THERMAL COMFORT IN AN AIRCRAFT MOCK-UP WHEN USING DISPLACEMENT VENTILATION

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Abstract

Displacement ventilation (DV) is an air distribution system, which supplies cool fresh air at floor level and extracts exhausted air at the ceiling. Air draught is reduced as heat sources – like aircraft passengers – generate the vertical air movement in the room. Of current interest is the question whether ordinary mixed air systems in an aircraft can be replaced by or combined with displacement ventilation systems without risking a decrease in thermal comfort. A reduction of energy consumption seems to be a valuable gain.

Three different versions of displacement ventilation were analysed in the research project "Innovative Cabin Systems"[1]. For this purpose, new air outlets were installed in an aircraft mock-up of a Dornier 728. Outlets were integrated into the existing air conditioning system and fixed under the passenger seats. They were suitable to supply a sufficient amount of cool air with low speed to the cabin.

Studies were conducted in the mock-up using 40 subjects each. They were aimed at analysing the thermal comfort of a) Study 1: 100% displacement ventilation, b) Study 2: a 70:30% hybrid solution combining DV and mixed ventilation (MV) and c) Study 3: a 50:50 % hybrid solution of DV and MV. Two climate scenarios corresponding to cruise flight conditions (23 °C and 24 °C) were tested. Objective and subjective data were gathered to gain a differentiated image of the climate situation. Various sensors were used to quantify the intensity of air velocity and temperature next to the subjects' bodies. Further, psychological questionnaires were filled out by the subjects, by which they evaluated intensity and comfort of the climate parameters.

Measurement data revealed a comparatively strong vertical temperature gradient for hybrid systems; the smallest temperature difference between feet and head was found for 100% DV. Air velocity was altogether low and increased with the amount of mixed air that was provided. Regarding subjective evaluations, temperature, air movement and humidity were rated as being most comfortable in 100 % DV and in the 50:50 hybrid system. The overall satisfaction with the climate was highest in the 50:50 hybrid system.

In sum, displacement ventilation can be used to provide a comfortable climate in an aircraft cabin. Even though known constraints as e.g. large vertical temperature differences are measurable, these did not have any negative influence on climate satisfaction ratings.

1. INTRODUCTION

For the development of new aircraft types, one important design criterion is the thermal comfort that can be provided for the passengers. Nowadays demands are changing, as for example the usage of electronic devices has become very common while traveling. Most airlines install individual screens in the seats for the entertainment of passengers and the principle of having a "second screen" via mobile devices is a current future plan. One result of additional electronic equipment is the amount of heat load that is created. Until now, mixed ventilation systems are used to dissipate the contaminated air of aircraft cabins. But this air distribution system has some deficiencies: especially when cooling large heat loads, it may lead to uncomfortable draughts, noise or distribution of pollutants.

As a consequence, advanced ventilation systems are considered by researchers and aircraft industries. In addition to the improvement of conventional mixing ventilation systems [1], new ventilation principles are developed and investigated. Displacement ventilation (DV) is one of the systems that have been taken into account for the usage in aircraft cabins since a few years [2; 3]. Of current interest is the question whether ordinary mixed air systems can be replaced by or combined with displacement ventilation in order to gain a comparable or even increased thermal comfort and ventilation efficiency.

2. DISPLACEMENT VENTILATION IN AIRCRAFT CABINS

Displacement ventilation is an air distribution system, which supplies cool fresh air generally at floor level and extracts exhausted air at the ceiling. Supply air has under-temperature and is 1 to 4 K lower than room air. Air velocity and turbulences are very low (< 0.3 m/s) as heat sources – like aircraft passengers – generate the vertical air movement via buoyancy [4]. The temperature distribution is

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characterised by stratification: while cool, fresh and clean air can be found at floor level (in the occupied zone) the contaminated air rises up to the ceiling and is extracted there very efficiently. Air quality in the occupied zone is thus improved.

But there are also disadvantages using DV: Melikov, Pitchurov, Naydenov and Langkilde [5] identified high velocities and low temperatures at floor level, i. e. next to the diffusors and the passengers' feet. These may lead to discomfort. Further, according to the ISO comfort standard (ISO 7730), the vertical temperature gradient in a room should be less than 3 K – since cool air is supplied in DV there is a risk of causing larger differences between floor and ceiling, where warm air gathers. Heating is not possible in DV, as cool air is required for the convection principle.

