

# Comfortable

Regulations and customer demands put pressure on rail designers to deliver passenger coaches with comfortable climates. In the past, Siemens engineers spent about four months testing passenger coaches in a climate wind tunnel to validate the design of the heating, ventilation and cooling (HVAC) system. Now they use ANSYS Fluent computational fluid dynamics (CFD) software to validate the design before building the first coach to reduce the testing time and cost by up to 50 percent.

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▲ Siemens' new ICE 4 train was recently approved for operation in Germany.



# Rail Travel

**“Siemens engineers *get the design right* the first time, which makes it *possible* to *reduce the amount* of wind tunnel testing by *50 percent* – a two-month reduction.”**

In many countries around the world, train travel is pervasive. For example, in Europe, passengers traveled over 475 billion kilometers by train in 2014, and in Asia and the Middle East the number was more than five times greater. [1] Climate control of rail passenger coaches is increasingly important due to growing government regulations and mounting customer demands. For example, European Standard 13129 (EN13129) sets out strict requirements for controlling the air temperature, relative humidity and air speed within passenger compartments. Designing the HVAC system of a new passenger coach to meet this standard used to require four months of testing and modifying the HVAC system design in a climate wind tunnel that costs thousands of euros per day for rental fees alone. In addition, simulation time was limited due to tight deadlines for coach delivery.

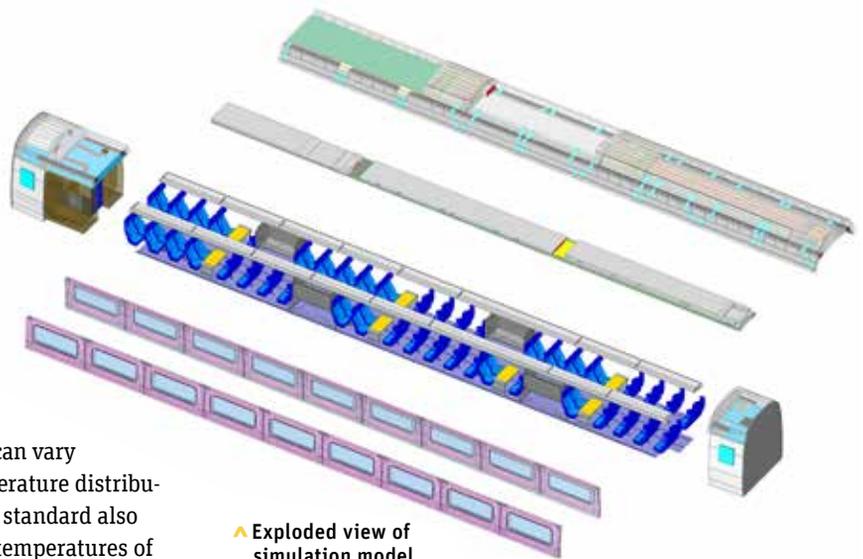
Over the last few years, Siemens engineers have succeeded in accurately simulating the complete passenger coach using ANSYS Fluent CFD software and producing detailed results that closely match physical measurements. Simulation results can be generated in a fraction of the time required for testing. Engineers can evaluate more design iterations than was possible in the past, often resulting in superior HVAC performance. The passenger coach still must be tested to validate conformance with the standard, but testing time has been reduced by 50 percent on the latest products, saving significantly in wind tunnel rental expenses, as well as considerable additional savings in personnel and equipment costs.

