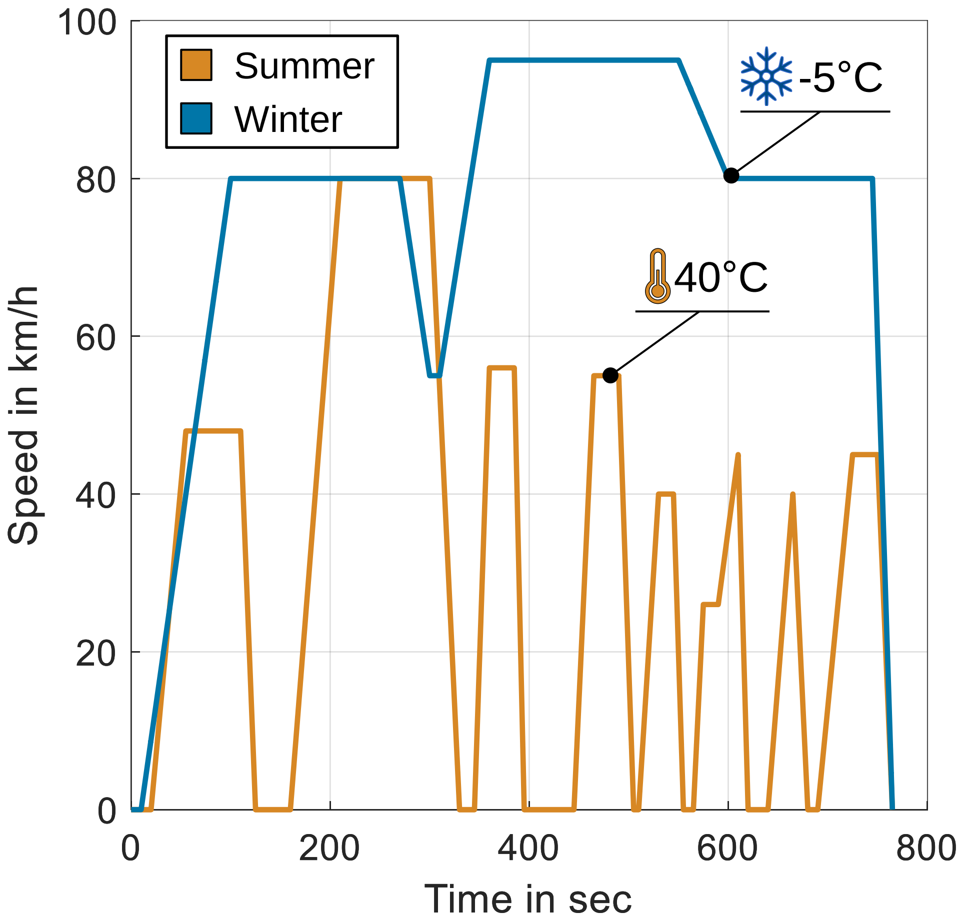


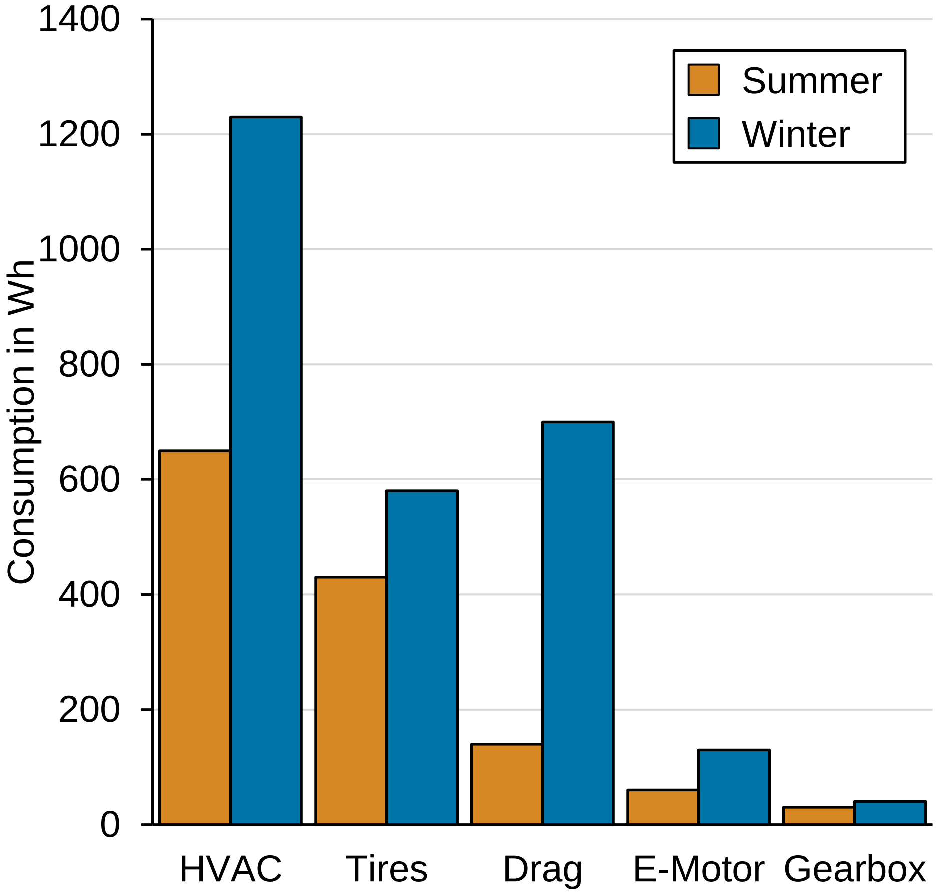
Simulate & Analyze



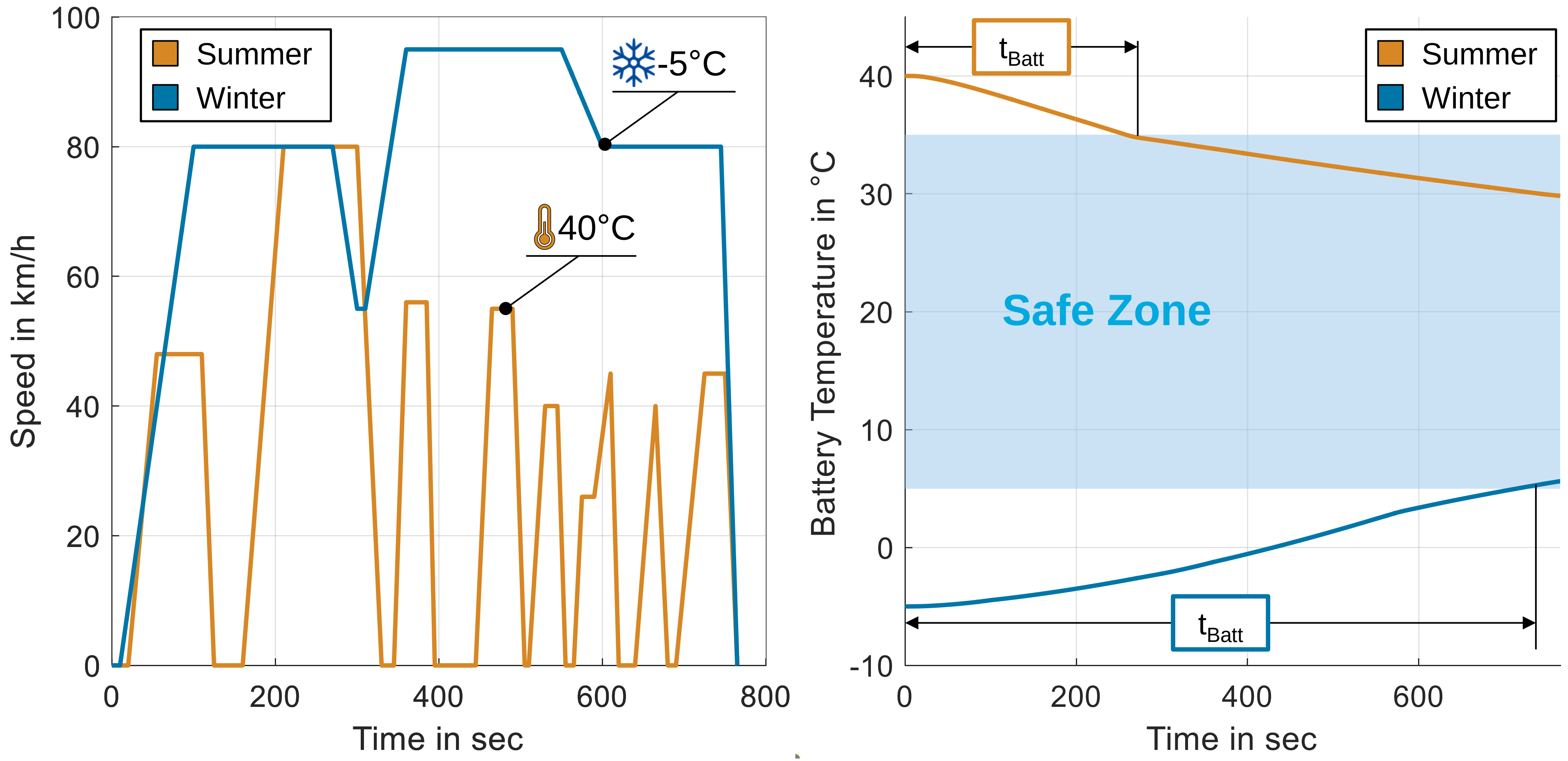
Optimize

Initial assessment: Drive style and weather conditions **influence vehicle consumption**