Some studies have been published comparing DV with other ventilation systems. Lin et al. [3] analysed the performance of DV and MV in different kinds of rooms (office, workshop). Computational Fluid Dynamics (CFD) models were calculated and used to compare DV and MV regarding airflow, temperature and comfort indices. DV turns out to provide a comparable or even better comfort level than MV, except for the space in the vicinity of floor diffusors or major heat sources. Zhang and Chen [6] analysed DV, MV and personalised ventilation in a section of a Boeing 767 cabin using CFD modelling. Temperature stratification was found in DV and personalised air distribution systems but the vertical gradient was less than 3 K. While in MV, high air velocities (and CO_2 concentrations) were found, DV provided more comfort. Taking into account the possibility to reduce CO_2 concentration in the breathing zone effectively, personalised ventilation was seen as creating the best cabin environment.

With the intention to combine the advantages of both MV and DV systems, Bosbach et al. [7] set up and analysed a hybrid system (HV) that used air supply from lateral air inlets in addition to DV. A cabin displacement and a hybrid ventilation system were tested during a flight in an Airbus A320-232 with thermal dummies (75 W) and thorough measurement equipment. It was found that the hybrid system led to less temperature stratification but tended to produce more turbulences and higher velocities at the aisle seats, which was not judged as impairing the passengers' comfort. In DV, low air velocities and turbulences were observed and heat removal efficiency was largest.

So far, mostly numerical simulations or experimental measurements have been performed to analyse and evaluate air distribution by DV systems in aircraft cabins. Human subject tests rarely have been published, even though the judgment of potential passengers is an important source in order to gather valid information about the comfort that is offered by a ventilation system [8]. Thus this study focuses on examining the thermal comfort passengers feel when sitting in an aircraft cabin (mock-up) that is ventilated by DV.

3. AIMS AND OBJECTIVES

This study was aimed at testing and analysing three different DV concepts regarding the thermal comfort they offer to passengers. In three human subject tests, a DV system was compared with two hybrid ventilation systems. These latter were designed to combine displacement and mixed ventilation princip-les. Two different relations were selected according to prior findings and theoretical considerations: 70 DV:30 MV and 50 DV:50 MV [7]. Thermal comfort was to be described parametrically and on the basis of test subjects' judgments.

4. MATERIALS AND METHODS

In all three studies, human subject tests were performed in an aircraft mock-up of a Dornier 728. This test facility provides a single aisle cabin and has a complete interior comprising 70 seats in 14 rows. Its air conditioning system is fully operative and allows the control of temperature, humidity and air velocity. Passengers are unable to adjust the climate individually via nozzles. The pressure situation in the cabin corresponds to ground conditions.

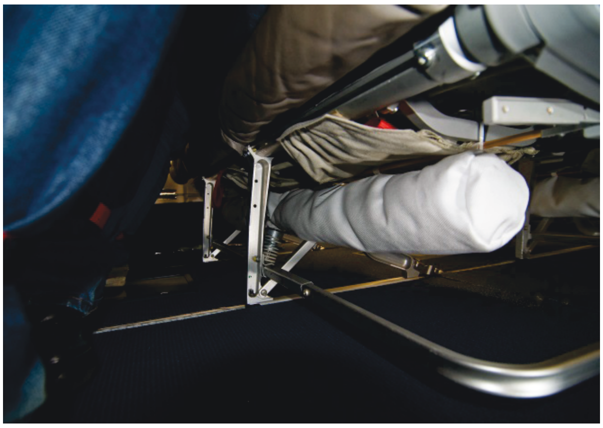

FIGURE 1. Air bag under a passenger seat © DLR

As a precondition to the study of displacement ventilation it was necessary to equip the mock-up with a respective ventilation system. For this pur-pose, new air outlets were designed, manufactured and installed by the DLR Institute of Aerodynamics and Flow Technology. Outlets were integrated into the existing air conditioning system and fixed under the passenger seats (see Figure 1). These air bags were suitable to supply a sufficient amount of fresh cool air with low speed to the cabin. Former air outlets at the ceiling were converted into air inlets so that it was possible to extract the exhausted air at the upper part of the cabin.

FIGURE 2. Ventilation system and subjects in the Do 728 mock-up © DLR

In addition to 100 % DV, in Study 2 and 3 hybrid ventilation systems were to be tested. For that purpose, lateral outlets were used as illustrated in Figure 2. Fresh air was supplied not only via air bags but also via lateral outlets, so that displacement and mixed ventilation were combined in a hybrid solution.

