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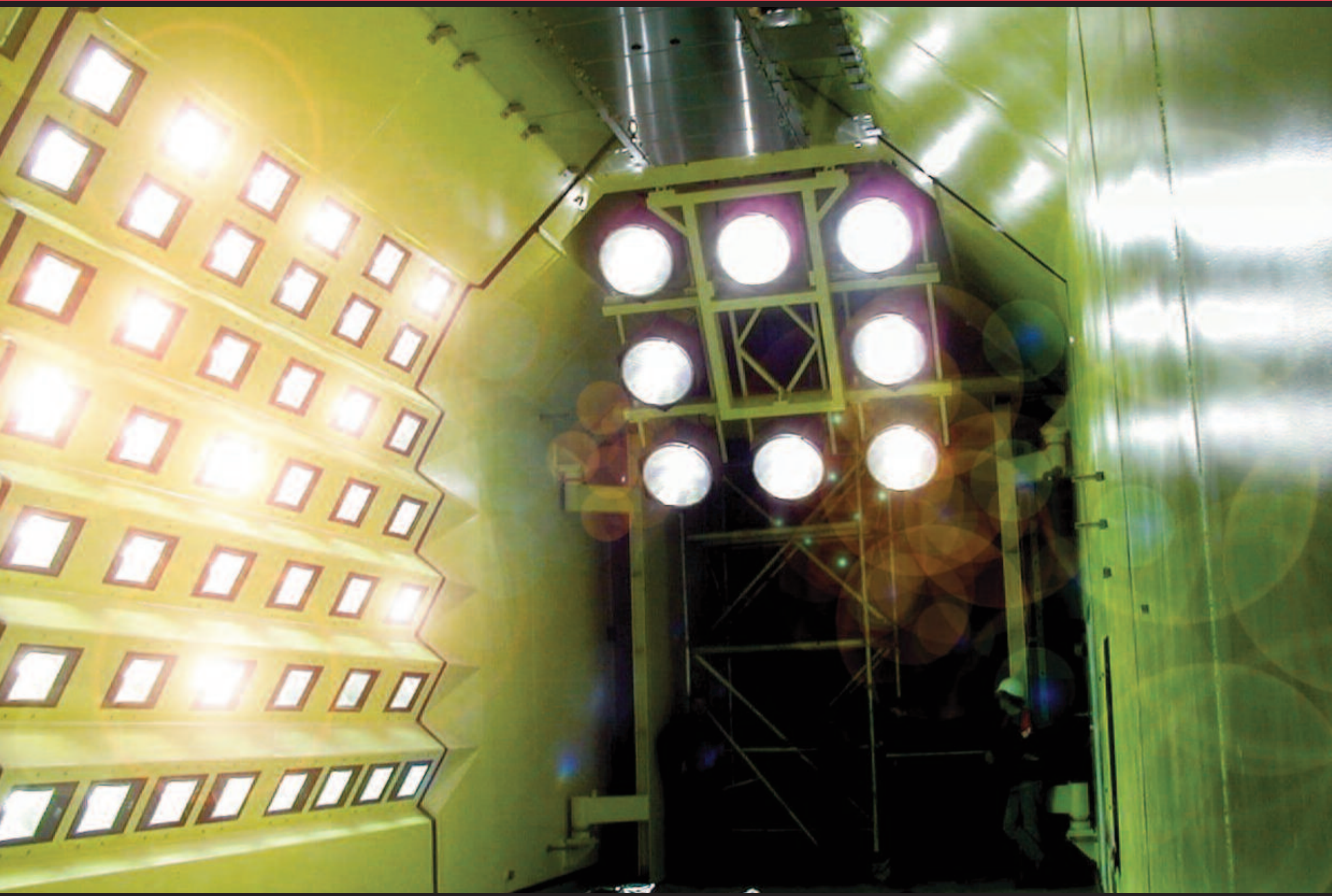


Rail Tec Arsenal Offprint

Investigation Of Sun Shading Effects On Rail Vehicles In Urban Areas

Assessment Of Solar Radiation For The Design Of Air-Conditioning Systems

Investigation Of Sun Shading Effects On Rail Vehicles In Urban Areas

Heat input from the sun is one of the main factors influencing thermal comfort in rail vehicles. The relevant European standards thus define solar radiation as a key parameter for the design and testing of air-conditioning systems.

Rail vehicles used for urban transport in particular raise the question as to what extent the shading effects from buildings or trees, underbridges, tunnel sections or the vehicle's orientation to the sun reduce solar radiation or influence the energy requirements for vehicle air-conditioning. Is there a savings potential for urban transport vehicles, or are the equivalent solar radiation values defined in the standard adequate?

