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Inhaled air quality with desk incorporated personalized ventilation (PV): parametric study

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SUMMARY
A workstation consisting of a desk with installed personalized ventilation (PV) and a dressed breathing thermal manikin simulating seated occupant was set in a full-scale test room. The room was conditioned by overhead ventilation at 26 °C. The PV consisted of two confluent jets incorporated along the front edge of the desk and supplying clean personalized air vertically towards the face of the manikin. The inner jet (closest to the body) delivered always clean outdoor air and the outer jet provided room air mixed with tracer gas (R134a) at the same flow rate as the inner jet. The breathing thermal manikin was seated with abdomen pressed against the table edge. The amount of clean air inhaled by the manikin was measured under numerous experiments studying different combinations of personalized airflow rates (isothermal) - 2, 4, 6, 8 and 10 L/s, widths of the two jets - 0.03 and 0.06 m, posture of the manikin - seated with the abdomen pressed against the table edge, moved backwards from or leaned over the table. The best performance was achieved with the 0.06 m openings: 85% of PV air was inhaled by the occupant at 10 L/s. The portion of clean PV air inhaled by the manikin was 80% when it was bent over the table, 76% when the manikin was seated upright and 45% when the manikin was moved backwards.

KEYWORDS
Personalized ventilation, control, confluent jets, air quality, body posture

INTRODUCTION
The air quality performance of personalized ventilation (PV) depends on many factors such as PV supply geometry, distance from occupant, temperature difference of PV air with surroundings, direction of supplying the PV jet, etc. (Melikov 2004). In most cases the PV units discharge the clean air close to the face from circular supply openings to benefit from the longer initial region of the circular free jet. In several reported studies (Kaczmarczyk et al. 2004, Bolashikov et al. 2003, Khalifa et al. 2009) the PV flow was supplied normal to the face. However the air quality performance of such PV will depend on the initial diameter of the air terminal device. A larger diameter will cover better the face and will be less sensitive to the natural body movements that are routine in typical office work, i.e. leaning forth and back, etc. However, increasing the supply opening will increase the amount of supply air needed in order to achieve a target velocity exceeding 0.2 m/s, which is needed for penetration of the free convection flow surrounding the human body at the facial region and for providing clean air in inhalation (Melikov 2004). Another option is to adjust manually or by sensor tracking the PV unit to the head of the occupant. However this strategy has certain drawbacks as it either requires occupant's participation and distracts him/her (manual control) or involves additional energy consumption (automated adjustment). Plane jets supplying the PV air from the table edge upward towards the breathing zone of the occupant can be less sensitive to routine movement of people: the length of the PV opening can be designed to be broad enough to compensate for those typical movements. The air quality performance of such vertical PV units has already been studied (Melikov et al., 2002). Bolashikov et al. (2009) managed to improve the air quality performance of the vertical PV jet by introducing control

over the flow interaction between the PV jet and the free convection. The PV slot was installed in a retractable board in direct contact with the abdomen of the occupant. In this way the convection flow was “cut off” and substituted by the vertically discharged PV flow. To avoid mixing with the room air on the “outer” side of the PV jet, a second jet of recirculated room air was discharged with the same or different initial velocity, forming a PV system named confluent PV jet unit. This prevents the PV air to entrain polluted room air and to keep it unmixed for a longer distance upstream. The application of confluent jets as PV improved the performance of the vertical PV jet by 25% at twice lowered flow. However the impact of the supply opening width as well as the effect of the occupant posture on the air quality performance of the confluent PV jet (vertical PV jet) design has not been studied yet. This was in the focus of the study presented in the present paper.

