Insight into the Volkswagen heatpump with the refrigerant R744

Nowak-Walenta, Schwerter, Wachsmuth

VW Group - custom BEV platform MEB

R744 heatpump availability in the EU [2020-2024]


Volkswagen ID.3


Volkswagen ID.4


Volkswagen ID.5


Volkswagen ID.7


Cupra Born


Audi Q4 etron


Audi Q4 etron Sportback


Volkswagen ID.7 Tourer


Volkswagen ID.Buzz


Škoda Enyaq


Škoda Enyaq Coupe


Škoda Elroq (SOP 11/2024)

To be continued in 2025+ (Cupra Raval, VW ID2.all,…)

Agenda

Thermal Management Systems Symposium 2025

- **Refrigerant: R744**
- **Thermal management**
- **Operating conditions of the heat pump**
- **Heat pump components**
- **Extension of the air-source heat pump**

Refrigerant: R744

Motivation and challenges

Motivation

Environmental compatibility

- Free of PFAS
- GWP 1
- ODP 0
- Biodegradable
- Non-flammable
- Nonhazardous to water

Heat pump operation

- Ambient air can be used as an energy source for the heat pump down to low temperatures

Challenges

Operating pressure

- Higher pressure level compared to conventional refrigerants:
  - 30 bar → 130 bar
- Development of R744 specific components

Transcritical process

Additional degree of freedom in the control of a transcritical process

→ New control logic necessary

Operating temperature

- Higher compression temperature
- New requirements for materials in refrigerant circuits, especially hoses and elastomers

Heat Pump Heat Sources

Waste heat from the traction components

There are basically two heat sources available for the heat pump in BEVs:

1. **Waste heat from the drive components and battery**
2. Ambient air

The availability of waste heat depends strongly on the load profile of the trip, the duration of the trip and the ambient temperature:

Heat pump source requirement

10°C

-20°C

Heat dissipation from powertrain

Fast Charging & racetrack driving

(fast) motorway driving

Country roads

Urban transport

Depending on the vehicle, the operating point and the ambient temperature, the heat discharge from the drive train can be too low, sufficient or higher than the requirement.

“Driving on Nordschleife at +10°C certainly generates enough waste heat, inner-city rush hour at -20°C certainly not enough."

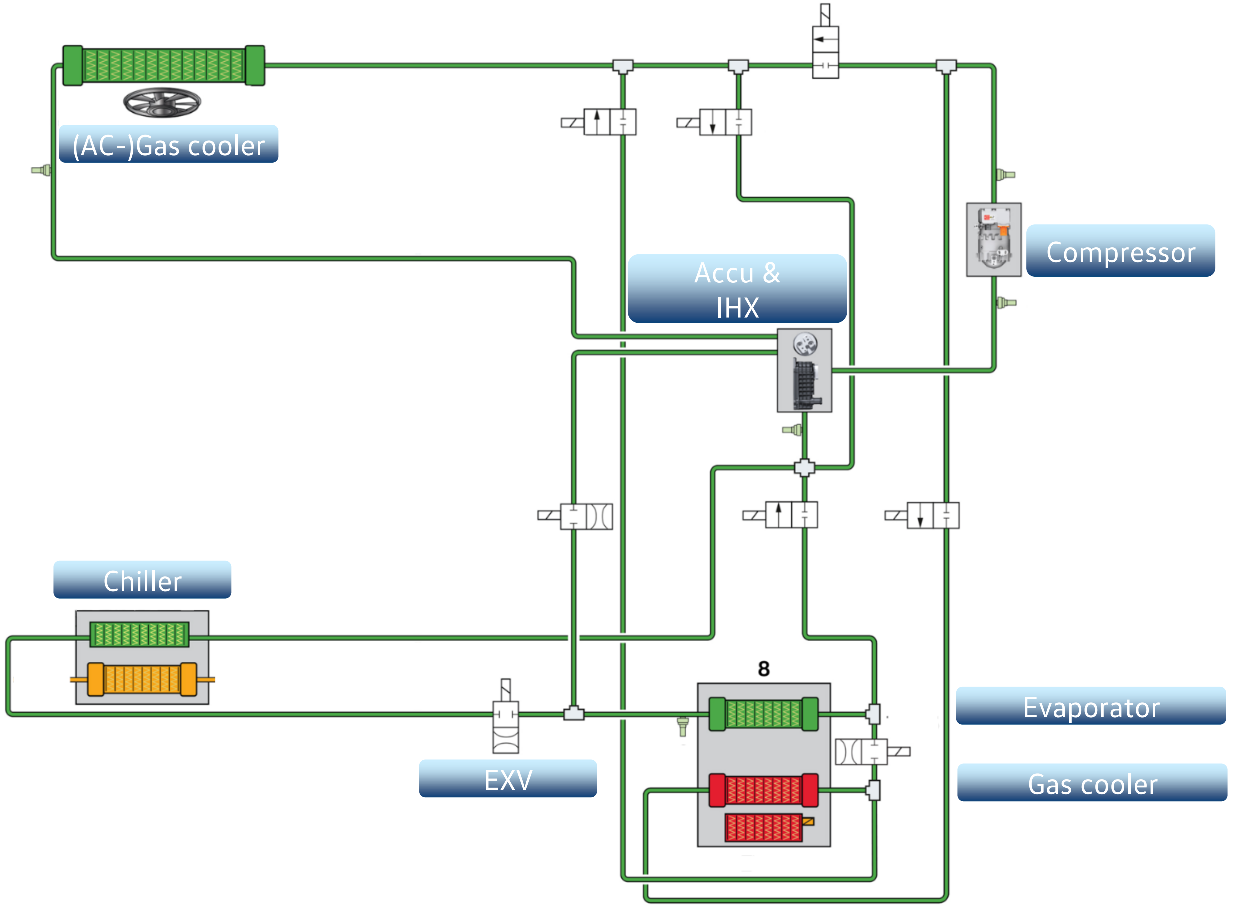
Thermal management

Refrigerant circuit

The refrigerant circuit is integrated into the vehicle's thermal management system.

The refrigerant circuit is shown in green with the following components:

- Compressor
- Gas cooler (front end)
- Battery & IHX
- Evaporator
- Heating gas cooler (air conditioner)
- Chiller
- Expansion & shut-off valves



Schematics from VW SSP 685 training document

Thermal management
Coolant circuit

<u>Coolant circuit:</u>

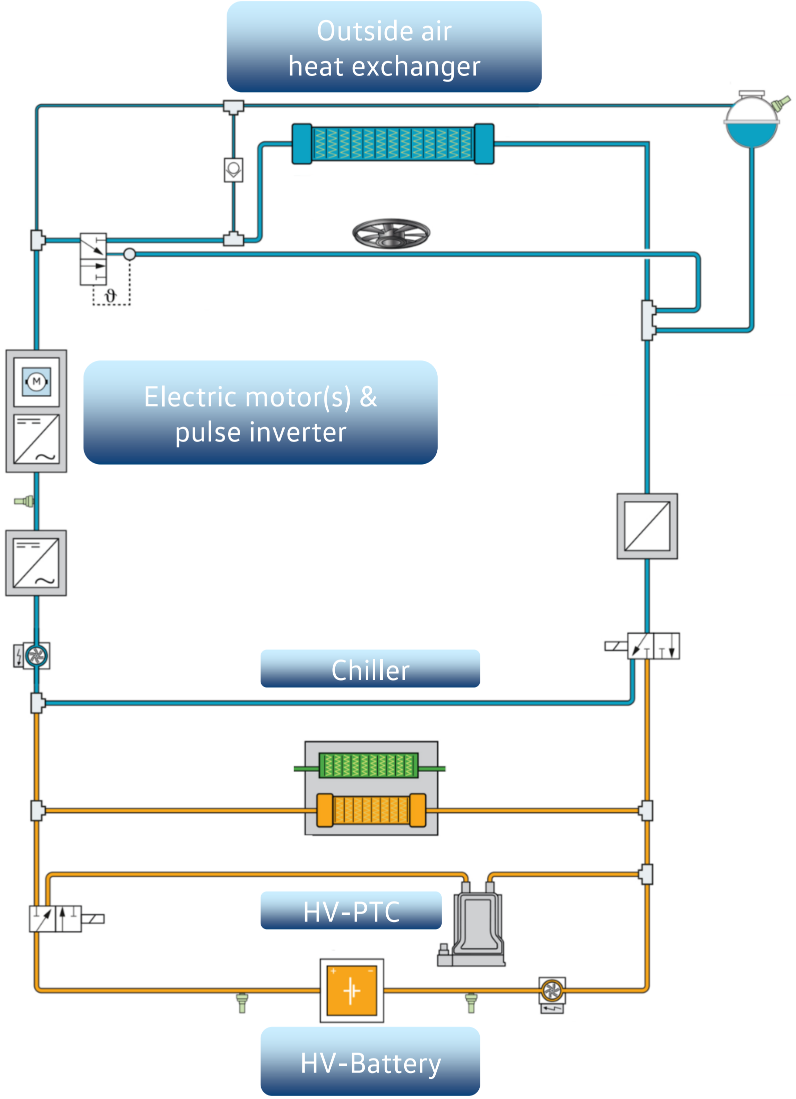
- 2 pumps
- 2 electronic switching valves
- 1 thermostatic switching valve

