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Realistic HVAC Climatic Testing

Door Opening Tests, Additional Humidity Introduced By Passengers With Wet Clothing

„Open Doors“ And „Wet Passenger Clothes“ Research Contributes To More Realistic HVAC Testing

Climatic tests have always been extremely important for the development of modern rail vehicles. Rail Tec Arsenal's Vienna Climatic Wind Tunnel offers the opportunity to investigate the impact of weather on vehicles and components under realistic operating conditions.

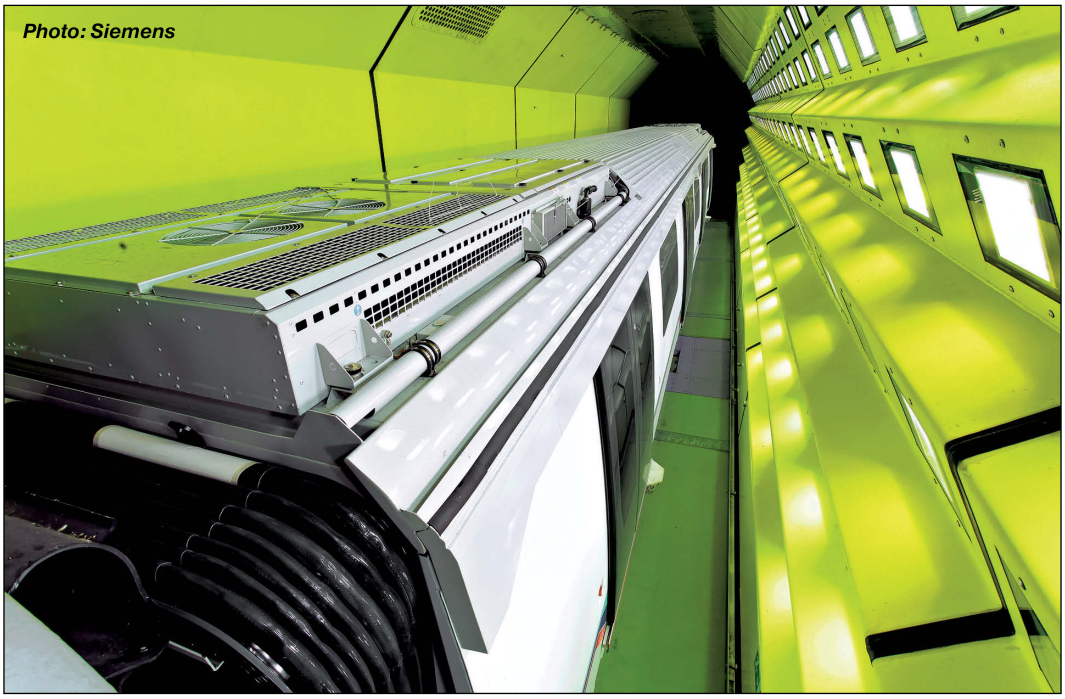
Photo: Siemens

Figure 1: HVAC unit under extreme weather conditions.

Any type of weather encountered in the world can be generated here at the push of a button - from extreme solar radiation to snow, rain and ice (see Figure 1). In combination with wind, load and driving cycle simulation it is possible to create realistic test scenarios. Realistic climatic testing is also becoming increasingly important for vehicle air conditioning to cope with operating and climatic requirements. This concerns both the proper functioning of the air conditioning system and the thermal comfort within the vehicle.

Since air conditioning systems must function properly under all possible operating modes and conditions, the range of different functional tests performed on these units is also increasing. The test procedures required are therefore continually being developed further and adapted. Typical **functional tests for air conditioning** systems include:

- shutdown tests and determining the limit temperature - the exterior temperature is increased until the air conditioning unit shuts down,
- simulation of high voltage disconnection - high voltage is switched off several times for approx. 30 seconds; this must not adversely affect HVAC operation,
- performance tests on air conditioning unit with soiled condenser or air filter,
- check of ice protection of air conditioning unit at variable external temperature and humidity,
- emergency operation in the event of failure of air conditioning unit or compressor,
- emergency battery-operated ventilation,
- check of CO_2 control system depending on number of passengers,
- stand by operation tests maintaining a certain minimum/maximum interior temperature during non-operational mode.

