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Performance of Ductless Personalized Ventilation in Open-Plan Office - Field Survey

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Abstract

A field survey was conducted in an architectural company located in Syracuse, USA. 54 employees who participated in the survey performed mostly design work. Large open-plan office and several single offices ventilated by displacement air distribution were included in the survey. Ductless personalized ventilation was installed on 38 of the workstations (53 %). The DPV equipped with small fan and filter, sucks the clean and cool air distributed over the floor by the displacement ventilation and supplies it to the breathing zone of the occupant. The DPV allows for individual control of flow rate (i.e. velocity) and direction of the supplied personalized air. During the survey, carried out in July – September 2011, both DPV users and non-users reported daily on their thermal comfort, air quality and SBS symptoms. Continuous measurements of air temperature, operative temperature and relative humidity were performed. The occupants at the desks with DPV reported increased satisfaction with the indoor environment.

Keywords – ductless personalised ventilation; thermal comfort; local cooling; air quality; field survey

1. Introduction

Numerous studies have documented that indoor air is important for occupants' health, comfort and performance. Total volume ventilation based on mixing or displacement air distribution is mainly used today in buildings. However this method of air distribution is ineffective because clean and conditioned air is supplied far from the occupants and is warm and polluted by the time it reached occupant's breathing zone. The goal is to obtain uniform environment (temperature, velocity, etc.) in the entire occupied zone. Thus the large differences that exist between people with regard to preferred temperature, air movement, clothing thermal resistance, activity level cannot be account for because it is difficult, almost impossible, to control the micro-environment at each workstation.

Personalized ventilation (PV) aims to supply clean and cool air directly to each workstation under the control of the occupant [1]. Thus significant improvement in people's thermal comfort and perceived air quality, decrease in the reported Sick Building Syndrome (SBS) symptoms and tendency for improved work performance can be achieved [2]. It has been also shown that PV can efficiently protect occupants from airborne transmission of infectious agents, which are present in air exhaled by sick occupants [3].

Desk installed personalized ventilation has been implemented in several buildings in Denmark [4]. Installation of personalized ventilation is easy in rooms with under-floor ventilation, i.e. when a plenum for distribution of ventilation air exists below the raised floor. In open-plan office the installation of personalized ventilation is more challenging because of air ducts affecting indoor aesthetics as well as flexibility of furniture layout. Several solutions have been introduced and tested, such as ceiling mounted nozzle above each workstation allowing for individual control of the locally supplied airflow [5]. Improvement in thermal comfort and perceived air quality with the ceiling mounted personalized ventilation has been documented in human subject experiments [6]. The potential for energy saving has been reported as well [7]. Another solution is the concept of ductless personalized ventilation [8]. Ductless personalized ventilation (DPV) in conjunction with displacement ventilation sucks and supplies to the breathing zone of each occupant the clean and cool air distributed over the floor area by displacement ventilation. The performance of DPV was studied by physical measurements performed in a full-scale test room with breathing thermal manikins resembling occupants [9, 10]. The results reveal that the inhaled air with the DPV was as clean as the air inhaled with displacement ventilation alone and even cleaner under some conditions. Recently the performance of the system has been studied in comprehensive human subject experiments focusing on people's health (SBS symptoms, eye symptoms) and comfort (thermal comfort and perceived air quality) [11, 12, 13, 14]. Energy saving potential of using ductless personalized ventilation has also been reported [15].

Ductless personalized ventilation was introduced in architectural consulting company located in Syracuse, USA. After installation field survey on occupants' response was performed. This paper reports on the first results from the analyses of the collected data.

2. Method

The survey, comprising physical measurements and occupants' response, was conducted among employees working in the office building located in Syracuse, New York state, USA. The building, an old warehouse, has been extensively retrofitted in 2009 in order to serve as a modern office and subsequently received the LEED-Platinum certificate. The period when the survey was conducted was two-month long, starting from July 27th 2011.

There were 72 workstations in the building; some of the workstations were not occupied during the whole period when the survey was conducted due to e.g. summer vacation or employees holding temporal positions. On the ground floor there were 5 single offices and 7 other workplaces located in the common area. Reception, library, kitchen and meeting places were also located on the ground floor. On the first floor there were 4 single offices and 56 workstations in an open-plan office. Three meeting rooms and a printing room were also located on the first floor. Workstations in the open-plan office were separated from each other by partitions.

Two air handling units (AHU), one for each floor, supplied air through displacement ventilation diffusers installed on the partition at each workstation. Part of the exhaust air was recirculated and supplied back to the occupied zone.