<u>Heat sources:</u>

- Electric motor(s) & pulse inverter
- Voltage converter (DC/DC & charger)
- HV-PTC
- HV battery

<u>Heat sinks:</u>

- Outside air Heat exchanger
- Chiller
- HV Battery

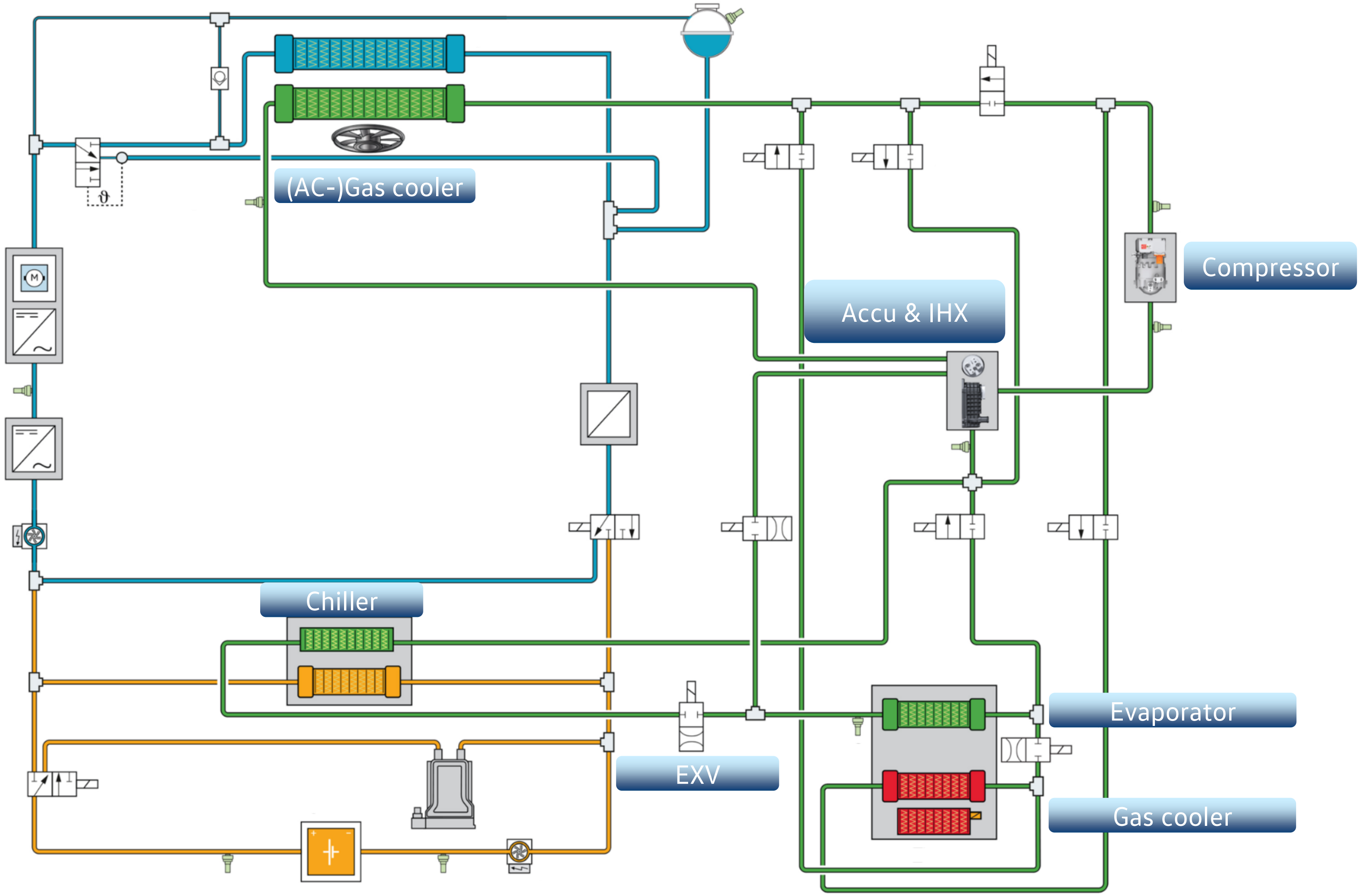


Schematics from VW SSP 685 training document

Thermal management
System level

Thermal management

- is used to control heat flows in the vehicle
- consists of all components of the vehicle with thermal energy requirements (source/sink)
- as well as all installed components to transport the heat flows at the respective temperature levels



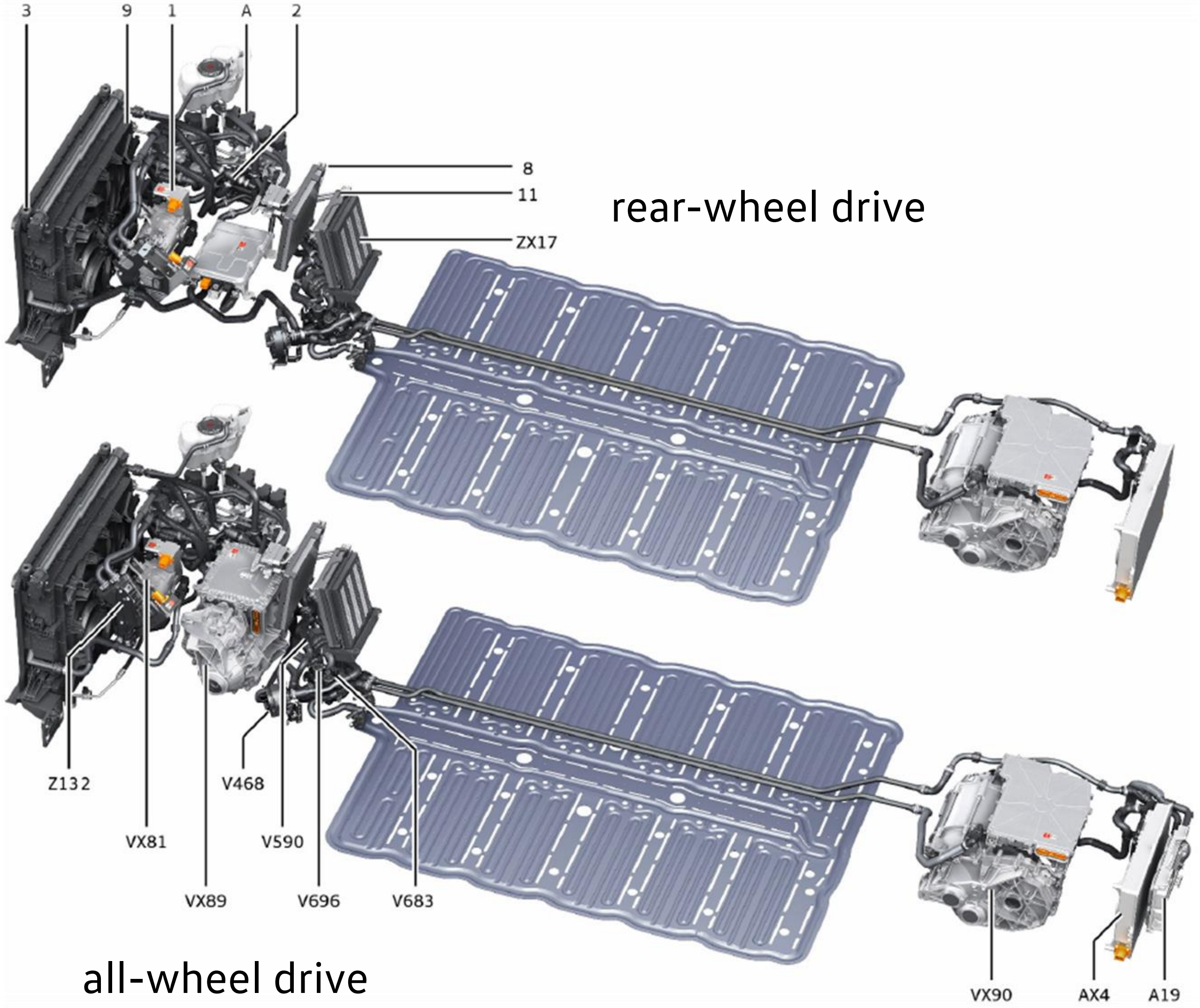
Schematics from VW SSP 685 training document

Thermal management

System level

in car package of components

VW ID.7 heatpump, car configuration [https://www.volkswagen.de/de/modelle/id7.html]



