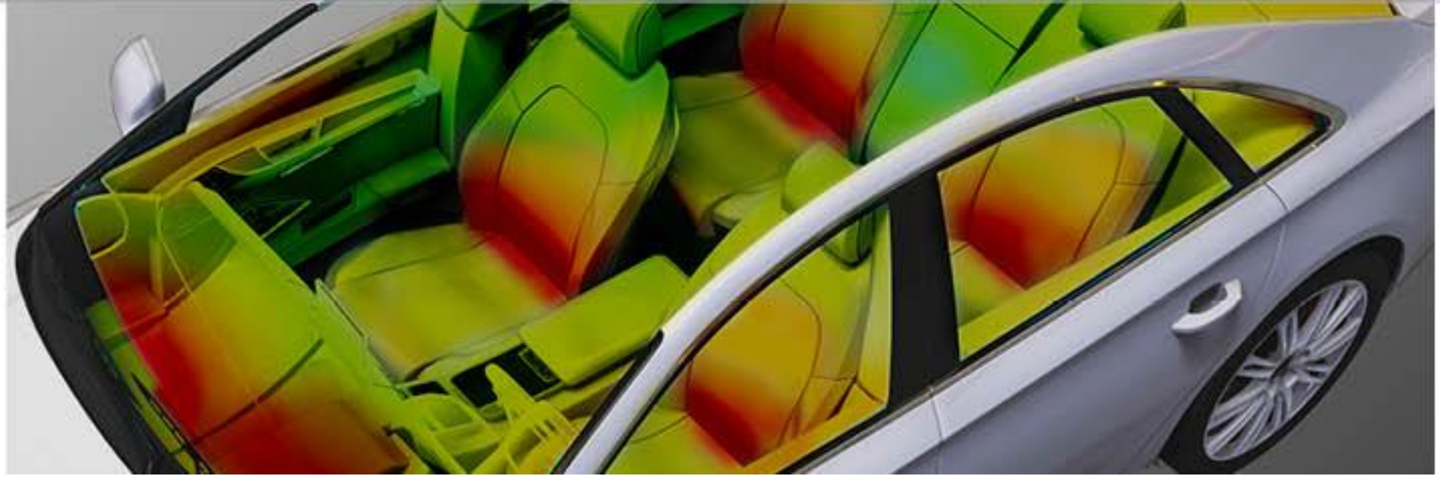
SAE INTERNATIONAL



Thermal Management Systems Symposium

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Ypsilanti, Michigan

DRAFT VERSION

NOT FOR PUBLICATION

Comparis[illegible]uation of R290 Refrigera[illegible]ystems for Electric Vehicles

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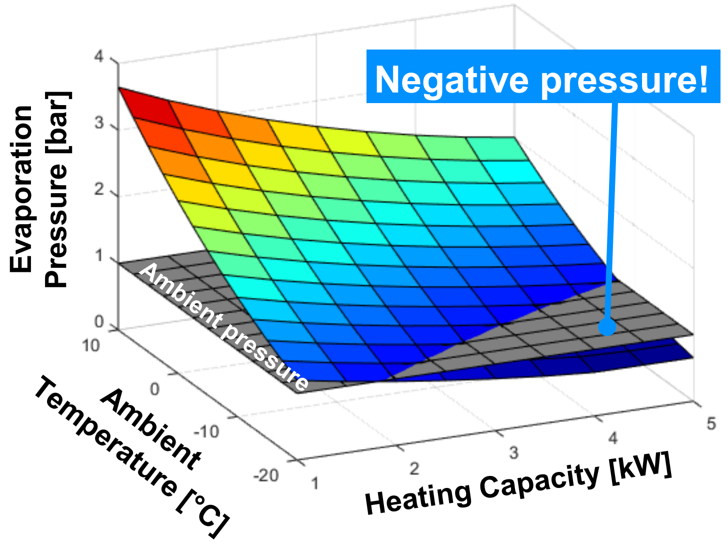
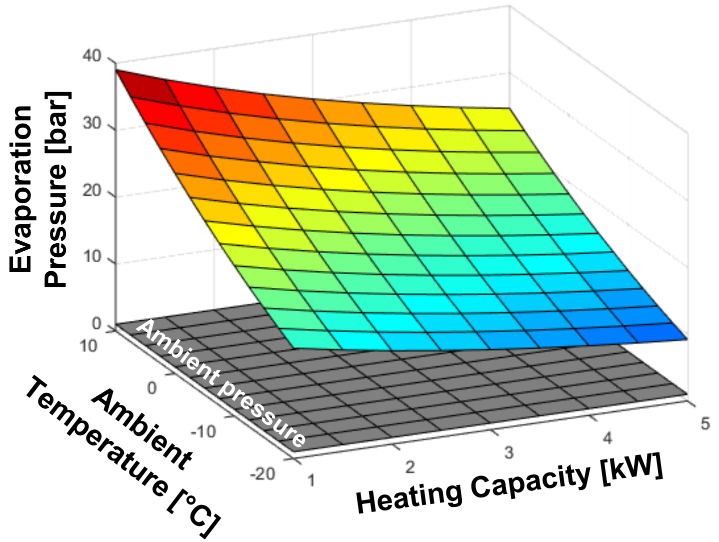
IAV

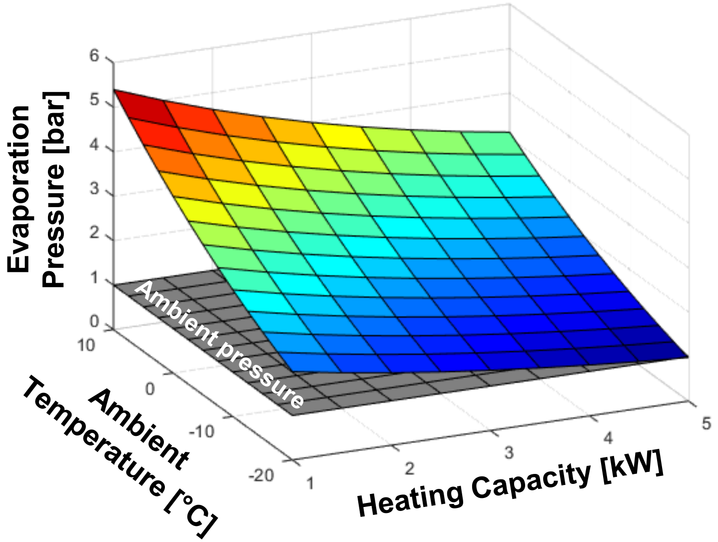
Motivation

- **The investigation and development of R290 refrigerant cycles are a major focus for many OEMs and suppliers.**
- **Main reasons: PFAS regulations, heat pump usage even at low temperatures, cost pressure for system and components**

