

# THERMAL MANAGEMENT IN BATTERY ELECTRIC AND HYBRID VEHICLES IN COLD CLIMATES

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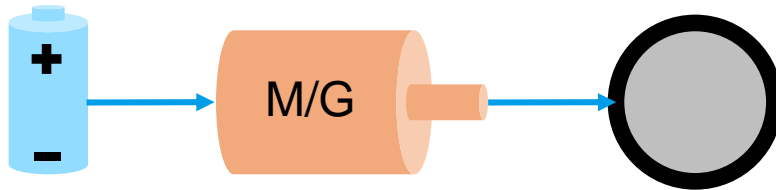
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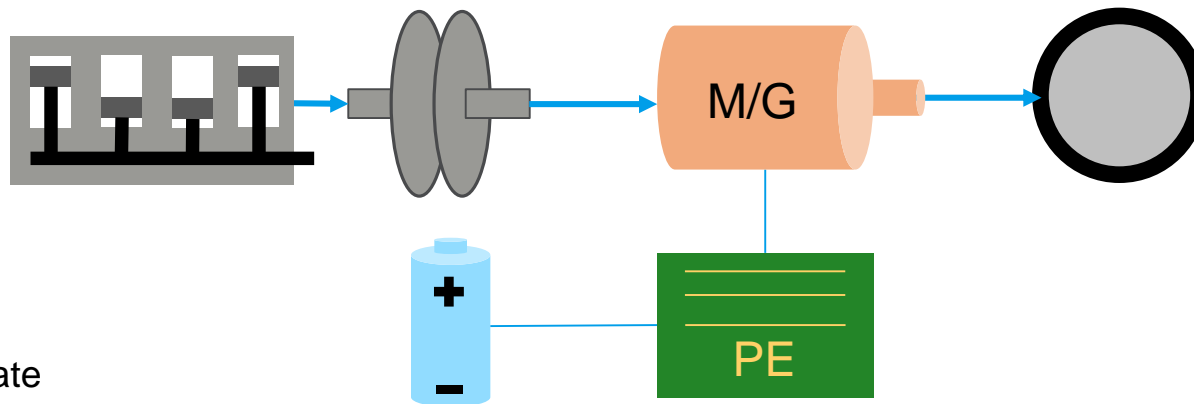
# Area of Research

## Vehicles

### Battery electric vehicle (BEV)



### Full parallel plug in hybrid electric vehicle (PHEV)



## Climate

- Cold, -20°C with no consideration given to solar heating.

Issues concerning the battery and cabin.

- High demand on the cabin heating system, with no engine waste heat
- Defrosting requirements
- Poor battery power capability due to higher internal resistance
- Reduced battery capacity
- Increased battery ageing (during charging/regenerative braking)

