HYBRID TRAIN VENTILATION SYSTEMS FOR SUMMER AND WINTER CONDITIONS

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Abstract

The present study is intended to investigate hybrid ventilation concepts in a generic train mock-up (GTM) in terms of fluid and surface temperatures and with regard to heat removal efficiencies. The ventilation concepts are based on a combination of cabin displacement ventilation with different overhead air inlets. The influence of summer and winter conditions on the performance of ventilation systems in trains is studied using a jacket heating/ cooling system. To simulate the heat release and the obstruction caused by passengers, 24 thermal manikins were placed in the GTM. Temperature sensors and an infrared camera were used to determine the relevant temperatures. The results in terms of spatial temperature homogeneity, local temperature stratifications, heat removal efficiency as well as surface temperatures of the manikins and the cabin interior under summer and winter conditions show a high potential of novel ceiling-based ventilation concepts in combination with cabin displacement ventilation (CDV).

Keywords: generic train laboratory, novel ventilation concepts, thermal comfort

1 Introduction

The HVAC system of a train is the second largest energy consumer during a train journey, requiring up to 20-30% of the total energy demand. Besides implementing new technologies, such as heat pumps or demand-oriented ventilation, the ventilation concept itself also offers potential for improvement. In the last few years, authors have aimed at transferring knowledge of aircraft cabin ventilation (Bosbach et al. 2013) to the ventilation of car cabins (Dehne et al. 2018) and train passenger compartments (Schmeling and Hörmann 2018). In this context, novel ventilation concepts for future high-speed trains have been investigated in the lower deck of a 1:1 scale GTM at the DLR in Göttingen within the framework of the Next Generation Train (NGT) project. In addition to “micro-jet” ventilation (MJV) used as reference case, two novel ceiling-based ventilation concepts were investigated in previous studies: low-momentum ceiling ventilation (LMCV) with a trickle ceiling above the aisle and hat-rack-integrated low-momentum ventilation (HLMV) with a trickle ceiling above the seats.

In the present study, all three ceiling-based ventilation concepts were combined with CDV, realized by a low-momentum air supply at floor level. The windows of the mock-up were replaced by a jacket heating/cooling system based on capillary tubes mounted on aluminium sheets to allow for the experimental simulation of winter and summer conditions. To simulate the obstruction and heat release of real passengers, 24 thermal manikins were used.

2 Materials and Methods

Three ceiling-based ventilation concepts (MJV, LMCV, HLMV) were combined with CDV to form hybrid ventilation systems and investigated in the GTM. State-of-the-art MJV is characterised by a high degree of mixing by jets of fresh air enter the cabin in the aisle area. In case of LMCV, the fresh air enters the cabin with low momentum through a trickle ceiling. HLMV was implemented by planar, large surface outlets, integrated in the lower part of the hat racks. For each hybrid ventilation concept, three air-mass flow ratios between ceiling and floor inlets — 67%-33%, 50%-50% and 33%-67% — were investigated. For the sake of brevity, abbreviations to identify the different concepts and volume flow ratios will be used in the following: For example, HLMV 67-33 indicates hybrid ventilation with 67% HLMV and 33% CDV. Detailed information on the different ventilation concepts can be found in Schmeling and Hörmann (2018).

Within the framework of the project Next Generation Train (NGT), a full-scale mock-up of the NGT-HST (high-speed train) with well-defined boundary conditions was constructed at the DLR in Göttingen. For our study, 24 thermal manikins (TM) were seated in six rows in the GTM. The heat release of the TMs was automatically adjusted corresponding to the human metabolism and depending on the mean temperature. The temperatures of the airflow at the inlets (T_{in}), outlets (T_{out}) and walls (T_{wall}) were monitored by resistance temperature detectors (RTDs). In addition, the surface temperatures of the TMs as well as the cabin surfaces were captured by an infrared camera. The mean cabin temperatures (T_{cab}) of 23°C for summer and 22°C for winter conditions were realised at a volume flow rate of approx. 230 l/s. Here, T_{cab} was calculated using nine RTDs at a height of 1.10 m across the cabin following the definition of T_{im} in EN 13129:2016. Further, the window temperatures were adjusted to 32°C for the summer and to 12°C for the winter scenario. Additional detailed information regarding the experimental set-up can be found in Schmeling and Hörmann (2018).