The **relevant „climate standards“** define the thermal comfort parameters to be met and the type tests to demonstrate compliance:

- EN 13129 Air conditioning for main line rolling stock,
- EN 14750 Air conditioning for urban and suburban rolling stock,
- EN 14813 Air conditioning for driving cabs.

Precisely **defined boundary/ambient conditions** are obviously required for the type tests. These must remain constant throughout each test in order to be able to interpret the results reliably. Furthermore, this is also required for the HVAC unit's control settings and performance record as this is the basis for a successful passenger service. What was not previously envisaged in the type tests was a variable element, i. e. typical routine conditions with changing operating and climatic parameters. The problem here is that the tests for different routine situations must be as representative and reproducible as possible.

When the standard for main line rolling stock (EN 13129) was revised, this was addressed in the form of three **daily cycles** for summer, winter and transition period. In these daily cycles a climatological diurnal cycle (temperature, humidity, solar simulation) and a journey profile are simulated with station stops (with passengers boarding and alighting = change in occupancy) and different travel speeds including stretches of tunnel (solar simulator switched off).

A similar approach is being adopted in the revision of the standard for urban and suburban rolling stock (EN 14750). However here the changes occur at much shorter time intervals which makes it harder to create a representative and reproducible test cycle.

Door Opening Tests

In this context door opening tests are increasingly gaining in importance (see Figure 2). These are currently carried out in one regulation test in heating and cooling mode involving at least 10 door opening/closing cycles. The standard also includes reference values for door opening and closing times for vehicle categories A (suburban/regional vehicles) and B (metro/tram), see Table 1.

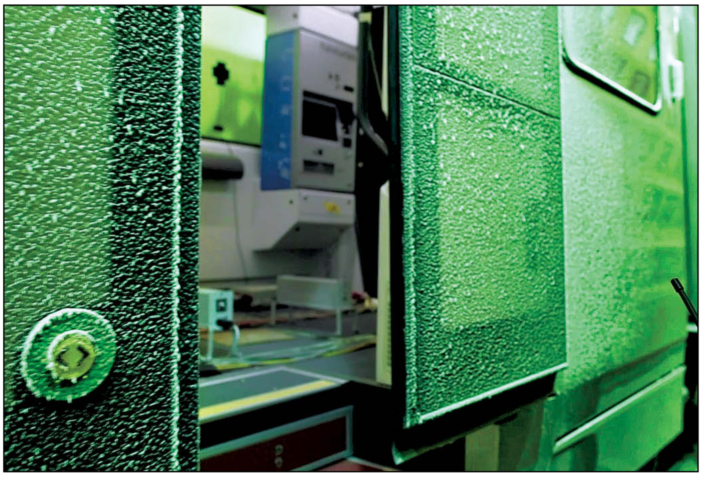

Figure 2: Example of door opening test.

Since previous experience with door opening tests showed that this element had minimal impact on comfort parameters, a Bachelor's thesis [1] was carried out to investigate to what extent door opening tests were comparable with routine operation and whether the tests required adapting.

Since measuring the interior conditions and air change caused by door opening would have been laborious and the results difficult to compare, the **additional cooling or heating power** required was selected as the benchmark in the door opening tests. This energy consumption was deter-

Table 1: Door Opening/Closing Cycles

	Category A	Category B
Duration doors closed	5 mins	2 mins
Duration doors open	30 s	20 s

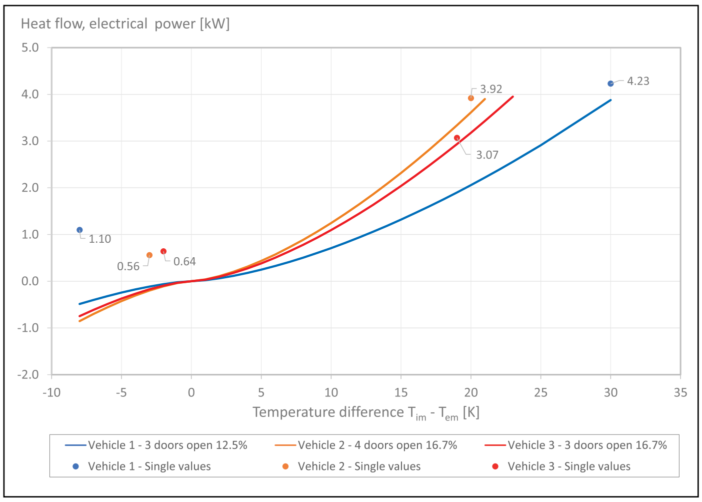

Figure 3: Additional heat flow due to door opening depending on temperature difference in three different vehicles - calculated according to ASHRAE Guideline 23P and individual power values measured.