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### HVAC Design Challenges

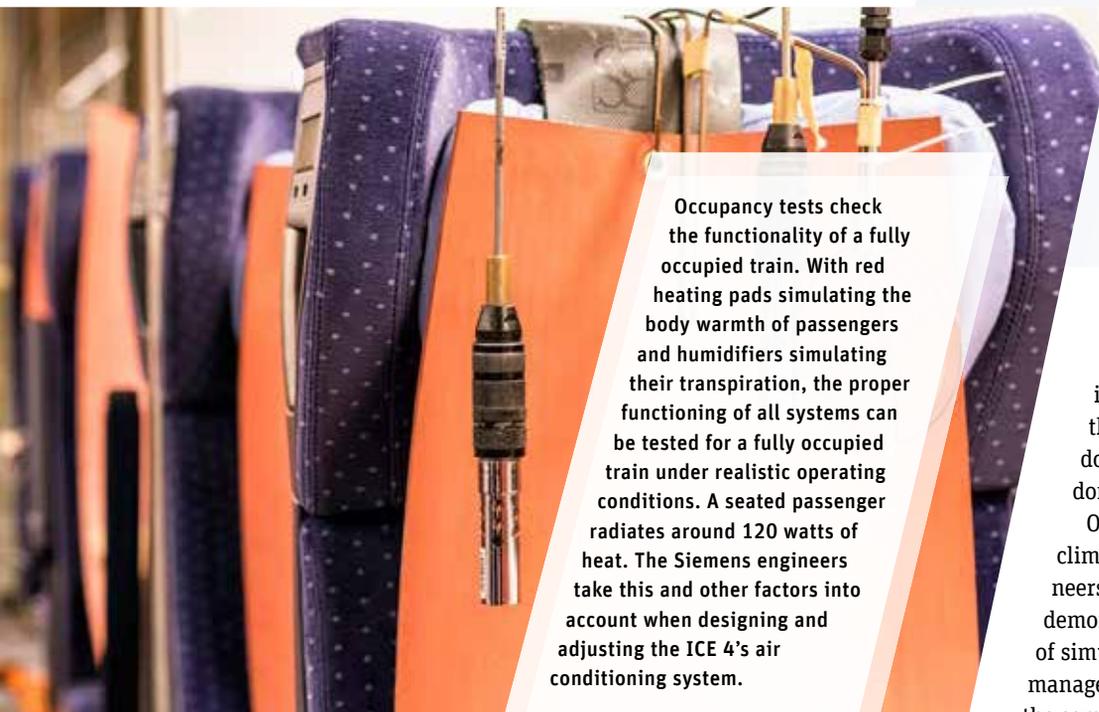
The European standard prescribes wide-ranging and challenging requirements for climate control in intercity passenger coaches. The mean interior temperature can vary by no more than +/- 1 C from the temperature setting. The horizontal temperature distribution in the car measured at 1.1 meters from the floor can vary by no more than 2 C. The vertical temperature distribution can vary by no more than 3 C. The standard also specifies requirements for the surface temperatures of walls, ceilings, windows, window frames and floors, as well as interior temperatures in corridors, bathrooms, annexes and other parts of the train. Finally, the standard defines requirements for relative humidity and fresh air flow.

In Siemens passenger coaches, warm air is delivered by a complex channel system over the side walls to the floor. Cold air is delivered by a central channel in the



▲ Exploded view of simulation model

ceiling with approximately 30,000 4-mm-diameter air inlet holes. In the past, Siemens relied upon experience and very expensive experiments to validate the HVAC system's ability to meet the requirements of the standard. Due to the high costs of building a complete passenger coach, building a prototype is out of the question. This means that feedback cannot be obtained



Occupancy tests check the functionality of a fully occupied train. With red heating pads simulating the body warmth of passengers and humidifiers simulating their transpiration, the proper functioning of all systems can be tested for a fully occupied train under realistic operating conditions. A seated passenger radiates around 120 watts of heat. The Siemens engineers take this and other factors into account when designing and adjusting the ICE 4's air conditioning system.

the airflow through these openings is to include the room on the other side of the door in the solution domain.

Over time, Siemens climate control engineers were able to demonstrate the value of simulation to their management and marshal the computing resources needed to enlarge the scope of their models until they

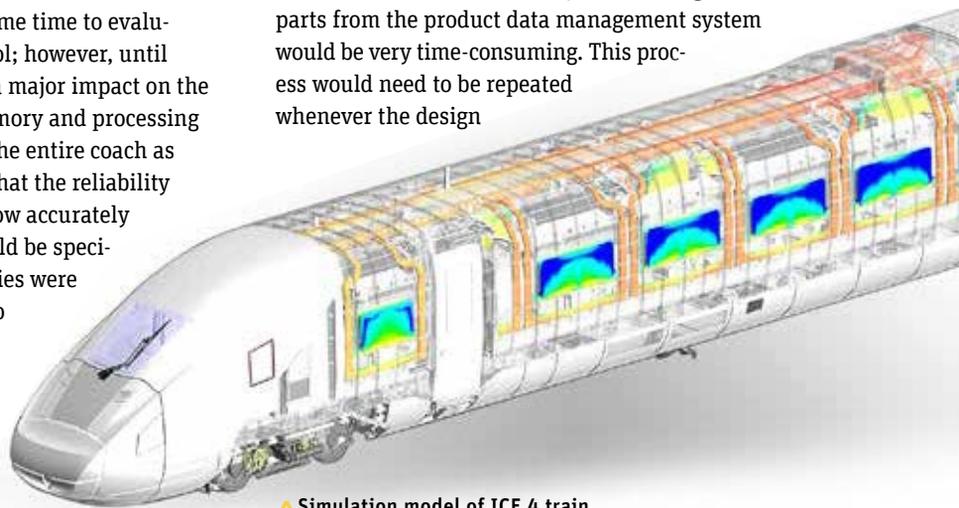
on the performance of the HVAC system until the first product has been built, at which point the customer is usually anxious to take delivery. The coach must be instrumented with 500 to 800 sensors, which takes about two weeks. Then about 14 weeks of testing are required to fully evaluate the compliance of a single coach design with the standard under many different climatic conditions. A typical cooling test would be run, with every seat in the car occupied at 40 C ambient temperature, at 15 km/h driving speed and at an interior temperature set point of 27 C.

