MAHLE

# Thermal management
## in electric and hybrid vehicles

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# Introduction

## How important are electric and hybrid technologies for the workshop?

For the first time, more than two million electric cars and plug-in hybrids were sold worldwide in 2018—with the total figure coming in at 2.1 million. As a result, their market share has risen to 2.4 percent of all new registrations—and the trend is continuing (source: Center of Automotive Management). In Norway, for example, the market share is already around 50 percent!

According to the International Energy Agency (IEA), the growth of electric and hybrid mobility is driven primarily by government programs such as sales bonuses, local driving bans for cars with internal combustion engines, and targets for clean air. The agency considers electric vehicles to be one of several current drive technologies that can be used to achieve the long-term sustainability goals of reducing emissions.

Based on a study by management consultants Pricewaterhouse-Coopers, every third new car registered in Europe in 2030 could be an electric car. So, it is no longer a question of whether vehicles with electric, hybrid, or even hydrogen technologies will really catch on. Rather, they will soon become part of everyday life on our streets.

These vehicles will also have to be serviced and repaired—and thus the subject of thermal management will become more complex. The temperature control of the battery and power electronics plays just as important a role in this respect as the heating and cooling of the vehicle cabin.

Air conditioning components are also required for these types of drive—and their importance is even increasing, since the air conditioning system often has a direct or indirect influence on the cooling of the batteries and electronics.

Air conditioning maintenance will therefore play an even more significant role in the future.

## Important safety information

The following technical information and practical tips have been compiled in order to provide professional support to vehicle workshops in their day-to-day work. The information provided here is intended for use by suitably qualified personnel only.

# Overview of hybrid technologies

## Comparison

*The term "hybrid" essentially means a mix or a combination. With respect to automotive engineering, this term indicates that an internal combustion engine with standard drive technology has been combined in one vehicle with the elements of an electric vehicle.*

*Hybrid technology has three stages of complexity: from micro hybrid to mild hybrid up to full hybrid technology. Despite technical differences, one thing all the technologies have in common is that the battery used is charged by recovering braking energy.*

- Micro hybrids
  are usually equipped with a standard internal combustion engine, a stop-start system, and a brake energy recuperation system.

- Mild hybrids
  in contrast also have an additional small electric motor and a more powerful battery. The electrical auxiliary drive is only used as assistance when starting and for greater power delivery when overtaking, a concept known as "boosting."

- Full hybrids
  can not only "boost," but also run solely on electricity. To this end, they are equipped with a full electric powertrain. However, this requires a much more powerful battery than a mild hybrid.

- Plug-in hybrids
  allow the batteries to be charged overnight, for example. The positive side effect of this vehicle type is that, at the same time, the cabin can be brought to the desired temperature before the journey starts. This means that the vehicle is immediately ready for use the following morning. The plug-in hybrid is a type of full hybrid.

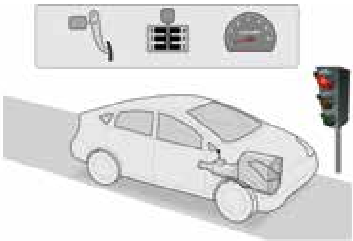
Current representatives that typify full hybrid vehicles include the Toyota Prius, the BMW ActiveHybrid X6 (E72), and the VW Touareg Hybrid. In contrast, the BMW ActiveHybrid 7 and the Mercedes S400 (F04) are examples of mild hybrids.

| Function | Micro hybrid | Mild hybrid | Full hybrid |
|---|---|---|---|
| **Output of the electric motor/alternator** | 2–3 kW<br>(regenerative braking via alternator) | 10–15 kW | >15 kW |
| **Voltage range** | 12 V | 42–150 V | >100 V |
| **Achievable fuel savings compared with a vehicle with conventional drive** | <10% | <20% | >20% |
| **Functions that help reduce fuel consumption** | Stop-start function<br>Recuperation | Stop-start function<br>Boost function<br>Recuperation | Stop-start function<br>Boost function<br>Recuperation<br>Electric driving |

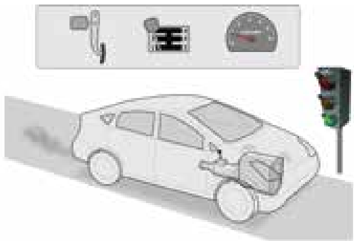
As the overview shows, each of the technologies has various functions that contribute to reducing fuel consumption. These four functions are briefly described below.

## Stop-start function

If the vehicle comes to a stop, e.g., at traffic lights or in a traffic jam, the internal combustion engine switches off. The engine starts automatically if the clutch is pressed and first gear is engaged to drive off. This means it is ready to start driving again immediately.



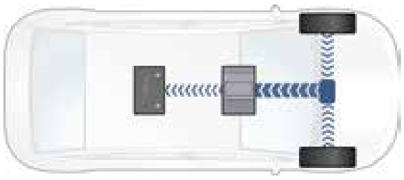
The vehicle comes to a stop—the engine switches off automatically.



Press the clutch, engage the gear—the engine starts automatically.

## Recuperation

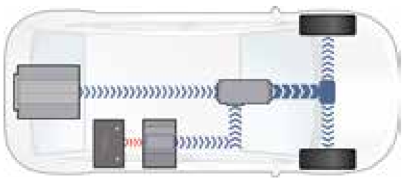
Recuperation is a technology that recovers a portion of the braking energy. Normally, this energy would be lost as thermal energy when braking. During recuperation, on the other hand, the vehicle's alternator is used as an engine brake in addition to the normal wheel brakes. The energy created by the alternator as the vehicle slows is fed into the accumulator (battery). This process specifically increases the drag torque of the engine, thus slowing the vehicle.



Braking vehicle—the battery is charged with more power.