Initial assessment: Drive style and weather conditions **influence thermal management performance**



MATLAB EXPO

The sensitivity analysis will **quantify the influence** of a set of parameters on two objectives

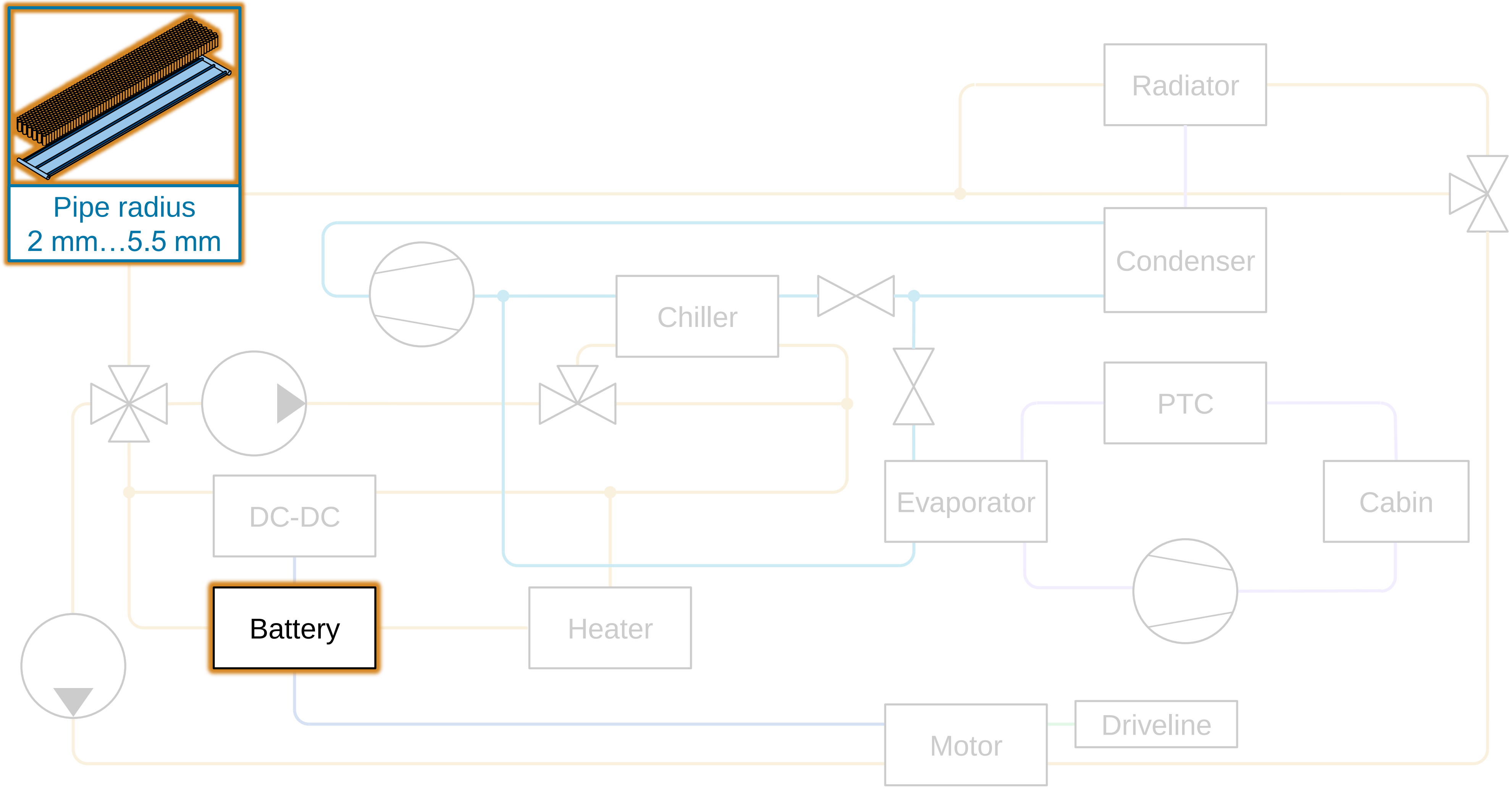
The objectives are:

1. Consumption: Total vehicle consumption during drive cycle (summer or winter)

2. t_{Batt} : The time (in seconds) that it takes to the battery to reach the safe temperature range (in summer or winter)

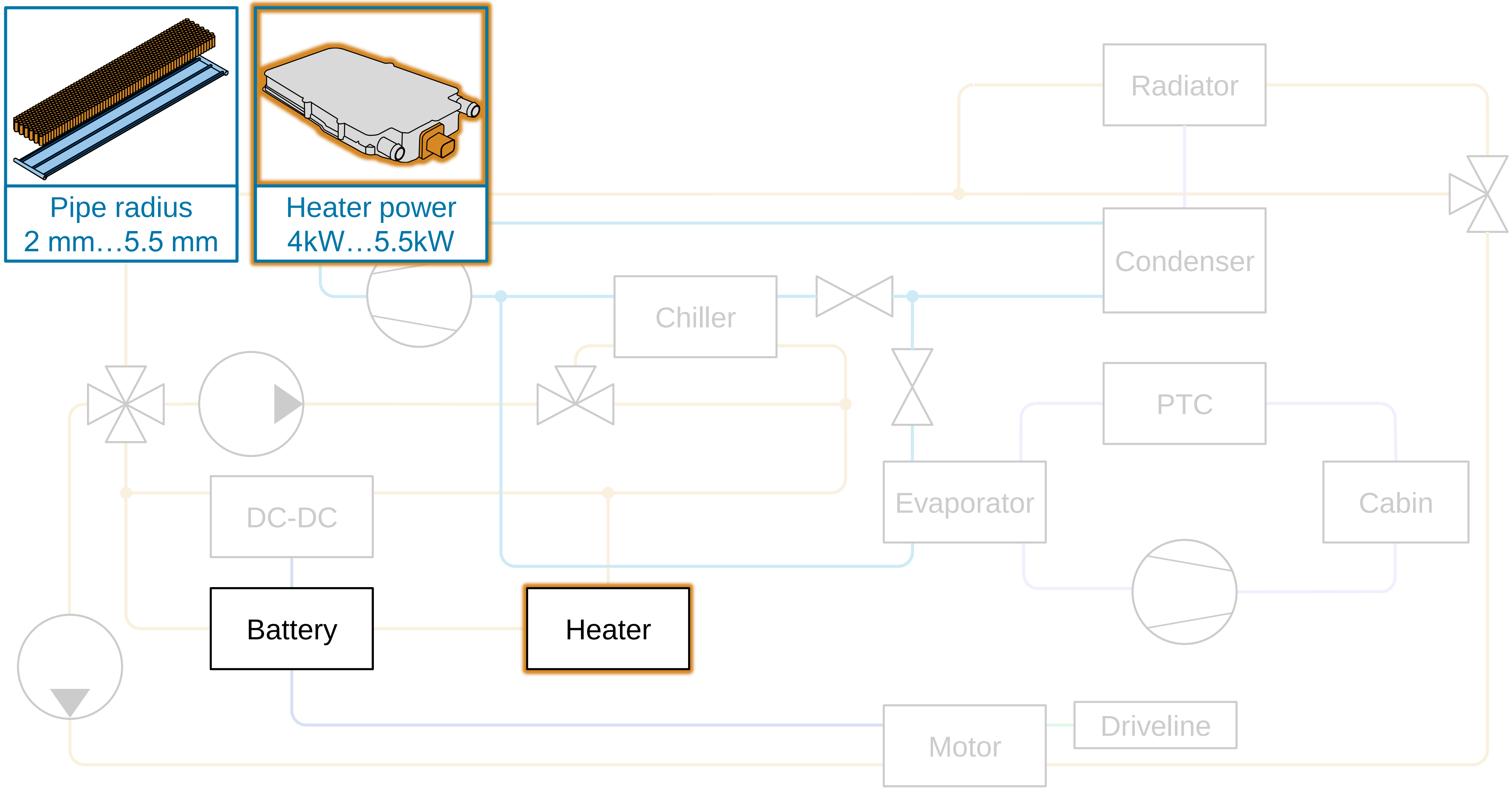
In the next step, the set of parameters is chosen

1st Parameter: Cooling pipe radius impacts on pressure losses and heat exchange with the battery