Schematics from VW SSP 685 training document

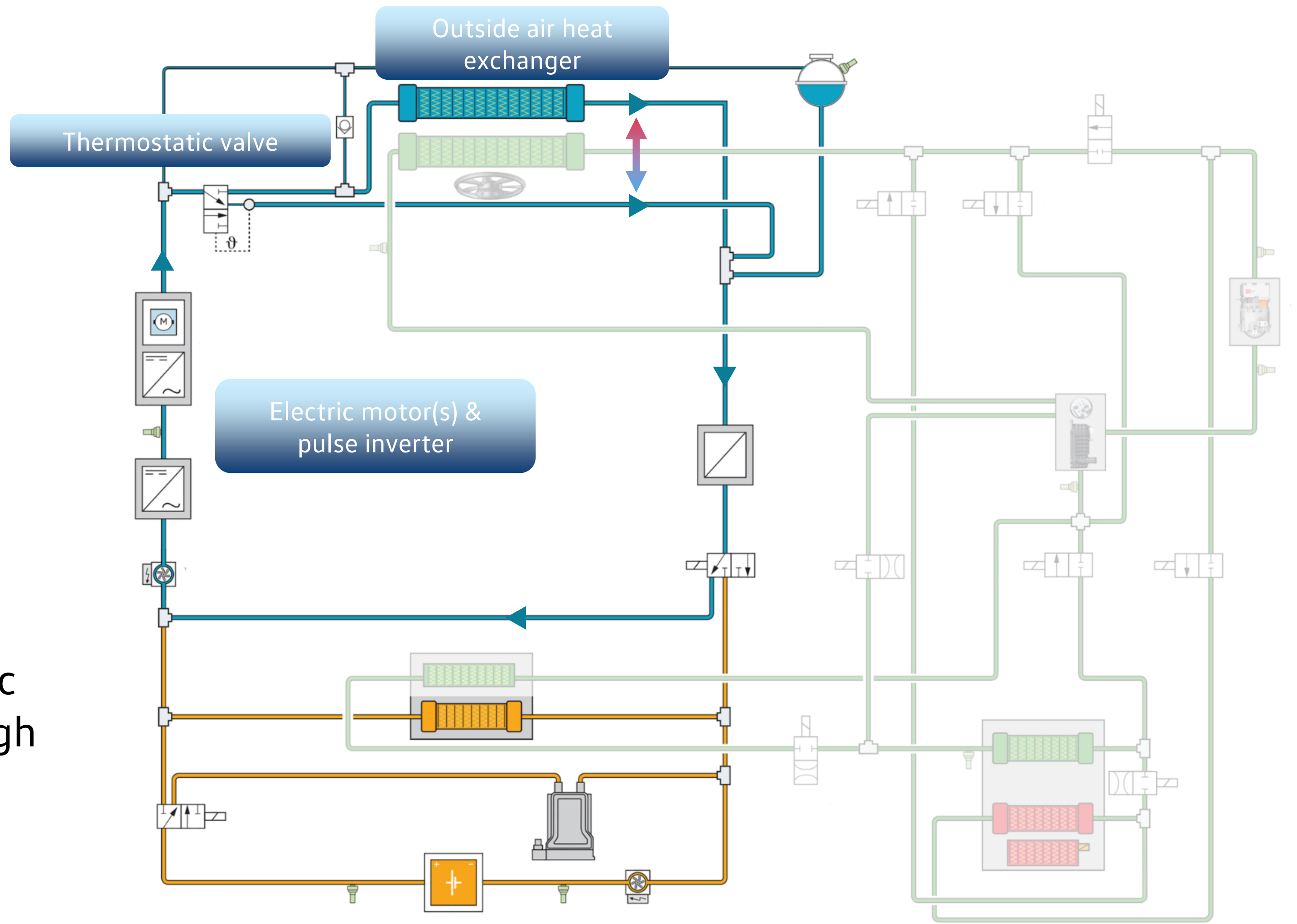
Thermal management

Operation modes | passive cooling of electric motor(s) and pulse inverter

The electric motors, power electronics and charger are continuously exposed to flow.

Depending on the temperature, the thermostatic valve switches between the bypass and cooling by the outside air heat exchanger.

The permissible temperatures in the electric motors and the power electronics are so high that cooling via the coolant circuit is sufficient.



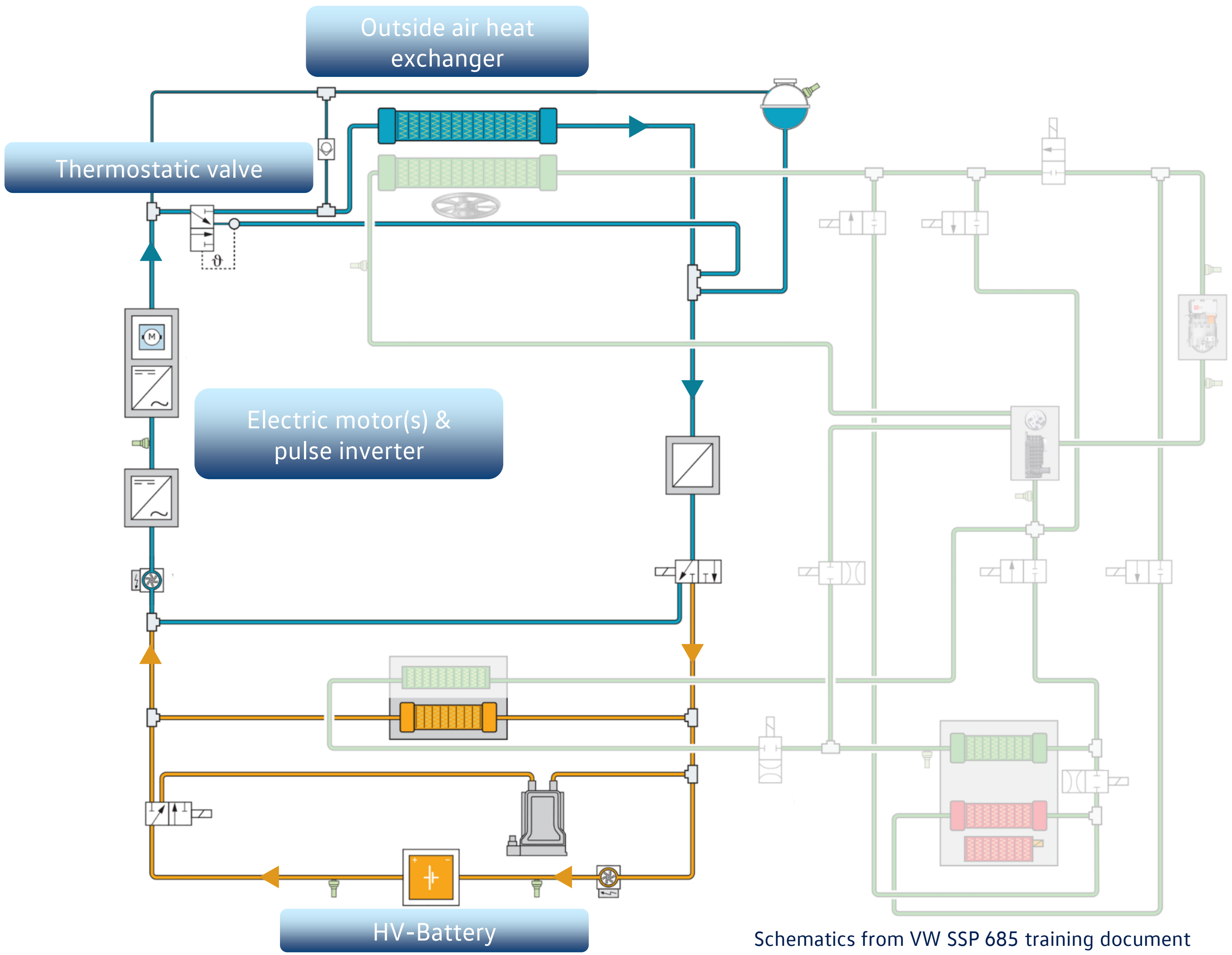
Schematics from VW SSP 685 training document

Thermal management

Operation modes | passive cooling of electric motor(s) pulse inverter and battery

Cooling of the battery via the outside air heat exchanger without refrigerant circuit :

- More efficient cooling
- Possible at low outside temperatures and/or low cooling requirements
- Not useful in heating mode, as waste heat can be used to heat the cabin.