R1234yf	**R744 (CO_2)**	**R290 (Propane)**







R1234yf

- **Widely used refrigerant, but PFAS!**
- **Limitations already at temperatures below -5 °C**

  ➔ PTC-Heater or other technical solutions required

R744 (CO_2)

- **favored refrigerant for very low temperatures**
- **very high system pressure (> 100 bar)**

  ➔ requires specially designed components (high costs)

R290 (Propane)

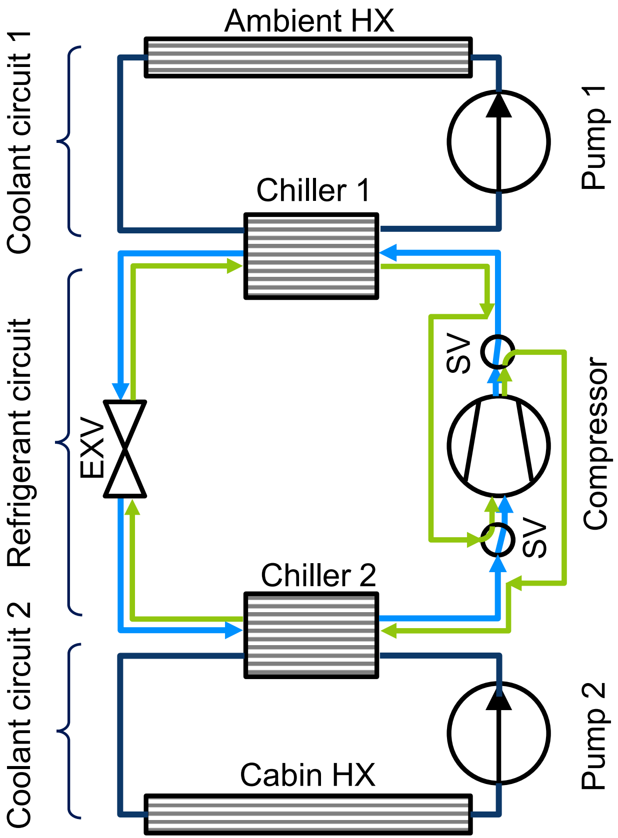
- **suitable for significantly lower temperatures than R1234yf**
- **only slightly higher pressures**
- **Highly flammable**

  ➔ safety concept required!

Hint: if evaporation pressure < ambient pressure ➔ negative pressure in the system ➔ tightness cannot be guaranteed ➔ negative pressure must be avoided!

Motivation

- **The investigation and development of R290 refrigerant cycles are a major focus for many OEMs and suppliers.**
- **Main reasons: PFAS regulations, heat pump usage even at low temperatures, cost pressure for system and components**
- **Due to safety concerns, there is a trend towards designing R290 circuits as fully indirect systems**
- **Simplified circuit:**



Advantages:

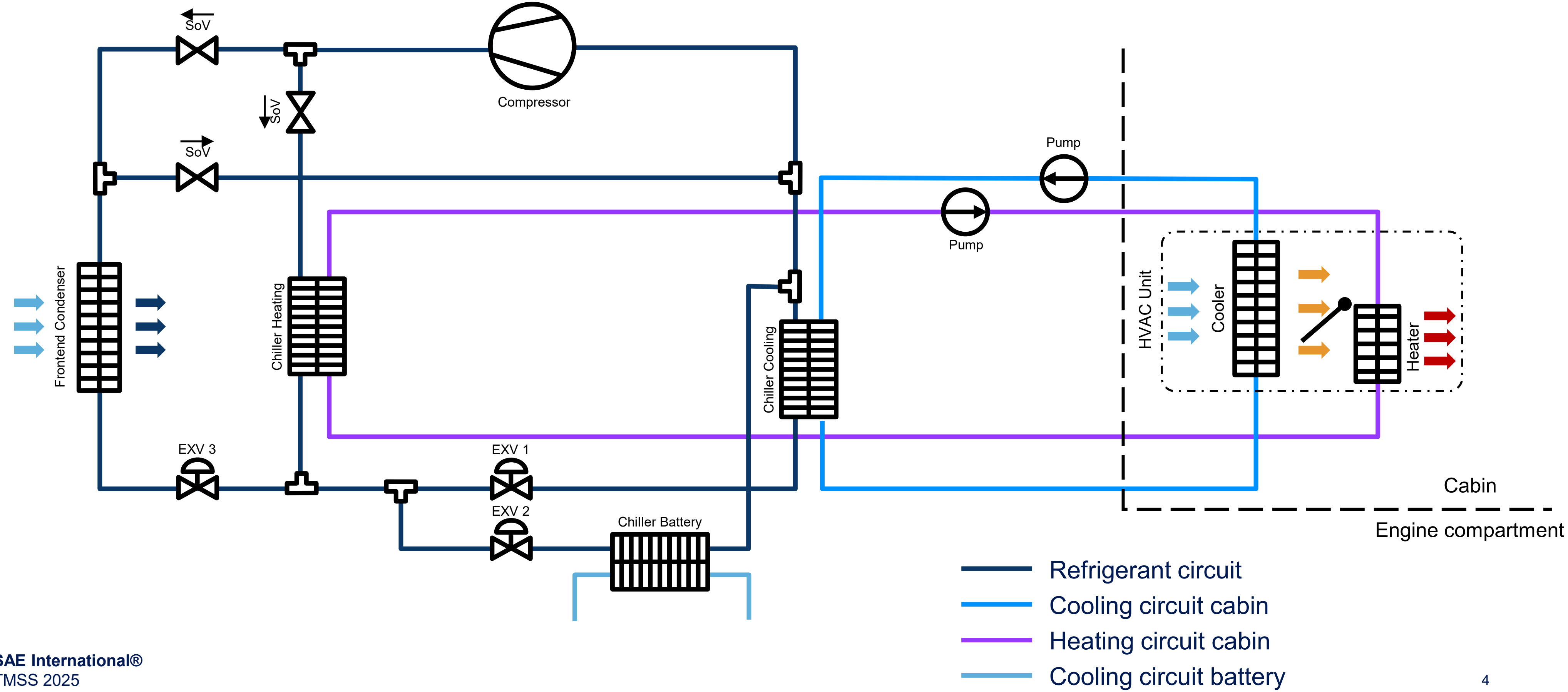
- very compact refrigerant circuit → low refrigerant charge
- Compact system might be filled and tested by the supplier
  → no flammable refrigerant at the OEM final assembly line