The open-plan office located on the first floor was provided with one thermostat located in the middle of the room where it could be easily accessible by every employee. Considering individual differences among people with respect to preferable thermal environment, as well as the size of the office (possible non-uniformity of indoor environmental parameters), such control system may not provide thermal comfort to all employees. That was one of the reasons why 38 units of ductless personalized ventilation (DPV) were installed at the beginning of summer 2011. Employees were given the choice whether they want their workstation to be equipped with DPV based on their experience after trying DPV installed at one test station.

DPV consisted of a floor-standing box with air intake section, basic air filter and build-in electric fan. The box was connected with the air supply device located above the desk top (preferably behind the computer screen) by a flexible hose. The position of the air supply device was adjustable and the personalized air flow was controlled by the controller. Figure 1 shows DPV installed at one of the workstations; at many workstations it was possible to position PDV air intake very close to the displacement ventilation diffuser as in the given example. After installation took place half of the employees (53 %) started using DPV. The users of the DPV could control the supplied personalized flow rate and its direction. The remaining workstations were not modified.

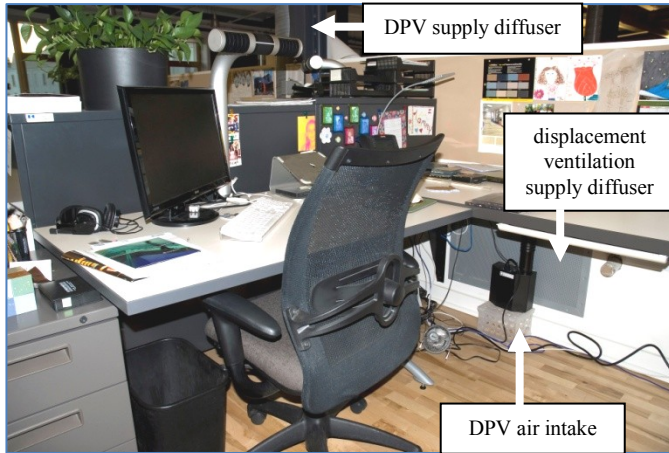


Fig. 1 DPV installed at one of the workstations

When the survey started, a link to the computerized questionnaire was sent by emails to all employees twice a day; at 9 am and 3 pm. Employees, both DPV users and non-users, were asked to answer the questions only if they were physically at their workstation, as some could be working from remote locations on that specific day. Every workstation received a unique number used while responding to the questionnaire. This allowed responses to be treated anonymously but position of the workstation remained known. The first questions focused on thermal sensation (thermal sensation scale [16]) and acceptability of thermal sensation, air quality and air movement (acceptability scale [17]). Next questions asked about preferences regarding air movement around head/chest and feet/legs, followed by questions defining prevalence of Sick Building Syndrome (SBS) symptoms (dry eyes, dry lips, tiredness, headache, difficulty to concentrate) and self estimated performance. Air freshness, noise level and clothing insulation were also reported. Employees using DPV were asked to specify the set-point of the personalized air flow controller at the time of the survey. This data were used later to define the preferred ranged of personalized air flow. In this paper only the results presenting thermal sensation and its acceptability, acceptability of air quality and acceptability of air movement are included. Also the results are limited to the afternoon questionnaire session (at 3 pm).

The physical measurements included both measurements in the occupied zone (at the workstations), as well as measurements focused on air handling units and their performance. 28 loggers measuring air temperature, operative temperature and relative humidity were placed at selected workstations covering uniformly the whole occupied zone. Those loggers were placed at 0,6 m height above the floor. Additional 6 loggers measured air temperature inside the air handling units (outdoor/supply/return air temperature);

20 loggers measured supply air temperature at selected displacement ventilation diffusers located at different distances from AHUs. CO₂ concentration was measured in the occupied zone at 11 workstations by sensors located at 1,1 m height above the floor. The physical parameters were logged with 1-min interval during the whole survey. The measuring instruments were calibrated before the measurements.

3. Results and Discussion

With Saturdays and Sundays excluded there were 44 workdays when the questionnaire was sent to the employees (the link to the questionnaire was automatically sent from Monday to Friday regardless of special holidays during weekdays). Analyzing the response rate day by day revealed that after initially high response rate during the first days of the survey, the response rate dropped and remained steady until the end of the survey. The response rate during the whole survey was 26 %.

