Effect of the Personalized Ventilation to a Human Thermal Comfort

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Abstract. The paper deals with effect of the personalized ventilation on thermal comfort of the human body. Especially the influence of different temperatures and velocities of the supply air provided by the personalized ventilation on sitting user during standard light office work. The goal is to figure out possible and comfortable range for the personalized ventilation system and to determine the maximum power of the device. For measurement we were using a prototype of the personalized ventilation system which is able to adjust temperature of the supply air using thermoelectric elements. A thermal manikin was used to simulate the human body and to measure the effect of the ventilation system to the human thermal comfort and the PIV (Particle Image Velocimetry) was used to measure vector field around the human body.

1. Introduction

Today we have to concede, that most of the people are most of their time separated from the external natural environment and are enclosed by the impermeable envelope of the building they are live in. According to studies we spend about 90% of our time inside the buildings or in the means of transport [1]. The separation of the outdoor and indoor world is necessary for our work, our life, our comfort and especially in the latest time, necessary for decreasing the energy we consume and need. Adjusting the environment we work and live in to our needs become a standard we easily get used to.

The environment we artificially create helps us work the whole day and whole year with minimal costs, but in many cases it makes us more bad than good. A lot of people today don’t have access to a healthy environment for the most of their time and it becoming a problem we should seriously deal with.

The personalized ventilation is one of the modern alternative to create a healthy, adaptable and energy efficient indoor environment in places shared by many people like open space offices, where it’s quite difficult to maintain a good quality environment by central ventilation systems. Personal ventilation provides fresh air directly to the places where it’s needed the most, in the personal zone of every users. It creates a customized space for every person in the room, which lowers risk of diseases transmission, increases wellbeing and productivity of the users [1]. It is also more adaptable to personal differences and needs caused by uniqueness of every person and his actual condition [9]. The impact of the standard personalized ventilation was measured many times before, but what if we can personalized not just the amount of supply air, but even a temperature?
2. Problem description
In our previous work, we have designed a system for a personalized ventilation, which uses micro air handling unit as personal device to customize the air temperature and volume. We have already dealt with efficiency of the fresh air distribution, shape of the airflow and other conditions of the personalized ventilation system in isothermal mode of operation (means that the supply air had a same temperature as the surrounding air) [3]. In this study we focused on thermal comfort and changes of ventilation efficiency in cases when the supply air temperature is changed. We used two different modes of operation – cooling and heating – and measured the differences and a human response to it. For thermal comfort measurement we used a thermal manikin and for the ventilation efficiency we used a particle image velocimetry to measure a shape of the flow around the thermal manikin.

3. The measurements

3.1. Thermal comfort measurement
Thermal manikin is well known device, widely used for measuring the temperature balance and feeling of the human body and translate the senses of human body to some solid data form [2]. It can be used in a wide variety of spaces, from tight vehicle cabins to opened indoor environment of buildings. It measures many separate zones of the body and can define the places of comfort and discomfort caused by draft or inappropriate temperature. It also produces heat as a standard human body does, which is crucial for the interaction of personal diffuser flow with conductive boundary layers of the human body.

For our measurement we used a Czech standard for measurement with thermal manikin ČSN EN ISO 14505-2 [5], which is made to measure the environment in a vehicle, but can be easily used for a building as well. The assessment is based on the measurement of the equivalent temperature, which integrates the independent effects of convection and radiation on the heat exchange of a person [2]. It describes the level of thermal neutrality on the separate zones. The equivalent temperature measurement is based on the measurement of energy consumed by manikin to heat the zone and keep the temperature on the set value.

The measurement of the thermal comfort by a thermal manikins uses methodic of TMS (thermal manikin sensation) instead of equivalent temperature teq. There are two values, TMSo (Thermal manikin overall sensation) and TMSz (Thermal manikin zone sensation). This new index is easier to interpret the results and even compare it with widely used PMV (Predicted mean vote) index. To compare the results with the PMV index the usual scale ASHRAE scale is used. It goes from -3 to +3, where -3 is cold, 0 is temperature neutral and comfortable and +3 is hot [4] [2].

3.2. Measured system description
For the measurement we used a prototype of the personalized ventilation system designed in our previous work [7] [10]. It is designed for open space offices with displacement ventilation, where the fresh air is supplied thorough the doubled floor. The system consists of micro air handling unit placed in the doubled floor space and personal diffusers mounted on the workspace. It is connected by insulated piping. You can see the system design in the figure 1. The micro air handling unit sucks the fresh air from the doubled floor and adjusts volume and temperature of the air supplied to the personalized ventilation. It is able to heat and cool the supply air approximately in the range of 8 K (from -4 to +4 K) and vary the supply air from 20 to 50 m³/h. The personalized diffusers are mounted on the back corners of the workspace, directed to the middle of the table.
3.3. The setting of the measurement
Measurement was set to simulate regular workspace in the office. Manikin was sitting in front of the table and diffusers were placed in the back corners as it should be used in a real situation. In the figure 2 we can see the layout of the measurement and a presumed flow from the diffusers based on previous CFD simulations [8] and measurement [3]. Laser layer for PIV anemometry was set in vertical position in the middle of the table in front of the manikin to measure airflows around his chest and head. Two cameras for PIV anemometry were placed in a vertical setting to extend the measured area. We can see in the figure that the main airflows will come from the sides and meet in the middle of the table, where it creates one flow parallel to the laser layer and directed to the manikin. We can see it in the figures from measurement, where the flow does not come from the side (as we could expect), but develops in the measured area.
The manikin was clothed to the clothing value commonly used in offices. We used a long-sleeved shirt and trousers to set the thermal insulation value to 0.54 CLO. The manikin was set to a surface temperature of 35 °C, he was not breathing neither was producing any moisture.