Schematics from VW SSP 685 training document

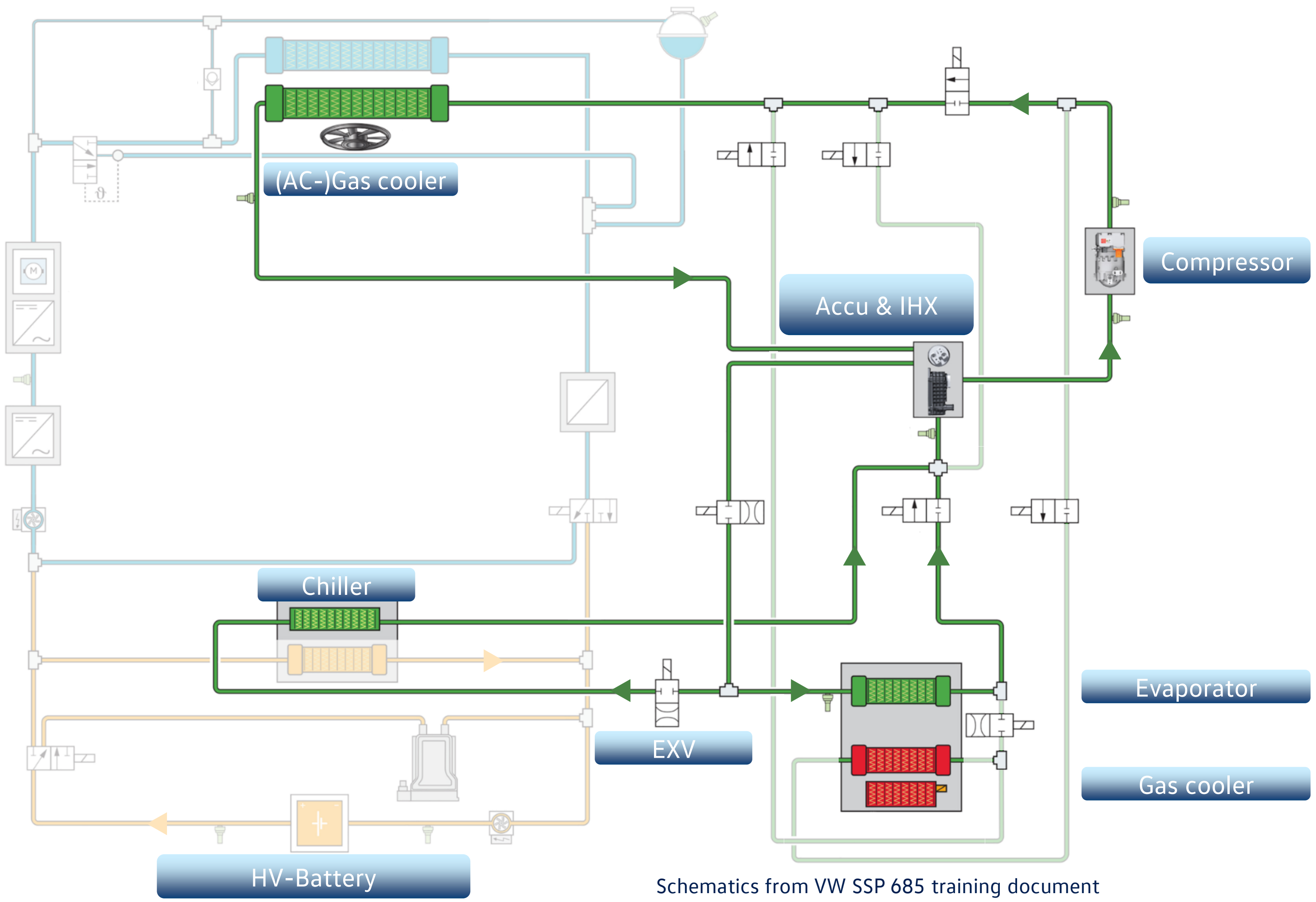
Thermal management

Operation modes | active cooling battery and passenger cabin

Coolant circulates between the battery and the chiller and is decoupled from the rest of the cooling circuit. (separate temperature levels)

Heat is absorbed at the chiller and dissipated together with the heat from the evaporator at the gas cooler.

Solo chiller and solo evaporator operation are also possible.



Schematics from VW SSP 685 training document

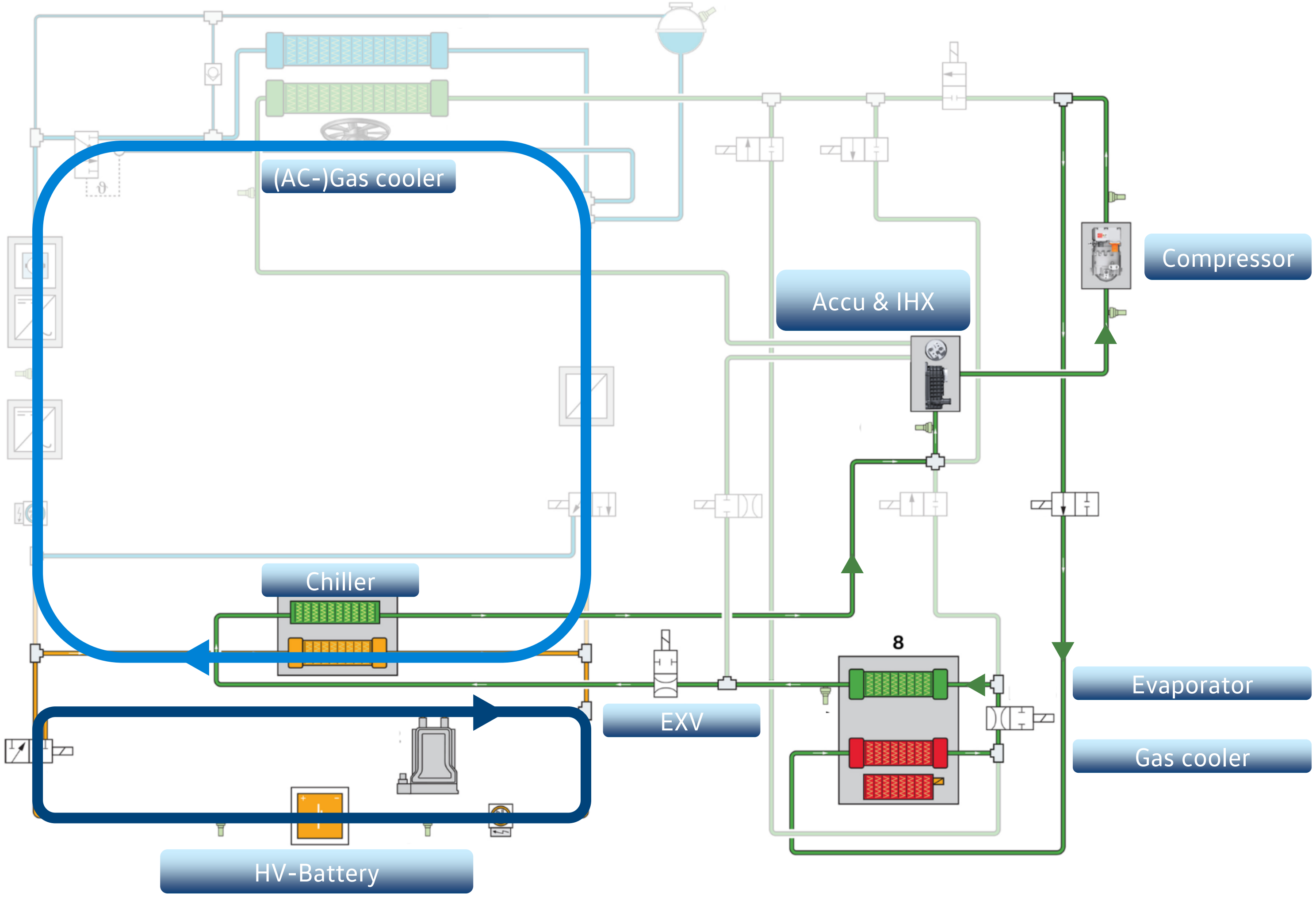
Thermal management

Operation modes | coolant heat pump

In this configuration, the source for the heat pump for heating the interior is the coolant running through the drive components.

For this purpose, either the battery or the drive motors can be used as a heat source.

The heat is dissipated to the cabin via the heating gas cooler and, if necessary, the evaporator.



