DTU Library

Airflow characteristics in the breathing zone of a seated person using desk incorporated pair of confluent jets as personalized ventilation - effect of supply velocities

Bolashikov, Zhecho Dimitrov; Nagano, Hideaki; Melikov, Arsen Krikor; Velte, Clara Marika; Meyer, Knud Erik

Publication date:
2012

Document Version
Peer reviewed version

Airflow characteristics in the breathing zone of a seated person using desk incorporated pair of confluent jets as personalized ventilation - effect of supply velocities

Zhecho Bolashikov[1], Hideaki Nagano[2], Arsen Melikov[1], Clara Velte[3] and Knud Erik Meyer[4]

[1] Technical University of Denmark, Civil Engineering Department, International Centre for Indoor Environment and Energy (ICIEE)
[2] Tokyo City University of Japan, Department of Mechanical Systems Engineering, Faculty of Engineering
[3] Technical University of Denmark, Department of Wind Energy
[4] Technical University of Denmark, Mechanical Engineering Department

SUMMARY
A workplace with desk, desk incorporated personalized ventilation (PV) and a dressed thermal manikin with realistic body and surface temperature distribution were set in a test room (4.70 m x 1.62 m x 2.6 m). 15 L/s were supplied from a ceiling diffuser to ventilate the room at 26 ^{o}C air temperature. The PV consisted of two plane jets placed beside each other (confluent jets) and along the front edge of the desk. The slots had dimensions: 0.06 m x 0.5 m (W x L). The manikin was seated upright with abdomen pressed against the front edge of the desk. The airflow supplied isothermally and upwards from the inner jet (closest to manikin) was the same, twice bigger or twice lower compared to that of the outer jet. The mean velocity field at the breathing zone was measured by Particle Image Velocimetry: a dual cavity laser (λ = 532 nm) and a CCD camera - 35 mm lenses. Glycerol droplets (seeding) were added to the total volume air supply. The maximum absolute mean velocity measured near the manikin's mouth was 0.25 m/s, when the two confluent jets supplied 8 L/s each. Same velocity was measured when the inner jet was supplying 8 L/s and the outer 4 L/s. The opposite combination, i.e. outer jet 8 L/s and inner 4 L/s, resulted in lower velocity (0.13 m/s) compared to that of the free convection layer alone: 0.20 m/s. The increased velocity at the face allowed more clean air to be inhaled.

KEYWORDS
Personalized ventilation, control, confluent jets, free convection, PIV

INTRODUCTION
Personalized ventilation (PV) supplies the clean conditioned air directly into the breathing zone, of each individual. It has been shown to improve perceived air quality and health (reduce sick building syndrome symptoms complaints), and even greatly diminish the risk of spread of cross infections transferred via the airborne route (Melikov 2004, Kaczmarczyk et al., 2006, Cermak and Melikov 2007). The PV designs reported in the literature are either furniture incorporated (attached to the table or the chair of the occupant) or designed to be used as wearable PV units (microphone incorporated headset PV). In these applications the supplied personalised flow is normal to the free convection flow formed around the human body or parallel to it. Velocities around 0.2 m/s are documented a few centimetres from the face region of a seated occupant within the breathing zone (Bolashikov et al. 2011). Therefore quite elevated air flow rates (exceeding 6 L/s/person) are needed so that the transverse PV jet penetrates the free convection "barrier". To achieve 100% clean PV air into inhalation over 10 L/s/person is needed. Supplying the clean PV air from the edge of a table upward towards the breathing zone of a seated occupant (assisting flows) can offer a plausible solution: the natural convection will "bring" the clean PV air on its way up directly into the mouth. However a study performed by Melikov et al. (2002) reported that the performance of such jets is limited

to a maximum of 60% clean air in the air inhaled at supply PV flow rates above 15 L/s. The vertically issued PV jet mixed intensively with the room air and was brought to the breathing zone already polluted. 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, Bolashikov et al. (2009) discharged a second jet of recirculated room air with the same or different initial velocity, forming a system of confluent jets. 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 resulted in nearly 80 % clean air into inhalation at almost twice lowered PV supply air. In order to improve the performance of the confluent PV jet design and understand the flow development at the breathing zone detailed study on the flow interaction is needed.

The characteristics and flow interaction at the face of a seated occupant using confluent jets as PV examined by using Particle Image Velocimetry (PIV) technique are reported in this paper.