Figure 1: Tram in urban shadow situation.

Introduction

Great efforts are being made to increase the attractiveness of urban transport. Special focus is placed on enhancing comfort, with air-conditioning being one of the most important but also expensive measures - both in terms of investment costs and operating costs (the HVAC system of a tram accounts for up to 34 % of total energy consumption, see EcoTram [1]). Given passengers' rising demands concerning comfort and the fact that most private cars already have air-conditioning, there is virtually no alternative to equipping all new rail vehicles with HVAC systems and to consider retrofitting older ones.

The thermal comfort requirements for rail vehicles is defined in the European standard **EN 14750-1** „Railway applications - Air conditioning for urban and suburban rolling stock - Part 1: Comfort parameters". The countries of Central Europe are assigned to climatic zone II, which means that the HVAC installations must be designed to cope with exterior temperatures of down to -20 °C in winter and up to +35 °C/50 % relative humidity and a solar radiation intensity of 700 W/m² in summer. In addition to the ambient conditions (temperature, relative humidity and solar radiation) of the respective climatic zone, the standard also specifies the number of passengers (occupation) as well as the mean air temperature and relative humidity to be achieved in the vehicle interior, thus providing the design basis for the HVAC system.

The European norm **EN 14750-2** „Railway applications - Air conditioning for urban and suburban rolling stock - Part 2: Type tests" defines the test programme and measurement methods to be used for assessing the comfort parameters and the capacity of HVAC systems. The tests must be carried out in a suitable testing facility such as the Vienna Climatic Wind Tunnel, which can simulate the specified ambient conditions with the required accuracy and reproducibility. This applies in particular to the „solar simulation", which must correspond to the radiation spectrum of the sun and must be provided at a defined angle of incidence of 30°.

Figure 2: Tram route of line 10 in Google Earth©.

The **test programme** specified in the standard is a sensible general approach, as it examines thermal comfort for different parameter combinations that are relevant in practice. Under special operating and climatic conditions and requirements, however, it may be possible to reduce the design capacity of the air-conditioning unit, thus saving weight and optimising the operating point. Solar radiation, for example, will not be necessary as a test parameter for metro vehicles running underground. Or another example: tramcars operating in an urban environment, as shown in **Figure 1**, are often shaded by buildings or trees, underbridges, tunnel sections or the vehicle's orientation to the sun. This raises the question as to what extent these effects reduce global radiation or influence the energy requirement for the air-conditioning of the vehicle.

Global Solar Radiation

Global solar radiation is defined as the total solar radiation incident on a horizontal surface on the earth. It consists of direct solar radiation and diffuse solar radiation, which is scattered by clouds, water and dust particles before reaching the earth's surface. The proportion of direct radiation depends on the incidence angle, which in its turn depends on the position of the sun and the inclination angle of the surface.

The **influence** of (partial) shading on effective global radiation on tramcars in an urban environment was examined by evaluating the solar radiation values measured on an ULF tram during the EcoTram project (see [1]). Global radiation was measured with a sensor mounted horizontally on the roof, which allowed conclusions to be drawn on actual shading of the roof. Although additional partial shading of the sidewalls cannot be excluded, the evaluations were made assuming simultaneous shading of the roof and sides for reasons of simplicity.

The tram was equipped with the required sensors and operated on lines 10, 46, 52, 58 and 62 of the Vienna tram network from June 2010 to September 2011. The evaluation was exclusively based on measurement values recorded on sunny days. The results obtained for line 10 (main direction of travel north - south) and 62 (main

Figure 3: Correlation of equivalent E_n, vertical E_v and horizontal E_h solar radiation (intensity) in the climatic wind tunnel.

direction of travel south-west - north-east) are described in the following. **Figure 2** shows the route of line 10 in Google Earth© by way of example.

The measured global radiation values were compared with reference values recorded at the meteorological station of the University of Natural Resources and Life Sciences (BOKU) in Vienna [2], which are also referred to a horizontal surface. The global solar radiation was additionally calculated theoretically for the purpose of comparison and to illustrate the influence of vehicle orientation or the distribution of radiation between the roof and the side walls.

The equivalent solar radiation (intensity) E_n of 700 W/m² at an incidence angle of 30° defined for climatic zone II by the European standard EN 14750-2 was also included in the comparative study. The solar radiation incident on the vertical side wall of the vehicle can be calculated at ~ 606 W/m² using the formula $E_v = E_n x \cos 30°$. The solar radiation incident on the horizontal roof area of the vehicle is calculated at ~ 350 W/m² using the formula $E_h = E_n x \sin 30°$. **Figure 3** illustrates the mathematical correlation between E_n, E_v and E_h for the solar simulator of the Vienna Climatic Wind Tunnel.

