Railvolution
The Professional Two-Monthly Magazine Of Rail Transport Worldwide

Volume 8 No. 2/08

Rail Tec Arsenal Offprint

Measuring The Energy Efficiency Of Air Conditioning Systems: *Analysis And Calculating Of Energy Consumption, Saving Potentials*

Climatic Wind Tunnel Tests For Higher Energy Efficiency

Energy efficiency has become a key issue in public transport in view of climbing energy prices and concerns about climate change. The Vienna climatic wind tunnel of Rail Tec Arsenal, which is renowned for thermal comfort and functional tests on rail vehicles under extreme climatic conditions, has now analysed the energy saving potential for air conditioning systems - revealing that energy consumption can be reduced noticeably without compromising on comfort.

*Figure 1: **New Pendolino in the large climatic wind tunnel of Rail Tec Arsenal.***

Introduction

The Vienna climatic wind tunnel of Rail Tec Arsenal has developed into a highly valued testing centre for major rail vehicle manufacturers and rail operators, providing a wide range of climatic tests under „artificial“ weather conditions, i. e. temperatures from -50 to +60 °C, wind speeds up to 300 kph, ice, rain and snow. It can draw on a wealth of experience in the testing and optimisation of heating, ventilation and air-conditioning systems to ensure a high degree of thermal comfort in passenger trains. An example for such thermal comfort test is the recently tested New Pendolino *(Figure 1)*. Functional tests are mainly carried out to test safety relevant parameters and the proper functioning and reliability of individual components under realistic operating conditions.

In view of the increasing economic and environmental significance of energy use, this broad expertise can now also be applied to measuring the energy efficiency of **air conditioning** systems, which may consume up to 100 MWh annualy for a passenger carriage. Energy consumption measurements provide a sound basis for assessing energy optimisation options, identifying saving potentials, calculating life cycle costs and developing energy labelling schemes for rail vehicles.

Rail Tec Arsenal has analysed two approaches in this context: demand-controlled fresh air supply and heat recovery from exhaust air. The analyses have shown that a combination of these measures may result in an energy saving - and with it a reduction in CO_2 emissions - of up to 17 %!

Analysis Of Energy Consumption

Measurements On The Tracks Or In The Climatic Wind Tunnel

Exact performance data under different environmental and operating conditions are needed for analysing the energy requirement and the power consumption of air conditioning systems in rail vehicles.

Measurements **on the tracks** can record the total energy consumption over a given period and under the conditions prevailing in the environment at the time. It is also possible to conduct parallel studies of two rail cars with different air conditioning systems in the same train in order to make a direct comparison of their energy consumption figures. However, due to the constantly changing conditions, it is impossible to achieve a precise and reproducible analysis of power consumption under different environmental and operating conditions on the tracks.

In contrast, studies **in a climatic wind tunnel** can reproduce different environmental and operating conditions on demand - for example, in the form of an occupancy simulation - and record power data under constant conditions. Many of the combinations of environmental and operational parameters that are considered necessary for energy analyses have already been covered by the climatic tests required by the relevant thermal comfort standards *(Table 1)*, so that the acquisition of performance data has an added benefit.

The **supplementary tests** are mainly concerned with the transitional area between heating and cooling. This area requires more detailed study in order to be able to map a continuous performance curve for different load conditions.

For determining performance data, it would essentially be sufficient to determine the overall energy consumption of the vehicle with all its auxiliaries, including the air conditioning system, converter, and battery charge. The energy consumption of the **other auxiliaries** is low and constant compared to that of the air conditioning system and can easily be factored out of the calculations at need. For a detailed analysis, and for drawing conclusions about the energy saving potential of the air conditioning system, it is of course possible to measure the energy consumption of various individual power consumers such as fans, auxiliary heating units, the principal heating unit, and the compressor.

The example shown below is based on measurements of overall energy consumption and thus includes the energy consumption of all auxiliaries. *Figure 2* shows the results of measurements of a double-deck passenger carriage at an exterior temperature of 0 °C with minimum wind (stationary vehicle) and zero occupancy. The in-

Occupation [%]	Wind speed [kph]	Sun [W/m²]	Temperature -20	-10	0	+10	+22	+35
0	Min.	0	x	x	x	x	x	x
0	>120	0	x	x	x	x	←	x
100	>120	0	x	x	x	x	→	x
100	>120	700				x	←	x

x, x ... Steady condition (1 hour steady state); →.. Non-steady condition (3 K/h)
x ...... Tests already included in EN 13129