### Implementation of Simulation in HVAC Design

Siemens has used CFD for quite some time to evaluate passenger coach climate control; however, until recently, simulation did not have a major impact on the design process. Limitations in memory and processing power made it impractical to use the entire coach as the solution domain. This meant that the reliability of the results was dependent on how accurately the boundaries of the problem could be specified. Unfortunately, most boundaries were in areas where it was impossible to accurately determine them with measurements or theoretical calculations. For example, many trains have internal doors with openings for return flow. The only way to accurately predict

encompassed the entire coach. The boundary of the computational domain was moved from the wetted surface of the extracted fluid interior to the exterior wall of the vehicle. The outside walls were included in the model as solids using conjugate heat transfer. The walls are usually a multilayer structure consisting of materials such as plastic, insulation and aluminum; each layer must be modeled. The ambient conditions are defined by the standard. Occupant heat sources are added to the model as specified by the standard.

Each car has over 150,000 components. The number of parts required for the HVAC simulation is greater than that for a structural simulation, but still much fewer than the total. Manually transferring the needed parts from the product data management system would be very time-consuming. This process would need to be repeated whenever the design



▲ Simulation model of ICE 4 train



“These savings also extend to earlier product delivery and increased revenues.”

▲ The ICE 4 in the climatic wind tunnel

changed significantly. So Siemens engineers developed a routine that automatically exports selected data from the PDM system in native or neutral format and converts the data to ANSYS SpaceClaim format. Engineers then use SpaceClaim semi-automatic tools to clean up small parts such as bolts and bolt holes and complex supplier parts. All geometrically relevant details are explicitly modeled. Engineers create the inverse geometry needed for flow analysis.

Siemens engineers use ANSYS Meshing automated routines for both surface and volume meshing. They create approximately 200 different subdomains so that meshing can be optimized for different areas of the model. Tetrahedral meshing is the first choice for areas with complex geometry. Hybrid tetrahedral-hexahedral meshes with hexahedral elements in the boundary layer are used where especially high boundary layer accuracy is needed to precisely calculate heat transfer to a solid surface. Conjugate heat transfer simulation is used to predict surface temperatures of walls that may be touched by passengers and channels that exchange heat with the inside of the car. The result is a simulation model with typically 500

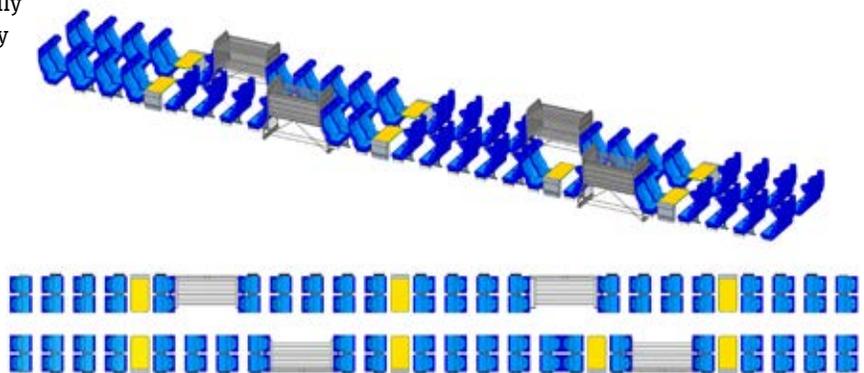
to 600 million cells, which is solved with ANSYS Fluent on a high-performance computing (HPC) cluster.

ANSYS CFD-Post assists engineers in examining simulation results such as volume flow rate and

energy distribution, as well as more than 400 measuring points, including all seat positions in the cabin. Siemens engineers evaluate the simulation results in detail and compare them to the EN13129 standard and additional customer requirements. The simulation results provide a good understanding of the temperature and airflow distribution inside the cabin and indicate opportunities for improving the design. Engineers frequently manually perform parametric studies to determine the best way to operate the HVAC system.

