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Overhead cooling device reducing thermal stratification at displacement ventilation

Daniel Schmeling[1*], Tobias Dehne[1], Pascal Lange[1], Axel Dannhauer[1], Andrej Shishkin[1], Ingo Gores[2]
[1]German Aerospace Center (DLR), Institute of Aerodynamics and Flow Technology, Bunsenstraße 10, 37073 Göttingen, Germany
[2]Airbus Operations GmbH, Kreetslag 10, 21129 Hamburg, Germany
*corresponding author: Daniel.Schmeling@dlr.de

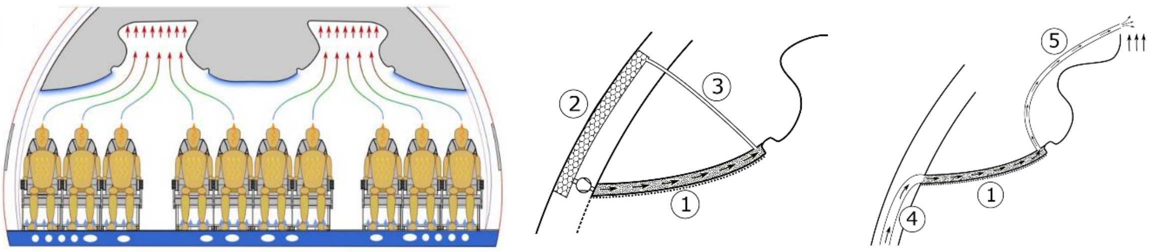
Introduction

The environmental control systems (ECS) of aircraft cabins ensures a viable environment in terms of pressure, temperature as well as oxygen supply and furthermore provides comfortable thermal conditions. Hereto, the heat that is released in the passenger compartment has to be removed by well-balanced ventilation concepts. As state-of-the-art, mixing ventilation with supply air below the ceiling and the lateral luggage bins is installed in all short- and long-range commercial passenger aircraft. Another ventilation concept that has not yet been used in aircraft cabins but has only been investigated in studies and described in patents, is based on floor-side displacement ventilation [Müller, 2011; Bosbach, 2013]: supply air is introduced in the area of the floor with a low momentum. Due to the heat loads in the aircraft cabin, in particular from the passengers, the cabin air is heated locally and rises and finally leaves the cabin in the ceiling area.

The floor-side displacement ventilation has a weight savings potential compared to the mixing ventilation system due to the omission of e.g. risers. Furthermore, displacement ventilation can result in a very high heat removal efficiency [Bosbach, 2013], which can be up to 0.9, while simultaneously providing low air velocities and a good spatial temperature homogeneity across the seats in the aircraft cabin. On the other side, disadvantages of floor-side displacement ventilation are strong vertical temperature stratification [Maier, 2017] and a rather high sensitivity on the supply air conditions with regard to the comfortable parameter.

Concept

The idea to reduce the temperature stratification of cabin displacement ventilation (CDV) is the integration of active cooling devices into the lower parts of the overhead luggage bins [Schmeling-2019], see also Figure 1 (a). The airflow itself will be similar as for plain CDV, whereas the "perceived" temperature especially in the head zone shall be decreased. To achieve a "radiant cooling" effect – being well aware, that this term is physically not correct – the surface temperature of the overhead



(a) (b) (c)

Figure 1: Integration of the cooling concept at CDV in the aircraft cabin and possible technical realisations of the element (b) as closed system and (c) as open system with the active element (1) a heat exchanger (2), the recirc pipes (3), a connection to the mixer unit (4) and an exhaust pipe (5).

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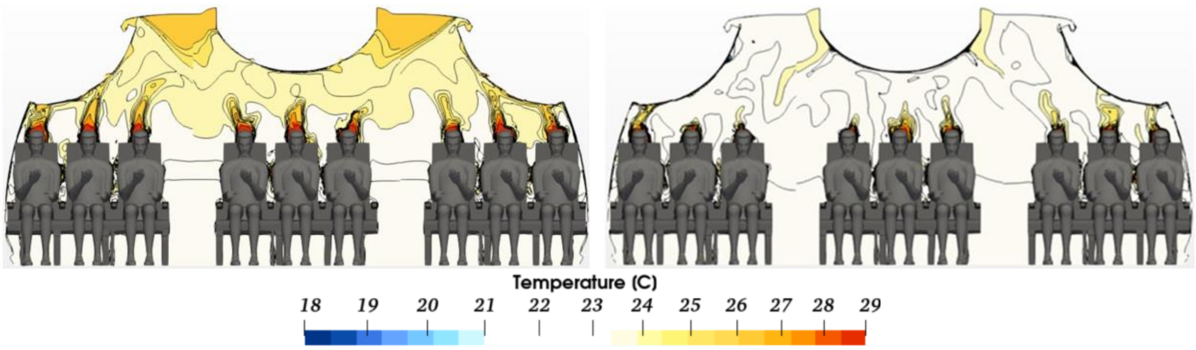
luggage bin is reduced. Thereby, a well-balanced temperature control has to ensure, that the dew-point temperature is not undercut. Possible technical realisations are sketched in Figure 1 (b) with a heat exchanger element at the outer shell and (c) connected to the ECS system.

Results & Discussion

The effectiveness of the new overhead cooling elements is analysed using computational fluid dynamics simulations in a simplified 5-row, 9-abreast twin-aisle configuration. Herein, both cabin displacement ventilation concepts, with and without active cooling, are evaluated. For both concepts a mean cabin temperature of 23°C in the passenger zone was realised by supply air temperatures of 21.5 and 22.5°C at a volume flow rate of 16.7 l/s/PAX. The surface temperature of the cooling elements is set to 15°C. Selected results highlighting the effectiveness are presented in Figure 2 showing the resulting temperature fields. Here much lower temperatures can be found in the upper cabin part with active cooling elements (b) clearly reducing the thermal stratification.



(a) (b)

Figure 2: Comparison of temperature distribution at CDV without (a) and with (b) cooling element.

Conclusion

We presented a new patent-pending technology brick for an enhanced cooling and ventilation concept for a passenger aircraft cabin. The new device helps to reduce the thermal stratification of displacement ventilation while maintaining the benefits. At the conference, we will discuss the new approach of the “radiant cooling” device with regard to effects on the temperature and velocity distributions as well as on comfort evaluation parameter such as PMV and PPD within the cabin based on computational fluid dynamics. Furthermore, we will point out possible technical realisations. The experimental validation with a thermally active demonstrator unit will be conducted during the ADVENT project in the modular cabin mock-up (MKG) [Lange, AEC-2020] located at the DLR site in Göttingen.

Remark

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