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Human Response to Ductless Personalised Ventilation: Impact of Air Movement, Temperature and Cleanness on Eye Symptoms

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Abstract

The performance of ductless personalized ventilation (DPV) in conjunction with displacement ventilation (DV) was studied in relation to peoples' health, comfort and performance. This paper presents results on the impact of room air temperature, using of DPV and local air filtration on eye blink rate and tear film quality. In a test room with DV and six workstations 30 human subjects were exposed for four hours to each of the following 5 experimental conditions: 23 °C and DV only, 23 °C and DPV with air filter, 29 °C and DV only, 29 °C and DPV, and 29 °C and DPV with air filter. At warm environment facially applied individually controlled air movement of room air, with or without local filtering, did not have significant impact on eye blink frequency and tear film quality. The local air movement and air cleaning resulted in increased eye blinking frequency and improvement of tear film quality at 23 °C.

Keywords – ductless personalised ventilation, air temperature; air movement; eye blink frequency; eye tear film stability

1. Introduction

Increasing ventilation rate has a positive impact on perceived air quality, as well as on health and performance of occupants [1]. However, increasing the ventilation rate while using total volume ventilation methods leads to increased energy use and higher risk of draught discomfort. Personalized ventilation (PV) supplies air at each workstation, close to occupant's breathing zone thus achieving cleaner inhaled air [2]. Occupants are provided with control of airflow rate and direction in order to achieve preferred conditions. It has been documented that use of PV improves occupants' health, comfort and performance [3].

However, PV system requires additional ducting, which implies in additional cost, and limits the flexibility of room layout. To overcome these disadvantages, ductless personalized ventilation (DPV) system has been developed and its performance in conjunction with DV has been studied by physical measurements [4], [5], [6]. DPV device is installed at each desk and works as an independent unit: it sucks clean and cool air supplied by displacement diffuser over the floor and redistributes it to the occupant's breathing zone. This design allows for a better utilization of the displacement air without affecting the flexibility of the room layout. The elevated velocity combined with lower temperature of personalized flow, compared to the room air temperature, provides cooling of the head and the upper body, and thus can improve occupants' thermal comfort. The clean and cool air supplied by DPV has also the potential to improve perceived air quality and reduce the prevalence of Sick Building Syndrome (SBS) symptoms.

However, the use of DPV will lead to a highly non-uniform environment, possibly resulting in discomfort due to a local cooling of feet (by displacement flow) and head (by DPV). Human subject study revealed that when indoor air temperature was above the comfort range, the use of DPV improved significantly perceived air quality and thermal comfort [7]. Using an activated carbon filter incorporated into the DPV system resulted in lower odor intensity and higher air freshness reported by people in a polluted room at high indoor air temperature of 29 °C [8].

Few studies have been conducted on the effects of elevated air movement on eye symptoms and performance [9], [10]. The eyes can be expected to be more sensitive in case of personalized ventilation because of the exposure to elevated air movement. Recent study [11] has shown that an increase of the indoor air temperature and relative humidity from 23 °C and 40 % to 26 °C and 70 % or to 28 °C and 70 % decreased the blink frequency. At temperature of 26 °C and relative humidity of 70 % facially applied flow of polluted room air did not have significant impact on blink frequency in comparison to the condition without air movement. Both at 26 °C and 70 % RH and at 28 °C and 70 % RH the exposure to clean, cool and dry air (24 °C & 40 %) had little (not significant) impact on the eye blink frequency compared to the condition without air movement. It was suggested that the increase of the eye blink frequency due to decrease of temperature and relative humidity and the increase of the velocity was compensated by the decrease of the eye blink frequency due to increased cleanness of the air.

Another recent study [3] reported that in a warm environment (26 °C and 28 °C at 70 % relative humidity) the exposure to facially applied personalized flow of clean and cool air (23 °C and 40 % relative humidity) did not decrease the tear film quality, while increasing the room temperature and relative humidity of the room air (without personalized flow) from 23 °C and 40 % relative humidity to 26 °C and 28 °C at 70 % relative humidity significantly decreased tear film quality. The use of PV improved tear film stability compared to that in a warm environment without PV.

