Personal Ventilation: from research to practical use

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SUMMARY

This paper describes an ongoing demonstration project on the use of personalized ventilation in practice. Several designs of air supply devices for PV were developed, tested and optimised based on the efficiency of clean air supply to occupants’ breathing zone, control functionality, aesthetic, etc. Pilot installation of the PV system in a number of offices was used to gather better experience on the interaction between occupants and the PV system. The second stage of the project includes installation of the system and its performance in an office building. Computer based questionnaire survey on occupants’ comfort and performance as well as measurement of the indoor environment in the offices will be performed before and after installation of the PV system. Surveys will be performed during the following winter and summer seasons. It is expected that the obtained results will provide knowledge important for future application of PV in practice.

INTRODUCTION

Numerous studies have associated the quality of indoor air with people’s complaints and with their performance. It has been shown that poor air quality causes Sick Building Syndrome (SBS) symptoms such as increased prevalence of headache, decreased ability to think, increased dizziness, etc. [1]. Providing good air quality, on the other hand, increases occupant’s productivity [2, 3, 4, 5]. Furthermore, it has been documented that the quality of inhaled air of low enthalpy (low temperature and humidity) is perceived to be better than when the enthalpy is high [6]. Thus an increased productivity due to improved indoor air quality and thermal environment will have an enormous economic impact which may cover all the capital and running costs of operating the building. The gain will often be greater than all other costs relating to the construction and operation of the building [7].

The first important step in improving indoor air quality is to remove or decrease the pollution sources. However it is not possible to remove all pollution sources. Occupants also generate pollution. Supply of more clean air to the room will dilute the polluted air and will improve air quality. This approach however leads to increase of initial costs due to larger ducts, air supply devices, etc., as well as increased energy consumption. Instead, it is better to keep the ventilation rate low but to distribute the air more efficiently in the room. With this respect the ventilation effectiveness, \(VE\), defined as the ratio of the pollution concentration in exhaust air divided by the pollution concentration in air inhaled by occupants can be used to assess the performance of ventilation systems.

The total-volume ventilation systems (mixing and displacement) are capable of achieving only relatively low levels of ventilation effectiveness. The mixing ventilation aims for as good as possible mixing of the supplied clean air with the polluted room air and therefore typically
VE = 1. Higher values of VE (VE > 6) can be achieved with displacement ventilation under laboratory conditions depending on the type and location of the pollution source. In practice VE ≤ 1.4 is typically achieved in rooms with displacement ventilation [8]. However displacement ventilation may cause draught discomfort. Field study in 120 rooms with displacement ventilation identified that up to 50% of occupants were dissatisfied with indoor air quality [9].

Personalized ventilation (PV) aims to supply clean air directly to the breathing zone of room occupants and therefore it has potential to achieve VE substantially higher (VE > 50 or more) than the VE of mixing and displacement ventilation [10]. The 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 when PV is used, has been documented in human subject experiments performed in field laboratories [11, 12, 13]. Furthermore it has been shown that PV can efficiently protect occupants from airborne transmission of infectious agents, which are present in air exhaled by sick occupants [14].

Personalized ventilation has been applied for many years in theatres and vehicle cabins, in most cases in order to improve occupants’ thermal comfort. Only few studies report on the performance of PV in office buildings [15, 16]. The effectiveness of the personalized ventilation depends greatly on the design of the PV Air-Terminal Device [17, 18, 19]. Design of PV with high VE easily applicable in practice is not an easy task. A part of the VE other factors, such as background room air distribution, control strategies, occupant activities, appearance of air supply devices, etc., are also important [20, 21].

This paper describes an ongoing demonstration project on development, optimization and installation of PV in an office building. Computer based questionnaire survey on occupants’ comfort and work performance as well as continuous measurement of the indoor environment in the offices is used for monitoring and evaluating the performance of the PV.