Table 1: ***Standard test cycle with occupation and environmental conditions as test parameters.***

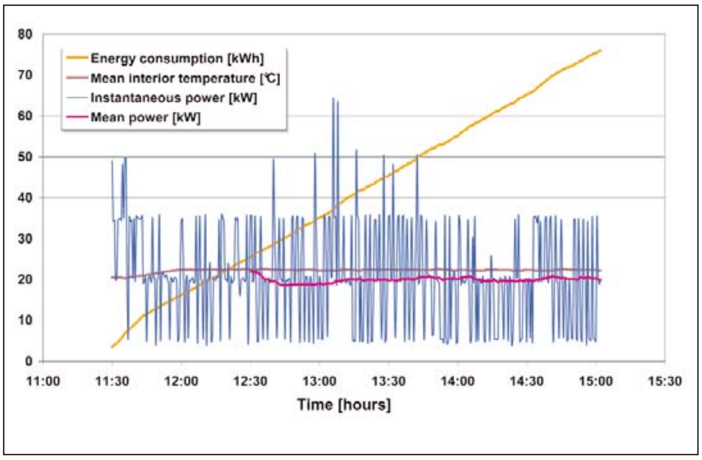

Figure 2: ***Energy consumption measurement of a double-deck passenger carriage at 0 °C, minimum wind (stationary vehicle) and no occupancy.***

stantaneous power measurement clearly shows that the interior temperature was controlled via the 16 kW heating units. The mean power consumption is approximately 20 kW at a steady-state mean interior temperature of 22 °C. The steady state after changing the set point from 20 to 22 °C at the start of the test was reached after only two hours.

The power consumption is determined in this way for all parameter combinations required, enabling the collation of temperature-independent power curves that serve as the basis for further calculations.

Calculating Energy Consumption

Figure 3 shows the pictorial schematic for calculating energy consumption. First of all, the procedure requires the power curves that were determined in the standard test cycle. The top left corner of Figure 3 shows two power curves for a passenger carriage with and without passengers at 120 kph. Additionally, the climatic data for the area in which the vehicle is operated is needed for calculating real-time power consumption. The mean temperature profiles for each month of the year are shown at the bottom left of Figure 3. The power curves, the climate data, and specific operating parameters such as vehicle use and occupancy rate can be used to calculate, for example, the annual energy consumption specific to each client. This consumption is shown on a per-month basis at the top right of Figure 3.

If identical standardised parameters are used for the calculations, **direct comparisons** can be made between the energy efficiency of different vehicles or different vehicle designs. Additionally, the quantitative effects of optimisation strategies can be documented and energy savings potentials can be identified and analysed. At the same time, these parameters can be used to document LCC figures objectively and to evaluate the energy efficiency of a vehicle's air conditioning unit under energy labelling schemes categorising vehicles into seven energy efficiency classes, labelled A through G.

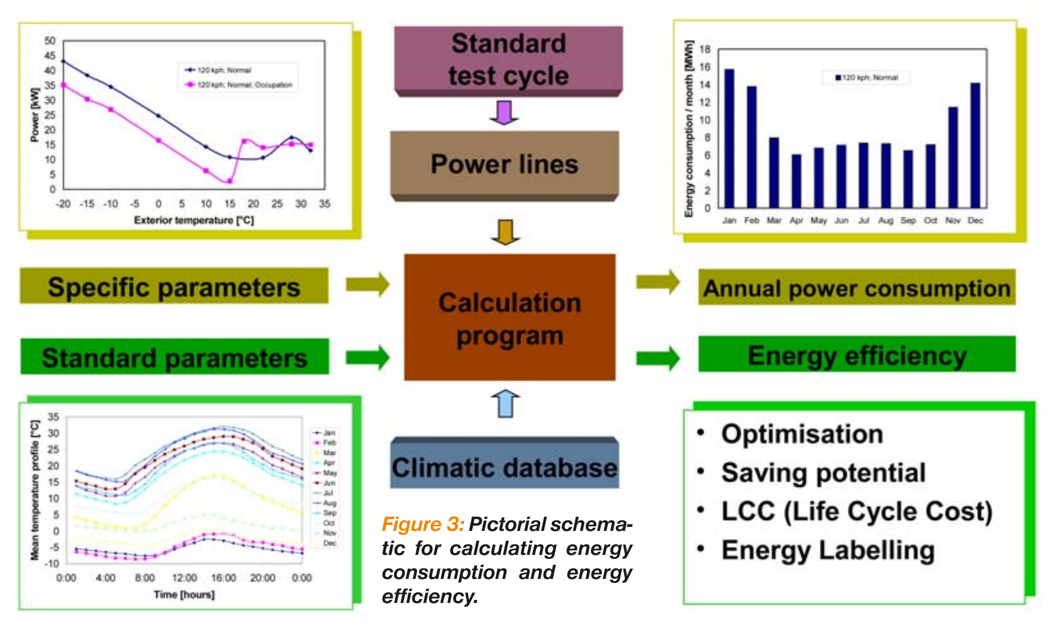

Figure 3: ***Pictorial schematic for calculating energy consumption and energy efficiency.***

Saving Potentials

Overview

The load calculation is the basis for determining the energy required for heating, cooling, dehumidifying and humidifying the supply air which serves to compensate for the thermal loads.

Thermal loads in the vehicle are caused by interior and exterior disturbance variables that have long-term effects on the specified state of the interior air and thus have a significant influence on thermal comfort in the passenger areas. In general, **disturbance variables** are classified as follows:

- interior disturbance variables such as heat and moisture emission by people, heat emission by light fixtures and switch cabinets;
- exterior disturbance variables such as heat flow through direct or diffuse solar radiation and transmission, enthalpy and moisture flow through accidental air change.

Figure 4 shows that the energy requirements for air conditioning rail vehicles are influenced by many factors, resulting in a wide variety of optimisation options. However, all **singular energy efficiency** measures must be evaluated for their effects on the overall system. For example, thicker thermal insulation for the car body may reduce the energy requirements for air conditioning, but the increased weight of the vehicle would cause an increase in the energy requirements for traction. An examination of the overall energy consumption would reveal a lower energy saving effect, or none at all. An examination and optimisation of the overall system is necessary because of the complexity of options and effects. For this reason, energy optimisation cannot be the exclusive task of the air conditioning supplier.

The **saving potentials** range from simple measures such as:

- demand-controlled fresh air supply;
- intelligent, optimised air conditioning control;
- demand-controlled set point adjustment;

to new concepts such as:

- optimised thermal insulation for car bodies and/or duct systems;
- active insulation, e. g. use of exhaust air heat for heating car body surfaces;
- exhaust air heat recovery;
- load-dependent cooling system;
- heat pump.

Additionally, regular maintenance and control of the specified parameters can help to bring about a significant reduction in energy consumption.

Controlled Fresh Air Supply And Exhaust Air Heat Recovery

In this section we will examine the energy saving potential of two different measures, namely demand-controlled fresh air supply and exhaust air heat recovery, in the air conditioning system of a passenger carriage.

The basic power curves with and without occupancy at a speed of 120 kph were taken from the passenger carriage already described above. The temperature-dependent amounts of fresh air intake in these measurements met the requirements of EN 13129.

As fewer passengers require less fresh air, **demand-controlled fresh air supply** can save energy during

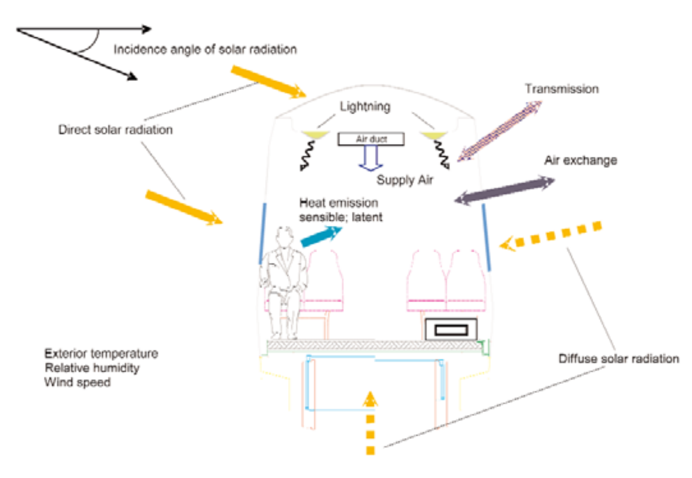

Figure 4: ***Schematic illustration of the disturbance variables affecting thermal comfort in a passenger carriage.***