No significant impact on eyes discomfort was found at 26 °C and 70 % RH and at 28 °C and 70 % RH during exposure to clean, cool and dry personalized air (24 °C and 40 %) compared to the exposure to air in a room with mixing ventilation only [11]. No significant difference in eyes irritation between conditions with DPV coupled with DV and DV alone was reported [7]. In practice DPV may be used in conjunction with mixing ventilation and in this case air cleaning can be incorporated with the DPV.

Comprehensive experiments were performed to study the physiological and subjective response of people at comfortable and high indoor air temperature when using DPV supplying filtered and unfiltered polluted room air. Large database comprising SBS symptoms, eye symptoms (blink frequency, tear film stability, eye irritation), comfort (PAQ and thermal comfort) and performance was collected and analyzed. This paper presents the results from the physiological measurements of eye symptoms.

2. Method

A human subject experiment was carried out in a climate chamber (6.4 x 4.8 x 6.0 m^3) with displacement ventilation (DV). The chamber was located in a tall hall with temperature controlled as in the chamber. There were six workstations in the chamber consisting of a desk and a laptop PC. All workstations were at approximately equal distance from the air supply diffuser. Four of the desks had DPV systems consisted of a fan, two flexible silencers and a movable arm with a round movable panel as a supply diffuser (described in [12]). Depending on the tested conditions, DPV systems were equipped either with Filter 1 (1.1 kg of activated carbon type CKV-3) or with Filter 2 (250 g of 8 % KMnO4 impregnated activated alumina; 230 g of BPL4x10) or did not have any filter. The DPV could provide 16 l/s of personalized flow at maximum and the intake height was limited to 10 cm above the floor. Thirty subjects (17 males and 13 females) participated in the experiment. The subjects were recruited among university students.

Experimental Conditions

The subjects were exposed to five experimental conditions comprising: 23 °C and DV only, 23 °C and DPV with Filter 2, 29 °C and DV only, 29 °C and DPV, and 29 °C and DPV with Filter 1. The room set point temperature was achieved at 1.1 m above the floor. DV supplied 135 l/s at temperature 5 °C lower than the room set point temperature. Recirculation was used during the entire experiment with constant ratio (60 % re-circulated air and 40 % outdoor air). Relative humidity of supplied air was not controlled but room air relative humidity was measured in the rage of 30-40 %. In order to simulate pollution load the floor was covered with one-year-old linoleum. Other pollution sources included bio effluents from human subjects and the desks with computers.

Physiological measurements

Samples of tear mucus were taken in order to study tear film stability. Subjects were asked to sample tear mucus by themselves from the inside of the lower eyelid. Samples were applied on the microscope slide, left to evaporate and photographed under the microscope. Afterwards, the photos were examined and sorted into four categories (Figure 1) describing tear film quality according to Rolando [12]. Samples categorized as grade I and II were considered as “healthy eyes”, with no tear film stability problems, while category III and IV were considered as “unhealthy eyes”, with tear film stability problems. The changes in tear film stability between the beginning and the end of the exposure, as well as the changes between different conditions, were examined.

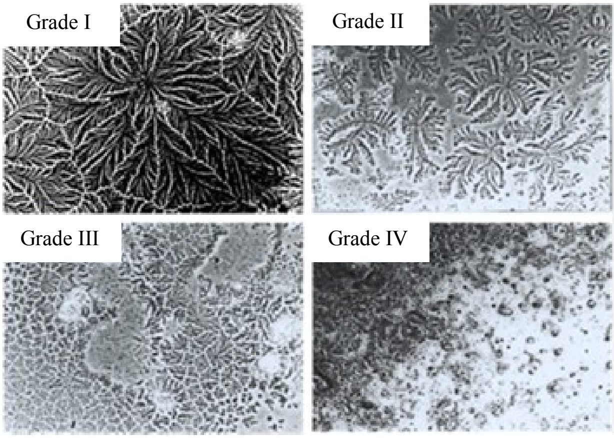


Fig. 1 Examples of the four grades of tear film quality

Subjects’ face was recorded during the whole exposure by web-cameras placed on every workstation. The records were analyzed to define eye blink rate. The analyses were performed on 15-minute long periods at the beginning and the end of each experimental session. A downward movement of the upper eyelid covering more than 50 % of the cornea was counted. The blinking rate (averaged for a period of 15 min) was determined for each subject and used to define the average blinking rate for all subjects.