For vehicles with ICE

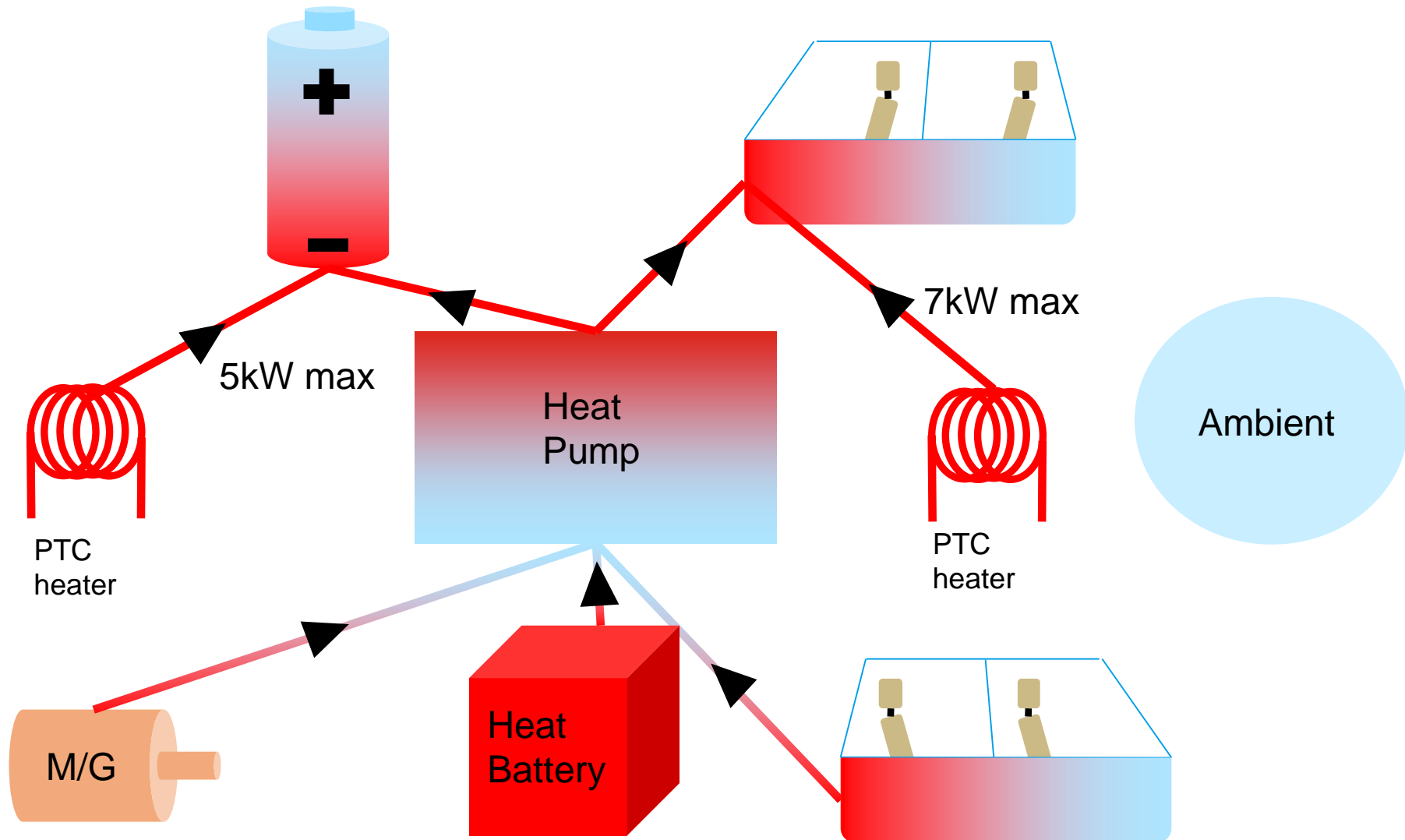
- Increased emissions/fuel consumption due to cold start

Optimizing a heat pump/heat battery thermal management system to give the most efficient performance at low temperatures. Focusing on the case of BEV or PHEV in EV only mode.

The scope of this project includes

- Passenger thermal comfort
- Battery performance at low temperatures
- Battery ageing (especially while charging)