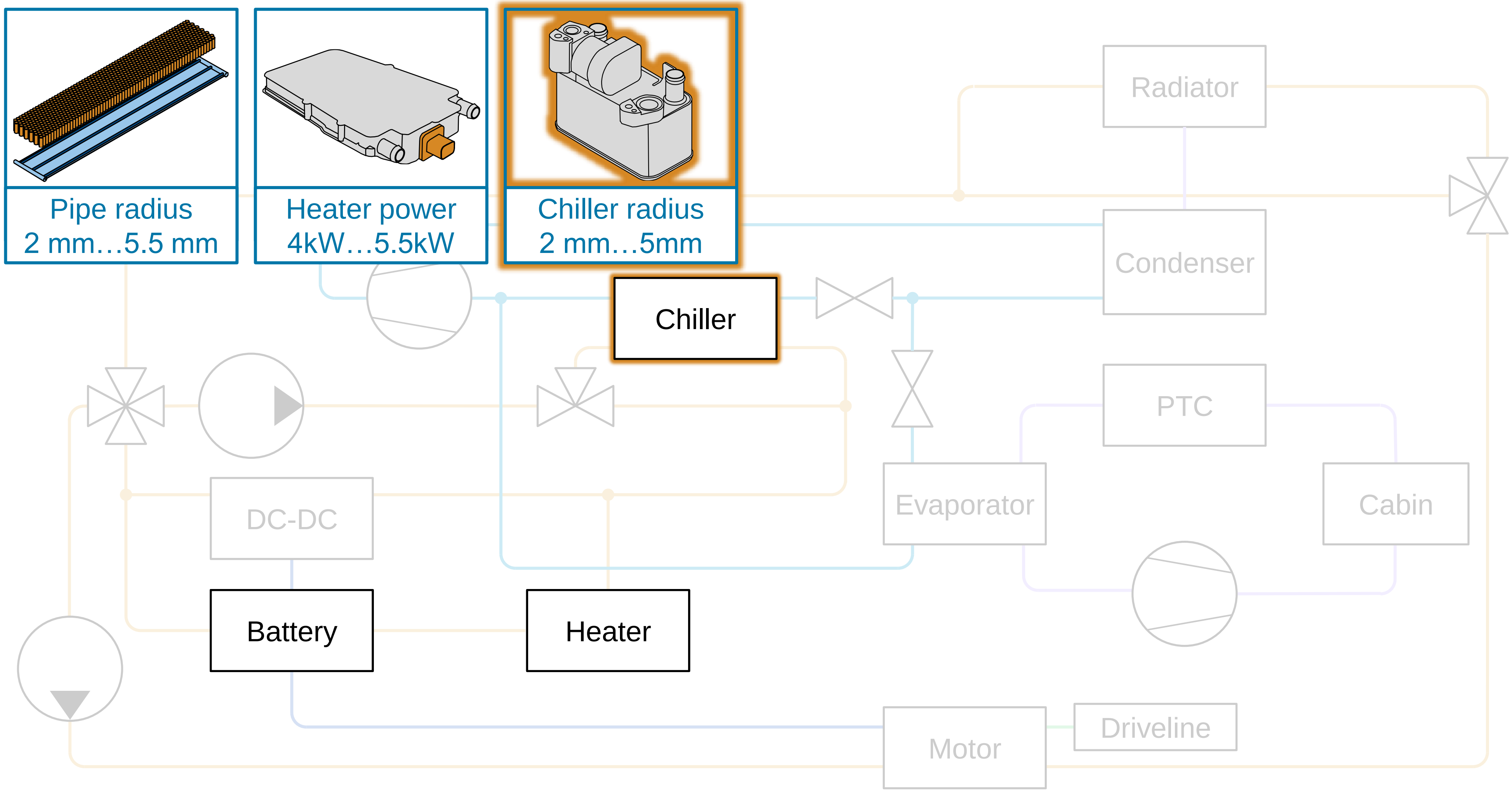


MATLAB EXPO

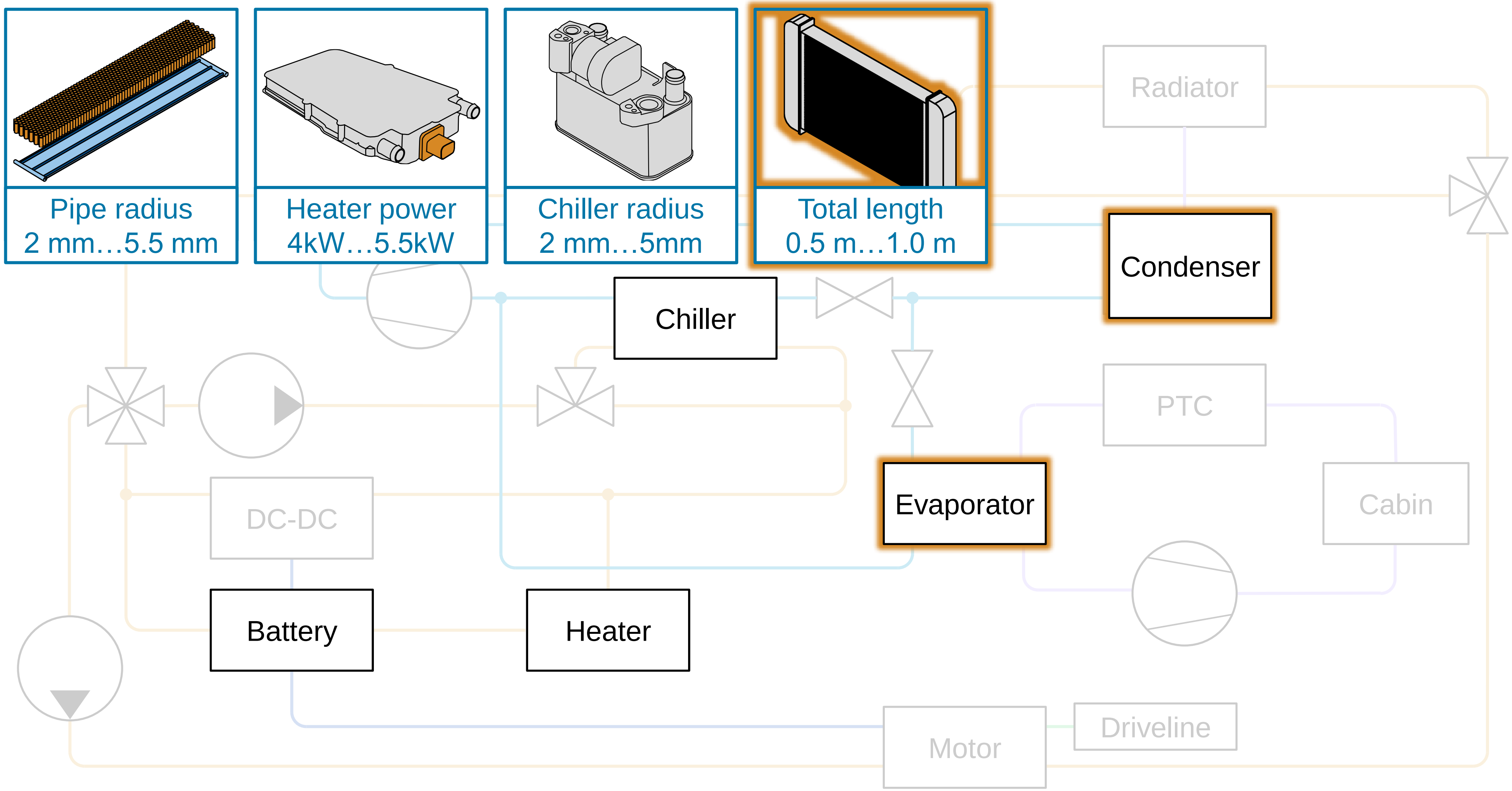
2nd Parameter: Heater power influences battery temperature in winter and impacts overall consumption