The room temperature was set to the 24 °C and measured in three points of different height (ankles, belly and head of sitting person) as required by the standard. The deviation of ambient air temperature during the measurement was 0.63 K and ambient air velocity was in the range of 0.05 to 0.13 m/s in a distance of 1.5 from the manikin. In the personal zone of the manikin the temperature range was higher due to heating and cooling of the zone but has deviation lesser than 0.3 K for each separate measurement. Room was equipped with a separate cooling and heating system to keep the steady temperature.

We measured three different states of the system – isothermal, heating (+4 K) and cooling (-4 K) and every state were measured in two airflow volumes – 25 and 50 m³/h. Measurement were made after a steady state was achieved. Thermal comfort was measured in a period of one hour, PIV anemometry were made by 50 continually captured images in the beginning of measurement.

4. Results and discussion

4.1. Impact on the air velocity field

In the result figures we can see that the main flow were influenced by the three main effects. The first is the interaction of the two diffusers, which is mostly visible on the flow with lower volume and velocities. The main connected flow is developing in front of the manikin in the edge of the table and continue towards the manikin. The second effect are convective boundary layers around the human body, caused by different temperature of the air and the surface of the body. It creates a vertical flow of speed in a range of 0.1 to 0.2 m/s [6]. This flow mixes with the main flow of the fresh air from diffusers and changes its direction upwards. It has a major influence on the efficiency of personalized ventilation and its ability to supply fresh air to the breathing zone [6]. The last effect is buoyancy force of the supply air of different temperature, which is quite strong although the difference is only 4 K. It has also significant impact on the efficiency of the ventilation, because the diffusers were primary designed for isothermal conditions.

First measurement were made in the isothermal state as the system was originally designed. And we can see in the figure 3 that the results looks very good. The airflow is developing as it should and transports the fresh air to the breathing zone. It is deflected by the convective layers upward but not too early. It creates a personal zone of microenvironment of moving fresh air as it was simulated and measured in previous studies. Even in higher volumes the air velocity of supply air doesn’t exceed the limits of draft. Around the manikin it ranges in optimal range between 0.1 and 0.2 m/s.

The air flow of the heating mode of personalized ventilation shows slightly worse results. The temperature of the supply air was set to 28 °C and in the figure 4 we can see that the buoyancy effect deflects fresh air flow upwards above the head of the user, which means that most of the fresh air does not reach the breathing zone and is ineffectively mixed with the ambient polluted air out of the personal zone. The impact of the fresh air is less efficient and in further development the design of the diffuser have to be changed to balance the buoyancy force by direction of the muzzle velocity vector.

In contrary to heating, during the cooling mode the air slides on the surface of the table and reaches the users breathing zone lower than the isothermal flow. We can see the results in figure 5. The temperature was to 22 °C. The airflow slightly cools the surface of the chest and lowers the velocity of convective layers, which both benefits the personalized ventilation efficiency, but it can cause a temperature discomfort for hands if the air temperature is too low. And it is also the velocity which can cause problem because in the zone of the hands it almost reaching the velocities of draft (about 0.25 m/s).
Figure 3. Isothermal state of ventilation for 25 and 50 m³/h volume of the supply air

Figure 4. The heating mode of the personalized ventilation for 25 and 50 m³/h volume of the supply air
4.2. Impact to the measured thermal comfort

The thermal manikin was measuring the thermal comfort in different zones of the human body. The figure 6 shows the impact of different mode and air volume to the whole body and separate zones. The horizontal axis of the figure shows the TMS, respective the PMV index. Because of the quite small differences, we used just the part of the scale from -1.5 to +1.5 to make the results more clear. Vertical axis shows different zones of the body and top line is for overall body sensation.

Each zone had its own different sensitivity to a different influences and we can see how the velocity field impact the results. In our case the thermal comfort shift is based on both air temperature and velocity, but it differs not simply by a mode. For example we can see in the face zone that for 25 m³/h in the heating mode it feels colder, than in the cooling mode. It is caused by the upward direction of the flow in the heating mode and higher velocities around the face. In cooling mode the main velocity field is centered by the hands and the belly and the air velocity around the face is lower. Another interesting fact is, that lower air volumes cools more the body under the desk. It is probably caused by high velocities of the air around the body, decreasing the effect of buoyancy of the cool air.

We also have to mention, that the posture of the body changes the impact and is more difficult to say how is the effect on someone working and changing his posture often. We can see the example of different impact in different place on the left and right hand. The left hand was placed closer to the centre of the table, which means more in the airflow direction and the impact of cooling on it was significantly higher, than on the right hand.

For the overall sensation we can say, that cooling and heating of the supply air have its impact on the thermal comfort. And although it’s not significant, it is in the scale we were trying to achieve, because the temperature customization is not meant to completely change the environment, just make it more personalized. But the environment is not as stable as we wanted to have.
5. Conclusion
In our study we were trying to measure the impact of the heating and cooling of the supply air of the personalized ventilation system. We heat and cool the air by 4 K to measure the difference and compare it with isothermal operation. Basically we can say, that the heating and cooling have an impact to a thermal comfort of the user and it can be used to adjust the temperature of the personal space. Possibility of the air customization could have a positive effect on wellbeing and the number of people dissatisfied with the environment.

On the other hand we have to say, that the present design of the personalized ventilation is not as efficient as it could be and in the next research we should focus to create a diffuser more adapted on the different temperatures and its buoyancy force. More stabilized environment could have better results in the both side of thermal comfort impact and ventilation efficiency.

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