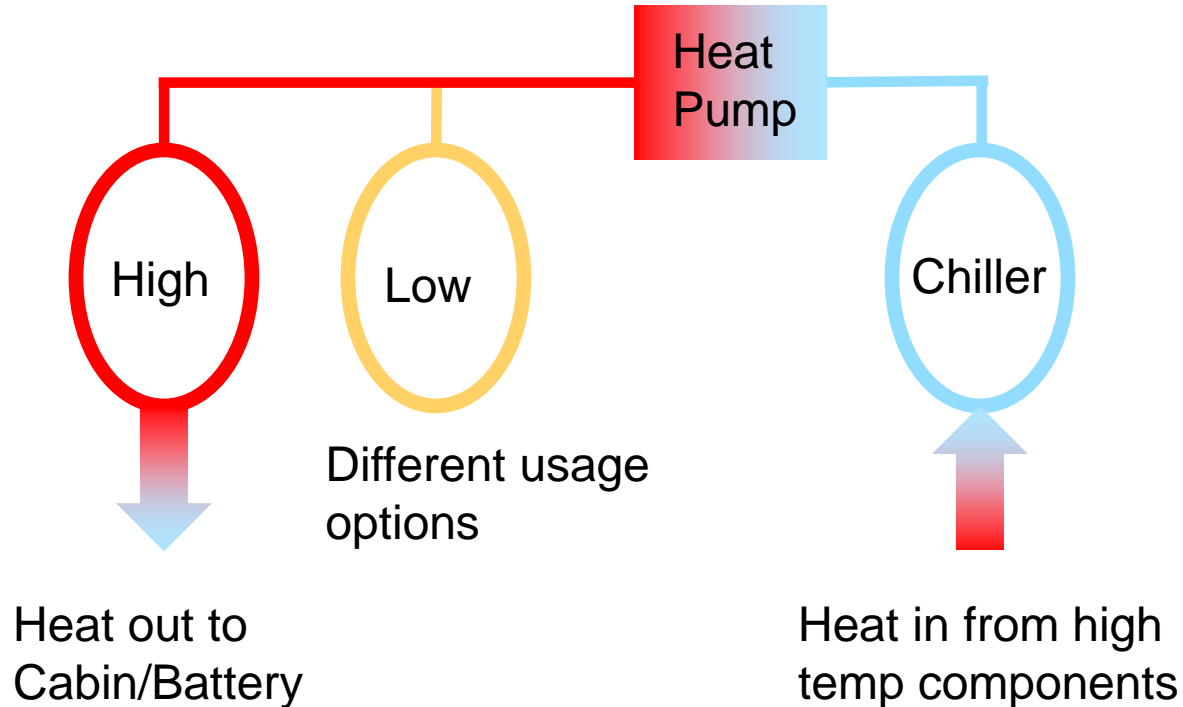
# System Diagram



## Configuration

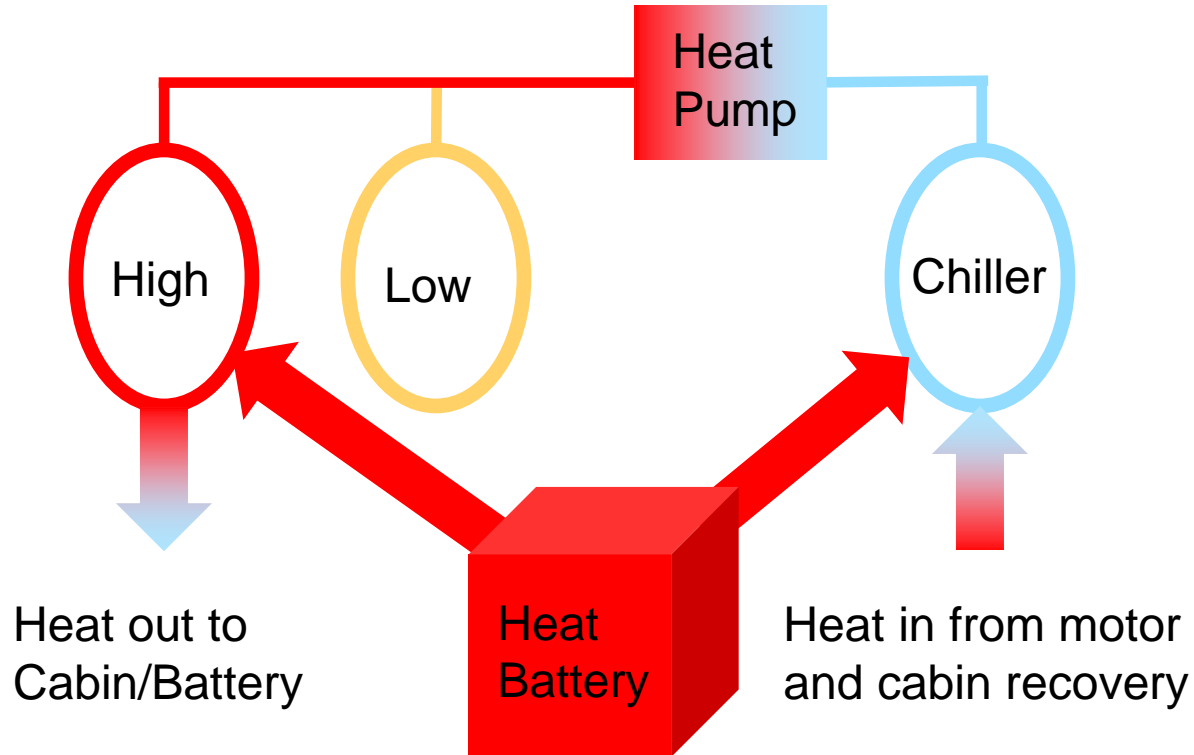
- Three loops, high temperature, low temperature and chiller.