3rd Parameter: Chiller radius impacts on heat exchange and pressure losses

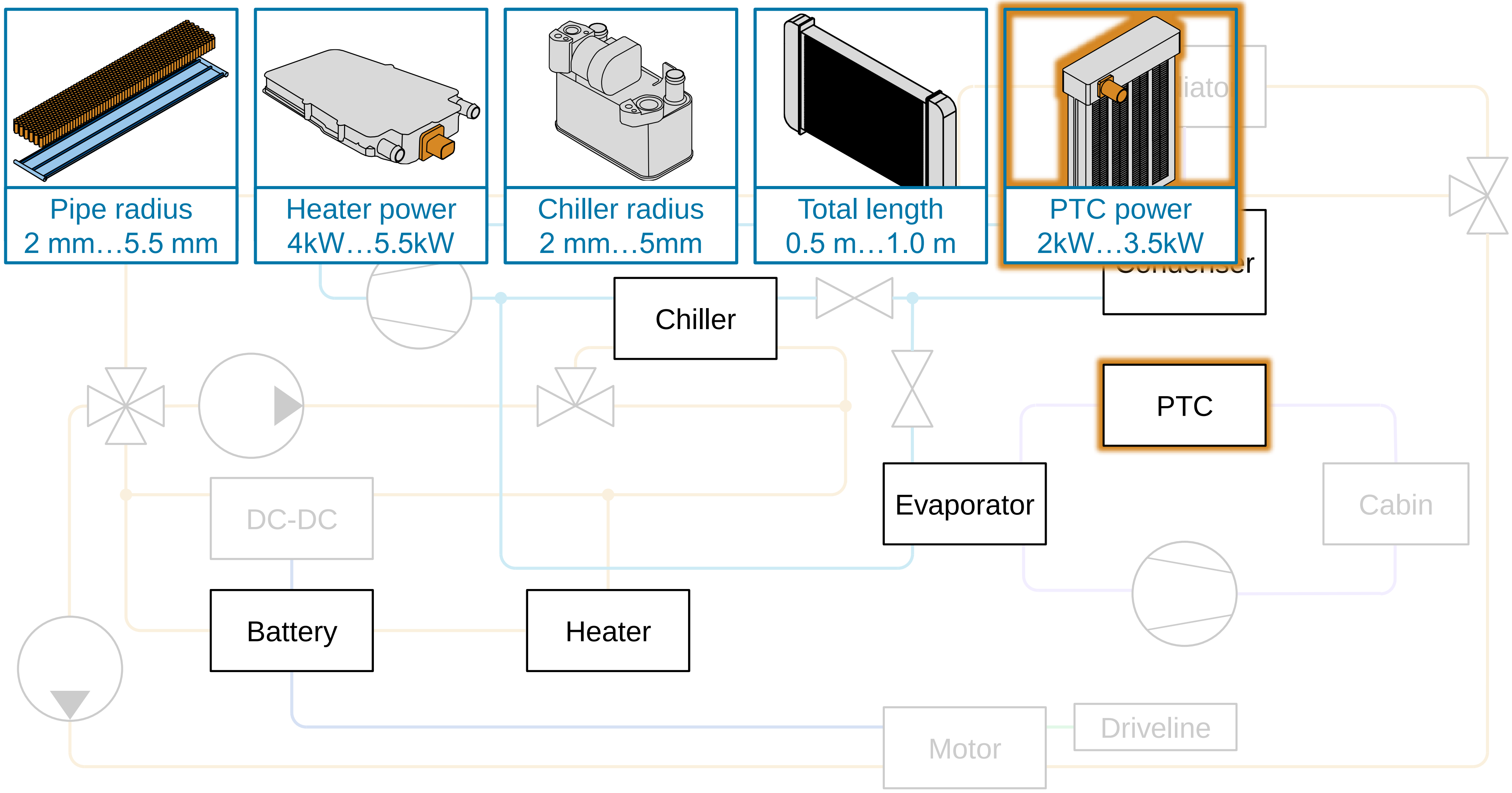


4th Parameter: The lengths of evaporator and condenser impact pressure losses and heat exchange

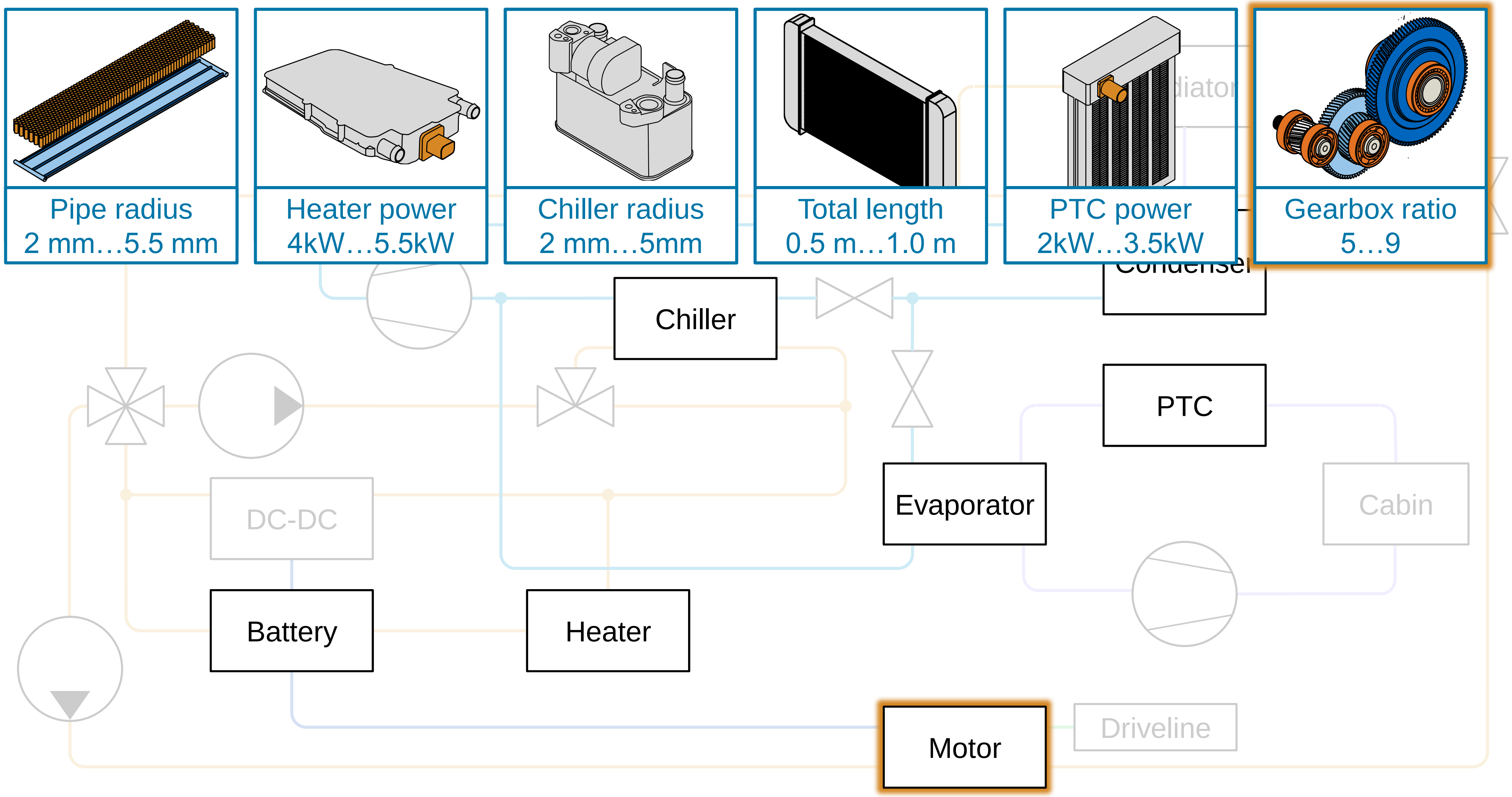


MATLAB EXPO

5th Parameter: PTC power influences cabin temperature in winter and impacts overall consumption