Disadvantages:

- More complex water side, especially for heat pump mode
- Lots of water pumps and valves
- high system inertia due to the coolant circuits
- critical in terms of installation space and costs
  → compact system might be difficult to package

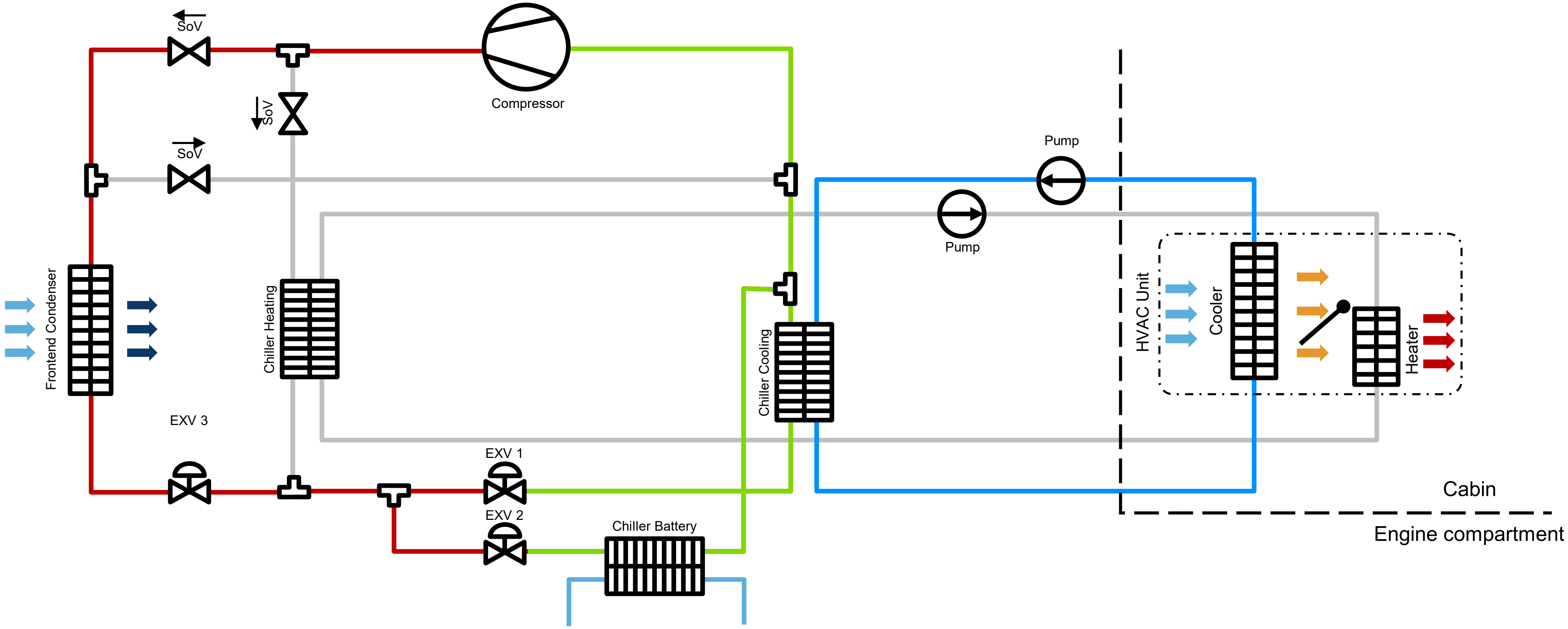
Motivation

- The investigation and development of R290 refrigerant cycles are a major focus for many OEMs and suppliers.
- Main reasons: PFAS regulations, heat pump usage even at low temperatures, cost pressure for system and components
- Due to safety concerns, there is a trend towards designing R290 circuits as fully indirect systems
- IAV approach: Semi-Direct R290 system