## Boost function

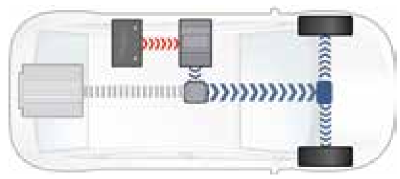
As the vehicle accelerates, the available torque of the internal combustion engine and electric motor are combined. This means that a hybrid vehicle can accelerate more quickly than a similar vehicle with a conventional drive system. The boost function is used to help during start-up and allows more power to be delivered when overtaking. This power is generated by an electrical auxiliary drive that only serves these two purposes. In the VW Touareg Hybrid, for example, this means a performance increase of 34 kW.



Boost function—the internal combustion engine and electric motor drive the vehicle.

## Electric driving

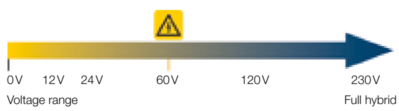
If less drive power is required, e.g., when driving in the city, only the electric motor is used as a power unit. The internal combustion engine is switched off. The advantages of this type of drive are no fuel consumption and no emissions. With these technologies in the vehicle, the conditions that you need to take into account in your daily routine have also changed.



Electric driving—driven solely by the electric motor

## Voltage in the vehicle electrical system

The requirements and performance levels that the electric drive of an electric/hybrid vehicle needs to satisfy cannot be achieved with voltage ranges of 12 or 24 volts. Much higher voltage ranges are required here. Vehicles with high-voltage systems are vehicles that operate the drive and auxiliary components with voltages from 30 to 1,000 VAC or 60 to 1,500 VDC voltage. This applies to most electric and hybrid vehicles.



# High-voltage systems in electric vehicles

## Function

By definition, an electric vehicle is a motor vehicle driven by an electric motor. The electrical energy required for its movements is obtained from a powertrain battery (accumulator)—i.e., not from a fuel cell or a range extender. Since the electric car itself does not emit any relevant pollutants during operation, it is classified as a zero-emissions vehicle.

In electric vehicles, the wheels are driven by electric motors. Electrical energy is stored in accumulators, in the form of one or more powertrain or supply batteries. The electronically controlled electric motors can deliver their maximum torque even at standstill. Unlike internal combustion engines, they usually do not require a manual transmission and accelerate strongly even at low speeds. Electric motors are quieter than gasoline or diesel engines, almost vibration-free, and do not emit any harmful exhaust gases. Their efficiency of more than 90 percent is very high.

The relatively large weight of the accumulators is offset by the weight saving due to the elimination of the various components (engine, transmission, tank) of the combustion engine. Electric vehicles are however usually heavier than corresponding vehicles with combustion engines. The capacity of the battery(ies) has a great influence on the vehicle weight and price.

In the past, electric vehicles had short cruising ranges with one battery charge. Recently, however, the number of electric cars that can reach distances of several hundred kilometers is increasing: for example, Tesla Model S, VW e-Golf, Smart electric drive, Nissan Leaf, Renault ZOE, BMW i3.

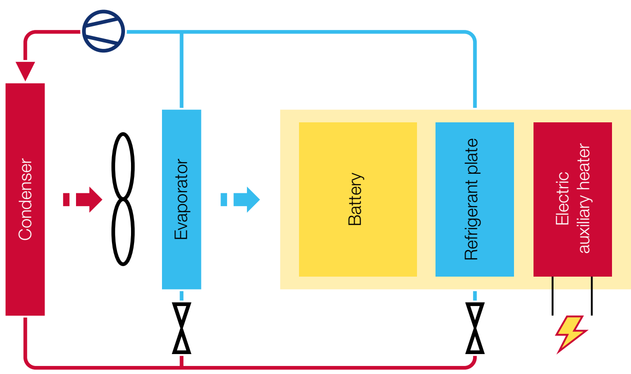
In order to further increase the cruising range of electric vehicles, additional devices (usually in the form of an internal combustion engine) are sometimes used to generate electricity. These are referred to as “range extenders.”

### Air conditioning and cooling in electric vehicles

To enable an electric vehicle to operate at a particularly high level of efficiency, it is necessary to maintain an optimal temperature range for the electric motor, the power electronics, and the battery. This requires a sophisticated thermal management system:

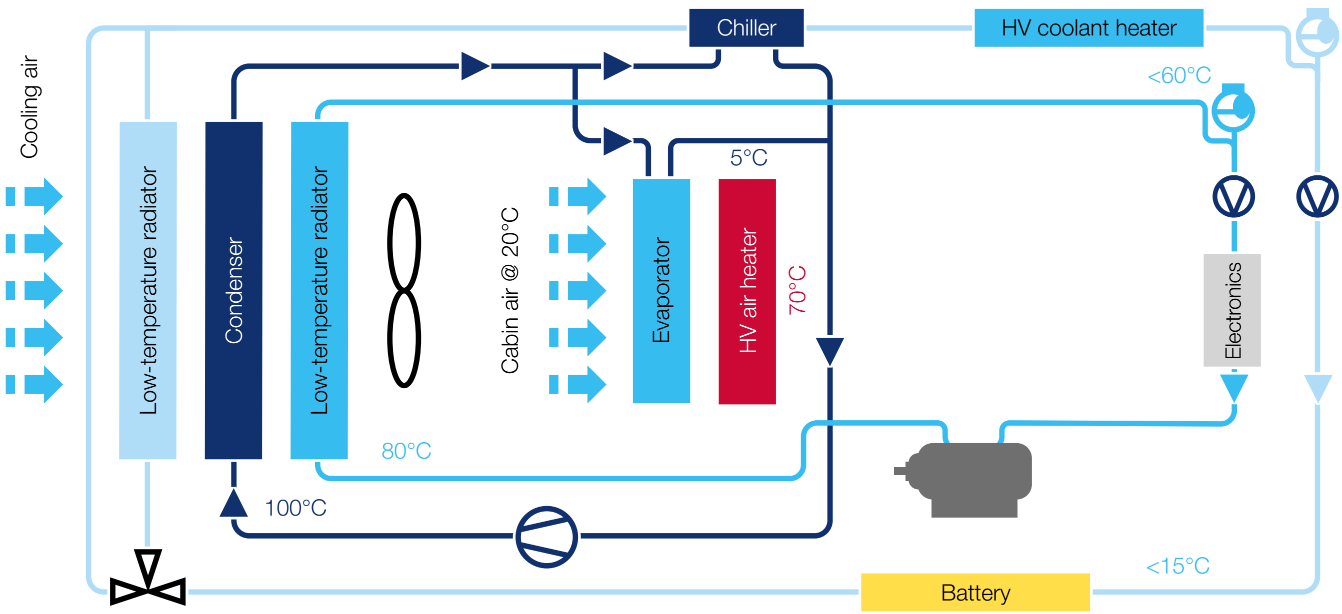
### Refrigerant-based system (or direct battery cooling)