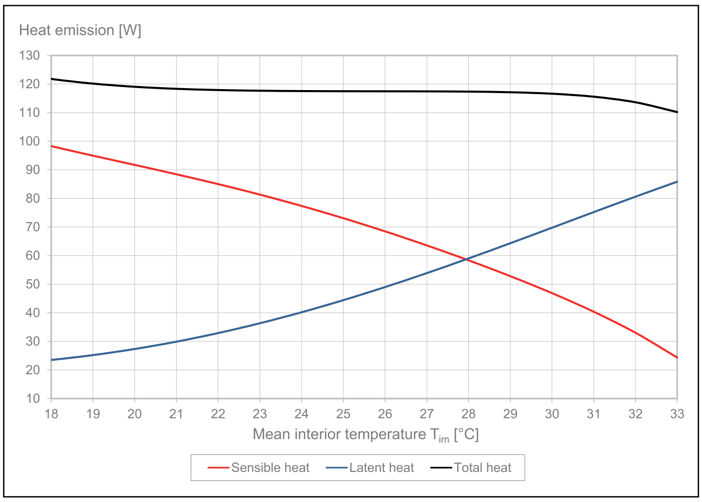

Figure 4: Heat emitted by an individual as a function of mean interior temperature T_{im} according to EN 14750-1.

mined by comparing energy consumption of tests with and without door opening under largely similar test conditions. Since usually only the total energy consumption of rail vehicles is measured and the data storage rate is also optimised according to the test (door opening tests every 5 seconds, in normal regulation test every minute), sufficiently precise analysis was only possible for three vehicles.

The additional cooling and heating load, caused by the inadvertent air change and the resulting flow of heat and humidity between the saloon and the exterior air when the doors are open, can also be calculated approximately with appropriate formulae. The basis for the calculations and the different approaches are explained and presented in more detail in [2]. The calculations were finally carried out according to ASHRAE Guideline 23P using the correction factors for the three selected vehicles.

The **results** of the heat flow calculations and the additional electrical power consumption of the three vehicles measured in two door opening tests, in heating and cooling mode, are summarised in Figure 3. The percentage door opening time shown is obtained from the „door opened“ to „door closed“ times (20/120 x 100 = 16.7 % or 15/120 x 100 = 12.5 %). It should be noted that the individual values determined represent the increase in electrical power consumption of the HVAC unit in each operating point. In heating mode (difference between interior and exterior temperature $T_{im} - T_{em} > 0$), this is comparable with the heat flow calculated in the respective operating points as all the electrical energy is converted into heat.

In cooling mode (difference between interior and exterior temperature $T_{im} - T_{em} < 0$) however, only the cooling power would be comparable with the heat flow calculated, which is negative in the selected representation (negative heat flow). The additional electrical power consumption measured in the three operating points in cooling mode obviously also increases the cooling power and causes „negative“ heat flow. This cannot be indicated however as the efficiency rate was not known or could not be determined from the available data material.

The **additional electrical power required** in the three vehicles investigated in heating mode ranged between 3.07 and 4.23 kW, which corresponds to 10 - 15 % of the total energy consumption of the HVAC unit. This percentage reflects that found in measurements in the field of similar vehicles, confirming the practical relevance, the additional electrical power consumption measured in the door opening tests and the calculation. The fact that only minimal impact on comfort parameters is evident in the tests is possibly due to the test conditions not being particularly extreme (door opening tests are usually conducted at 0 °C and 28 °C) so the HVAC unit still generally has sufficient power reserves. Rapid restoration of the original interior air temperature, particularly with extreme temperature differences, however, still requires considerable (additional) power (especially in heating mode) [2].