4.1. Sample

As a result of the new ventilation system and the measuring equipment in the aircraft cabin, 30 of actually 70 seats were occupied and not available for the subject tests. Thus, 40 subjects were recruited as "passengers" for each study. Half of the subjects were female (n = 20), half male (n = 20). All three samples were comparable regarding demographic characteristics: the subjects' mean age ranged between 31 and 34 years, the subjects' mean height was between 1.73 m and 1.76 m and their mean weight ranged from 76 to 79 kilos. The minimum educational level of the participants was the "General qualification for University entrance" certificate (German Abitur).

Clothing was standardised beforehand, for example no boots or turtle necks were allowed and all subjects had to wear long sleeves and trousers. Eight subjects did not have experience of flying as a passenger in a commercial aircraft. Subjects were paid 60 Euros each for taking part in the study.

4.2. Instruments

The objective surrounding of the passengers in terms of temperature and air velocity was measured in each study using various sensors next to anthropometric dummies (heat load ca. 75 W). These were seated in the three middle rows of the aircraft cabin. Temperature was determined via RTDs (resistance temperature detectors) which were installed in 9 positions from 5 cm to 138 cm height in front of five of the dummies. Probes were fixed at a distance of 5 cm from the dummy surface. Highly sensitive omnidirectional sensors in front of eight of the dummies were used to measure air velocity in three heights (ankle, knee and head). Relative humidity was measured via USB-Loggers that were installed in the aisle next to rows six and twelve.

Subjective data were assessed using established psychological questionnaires. Items were administered on PDAs (HP iPAQ214, input by stylus pen). Participants rated the intensity of four climate parameters, namely temperature, air velocity, humidity and air quality, using a seven-point scale (temperature: 1 = very cold to 7 = hot; air draught: 1 = not at all to 7 = strong; humidity: 1 = very dry to 7 = very humid; air quality: 1 = very stifling to 7 = very fresh). In a second step, the corresponding comfort level was evaluated for each climate parameter on a five-point rating scale, ranging from 1 = very uncomfortable to 5 = very comfortable. For temperature and air velocity, local judgments relating to body parts were assessed in addition to global ratings. Finally, a general satisfaction judgment was given on a five-point scale ranging from 1 = very dissatisfied to 5 = very satisfied.

4.3. Experimental design

In order to compare the three ventilation concepts, climate parameters were kept constant throughout the analyses. In each study, one colder (23 °C) and one warmer (24 °C) climate scenario corresponding to real-flight conditions were used as independent variables. The volume flow of air was 610 l/s (9,4 l/s per person, cf. ASHRAE 161-2007) and relative humidity was adjusted to a maximum of 18 %. Both scenarios were presented twice to the subjects and in a reversed order to eliminate order effects.

4.4. Procedure

After entering the aircraft cabin, the participants were instructed and familiarised with the handling of the PDAs. The target climate was adjusted during this phase and subjects acclimatised to the aircraft climate. When the climate was stable, the experimental phase started and each scenario was presented for 15 minutes. In the meantime a movie was shown to entertain the subjects. After the set exposure time, subjects had ten minutes to fill out the questionnaire so that they stayed in one scenario for altogether 25 minutes. The next climate scenario was then implemented. In the transition phases between the colder and the warmer climate, snacks were offered and questions relating to personal characteristics were answered. The whole procedure lasted about three and a half hours (s. Figure 3).

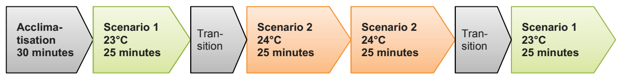

FIGURE 3. Experimental procedure

5. RESULTS

For the further processing of results, data from all 120 (60 female, 60 male) subjects were considered. In order to analyse results per climate condition, arithmetic means from both runs (cf. Figure 3) were calculated.

5.1. Objective parameters of the climate situation

Objective climate parameters were measured and documented for each study. Table 1 gives an overview of means for temperature, air velocity and humidity as they were realised during the three subject tests. Values describe the actual situation in the cabin that was experienced by the subjects.