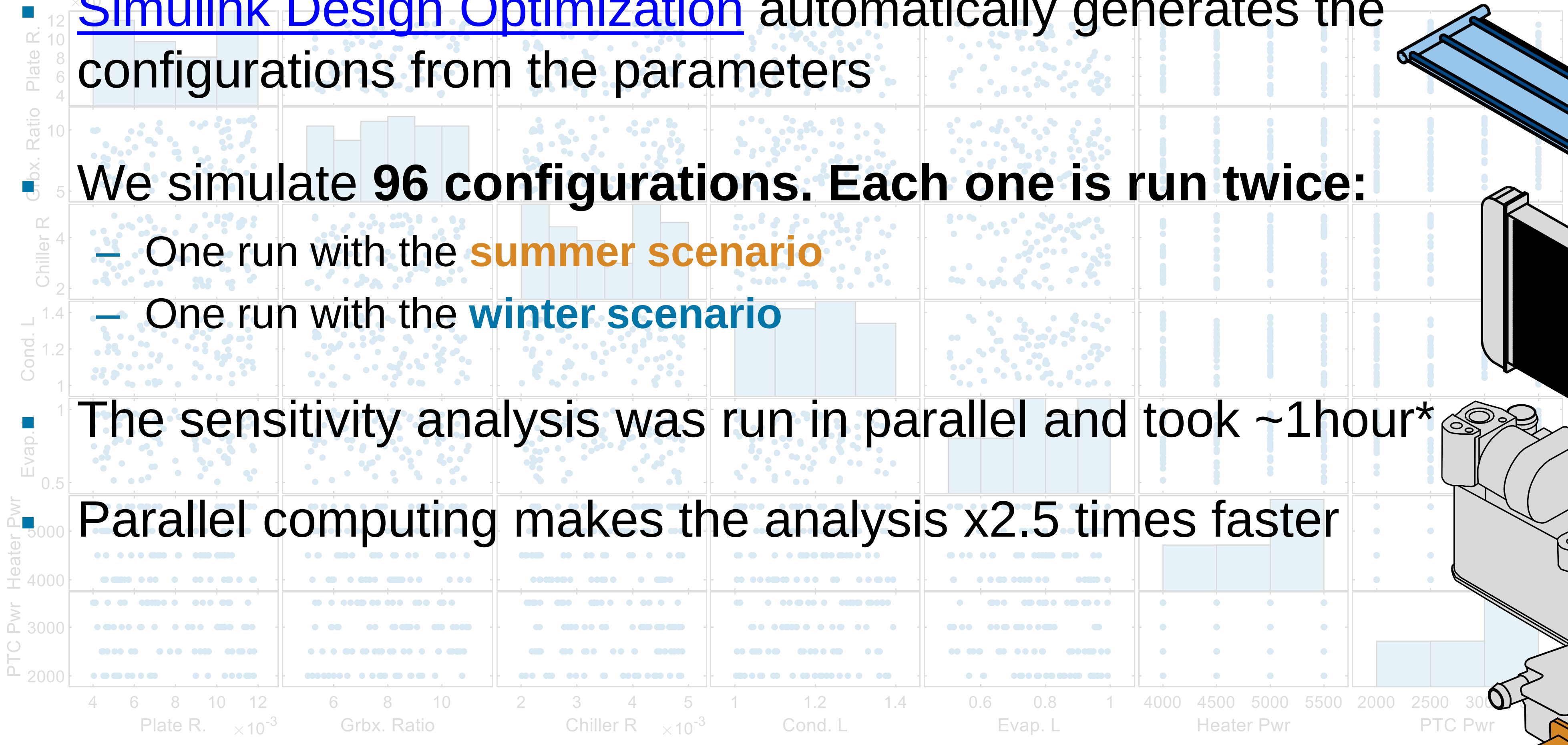


6^{th} Parameter: Gearbox ratio determines load points of the electric machine during the drive cycle

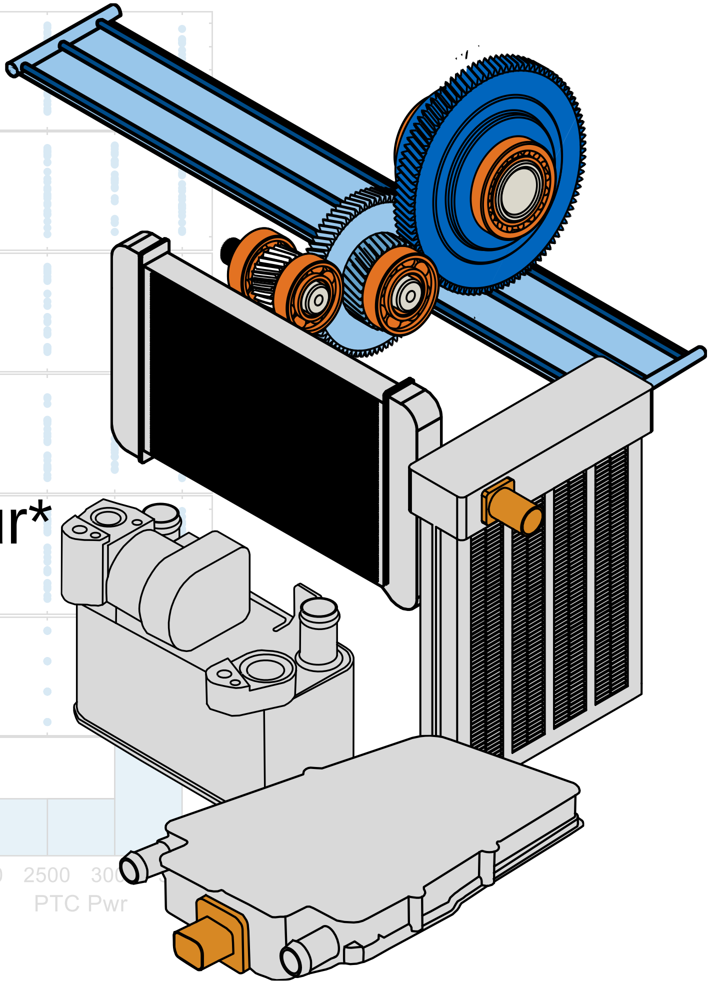


MATLAB EXPO

Once the objective and the parameters are chosen, we can set up the sensitivity analysis

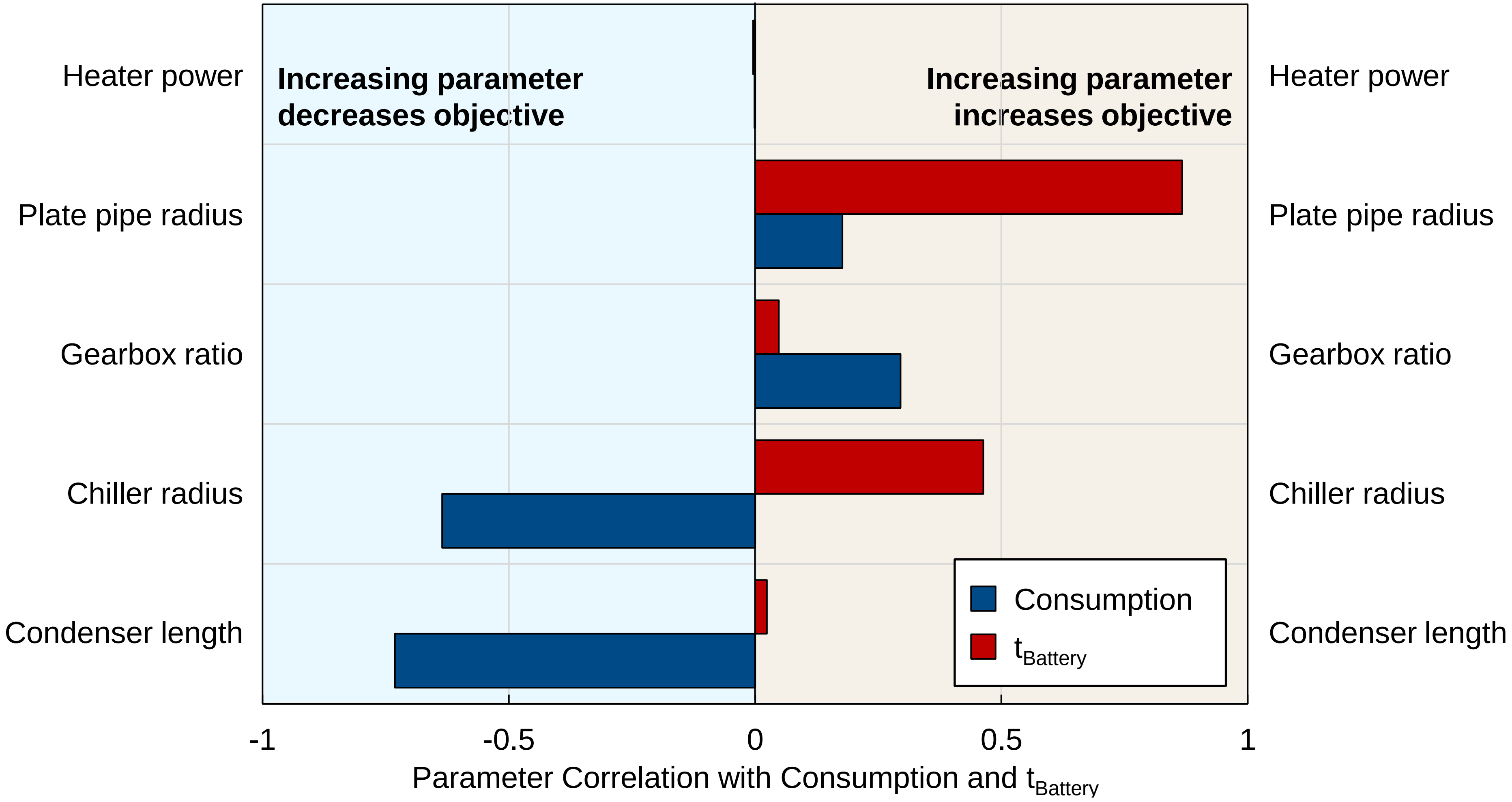


- Simulink Design Optimization automatically generates the configurations from the parameters
- We simulate **96 configurations. Each one is run twice:**
  - One run with the **summer scenario**
  - One run with the **winter scenario**
- The sensitivity analysis was run in parallel and took ~1hour*
- Parallel computing makes the analysis x2.5 times faster