3 Results

To discuss the influence of cold and warm windows, infrared panoramas (Fig. 1 a) and b)) were created for all ventilation cases under summer and winter conditions. Fig. 1a) shows the hybrid HLMV 67-33 under summer conditions. Warm windows with high spatial temperature homogeneity in longitudinal direction can be observed and the head region of the TMs is in general warmer than the rest of the body. For HLMV the cold hat racks and supply pipes are also visible in the IR thermography, see Fig. 1a). When comparing LMCV to MJV, no major differences were found, neither for summer nor for winter conditions. For the winter cases and HLMV an increasing CDV percentage led to higher temperatures at the lower sidewalls. In contrast, for LMCV and MJV, an increased percentage of CDV resulted in lower temperatures. This finding can be explained by the counter-rotating main flows for HLMV (downward flow next to the windows) on the one hand and MJV as well as LMCV (downward flow in the aisle) on the other hand.

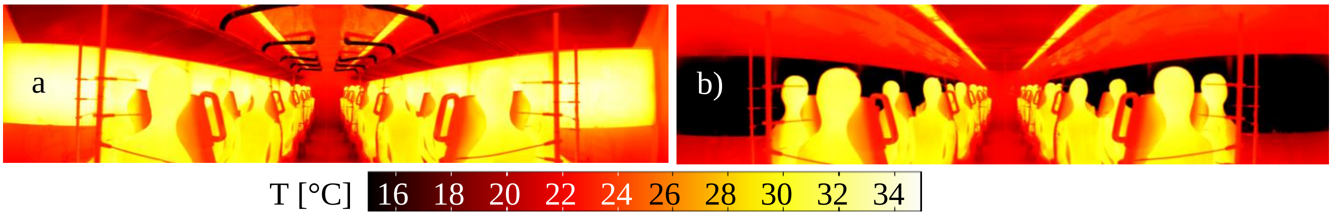

Figure 1*. IR thermography of a) hybrid HLMV ventilation 67-33 under summer conditions and b) hybrid LMCV ventilation 50-50 under winter conditions*

In the following, we will focus on the discussion of the local fluid temperatures. As an example, Fig. 2 depicts the temperature stratifications for the summer scenarios in solid lines and for winter conditions in dashed lines for air flow distributions of 33-67 and 67-33, respectively. The mean values for the different height levels were determined by time-averaging over 1800 s and spatial averaging over four seat positions in the third row. Further, the vertical temperature differences between head and ankle (ΔT_v) are summarised in Tab. 1 for all investigated cases. For the winter scenario, all ventilation concepts were evaluated as very good with regard to the temperature stratification. With increased thermal buoyancy due to the greater part of CDV under summer conditions, clearly uncomfortable values (EN 13129:2016) up to 8.2 K were observed between head and ankle, see Fig. 2 and Tab. 1. Further findings — not visualised for the sake of brevity — are: a) Independent of summer and winter conditions, rising temperatures were found with an increased proportion of CDV. b) No major differences between the ventilation systems were found for both summer and winter conditions. With regard to the vertical temperature distributions, all hybrid ventilation cases with an air-mass flow distribution of 67-33 were evaluated as the best concepts.

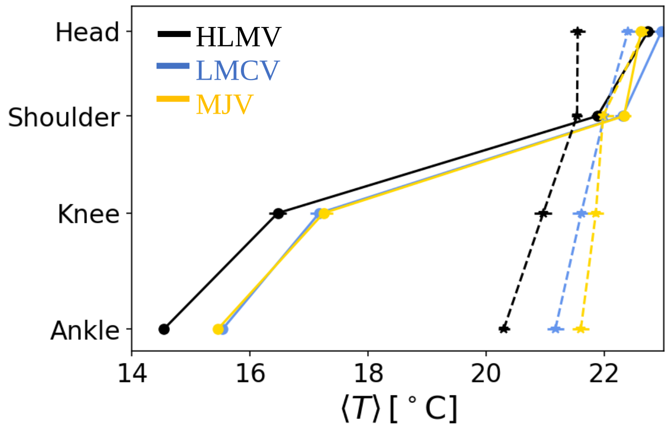

Figure 2*. Spatially averaged temperatures at different height levels in the proximity of the TMs in row 3 for air-mass flow 67-33 in case of winter (dashed,★) and 33-67 summer (solid,●) conditions.*