TAB 1. Objective climate situations during Study 1-3, mean values

	100 % DV	70:30 Hybrid	50:50 Hybrid
Temperature	°C	°C	°C
Scenario 1: 23 °C	23.2	22.8	23.4
Scenario 2: 24 °C	24.4	24.2	24.2
Air velocity	m/s	m/s	m/s
Scenario 1: 23 °C	0.07	0.06	0.08
Scenario 2: 24 °C	0.07	0.06	0.08
Humidity	%	%	%
Scenario 1: 23 °C	17.4	19.6	24.9
Scenario 2: 24 °C	17.4	19.3	22.9

In each study, a cooler and a warmer climate were generated and the two climate scenarios differed in a sufficient amount. Temperatures were comparable throughout the three studies for both scenarios. The same is true for air velocity, which was altogether very low (max = 0.08). Humidity was around 17 % - 19 % in Studies 1 and 2, in Study 3 it was slightly higher with a maximum of almost 25 % in the colder case of the 50:50 scenario.

The vertical distribution of climate parameters has to be taken into account when evaluating DV. Figure 4 shows the vertical heat flow for heights between 5 and 138 cm. A large temperature difference is obvious in all three ventilation systems between floor level (and the passengers' ankles respectively; 10 cm) and the head of a seated person (110 cm). The largest temperature gradient is found for the 50:50 hybrid system with Δ = 5.8 K in the colder climate condition, the smallest for 100 % DV with Δ = 3.6 K in the warmer condition.

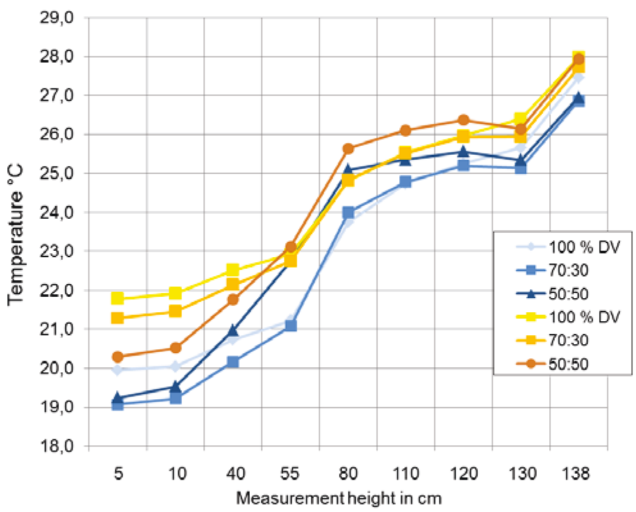

FIGURE 4. Vertical temperature flow in the aircraft cabin for 23 °C (blue) and 24 °C (yellow)

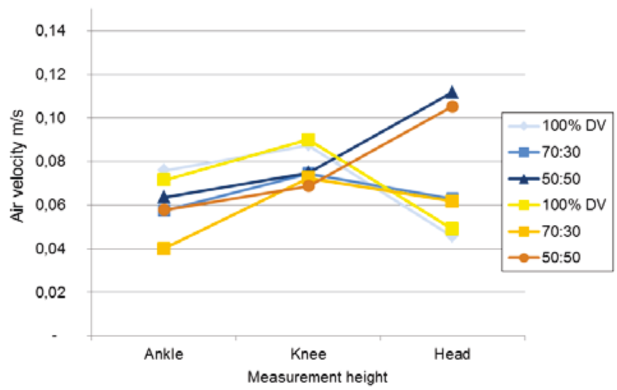

FIGURE 5. Vertical air velocity flow in the aircraft cabin for 23 °C (blue) and 24 °C (yellow)

In Figure 5, air velocity is shown for the three measured heights. The largest differences between the three ventilation concepts were found for the head. Both hybrid systems lead to more air movement here, especially the 50:50 hybrid system. In 100 % DV, air velocities were highest at the lower part of the body (knee); very small velocities were found for the head.

5.2. Subjective evaluation of the cabin climate

Subjects rated the intensity and comfort of the climate situation. In Table 2, values for the global perception of the climate parameters' intensities are illustrated. Small descriptive differences were identified for the comparison of the three ventilation concepts. In the colder climate, temperature was rated as being coldest in the 50:50 hybrid system (in the warmer scenario: warmest), air draught as being highest (in the warmer scenario: lowest) and humidity as being highest. In the 100% scenario the best air quality was given ($p < .10$).

TAB 2. Descriptive statistics of climate parameter perceptions.