The circuit of the refrigerant-based system consists of the main components: condenser, evaporator, and battery unit (battery cells, cooling plate, and electric auxiliary heater). It is supplied by the refrigerant circuit of the air conditioning system and controlled separately via valves and temperature sensors. The functions of the individual components are described in the explanation for the illustration of the coolant- and refrigerant-based system.




Refrigerant-based circuit

## Coolant- and refrigerant-based circuit (or indirect battery cooling)




The more powerful the batteries are, the more it makes sense to use a comparatively complex coolant- and refrigerant-based circuit. The entire cooling system is subdivided into several circuits, each comprising a separate radiator (low-temperature radiators), a coolant pump, thermostat, and coolant shut-off valve. The refrigerant circuit of the air conditioning system is also integrated via a special heat exchanger (chiller). A high-voltage coolant heater provides sufficient battery temperature control at low outside temperatures.

The coolant temperature for the electric motor and the power electronics is maintained at below 60°C inside a separate circuit (inner circuit on the figure) using a low-temperature radiator. To achieve full performance while ensuring the longest possible service life, it is necessary to always maintain the coolant temperature of the battery between approx. 15°C and 30°C. When temperatures become too low, the coolant is heated via an auxiliary high-voltage heater. When temperatures become too high, it is cooled via a low-temperature radiator. Should this not suffice, a chiller integrated into both the coolant circuit and the refrigerant circuit will further reduce the coolant temperature. Here, the refrigerant of the air conditioning system flows through the chiller and further cools down the coolant, which also flows through the chiller. The entire control is carried out via individual thermostats, sensors, pumps, and valves.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# Component description

## Chiller

The chiller is a special heat exchanger connected to both the coolant circuit and the refrigerant circuit, which allows the temperature of the coolant to be further reduced by the refrigerant in the air conditioning system. This permits additional indirect cooling of the battery by the air conditioning system if required. For this purpose, the coolant of a secondary circuit flows through the cooling plates of the battery. After the heat has been absorbed, the cooling medium is cooled to the initial temperature in a chiller. The temperature reduction in the chiller is caused by the evaporation of another refrigerant circulating in a primary circuit.

## Electric A/C compressor

The compressor is electrically driven with high voltage. This allows for vehicle air conditioning, even when the engine is turned off. In addition, the coolant can also be cooled down with the help of the air conditioning system.

## Low-temperature radiator

The coolant temperature for the electric motor and the power electronics is maintained at below 60°C inside a separate cooling circuit using a low-temperature radiator.

## Thermostat

Thermostats, whether electric or mechanical, maintain the coolant temperature at a constant level.

## Battery cooler

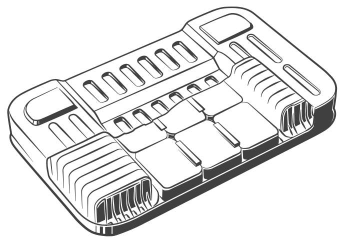
A battery segment is located on each side of the cooling plates. Battery segments and cooling plates form a permanently fixed battery module. With direct battery cooling, refrigerant from the air conditioning system flows through the cooling plates. With indirect battery cooling, coolant flows through the cooling plates. If the cooling capacity is not sufficient for the indirect cooling of the battery, the coolant can be additionally cooled down via a chiller. The chiller is a special heat exchanger that is used for indirect battery cooling and is integrated in both the refrigerant circuit and the coolant circuit.

## Electric auxiliary heater/ high-voltage auxiliary heater

Electric vehicles lack the dissipated heat from the engine, which is transferred to the coolant. It is therefore necessary to warm up the interior with the help of an electric auxiliary heater located in the ventilation system.

## High-voltage battery

The high-voltage battery (HV battery) is, along with the electric motor, one of the key components of the electric vehicle. It consists of interconnected battery modules, which in turn are made up of cells. Batteries are usually based on lithium-ion technology. They have a high energy density. Due to a decreasing chemical reaction, the performance at temperatures below 0°C drops significantly. At temperatures above 30°C, the aging process increases strongly and at temperatures above 40°C, the battery can be damaged. In order to achieve the longest possible service life and effectiveness, the battery must be operated in a certain temperature spectrum.

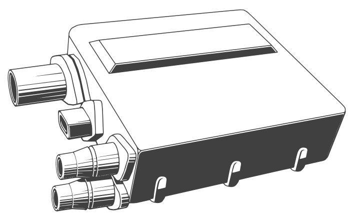


## Coolant/refrigerant shut-off valve

Coolant/refrigerant shut-off valves are electrically controlled and open or close parts of the coolant/refrigerant circuit as required or connect several circuits with one another.

## Power electronics

Their task in the vehicle is to control the electric motors, communicate with the vehicle control system, and perform diagnostics on the drive. As a rule, the power electronics consist of an electronic control unit, an inverter, and a DC/DC converter. In order to maintain the power electronics within a certain temperature range, they are connected to the vehicle's cooling/heating system.