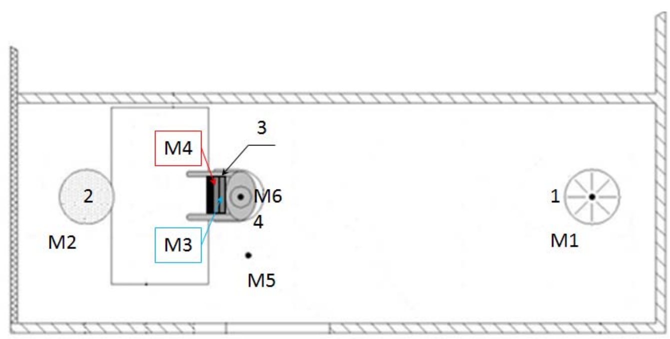
MATERIALS/METHODS

The experiments were performed in a full-scale test room with dimensions 4.70 m × 2.40 m × 2.60 m (W×L×H). A workplace consisting of a desk with confluent jet device for PV, a light office chair (0.1 Clo) and a seated thermal manikin (0.5 Clo) was simulated in the room. Three fixtures (6 W each) located in the ceiling provided the background lighting. The room itself was built in a laboratory hall, 70 cm above the floor. The walls of the test room were made of particleboard and were insulated by 6 cm thick styrofoam. One of the walls was made from single thick layer glazing. Mixing type ventilation was used to condition the air in the test room to 26 ^{o}C supplied 100% clean air (no recirculation) with an air change rate of 2.2 h^{-1}. This flow rate provided good mixing in the room at low velocity (below 0.2 m/s within the occupied zone). A rotation type air supply diffuser and a perforated circular air exhaust diffuser were installed on the ceiling. Air humidity was not controlled but was measured as being relatively constant (30% - 35%).

The air terminal device of the personalized ventilation, generating the two confluent jets, consisted of two plenum boxes nested in each other and placed below the desk top. The two boxes had discharge slots (60 mm x 500 mm, width x length) attached with no distance between and pressed firmly against the abdominal area of the thermal manikin. Each box had a separate supply fan to drive the air trough the boxis. The jet closer to the manikin supplied always clean PV air (inner jet) while the outer jet (close to table board rim) discharged room air. The fan of the outer jet that was used to drive room air was placed in the tes-room at the opposite corner relative to the manikin at a distance of more than 2.5 m (along the width of the room).The temperature of the personalized air was maintained constant to the set value of 26 ^{o}C (same as that of the room) by an electrical heater installed in the PV supply system and a temperature sensor placed in the ducting before the PV supply box (inner jet). The temperuture of the outer jet was not controlled but was measured to be on average 0.5 ^{o}C higher than the room air temperature (due to the heat generated by the fan motor).

Tracer gas, Freon R134a, supplied at constant dose in the duct of the background ventilation system before the ceiling diffuser, was used to simulate polluted room air. The personalized air supplied through the inner jet was free of tracer gas. The tracer gas sampling and its concentration measurement was performed at 6 points by a real-time gas monitor based on the photo-acoustic principle of measurement. The points were (Figure 1): supply (M1), exhaust (M2), inner confluent jet (M3), outer confluent jet (M4), in the center of the room (M5) and at the mouth of the manikin (M6). The point in the center of the room (M5) was used to assess whether or not good mixing was achieved in the room and was positioned at a height of 1.1 m above the floor. A tube attached at the upper lip of the manikin at a distance of 0.005 m from the face was used to sample air for measuring the tracer gas concentration in inhaled air as recommended by Melikov and Kaczmarczyk (2007). The airflow rates from the inner and outer jets were measured by two flow sensor based on pressure difference measured by a micro-manometer with an accuracy of 0.01 Pa ± 0.25% of reading. The required flow rate was adjusted by a pair of manually operated dampers installed in the two systems for the inner and outer jets respectively.

The inhaled air quality was assessed by the index known as Personal Exposure Effectiveness (PEE) introduced by Melikov et al. (2002). The PEE calculates the portion of clean personalized air in the air inhaled by an occupant and is given as; $PEE=(C_{I,0}-C_I)/(C_{I,0}-C_{PV})$ where $C_{I,0}$ is the pollution concentration if no PV, C_I is the pollution concentration in inhaled air and C_{PV} stands for pollution concentration in personalized air. PEE is equal to 1 (or 100%) when only clean personalized air is inhaled, i.e. best performance of the personalized ventilation. PEE equal to 0 (or 0%) means that the inhaled air is the polluted room air.