		23 °C			
		100%	70:30	50:50	η_p^2
Temperature	*M*	3.49	3.51	3.36	.01
	SD	1.03	.98	.95	
Air draught	*M*	2.69	2.74	2.81	.00
	SD	1.39	1.14	1.10	
Humidity	*M*	3.04	3.05	3.25	.01
	SD	.79	.85	.84	
Air quality	*M*	3.83	3.33	3.64	$.05^{+}$
	SD	1.05	.84	.96	
		24 °C			
		100%	70:30	50:50	η_p^2
Temperature	*M*	3.69	3.58	4.00	.02
	SD	1.16	1.08	1.21	
Air draught	*M*	2.63	2.49	2.16	.03
	SD	1.47	1.07	1.11	
Humidity	*M*	2.80	2.95	3.06	.01
	SD	1.01	.98	.99	
Air quality	*M*	3.38	3.11	3.14	.01
	SD	1.28	.97	.97	

Note. N = 40 in each ventilation; $^{+}p < .10$. Perception scales: room temperature: 1 = very cold to 7 = hot; air quality: 1 = very stifling to 7 = very fresh; air draught: 1 = no air draught to 7 = strong air draught; humidity: 1 = very dry to 7 = very humid.

Even though descriptive differences were found, there were no general significant effects in the colder ($F_{(223;8)} = 1.21$, n. s., $\eta_p^2 = .04$) or warmer ($F_{(223;8)} = 1.12$, n. s., $\eta_p^2 = .04$) climate scenario. Comfort ratings are displayed in Table 3. Regarding all climate parameters, the lowest comfort ratings were obtained for the 70:30 hybrid solution. Accordingly, the overall satisfaction with the climate was lowest in this ventilation system. The highest satisfaction was given in the 50:50 hybrid system. Again, differences were not significant for both climate scenarios (23 °C: $F_{(223;8)} = 0{,}61$, n. s., $\eta_p^2 = .02$; 24 °C: $F_{(223;8)} = 0{,}95$, n. s., $\eta_p^2 = .03$).

TAB 3. Descriptive statistics of climate parameter evaluations.

		23 °C			
		100%	70:30	50:50	η_p^2
Temperature	*M*	2.79	2.59	2.81	.01
	SD	1.03	.65	.90	
Air draught	*M*	2.94	2.74	2.94	.01
	SD	.94	.68	.86	
Humidity	*M*	2.91	2.60	2.90	.04
	SD	.81	.61	.80	
Air quality	*M*	3.04	2.76	3.03	.03
	SD	.77	.64	.77	
Overall satisfaction	*M*	3.00	2.93	3.21	.02
	SD	1.02	0.58	.76	
		24 °C			
		100%	70:30	50:50	η_p^2
Temperature	*M*	2.93	2.64	2.80	.02
	SD	1.07	.80	.99	
Air draught	*M*	3.01	2.96	3.00	.00
	SD	1.00	.73	.82	
Humidity	*M*	2.71	2.64	2.71	.00
	SD	.98	.72	.95	
Air quality	*M*	2.95	2.65	2.76	.02
	SD	.95	.60	.85	
Overall satisfaction	*M*	2.93	2.94	3.09	.01
	SD	0.96	0.60	.88	

Note. N = 40 in each ventilation. Evaluation scales: 1 = very uncomfortable to 5 = very comfortable. Satisfaction scale: 1 = very dissatisfied to 5 = very satisfied.

In addition to global climate parameter ratings, subjects evaluated the parameters' effects on different parts of their body for temperature and air velocity. As shown in Figures 6 a)-c) and Table 4, temperature sensations differed significantly depending on the body part taken into account: in all three ventilation systems, temperature was judged as being lowest at both ankles. While these were rated as being "rather cold", torso and head were characterised as "neutral". The largest vertical difference was found for 23 °C in the 70:30 hybrid (Table 4). Comparing the three ventilation concepts, only moderate differences were found between the warmer and the colder climate in 100 % DV and in the 70:30 hybrid system. As opposed to this, in the 50:50 hybrid system, a clear distinction of both climate scenarios was obvious: the warmer climate was judged as being warmer for all body parts.