### Validation of Simulation Results

Validation of the simulation is a crucial requirement in the CFD process. Engineers performed this validation for a reference project that was simulated and also tested in a climate wind tunnel. The results of

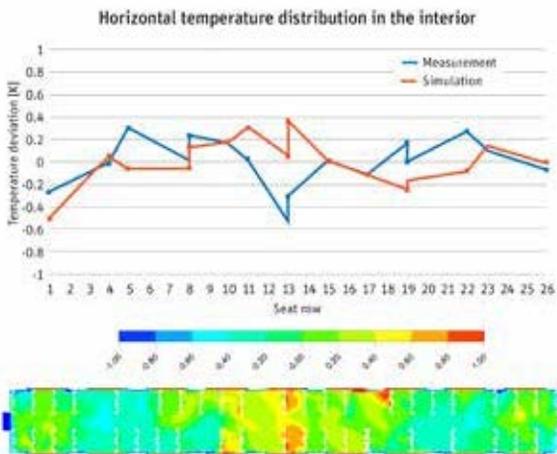


▲ Detailed view of simulation model of coach interior

“Siemens engineers get the design right the first time, which makes it possible to reduce the amount of wind tunnel testing by 50 percent — a two-month reduction.”

the experimental investigation and the CFD simulation show good agreement but they also show areas where the process can still be improved.

The ability to accurately predict HVAC system performance with simulation enables Siemens engineers to validate conditions inside the coach with a high level of accuracy prior to building and testing the first product. In most cases, they are able to get the design right the first time, which makes it possible to reduce

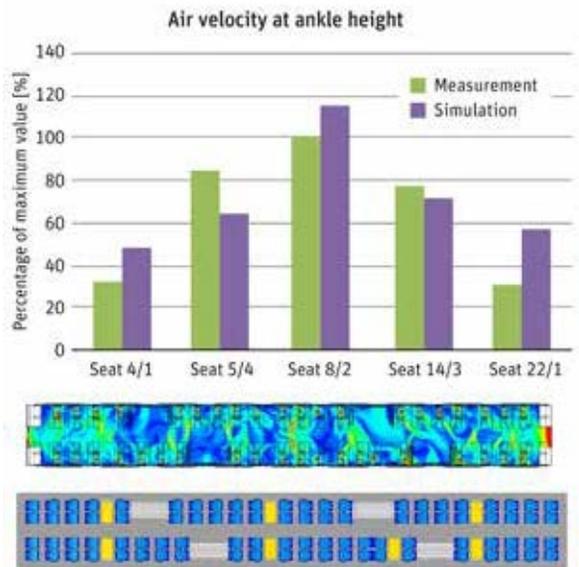


▲ Comparison of horizontal temperature distribution simulation results with physical testing

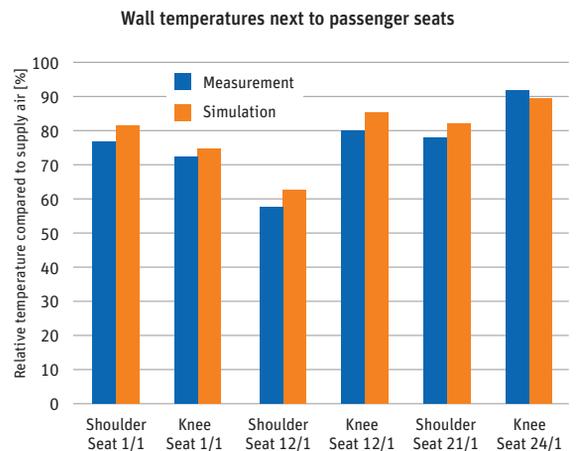
the amount of wind tunnel testing by 50 percent — a two-month reduction. This saves on wind tunnel rental fees, manpower and equipment. The ability to much more easily evaluate alternative designs often enables Siemens engineers to improve passenger comfort beyond the requirements of the standard and to eliminate the need for testing product variants. When the HVAC system is on the critical path for the program, which is not unusual, these savings also mean earlier product delivery and increased revenues. ▲

**Reference**

[1] International Union of Railways, Railway Statistics 2014, [http://www.uic.org/IMG/pdf/synopsis\\_2014.pdf](http://www.uic.org/IMG/pdf/synopsis_2014.pdf)



▲ Comparison of air velocity simulation results with physical testing. The difference between simulation and measurement is around 20 percent, which is quite good considering this is a local point value of air velocity in a convective turbulent flow.



▲ Comparison of wall temperature simulation results with physical testing



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