MATERIALS/METHODS

The experiment was designed and performed in a full-scale test room with dimensions 4.70 m × 1.62 m × 2.60 m (W×L×H). Three ceiling-mounted light fixtures (6 W each) provided the background lighting. The test room itself was built in a laboratory hall, 0.7 m above the floor with a separate ventilation system. Mixing ventilation (MV) was used to condition the air in the test room. The air supply diffuser (a rotation diffuser) and the air exhaust diffuser (a perforated circular diffuser) were installed on the ceiling (Figure 1a). The supplied air was 100% outdoor (no recirculation was used) with a flow rate of 15 L/s. The air temperature in the test room and in the surroundings was kept at 26 ^{o}C. A workplace consisting of a desk with a seated breathing thermal manikin, an ordinary light office chair and personalized ventilation device were placed in the test room (Figure 1). A thermal manikin with body shape and size of an average Scandinavian woman 1.7 m in height was used to resemble a seated occupant. The surface temperature of the thermal manikin was controlled to be the same as that of an average person in a state of thermal comfort at light sedentary activity to recreate realistically the convective boundary layer surrounding the body.

The PV air terminal device consisted of two plenum boxes (referred to as "inner" and "outer" boxes in the text) nested in each other and placed below the desk top (Figure 1c). Each box has a discharge slot of rectangular shape (plane jet) with dimensions 0.5 m × 0.06 m (L ×W). The distance between the two slots was 0.004 m (thickness of the box material). The PV design was pressed firmly against the abdomen area of the thermal manikin (Figure 1d). Room air was supplied from the two boxes. When the box with the confluent jets was not installed the manikin was positioned 0.12 m backwards from the edge of the table (equal to the width of the two slots of the confluent PV jet box).

The used PIV equipment comprised a double cavity New Wave Solo 120XT Nd-YAG laser (wavelength 532 nm), capable of delivering light pulses of 120mJ. The light pulses emitted were 60% of the maximal power. The duration of each illumination pulse, was 10 ns. The light sheet thickness at the measurement position was 2 mm. The laser sheet generated was within the plane bisecting the body in two symmetric halves. One Dantec Dynamics Hi Sense MkII CCD camera (1344×1024 pixels) equipped with 35 mm lens and filter that only pass light with wavelengths close to that of the laser light was placed on one side of the light sheet (Figure 1b). The f-numbers (the focal length divided by the "effective" aperture diameter) were set to values between 4 and 5.6 to reduce the light budget of the particle scattering and reflections from the face of the breathing thermal manikin. A particle generator was used to produce the seeding with a diameter of 2-3 μm from a homogeneous mixture of water and pure glycerol in volume parts of 7 to 3. The particles were continuously injected before the TV supply plenum box in order to obtain a homogeneous distribution of the tracers within the measurement chamber without significantly disturbing the flow pattern inside. The images were processed using DynamicStudio © software version 2.3. For each measurement position 1000 realizations were acquired. Unwanted reflections were suppressed by applying a paper tape strip along the reflecting surfaces painted with a mixture of Rhodamine 6G (a fluorescent dye, re-emits the laser light with slightly shifted the wavelength) and black non-shiny paint.