**THE PERSONALIZED VENTILATION**

**Design**

The first step of the project was focused on development and optimization of an air terminal device (ATD) for the personalized system. Some of the important criteria for the design of the ATD were: 1) to be able to supply maximum clean (personalized) air to inhalation; 2) to cause minimum draught discomfort for the occupants; 3) to improve occupants’ thermal comfort and 4) to cause minimum transport of infectious agents between occupants. With this respect the knowledge obtained from previous research was carefully evaluated [10, 17, 19]. Other factors important for the practical use of the PV were considered as well. The most important of those were related to levels of control provided to users, installation at different workplaces, aesthetic and appearance. As a result several prototypes were developed. Figure 1 shows one of the designs. The ATD is attached to an arm which can be rotated around its vertical axis. This allows for changing the direction of the personalized flow in horizontal plan. The design of the ATD allows also for changing the direction of the supplied personalized flow in a vertical plan. In this way the occupant can direct the personalized flow to the face or chest or any other angle. The flow rate of the personalized air supplied through the arm to the ATD can be controlled, i.e. the occupant can adjust the preferred target velocity at his/her face or body. The size of the ATD was defined based on its appearance and on the aerodynamic of the generated personalized flow.
Performance of the ATD

The performance of the ATDs was tested in a full-scale air movement room. The room was ventilated by mixing ventilation (swirl diffuser placed in the middle of the ceiling). Breathing thermal manikin resembling human was used during the experiments. Experiments at different flow rate supplied from the PV, different distance between the ATD and the manikin and different angle of discharge of the personalized flow were performed. The velocity field in the personalized flow generated by the developed ATD was carefully identified. The most important part of the test was to identify the performance of the PV with regard to providing clean air in inhalation. For this purpose tracer gas was mixed with the supplied ventilation air (mixing ventilation). The supplied personalized air was free of tracer gas. The concentration of tracer gas in air inhaled by the manikin, the air exhaust from the room, at several points in the room and in the supplied personalized flow was measured. The data were used to calculate the personal exposure effectiveness (PEE) defined as:

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\text{PEE} = \frac{C_{\text{I,0}} - C_{\text{I}}}{C_{\text{I,0}} - C_{\text{PV}}} \tag{1}
\]

where:

- \(C_{\text{I,0}}\) is the pollution (tracer gas) concentration in the inhaled air without PV;
- \(C_{\text{I}}\) is the pollution (tracer gas) concentration in the inhaled air with PV;
- \(C_{\text{PV}}\) is the pollution (tracer gas) concentration in the personalized air;

The personal exposure efficiency, PEE, is an index representing the percentage of clean air contained in the inhaled air. It is developed for evaluation of the performance of personalized ventilation systems [17].

The results of the tests showed an improvement in inhaled air quality by 40% (\(\text{VE}\approx1.7\)) in comparison with mixing ventilation alone (\(\text{VE}\approx1\)). The ATDs were further improved in order to increase their performance.

Testing of the PV under real conditions

Pilot installations of the PV system were tested in order to gather better experience on the interaction between occupants and the PV system. The administration building of the
The manufacture of the PV systems was used. The PV was installed at three workplaces used by several of the employees for shorter (several hours) or longer (several days) periods of time. The response of the users was very positive. A part of the achieved preferred thermal comfort and improved quality of the inhaled air (the inhaled air was felt fresh and clean) the users reported an improved self-estimated performance with the PV, especially during the afternoon hours. The response of the users with regard to the provided control of the local velocity and direction of the personalized flow as well as the appearance of the PV was positive as well. Further modifications and improvements of the developed PV systems are in progress.

**APPLICATION OF THE PV IN PRACTICE**

**Installation of the PV system in an office building**

A consulting company (partner in this project) was requested by a building owner to improve the indoor environment of a 200 years old building where severe indoor climate problems were reported. The building, located downtown Copenhagen, is occupied by a company dealing with preparation of regulatory documents (low, taxation, etc.). Thus the employees perform office work in front of computer screens. The building (the old building) does not have mechanical ventilation. The ventilation through the windows is insufficient to ventilate and cool down the building. The opening of the windows for getting fresh air creates a lot of thermal discomfort during the winter. Therefore among other improvements of the building (better roof isolation, better solar shading, floor renovation with low polluting materials, etc.) installation of mechanical ventilation was requested. Since the office work performed in the building is rather responsible and requires deep concentration a high quality environment for each occupant was requested.