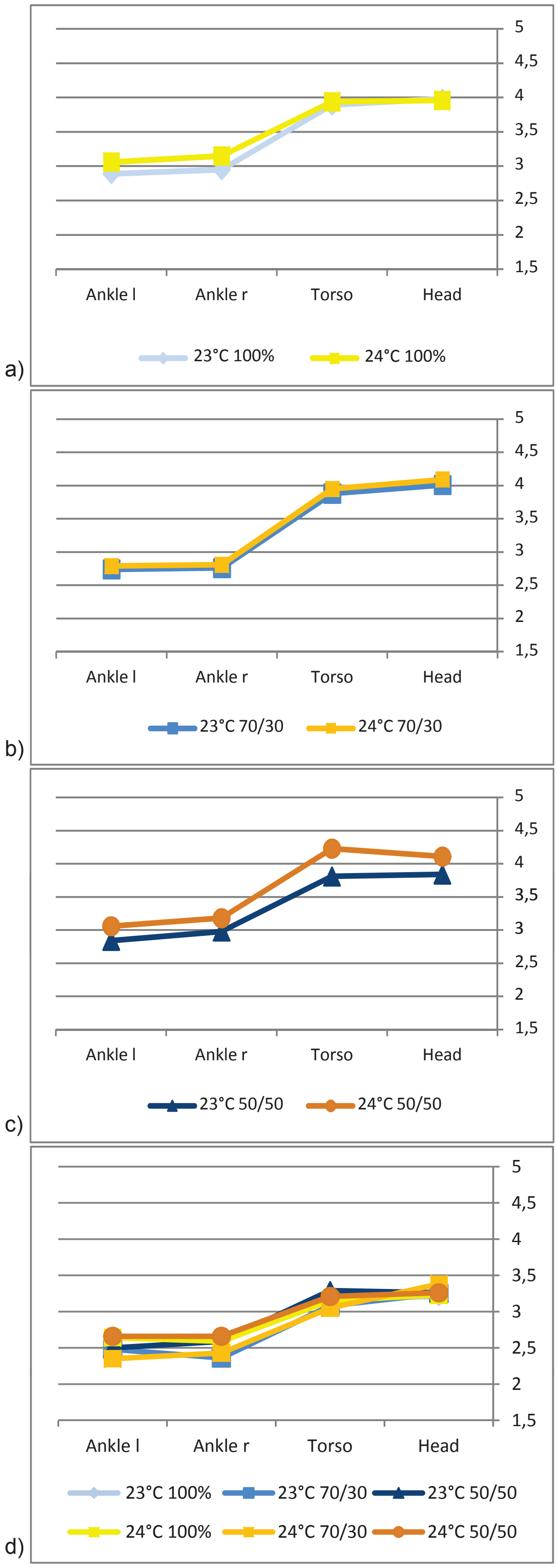

FIGURE 6. Temperature ratings (1 = very cold to 7 = hot) for body parts in 23 °C (blue) and 24 °C (yellow): a) 100 % DV; b) 70/30 hybrid solution; c) 50/50 hybrid solution; d) Temperature evaluation for all three ventilation systems (1 = very uncomfortable to 5 = very comfortable)

TAB 4. Results for analyses of variance (ANOVAs) with repeated measures for temperature and effects of body parts.

	Temperature perception				
	df	*df* $_{Error}$	*F*	η²	*p*
100 % DV					
Scenario 1: 23 °C	3	37	19.38	.61	.00
Scenario 2: 24 °C	3	37	10.64	.46	.00
70/30 hybrid					
Scenario 1: 23 °C	3	37	25.95	.68	.00
Scenario 2: 24 °C	3	37	15.85	.56	.00
50/50 hybrid					
Scenario 1: 23 °C	3	37	12.82	.51	.00
Scenario 2: 24 °C	3	37	12.20	.50	.00
	Temperature evaluation				
	df	*df* $_{Error}$	*F*	η²	*p*
100 % DV					
Scenario 1: 23 °C	3	37	5.36	.30	.00
Scenario 2: 24 °C	3	37	6.36	.34	.00
70/30 hybrid					
Scenario 1: 23 °C	3	37	8.63	.41	.00
Scenario 2: 24 °C	3	37	10.38	.46	.00
50/50 hybrid					
Scenario 1: 23 °C	3	37	12.39	.50	.00
Scenario 2: 24 °C	3	37	4.35	.26	.01

Regarding temperature evaluation, differences between body parts were smaller but still significant (see Figure 6 d and Table 4). Temperature was rated as being “rather uncomfortable” at the ankles in each scenario that was tested; the upper part of the body was “neutral” to “rather comfortable”.

Air draught perception ratings for different parts of the body are displayed in Figures 7 a)-c). In all three systems, air draught was judged to be highest at the ankles, while at torso and head only very low draughts were perceived. The differences were significant (see Figure 7) with the largest delta for the colder climate (23 °C) in the 70:30 hybrid. Altogether, in the two hybrid systems air draught was rated as being higher in the cooler climate, especially at the ankles.