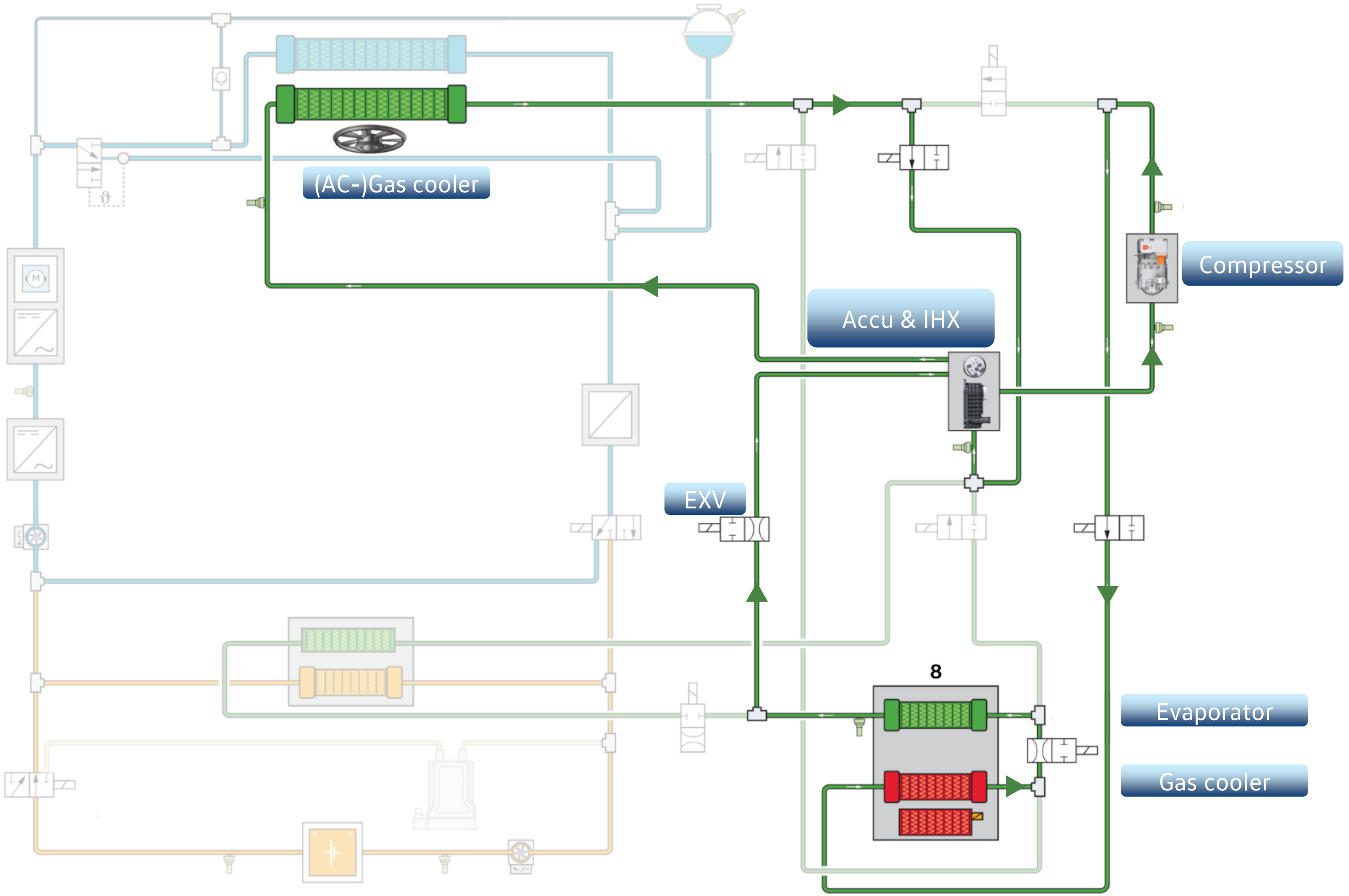
Schematics from VW SSP 685 training document

Thermal management

Operation modes | ambient air heat pump

The heat source is the outside air, the gas cooler acts as an evaporator and cools the outside air, absorbing heat energy.

The absorbed heat is transferred to the supply air of the interior via the heating gas cooler and, if necessary, the evaporator.



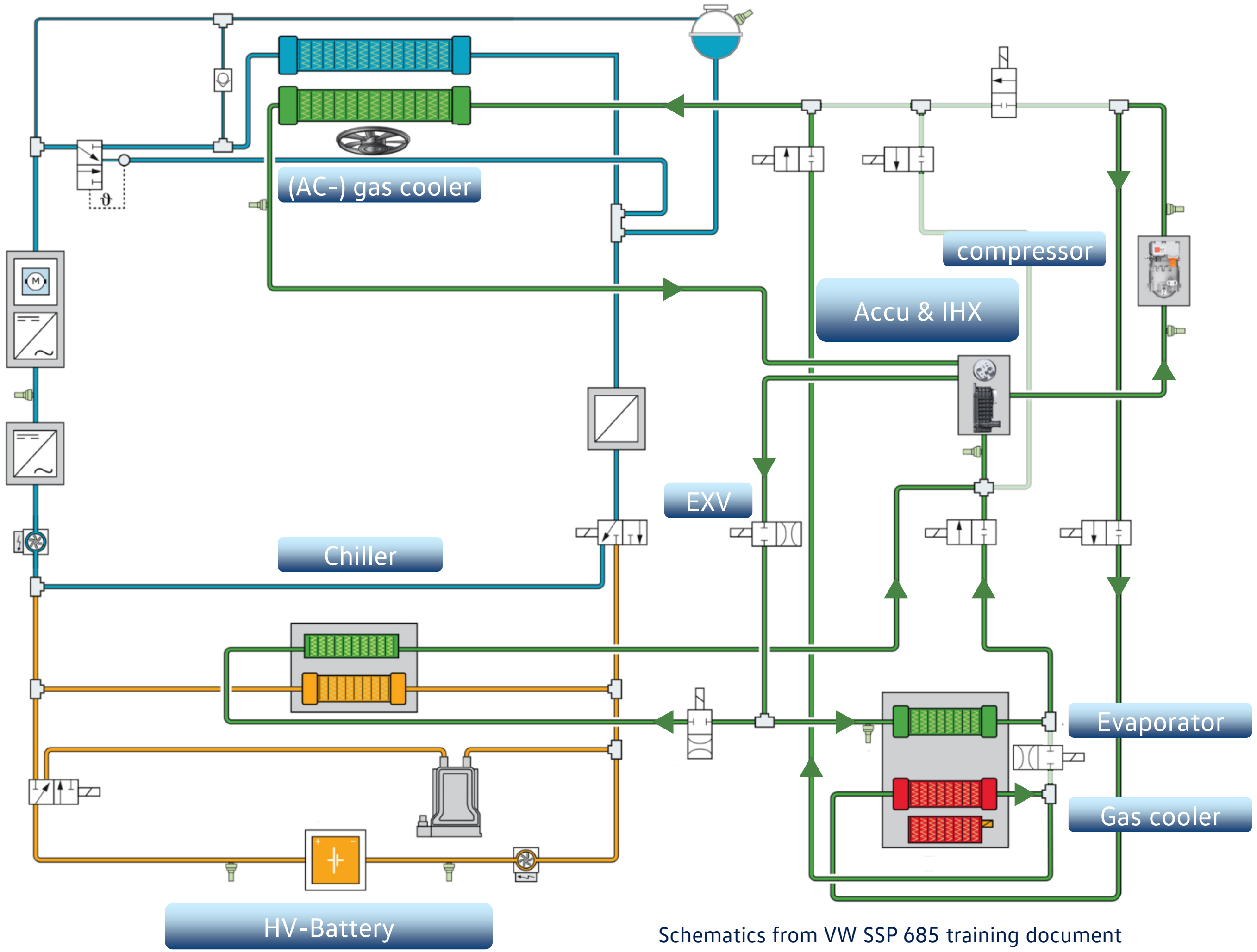
Schematics from VW SSP 685 training document

Thermal management

Operation modes | Reheat

Reheat operation

- This operation mode is mainly chosen in case of different cooling/heating requirements between vehicle right and left side (customer requested temperature, position of the sun, …)
- common during summer months
- Efficiency advantage of heat pumps in summer:
  - Electrical energy input at the compressor provides cooling capacity at the evaporator and heating capacity at the hot gas cooler
  - Heating and cooling (dehumidification) can be provided very efficiently
- Non-heatpump vehicles must provide heating via an additional PTC for identical comfort levels



