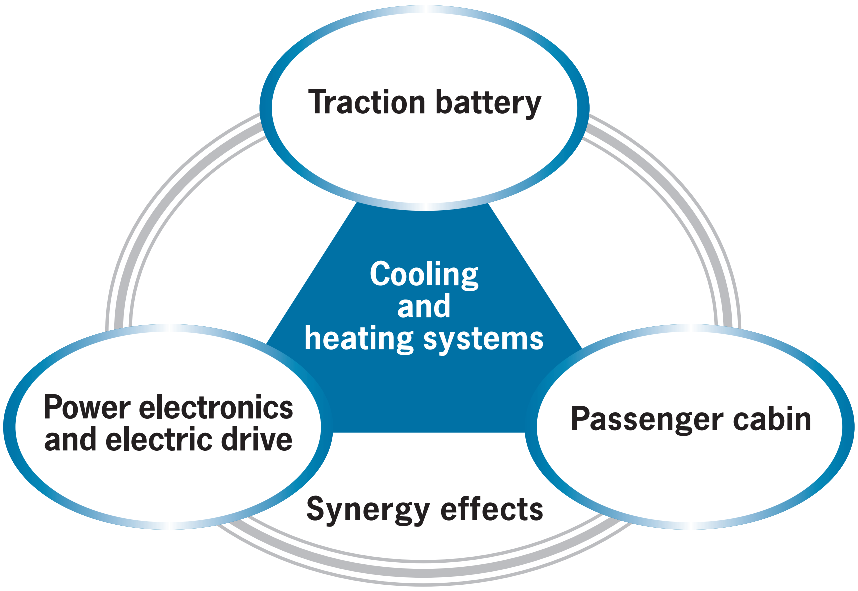
Thermal management in vehicles with electric drive system

Transforming the drive train into an electric drive sets new and exciting challenges for the thermodynamics specialists at Porsche Engineering.



Up until now, thermodynamics specialists at Porsche were responsible for efficiently conducting waste heat away from the combustion engine, ensuring thermal stability and functionality with an optimized cooling system and reducing fuel consumption at all operating points using sophisticated thermal management strategies. They also had to ensure that components, auxiliary equipment and the transmission were cooled, ventilated and protected from high temperatures.

Electric vehicles have completely changed the core tasks required. Along with controlling the temperature in the traction battery and cooling the power electronics, electric motor and range extender, integrating these different cooling systems and the efficient climate control in the vehicle interior while also saving energy is now the main focus.

Because traction batteries in electric vehicles still have a limited capacity in comparison to conventional cars, electric vehicles have a significantly smaller range. This means that it is of central importance to ensure that all operating functions are reliable, while also maintaining comfort and the energy efficiency of all technical systems. This limited range can be even more drastically reduced by auxiliary loads such as heating and climate control.

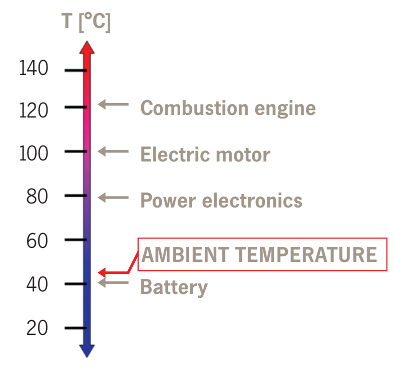
Cooling the battery, power electronics and the electric motor

From a thermal point of view, there are three main aspects to take into account when using lithium-ion batteries in electric vehicles. At temperatures below zero degrees Celsius (32 degrees Fahrenheit), the performance and therefore the range drop significantly due to slower chemical reactions taking place in the battery. At temperatures above 30 degrees Celsius (86 degrees Fahrenheit) the battery deteriorates exponentially, while extreme temperatures of above 40 degrees Celsius (104 degrees Fahrenheit) can lead to serious and irreversible damage in the battery.

The ideal temperature for a lithium-ion traction battery is approximately the same temperature that is ideal for human beings. In order to achieve the maximum power output and a long lifespan for the battery, it must be kept within an ideal temperature range of between 20 and 30 degrees Celsius (68 and 86 degrees Fahrenheit). To achieve this, it must be ensured that the battery does not exceed a maximum temperature limit, while heat must also be distributed as evenly as possible in the battery cells.

The thermal influence on a battery, such as fluctuations in the battery's own temperature caused by resistance inside the battery, external temperatures, sunlight and waste heat, must therefore be monitored and controlled by appropriate thermal control systems, i.e. by means of heating or cooling as necessary. This ensures proper functioning

Temperature levels



in the temperature range of −20 to +45 degrees Celsius (−4 to +113 degrees Fahrenheit) as required by customers.

Depending on the type of electrically powered vehicle (for example mild hybrids, full hybrids, plug-in hybrids, completely electric vehicles), requirements profile, battery type, cell chemistry and cell geometry, various cooling agents and methods can be used. These methods include air-cooling, cooling with coolants or refrigerants, and direct cooling or secondary cooling.

The latter involves cooling the battery using an external low-temperature cooler. Only if necessary, e.g. at high outdoor temperatures, an additional heat exchanger (chiller) is used to transfer the low temperature of the evaporating refrigerant from the climate circuit to the battery cooling circuit.

Along with the traction battery, it is important to take the temperature of other components in an electric vehicle into account, such as electric motor(s), power electronics and range extenders.