$$\text{Power} = \text{Chiller\_Q\_flow} \div (\text{COP} - 1)$$



# The Heat Pump

## Optimum Scenario



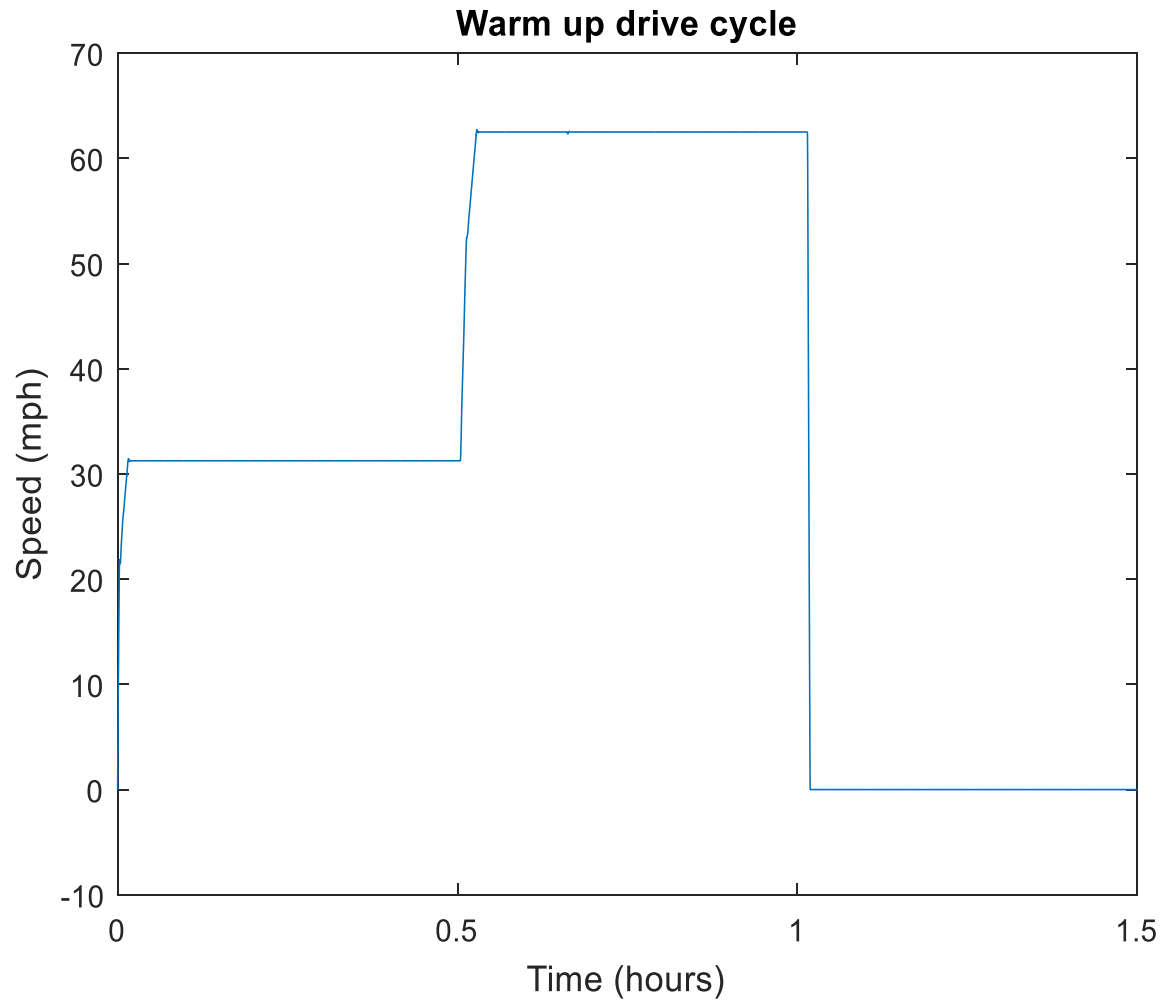
## Phase Change Material

- Melting Point - 80°C
- Specific Thermal Capacity – 2500 J/K kg
- Latent Heat Capacity – 190,000 J/kg
- Total energy release from fully charged (90°C ) to empty (0°C) – 415,000 J/kg (0.12 kWh/kg)