Figure 4 shows the theoretical global radiation on the roof and the side walls of a north-south oriented vehicle (no shadows, clouds, haze etc.) in Vienna for 20 July 2010, from 5:00 to 21:00, in comparison with the equivalent solar radiation according to the standard. The solar radiation incident on the side walls corresponds to and even slightly exceeds the equivalent solar radiation specified in the standard (in this case twice a day, in the morning and in the afternoon). This is more or less the case for the entire period from March to October and for other vehicle orientations so that the standard can be considered as adequate.

Figure 5 shows the solar radiation measured on tram line 10 on 20 July 2010 compared with the radiation values measured at the meteorological station of BOKU University in Vienna and the theoretical calculations. The example clearly shows that the measurements are generally in good agreement with the calculated solar radiation values. Short local cloudy spells (e. g. at 9:00) are clearly visible in the diagram. The tram measurements also show the expected shading effects to be expected in an urban environment. The integral of solar radiation over the whole day reveals the differences even more clearly - see **Table 1**.

The theoretically calculated global radiation values differ from the data recorded at the BOKU meteorological station by approx. 8 %, which allows conclusions to be drawn on the conditions prevailing on that day, such as clouds, water and dust particles in the atmosphere. The BOKU data in their turn differ from the global radiation values measured on tram line 10 on 20 July 2010 by approx. 28 %, which is primarily due to temporary shading effects in the urban environment. These evaluations were made for tram lines 10 and 62 on several representative days. The average reduction in radiation intensity was 32 % for tram line 10 and as high as 38 % for tram line 62, which is due to an extended tunnel section on this line.

Table 1: Integral Of Global Solar Radiation For 20 July

	(Wh/m²)
Measured On Tram	4,969
Theoretical	7,497
Measured At BOKU	6,902

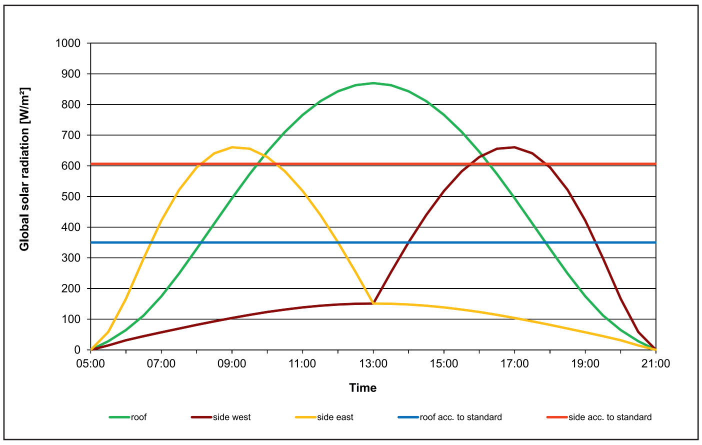


Figure 4: Theoretical global solar radiation on the roof and sides of a north-south oriented tram for the latitude of Vienna on 20 July in comparison with equivalent solar radiation intensity according to the standard.

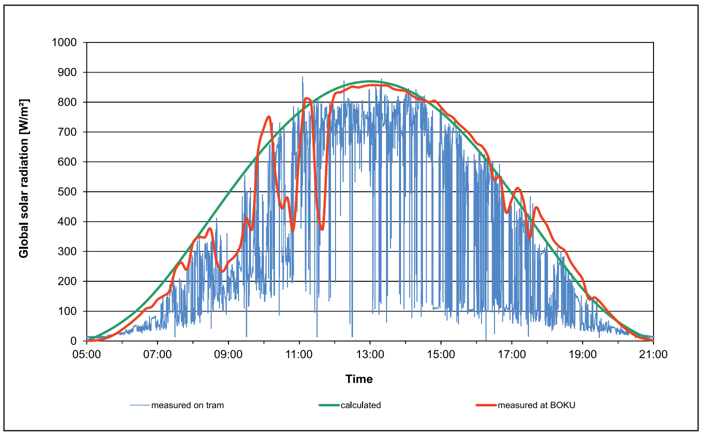


Figure 5: Comparison of global solar radiation measured in tram line 10, at the BOKU meteorological station and theoretical calculation for 20 July.

