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Ductless personalized ventilation with local air cleaning

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SUMMARY
An experiment with 28 human subjects was performed to examine effects of using a local air cleaning device combined with ductless personalized ventilation (DPV) on perceived air quality. Experiments were performed in a test room with displacement ventilation. The DPV at one of two desks was equipped with an activated carbon filter installed at the air intake, while the DPV at the second desk was without such a filter. The air temperature in the occupied zone (1.1 m above the floor) was 29 °C. The pollution load in the room was simulated by PVC floor covering. The subjects assessed acceptability of air quality, odour intensity and air freshness at both desks in random order. Lower odour intensity and higher air freshness was reported at the desk with DPV with the activated carbon filter. The results suggest that using local air cleaning devices integrated with DPV may improve perceived air quality.

KEYWORDS
Human response, perceived air quality, warm environment, HVAC, laboratory studies

1 INTRODUCTION
Personalized ventilation aims at providing clean and cool air directly to the breathing zone of occupants. Its positive effect on occupants' health, comfort and performance has been documented (Kaczmarczyk et al. 2004). Numerous designs of desk incorporated personalized ventilation ducted with central HVAC system has been proposed and studied. Ductless personalized ventilation (DPV) has been also introduced. DPV sucks the cool and clean air spread over the floor by displacement air distribution and supplies it to the breathing zone of each occupant thus improving his/her thermal comfort and inhaled air quality. Comprehensive physical measurements performed with breathing thermal manikins have shown that the DPV has potential to improve the inhaled air quality (Halvoňová and Melikov, 2008, 2010). Due to the fact that the DPV may not always suck the clean displacement air, as well as supply air may not always be clean (mixed with recirculated room air), using the local air cleaning at each workstation might be beneficial. The objective of this human subject experiment was to identify whether cleaning of room air supplied to the breathing zone of occupants by personalized ventilation improves perceived air quality (PAQ).

2 MATERIALS/METHODS
The experiment with 28 human subjects was conducted in a test room with dimensions 3,6 x 4,8 x 2,6 m^3 (length x width x height). Two workstations with DPV were placed in the test room. The DPV at one of the workstations was equipped with an activated carbon filter installed at the air intake, while DPV at the second workstation was without such a filter. Both DPV systems consisted of a fan, two flexible silencers, and a moveable arm with a round moveable panel (RMP) used as a personalized ventilation supply diffuser. Detail description of RMP can be found in Bolashikov et al. (2003). Position of RMP and personalized air flow were kept unchanged and were pre-adjusted to supply air to the breathing zone of the seated person. The personalized air flow rate was adjusted to 18,3 l/s at both workstations resulting in local air velocity at the face region of 3 m/s. The test room was ventilated using displacement ventilation supplying 42 l/(s·person) with 50% recirculation. The room air

temperature was 29 °C (at 1,1 m above the floor) and supply air temperature was 26 °C. The supplied air was directed through a specially designed pollution box containing PVC floor covering material with surface area corresponding to the floor area of the test room. Relative humidity was not controlled and ranged from 11 to 30%.

Subjects were divided into groups of two persons. Each group participated in one experimental session. The experimental session lasted 1 hour and consisted of one 15-minute exposure to the DPV with the activated carbon filter and one 15-minute exposure to the DPV without such a filter. There was a 15-minute acclimatization part before the first exposure and 10-minute break in between two exposures. During the experiment the response of the subjects was collected with the following questionnaires. Acceptability of air quality was assessed on acceptability scale having two parts – from "clearly unacceptable" to "just unacceptable" and from "just acceptable" to "clearly acceptable". Odour intensity and air freshness were assessed using the continuous scales from "Overwhelming odour"/"Air stuffy" to "No odour"/"Air fresh". Experimental procedure can be seen in Figure 1.

	acclimatization room		test room - workstation 1						acclimatization room		test room - workstation 2						acclimatization room
				using DPV								using DPV					
Time [min]	0	14	15	16	21	26	31	32	33	41	42	43	48	53	58	59	60
Acceptability of air quality		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Odour intensity		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Air freshness		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Thermal sensation & Acceptability of thermal sensation							•								•		

Figure 1. Experimental procedure.

The first questionnaire was filled in the acclimatization room, ventilated at high rate with 100% outdoor air, after the acclimatization period. After entering the test room but before the subjects took their place (still standing), they were asked to fill the second questionnaire. Then they sat at the workstations and started using the DPV. They filled out four questionnaires in 5-min intervals. During the exposure subjects were asked to perform typical office work. Before leaving the test room they were asked to stand up and to fill the next questionnaire. After leaving the test room they assessed the environment in the waiting room on the next questionnaire. This procedure was repeated after the break, but the subjects switched the workstations. The subjects were encouraged to adjust their clothing whenever needed during the whole session. The subjects were not allowed to adjust either personalized air flow or the position of the round moveable panel. The position of the round moveable panel was adjusted by the experimenters for all subjects after they took their places; the round moveable panel was directed to the face from the distance of 40 cm.