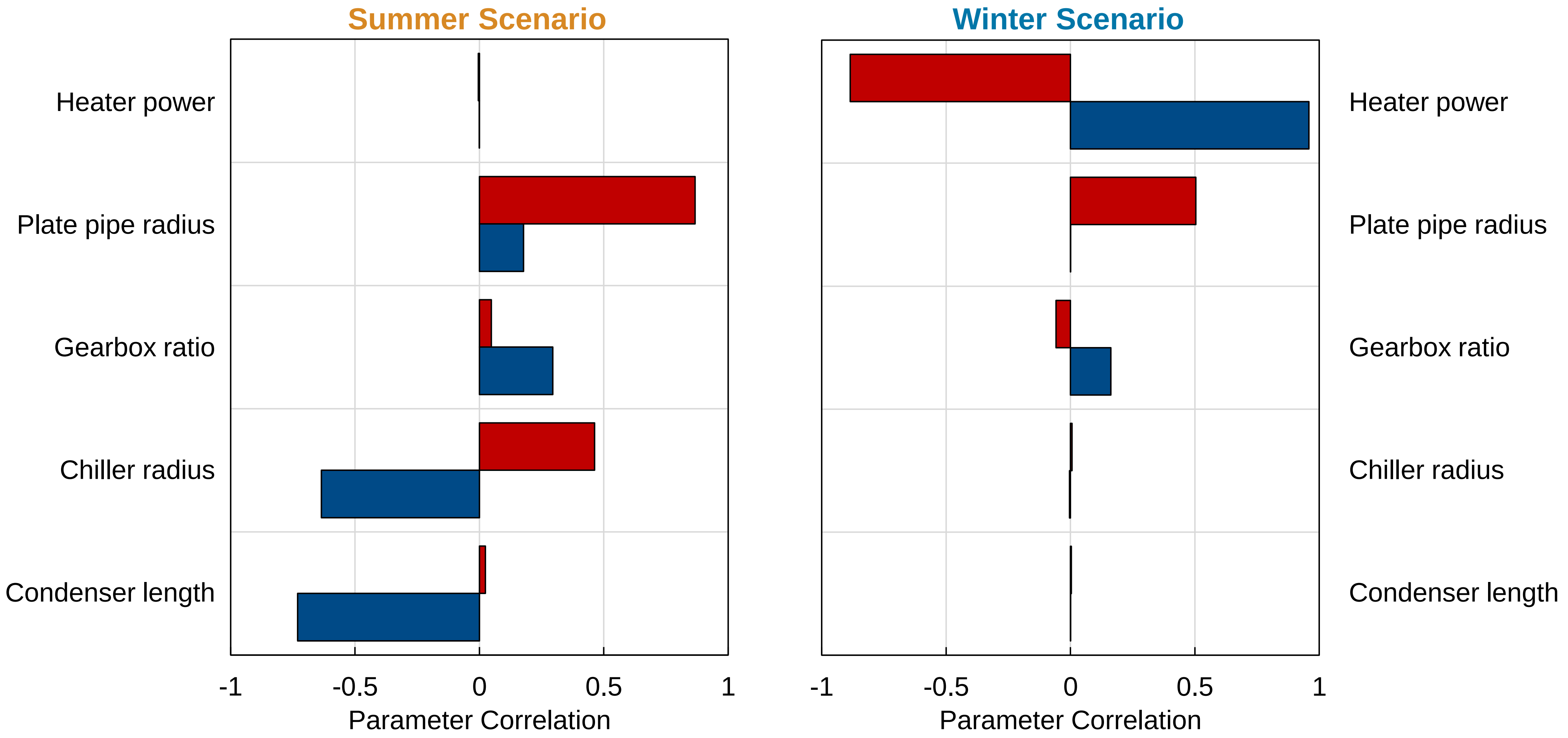
*Performed on a laptop with the following specs: 13th Gen Intel® Core™ i7-1365U, 32GB RAM, 8 cores

Summer Scenario: The tornado plot highlights the type of correlation between parameters and objectives



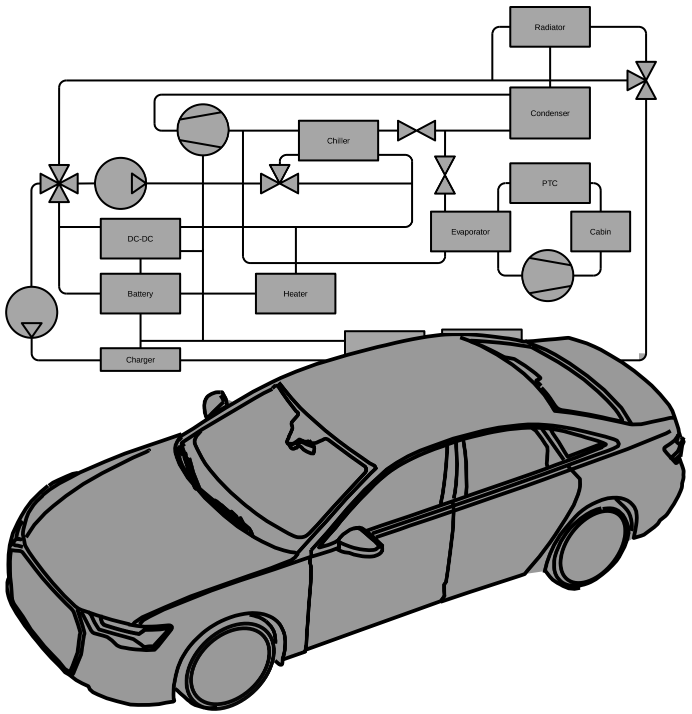
MATLAB EXPO

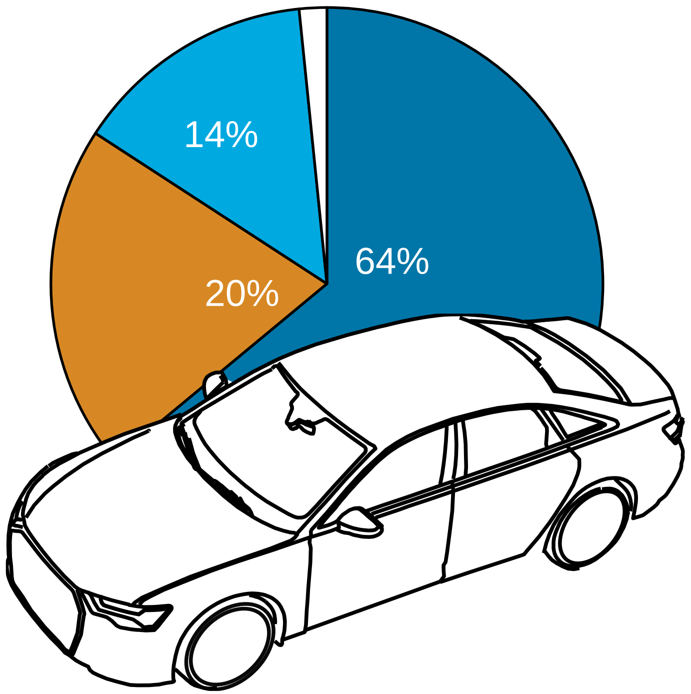
Comparison between winter and summer scenario highlights **completely different sensitivities**