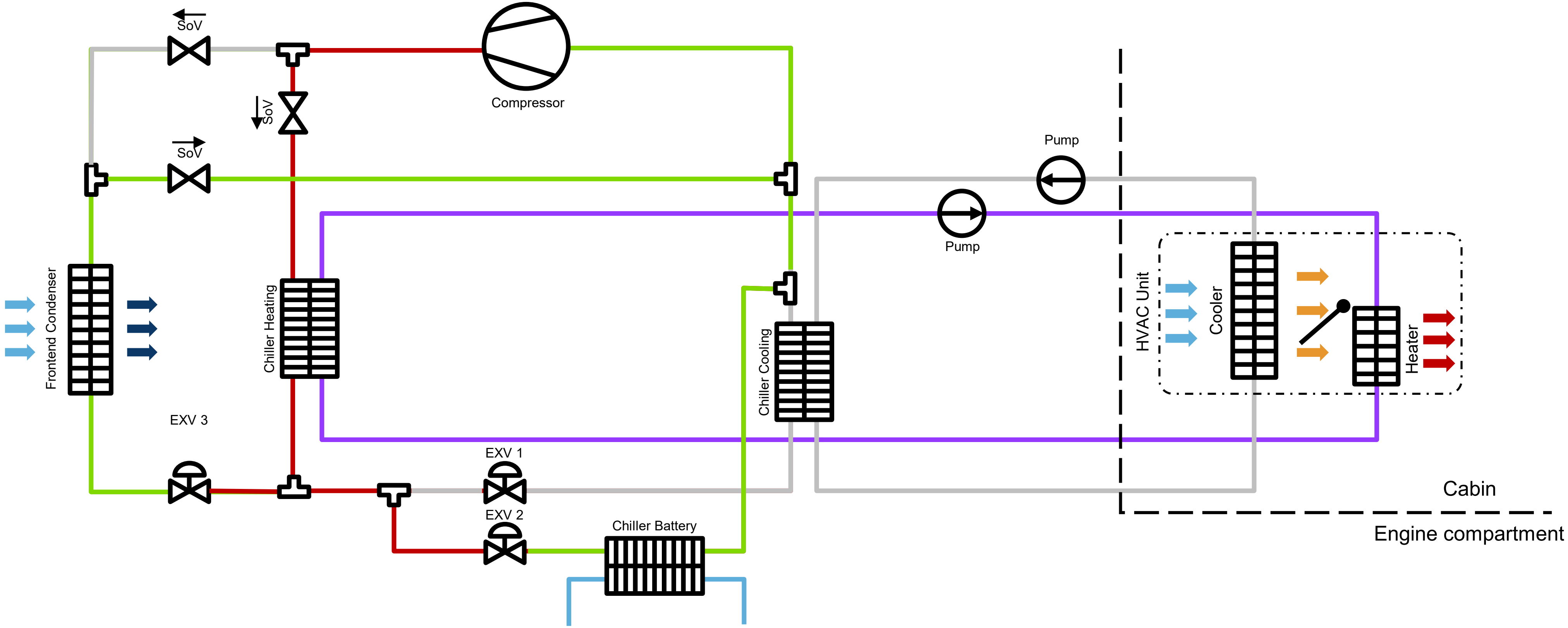
Semi-Direct R290 system

Cooling mode



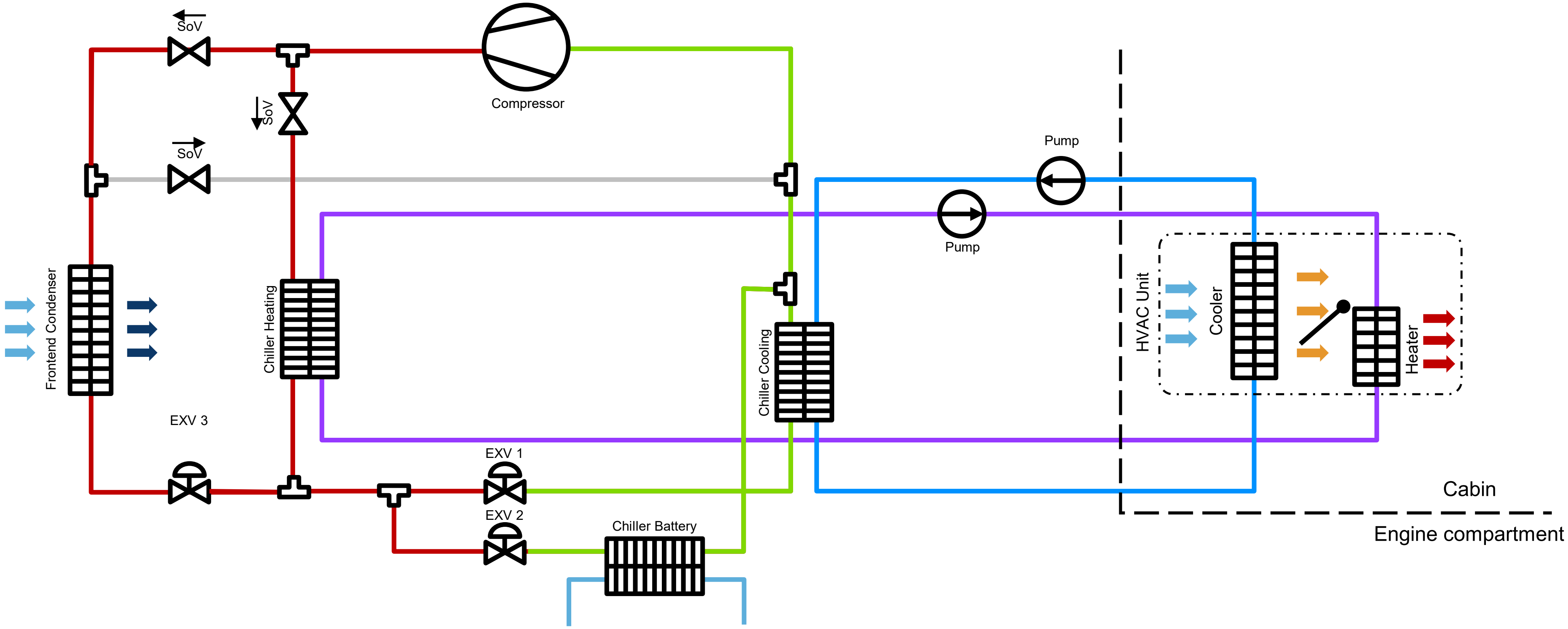
Semi-Direct R290 system

Heating mode



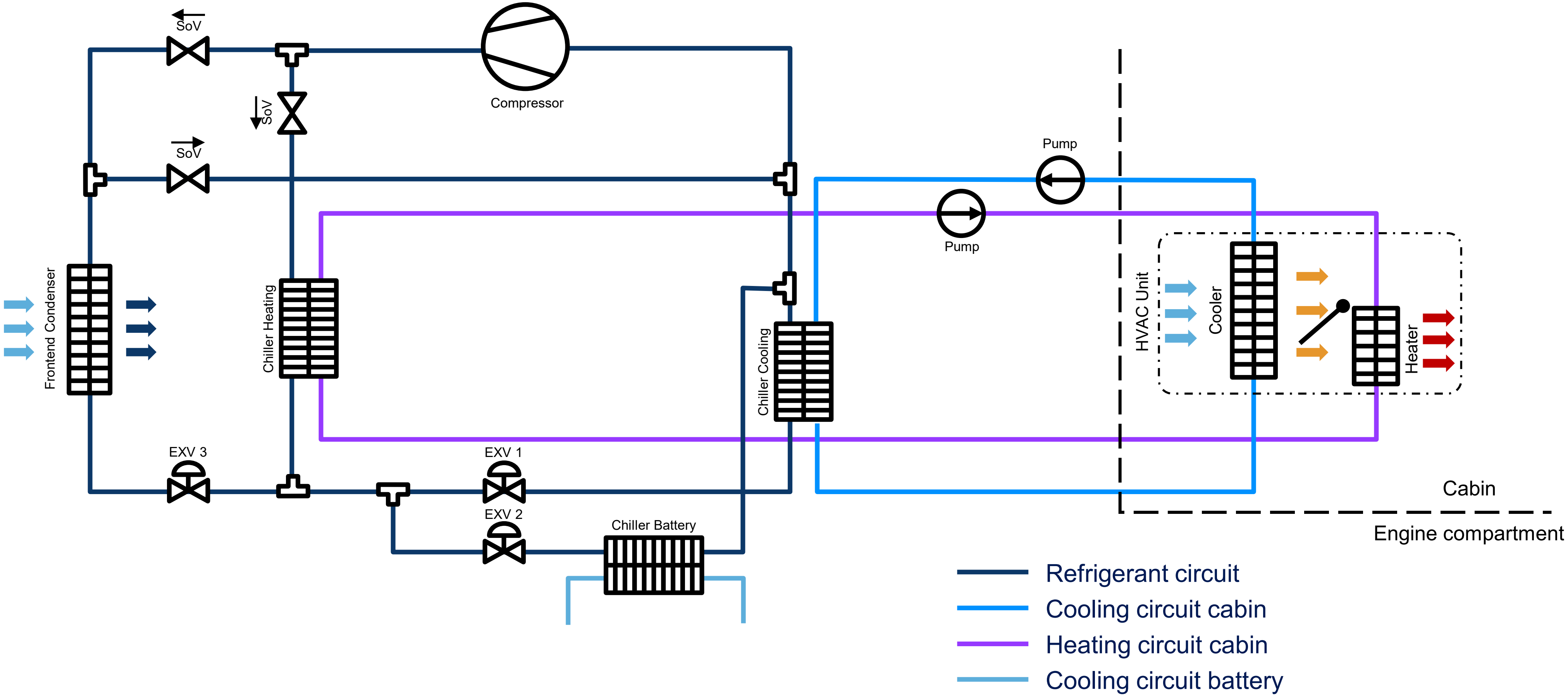
Semi-Direct R290 system

Reheat mode



Investigation goals

- **Comparison of the Semi-Direct System with a fully indirect system (and a direct system)**