## Sizing

- 20kg package to be used in BEV
- 10kg package to be used in PHEV

# The Drive Cycle



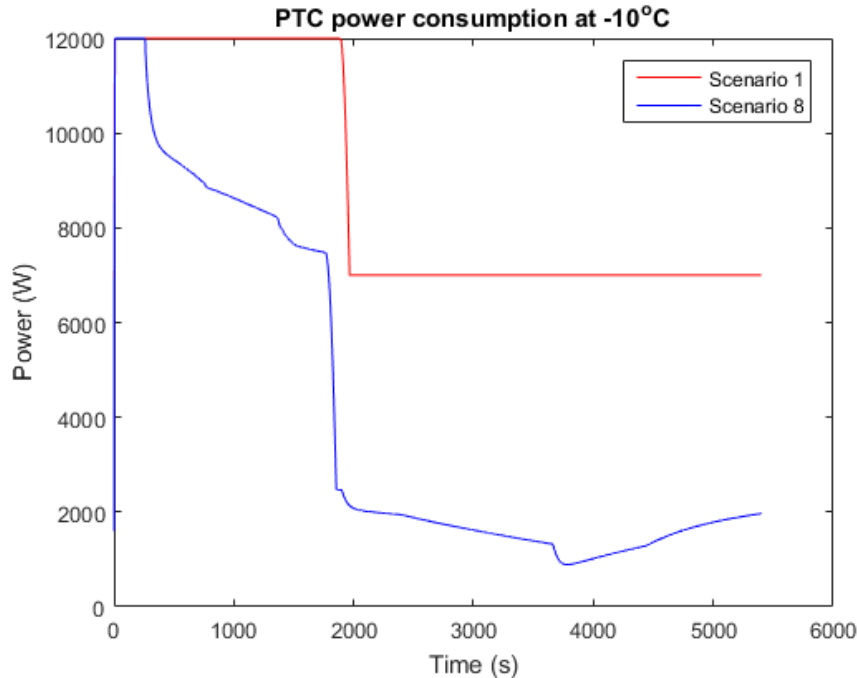
# Heating Scenarios

Scenario	PTC heaters	Heat Pump	Heat Battery Preconditioned	M/G
1	✓	✗	✗	✗
2	✓	✗	✓	✗
3	✓	✓	✓	✗
4	✓	✓	✓	✗
5	✓	✓	✓	✗
6	✓	✓	✗	✗
7	✓	✓	✗	✓
8	✓	✓	✓	✓