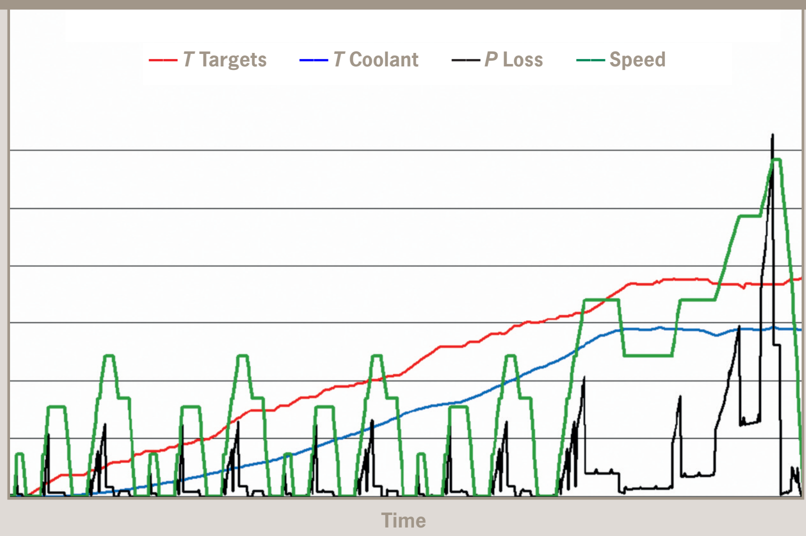
As these systems all operate at different temperature levels and must be cooled to different degrees (see graphic on the left), the aim is always to create synergy effects by harmonizing all the various cooling and heating circuits (see graphic on opposite page). By harmonizing the temperature levels, the number of different cooling circuits can be minimized, which in turn results in lower weight and costs, as well as more space in the vehicle.

The engineers at Porsche Engineering select the cooling agents and methods as early as during the first design concept phase. For this purpose, Porsche Engineering has developed a thermal simulation tool and validated it in tests. This can be used to work out and define the optimum cooling and heating system design at an early stage of vehicle development using previously identified performance data and driving profile requirements.

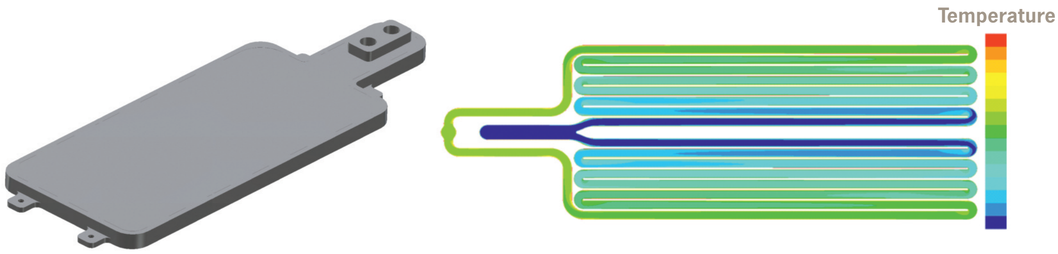
The graphic below shows an example of some of the results from a thermal simulation of a battery cooling process for the New European Driving Cycle (NEDC). Based on the calculation of the power loss, the increase in the temperature of components as well as the cooling requirement can be defined. Furthermore, the energy requirements for various cooling systems can be calculated and the optimum design for low energy consumption in the entire vehicle can be selected.

Thermodynamic engineers at Porsche Engineering develop and optimize the vehicle's entire cooling system, individual cooling and heating circuits or components according to customer requirements. An example of this process is the cooling plate from the traction

Simulation results for a vehicle in the NEDC



Boxster E battery cooling plate



battery in the Boxster E, as it can be seen above. Based on the analysis results from the thermal model described above, the cooling plate was designed geometrically and optimized using computational fluid dynamics (CFD). The result is a highly efficient and lightweight heat exchanger, optimally tailored and adapted to the battery pack, with low pressure losses, high cooling performance and a very even distribution of temperature.

Vehicle interior climate control

Another challenge in the design of electrically powered vehicles is the provision of heating and cooling systems for passenger comfort, as well as considering aspects relevant to safety such as keeping the windows free of condensation or ice (defrost function). The climate control systems customers are familiar with and expect from conventional vehicles require an energy input of up to 3 kW on hot and humid days, and up to 7 kW in the cold winter months for heating the vehicle. As there is no waste heat from the combustion engine, this energy requirement must be met by the traction battery, e.g. using a high-voltage PTC auxiliary heater. Calculations show that these kinds of heating systems can actually absorb just as much power as driving itself and can therefore reduce the range by up to 50 percent. Porsche Engineering has developed new and innovative approaches to relieve customers from the need to pick whether to drive or freeze. Integrated auxiliary heating systems based on renewable fuels or combinations of heat pumps, latent heat-storage units and air- and water-based auxiliary heaters can be designed and built according to the vehicle model and the requirements profile.

The Porsche engineers and designers always have the whole vehicle in mind, which means that secondary methods are also taken into account and tested for efficiency and feasibility in the optimization of thermal management. The use of innovative (insulation) materials and designs to insulate the interior and components can therefore lead to targeted results in order to promote heat transfer or specifically insulate it.

Conclusion: challenges and solutions

Electrically powered vehicles no longer require conventional cooling as in combustion engines, or they require it only to a limited extent. With the lack of engine waste heat and the option of powering accessories using the combustion engine, new solutions must be developed from the viewpoint of both thermal and energy requirements.

This leads to complex thermal management systems at various temperature levels for cooling the battery, the electric motor, the power electronics and any range extender. Climate control in the vehicle interior is also becoming more complex.

The specialized engineers at Porsche Engineering meet these challenges with solid thermal management experience and expertise from classic sports car design and construction as well as experience from electromobility projects.

Using all available development tools from simulation to calculation, from conventional component testing in the testing facility to the testing of the entire vehicle on the test track, Porsche Engineering develops components, modules and entire systems for the thermal protection and optimization of vehicles and products of all kinds.