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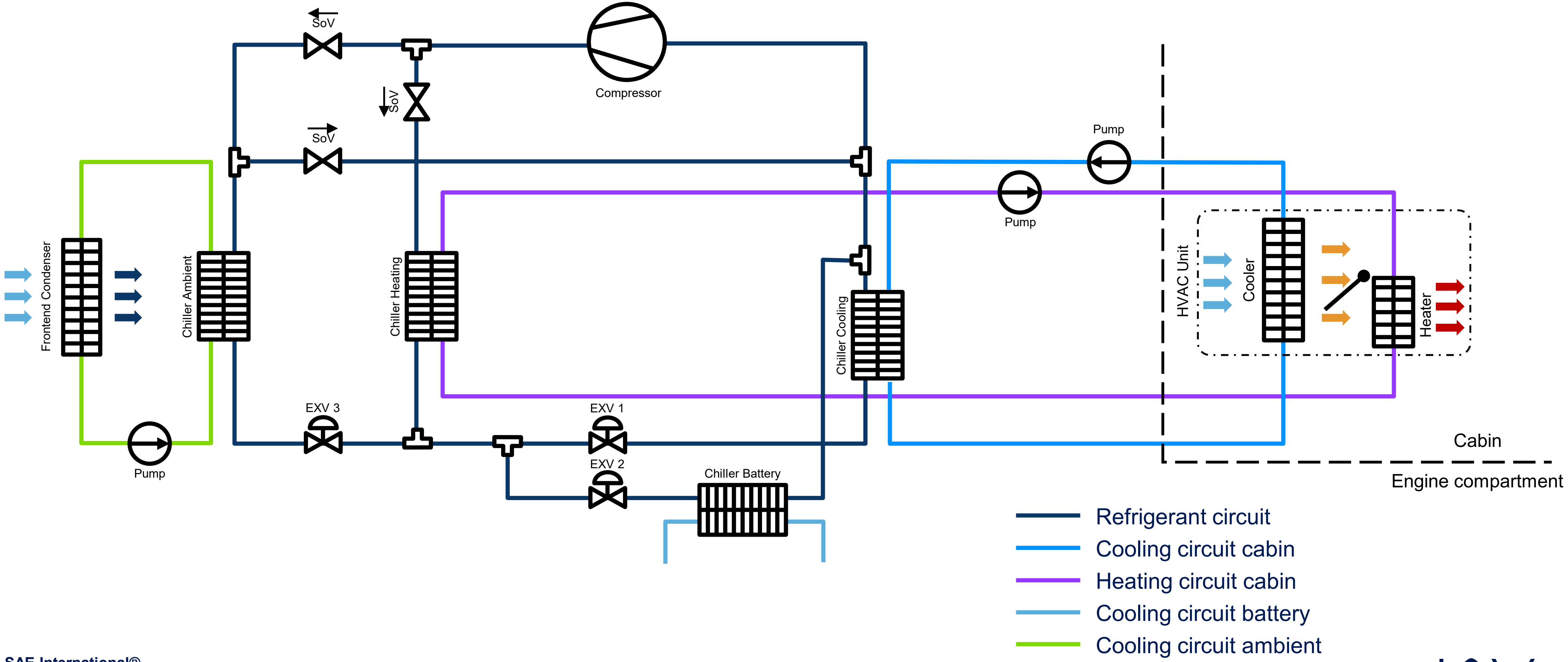