## High-voltage coolant auxiliary heater

When temperatures become too low, the coolant is heated via an electric auxiliary high-voltage heater. This is integrated in the cooling circuit.

## Condenser

The condenser is needed to cool down the refrigerant that has become heated during compression in the compressor. The hot refrigerant gas flows into the condenser, discharging heat to the surroundings via the pipe and fins. Cooling reduces the refrigerant state of aggregation from gaseous to liquid.

## Electric water pump

Electric water and coolant pumps and their integrated electronic control are variably activated according to the required cooling performance. They can be used as main, minor, or circulation pumps. They operate independently of the engine and as required.

## Air conditioning

Due to their high efficiency, electric drives emit little heat to the environment during operation and no heat at all when stationary. In order to heat the car in the event of low outside temperatures or to defrost the windows, auxiliary heaters are necessary. These represent additional energy consumers and are very significant due to their high energy consumption. They consume some of the energy stored in the battery, which has a considerable effect on the cruising range, especially in winter. Electric auxiliary heaters integrated in the ventilation system are a simple, effective, but also very energy-intensive form. Energy-efficient heat pumps are therefore now also being used. In summer, they can also be employed as an air conditioning system for cooling. Seat heaters and heated windows bring the heat directly to the areas to be heated and thus also reduce the heating requirement for the interior. Electric cars often spend their downtimes at charging stations. There, the desired vehicle temperature can be achieved before the start of the journey without loading the accumulator battery. On the go, considerably less energy is required for heating or cooling. Smartphone apps are now also available for controlling the heating remotely.

## Charging and discharging management

Different management systems are used for the accumulators, which take over the charge and discharge control, temperature monitoring, cruising range estimation, and diagnostics. The durability depends essentially on the operating conditions and compliance with the operating limits. Battery management systems including temperature management prevent harmful and possibly safety-critical overcharging or exhaustive discharge of the accumulators and critical temperature conditions. The monitoring of each individual battery cell allows it to react before a failure or damage to other cells occurs. Status information can also be stored for maintenance purposes and, in the event of an error, corresponding messages can be issued to the driver.

Basically, the battery capacity of most electric cars today is enough for the majority of all short and medium-length journeys. A study published in 2016 by the Massachusetts Institute of Technology concluded that the cruising range of current standard electric cars is sufficient for 87 percent of all trips. However, cruising ranges fluctuate significantly. The speed of the electric vehicle, the outside temperature, and especially the use of heating and air conditioning lead to a significant reduction in the radius of action. However, the ever-shorter charging times and the constant expansion of the charging infrastructure are making it possible to further increase the action radius of electric cars.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# Basic rules for working on electric and hybrid vehicles

## Practical tips

Electric and hybrid vehicles necessitate the installation of high-voltage components. These are clearly identified by uniform warning signs. Also, all manufacturers mark high-voltage lines with a bright orange color.

The following procedure applies when working on vehicles with high-voltage systems:

**1. Completely switch off the electrical system.**

**2. Secure against current being switched on again.**

**3. Check there is no voltage present.**

**Please observe the specifications of the vehicle manufacturers and our workshop tips.**

### *What do I have to pay attention to as a workshop (employee)?*

#### Starting and moving the vehicle:

In order to drive a vehicle with a high-voltage system—even if only from or to the workshop—the respective person must receive instruction.

#### Service and maintenance:

Service and maintenance work (changing wheels, inspection work) on high-voltage vehicles may only be carried out by persons who have previously been informed of the dangers of these high-voltage systems and instructed accordingly by a *Fachkundiger für Arbeiten an HV eigensicheren Fahrzeugen* (expert for work on HV intrinsically safe vehicles).

#### Replacement of high-voltage components:

Persons replacing high-voltage components, such as an air conditioning compressor, must have the appropriate qualifications (expert for work on HV intrinsically safe vehicles).

#### Replacing the battery:

The repair or replacement of live high-voltage components (batteries) requires special qualification.

#### Breakdown assistance/towing/recovery:

Anyone providing breakdown assistance on a vehicle with high-voltage systems or towing or recovering such must have received instruction in the structure and functioning of the vehicle and its high-voltage system. Furthermore, the respective instructions of the vehicle manufacturer must be taken into account in advance. If high-voltage components (battery) are damaged, the fire brigade should be consulted.

# Interior air conditioning

## Basics

In conventional drive concepts with internal combustion engines, the air conditioning inside the vehicle is directly dependent on the engine operation due to the mechanically driven compressor. Compressors with belt drives are also used in vehicles that are referred to by specialists as micro hybrids and only have a stop-start function. The problem here is that when the vehicle is at a standstill and the engine is switched off, the temperature at the evaporator outlet of the air conditioning system starts to increase after just two seconds. The associated slow rise in the discharge temperature of the ventilation and the increase in humidity can be annoying for passengers.

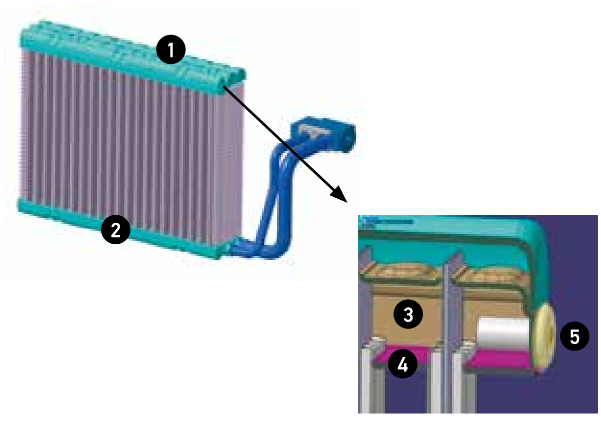
In order to counter this problem, newly developed cooling batteries, so-called storage evaporators, can be used. The storage evaporator comprises two cores: an evaporator core and an accumulator core. Refrigerant flows through both cores in the start-up phase or when the engine is running. In the meantime, a latent medium in the evaporator is cooled to the extent that it freezes. This makes it a cooling battery.