Face temperature (forehead area) was measured with an infrared thermometer several times during the exposures. The collected data will be included in a following paper.

Subjective measurements

During the experimental sessions, several questionnaires were used to collect subjects’ response to the environment. The questionnaires were included in the computer software at regular intervals, as described in the procedures. Acceptability of perceived air quality (PAQ), whole body thermal sensation and comfort, local thermal sensation and comfort of separate body parts, acceptability of the air movement and air movement preference, eye dryness and irritation, numerous SBS symptoms, etc. were collected. The analyzed data will be reported in a separate paper.

Performance measurements

The performance measurements included subjective measurements (self-assessed performance) and objective measurements based on speed and accuracy of solving different tasks (multiplication, Sudoku game, etc.). These data are reported in a separate paper.

Experimental procedure

The subjects were divided into five groups of six people each. In five experimental sessions the subjects were exposed randomly to the five experimental conditions. Each experimental session took four hours and consisted of several parts.

Right after arrival, participants entered the tall hall and were asked to fill in paper questionnaire about PAQ and face temperature measurements were taken. Subjects adjusted their clothing to feel thermally comfortable and entered the chamber. Before the subjects took their places, while standing, they again filled in a paper questionnaire regarding the PAQ. After that each subject seated at the workstation with his/her name and ID already displayed on the computer screen. Then the acclimatization part started and subjects were exposed in the chamber for approximately 20 min in order to adapt to environmental conditions. This time was used to build-up the pollution level in the chamber. During the acclimatization, subjects were not allowed to use the DPV systems. At the end of the acclimatization period tear film sampling and skin temperature measurements were taken. Then subjects were asked to stand up and fill in paper questionnaires about PAQ and overall thermal sensation (TC). Then the subjects left the chamber and entered the tall hall, where they filled in paper questionnaire (PAQ) and then rested for 5 min.

The subjects entered the chamber again. They first filled in paper PAQ questionnaire while standing and then each of them took their place at the designated workstations. Subjects who had DPV started the device and were asked to adjust the position of the RMP and the supply air flow rate to their preferences. Then subjects started the software on the computers and continued answering questions and performing various tasks for 90 min.

After the first block of performance tasks was completed there was a short break of approximately 10 min. Right before the break, face skin temperature measurements of the subjects were taken again. During the break subjects could go to the restroom. After the break they continued answering to the questionnaires and performing tasks.

At the end of the exposure in the chamber, when subjects finished completing questionnaires and tasks, the face skin temperature of the subjects was measured. Then tear film was sampled (the subjects who had DPV were asked to turn it off before the sampling). After the tear film sampling, subjects were asked to stand up and to assess PAQ (on paper form questionnaire). Finally, they left the chamber, entered the tall hall and filled in the last PAQ questionnaire (paper form).

During the experiment subject were encouraged to modify their clothing in order to feel comfortable.

3. Results

The eye blink rate, averaged for all subjects at the beginning and at the end of the exposures is shown in Figure 2. At the end of the exposure the blink rate at "23 °C DV" was significantly ($p<0.02$) lower than in any of the other conditions. Only at the condition "23 °C DV" (i.e. without DPV) the blink rate decreased significantly ($p<0.03$) with the exposure time.

The blink rate at the condition "23 °C DPV with Filter 2" was significantly lower ($p<0.03$) than the blink rate at "29 °C DPV" and "29 °C DPV with Filter 1". The results suggest that high air temperature increased the blinking rate. The local air movement increased significantly the blink rate at 23 °C. No significant difference was found between the blink rate at "29 °C DV" and both conditions at 29 °C with DPV (with and without activated carbon filter), suggesting no influence of the local air movement and filtration by Filter 1 on the blinking rate at high air temperature (29 °C).