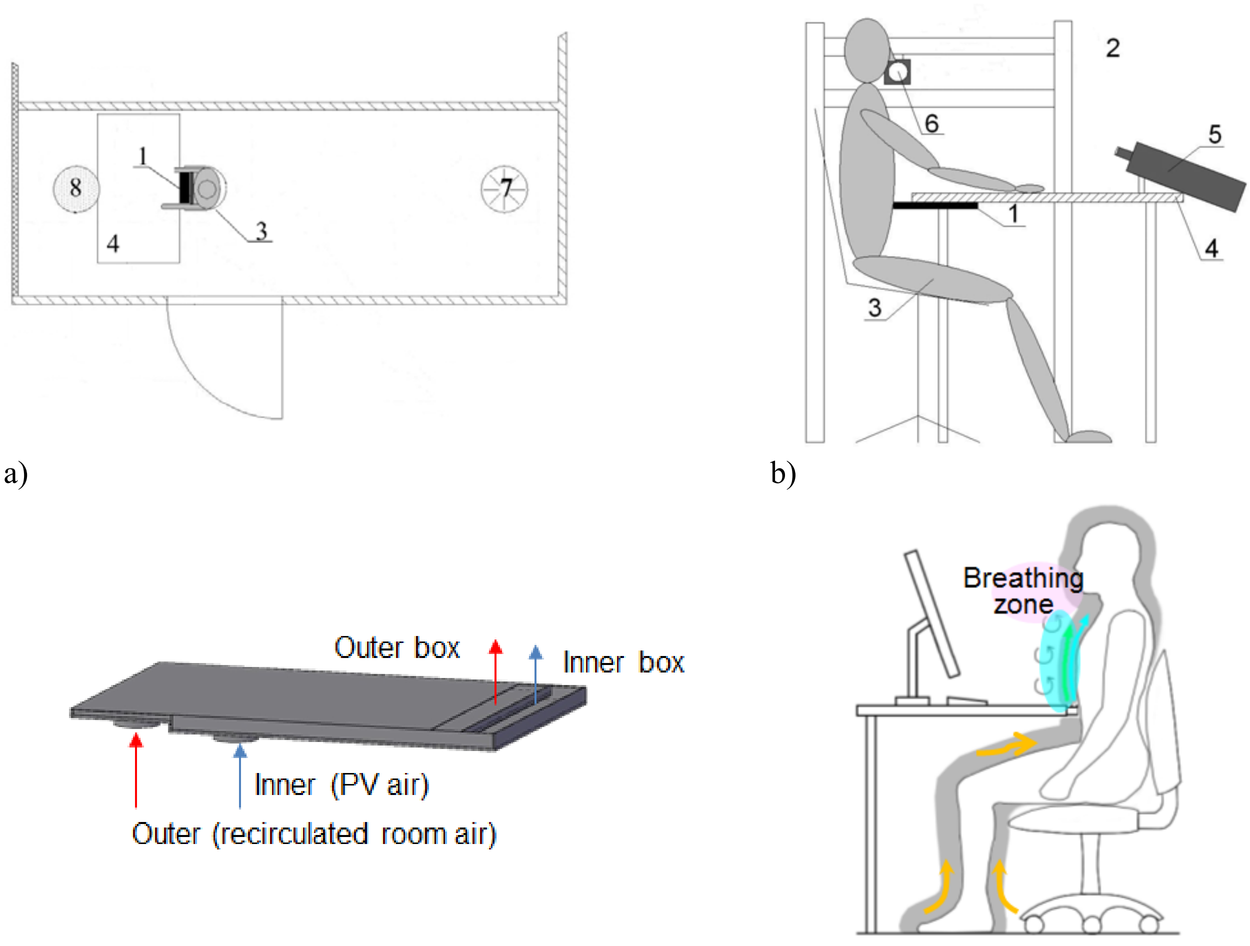

Figure 1. PIV set-up of the experiment with the confluent PV jet box a) chamber set-up and b) closer side view. 1) PV box with confluent jets, 2) stand, 3) thermal manikin, 4) table, 5) laser generator, 6) CCD cameras, 7) TV supply, 8) TV exhaust c) confluent PV jet design, d) application of confluent jets as a table incorporated PV unit.

Measurements at numerous combinations of the flow rate supplied by the confluent jets were performed. In the present paper the cases when the air flow supplied by the inner jet was equal to, two times larger or was half of that provided by the outer jet are reported (Table 1).

Table 1. Reported cases.

Case	Outer jet [L/s]	Inner jet [L/s]	PV Box
Case 1 – Figure 2a	N.A.	N.A.	removed
Case 2 – Figure 2b	0	0	installed
Case 3 – Figure 2c	8	8	installed
Case 4 – Figure 2d	8	4	installed
Case 5 – Figure 2e	4	8	installed

RESULTS

The results from the PIV measurements are presented in Figure 2 in the form of vector (direction) and contour (magnitude) plots of the averaged velocity within the x-y plane normal to the face and bisecting the manikin. The mean velocity magnitude within the x-y plane is given as:

$$\overline{v} = \sqrt{\overline{v_x}^2 + \overline{v_y}^2},$$

where $\overline{v}$, stands for mean velocity magnitude within x-y plane; $\overline{v_x}$, is the component of the mean velocity along the x axis; $\overline{v_y}$, is the component of the mean velocity along the y axis.

The placement of the confluent PV jet box tightly to the abdomen of the thermal manikin weakened the boundary layer in front of the face of the manikin compared to the case when the manikin was sitting 0.12 m away from the table (Figure 2a, 2b). The highest absolute velocity, when the PV unit was not installed, was measured across the mouth of the seated manikin and was around 0.18 m/s. The use of the PV unit to close the air gap between the manikin's body and the table decreased the maximum absolute mean velocity down to 0.11 m/s, or by 39% (Figure 2a, 2b).