Operative temperature was measured at 5 locations on the ground floor and 22 locations on the first floor (one sensor was damaged during the survey). The measured data have been averaged for the period between 2 pm and 4 pm, as only the results from the afternoon survey are presented in this paper. Average operative temperature measured at the specific day at a given workstation was taken into account only if at that day the employee working at that workstation answered the questionnaire. In such way the results from the survey can be correlated with physiological measurement. Average operative temperature on the first floor was $23,8 \pm 0,4$ °C for workstations equipped in DPV, and $23,5 \pm 0,5$ °C for workstations without DPV. Average operative temperature on the ground floor was about 1 °C lower than on the first floor. This difference was due to lower heat gains at the ground floor i.e. lower occupation density, lower solar heat gains.

The distribution of thermal sensation votes for DPV users and non-users is presented in Figure 2. As can be seen, the responses from DPV users were more frequent between “slightly cool” and “cool” on the thermal sensation scale probably due to the cooling effect of personalized flow. The neutral thermal sensation was more often reported among non-users. Employees could test DPV system before the survey and decide whether they want to have personalized ventilation installed at their workstations. They were informed about possible positive effects of using DPV on thermal comfort and inhaled air quality based on experiments with human subjects in a simulated office environment [11, 13]. The employees who decided to have DPV installed at their workstation possibly were not satisfied with their work environment. The driving forces and reasons why some employees decided to have personalized ventilation installed at their workplaces are not discussed in this paper. The non-users were among employees most probably satisfied with indoor environment in the building or sensitive to elevated air movement (draught, eye discomfort, etc.).

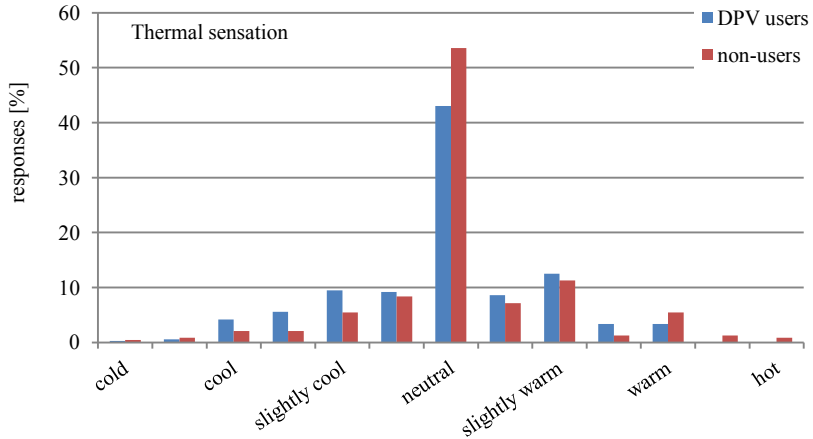


Fig. 2 Thermal sensation among DPV users and non-users

Acceptability of thermal sensation is shown in Figure 3. DPV users reported higher acceptability of thermal sensation – their responses were more frequent on the right side of the scale close to “totally acceptable”. There were more responses from non-users starting from “just acceptable” towards “totally unacceptable”. The results confirmed what has been found in the human subject experiments that DPV increased the body cooling compared to displacement ventilation used alone. The use of DPV in conjunction with displacement ventilation under realistic conditions showed that employees could benefit from the personalized flow of cool air under individual control to achieve preferred thermal environment.