Schematics from VW SSP 685 training document

Components of the R744 refrigeration circuit

HV-Compressor

Scroll compressor with 5.3 cm³ displacement

Power supply via HV network at 400V voltage level

Power electronics and electric motor cooled by suction gas

Speed: 600 – 8,600 rpm

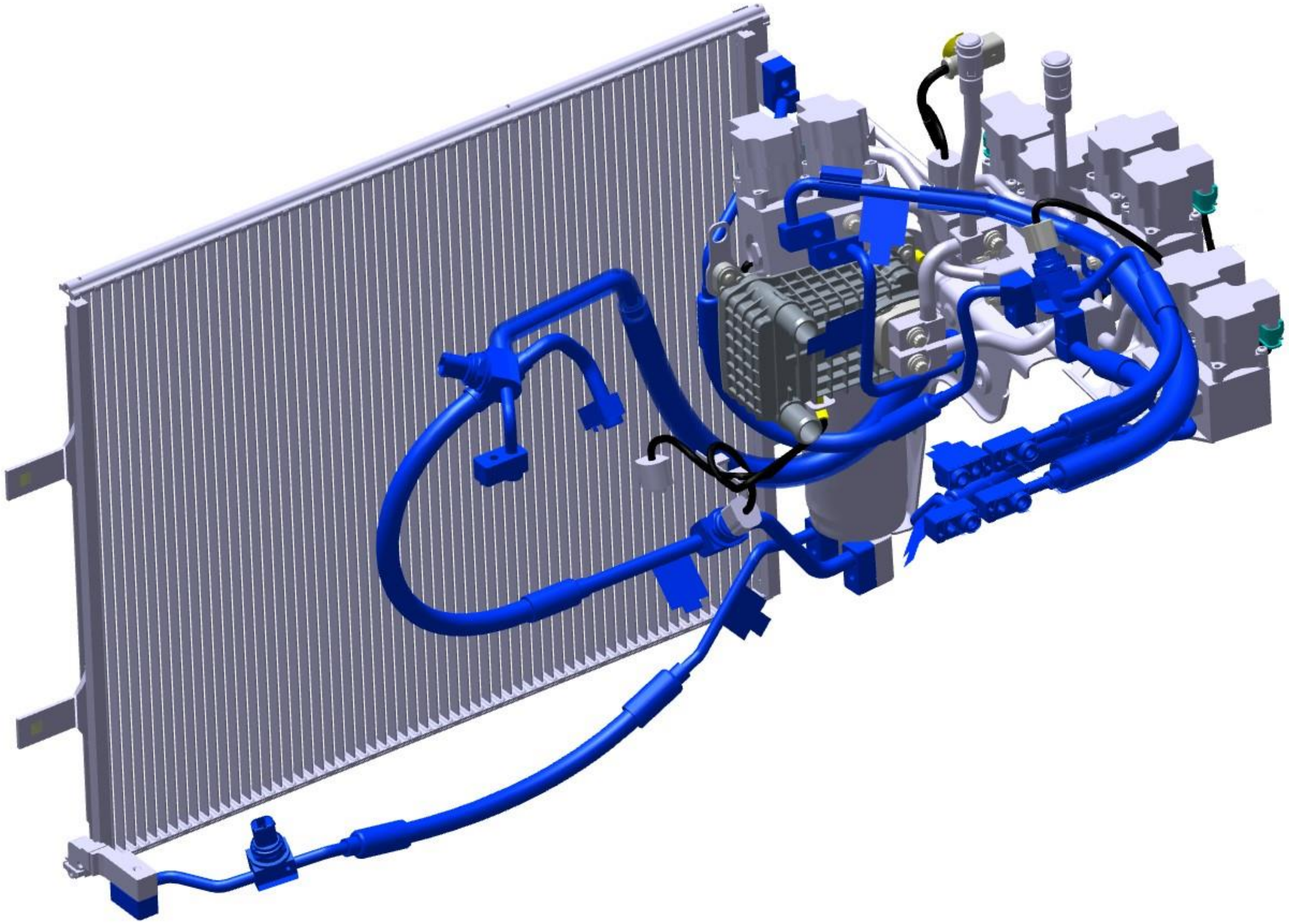
Power consumption: 5.5 kW

Schematics from VW SSP 685 training document

Components of the R744 refrigeration circuit

Refrigerant lines

- Adaptation to high operating pressures required (SAE J639)
- Material strengthening necessary for high hot gas temperatures
- Stiffness of the refrigerant lines under high pressures must be taken into account

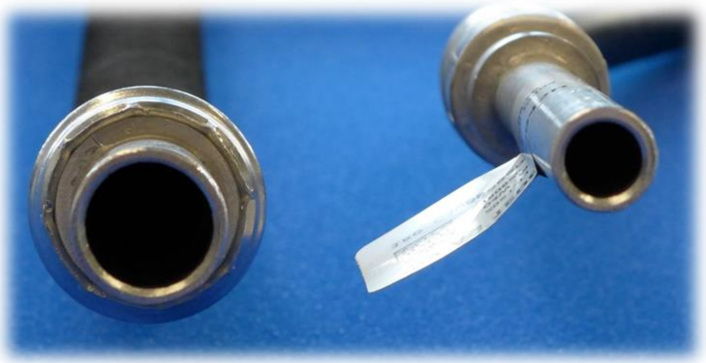


Exemplary hardware comparison - Package

R1234yf vs. R744

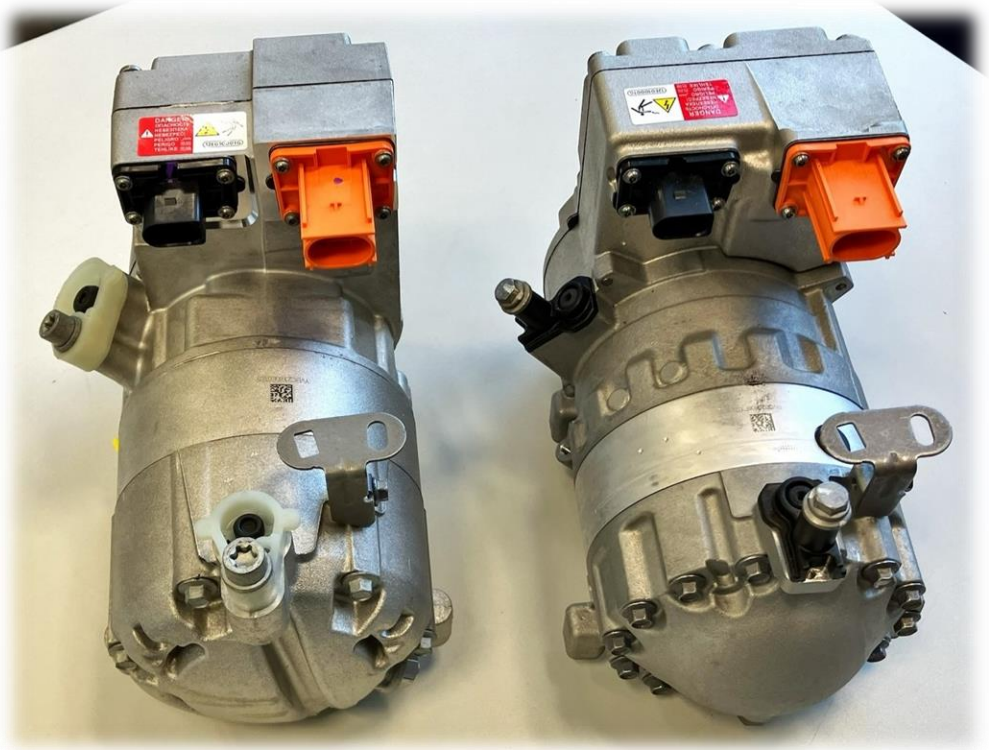
High pressure lines

R1234yf R744



Suction pressure lines

R1234yf R744



R1234yf compressor R744 compressor

Refrigerant lines with identical

- Wall thickness
- Aluminum alloy

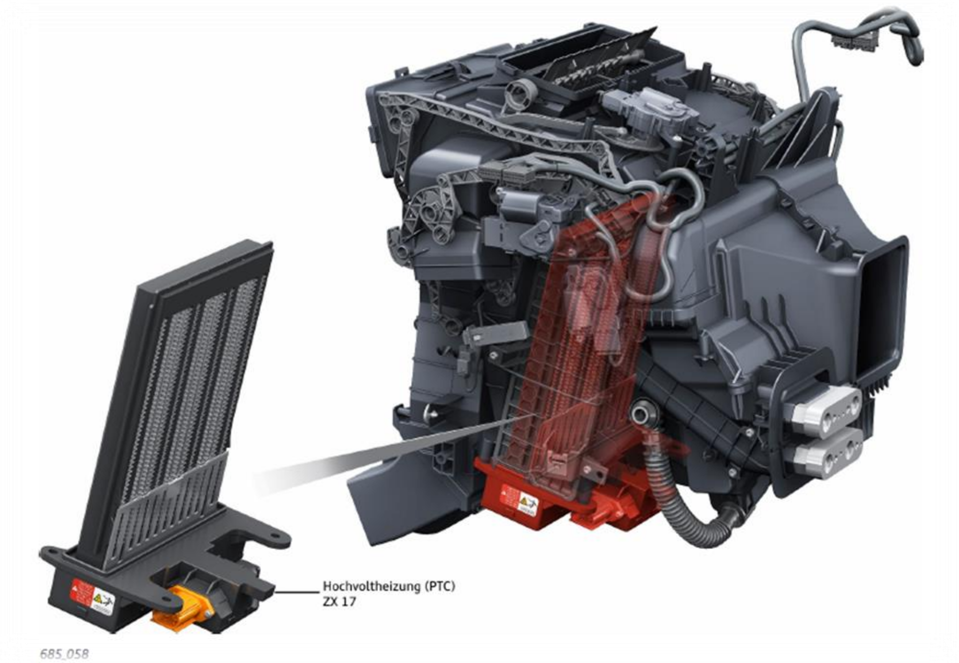
Components of the R744 refrigeration circuit