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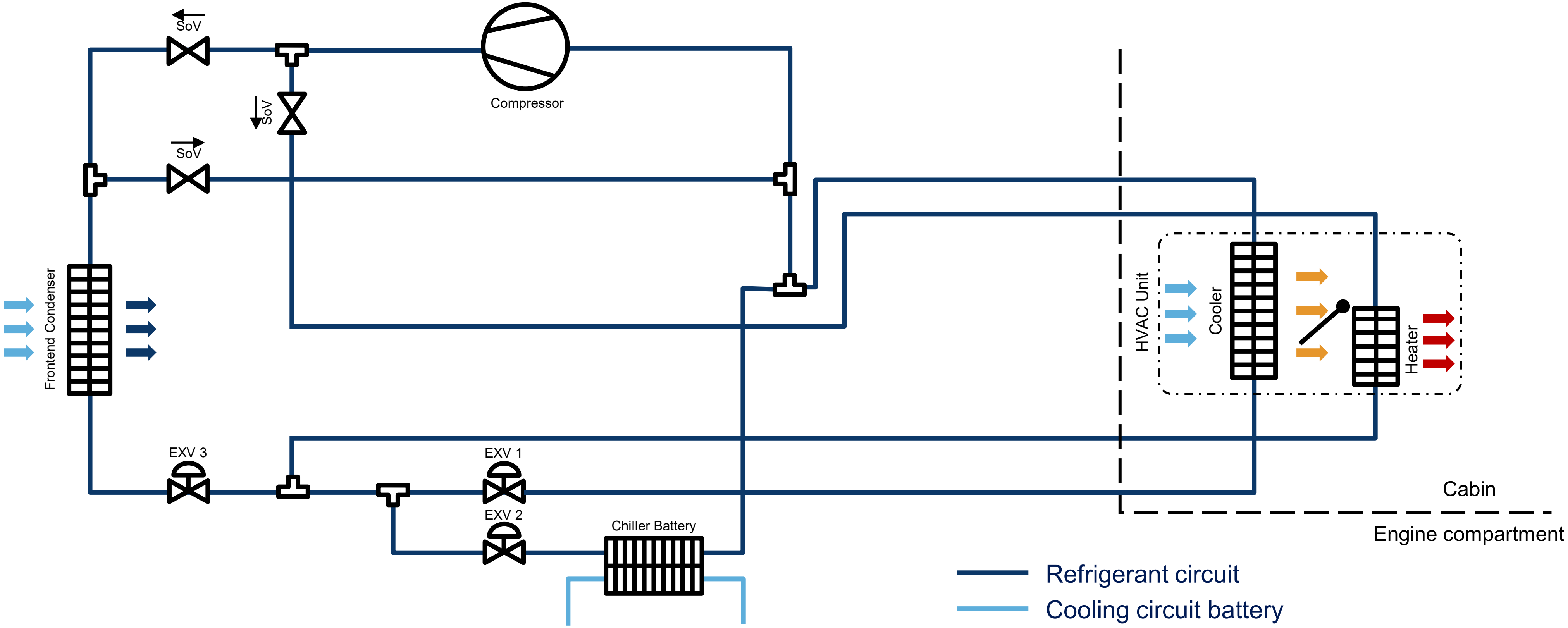
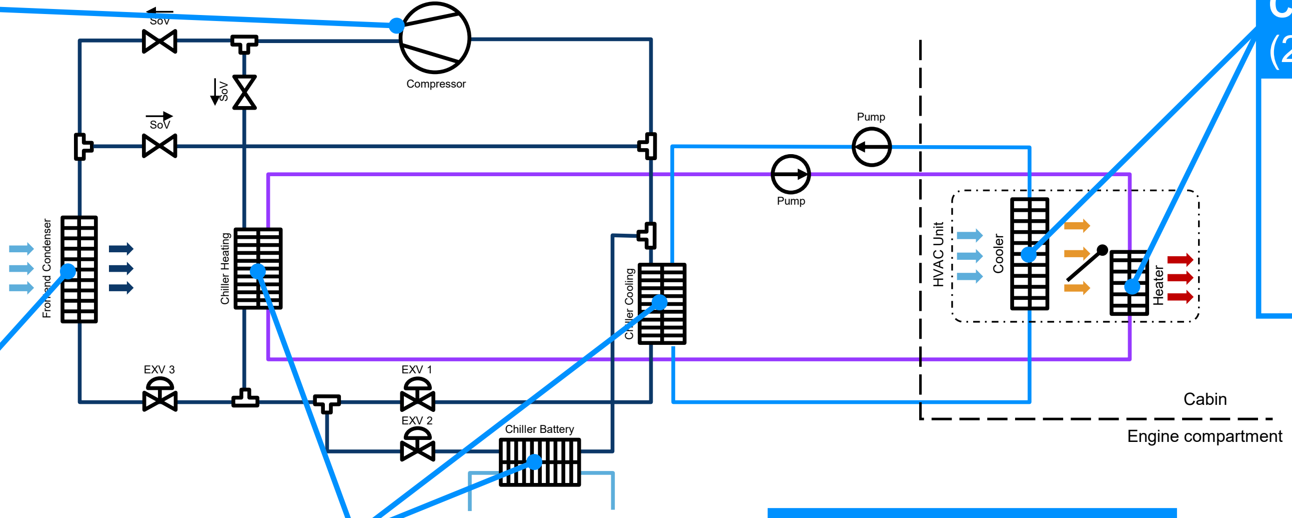


Simulation Models

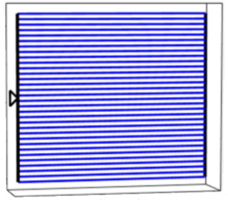
- **Simulation of the whole system using geometrical and physical based simulation models**
- **Modeling of any component and connection to an overall system model**
- **Components were selected to meet today's heating and cooling capacities, installation space and operating range**

Compressor
(Scroll type)

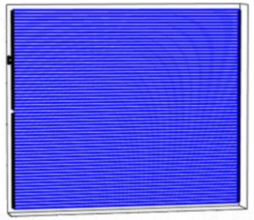
V_{Disp} = 33,8 cm³



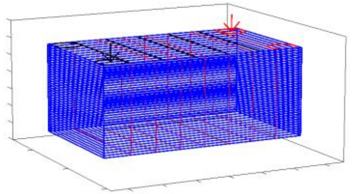
Cabin heat exchangers
(250 x 225 x 26 mm)



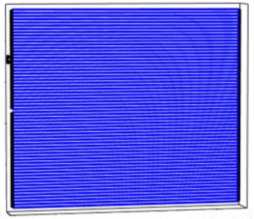
Frontend Condenser
(565 x 480 x 14 mm)

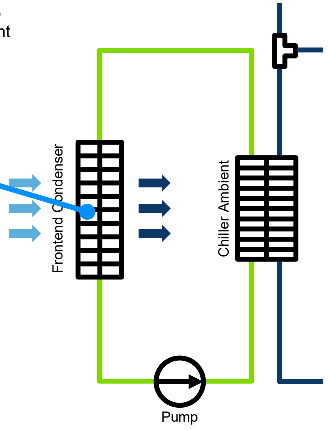


Coolant-Refrigerant-HX
(180 x 90 x 90 mm)



Frontend Radiator
(565 x 480 x 30 mm)