Shapiro-Wilk's W test was used to test normality of distribution. Data not normally distributed were subjected to non-parametric Friedman Anova and to Sign test.

3 RESULTS

The **first assessment** in following figures is the assessment in the **acclimatization room**; the **second** one represents the air quality in the **test room without using DPV**. Then the subjects made **four assessments in 5-min intervals while using DPV**. After they **stopped**

using DPV subjects assessed again the air in the **test room. Final assessment** was done again in the **acclimatization room**.

Acceptability of air quality.
All four assessments, while the subjects were using the DPV with the activated carbon filter, were significantly ($p<0,05$) higher than the assessments of the DPV without the filter. However, significant difference ($p<0,05$) was also observed at the first assessment in the chamber before using the DPV, therefore the significance while using the DPV is questionable. Acceptability of air quality averaged for 28 subjects with and without the activated carbon filter is presented in Figure 2.

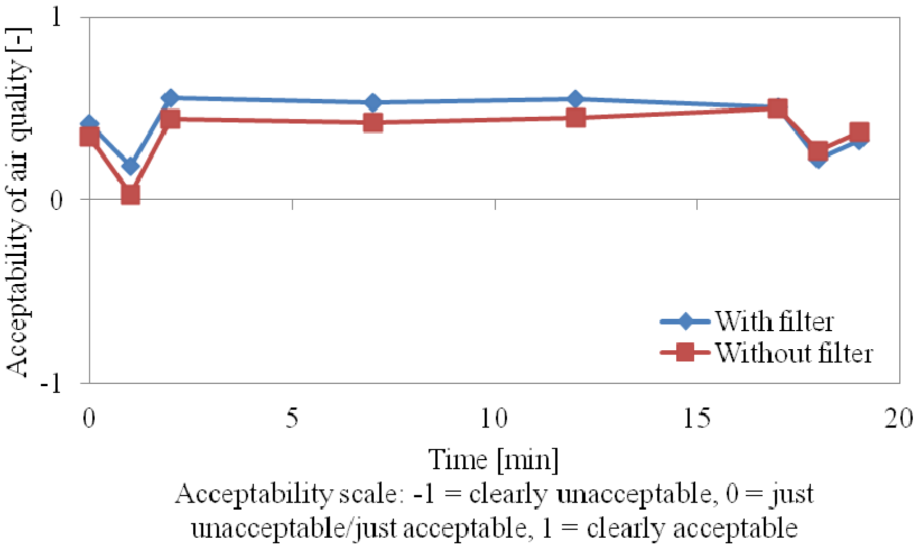

Figure 2. Acceptability of air quality with and without local air cleaning.

Odour intensity.
The odour intensity was significantly ($p<0,05$) higher without the activated carbon filter in all assessments with DPV except the 12th minute of the exposure. This may imply the positive effect of the air cleaning on the perception of odour. Odour intensity averaged for 28 subjects is shown in Figure 3.

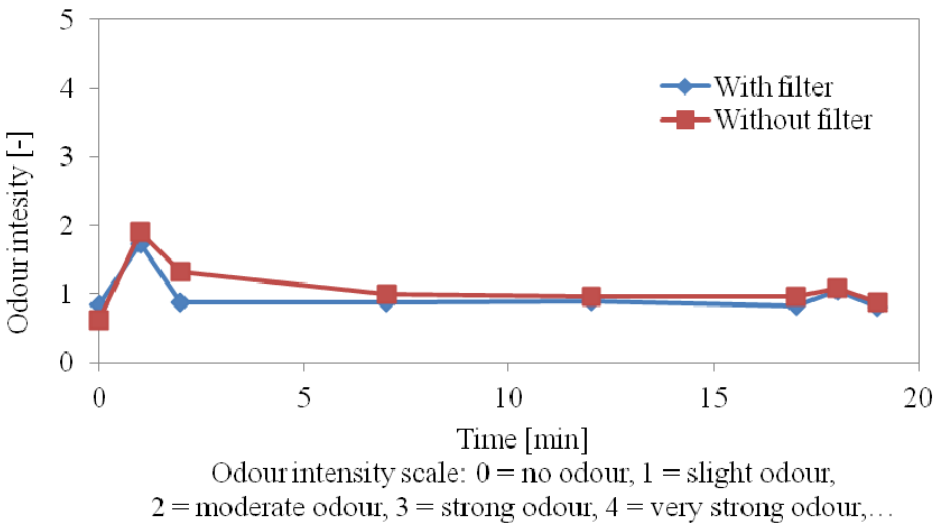

Figure 3. Odour intensity with and without local air cleaning.