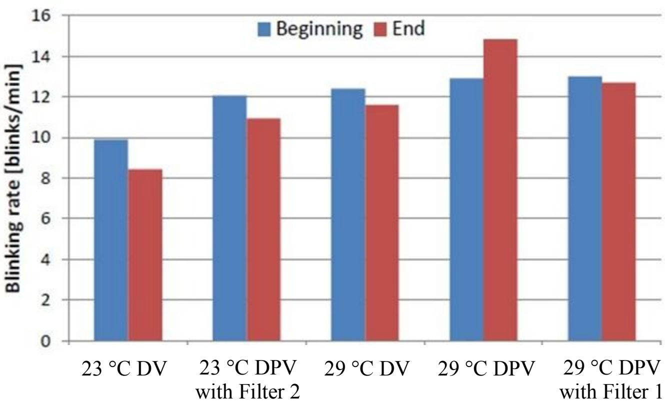
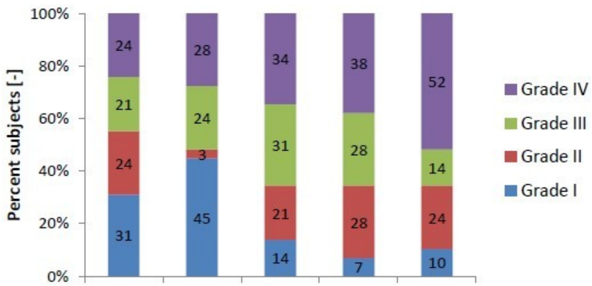


Fig. 2 Eye blinking rate at the beginning and end of exposure for each condition

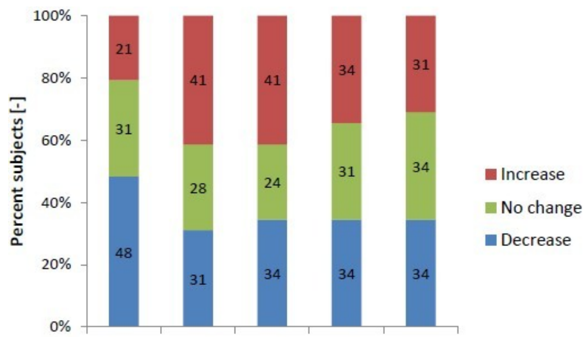
Figure 3 shows the tear film quality at the end of each exposure. The tear film quality at the end of exposure differs among the conditions. The low grade samples (grades III and IV) were more present at 29 °C than at 23 °C. The grade I samples were more frequent at 23 °C with DPV compared to 23 °C without DPV. However this was not the case at 29 °C. The percentage of low grades and high grades were similar for all three conditions at 29 °C.

The evolution of tear film stability during the exposures was studied by calculating the change in tear film quality between the beginning and the end of each exposure. The results are shown in Figure 4. A decrease in tear film quality means that the tear film grade was worse at the end of exposure than it was at the beginning; an increase means that the grade was better at the end of exposure compared to the beginning. Tear film quality decreased more at 23 °C without DPV than in the other conditions. The change in tear film quality for the three conditions at 29 °C shows similar pattern. The decrease of tear film quality at 29 °C with and without DPV is the same suggesting that using movement of room air at elevated velocity did not have impact on the change in tear film quality. It becomes also clear that the use of Filter 1 (activated carbon) did not have effect on tear film quality. For greater percent of the subjects tear film quality increased at 23 °C with DPV than at 23 °C with DV suggesting that movement and filtering of the room air may have positive effect on tear film quality. The results in the figure show that increase of air temperature increased tear film quality.



23 °C DV 23 °C DPV with Filter 2 29 °C DV 29 °C DPV 29 °C DPV with Filter 1

Fig. 3 Tear film quality at the end of exposure to the five conditions



23 °C DV 23 °C DPV with Filter 2 29 °C DV 29 °C DPV 29 °C DPV with Filter 1

Fig. 4 Changes in tear film quality between the beginning and the end of exposure for each condition

Preferred air movement

Subjects were provided with individual control of the personalized flow rate. They changed the flow during the experiments in order to achieve the preferred air movement. This reflected their preference for air movement as it can be seen from the results in Figure 5.