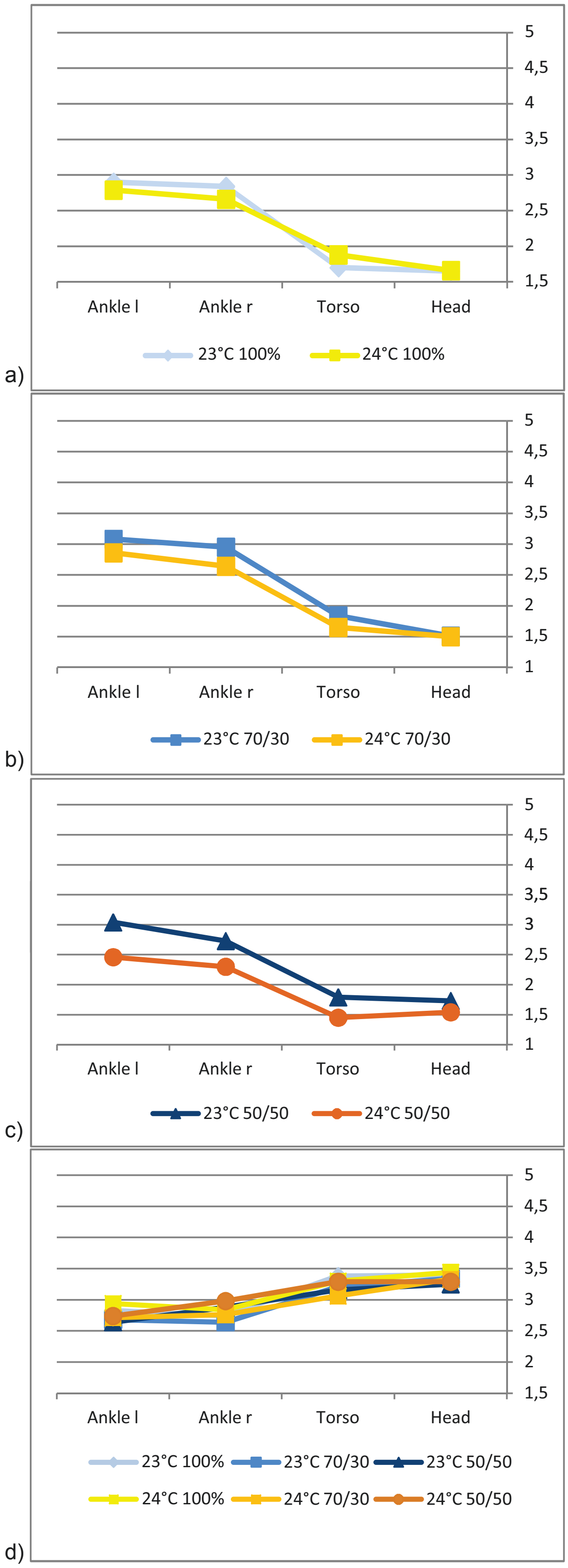

FIGURE 7. Air draught ratings (1 = not at all to 7 = very strong) for body parts in 23 °C (blue) and 24 °C (yellow): a) 100 % DV; b) 70/30 hybrid solution; c) 50/50 hybrid solution; d) Air draught evaluation for all three ventilation systems (1 = very uncomfortable to 5 = very comfortable)

TAB 5. Results for analyses of variance (ANOVAs) with repeated measures for air draught and effects of body parts

	Air draught perception				
	df	*df* Error	*F*	η²	*p*
100 % DV					
Scenario 1: 23 °C	3	37	13.85	.53	.00
Scenario 2: 24 °C	3	37	9.35	.43	.00
70/30 hybrid					
Scenario 1: 23 °C	3	37	21.40	.63	.00
Scenario 2: 24 °C	3	37	11.33	.48	.00
50/50 hybrid					
Scenario 1: 23 °C	3	37	11.22	.48	.00
Scenario 2: 24 °C	3	37	7.20	.37	.00
	Air draught evaluation				
	df	*df* Error	*F*	η²	*p*
100 % DV					
Scenario 1: 23 °C	3	37	6.40	.34	.00
Scenario 2: 24 °C	3	37	6.10	.33	.00
70/30 hybrid					
Scenario 1: 23 °C	3	37	9.48	.44	.00
Scenario 2: 24 °C	3	37	5.42	.31	.00
50/50 hybrid					
Scenario 1: 23 °C	3	37	9.51	.44	.00
Scenario 2: 24 °C	3	37	4.98	.29	.01

Parallel to these perceptual differences in climate parameter intensities, comfort evaluations differed from each other (Figure 7 d and Table 5). Again, rather positive evaluations were found for torso and head, which were rated as being “neutral” to “rather comfortable”. As opposed to this, the ankles were judged as being “neutral” to “rather uncomfortable”. These effects were independent from the ventilation system.