Equivalent Solar Load

The effect of global radiation on cooling load depends not only on vehicle design, such as insulation, type and size of windows etc., but also on the solar radiation intensity and the angle of incidence. Therefore the equivalent solar load was also calculated and comparatively analysed using a cooling load program. The calculations were carried out for a three-car ULF tram with a total length of 24 m based on standard design conditions, varying only the global radiation.

Figure 6 shows the equivalent solar load based on theoretical global radiation for different travel directions of the three-car tram for 20 July 2010. The maximum equivalent solar load varies only slightly and even integration over time reveals differences of approx. 20 % for the different directions of travel - see **Table 2**. As the global radiation values measured on the tram roof and at the BOKU meteorological station were only available for horizontal orientation, the equivalent solar load on the side walls had to be calculated separately.

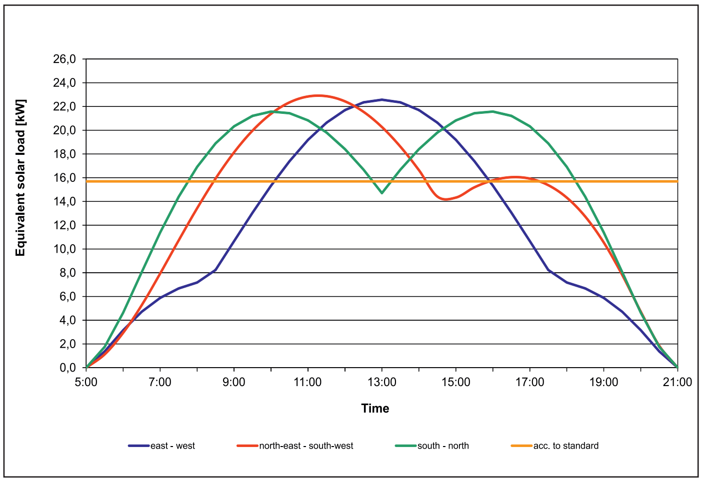


Figure 6: Comparison of equivalent solar load for different tram orientations.

Figure 7 shows the results of the equivalent solar load calculation for 20 July. The equivalent solar loads calculated on the basis of global radiation measurements are in good agreement with the theoretical calculations. The equivalent solar load calculated according to the standard (700 W/m^2) amounts to approx. 16 kW. The smoothed equivalent solar load curve based on the global radiation measured on the tram occasionally exceeds this value, especially in the time between 10:00 and 12:00. In this case the cooling capacity of the HVAC system would not be sufficient if all other design conditions applied, e. g. full occupation. It should be noted, however, that the other design parameters were kept constant in the calculations and that short-term exceedance could be most likely compensated by the inertia of the overall system.

Integration shows that the equivalent solar load values calculated for the three-car tram based on global radiation measurements are significantly below the corresponding integral values obtained from theoretical calculations and standard requirements (700 W/m^2) - see **Table 3**.

Summary And Outlook

Global radiation is a key factor influencing thermal comfort in rail vehicles. As expected, the measurements revealed a significant reduction in global radiation on urban transport vehicles as a result of shading effects from buildings or trees, underbridges, tunnel sections or vehicle orientation to the sun. The average reduction for the two tram lines investigated was 32 % and 38 %, respectively.

The equivalent solar load values calculated on the basis of the „effective" global radiation measured were mostly lower than the equivalent solar load calculated according to the standard. In some cases, however, the values also exceeded the standard requirements so that it is not possible to derive a general conclusion on a possible reduction in design capacity. As all other design parameters were treated according to the standard and kept constant for reasons of comparison, a detailed examination of specific climatic and operating conditions is necessary in order to be able to provide evidence of a possible reduction in design capacity without restrictions.

If specific climatic and operating conditions are taken into account in energy-efficient design, these conditions should also be simulated in the type tests carried out in the climatic wind tunnel. This is already the case for innovative projects, where the diurnal variation of global radiation and other parameters are included in type testing. This new approach will contribute to enhancing both the thermal comfort and energy efficiency of future rail vehicles.