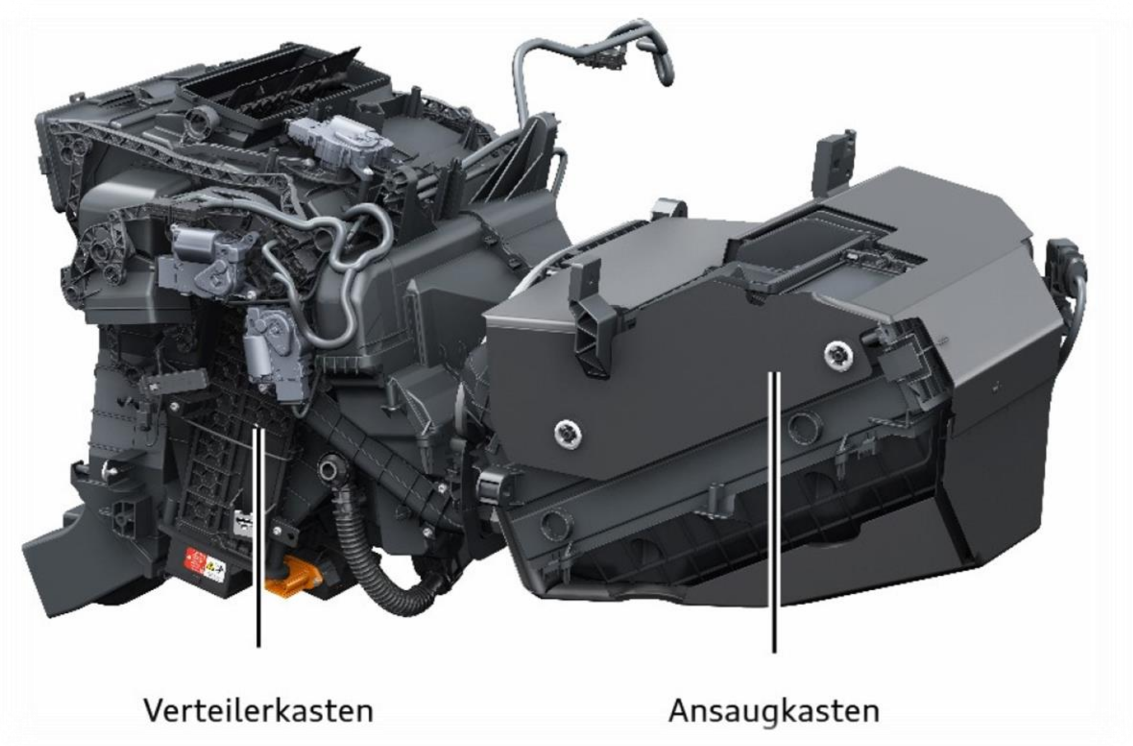
Air conditioning unit

Split air conditioning unit with intake box in the front end

Evaporators and heating gas coolers

Air PTC with 6 kW on 400V located behind the gas cooler





Schematics from VW SSP 685 training document

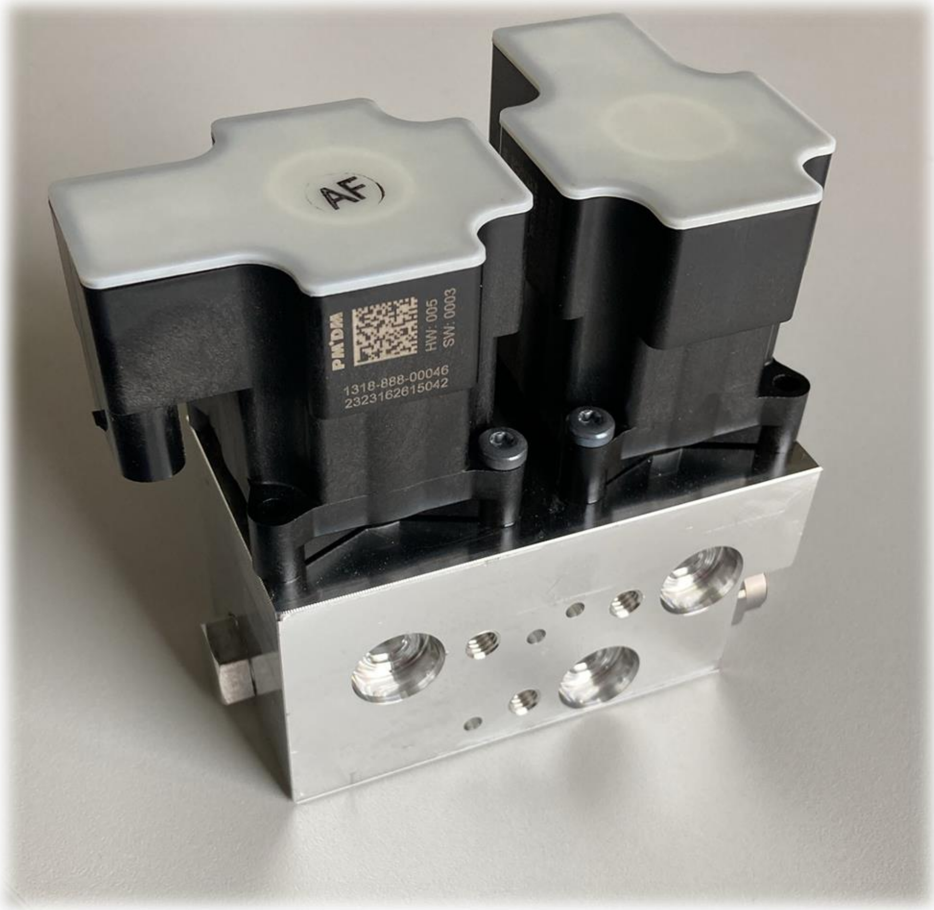
Components of the R744 refrigeration circuit
Expansion valve

The expansion valve is designed as a needle valve.

This allows to switch between complete shut-off, throttling and flow through operation with a low pressure loss.

The valves are installed in the vehicle as a double unit and can be used bidirectionally.

Two valves with pressure relief valve for the low pressure side.



Components of the R744 refrigeration circuit

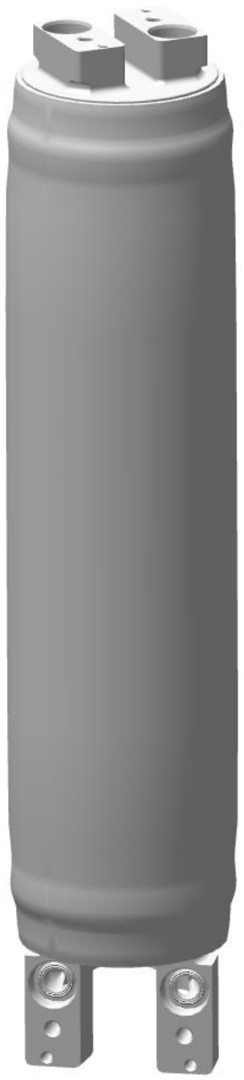
Accu IHX

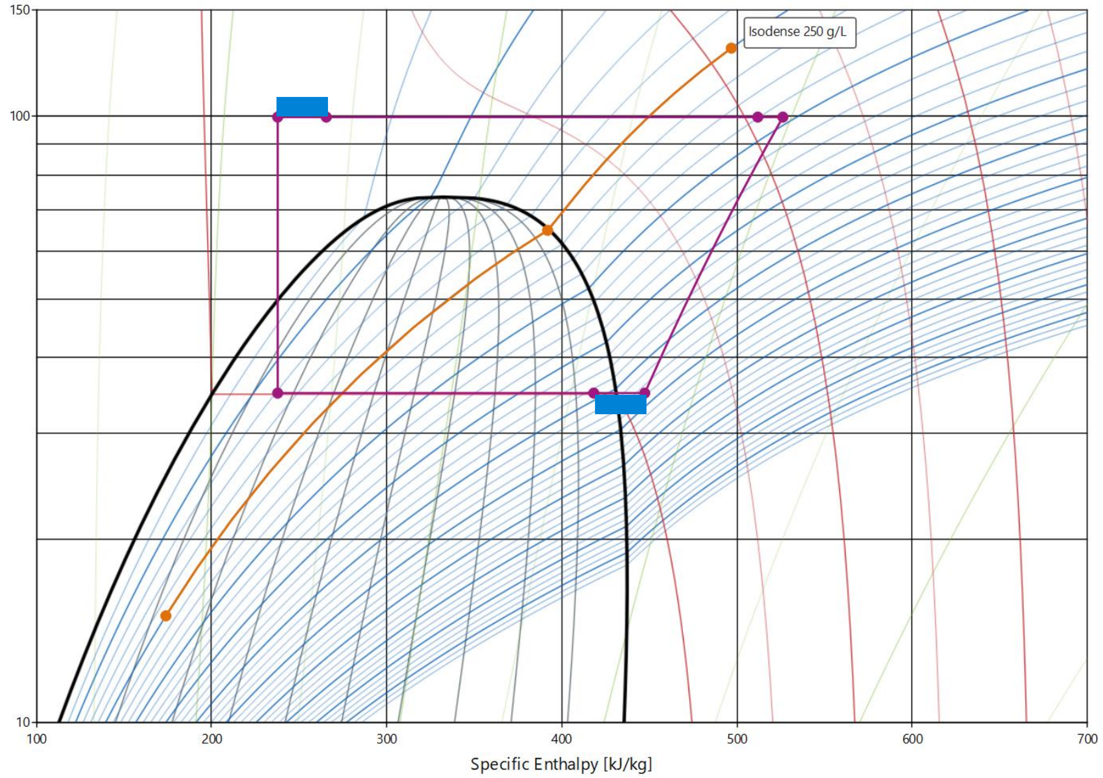
The accu-IHX has the following features

- Refrigerant charge management & regulation
- Control of vapor quality (HP operation)
- Regulation of superheating and cooling of hot gas (A/C operation)
- Regulation of the oil circulation rate (OCR)

- The pressure vessel directive must be observed when designing the component volume.

