Mitteilung

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Efficient cooling of a generic car cabin by novel ventilation systems

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The heating and cooling dynamics for vertical ventilation concepts for future cars gains interest in the recent years. Such ventilation concepts have the potential of improving thermal passenger comfort, increasing efficiency and attended energy reduction [1]. Further, they have attracted the attention of scientists and car manufacturers with regard to successful commercialization of modern electric cars and are necessary for autonomous driving, in particular for configurations with rotating front seats [2].
A full-scale generic car mock-up (GCM) was developed and constructed at the German Aerospace Center (DLR) in Göttingen to evaluate vertical ventilation concepts for future cars in a realistic measurement environment [3]. The dimensions of the GCM follow the interior of typical mid-size cars. To investigate winter and summer conditions, a jacket heating/cooling was implemented in the structure. The heat release as well as the obstruction of passengers were simulated by four thermal manikins (TM) with a constant heating power of 75 W. More than 70 resistance temperature detectors (RTDs) were conducted in order to observe the boundary conditions air inlet, air outlet and ambient temperatures. The manikin surface temperature was captured using an IR- camera in the dashboard. Local equivalent temperatures were calculated by dummy surface temperature to verify the thermal comfort.

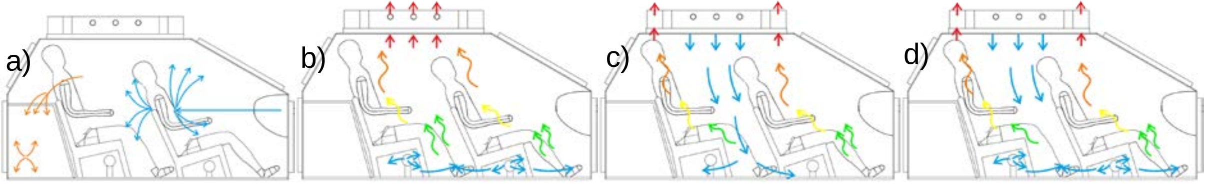

Figure 1: Illustration of the four investigated ventilation system in the generation car cabin. a) mixing ventilation (MV), b) cabin displacement ventilation (CDV), c) low momentum ceiling ventilation (LMCV) and d) hybrid ventilation (HV), a combination of CDV and LMCV

The present study has two aims. The first one is the verification of the cooling efficiency of the different ventilation systems and the second one is the evaluation of the thermal comfort. The reference case is the mixing ventilation (MV, Figure 1a)), which is state of the art for ventilation of passenger car compartments. The present application of MV represents a simplified configuration with four circular air supply tubes in the dashboard of the GCM. MV is characterized by a high mixing degree of the inflowing air jet with cabin air. This horizontal ventilation concept was compared to three vertical ventilation systems. The additional concepts are: cabin displacement ventilation (CDV, Figure 1b)), low momentum ceiling ventilation (LMCV, Figure 1c)) and hybrid ventilation (HV, Figure 1d)). All concepts are featured by very low inflow velocities, where in case of CDV the air supply is realized by airbags mounted under the seats, for LMCV by a trickle membrane at the ceiling. CDV and LMCV have been evaluated in various studies in aircrafts, trains and car cabins in the last years. Further, a hybrid ventilation (HV, Figure 1d)) system was investigated to combine the benefits of CDV and LMCV [3].

For sake of comparability of the dynamic processes it is necessary to have stationary starting conditions. To obtain thermal equilibrium for the summer season condition ($T_{ambient}$ = 30 °C) the GCM operated three hours with heated TMs before starting air supply with air inlet temperature of 15 °C. Further, we run the setup at least 2.5 hours for stationary conditions of the cabin surfaces. For the evaluation of thermal comfort, the investigation of single thermal parameters is insufficient. To evaluate the equivalent temperature, which includes air temperature, air velocity as well as radiation [4], a calibration methodology was validated with a TM in an isolated box [5].

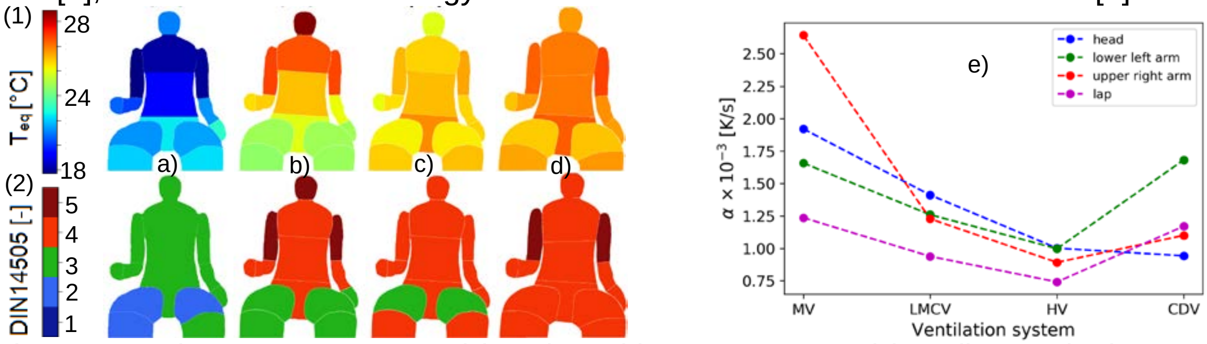

Figure 2: Equivalent temperatures (1) and empiric comfort zones (2) of different body parts at the end of cooling down for a) MV, b) CDV, c) LMCV and d) HV. e) shows the response time of decay curves of averaged equivalent temperature for four body parts

Figure 2(1) depicts the mean equivalent temperatures for the different body parts at the end of cooling period for the investigated ventilation systems (a) – d)). Significantly lower temperatures for MV were observed in comparison to the vertical ventilation concepts. Since the TMs operated under constant heat release, the reduced temperatures unveil an increased heat transfer due to forced convection. Further, CDV reveals temperature stratifications with differences of 6 K between head and legs. In contrast, homogeneous temperatures could be observed for LMCV. At HV, temperature differences between left and right are found. Figure 2(2) depicts the appraisal of the thermal comfort based on empiric comfort zones ([4]) from too cold (1) to too warm (5). For MV, all body parts exempt the legs are neutral comfortable. The vertical systems reveal comfortable but warm upper body parts which indicates potential to warm inflow temperatures. The response time of decay curves α in Figure 2e) ($T(t)=Ae^{-\alpha t}+c$) shows fast changes of equivalent temperatures for upper right arm position of MV because of the higher forced convective heat transfer. At the conference, we will present the results and a detailed analysis of the cooling dynamics as a function of thermal comfort and energy efficiency.

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