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6	✓	✓	✗	✗
8	✓	✓	✓	✓

# PTC Power and Energy Consumption



## Scenario 1

$$E_{PTC}^{-10^{\circ}C} = 0.98 E_0$$

## Scenario 8

$$E_{PTC}^{-10^{\circ}C} = 0.46 E_0$$

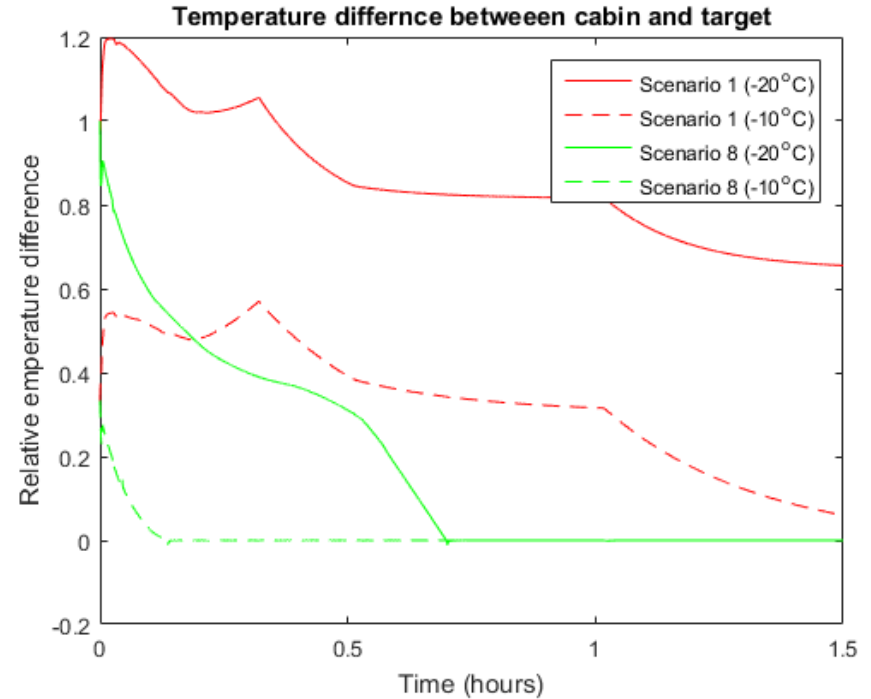
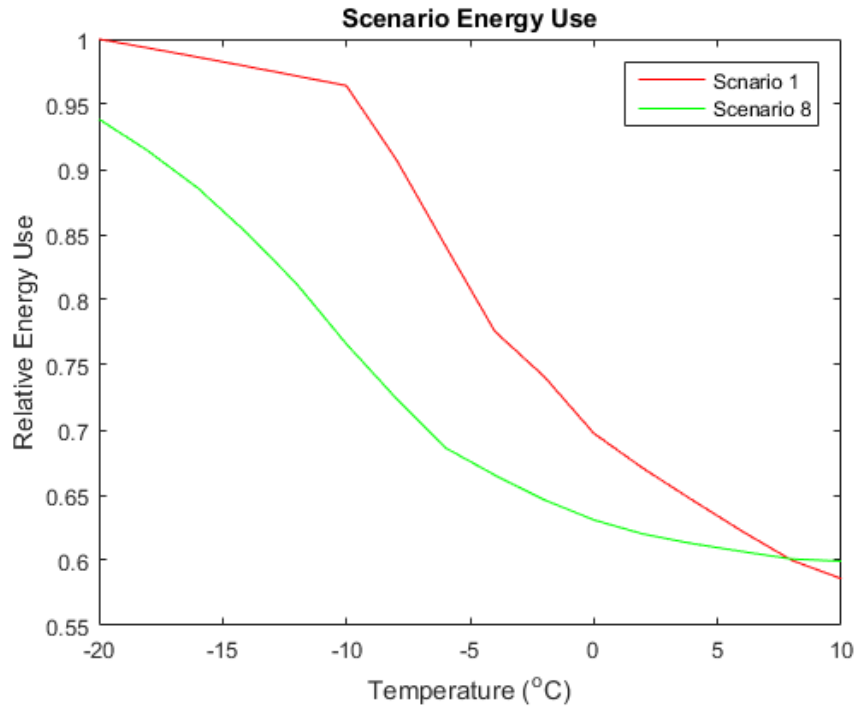
$$E_{HP}^{-10^{\circ}C} = 0.04 E_0$$

$$E_{total} = 0.5 E_0$$

$E_0$  is the energy consumed through the drive cycle with an ambient temperature of 22°C. No power is used on heating in this case.