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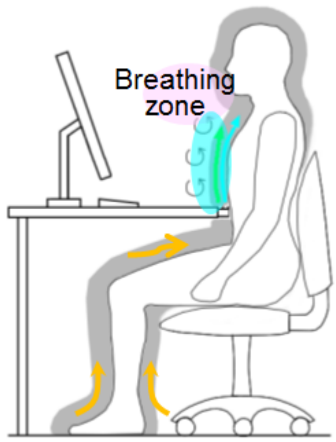

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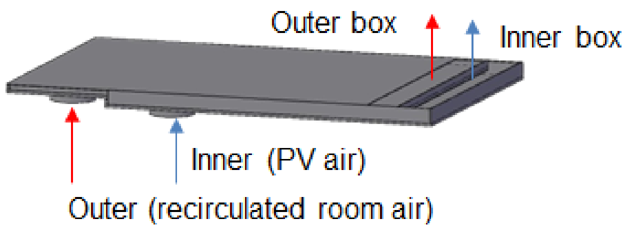


c)

Figure 1. Set-up of the experiment with the confluent PV jet box a) chamber set-up and b) application of confluent jets as a table incorporated PV unit, c) confluent PV jet design, 1) TV supply, 2) TV exhaust, 3) confluent PV jet design, 4) breathing thermal manikin.With M are shown the tracer gas measurement locations: M1 – supply, M2 – exhaust, M3 – inner jet, M4 – outer jet, M5 – room and M6 – manikin mouth.

RESULTS

The results for the air quality performance of the method of confluent jets with width either 0.03 m or 0.06 m as obtained at different supply flow rate are shown in Figure 2. Both boxes discharged same amount of air; the inner box supplied only clean PV air while the outer box operated with recirculated room air mixed with tracer gas R134a.

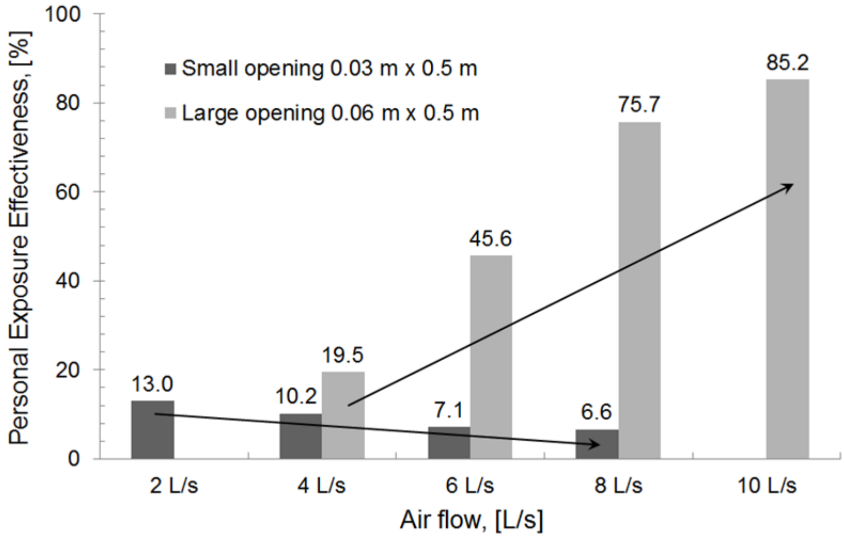
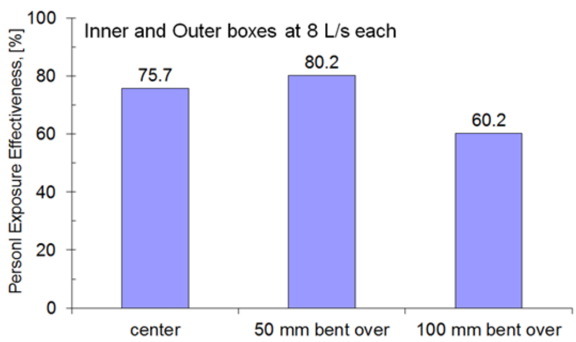


Figure 2. PEE as a function of flow rate. Both inner (PV air) and outer (room air) jets provide same amount of air

When the width of both openings was kept at 0.03 m almost no clean air ended into inhalation. The reason is that the initial (potential core) region of the jet, where it preserves its initial characteristics and the air is still clean and not mixed with the surroundings, is two times shorter compared to the case with 0.06 m width of supply opening. The distance from the box position to the mouth of the breathing thermal manikin was about 0.42 m. Therefore by the time it reaches the mouth the jet is completely mixed with the surrounding room air. A clear trend of reducing the PEE with increase of the supplied flow rate is observed. This is due to the fact that increased velocities promoted more mixing.

For the large opening of 0.6 m it can be clearly seen that the inhaled air quality improves with the increase of the supplied flow rate. Already at 8 L/s the PEE reaches a value of 76% and 85% at 10 L/s.