- Areas of high refrigerant densities must be dimensioned as small as possible in the system design for optimized charge quantity management.



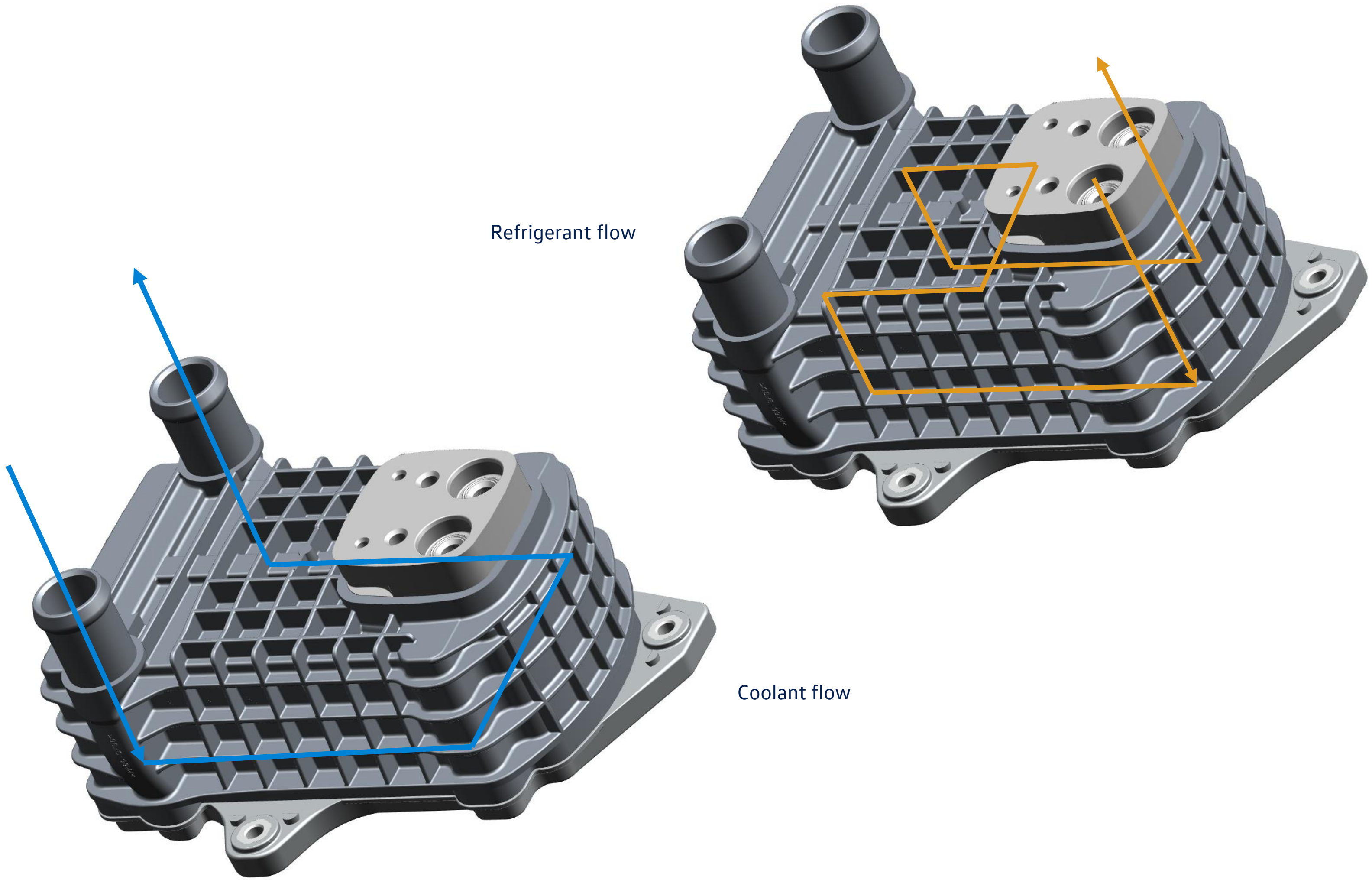


log ph-diagram shows a summer operation mode

Components of the R744 refrigeration circuit

Chiller

- Power level: 5.6 kW (1000 l/h coolant volume flow)
- 4-pass U-Flow
- Location of coolant nozzle optimized for ventilation



Heat Pump Heat Sources
Ambient air

There are basically two heat sources available for the heat pump in BEVs:

1. Waste heat from the drive components and battery
2. **Ambient air**

The availability of waste heat depends strongly on the load profile of the trip, the duration of the trip and the ambient temperature:

Depending on the vehicle, the operating point and the ambient temperature, the heat discharge from the drive train can be too low, sufficient or higher than the requirement.

"Driving on Nordschleife at +10°C certainly generates enough waste heat, the inner-city rush hour at -20°C certainly not enough."

Heat Pump Heat Sources
Ambient air

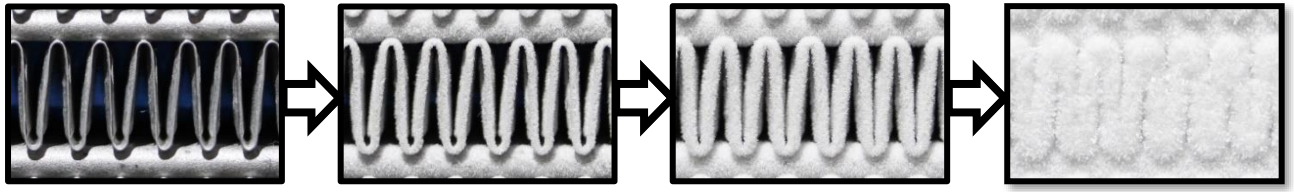
If the waste heat from the traction components is limited as a heat source, the outside air remains as a heat source for the vehicle.

The heat flow from the outside air (without latent heat) is equivalent to the product of mass flow and temperature difference:

$$\dot{Q} = c_p * \Delta T * \dot{m}$$

If the temperature difference in the air increases, the dew point can fall below the dew point.

If the dew point falls below 0°C, the heat exchanger will freeze.



Fotos von VW erstellt

White frost increases the pressure loss coefficient, which leads to a lower air mass flow through the heat exchanger.*
With the lower air mass flow, the cooling of the air mass flow increases with a given power requirement, which leads to a greater drop below the dew point.

Icing of the heat exchanger hinders the prolonged operation of the heat pump from the outside air!

*With constant pressure loss difference across the heat exchanger, e.g. at the same travel speed and fan speed.

Heat Pump Heat Sources
Ambient air

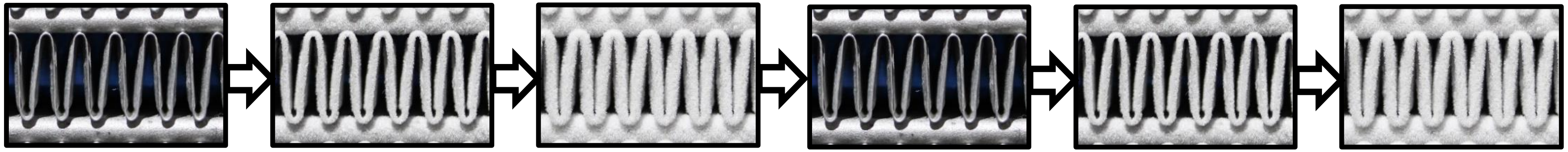
With a given air mass flow, which cannot be increased much, this leads to a restriction of heat absorption from the outside air!

So if neither sufficient waste heat can be extracted from the traction components nor sufficient heat from the outside air, electric heating must be provided via the high-voltage PTC.

→ This reduces the efficiency of the heat pump!

Outlook:

De-icing of the heat exchanger enables long-term operation with high power extraction from the outside air.



Picture source: VW

Conclusion

1 Thermal management for a modern BEV with a large number of heat sources and heat sinks is challenging

2 Direct heat transfer refrigerant to air can be displayed on the source and sink side

3 Coolant and refrigerant circuits must be coordinated with each other

4 Efficiency can be increased by controlled icing of the outdoor air heat exchanger.

5 R744 as a refrigerant suitable for large-scale production even with high complexity in the refrigerant circuit connection