Experimental investigation of occupants’ thermal sensation under a personalized ventilation system

P Ebrahimi Naghani1, S A Zolfaghari2, M Maerefat3, J Toftum4, S M Hooshmand1 and M Izadi5

1 Ph.D. candidate, University of Birjand, Birjand, Iran
2 Associate professor, University of Birjand, Birjand, Iran
3 Professor, Tarbiat Modares University, Tehran, Iran
4 Professor, Technical University of Denmark, Kgs. Lyngby, Denmark
5 M.Sc., University of Birjand, Birjand, Iran

E-mail: ebrahimi.naghani@birjand.ac.ir
zolfaghari@birjand.ac.ir
maerefat@modares.ac.ir
jt@byg.dtu.dk
hooshmand@birjand.ac.ir
mostafaizadi@birjand.ac.ir

Abstract. By considering the importance of providing proper indoor environment conditions for occupants and also due to energy costs, one of the solutions for indoor local air-conditioning is Personalized Ventilation System (PVS). In this paper, the occupants’ thermal sensation was experimentally studied for body segments that are mostly affected by the PVS. The local sensation of head, chest, arm, and hand at two supply air temperatures of 16 and 32°C were investigated. Eight volunteer subjects participated in this survey. The subjects reported the most thermal satisfaction on their hands. Also, the arms were the segments with the coolest thermal sensation (-1.28, between slightly cool and cold). Results indicate that the head’s thermal sensation at both supply air temperatures was neutral and the hand was the only body part that experienced warm thermal sensation during the test. Also, by increasing the supply air temperature to 32°C whole body thermal sensation changed from -0.46 to -0.09 on the seven-point scale, which means that the cooling system worked properly for occupants’ cooling. In this system, cooling occurred at 32°C instead of the common 16°C supply air temperature, which results in energy-saving and decreases annual running costs.

1. Introduction
The personalized Ventilation system is an air distribution system that provides conditioned, fresh and clean air with the ability to control air temperature and direction to the breathing zone [1]. Measurements at the breathing zone were made with the PVS [2] and different types of PVS were analyzed [3].

Kaczmareyk et al. [4] perceived air quality and thermal comfort of 60 human subjects using PVS and mixing ventilation. They reported in higher temperatures, PVS provided local cooling that resulted in a whole body thermal sensation close to neutral in comparison with mixing ventilation. Gao and Niu [5] evaluated the performance of personalized ventilation system with different air temperatures and air humidities. They reported that the PV air supply temperature specifies the intensity of the jet.
flow and that relatively lower supply temperature brings the benefits of reduced pollutant exposure and better perceived air quality. In another research Gao and Niu [6] studied micro-environment around the human body and personalized ventilation using CFD. The study showed that PVS only increases the convective heat transfer from the face to the surrounding environment while it has little impact on the heat loss of the overall human body. Pan et al. [7] concluded that the personal ventilation system might have lower energy consumption than the central air-conditioning system. Conceição et al. [8] numerically investigated the air quality, thermal comfort, and draft risk for a virtual classroom with 6 and 12 persons with a desk-type personalized ventilation system. The results showed that air distribution index, which is a function of the thermal comfort and the air quality, was higher with twelve persons than with six persons in the classroom. Muhic and Butala [9] reported that PVS in contrast to a central system can shorten the operation time for the same level of thermal comfort and save up to 45% of the energy consumed by the central system. Melikov [10] analyzed the airflow interaction with the human body and its impact on thermal comfort and reported that personalized ventilation could improve the occupants’ thermal comfort conditions. Zolfaghari et al. [11] experimentally investigated the effects of air movement on thermal sensation of office workers under two different arrangements for UFAD system as the PVS. Ebrahimi Naghani et al. [12] based on experiments with desk-type personalized ventilation system reported that variations in some clothing garments in clothing ensembles with the same thermal insulation could affect the overall thermal sensation.

In the present study, the occupants’ transient thermal sensation was investigated in an office environment with a desktop personalized ventilation system

2. Research method

The measurements were carried out in a climate chamber with dimensions of 3m×3m and 2.7m height (‘figure 1’). The climate chamber was located inside another indoor space. The climate chamber can be controlled in terms of temperature, relative humidity, and air velocity. The temperature in the climate chamber was controlled in the range of 24±0.5°C. Also, the and relative humidity was controlled in the range of 25±0.2%. The discharge flow rate from each desktop diffuser was about 10 lit/s. In the chamber, there was an office chair, table, a personal computer, and TESTO 480 data logger (‘Figure 2’). The experiment was carried out at the University of Birjand.