The ceiling height in many of the rooms in the old building is below 2.4 m (2.2 m in several rooms). Furthermore there is not enough space (typically needed in practice) for installation of air terminal devices and ducting system. This made the task more difficult. The design of the total volume ventilation ended with mixing room air distribution with air supply devices located on the walls. In order to account for the occupants’ preferences with regard to thermal comfort and to provide them with high quality of inhaled air personalized ventilation in conjunction with the mixing ventilation was designed. The mixing ventilation can be used alone or in conjunction with the personalized ventilation. The design allows for maximum 20 L/s per occupant outdoor air in total, supplied by the two systems. The minimum amount of outdoor air supplied to each room is 5 L/s per occupant. The outdoor air is distributed between the total volume system and the personalized ventilation systems depending on the occupants’ preferences. The PV systems at each workplace supply maximum of 15 L/s and the personalized flow rate can be reduced to 0 L/s. The installation of the system will start by the end of April 2007.

**Field survey**

A survey on the impact of the PV system in regard to occupants’ health, comfort and performance is designed. Occupants’ cognitive stress level is in the focus of the survey as well.

The survey will be performed before and after renovation of the building. Two groups of occupants are included in the survey: group A includes occupants working in the building which will be renovated (the old building) and group B includes occupants working in the attached relatively new building (the new building) which will not be renovated (this group will be used as a reference). Much less complains due to poor indoor environment have been
recorded in the new building. The two buildings are interconnected. They are rented by the same company. Three Phases are considered. Phase 1 includes a survey before renovation of the old building. This phase is in progress. After renovation of the old building two more phases are planned: Phase 2 when mixing ventilation is used alone and Phase 3 when personalized ventilation in conjunction with mixing ventilation is used. In this way the effect of the ventilation in general and of the personalized ventilation in particular will be identified. Future surveys during following winter and summer seasons are planned in order to identify the level of occupants’ satisfaction after use of the personalized system for relatively long period of time.

The method of survey includes long term survey and short term survey. Both, the long term and the short term surveys will be performed before and after the renovation of the old building. The long term survey is planned to continue for 3-4 weeks during each of the phases of the project, i.e. before the renovation and after the renovation twice (only mixing ventilation and mixing ventilation in conjunction with personalized ventilation). The long term survey includes occupants’ response to the indoor environment collected by questionnaires, work performance test and continues physical measurements. The questionnaire survey and the work performance tests are computer based and performed via internet [22]. At least three times during a week (in the afternoon of different days) an invitation for participation appears on the screen of each participant in the survey. The occupant votes on short questionnaire including questions on occupants’ thermal comfort (7 point ASHRAE scale) and its acceptability (continues scale from clearly unacceptable to unacceptable and then from acceptable to clearly acceptable), acceptability of air quality, acceptability and preferences of air movement as well as where it is felt, SBS symptoms (eye irritation, headache, ability for concentration, tiredness, stress level, etc.) and self-assessed performance. A fter completion of the short questionnaire follows work performance test which includes proof reading of text with errors which have to be found. The time for this test is limited to 5 min. The work performance of each participant will be analyzed based on the number of identified errors and the length of the processed text. The long term survey includes also continuous measurement of air temperature, relative humidity and CO₂ concentration in the surveyed rooms.

The short term survey will be performed during each of the three phases. It will be performed only once during the 3-4 weeks long survey. It will include detail paper questionnaire on occupants’ comfort, health conditions, work environment. Simultaneously spot measurements of velocity and temperature at each workplace at different heights will be performed as required in the present thermal comfort standards [23, 24]. This short term survey will last not more 15 min at each workplace.

CONCLUDING REMARKS

The field survey before installation of the ventilation system and renovation of the building (Phase 1) is in progress. Phases 2 and 3 are expected to take place in August-September 2007. It is expected that the obtained results will provide knowledge important for future application of PV in practice.

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REFERENCES