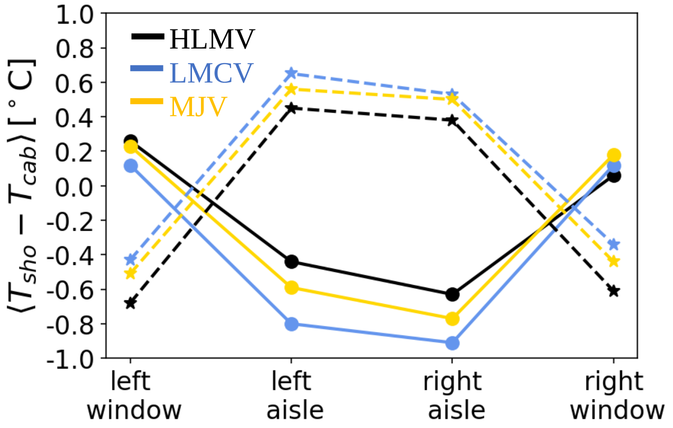

Figure 3*. Horizontal temperature distribution on shoulder height spatially averaged over three rows for the investigated hybrid ventilation scenarios with an air-mass flow of 33-67. Solid lines (●) and dashed lines (★) indicate the summer and winter cases, respectively.*

Fig. 3 depicts the temperatures at shoulder height (T_{sho}) for four seat positions averaged over the longitudinal direction. Only the volume flow rate distribution of 33-67 is shown for all investigated ventilation systems under summer and winter conditions. To illustrate the spatial temperature distribution, the values are indicated as difference to T_{cab}. Further, all differences between outer and inner seats are given as ΔT_h in Tab.1. The thermal fingerprint of the tempered windows is clearly visible at the outer seats (left window, right window), see Fig. 3. In contrast, negative temperature values for summer and positive values for winter conditions reveal no influence of warm or cold windows on the aisle positions. For the variation of the air-mass flow distribution (not visualised for the sake of brevity) similar temperature distributions with an averaged maximal deviation of 0.11 K were observed for all LMCV hybrid concepts. MJV (0.3 K) and HLMV (0.45 K) revealed larger temperature differences. Obviously, the air-mass flow distribution of LMCV has no influence on the spatial temperature distribution. No major differences for ΔT_h were found for all investigated cases under winter conditions, see Tab. 1. For the summer scenario, an increase of ΔT_h was observed for a growing share of CDV for the HLMV 67-33 case. However, HLMV showed temperature stratifications up to 0.5 K from the left to the right for the summer case with the hybrid variations 67-33 and 50-50 (no figure). With regard to the horizontal temperature distribution, LMCV was evaluated as the best concept with the most homogeneous distribution. In addition to the local temperatures, the fluid velocities near the passengers are an important indicator for determining the thermal comfort. Tab. 1 shows the spatially averaged velocities $\langle U \rangle$ and the associated standard deviations averaged over four seats in row 3 for four different height levels. As expected, both the mean velocities and the standard deviations decrease with an increasing proportion of CDV. Finally, the heat removal efficiency (HRE), defined as $HRE = 0.5 \cdot (T_{out} - T_{in}) \cdot (T_{cab} - T_{in})^{-1}$, will be discussed. Previous studies (Schmeling and Hörmann, 2018) revealed a good HRE for pure CDV and LMCV as compared to MJV and HLMV. The results for the hybrid ventilation systems, subdivided into summer and winter conditions in Tab. 1, show no major differences between HLMV, LMCV and MJV. However, all values are above the values of the solitary systems, except for pure CDV, (Schmeling and Hörmann, 2018). This finding highlights the potential of hybrid ventilation concepts for energy efficient cooling under summer conditions. Further, contrary to expectations, an increased share of CDV has not led to a rise in the HRE. Under winter conditions, the use of HRE has to be discussed, since the heat should not be removed from the passenger. For further investigations, the heating/cooling efficiency based on local equivalent temperatures, as determined by Dehne et al. (2018) for a passenger car compartment, should be evaluated.