The investigations confirm that door opening tests have **practical relevance for thermal comfort**. They also reveal that they are necessary for measuring the energy consumption of urban and suburban rail vehicles, as door opening increases the HVAC unit's energy consumption by up to 15 %.

Simulating Passenger Load

„Passenger load simulation“ is an important parameter for realistic tests in rail vehicle air conditioning. Each seated passenger emits approx. 120 W heat to the environment (passenger area). The total heat emitted consists of sensible (convection, radiation) and latent (moist breath, skin diffusion, transpiration) heat.

The **latent heat** increases with the ambient temperature, while the **sensible heat** decreases. This connection, as defined in EN 14750-1 standard, is illustrated in Figure 4 whereby the number of simulated passengers depends on the vehicle category and the area of deployment. In main line rolling stock the number of passengers to be simulated is the same as the number of available seats, while additional standing space for two people per m^2 is specified for urban and suburban rolling stock.

Obviously the „passenger load simulation“ for a vehicle is, and can be, adapted to the actual operating conditions, e. g. standing space for up to 8 people per m^2 is stipulated for underground vehicles intended for the Asian region. Conversely, tests are also conducted with partial occupancy as, in passenger operation, vehicles only run at full occupancy for very brief periods and consequently partial load operation more closely reflects the actual situation. Figure 5 shows a typical test set-up with heating pads on the seats and

Figure 5: Typical test set-up with passenger load simulation in a rail vehicle.

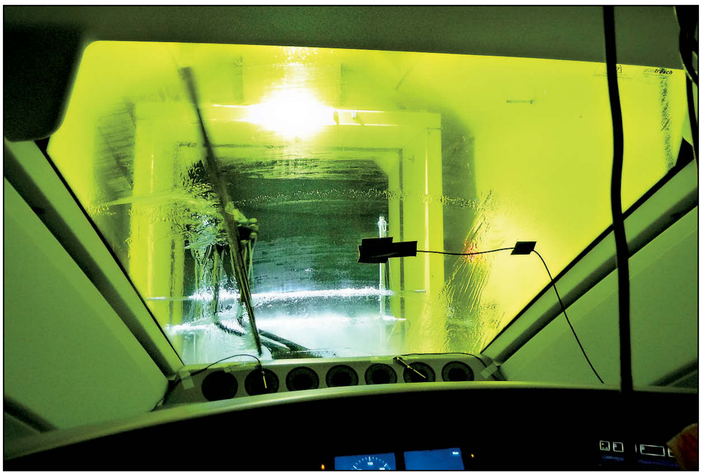

Figure 6: Condensation investigation in driver cab - front screen.

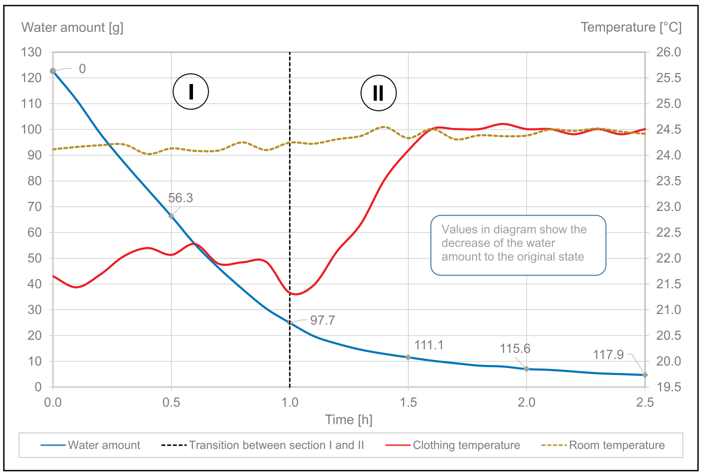

Figure 7: Drying rates and clothing temperatures - test with a combination of summer clothing and 123 g water applied in interior conditions of 24 °C/45 %.

Table 2: Combinations Of Clothing Tested

Clothes composition	CLO*)	Weight of dry clothes in g	Clothes composition surface in m²
Summer	0.48	1,364	1.5
Transition period	0.63	1,844	1.6
Winter	1.20	4,065	2.2

*) Thermal insulation value of the items of clothing used according to ISO 7730

heaters in the aisle to simulate sensible heat emission and electrode steam humidifiers for latent heat emission from seated and standing passengers.