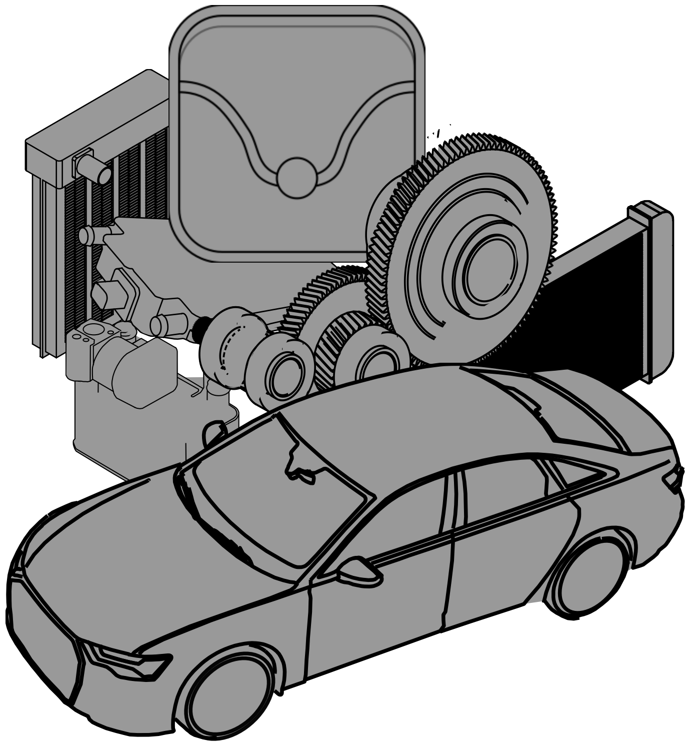


MATLAB EXPO

Use the BEV model to **understand your design**





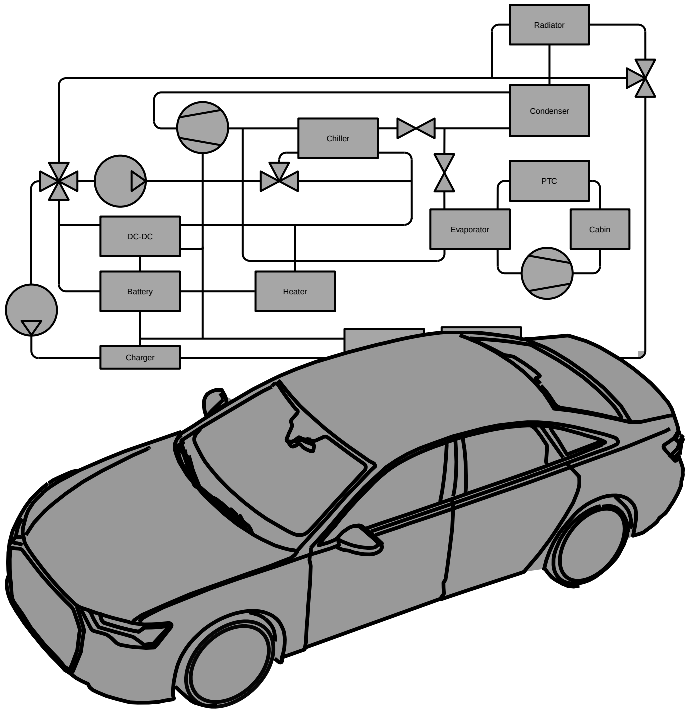


Build Holistic BEV Model

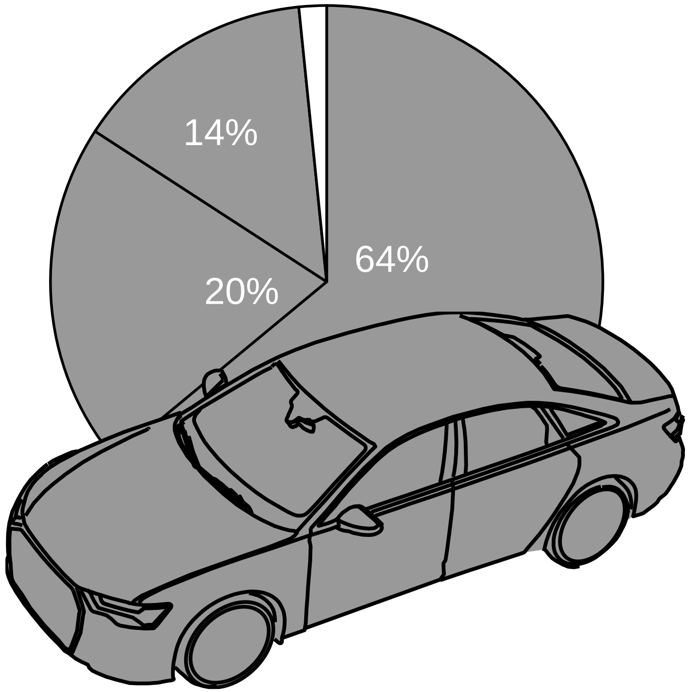
Simulate & Analyze

Optimize

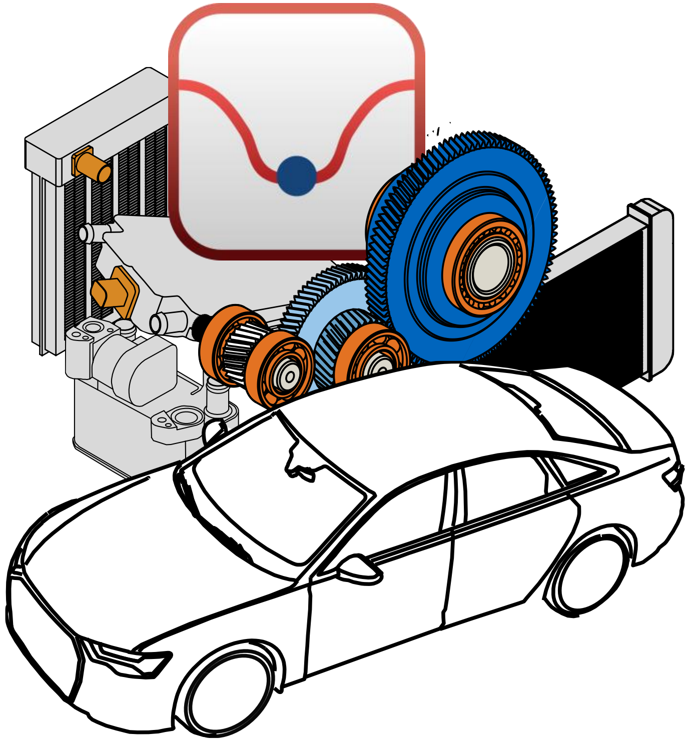
Use the BEV model to **optimize your design**



Build Holistic BEV Model



Simulate & Analyze



Optimize

The objective is to reduce consumption while ensuring acceptable thermal management performance

- **Goal:** Minimize combined consumption[1]

  $$f(x) = s_{Summer} \times \text{Consumption}_{Summer} + s_{Winter} \times \text{Consumption}_{Winter}$$

- **Constraint:** Battery & cabin reach target temperature quickly
  - C1: $t_{Battery} \leq 600$ sec
  - C2: $t_{Cabin} \leq 720$ sec

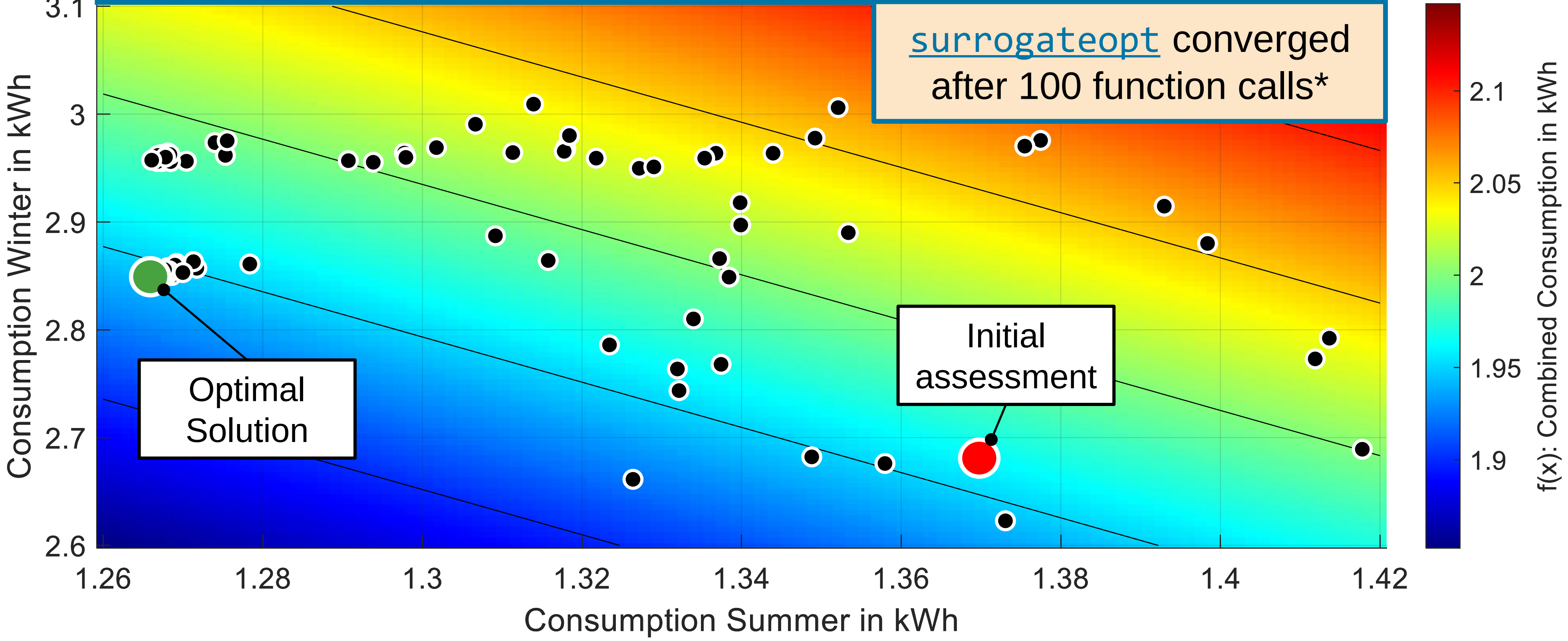
- **Design Parameters:**
  - D1: Plate pipe radius
  - D2-D3: Heater and PTC power
  - D4: Chiller radius
  - D5-D6: Evaporator and condenser length
  - D7: Gearbox ratio

The algorithm of choice is `surrogateopt`[2]

[1] s_{Summer} and s_{Winter} are scaling factors [2] Nonlinear, global optimizer for mixed-integer problems with inequality constraints

surrogateopt finds an optimal solution that satisfies the constraints for battery and cabin