Table 1*: Evaluated temperatures [K] and velocities [m/s] for the investigated mass-flow distributions of HLMV, LMCV and MJV hybrid ventilation in case of the summer and winter scenario.*

		Summer					Winter				
		ΔT_h	ΔT_v	$\langle U \rangle$	T_{in}	HRE	ΔT_h	ΔT_v	$\langle U \rangle$	T_{in}	HRE
HLMV	67-33	0.2	2.5	0.09(4)	13.0	0.54	1.0	1.2	0.09(4)	16.5	0.63
	50-50	0.5	6.1	0.07(3)	12.2	0.54	1.0	2.3	0.07(3)	16.9	0.66
	33-67	0.7	8.2	0.06(2)	12.0	0.55	1.0	3.7	0.06(2)	16.2	0.64
LMCV	67-33	0.8	3.0	0.09(4)	13.2	0.57	0.8	1.2	0.09(4)	17.5	0.68
	50-50	0.8	5.3	0.07(3)	14.8	0.55	0.8	2.2	0.07(3)	17.2	0.66
	33-67	1.0	7.4	0.06(2)	12.3	0.56	1.0	3.0	0.07(3)	17.2	0.65
MJV	67-33	0.7	2.7	0.10(4)	13.2	0.58	1.0	1.1	0.11(5)	17.2	0.69
	50-50	0.8	5.7	0.08(4)	12.8	0.56	0.9	2.5	0.09(4)	16.6	0.66
	33-67	0.9	7.2	0.06(2)	12.3	0.55	0.9	3.3	0.07(3)	16.5	0.67

4 Conclusion

We presented an experimental study of fluid as well as surface temperatures and their impact on the thermal comfort in a generic train mock-up for three hybrid ventilation systems.

A comparison of the surface temperatures of the thermal manikins and the cabin surfaces revealed no temperature changes between the different mass-flow distributions. Regarding the vertical temperature stratifications, the hybrid ventilation concepts with 33% CDV should be favoured, particularly for summer conditions, since a higher proportion of CDV induces stronger temperature stratifications resulting in reduced thermal comfort. For the winter case, such comfort-critical temperature stratifications were not found for an increased proportion of CDV. The hybrid LMCV revealed benefits in terms of the horizontal temperature distributions. Here, temperature differences were observed for HLMV 67-33 in the cross section and for MJV 67-33 in longitudinal direction. However, an improvement was reached by switching to 33-67 for both systems. Finally, the HRE indicated no benefits when increasing the percentage of CDV.

An issue, which will be addressed in future studies, is a modification of HLMV by an air exhaust above the head and an air supply in front of the face. This modification could lead to further improvement of thermal comfort and energy efficiency.

5 References

J. Bosbach. S. Lange, T. Dehne, G. Lauenroth, F. Hesselbach, M. Allzeit, *Alternative Ventilation Concepts for Aircraft Cabins*, CEAS Aeronaut. J. 4, 301- 313

T. Dehne, P. Lange, A. Volkmann, D. Schmeling, M. Konstantinov, J. Bosbach, *Vertical ventilation concepts for future passenger cars*, Build. Environ. 129, pp 142-153, 2018.

EN 13129:2016, *Railway Applications; Air Conditioning for Main Line Rolling Stock, Comfort Parameters and Type Tests*. German version EN 13129:2016.

D. Schmeling and H.-J. Hörmann, *Evaluation of novel ventilation concepts for train compartments using thermal manikins and subject trials*, Proceedings of the 4th Int. Conf. on Railway Technology, Sitges, Spain, 2018.