In the stop phase, the engine is switched off and the compressor is not driven as a result. The warm air flowing past the evaporator cools down, and a heat exchange takes place. This exchange continues until the latent medium has completely melted. Once the journey is resumed, the process starts again so that the storage evaporator can start cooling the air again after just one minute.

On vehicles that do not have a storage evaporator, the engine has to be started again after a short standstill period in very warm weather. This is the only way to maintain interior cooling. Air conditioning inside the vehicle also includes heating the passenger compartment if required.

In full hybrid vehicles, the internal combustion engine is switched off when driving using the electric motor. The prevailing residual heat in the water circuit is sufficient to heat the interior for a short period of time only. As support, high-voltage air auxiliary heaters are then switched on to take over the heating function. The operation is similar to that of a hair dryer: the air that is drawn in by the interior fan is heated up as it flows past the heating elements and then passes into the interior.

Storage evaporator

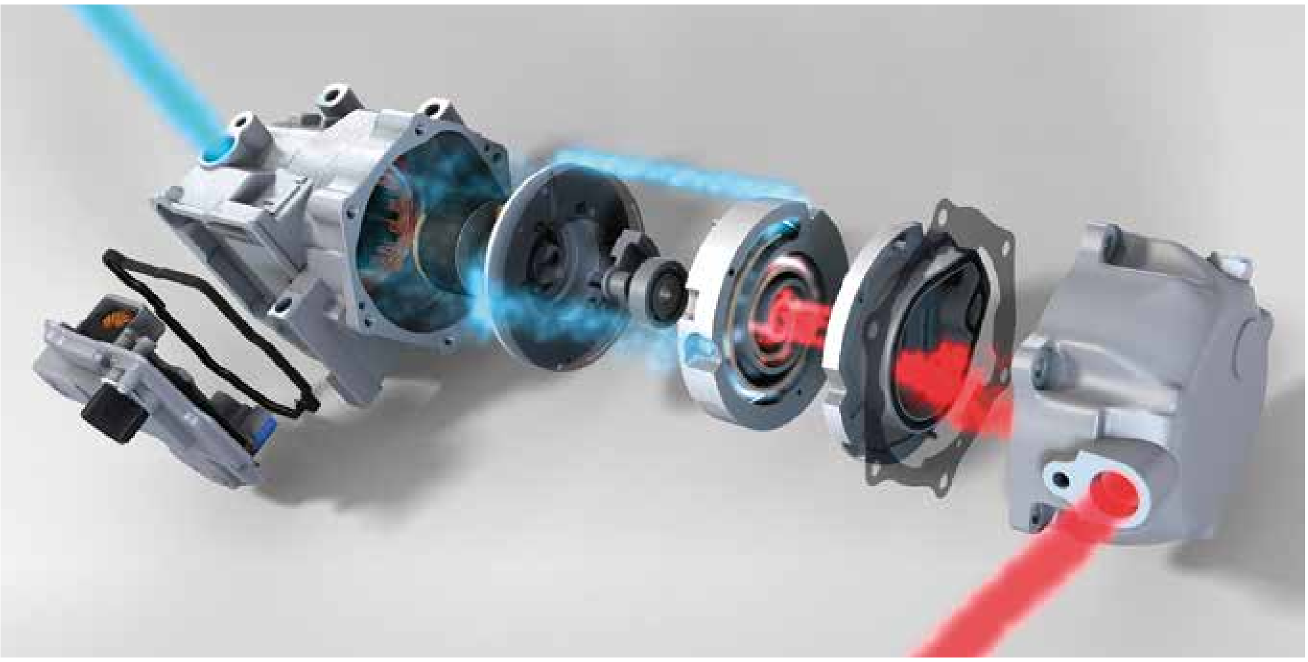



Schematic diagram of storage evaporator: (1) evaporator core 40 mm deep, (2) storage core 15 mm deep, (3) refrigerant, (4) latent medium, (5) blind rivet

# High-voltage air conditioning compressor

## Function

*Vehicles with full hybrid technology use high-voltage electric compressors that do not depend on the internal combustion engine running. This innovative drive concept allows functions to be carried out that lead to a further increase in comfort with regard to the air conditioning in the vehicle.*



It is possible to precool the heated interior to the desired temperature before starting the journey. This can be activated via remote control.

This process of cooling while stationary is possible only if there is enough battery charge available. The compressor is controlled with the lowest possible output taking into account the necessary air conditioning requirements.

In the high-voltage compressors used today, the power is regulated by adjusting the speed in steps of 50 rpm. It is therefore not necessary to have an internal power control.

In contrast to the swash plate principle, which is primarily used in the belt-driven compressor field, the high-voltage compressors use the scroll principle to compress the refrigerant. The benefits are that the weight is reduced by around 20 percent and there is a reduction in the displacement of the same amount while the output remains identical.

A DC voltage of over 200 volts is used to generate the right amount of torque to drive the electric compressor—a very high voltage in this vehicle sector. The inverter fitted into the electric motor unit converts this DC voltage into the three-phase AC voltage required by the brushless electric motor. The return flow of refrigerant to the suction side facilitates the necessary heat transfer from the inverter and the motor windings.

# Temperature management of the battery

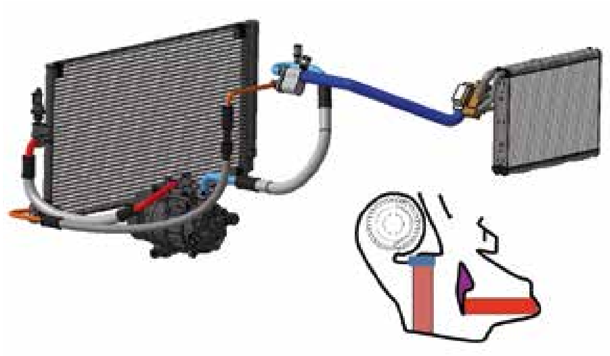
## Comparison

### Temperature management of the battery

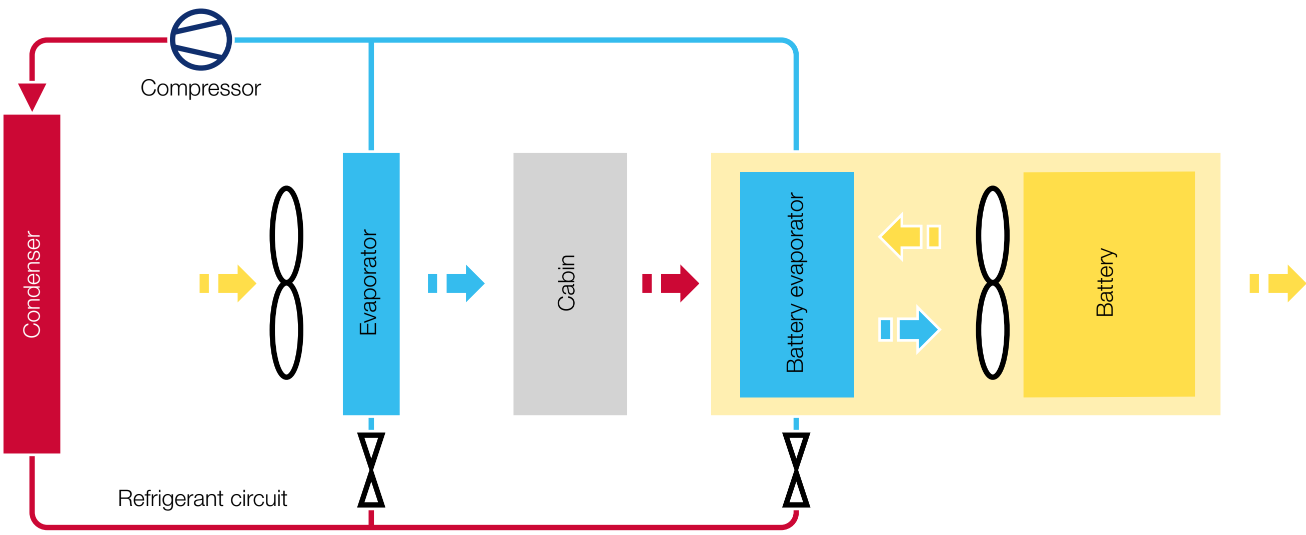
The battery is essential for the operation of an electric and hybrid vehicle. It must provide the high amount of energy required for the drive quickly and reliably. Most of these are lithium-ion and nickel-metal hybrid high-voltage batteries. This further reduces the size and weight of the hybrid vehicle batteries.

It is essential that the batteries used are operated within a defined temperature window. Service life decreases at operating temperatures of +40°C or higher, while efficiency drops and output is lower at temperatures below 0°C. Furthermore, the temperature difference between the individual cells must not exceed a particular value.

Brief peak loads in connection with high current flows, such as from recuperation and boosting, lead to a significant increase in the temperature of the cells. Also, high outside temperatures in the summer months can mean that the temperature quickly reaches the critical 40°C level. The consequences of exceeding this temperature are faster aging and the associated premature failure of the battery. Vehicle manufacturers strive to ensure that the calculated battery service life is one car life (around eight to ten years). Therefore, the aging process can only be countered with an appropriate temperature management system. Until now, three different temperature management options have been used.



### Option 1



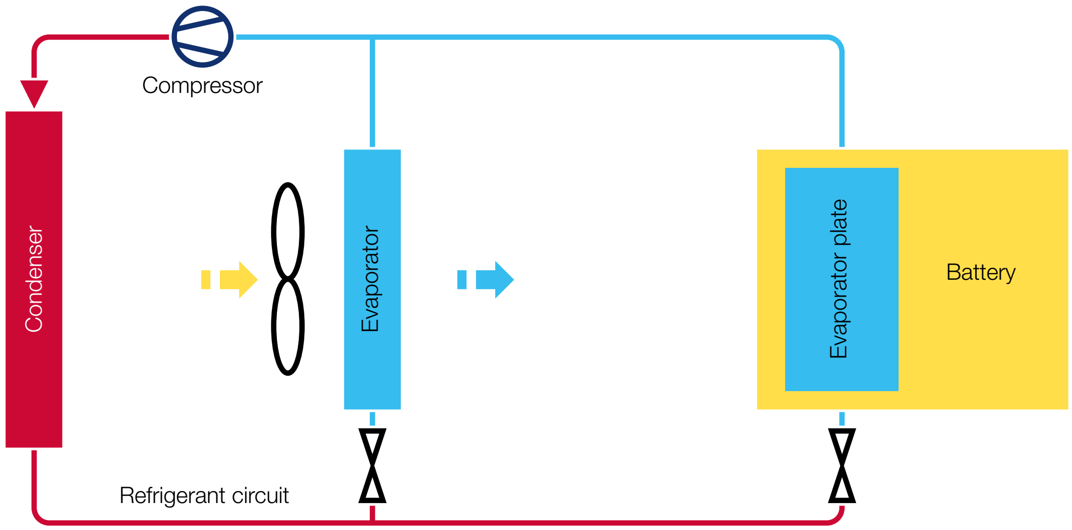

Air is drawn in from the air-conditioned vehicle cabin and used to cool the battery. The cool air drawn in from the cabin has a temperature of less than 40°C. This air circulates around the accessible surfaces of the battery pack.

### This has the following disadvantages:

- Low cooling effectiveness.
- The air suctioned from the cabin cannot be used to reduce the temperature evenly.
- Considerable effort required to guide the air.
- Possible annoying noises in the cabin due to the blower.
- There is a direct connection between the passenger cabin and battery via the air ducts. For safety reasons (e.g., outgassing of the battery) this is problematic.
- Another factor that should not be underestimated is the risk of dirt entering the battery pack because the air from the interior of the vehicle also contains dust. The dust is deposited between the cells and forms a conductive layer together with condensed humidity. This layer facilitates the creation of leak currents in the battery.

To avoid this risk, the intake air is filtered. Alternatively, air cooling can also be carried out by a separate small air-conditioning unit similar to the separate rear air conditioning systems in premium-class vehicles.

### Option 2




A special evaporator plate inside the battery cell is connected to the air conditioning system in the vehicle. This is done using what is known as the splitting process on the high-pressure and low-pressure side via pipelines and an expansion valve. This means that the interior evaporator and the evaporator plate of the battery, which works like a conventional evaporator, are connected to the same circuit.

The different tasks for the two evaporators result in correspondingly different requirements for refrigerant flow. While the interior cooling system aims to satisfy the comfort requirements of the passengers, the high-voltage battery must be cooled to varying degrees of intensity depending on the driving situation and the ambient temperature.

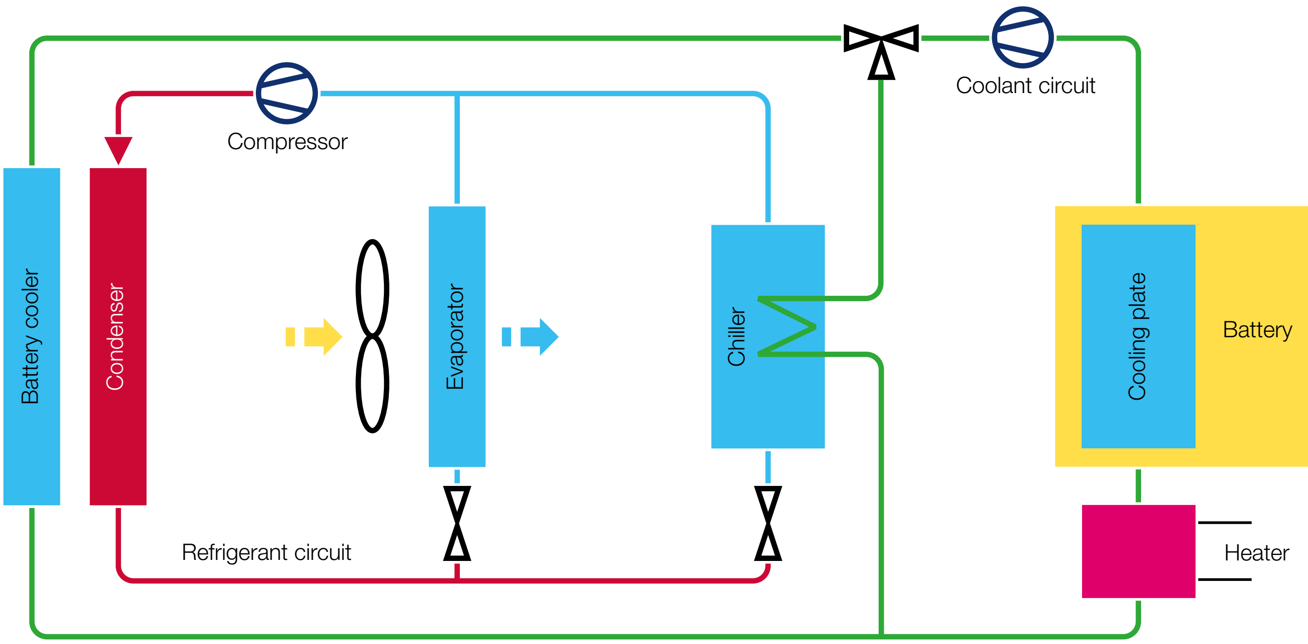
These requirements are the defining factors for the complex control of the quantity of evaporated refrigerant. The special design of the evaporator plate and its resulting integration into the battery offer a large contact surface for the heat transfer. This means it is possible to guarantee that the critical maximum temperature of 40°C is not exceeded.

When outside temperatures are very low, an increase in the temperature of the battery to bring it to its ideal temperature of at least 15°C may be required. However, the evaporator plate cannot help in this situation. A cold battery is less powerful than one at the right temperature. It is also difficult to charge the battery when temperatures are significantly below freezing. In a mild hybrid, this can be tolerated: in extreme cases, the hybrid function is only available in a limited capacity. It is, however, still possible to drive with the internal combustion engine. In a battery electric vehicle, on the other hand, a battery heater needs to be fitted so that the vehicle can be started and driven in any situation in winter.

## Note

Evaporator plates integrated directly into the battery cannot be individually replaced. Therefore, the whole battery needs to be replaced in the event of damage.

### Option 3




The correct temperature plays a key role for batteries with higher capacities. Therefore, at very low temperatures, additional heating of the battery is required to bring it to the ideal temperature range. This is the only way to achieve a satisfactory cruising range when in "electric driving" mode.

To enable this additional heating, the battery is integrated into a secondary circuit. This circuit ensures that the ideal operating temperature of 15°C to 30°C is maintained at all times. Coolant, made of water and glycol (green circuit), flows through a cooling plate integrated into the battery core. At lower temperatures, the coolant can be quickly heated by a heater to reach the ideal temperature. The heater is switched off if the temperature in the battery rises when the hybrid functions are being used. The coolant can then be cooled via a battery cooler located in the vehicle front or a low-temperature radiator using the airstream from the vehicle driving forward.

If the cooling by the battery cooler is not sufficient at high outside temperatures, the coolant flows through a chiller. In it, refrigerant from the vehicle air conditioning system is evaporated. In addition, heat can be transferred from the secondary circuit to the evaporating refrigerant in a very compact space and with a high power density. An additional recooling of the coolant is performed. Thanks to the use of the special heat exchanger, the battery can be operated within the most efficient temperature window.