The effect of different supply velocities for the outer (recirculated room air) and inner (clean PV air) jets on the resultant flow velocity distribution at the face of the seated occupant, is shown on Figures 2c, 2d and 2e. The highest absolute mean velocities were measured when the two slots discharged air at 8 L/s. Near the breathing zone velocities as high as 0.24 m/s were registered. When the inner jet supplied twice as less air (4 L/s) as the outer jet (8 L/s), the maximum mean absolute velocity dropped below 0.16 m/s within the breathing zone. In this case, the measured mean absolute velocity close to the face increased with height (from abdomen to face), as result of the flow interaction: due to the difference of the initial jet velocity the turbulence increased and thus the mixing between the two confluent flows. The outer jet due to its twice higher initial velocity pushed the inner jet closer to the face. In the opposite case, i.e. when the inner jet was supplying 8 L/s and outer 4 L/s, the maximum values of the mean absolute velocities measured within the breathing zone were around 0.24 m/s. They were comparable to the case when both slots discharged air at 8 L/s. In all cases, when the confluent PV jet unit was supplying air, part of the clean PV air discharged from the inner jet was deflected by the chin and the mandible passed the shoulders and moved away from the head of the seated person.

When studying the flow characteristics at the face of an occupant, breathing and its interaction with the PV flow and the boundary layer around the occupant's body need to be considered as well. This however remains to be further investigated when used with the reported here confluent PV jet unit.