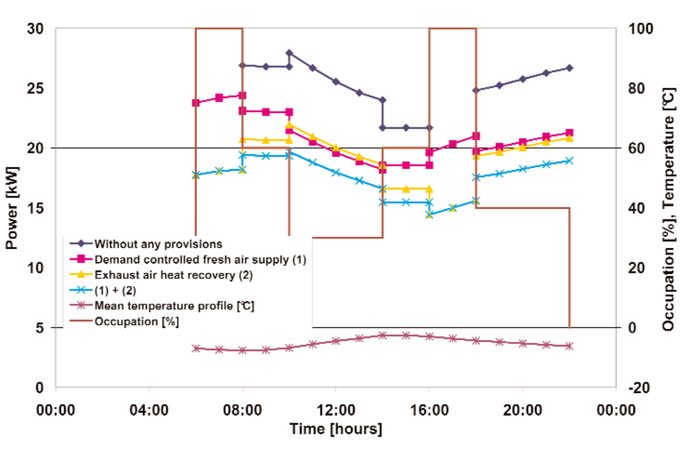

Figure 5: ***Comparison of power consumption for air conditioning with and without optimisation measures using a selected occupancy profile for the mean temperature profile of January.***

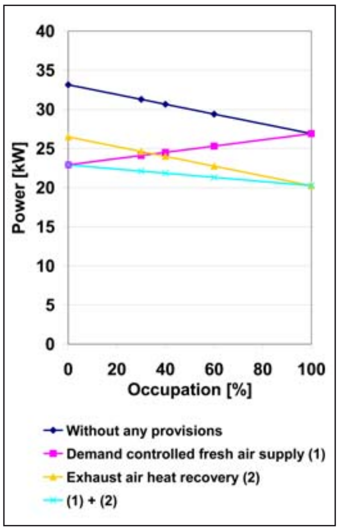

Figure 6: ***Power requirements with and without optimisation measures for different occupancy rates at an exterior temperature of -10 °C.***

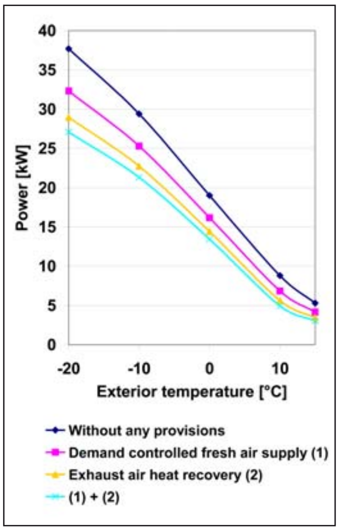

Figure 7: ***Power requirements with and without optimisation measures for different exterior temperatures at an occupancy rate of 60 %.***

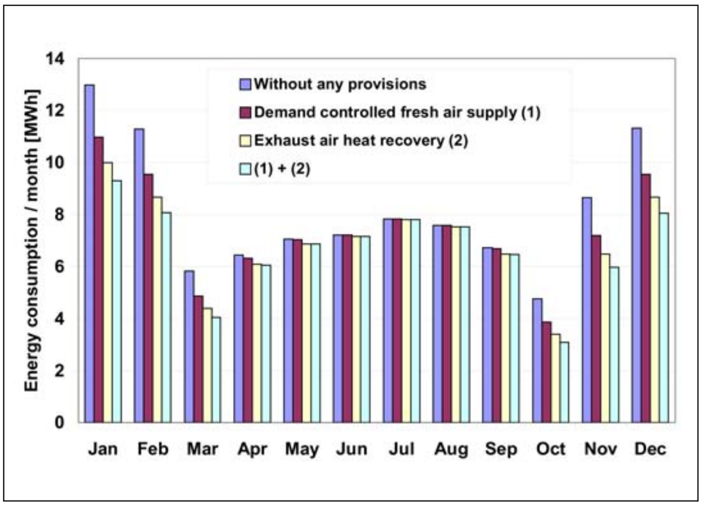

Figure 8: ***Comparison of monthly energy consumption with and without optimisation measures.***

fresh air conditioning, heating, and cooling/dehumidifying at occupancy rates below 100 %. To implement this measure, the air conditioning system must receive current information about the vehicle occupancy rate and must be able to adjust the fresh air supply by means of the fan speed or flaps. The occupancy rate can be determined using an air quality sensor, a CO_2 sensor, or vehicle weight sensors, which are already installed in many mass transit vehicles for braking control.

In **exhaust air heat recovery** systems, an air-to-air heat exchanger is used to transfer the exhaust air heat energy to the supply air, thus significantly reducing the energy requirement for the remaining air conditioning steps. In the following observations, we will assume a heat exchanger efficiency of 60 %. Additionally, the comparative observations were based on the following **general specifications** and assumptions:

- effect of occupancy (body heat of passengers) taken into account;
- daily vehicle operation from 6:00 to 22:00;
- seat occupancy rate between 30 and 100 % (56 % average occupancy), in accordance with occupancy profile shown in Figure 5;
- savings effects considered for heating mode only.

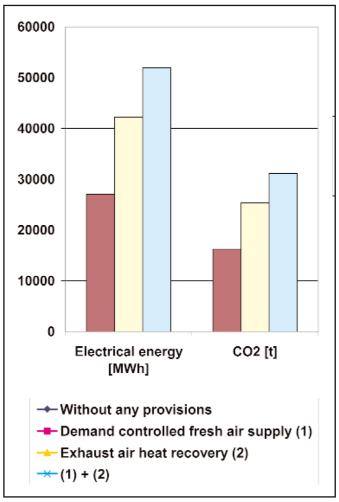

Figure 9: ***Annual energy saving potential of optimisation measures for 3,000 vehicles.***

Figure 5 shows the **power requirements** for the described measures using the selected occupancy profile for a mean daytime temperature pattern in January. The figure shows that the energy saving effect of a demand-controlled fresh air supply varies with the occupancy rate and, by definition, amounts to zero at an occupancy rate of 100 %. In contrast, the savings effect of exhaust air heat recovery is independent of the occupancy rate. Additional energy savings are achieved when both measures are combined.

Figure 6 illustrates this result. Here the power requirement of the measures examined is shown as a function of the **occupancy rate** at an exterior temperature of -10 °C. The relationship of the power curves to one another applies for all exterior temperatures in heating mode. The power requirement shown by the no measures and exhaust air heat recovery curves decreases as the occupancy rate increases because of the increase in heat input from the passengers. At high average occupancy rates, the best energy saving effects will be achieved through exhaust air heat recovery; at average occupancy rates, however, even demand-controlled fresh air supply, which is easier to implement, will result in noticeable energy savings.

Figure 7 illustrates the power requirement of the measures examined as a function of the **exterior temperature** for an occupancy rate of 60 %. The figure shows that there is a significantly higher energy saving at low exterior temperatures and at higher temperature differences between the interior and the exterior than at moderate exterior temperatures and small temperature differences. *Figure 8* presents a comparison of the monthly energy consumption for the measures examined.

Table 2 shows the annual energy consumption and the possible energy savings compared to the original consumption figures. The saving potential of 8.8 % for demand-controlled fresh air supply makes it feasible to retrofit existing vehicles with **CO_2 sensors**; the investment would pay off in a short time provided that the vehicle is furnished with the necessary equipment, such as an adjustable fresh air flap and a programmable control unit, which are standard for most modern vehicles. Exhaust air heat recovery, with a saving potential of 13.8 %, is more efficient and, above all, independent of the occupancy rate. However, this measure is more likely to be advisable for new vehicles as it usually requires changes in the airflow routing concept.

Energy consumption / year	Description of measure	Energy saving
97.6 MWh	No measures (initial condition)	-
88.6 MWh	Demand-controlled fresh air supply (1)	8.8%
83.5 MWh	Exhaust air heat recovery (2)	13.8%
80.4 MWh	(1) + (2)	16.9%

Table 2: ***Annual electrical energy consumption for air conditioning and savings effect of the measures examined.***

In each case, the measures under review show that there are energy saving potentials which, if consistently realised in rail vehicles, would result in significant reductions in overall energy consumption and emissions. *Figure 9* shows the annual saving potential and the reduction in CO_2 emissions achievable by implementing the measures examined for an assumed fleet of 3,000 vehicles.

Conclusions And Outlook

By analysing two specific measures, the team of Rail Tec Arsenal has successfully demonstrated the energy saving potentials for air conditioning systems and pointed out the economically beneficial effects of the concomitant reduction in CO_2 emissions.

The standard climatic wind tunnel test cycle presented here is suitable not only for determining the power consumption of air conditioning systems, but also for optimising and verifying energy saving measures. The **climatic wind tunnel can simulate** all environmental and operating conditions required to gather precise performance data, which can serve as the basis for further analysis. Additionally, climatic wind tunnel tests can be used to verify specific annual power consumption values under defined conditions for LCC analyses and to evaluate the energy efficiency of air conditioning systems according to the standards of a future energy labelling scheme for rail vehicles.

Rail Tec Arsenal makes a significant contribution to these studies and analyses with the aim to make rail transport more energy-efficient. For more information on the climatic wind tunnel of Rail Tec Arsenal see Railvolution 2/05.

Gabriel Haller
Manfred Kreitmayer
RTA Rail Tec Arsenal
Fahrzeugversuchsanlage GmbH

Photos and diagrams
by authors