# BLOWING HOT AND COLD
# USING SIMULATION TO OPTIMIZE VEHICLE CLIMATE CONTROL SYSTEMS

A whitepaper discussing the issues thermal engineers face every day attempting to accurately predict cabin comfort

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## Using Simulation to Optimize Vehicle Climate Control Systems

### EXECUTIVE SUMMARY


The design of vehicle climate control systems is becoming more challenging with each new model year. Competitive pressures are forcing automotive Original Equipment Manufacturers (OEMs) to provide higher levels of cabin comfort while overcoming conflicts with fuel economy, safety and other regulatory requirements. The design of the climate control system is further complicated because its vents are positioned around the vehicle cabin which necessitates compromises with other important design goals and attributes such as interior styling, interior space, and noise.

In the traditional design methodology, 1D simulation tools are often used to make preliminary sizing decisions. Then a prototype car is used to evaluate the performance of heating and cooling systems. This approach is costly and time-consuming because of the physical hardware that must be built and tested so only a few iterations are usually possible. Traditional Computational Fluid Dynamics (CFD) is used for 3D simulations but cannot address all the requirements for detailed spatially varying temperature prediction affected by natural and forced convection phenomena during cabin heat-up and cool-down. This temperature distribution is crucial for the perception of passenger comfort.

PowerFLOW overcomes these challenges by replacing the Navier-Stokes equations used in traditional commercial CFD solvers with the Lattice Boltzmann Method which provides a far more efficient method of computing transient flows. PowerFLOW can accurately simulate key climate control performance parameters for detailed geometries and time periods relevant to standard industry tests such as 9-hour solar soak followed by a 30-minute cooldown. PowerFLOW solutions capture all of relevant physics including radiation, conduction, natural convection, and forced convection as well as a human thermal comfort model. The end result is that engineers can accurately evaluate climate control system design alternatives under a wide range of conditions much earlier in the design process to deliver higher performance with reduced prototyping and testing costs and shorter time to market.


### CLIMATE CONTROL DESIGN CHALLENGES

Climate control systems are typically designed using standard tests such as solar soaks and cool-downs. These tests are designed to match what happens when the car is parked on a hot day, and during cool downs. The design of vehicle climate control systems is complicated by the many trade-offs that are required with other design attributes such as styling, comfort, interior space, noise/vibration/harshness, safety, energy efficiency, etc. For example, the location and design of the vents cannot be selected simply based on their climate control characteristics but must also take into account their importance as a very visible design element. Likewise, the HVAC ductwork is limited by its effect on cabin space. The power required for the cooling fan, blower, compressor and control electronics means that up to 5% of the fuel used in a conventional vehicle goes towards climate control. In an electric vehicle, more than 30% of the battery energy can be used for passenger comfort. Another factor affecting the HVAC system design is that engines are becoming more efficient, meaning they produce less waste heat, reducing the amount that is available for defrosting on cold winter days.

### CURRENT APPROACHES TO CLIMATE CONTROL SYSTEM DESIGN

The HVAC design process typically starts with building an initial prototype of the HVAC system. One dimensional tools or handbook equations that include a parametric description of the cabin and heat transfer from the cabin to the air conditioning system are often used at this point to estimate the size of the blower module and compressor needed to achieve performance requirements. HVAC designers also package and design other climate control system components such as ductwork, vents, controls, gauges, etc. They also select surface materials, acoustic and thermal insulation and glass properties. Then they typically build prototypes based on previous designs whose cost typically ranges from $250,000 to $500,000.

Engineers instrument the prototype with thermocouples and other sensors and perform tests in climate wind tunnels to evaluate the performance of the initial design. The prototypes are typically shared between HVAC engineers and other development activities so it may be necessary to install, remove, install again, and remove again the sensors. For example, the vehicle may be cooled to a very low temperature in the wind tunnel and then the time for the heating system to warm up the vehicle is measured. Vehicles have thermal inertia which creates limits on how fast their temperature can be changed. So it typically takes up to 12 hours for a hot or cold soak and up to 24 hours to set up a deicing test. The length of time required for these tests often makes it necessary to build additional prototypes so that tests can be performed in parallel.

Climate wind tunnels can be used at any time of year but they require many assumptions that result in limited correlation with real world testing results so testing is usually also required in locations with special climate conditions. For example, evaluation of comfort in hot ambient conditions is often performed in Las Vegas and cool-down from a soak is commonly performed in Death Valley. Some OEM's test in more extreme conditions in the middle east and Africa. Considerable costs are required to ship vehicles and equipment and for people to travel to these locations. Vehicles rarely meet their performance targets on the first try which means that the prototype must be modified and the tests re-run multiple times. If an issue is discovered during physical testing, test variation and limitations on sensor number and location can make it difficult to isolate and identify the root cause.