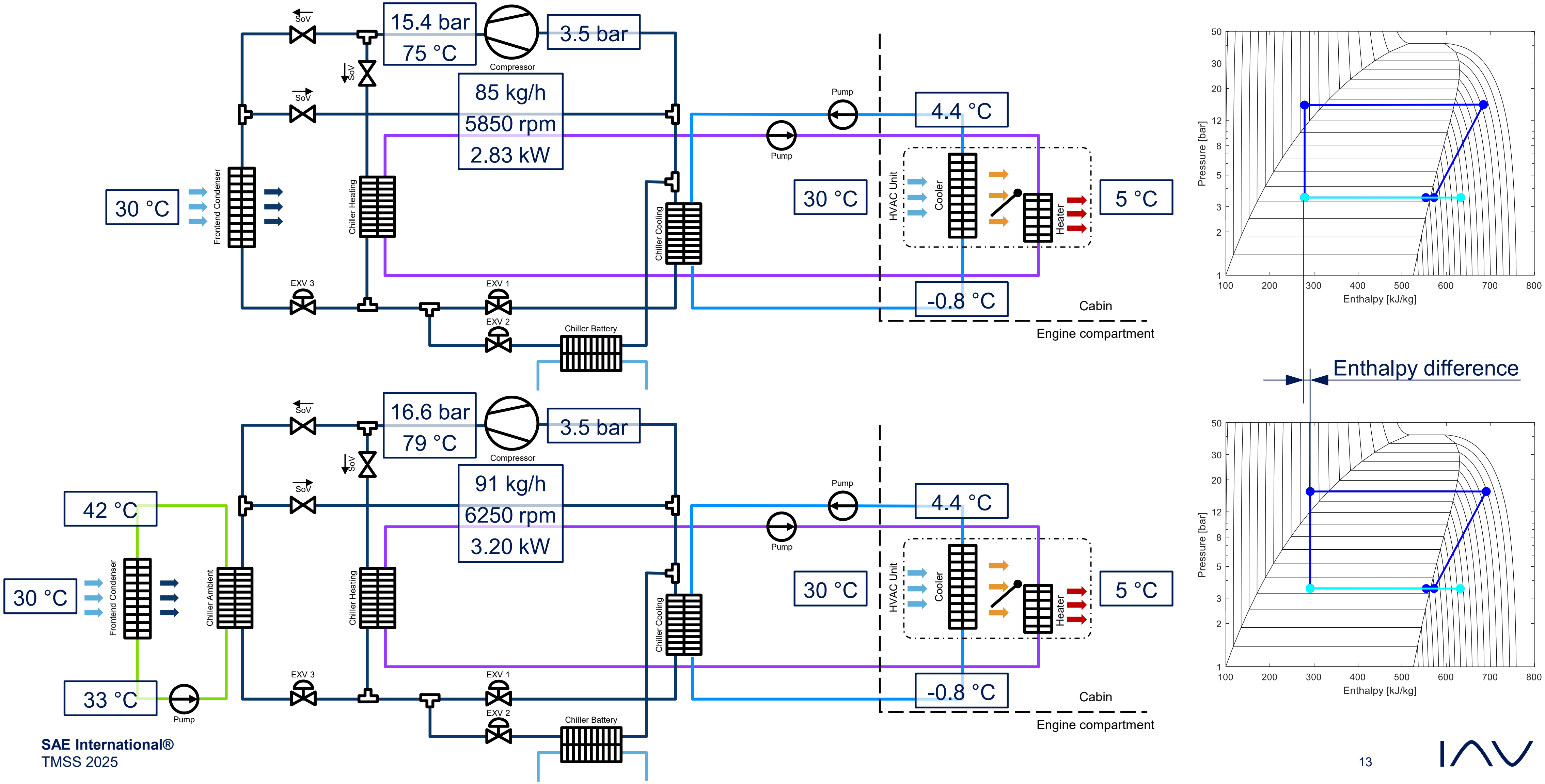
Boundary Conditions

- **Simulations for typical summery conditions:**

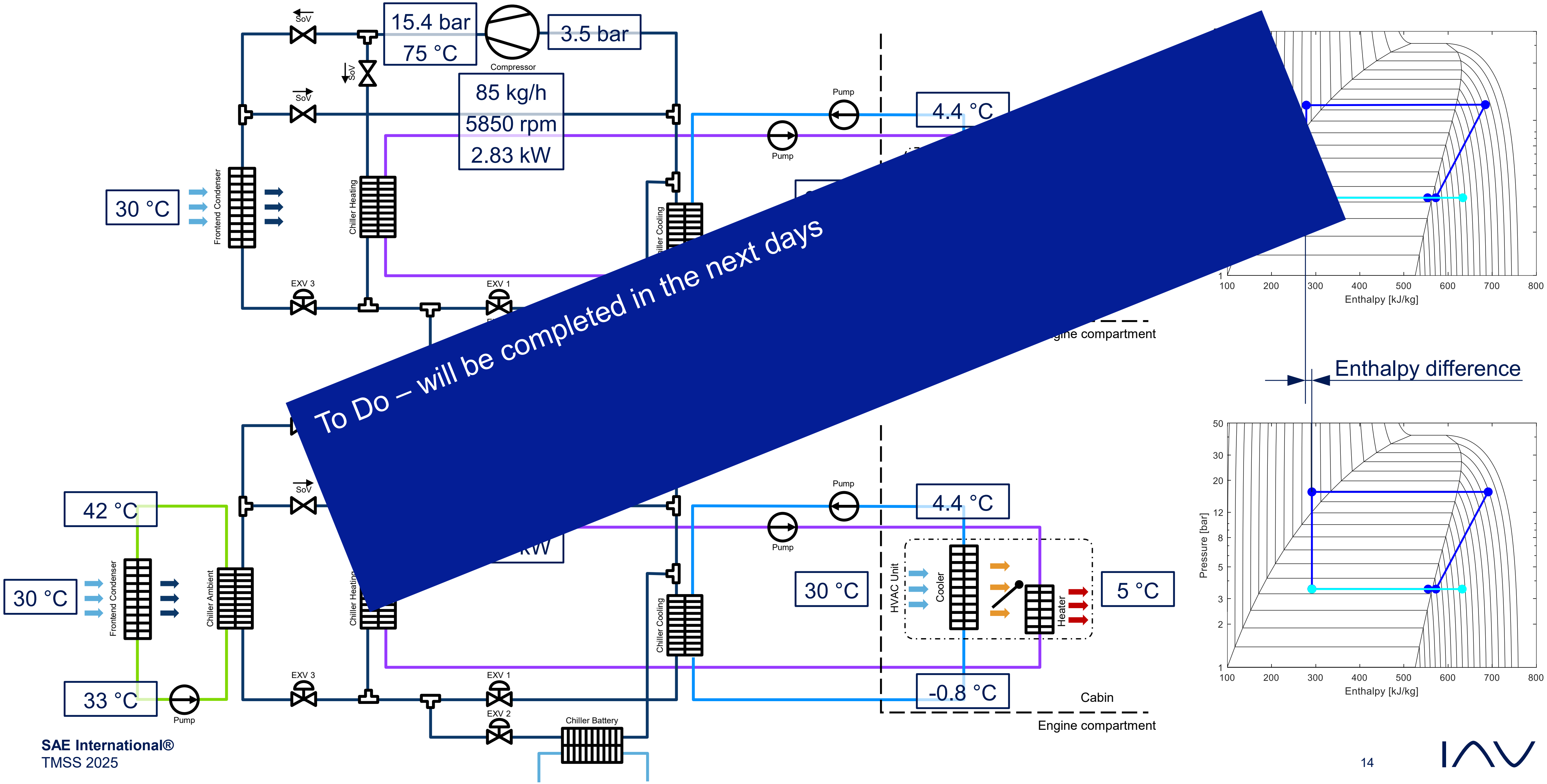
Parameter	Unit	I	II	III	IV	V	VI	VII	VIII
Ambient temperature	°C	20	25	30	32.5	35	0	-5	-10
Relative humidity	%	40							
Evaporator mass flow rate	kg/h	550							
Air temperature after Evaporator	°C	5					50		
Gas cooler air speed	m/s	4							