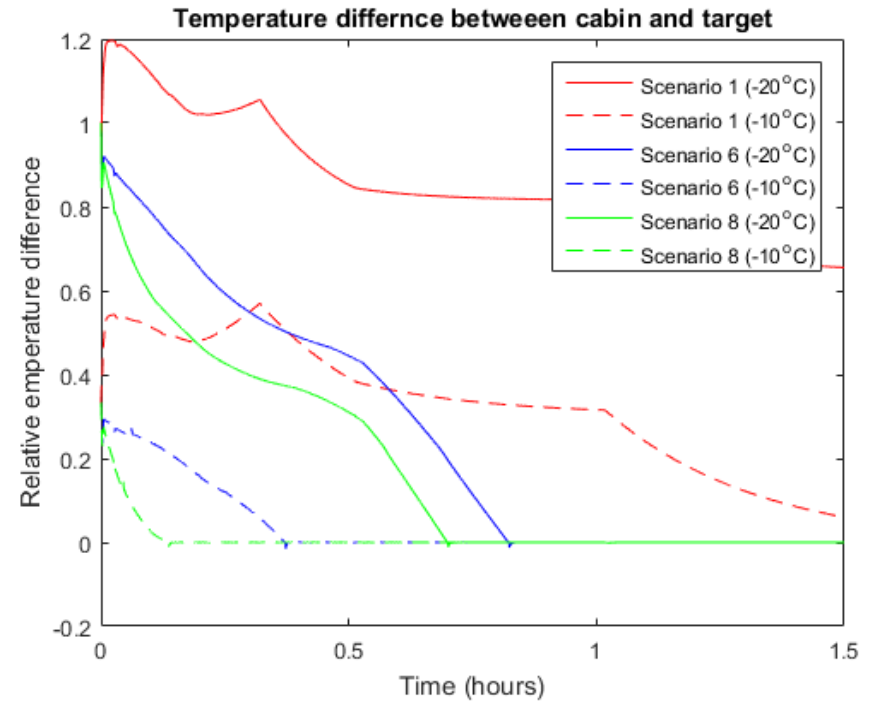
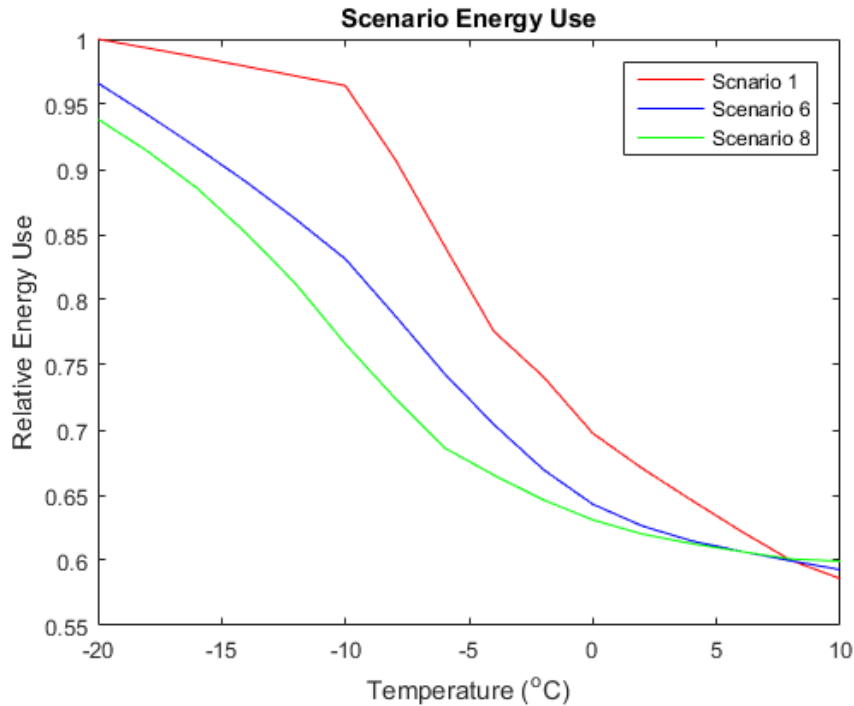
- Scenario 1, PTC power stays full for cabin for duration of cycle
- Scenario 8, PTC power is able to reduce to lower power, but still needs to support heat pump in heating cabin.