6. DISCUSSION

Three different versions of displacement ventilation were analysed regarding the thermal comfort they provide for passengers. In an aircraft mock-up, three human subject tests were conducted to analyse the thermal comfort of a) Study 1: 100% displacement ventilation, b) Study 2: a 70:30% hybrid solution and c) Study 3: a 50:50% hybrid solution. Physical measurements of climate parameters were performed to describe the climate situation in the cabin thoroughly. Furthermore, judgments of test subjects were assessed to account for their perception of climate parameters as well as their respective comfort evaluation.

Temperature stratification was confirmed in all three air distribution systems. Contrary to earlier results found in an A320 with different air inlets [7], the largest vertical temperature gradient in this study was found for the 50:50 hybrid system. The smallest gradient was identified for 100% DV. One explanation for this unexpected effect is that in the hybrid system, the supply air from the lateral inlets immediately went up along the overhead bins and to the ceiling without mixing with the cabin air beneath. High velocities were measured at 110 cm in the 50:50 hybrid system, a fact that supports this assumption. Thus, less fresh and cool air was available in the occupied zone resulting in stronger stratification. Reasons for this may be the characteristics of the cabin architecture in the Do728 mock-up and the special type of DV air inlets that were used.

Comparing the three ventilation systems regarding the comfort they provide, temperature, air draught, humidity and air quality were rated as being most comfortable in 100% DV and in the 50:50 hybrid system. In all three systems, the climate at the feet was judged as being rather cold, draughty and uncomfortable, confirming the findings of Lin et al. [3]. The overall satisfaction with the climate was highest in the 50:50 hybrid system. As shown in an earlier study [8], warmer temperatures are preferred to colder ones. Figure 4 shows that temperatures were slightly higher in the 50:50 hybrid system at torso and face level. Paralleling this, air velocities were comparatively high at the upper body, too. Evidently, higher temperatures combined with higher air velocities provided the most comfortable climate for the subjects. Nevertheless it has to be taken into account that humidity was also higher in this system (Table 1), which may additionally have contributed to higher comfort values. The 70:30 hybrid system proved to be less comfortable than the other two because of uncomfortable parameter manifestations in the vicinity of the subjects' bodies: the subjects felt the largest difference between ankle and head temperatures with the ankles being cooler, more exposed to air draught and less comfortable than in the other two systems. Obviously, the subjective sensation differs from the objective measures of temperature stratification (which was largest in the 50:50 hybrid system), and seems to be more essential for comfort ratings.

The temperature difference between ankles and head was larger than 3 K in all tested thermal environments. According to ISO 7730, all three systems would have to be classified as being uncomfortable. Nonetheless, the overall satisfaction with the climate ranged between "neutral" and "satisfied" for all conditions. Obviously the temperature gradient may be larger in DV than in MV without causing any severe limitations regarding thermal comfort. Similar results have been reported earlier [9; 10].

Results from this study can finally be compared with earlier studies dealing with thermal comfort in the Do728 Mockup under MV conditions [11]. Data had been assessed using the same satisfaction scale. For an average temperature of 23 °C, an overall satisfaction of M = 3.02 (SD = 0.74) was identified for MV. In a warmer environment with 24 °C, the satisfaction was comparable with M = 3.05 (SD = 0.74). Seen as a whole, comfort values for DV are comparable to these results (Table 3). Satisfaction was even higher in the 50:50 hybrid system.

7. CONCLUSION

In sum, displacement ventilation can be used to provide a comfortable climate with low air velocities for aircraft passengers. Even though known constraints as e.g. vertical temperature differences or colder temperatures around the feet are measurable, these did not have any negative influence on global climate satisfaction ratings. The usage of hybrid systems has to be further explored. Results indicate comfort gains for a 50:50 hybrid version but constraints for a 70:30 hybrid version. The analysis of corresponding CFD simulations can be helpful in order to better understand airflow patterns and the consequences they have.

Concluding from our results, no severe losses of comfort have to be expected with DV compared to current mixed ventilation standards for the tested climate scenarios. As less energy is consumed with DV systems in comparison to MV, the implementation of DV systems has a potential to improve the efficiency of airplanes. A revision of comfort standards with reference to DV systems seems to be consequential and valuable for further DV implementations.

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