- **Cooling capacities between 4.9 kW and 8.0 kW**
- **Coolant conditions at Chiller inlet: Ambient temperature, 10 L/min, 2 kW (Cooling mode)**
- **Tubes and hoses were not considered**
- **Fan powers were not considered either**
- **Refrigerant: R290 (Propane)**

Results - Cooling mode at 30 °C

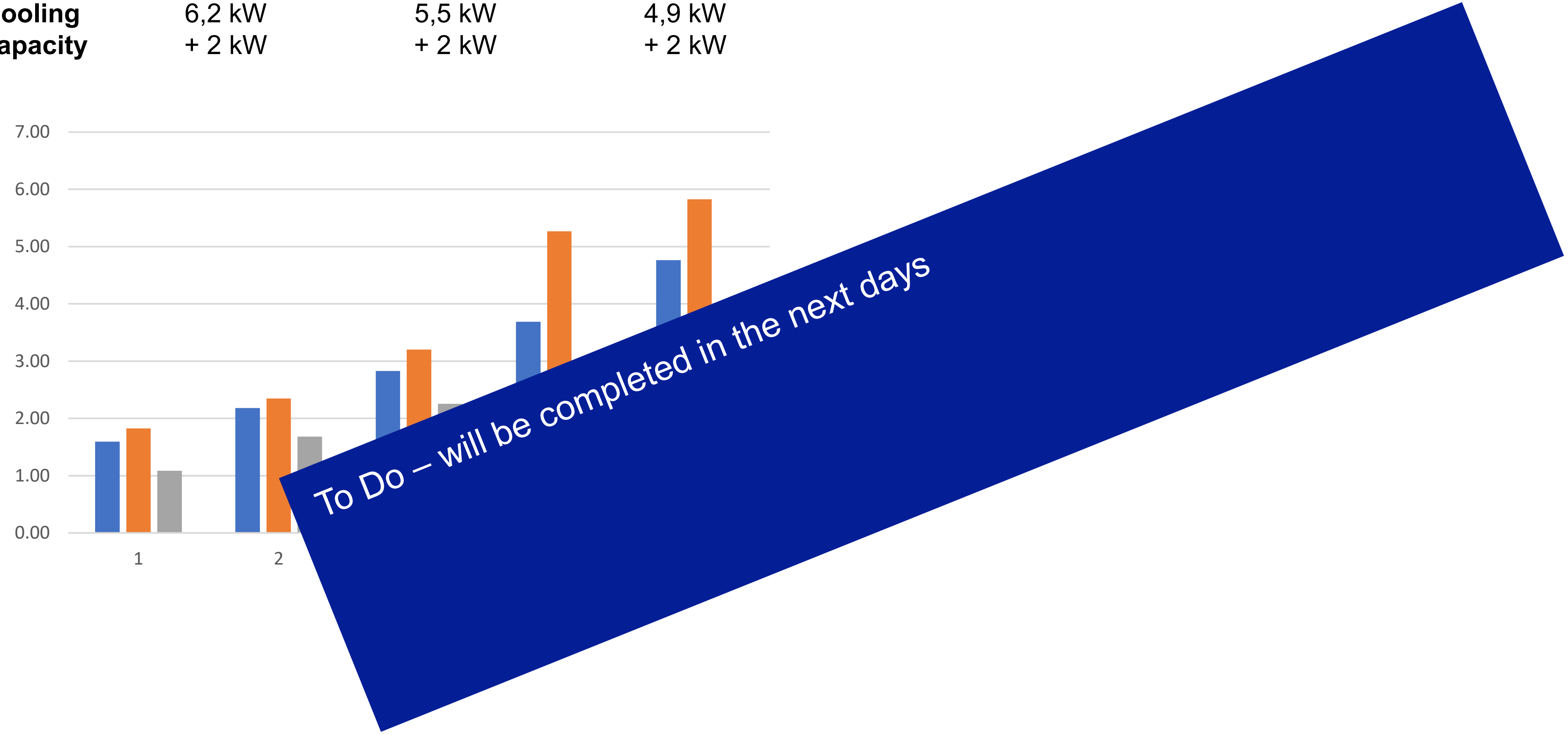


Results - Heating mode at -5 °C

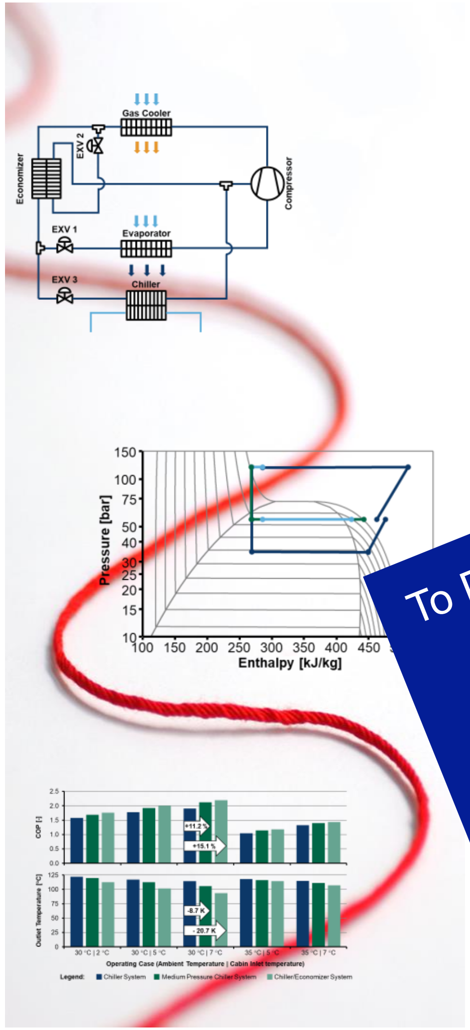


Results – System comparison

Cooling capacity	6,2 kW + 2 kW	5,5 kW + 2 kW	4,9 kW + 2 kW



Conclusion and Outlook



- Simulation and Comparison of common injection systems:
  - Flash Tank, Liquid Injection and Economizer
  - Use of typical automotive components and bound [redacted] oday‘s electric cars

  ➔ significant reduction of the compressor ou [redacted]

  ➔ Flash Tank and Economizer offers p [redacted]
- Injection port of a compressor mi [redacted] iller
  - Standard Chiller sys [redacted] mizer-system

  ➔ COP improve [redacted]

  ➔ reduced [redacted]
- Pote [redacted] oling power for fast charging

[redacted] ortunities e.g., for direct evaporation battery
[redacted] w cell temperatures and a dew point dropping

[redacted] se of the injection port in heat pump operation

[redacted] elopment of optimal control strategies

- Prototype validation and testing

To Do – will be completed in the next days

Thank you!

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