# Comparison to PTC Heating Only



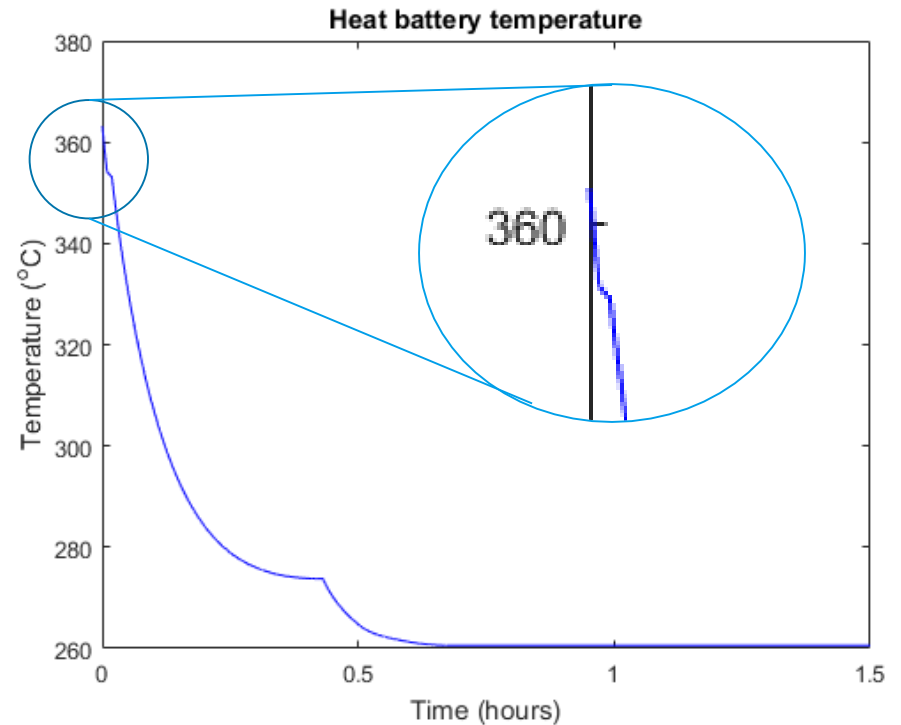
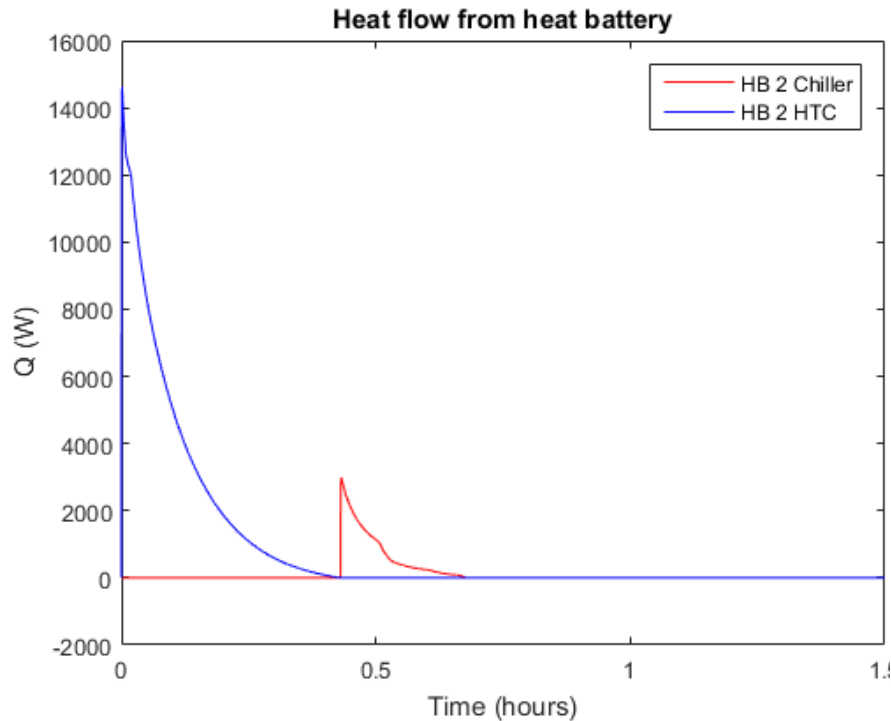
- Up to 20% energy saving at -10°C
- Large savings through 0 to -20 (min 6%)
- Improved ability to reach cabin target temperature

# Comparison of Heat Battery and Motor to Just Heat Pump



- Must use waste heat around the vehicle to get highest savings
- Improved ability to reach cabin target temperature

# Heat Battery Performance



- Heat from the battery flows to HTC then Chiller
- Latent heat holding temperature at melting point, supplying more heat

General development of the model.

- Top level system model, many sub-models
- Parameterizing the electric battery down to  $-30^{\circ}\text{C}$
- Validating electric battery pack model
- Testing compatibility with high temperature scenarios
- Validating assumptions made about the heat battery
- Battery ageing model and minimization

## Improvements to the system

- Component sizing optimization
- Heat flow management options
- Other opportunities for heat extraction