Additional Humidity Introduced By Passengers With Wet Clothing

In the past there were no reference values or guidelines for another, relatively infrequent scenario, namely additional humidity introduced by passengers with wet clothing. The introduction of additional humidity or generally too high interior humidity and low exterior temperatures can cause **condensation** (see Figure 6) to build up on the inside of the windows, for example, which is to be avoided for various reasons. This topic was consequently examined in more detail in a Bachelor's thesis [3].

This also included a practical experiment with a dummy (measuring boom with heat pad to simulate body temperature with different combinations of clothing) and different levels of wetting. The dummy's weight loss, corresponding to the amount of water evaporated, was measured over time under defined ambient conditions - see Table 2.

Figure 7 illustrates the course of a test over time. The amount of water applied (123 g) represents the initial state. The drying process can be analysed in more detail by measuring the temperature of the clothing. This process can be divided into two stages.

In drying stage I pure surface evaporation occurs. Here the drying rate, or moisture release to the environment, is virtually constant. The amount of moisture supplied from within the clothing is exactly the same as the amount of moisture evaporated. The drying rate reaches its maximum in this stage. In this test around 98 g of the water originally applied had already evaporated after one hour.

In drying stage II the evaporation rate drops as sufficient moisture can no longer be supplied. This is also noticeable in the temperature of the clothing, which now rises until it reaches ambient temperature.

Tests were carried out with the combinations of clothing described and various amounts of water in two different air-conditioned rooms at 24 °C/45 % relative humidity and 19 °C/45 % relative humidity. Since there was minimal difference between the results from the two rooms, they are not listed separately here.

The summarised results relate to the first hour of the drying time as the maximum moisture emission in drying phase I is of interest for simulating the additional humidity introduced by passengers. As can be seen from Table 3, there are differences in evaporation volume with the three combinations of clothing due to their different surfaces. The evaporation volume amounts to approx. 60 g for all conditions if related to one square metre.

The heat of evaporation (W) is significant for experimental use. This is calculated using the specific enthalpy of the vapour (J/kg), multiplied by the amount of water evaporated (kg), divided by the time (s).

For the sake of simplicity, the specific enthalpy of the vapour was assumed to be constant at 2,453.4 kJ/kg at 20 °C, since the enthalpy in the clothing temperature range measured between 12 °C and 27 °C has only a marginal effect on the calculation. This gives the heat of evaporation for all three combinations of clothing as approx. 40 W based on a clothing surface of 1 m².

Assuming that normally only some of the clothing gets wet, the evaporation heat based on 1 m² is definitely realistic. For a realistic test with additional humidity due to wet clothing, 40 W additional latent heat would therefore need to be introduced. At an interior temperature of 19 °C the latent heat generated by a passenger is approx. 25 W (see Figure 4). The additional humidity introduced by wet clothing would be 1.6 times this value.

The moisture given off by wet clothing naturally depends on the moisture absorption capacity of the air. In other words the amount of water released to the environment by clothing decreases with increasing humidity. In a test however the additional humidity introduced by wet clothing would need to be maintained at a constant level in order to observe the possible build-up of condensation and to test specific dehumidification measures. [4]

Outlook

New technological developments and increasing demands as regards the safety, reliability, comfort and energy efficiency of rail vehicles require test procedures to be continually adapted and further developed. These include climatic tests to demonstrate the proper functioning of HVAC units in all possible operating modes and conditions and the implementation of realistic test cycles in relevant „climate standards".

These studies of the effects of door opening tests and the additional humidity introduced by passengers with wet clothing demonstrate the fundamental approach to devising new test procedures and verifying their practical relevance. This represents a significant contribution to the development of test procedures which reproduce the operational and climatic conditions in real life as closely as possible.

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Table 3: Mean Values Of The Test Results - Evaporation Volume And Evaporation Heat

Clothes composition	Mean applied water amount in g	Mean water evaporation (loss of weight in g) during one hour		Evaporation heat in W
		with clothes composition surfaces	with regard to a surface of 1 m²	with regard to a surface of 1 m²
Summer	128.5	92.8	61.8	42.1
Transition period	286.0	97.0	60.6	41.3
Winter	311.5	123.3	56.0	38.2