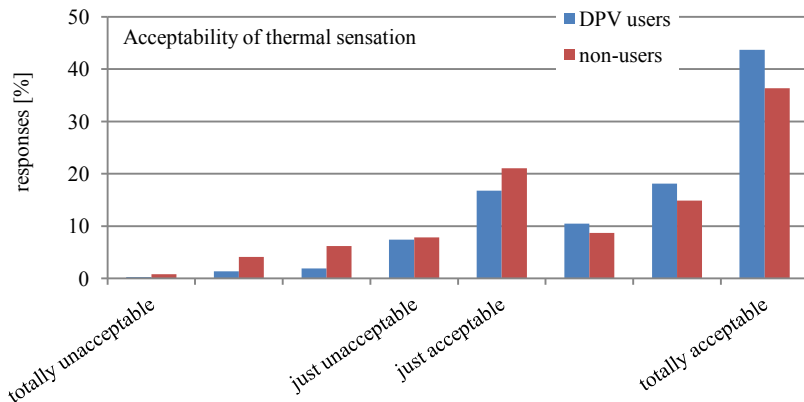


Fig. 3 Acceptability of thermal sensation among DPV users and non-users

Acceptability of air quality (Figure 4) shows similar trend to acceptability of thermal sensation i.e. perceived air quality reported by DPV users was better than that reported by non-users. These results confirm previous findings obtained during the experiment with human subjects in a climate chamber [11]. In this experiment immediate improvement of the PAQ was observed when the subjects started using the DPV. It has been found that elevated velocity supplied to the breathing zone improves PAQ [18]. It diminished the negative impact of high temperature, relative humidity and pollution concentration on PAQ. The performance of DPV was also studied by physical measurements performed in a full-scale test room with breathing thermal manikins resembling occupants [9, 10]. The results reveal that the inhaled air with the DPV was as clean as the air inhaled with displacement ventilation alone and even cleaner under some conditions. These results may explain the higher PAQ reported by the DPV users compared to non-users.

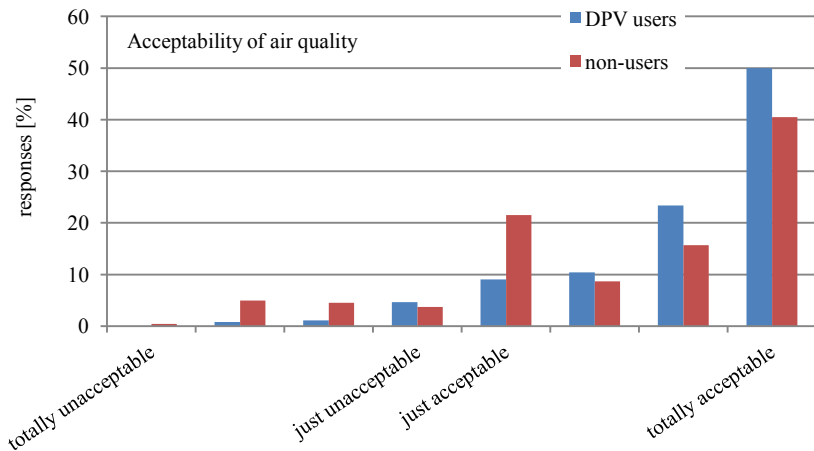


Fig. 4 Acceptability of air quality among DPV users and non-users

Before the installation of DPV some employees were using small electric fans in order to increase convective cooling during hot summer days. Those employees were among the first to decide about trying DPV and having it installed at their workstations. The individually controlled DPV allowed for adjusting air movement at their workstations. Because employees were given the choice whether they wanted to have DPV installed at their workstations or not, it was expected that those unsatisfied with indoor environment will decide to use DPV. Therefore non-users could be defined as employees who were satisfied with indoor environment and did

not need DPV for further improvement. Then both groups would show similar results however, acceptability of air movement (as well as acceptability of thermal sensation and air quality) among DPV users were higher compared to non-users. Acceptability of air movement is shown in Figure 5.

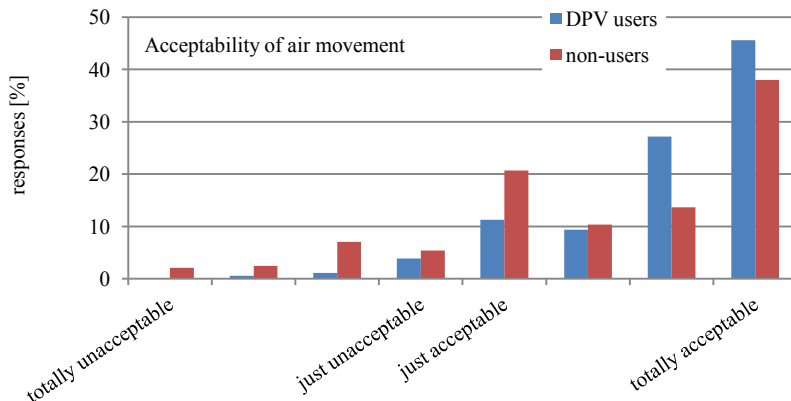


Fig. 5 Acceptability of air movement among DPV users and non-users

4. Conclusions

The first analyses of the results collected during the field survey reveal that implementation of ductless personalized ventilation will be beneficial for providing preferred microenvironment at workstations and for increasing occupants satisfaction.

The results of this field survey confirmed findings from climate chamber experiments that combining ductless personalized ventilation with displacement ventilation has potential for improving PAQ and thermal comfort. Acceptability of thermal sensation/air quality/air movement was higher among DPV users compared to non-users.

5. Acknowledgment

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