Air freshness.
As shown in Figure 4, air freshness was significantly higher ($p<0,05$) with the activated carbon filter in all assessments with DPV, what may suggest the positive impact of air cleaning on the perception of air freshness.

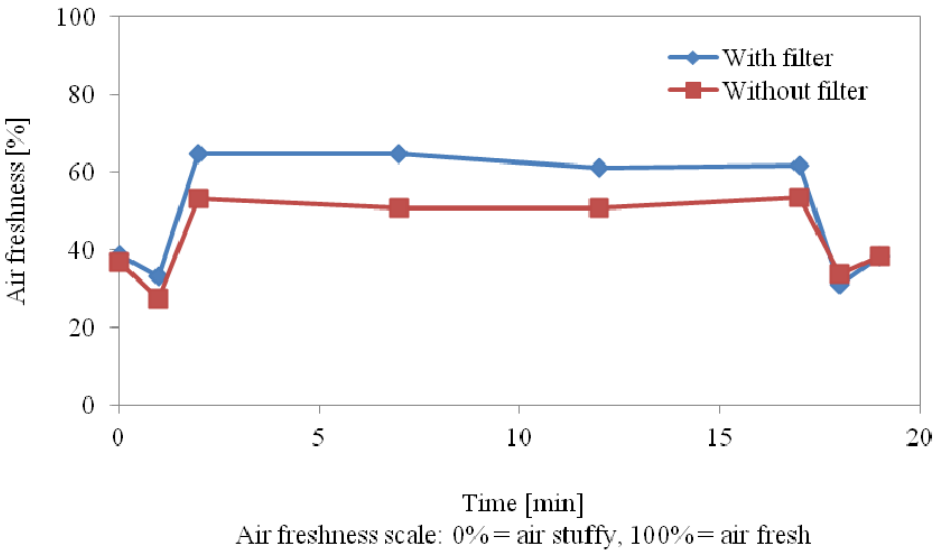

Figure 4. Air freshness with and without local air cleaning

4 DISCUSSION

The findings of Schiavon and Melikov (2008) showed the potential of energy savings by increased air movement. The study assumed compensation of increased room air temperature by elevated air velocity. The energy simulation performed for six cities with different climate conditions (from Helsinki to Athens) showed substantial cooling energy savings (in the range of 17–48%). The critical factor determining overall energy savings with DPV is the power used by the DPV fan. The advantages of the DPV system, such as the possibility of local air cleaning and supplying cooler and cleaner air in conjunction with the DV, suggest using the DPV instead of traditional ceiling, standing or desk fans. The DPV with a proper design i.e. low pressure drop in the system and thus low fan energy use may be applied to achieve energy savings.

According to Hoyt et al. (2009) both increasing the cooling set point and lowering the minimum supply air flow may bring significant energy savings. The savings were estimated to be 35–45% when indoor air temperature increased from 24 °C to 28 °C depending on location (San Francisco, Miami or Phoenix, USA). Additionally, if cooling set point was expanded to 28 °C then lowering the minimum supply volume, i.e. reducing the minimum supply air volume of the VAV terminal units from the base value of 30% to 10%, reduced energy use up to 60%. However, these energy saving strategies, i.e. increasing room air temperature and lowering supply air flow, may negatively affect occupants' thermal comfort and deteriorate indoor air quality. Human response to DPV coupled with displacement ventilation at elevated room air temperature is described in Dalewski et al. (2012). The results of the present short-exposure study showed significant improvements of PAQ, mainly air freshness, when the local cleaning of the personalized air is used. The improvement effect observed in this study may be even higher when more efficient filters are used. The implementation of the DPV in practice may be efficient for decrease the risk of airborne transmission of infectious agents. Presently used room air cleaning technologies (e.g. floor standing air cleaners) are inefficient because even if they are able to disinfect the air, the treated air is supplied back to the room and mixed with the room which might be polluted with viruses and bacteria generated due to respiration activities of sick occupants. The use of DPV with air cleaning will ensure occupants to breathe much cleaner and disinfected air.

DPV with local air cleaning may become highly desirable when energy saving measures will be applied. However the possibility of energy savings while using DPV needs to be studied in details, as well as long-term human subject experiments are recommended to investigate its positive health impact.

5 CONCLUSIONS

The activated carbon filter at the intake of the DPV system improved the PAQ, odour intensity and air freshness. However study of its impact on SBS symptoms with longer exposure time may be needed.

The use of DPV equipped with appropriate air cleaning filter(s) may be used with total volume background ventilation (displacement, mixing and natural ventilation) at reduced supply of outdoor air. This strategy may lead to energy savings and needs to be studied.

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