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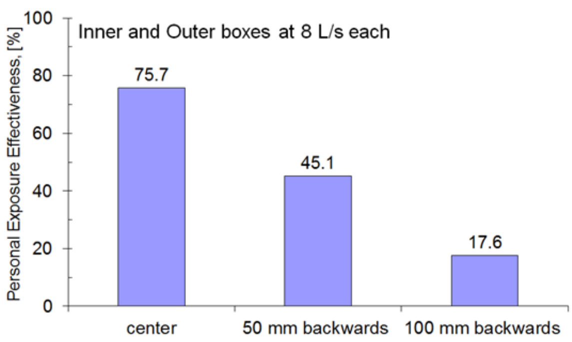

b)

Figure 3. PEE as a function of the positioning of the thermal breathing manikin a) when moving backwards from the table and b) when bending over the table when the width of both jets are at 0.06 m and both supply at 8 L/s.

Rarely does a person keep a fixed position when seating at a workstation in office. Usually people lean forth or move back from the table. The impact of body posture on the performance of the confluent jet PV was studied as well. The breathing thermal manikin was positioned backwards or forward (bending over the table to simulate writing or reading tasks).

The results obtained at 0.06 m width of the supply openings (for both inner and outer jets) and at the flow rate of 8 L/s for both slots are shown in Figure 3. When bending over the table initially the PEE keeps relatively constant values (approx. 80%) and decreases to 60% when the tip of the manikin's nose is moved 0.11 m relative to the edge of the table, Figure 3a. When tilting slightly the body over the table the angle formed by the jaws and the neck is not as acute as when the manikin is in horizontals direction and therefore it is much easier for the air to overcome the chin and end up in the breathing zone. As can be seen in Figure 3b when moving backwards the effect of the PV on the amount of clean air into inhalation is quickly diminishing and at 0.1m away from the table the PEE is already less than 20%.

DISCUSSION

The method of confluent jets not only assisted the convective layer but also replaced it by a clean PV air as the nozzle was incorporated in the board used as passive control over the convective layer. This managed to boost the amount of fresh air into inhalation up to 85% at 10 L/s compared to the vertical PV design suggested by Melikov et al. (2002): 60% of fresh air in inhalation at flow rates exceeding 20 L/s. The reason for the poorer performance of the design studied by Melikov et al. (2002) can be the gap between the nozzle and the breathing manikin's body allowing the upcoming boundary layer to dilute and mix more with the clean PV air. This was also confirmed by the present study when the manikin was moved backwards by 0.1 m from the confluent PV jet unit. In this case the amount of clean air into inhalation, i.e. PEE dropped to 17% at 8 L/s supply flow of clean PV air, Figure 3b.

The width of the opening was also found to be an important factor for the effectiveness of the unit in supplying clean air upward in front of the body into inhalation. The nozzle of width of 0.030 m was able to provide a maximum of 12% of clean PV air into inhalation and at 2 L/s (Chapter 4.3). At the higher flow rates the performance was even lower due to the enhanced mixing and the shorter length of the potential core region of the jet, the region with the initial characteristic of the jet. Regardless of the flow rate and the presence of confluent jet, the amount of clean air into inhalation never exceeded 85%. The reason for this was the pretty complicated geometry of the human body and the separation of the flow at the neck level.

The present results suggest that for PV flow supplied from below and with rectangular opening, the position of the occupant within the PV jet is quite an important factor to be considered. For the confluent PV jet unit the movement backwards (away) from it had the strongest negative impact and lowest PEE. Leaning forward (a typical posture for office work) can be beneficial and can enhance even further the performance of the confluent PV jet design.

CONCLUSIONS

The conclusions of this study are:

- The use of confluent jet (outer jet) of polluted air to protect the inner jet of clean air (both supplied at the lower chest) increased PEE up to 85% compared to the single jet application (PEE=60%).

- The initial width of the outer and inner jets had effect on the performance of the PV. Better performance was achieved with the wider opening;

- The posture of the manikin had effect on the amount of clean air into inhalation provided by the confluent jets. For the same amount of PV air supply better results were achieved (PEE = 80%) when bent over the table compared to the case when the manikin was seated upright (PEE = 76%) Moving manikin backward from the table resulted in very low air quality performance of the PV: PEE dropped to 17%.

ACKNOWLEDGEMENT

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