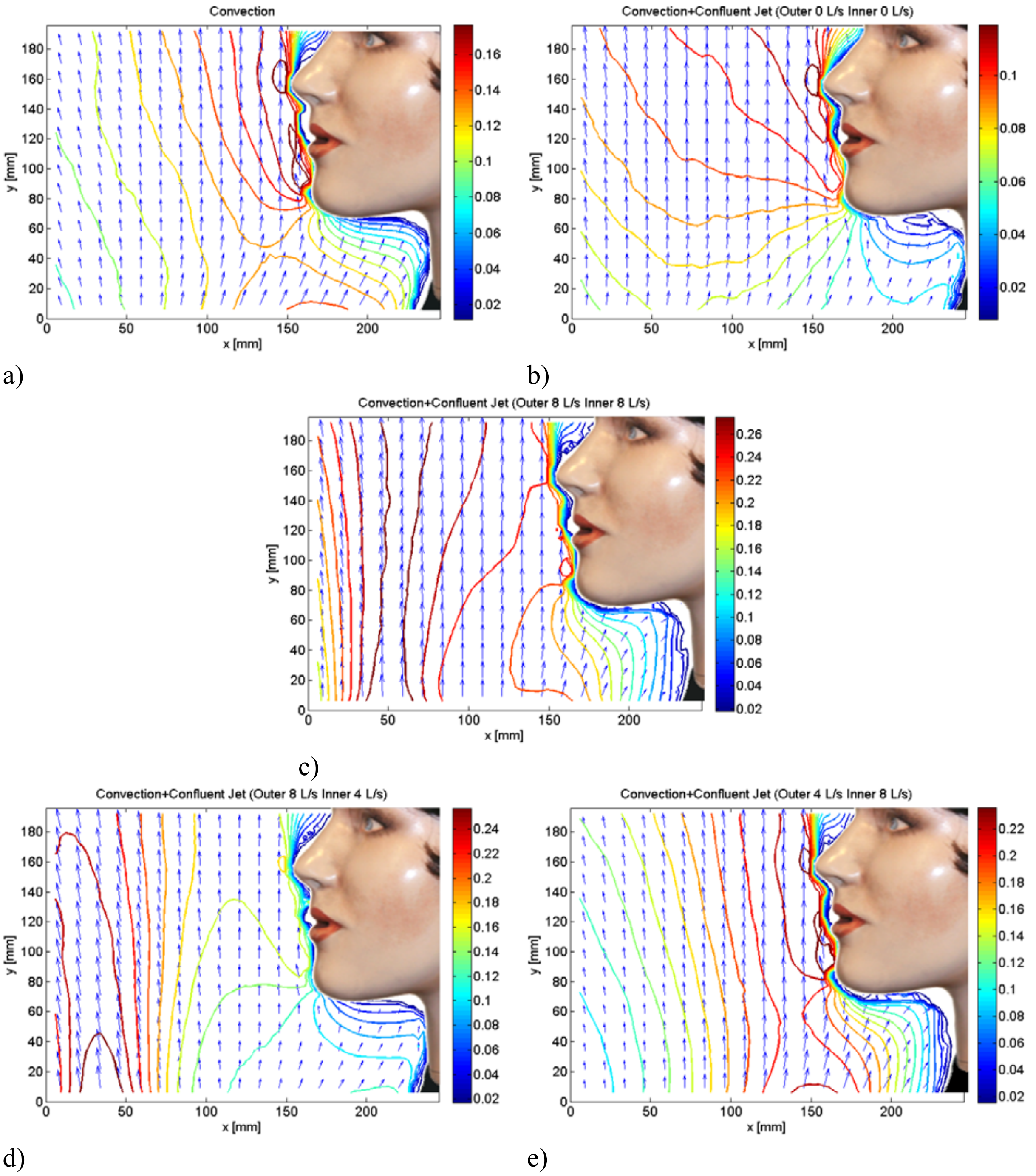

Figure 2 Vector and contour plots of velocity field in the x, y plane bisecting the manikin measured with the PIV when a) there was 0.12 m air gap between the manikin and the table, b) the confluent PV jet design was installed but not operational (used as an obstacle), c) both slots supplied 8 L/s upwards, d) the outer slot supplied 8 L/s and the inner slot (closer to body) supplied 4 L/s, e) the outer slot supplied 4 L/s and the inner slot (closer to body) supplied 8 L/s.

DISCUSSION

The results from the current study suggest that the supply velocity of the inner and outer jet is an important factor to be considered in the confluent PV jet design. In an air quality performance study of the confluent PV jet unit with a thermal manikin Bolashikov et al. (2009) studied the impact of the initial velocity of the two jets on the amount of clean PV air inhaled by a seated occupant. They found out that the confluent PV performed worse when the inner slot (clean PV air) supplied twice as low flow as the outer (recirculated room air), at

4 L/s and 8 L/s respectively, i.e. 33% clean air into inhalation. The reason, explained by the present measurements, is the shorter length of the initial region of the inner clean jet and the extensive mixing between the two flows. However almost no difference was found when the inner jet supplied twice as much as the outer jet, 8 L/s and 4 L/s respectively, compared to the case when both slots discharged the same amount of 8 L/s, i.e. 74% and 76%. In both cases the velocities close to face were similar. Thus having the outer jet supplying recirculated room air at initial velocity lower than that of the inner jet is recommended because of reduced energy consumption. Due to its close contact with the body the PV unit may also improve the thermal semsation of the occupants and allow for higher background air temperatures and thus realise additional energy savings. However this needs to be further studied.

The use of increased flow rates may result in eye discomfort (sensation of dryness) and enhanced blinking. This however needs to be further studied in a set of human subject experiments.

CONCLUSIONS

Based on the performed measurements the following conclusions can be made:

- Blocking the free convection flow by a physical barrier at the lower abdomen region in front of a seated person can reduce almost twice the velocity within the boundary layer at face region, i.e. from 0.20 m/s to 0.10 m/s;
- Similar maximum mean velocity was measured within the breathing zone of the occupant when the initial velocity of the outer jet was the same (at 8 L/s) or twice lower (at 4 L/s) than the inner jet (at 8 L/s);
- The inner jet velocity exhibits positive trend with the air quality performance of the confluent PV jet design: increasing the velocity lead to more clean air into inhalation.

ACKNOWLEDGEMENT

This research was supported by the Danish Agency for Science Technology and Innovation. Project No. 09-064627.

REFERENCES

Bolashikov Z. D., Nagano H., Melikov A. K., Meyer K. E. and Kato S., 2009, Control of the Free Convection Flow within the Breathing Zone by Confluent Jets for Improved Performance of Personalized Ventilation: Part 2 – Inhaled Air Quality, Proceedings of Healthy building 2009, Syracuse. NY. USA. September 13 to 17, 2009.

Bolashikov Z.D., Melikov A.K., Velte C. Meyer K.E., 2011, Airflow characteristics at the breathing zone of a seated person: interaction of the free convection flow and an assisting locally supplied flow from below for personalized ventilation application, Roomvent 2011, Norway, Trondheim, Paper ID: 272.

Cermak R.. Melikov. A.K.. 2007. Protection of occupants from exhaled infectious agents and floor material emissions in rooms with personalized and underfloor ventilation. HVAC&R Research. 13(1). pp. 23-38.

Kaczmarczyk J., Melikov A.K., Bolashikov Z., Nikolaev L. and Fanger P.O., 2006, Human response to five designs of personalized ventilation, International Journal of Heating, Ventilation and Refrigeration Research 12 (2), pp.367-384.

Melikov A.K., Cermak R. and Majer M., 2002, Personalized ventilation: evaluation of different air terminal devices, Energy and Buildings 34 (2002), pp. 829–836.

Melikov A.K., 2004, Personalized ventilation, *Indoor Air* 14 (7), pp. 157-167.Engineering, Fanger P.O. 1970. *Thermal Comfort*. Copenhagen: Danish Technical Press.