![Figure 1. Experimental climate chamber.](image1)

![Figure 2. Subject during the test.](image2)

In order to experimentally investigate the PVS thermal comfort conditions, eight students took part in this study. All the subjects were volunteer male students of the University of Birjand. They were asked not to eat within 2 hours before the test, and they were prohibited from heavy activity. Also, subjects did not use any medicine within 12 hours before the experiment. The subjects wore a long-
sleeved shirt, thick straight trousers, calf-length socks, underwear T-shirt, men’s briefs, and shoes (about 0.6 clo). The average BMI of the subjects was 23 kg/m², and their mean height was 174.8 cm. Also, the average age of the subjects was 22.7 years, and their average weight was 68.3 kg.

3. Experimental procedure
Two air terminal devices were located on the desk in front of the subject. In this study, the inlet diffusers with two different supply air temperatures of 16°C and 32°C were investigated. Local thermal sensation changes due to this supply air temperature difference will help to identify sensitive body parts. Subjects stayed in the preparation room for 20 minutes and then 10 minutes in the climate chamber at 24°C and relative humidity of 25% before the actual test began. During the test, the subjects were asked to fill in a questionnaire after 5, 15, 25 and 30 minutes from the beginning of the test. The test took 30 minutes, and the subject carried out sedentary office activities such as writing or internet surfing (1.2 met). The geometry of the inlet terminal device is shown in ‘Figure 3’.

Figure 3. The inlet terminal device.

4. Result and discussion
In this paper, the thermal sensation of four sensitive parts of the body (hand, head, arm, and chest) affected by the inlet air diffusers at 16 and 32°C inlet temperature was investigated. The scale used for this study is the scale recommended by ASHRAE handbook of fundamental [13], which is shown in table 1.

| Thermal sensation    | Numerical value |
|----------------------|-----------------|
| Very hot             | 4               |
| Hot                  | 3               |
| Warm                 | 2               |
| Slightly warm        | 1               |
| Neutral              | 0               |
| Slightly cool        | -1              |
| Cool                 | -2              |
| Cold                 | -3              |
| Very cold            | -4              |

Table 1. Thermal sensation scale.
The mean thermal sensation of the subjects’ body parts is shown in ‘Figure 4’. At the supply air temperature 16°C the arm had the lowest thermal sensation between the body segments and made the subjects feel cold. The thermal sensation of the hand was closer to neutral than the other segments. By increasing the supply air temperature to 32°C, the thermal sensation for all the body segments got closer to neutral.

![Figure 4. Thermal sensation of the body parts.](image)

‘Figures 5 to 9’ show the variation of thermal sensation with time for each segment and whole body. Because of the subjects' preparation, thermal sensation started at zero in all cases. ‘Figure 5’ shows the whole body thermal sensation during the test. ‘Figure 5’ shows that at an inlet air temperature of 16 °C, the whole body thermal sensation decreased and reached -0.46 unit of thermal sensation at the end of the test. By increasing the inlet air temperature from 16 to 32°C, the whole body thermal sensation got closer to neutral, and at the end of the test, it reached -0.09 unit of thermal sensation. Also, no significant change in thermal sensation from the beginning is observed.

![Figure 5. Thermal sensation of the whole body during the test.](image)

‘Figure 6’ shows that the hand’s thermal sensation, especially at the end of the test, was very similar to that of the whole body (‘figure 5’). This was the only case that one of the body segments’ thermal sensation was partially in the warm zone of the thermal sensation scale and it occurred at an inlet air temperature 32°C as expected.
As shown in ‘figure 7’, due to the distance between the head and inlet diffusers, this body segment did not affect by the inlet air. The head thermal sensation in both inlet temperatures was close to neutral.

‘Figure 8’ shows the variation of the thermal sensation with respect to time for the arm. The arm is one of the segments that was affected directly by the inlet diffusers. Also, compared with the hand this body segment was not without clothing most of the time, so when it affected by airflow, especially in low temperature, the thermal sensation will decrease. By increasing the supply air temperature, the thermal sensation of the arm got closer to the neutral condition.