# Further training for the repair of electric and hybrid vehicles

## Key facts

Continuous ongoing education is required to maintain and repair the complex systems, especially those for thermal management, found in electric and hybrid vehicles. In Germany, for example, employees working on such high-voltage systems require an additional two-day training course to become "experts for work on high-voltage (HV) intrinsically safe vehicles."

This course teaches the participants to recognize the risks when working on systems of this kind as well as how to switch off all the current to the system for the duration of the work. People who have not received appropriate training are prohibited from working on high-voltage systems and their components. The repair or replacement of live high-voltage components (batteries) requires special qualification.

## Thermal management training from MAHLE:

Whether trainees, experienced mechanics, master mechanics, or engineers, MAHLE Aftermarket offers the right course for everyone.

In addition to teaching theory, MAHLE Aftermarket offers special practical training on damage prevention for passenger cars and trucks as well as for agricultural and construction machinery.

At MAHLE Aftermarket, we're flexible: you select the topic, tell us when and where the training should take place, and we'll take care of the rest. Simply speak to your MAHLE Aftermarket trading partner or contact us directly at: **ma.training@mahle.com**.

MAHLE Aftermarket's technical experts look forward to organizing interesting and exciting events for you.

- T-AC Air conditioning in the vehicle: air conditioning system design, function, and common causes of failure
- C-SK Expertise in vehicle air conditioning

# Workshop tips

## Maintenance of electric and hybrid vehicles

Special attention is also required when performing routine inspections and repair work (e.g., on exhaust systems, tires, and shock absorbers, and oil and tire changes). This work may only be performed by employees who have been trained by an "expert for work on HV intrinsically safe vehicles" on the dangers of these high-voltage systems and instructed accordingly. It is also essential to use tools that comply with the specifications of the vehicle manufacturer.

Motor vehicle companies are required to instruct all employees involved in the operation, maintenance, and repair of electric and hybrid vehicles. Please note the respective country-specific conditions.

Tools for working on high-voltage systems

## Breakdown assistance, towing, and recovery of electric and hybrid vehicles

Drivers of vehicles with high-voltage (HV) systems are not exposed to any direct electrical hazards—not even in the event of a breakdown. A large number of measures taken by vehicle manufacturers secure the HV system. Breakdown assistance for vehicles with HV systems is also harmless as long as no intervention in the HV system is necessary to eliminate faults.

However, there are dangers in the event of a breakdown or towing of vehicles damaged in an accident or that have to be recovered from snow and water. Although the intrinsic safety of the vehicles to protect against hazards from electric shock or arcing is very high, not every case of damage is completely or 100 percent safe. In case of doubt, the respective information from the vehicle manufacturer must be taken into account or requested.

## How do I tell if the vehicle has a high-voltage system?

- By the lettering on the dashboard or on the vehicle.
- By orange high-voltage cables (see illustration). As a general rule, do not touch high-voltage components or orange cables.
- By the marking on the HV components (see illustration).

High-voltage components in the engine compartment

## Who is allowed to provide breakdown assistance?

Breakdown assistance for electric and hybrid vehicles may be provided by anyone who has been specially qualified for this purpose. Anyone providing breakdown assistance therefore receives instruction in the design and operation of vehicles with high-voltage systems. The respective country-specific requirements and conditions for “non-electrical work” apply. (For Germany, the German Social Accident Insurance (DGUV) publication 200-005 *Qualifizierung für Arbeiten an Fahrzeugen mit Hochvoltsystemen* [Qualification for work on vehicles with high-voltage systems); (previously BGI 8686] applies. Please note the respective country-specific conditions.)

## First steps in roadside assistance?

- Remove the ignition key (caution: transponder systems switch on automatically when approaching) and then pull the disconnector of the high-voltage battery.
- Visually check whether HV components are damaged.
- Do not carry out any work on the HV components. This may only be carried out by persons who are qualified to work on vehicles with high-voltage systems. This also applies if HV components are damaged or found to be damaged during the breakdown service.
- A residual voltage can also be present after the HV system has been switched off—this may last for several minutes depending on the manufacturer.

Disconnector

## Jump starting, towing, and recovery—what should be taken into account?

### Jump starting

It is essential to observe the manufacturer's instructions. Only a few vehicles can be jump started via the 12/24 VDC vehicle electrical system. Dangerous residual voltages that are not discharged via continuous discharge resistors may be present even after switching off. Before opening, observe the instructions in the operating manual and/or technical information from the vehicle manufacturer.

### Towing and recovery

- Undamaged vehicles can generally be loaded onto a recovery vehicle (platform vehicle).
- When towing with a rod or cable, the manufacturer's specifications must be observed.
- In order to recover vehicles safely, all measures from the chapter "Safe assistance with electric cars" must be taken into account.
- If the vehicle is towed/recovered with a winch, no HV components may be located in the area of the attachment points or be damaged. The same applies when lifting with a jack or loading crane.

### Behavior in the event of an accident

- In the event of an accident, in most cases the HV system is switched off when the airbag is deployed. This applies to almost all passenger cars, but not necessarily to commercial vehicles.
- To be able to work without danger, all measures from the chapter "Basic rules for working on electric and hybrid vehicles" must be taken into account.
- Some manufacturers recommend or prescribe that the negative terminal of the 12/24 VDC vehicle electrical system battery be disconnected (further information can also be found in the respective rescue guidelines).
- If HV batteries or HV capacitors (energy storage devices in commercial vehicles) have been damaged or torn out by an accident, this poses a particular hazard. The fire brigade should be called in to help in this case. When handling damaged HV batteries, appropriate personal protective equipment (face protection, protective gloves for working with voltage) is required.
- Spilled battery fluids may be corrosive or irritant, depending on the battery type. Contact should be avoided in all cases. After an accident, HV batteries may still catch fire later as a result of internal reactions. Damaged vehicles should therefore not be parked in enclosed spaces.

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