Mickael Deroux
Internship June - August 2011
Rail Tec Arsenal

Gabriel Haller
Technical Director
Rail Tec Arsenal

Sources:
[1] G. Richter; How much energy is used by the HVAC unit of a tramcar? - Investigations in the climatic wind tunnel and in service operation; Railvolution 6/10

[2] www.wau.boku.ac.at/wetter.html

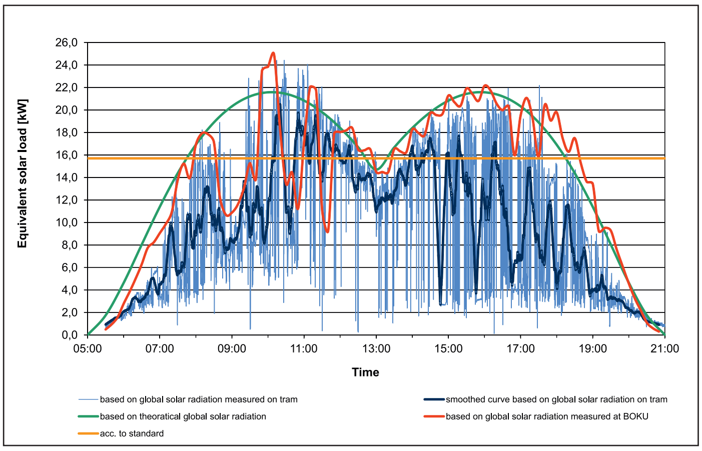


Figure 7: Comparison of equivalent solar load calculated on the basis of theoretical and measured (tram line 10, BOKU meteorological station) global solar radiation values on 20 July and according to the standard.

Table 2: Equivalent Solar Load For Different Directions

Direction Of Travel	Maximum Equivalent Solar Load (kW)	Integral Of Equivalent Solar Load (kWh)
North - South	21.6	244
East - West	22.5	189
North-East - South-West	23.0	222

Table 3: Equivalent Solar Load For 20 July

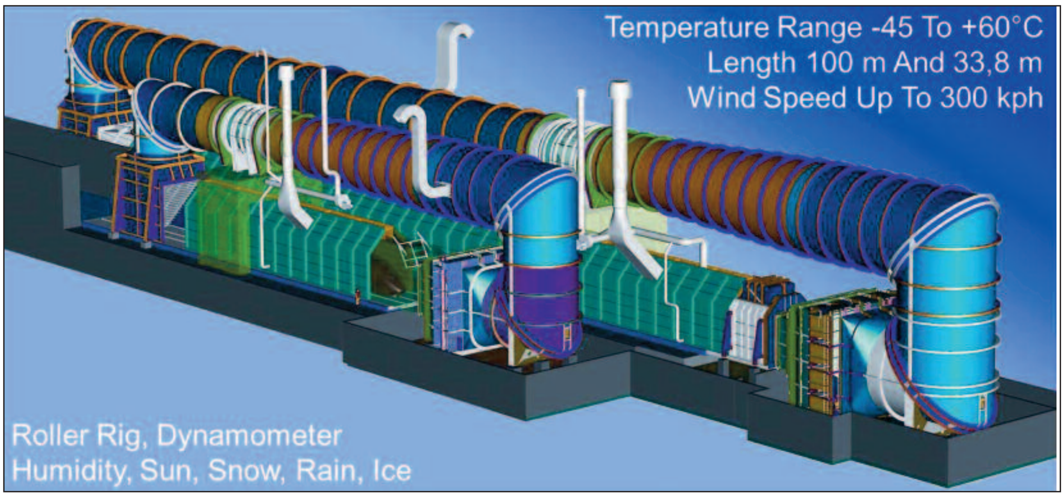
Direction Of Travel	Maximum Equivalent Solar Load (kW)	Integral Of Equivalent Solar Load (kWh)
Measured On Tram	24.4	149
Measured At BOKU	24.9	223
Theoretical	21.6	244
According To Standard	15.7	251

Vienna Climatic Wind Tunnel - Any Weather On Earth

The Vienna Climatic Wind Tunnel operated by **Rail Tec Arsenal** provides the opportunity to investigate the **impact of weather** on vehicles and components under **realistic operating conditions**. Any weather conditions can be produced at the push of a button - from intense solar radiation through to snow, rain and ice. The combination with wind, load and drive cycle simulations allows the implementation of realistic test scenarios.

The facility has been specially designed for rail vehicles, such as high speed and regional trains, trams, metros and urban transport vehicles.

In its capacity as an accredited testing facility, Rail Tec Arsenal is authorised to carry out all climate related **conformity tests** in accordance with **international standards** and also offers professional support in the quality assurance of new vehicles and the development of airconditioning components. The focus is both on the optimisation of thermal comfort and the improvement of general **reliability, safety and energy efficiency.**



Performed services:

- **Testing of thermal passenger comfort** in accordance with all relevant standards.
- **Functional tests on critical components** using specially developed standardised test procedures.
- **Customer specific tests** such as comfort and functional tests under rapidly changing climatic conditions.
- **Measurement of energy consumption** in defined test cycles and calculation of annual energy consumption.

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