## POWERFLOW ADVANTAGES FOR THE CABIN CLIMATE SIMULATIONS

PowerFLOW provides all of the relevant physics needed for accurate simulation of climate control systems. A tightly integrated radiation solver predicts the effects of the natural environment such as the sun angle and clouds. PowerFLOW calculates heat transfer coefficients through turbulent flow from cooling vents, natural convection during soak and thermal conduction to solid surfaces. This approach ensures accurate prediction of temperature stratification and surface temperatures throughout the cabin. A forced convection model simulates the flow from the vents and its effects on cabin temperature.

Climate control system performance is usually evaluated based on measuring air and surface temperatures. Understanding these temperatures is important but the actual goal is to improve passenger comfort which is a function of both the cabin conditions and the human thermoregulation that occurs due to physiology, clothing, and activity. PowerFLOW incorporates a physiology-based passenger model that uses the air temperatures calculated by CFD to determine localized comfort results for each body segment. Rating the cabin performance in terms of a comfort index enables engineers to explore the benefit of zonal climate control systems, seat heaters/coolers and surface heaters. Designing for comfort rather than temperature often makes it possible to reduce the amount of energy required to make the cabin comfortable. This is critical for improving vehicle fuel economy and help reducing $C0_2$ emissions to comply with the regulations like WLTP.

## CASE STUDIES

Engineers for a Japanese automobile manufacturer used PowerFLOW to simulate a complete air conditioning performance cycle including a 9-hour solar soak and a 30-minute cool down at a high level of detail. This is not possible with other traditional solutions. The simulation replicated a test setup in a climate wind tunnel by incorporating convection, conduction and radiation heat transfer to model the solar lamp heating the exterior and interior surfaces of the vehicle and the resulting temperatures throughout the cabin. Next, the performance of the air conditioner was simulated in cooling the vehicle. Comparison of surface and air temperatures throughout the cabin and in the blower during the soak and cool-down matched experimental results within a narrow margin.

As an example of how these methods can solve real world problems, a European car manufacturer had a problem with overheating electronics in the infotainment system of one of its vehicles. Physical testing was slow and expensive because the car had to be heated up during the day with a solar lamp in a climate wind tunnel and cooled down overnight. This approach only provided limited insight because of the limitations in the number of sensors that could be used to instrument the vehicle. PowerFLOW was used to simulate solar soak and cool down and accurately predicted temperatures of the electronics throughout the entire cycle. Once the model was validated, engineers used insights from the simulation to create a series of design iterations that eliminated the cooling problem.

In another case, a vehicle manufacturer needed to estimate its vehicle's ability to remove frost generated from human breath in extreme climates. PowerFLOW simulated sublimation, melting and moisture transport in order to predict defrosting patterns on the windshield and side glass which were rendered on a photorealistic background and animated. Investigated were the effects of different ambient temperatures, vehicle speeds, blower speeds, heat core size, and wind speeds.

Finally, a Tier 1 supplier needed to determine the effect of special radiant under-dash heaters on passenger comfort. Engineers ran cases with and without the foot heaters. The human comfort model showed that the foot heater had only a small effect on air temperature but a large effect on surface temperatures of the passengers' feet. This zonal heating enabled reductions in airflow requirements that improved energy efficiency.

## CONCLUSION

PowerFLOW provides improvements in transient simulation efficiency along with all the relevant physics and a passenger comfort model, making it the ideal tool for simulation-driven design of climate control systems at any stage of the design process. Engineers can easily simulate different design alternatives, cabin geometries, climate conditions, etc. in a fraction of the time and expense required to perform physical testing. They can visualize simulation results and compare different designs to find the root cause of problems. The end result is that engineers can optimize the performance of climate control systems while managing trade-offs with other attributes in less time and at a lower cost than is possible using current design methods.




**Americas**
Dassault Systèmes
175 Wyman Street
Waltham, Massachusetts
02451-1223
USA

**Europe/Middle East/Africa**
Dassault Systèmes
10, rue Marcel Dassault
CS 40501
78946 Vélizy-Villacoublay Cedex
France

**Asia-Pacific**
Dassault Systèmes K.K.
ThinkPark Tower
2-1-1 Osaki, Shinagawa-ku,
Tokyo 141-6020
Japan