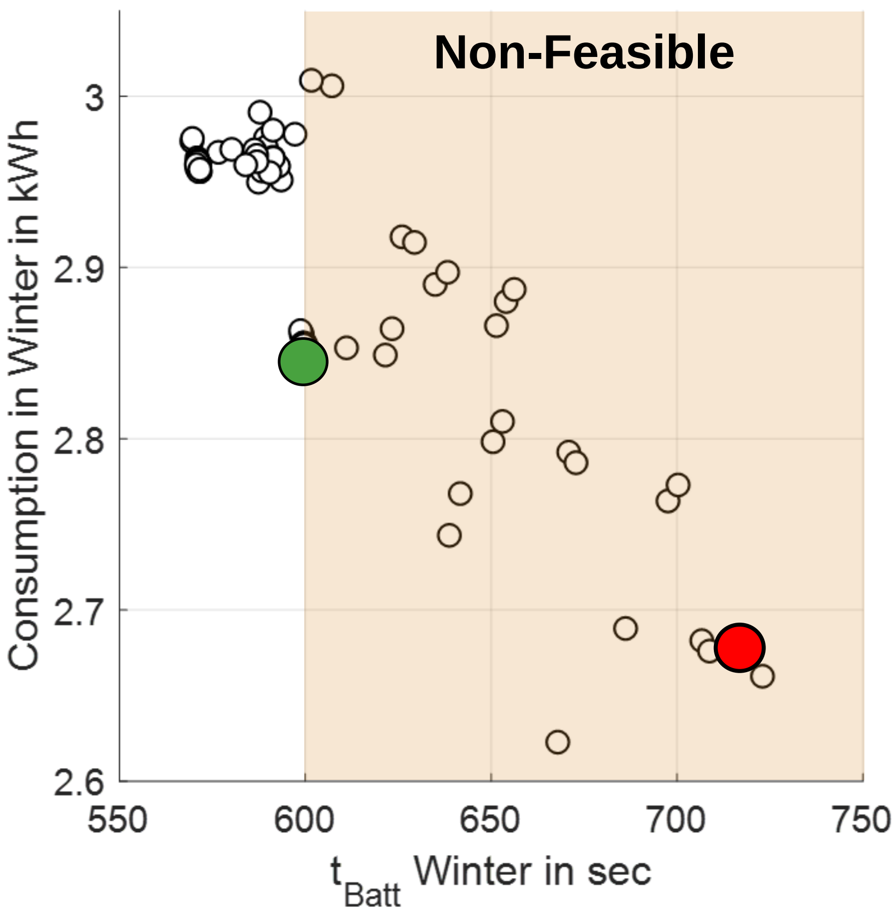
	Grbx. Ratio	Evp. Length	Chiller Diam	Cond Length	Heater Pwr	PTC Pwr	Plate Diam
	9	0.75 m	0.0035m	1.2 m	4 kW	2.5 kW	0.009
	5	0.74 m	0.005m	1.4 m	5 kW	3 kW	0.004

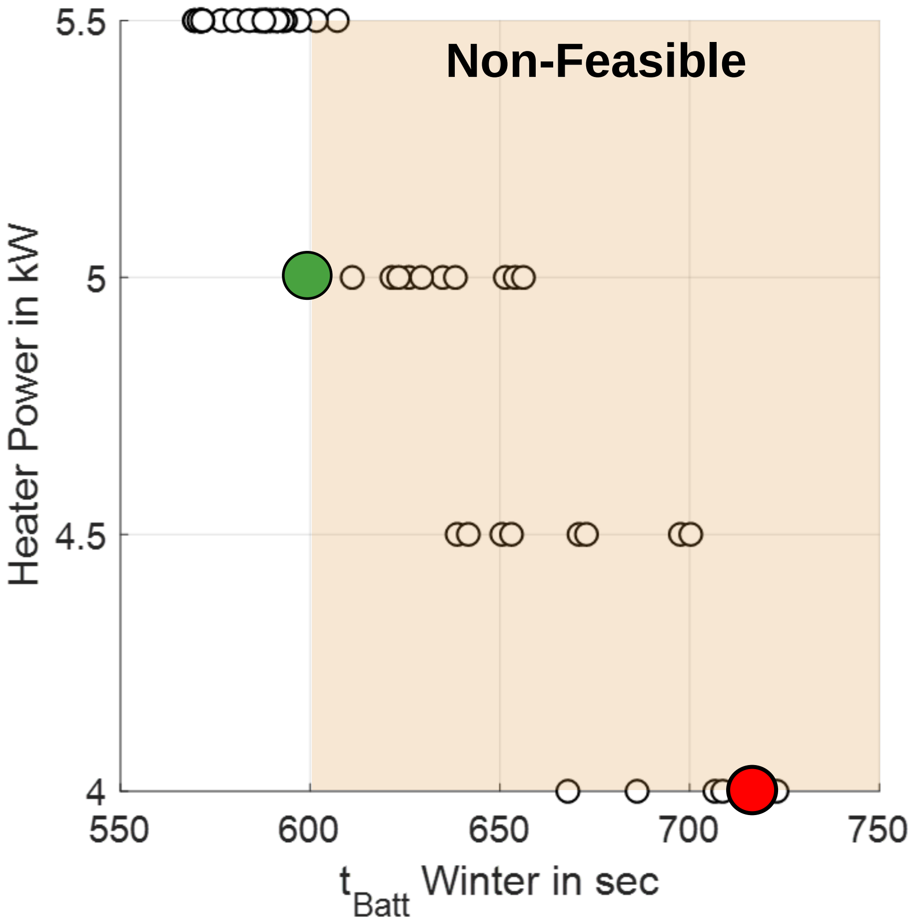


*Optimization lasted ~1h on a laptop with these specs: 13th Gen Intel® Core™ i7-1365U, 32GB RAM, 8 cores

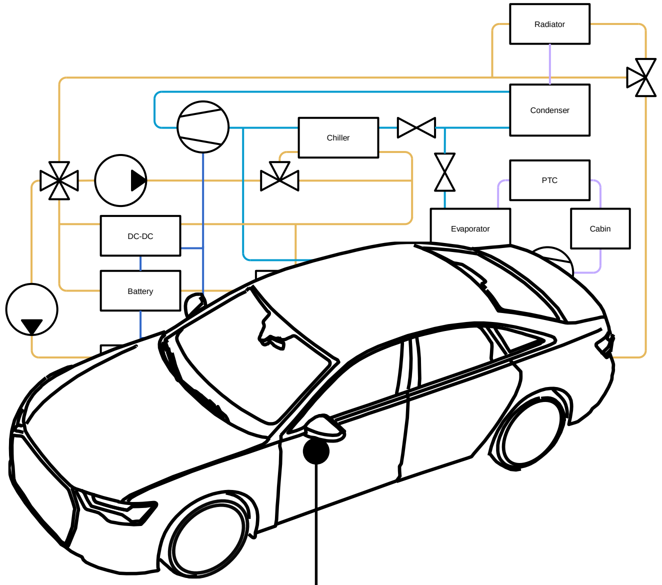
MATLAB EXPO

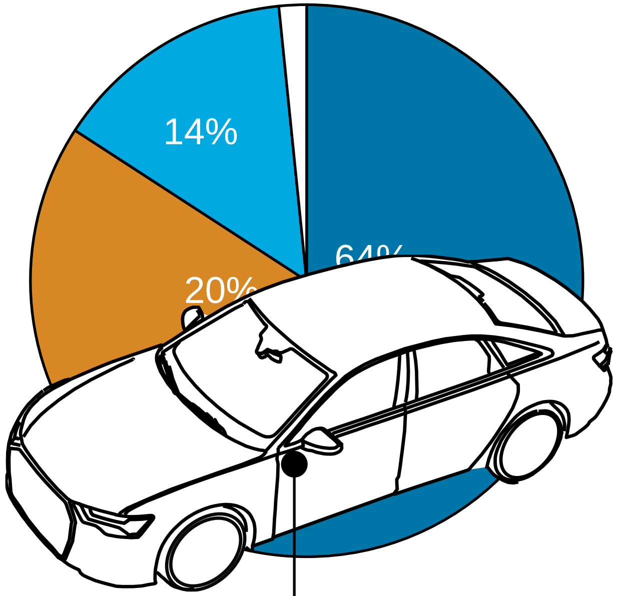
The constraint for heating the battery in less than 600 sec is fulfilled at the cost of a slight increase in consumption

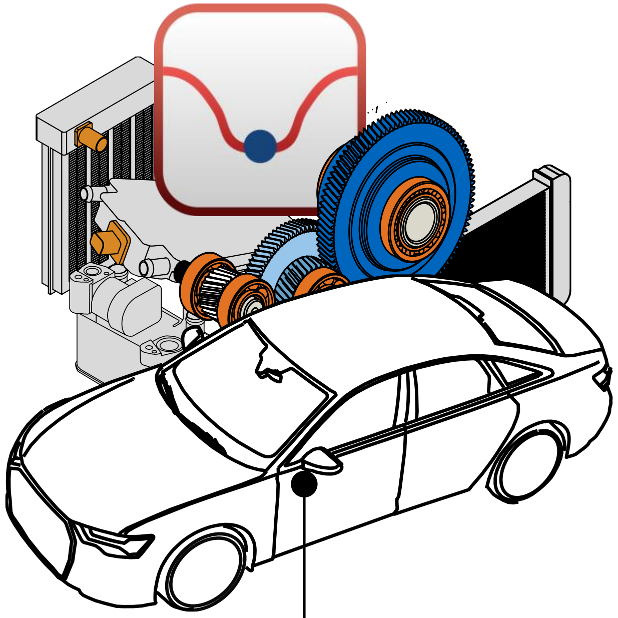




In summary, MathWorks enables smooth workflows for building, analyzing, and optimizing your design







Key Takeaway I	**Key Takeaway II**	**Key Takeaway III**
Model complex multi-domain physical systems with Simscape	Easily and quickly set-up a sensitivity analysis with Simulink Design Optimization	Easily optimize designs with multiple variables and constraints with surrogateopt

MATLAB EXPO

Thank you

MathWorks