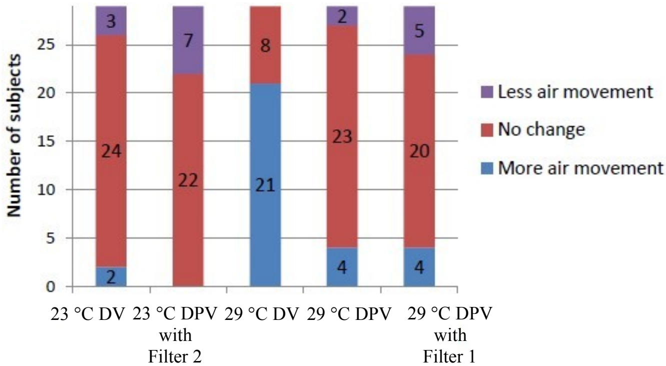


Fig. 5 Preferred changes in the air movement

The flow rate, i.e. facial airflow velocity, selected by the subjects differed widely. The ranges of the selected facial velocity at the end of the exposures with DPV are shown in Figure 6. Even at 29 °C there were subjects who preferred low air velocity. Majority of the subjects preferred velocity higher than 1 m/s at 29 °C and lower than 1 m/s at 23 °C. It is also important to note that subjects changed the velocity during the experiment, i.e. the obtained results can be used only for design of systems under individual control and providing facial flow.

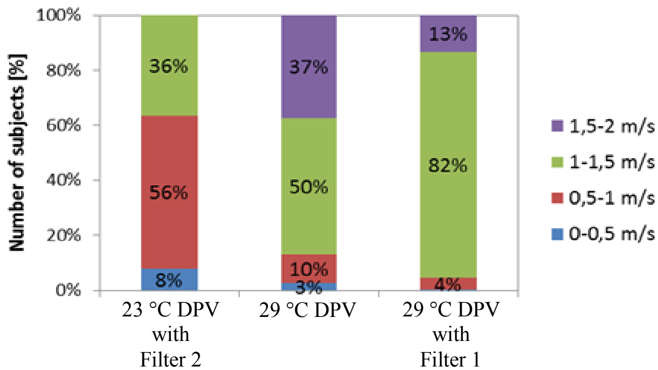


Fig. 6 Preferred air velocity at the end of the exposures with DPV

4. Discussion

The results of the present study concur with the results reported in [11] that in warm environment facially applied movement of room air under control of occupant do not have impact on blink rate. Present results also concur with findings reported in [3] that at 23 °C facially applied air movement decrease blinking rate with increased velocity. In [3] air movement of clean air was applied while in the present study the polluted room air was cleaned. It is difficult to separate the impact of air cleanness and air movement on blink rate; this needs to be studied in specially designed experiment. Present results also reveal that blink rate increases with increase of air temperature, although the increase is small. This contradicts with previous findings that increase in air temperature and humidity leads to decrease in blink rate [11, 3]. In the present study relative humidity was low (below 40 %) and not controlled. The reason for the difference in the findings needs to be study in deep.

Previous studies [3] suggest that at warm environment facially applied air movement of cooler and cleaner air does not have negative impact on tear film quality. Present study reveals that at warm environment facially applied polluted air under individual control of the occupant also does not affect tear film quality compared to the case without air movement. It may be concluded that air movement, when under control of the occupant, does not have impact on tear film quality. However, it has to be noted that in the present and the previous study [3] the facially applied air movement was steady-state and not highly turbulent. Further study is needed to identify whether fluctuations and turbulence intensity, as well as direction of facially applied airflow, affects tear film quality and blink rate. The impact of air temperature and RH on tear film quality remains to be studied. Present and previous [3] results reveal that at the end of 4-hour exposure tear film quality decreased with increase of room air temperature. In the present study the first tear film samples were taken after 20 min exposure to the environment. It may be assumed that during the first 20 min the initial impact of air temperature on tear film quality was already completed and the identified changes were result of the exposure time. This hypothesis is supported by the fact that the first samples of tear film (taken after 20 min) also showed decrease of tear film quality with increase of the air temperature. Further research is needed.

5. Conclusions

At warm environment facially applied air movement of room air under individual control does not have impact on eye blink frequency and tear film quality.

The impact of air temperature, exposure time, cleanness of the air on tear film quality needs to be studied. The impact of direction and velocity fluctuation of facially applied air movement on eye blink frequency and tear film stability also remains to be studied.

6. Acknowledgment

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