Personalized ventilation: experimental apparatus to evaluate high induction air terminal devices

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ABSTRACT

The thermal environment in vehicles varies greatly. The interaction of the cabin thermal environment, created by the HVAC system, the outdoor conditions as well as the occupants, is rather complex.

In this regard, in order to improve occupants' comfort, we thought of locally differentiating the parameters which influence people's satisfaction. In particular, the possibility of controlling the air distribution around passengers in an autonomous and customized way has been analysed.

To this end a room simulating the geometrical conditions of a compartment for passengers in a railway coach has been realized. The realized experimental setup permits the evaluation of the thermofluidynamic performances of diffusers. The idea of new diffusers for restricted-dimension spaces, as is the case for railway compartments, derives from the requirement of reducing the draught risk in the occupied zone and personalizing as much as possible the local comfort as a function of the restricted geometry of these spaces.

INDEX TERMS

Ventilation system; Air distribution; Mean velocity; Turbulence

INTRODUCTION

Recently, several factors have contributed to an increase in interest in the evaluation of comfort in vehicles and particularly in trains. Some work on the subject of the thermal comfort in railway vehicles has been done in Chow (2002), Chow and Wong (1997) and Vallati and Grignaffini (2002a).

Total-volume ventilation of indoor environments is at present the method most used in practice, and the mixing principle for air distribution is one of the most applied. The study of mechanically ventilated rooms is very important in obtaining comfortable environmental conditions. A correct circulation of air is a fundamental factor in avoiding draught sensation in the occupied zones and to guarantee a good cleansing of the environment (Fanger *et al.*, 1988; Etheridge and Sandberg, 1996; Grignaffini and Vallati, 2002b).

These studies are most important when the occupied zone is near the inlet zone. In this case it is necessary to devise air terminal diffusers for which it is possible to provide customized and controlled variation of airflow resulting in personalized comfort.

Indoor environment are used by occupants with different psychological and physiological response, clothing, activity, individual preferences to the air temperature and movement, time response of the body to changes of the room temperature, etc. Thus, total-volume ventilation has limitations and is often unable to provide each occupant simultaneously with high thermal comfort and air quality (Melikov *et al.*, 2001). Often, occupants in room with mixing ventilation have to compromise between preferred thermal comfort and perceived air quality. The compromise is different for each occupant and also differs in time. The disadvantage of the total-volume ventilation principle is that, if the space is restricted and there are persons

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closer to the inlet air terminals than others, this may increase occupants' complaints of draught and/or poor air quality.

Environmental conditions acceptable for most occupants in a room may be achieved by providing each occupant with the possibility to generate and control his own preferred local environment. Personalized ventilation (PV), often referred as to task/ambient conditioning, aims to provide each occupant with personalized clean air direct to the breathing zone. Each occupant can control the environment at his site. Thus occupants' satisfaction can be increased as a result of improved air quality, thermal comfort and control over the environment. The supply air terminal devices are an essential part of any personalized ventilation system. They play a major role in the distribution of personalized air around the human body and thus determine occupants' thermal comfort and perceived air quality. Ventilation with high induction terminal provides, thanks to the inductive effect, limiting annoying air currents in the occupied zone and at the same time carries out a cleansing of the environment. A recent study (de Lieto *et al.*, 2003) considered the use of linear air terminal diffusers in railway compartment coaches.

This paper studies the performance of a high induction air terminal device by evaluating the thermal environment in train compartments for improving occupants' thermal comfort. The employed nozzles can be closed and oriented in all directions in order to direct the airflow according to passengers needs.

EXPERIMENTAL MEASUREMENTS

The experimental measurements have been realized inside the test room built in a laboratory at the Dipartimento of Fisica Tecnica at 'La Sapienza' University of Rome. Figure 1 shows the environmental room used for the experiments, and the position of the supply diffuser. The climate chamber was $3 \times 3 \times 2.7$ m^3.

The air velocity was measured at different points inside the room through hot-wire anemometers placed on different planes, as described in Figure 1.

In order to verify the thermofluidynamic performances of the air terminal devices, a set of measurements has been realized inside the test room. The employed experimental apparatus consists of omni-directional hot-wire anemometers connected to Dantec multi-channel flow analyser type 54N10. The anemometric probes (54R10), externally constituted by quartz inside which the sensors are printed in a nickel film, have diameter of 10^{-3} m and resistance of 25 Ω (Bruun, 1995). The omni-directional hot wire anemometers and their automatic logging meet the specifications in Standard EN 13182 (2002) for accuracy and response time. These sensors have been calibrated in stationary flow wind gallery equipped with micrometric pitot tubes capable of providing an absolute velocity reference in a range comprised between 0.05 and 1 m/s with an accuracy of ±5% of the reading.

Winter conditions were simulated in the test room with the temperature of personalized air at 20°C. A qualitative analysis of the airflow surrounding the inlet air terminal devices has been performed through a fog test.

ANALYSIS OF THE RESULTS

The experimental set up has been conceived with the characteristic of allowing a variable air flow rate in the space by using an inverter acting on the working frequency of the fan.

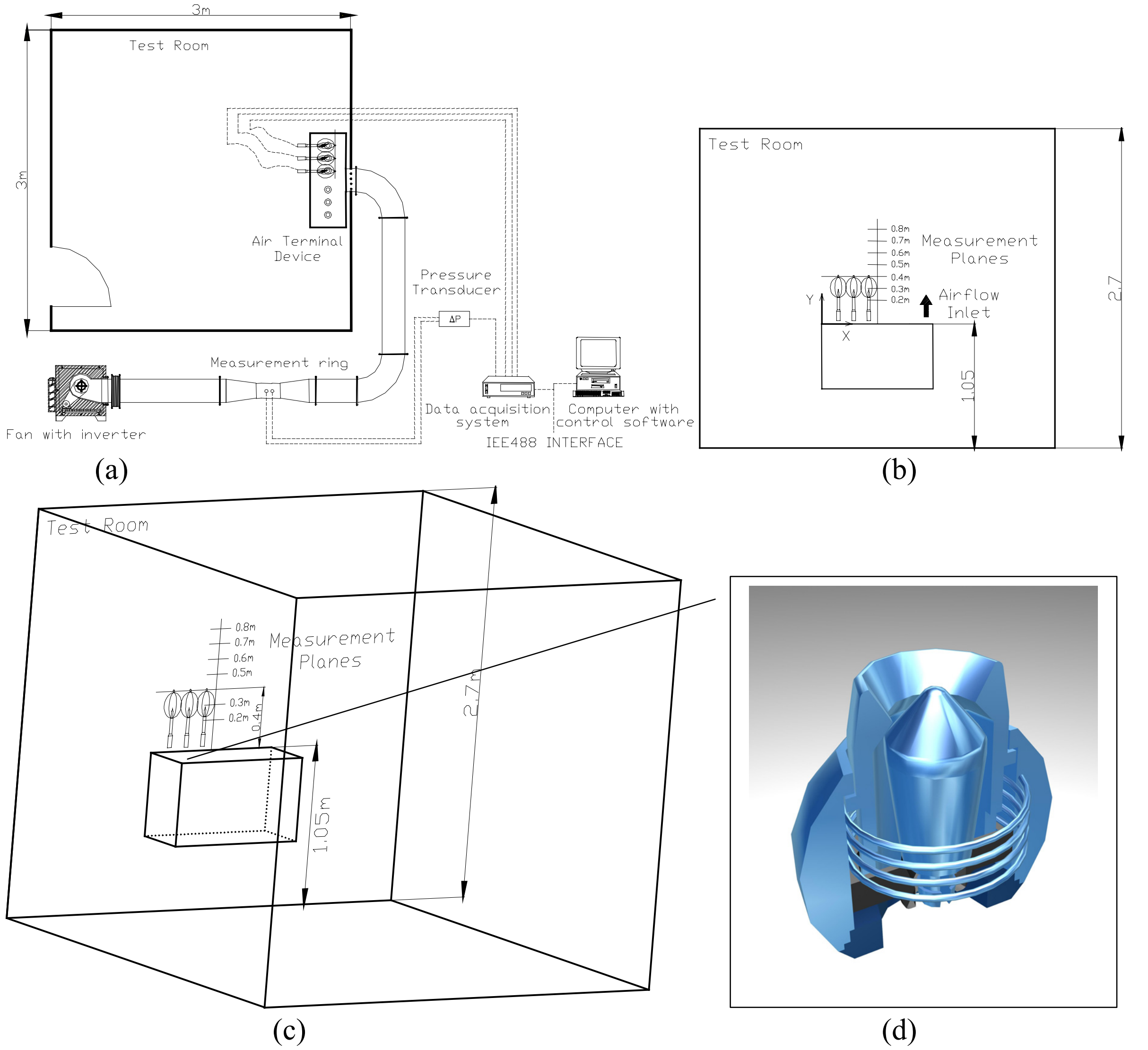


Figure 1 Cross-section (a, b) and perspective views (c) of the environmental room and measurement set-up with measurement points on a vertical plane; nozzle detail (d).

Figure 2 shows the curve characterizing the installed aeraulic apparatus, with the flow rate plotted against the pressure drop.

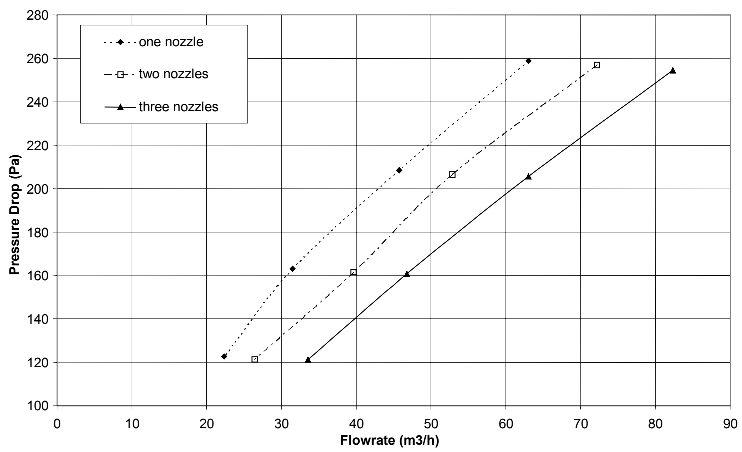


Figure 2 Characterizing curve of the experimental aeraulic apparatus.

The air terminal designed and studied in this work allows airflow customization around the passenger, letting direction and flow rate of the air jet vary. In this study, we kept the jet direction perpendicular to the plane of the diffusers and we let the flow rate vary, turning on and off the three nozzles constituting the air terminal diffuser.

We verified the air distribution at different levels around the jet, as shown in Figure 1.

The selection of the personalized flow rate has been made in accordance with (Melikov *et al.*, 2001), by choosing then the optimal value in terms of passengers comfort. Table 1 presents the flow rate values employed in this work.

Table 1 Flow rate values employed in the performed measurements

Number of open nozzles	Flow rate (l/s)
3	10 and 15
2	7 and 11
1	6 and 9

Figures 3–5 show the contour plot of the velocity magnitude in the plane shown in Figure 1, with one, two and three nozzles open.

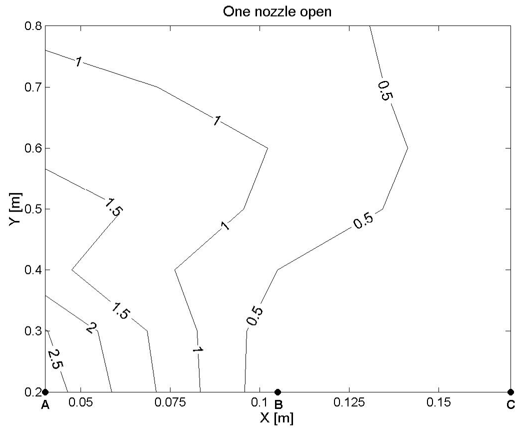


Figure 3 Contour plot of the velocity magnitude (m/s) when nozzle A is open.

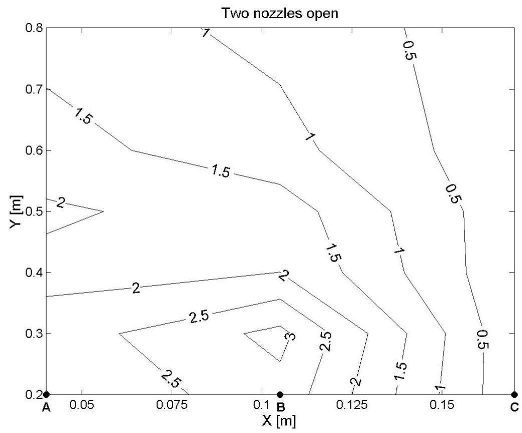


Figure 4 Contour plot of the velocity magnitude (m/s) when nozzles A and B are open.

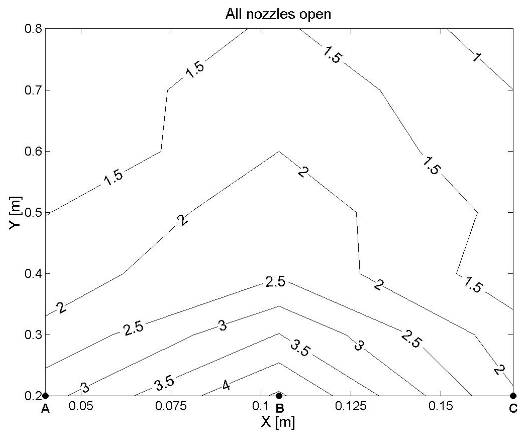


Figure 5 Contour plot of the velocity magnitude (m/s) when all nozzles (A, B and C) are open.

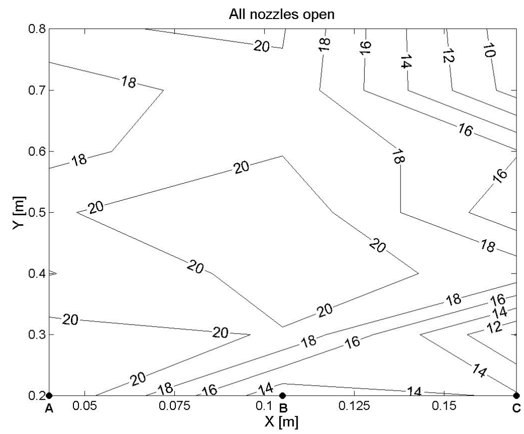
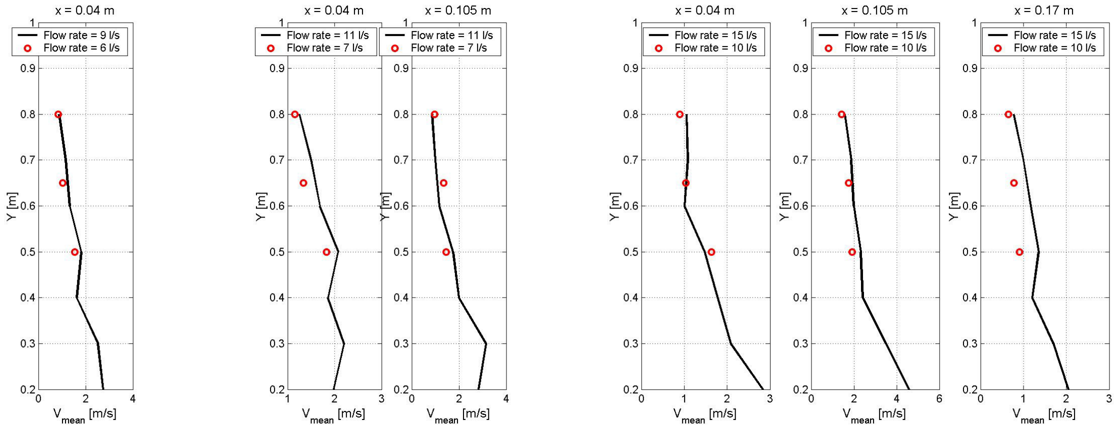


Figure 6 Percentage of energy comprised between 0.3 and 0.5 Hz in the measurement plane.

Figure 3 allows the evaluation of the jet width, approximately 0.1 m, and Figures 4 and 5 show the interaction of the individual jets and their mixing.

Figure 6 shows the percentage of turbulent energy causing discomfort, in the frequency range 0.3–0.5 Hz (Hanzawa *et al.*, 1987).

We measured the mean velocity along the axis of the jets with different flow rates. The results are reported in Figure 7, which points out the negligible differences of the velocity field at a distance of 0.7–0.8 m from the terminal device.



(a) (b) (c)

Figure 7 Velocity magnitude along the axis of the nozzles for different flow rates, when nozzle A is open (a), A and B are open (b), A, B and C are open (c).

Finally, the turbulent air flow characteristics have been studied; in particular, the analysis of the turbulent energy spectrum has been performed. Figure 8 shows the normalized energy spectrum as a function of the normalized wave number k/k_d where k_d is the inverse of the Kolmogorov microscale. We observe from the spectrum analysis that at 0.8 m distance from the airflow inlet the inertial subrange begins to appear, whereas at lower heights the energy is uniformly distributed over the wave numbers.

Figure 9 shows the fog test used in this study for visualizing the air distribution near the inlet supply. It is evident that at approximately 0.3 m from the inlet a unique jet is fully developed, in accordance with the experimental measurements.

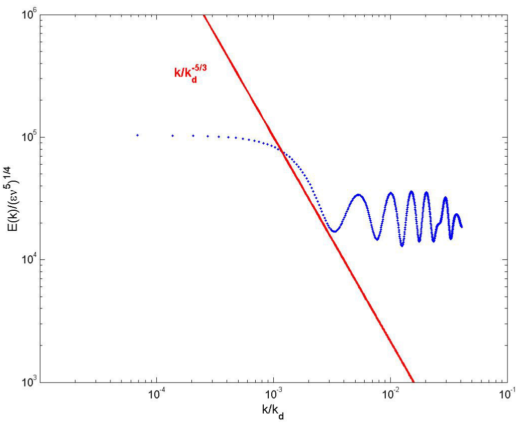


Figure 8 Normalized energy spectrum at $y = 0.8$ m.

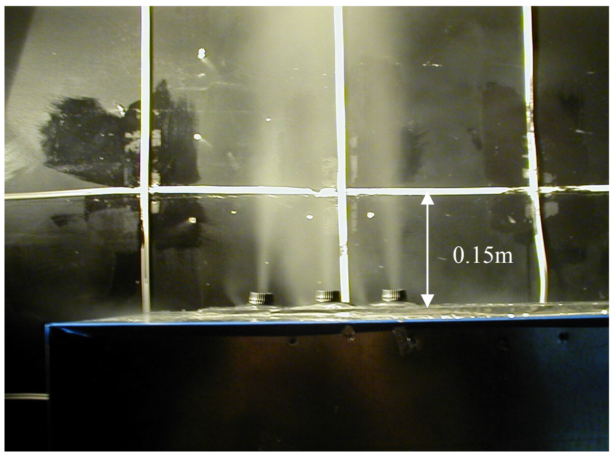


Figure 9 Fog test for visualizing the air flow near the terminal supply.

CONCLUSIONS

The performance of a supply air terminal device for a personalized ventilation system was tested.

The analysis of the results points out that, by adjusting air flow and launch inside a restricted environment, it is possible to improve occupants comfort conditions. In particular, it is necessary to provide an air distribution system controllable by the occupants, allowing the free adaptation of thermal exchange between body and surrounding air. These results suggest that, for peculiar spaces as those existing for passengers in moving systems, it is advisable to provide the customization of the air flows introduced in the space.

Future work will be devoted to the test of this air terminal device inside a moving compartment railway coach with passengers for computing the thermal comfort parameters and to compare the performance with those of the linear air terminal device.

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