As shown in ‘figure 9’, the chest, like the arm, was affected directly by the airflow. After the test started, the chest thermal sensation decreased, especially in the inlet air temperature 16°C. Also, after 15 minutes, subjects reached steady-state condition at this temperature, and their thermal sensation did not change significantly.

This study was carried out using a personalized ventilation system as a cooling system. Results indicate that at a supply air temperature of 16°C some body segments such as arm and chest experienced -1.28 and -0.81 unit of thermal sensation, which showed that these body were clearly too cold. By increasing inlet air temperature to 32°C the whole body thermal sensation changed from -
0.46 to -0.09 units, which means that the cooling system worked properly and met the cooling need. Also, increasing the temperature of the inlet air of a cooling ventilation system is very important in terms of energy consumption and may result in energy-saving and a decrease in the annual running costs.

5. Conclusions
- Arm with -1.28 and -0.25 unit of thermal sensation for inlet air temperature 16 and 32°C had the lowest thermal sensation of all body segments.
- Head thermal sensation was close to neutral in both supply air temperatures.
- Because of the usual hand condition and its adaptation to regular exposure to airflow, it did not influence the perception as much as the arm and chest, and its thermal sensation did not decrease significantly.
- By increasing the supply air temperature from 16 to 32°C the thermal sensation of all segments increased with the amount shown below:
  - Hand: 0.38 unit of thermal sensation
  - Arm: 1.03 unit of thermal sensation
  - Head: 0.19 unit of thermal sensation
  - Chest: 0.62 unit of thermal sensation
  - Whole body: 0.37 unit of thermal sensation

So, arm and chest are the most sensitive body parts in this experiment. Knowing the sensitive body parts is important in designing personalized ventilation systems. The designer can design PVS based on sensitive body segments' thermal condition and reach proper local and overall thermal sensation and comfort. Also, using air at a higher temperature for cooling reduces the energy demand and costs in buildings.

In these systems, subjects' air preference could be an effective parameter. So, investigation of this parameter also could lead to helpful knowledge to improve PVS designing.

References
[1] Yang B, Sekhar C and Melikov A K 2010 Ceiling mounted personalized ventilation system in hot and humid climate Energy Build. 42 2304–2308
[2] Cermark R, Holsoe J, Mayer E and Melikov A K 2002 PIV measurements at the breathing zone with personalized ventilation 8th Int. Conf. Air Distrib. Room 349–352
[3] Melikov A K, Cermak R and Majer M 2002 Personalized ventilation: evaluation of different air terminal devices Energy Build. 34 829–836
[4] Kaczmarczyk J, Melikov A K and Fanger P O 2004 Human response to personalized ventilation and mixing ventilation Indoor Air 14 17–29
[5] Gao N and Niu J 2005 Modeling the performance of personalized ventilation under different conditions of room air and personalized air HVAC&R Res. 11 587–602
[6] Gao N and Niu J 2004 CFD study on micro-environment around human body and personalized ventilation Build. Environ. 39 795–805
[7] Pan C, Chiang H, Yen M and Wang C 2005 Thermal comfort and energy saving of a personalized PFCU air-conditioning system Energy Build. 37 443–449
[8] Conceição E Z E, Santiago C I M, Lúcio M M J R and Awbi H B 2018 Predicting the air quality, thermal comfort and draught risk for a virtual classroom with desk-type personalized ventilation systems Build. 8 35
[9] Muhić S and Butala V 2006 Effectiveness of personal ventilation system using relative decrease of tracer gas in the first minute parameter Energy Build. 38 534–542
[10] Melikov A K 2004 Improving comfort and health with personalized ventilation 9th Int. Conf. Air Distrib. Room
[11] Zolfaghari S A, Teymoori S, Hooshmand S M, Izadi M and Afzalian M 2019 Experimental investigation of the effects of air temperature on the air movement acceptability in an office
with UFAD system 18th Fluid Dyn. Conf.

[12] Ebrahimi Naghani P, Zolfaghari S A, Maerefat M, Toftum J and Hooshmand S M 2021 Experimental investigation of the effects of non-uniform clothing ensembles on the occupants’ thermal perceptions under a local ventilation system Int. J. Air-cond. Refrig.

[13] ASHRAE 2009 ASHRAE Handbook of Fundamentals (Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers)