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Personalised Ventilation with Air Temperature Customisation: Impact on the Design and Thermal Comfort of the User

Osobní větrání s úpravou teploty vzduchu: Dopad na návrh zařízení a tepelnou pohodu uživatele.

The paper deals with the customisation of the supply air temperature in a personalised ventilation system and its impact on the air flow, the efficiency of the ventilation, and the thermal comfort of the human body. The system was designed to enable customisation of the surrounding environment conditions mainly for people working in open space types of offices. Our measurement evaluated the system design and efficiency in different temperature states of the air: for the isothermal flow and for the heating and cooling of the supply air. A prototype of the micro air handling unit (a device for personal air customisation) was used for the measurement, a thermal manikin was used to simulate the convective boundary layers around a sitting human body. A Particle Image Velocimetry (PIV) was used to measure and visualise the air conduction and airflow interaction. The thermal manikin was also measuring the thermal comfort of the user in different modes of operation.
Keywords: *personalized ventilation, micro air handling unit, thermal comfort, thermal manikin, PIV anemometry*

Článek se zabývá možností přizpůsobení teploty přiváděného vzduchu v systému personalizovaného větrání a dopadem takové úpravy na efektivitu daného systému a tepelný komfort uživatele. Systém personalizovaného větrání byl navržen pro úpravu prostředí v blízkém okolí uživatele a to převážně pro pracovníky ve sdílených kancelářích typu open-space. Prováděná měření mají za cíl zhodnotit, jaký má navržený systém s úpravou teploty reálný dopad na tepelný komfort, a jestli je pro takovou možnost správně nastaven. Pro měření bylo použito prototypu mikro klimatizační jednotky (zařízení pro osobní úpravu a distribuci vzduchu), termálního manekýna, který zároveň simuloval chování konvektivních proudů vzduchu kolem lidského těla a měřil dopad teploty a množství přiváděného vzduchu na uživatele. Pro měření a vizualizaci proudění bylo využito anemometrie typu PIV (Particle Image Velocimetry).
Klíčová slova: *osobní větrání, personalizované větrání, mikro klimatizační jednotka, tepelný komfort, PIV anemometrie, termální manekýn*

INTRODUCTION

We live in an age where the majority of people are continuously separated from the outside world and are enclosed by an impermeable building envelope. We spend almost 90 % of our time inside buildings or in means of transport [1]. Separation between the indoor and outdoor environment is necessary to decrease our energy needs, but, in many cases, it has a negative impact on the environment in which we spend the majority of our time. A lot of people do not have access to a healthy environment today and it is becoming a problem that we should seriously deal with.

A personalised ventilation system is one of the modern alternatives to create a healthy, adaptable and energy efficient indoor environment in places shared by many people, like open space offices, where it is quite difficult to maintain a good quality environment by a central ventilation system. Personalised ventilation provides fresh air directly to the places where it is needed the most, in the personal zone of every user. It creates a customised space for every person in the room, which lowers the risk of disease transmission, increases the wellbeing and productivity of the users [1]. It is also more adaptable to personal differences and needs caused by the uniqueness of every person and their actual condition [9]. The impact of the standard personalised ventilation has been measured in several studies [1, 6], but what if we can personalise not just the amount of air supply, but even its temperature?

Problem description

In our previous work, we designed a personalised ventilation system, which uses a micro air handling unit as personal device to customise the air temperature and volume. In previous studies we dealt with the efficiency of the fresh air distribution, the shape of the airflow and other conditions of the personalised ventilation system in an isothermal state (which means that the supply air had the same temperature as the room's air) [3]. But the unit was designed to mainly operate in non-isothermal modes. In this study, we focused on the thermal comfort of the user and the efficiency of the ventilation, if the unit is in a heating or cooling mode.

Experimental setup

For the measurement, we used a prototype of the personalised 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 a micro air handling unit placed in the doubled floor space and personalised ventilation diffusers mounted on the workspace. It is connected by insulated piping. The system design and layout is shown in Figure 1. The micro air handling unit sucks the fresh air from the doubled floor. Through its fan and Peltier cells, it is able to adjust the volume and temperature of the air supplied to the personalised ventilation. The range of the air temperature supply is approximately 8 K (from -4 to +4 K) and the air flow supply rate is from 20 to 50 m^3/h. The personalised diffusers are mounted on the

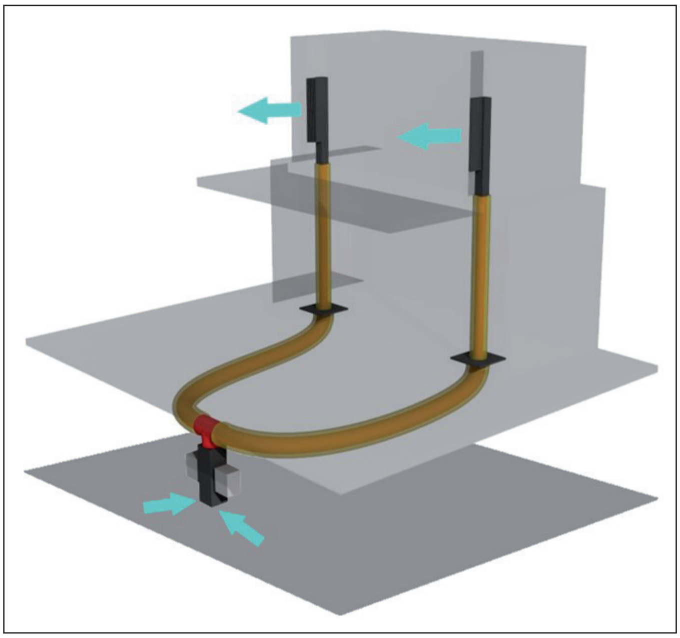

Fig. 1 The system of the personalised ventilation used in the measurement.

back corners of the workspace table (from the users perspective), and are directed to the middle of the opposite side.

To simulate the real velocity field of the air around the human body and to measure the thermal comfort of the user, a thermal manikin was used. It is a physical model of a male human body and produces convective boundary layers similar to a real user. For measurement of the air velocities, a Particle Image Velocimetry (PIV) was used. It creates a thin laser layer illuminating the particles spread into the air. The movement of those particles is captured on fast capturing cameras and the velocity field is then computed from the particle shift.

The measurement was set to simulate a regular workspace in the office. The manikin was sitting in front of the table and the diffusers were placed in the back corners as should be used in the real situation. In Figure 2, we can see the layout of the measurement and a presumed flow from the diffusers based on the previous CFD simulations [8] and measurements [3]. We can see, from Figure 2, 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 (the airflow shape used in Figure 2 is based on the CFD simulation and was verified by the measurement, it is noticeable that the flow does not come from the side, but develops in the measured area in the figures in the result part).

The manikin was clothed to a clothing value commonly used in offices. We used a long-sleeved shirt and a pair of trousers to set the thermal insulation value to 0.54 clo. The manikin was set to a surface

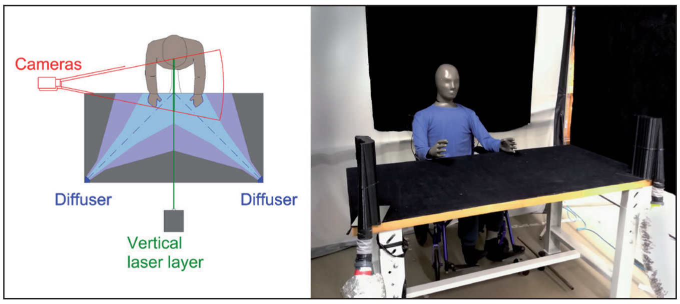

Fig. 2 The measurement setting

temperature of 35 °C, it was neither breathing nor was producing any moisture.

The room temperature was set to 24 °C and measured at three points of different height (the ankles, belly and head of sitting person) as required by the standard. The deviation of the ambient air temperature during the measurement was 0.63 K and the ambient air velocity was in the range of 0.05 to 0.13 m/s at 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 a deviation of less than 0.3 K for each separate measurement. The room was equipped with a separate cooling and heating system to keep a steady temperature.

Three different modes of operation were measured – isothermal, heating (+4 K) and cooling (-4 K) and every mode of operation were measured for two airflow volumes – 25 and 50 m^3/h.

EXPERIMENT 1 VELOCITY FIELDS

One can see the setting of the PIV anemometry in Figure 2. The laser was set in a vertical position in the middle of the table in front of the manikin to measure the airflows around its chest and the head. Two cameras for the PIV anemometry were placed in a vertical setting (to extend the measured area) and measured the 2-dimensional array.

The average vector field is computed from 50 continually captured images and the time sample (length of capture) is about 2 minutes. Measurements were conducted after a steady state was achieved.

The velocity field results

In the results, we can see that the main flow was influenced by three main effects. The first is the interaction of the two diffusers, which is mostly visible on the flow with a lower volume and velocities. The main connected flow develops in front of the manikin at the edge of the table and continues towards the manikin. The second effect represents the convective boundary layers around the human body, caused by the difference between the air temperature and the surface of the body. It creates a vertical flow with air 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 the diffusers and changes its direction upwards. It has a major influence on the efficiency of the personalised ventilation and its ability to supply fresh air to the breathing zone [6]. The last effect is the buoyancy force of the air supply of different temperature, which is quite strong, although the difference is only 4 K. It also has a significant impact on the efficiency of the ventilation, because the diffusers were primarily designed for isothermal conditions.

The first measurement was made in the isothermal state as the system was originally designed. One can see from Figure 3 that the results look 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 a microenvironment of moving fresh air as was simulated and measured in previous studies. Even in higher volumes, the air velocity of supply air does not exceed the limits of the draft. It ranges in an optimal range between 0.1 and 0.2 m/s around the manikin.

The air flow of the heating mode of the personalised ventilation shows slightly worse results. The temperature of the air supply was set to 28 °C and we can see that the buoyancy effect deflects the fresh air flow upwards above the head of the user in Figure 4, 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 the design of the diffuser has to be changed in further development to balance the buoyancy force by the direction of a muzzle velocity vector.

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 set to 22 °C. The airflow slightly cools the surface of the chest and lowers the velocity of the convective layers, which both benefits the personalised ventilation efficiency, but it can cause a temperature discomfort for the hands if the air temperature is too low. The velocity can also cause a problem because it is almost reaching the velocities of the draft (about 0.25 m/s) in the zone of the hands.

EXPERIMENT 2 THERMAL COMFORT

The thermal manikin is a well-known device, widely used for measuring the temperature balance and feeling of the human body and translates 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 the open space indoor environment of buildings. It measures many separate zones of the body and can define the places of comfort and discomfort caused by drafts or inappropriate temperatures. It also produces heat as a standard human body does, which is crucial for the interaction of the personalised ventilation diffuser flow with conductive boundary layers of the human body.

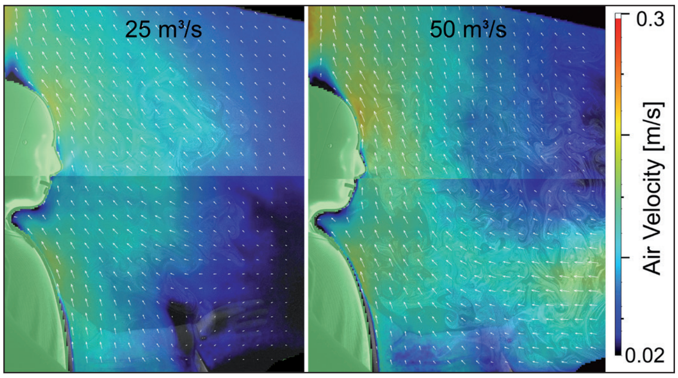

Fig. 3 The isothermal state of the ventilation for a 25 and 50 m³/h volume of air supply

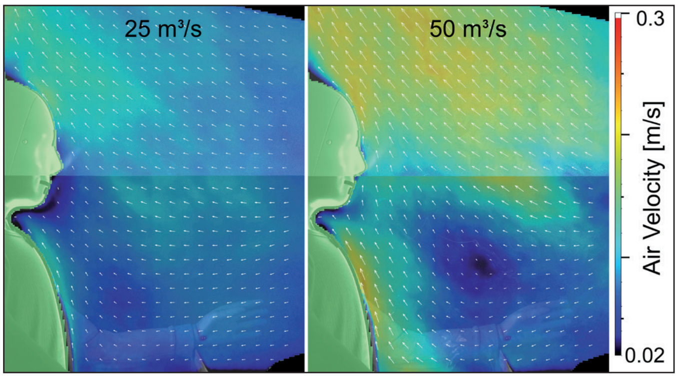

Fig. 4 The heating mode of the personalised ventilation for a 25 and 50 m³/h volume of air supply

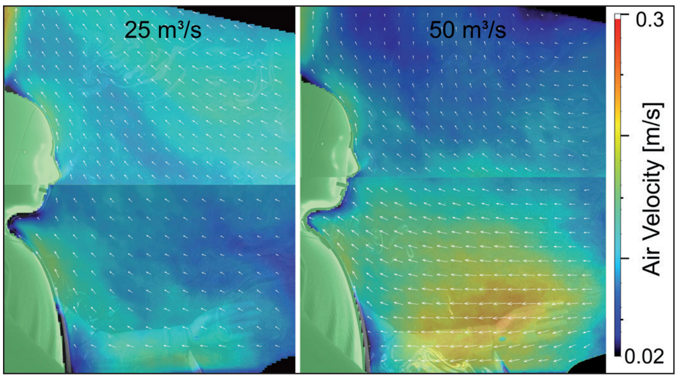

Fig. 5 The cooling mode of the personalised ventilation for a 25 and 50 m³/h volume of air supply

For our measurement, we used a Czech standard for the measurement with the 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 the manikin to heat the zone and keep the temperature on the set value.

The measurement of the thermal comfort by a thermal manikin uses the TMS (thermal manikin sensation) method instead of the equivalent temperature t_{eq}. There are two values, TMSo (thermal manikin overall sensation) and TMSz (thermal manikin zone sensation). This new index enables the easier interpretation of the results and comparison with the widely used PMV (Predicted Mean Vote) index also. To compare the results with the PMV index, the standard 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].

Results and discussion

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

Each zone had its own different sensitivity to the different influences and we can see how the velocity field impacts the results. In our case, the thermal comfort shift is based on both the air temperature and the velocity, but it differs not simply by the mode. For example, we can see that the heating mode feels colder than the cooling mode in the face zone that for 25 m³/h. It is caused by the upward direction of the flow in the heating mode and higher velocities around the face. In the cooling mode, the main velocity field is centred by the hands and the belly and the air velocity around the face is lower. Another interesting fact is that the lower air volumes cool the body under the desk more. It is probably caused by the 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 the effect is on someone working and changing their posture often. We can see the example of the different impacts in different places 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 the cooling and heating of the air supply has its impact on the thermal comfort. And although it is not significant, it is in the scale we were trying to achieve, because the temperature customisation is not meant to completely change the

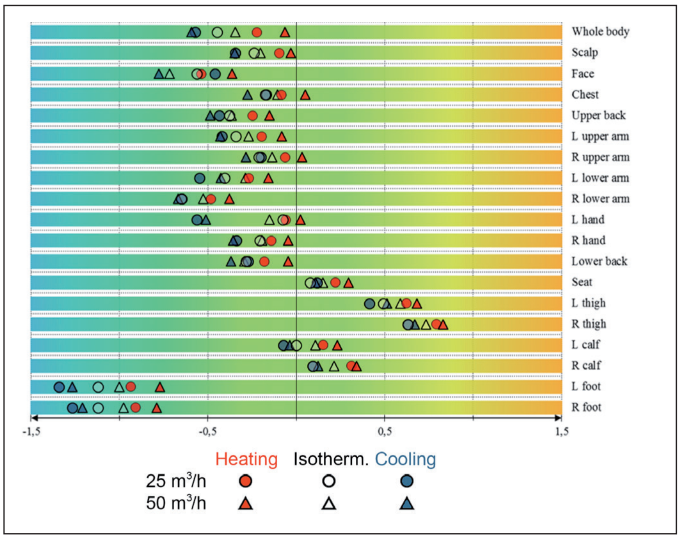

Fig. 6 The impact of the heating and cooling system to the thermal comfort zone

environment, just make it more personalised. However, the environment is not as stable as we wanted to have it.

CONCLUSSION

In our study, we were trying to measure the impact of the heating and cooling of the air supply of the personalised ventilation system. We heated and cooled the air by 4 K to measure the difference and compare it with the isothermal operation. Basically, we can say that the heating and cooling has an impact on the thermal comfort of the user and it can be used to adjust the temperature of the personal space. The possibility of the air customisation could have a positive effect on the wellbeing and the number of people dissatisfied with the environment.

On the other hand, we have to say that the present design of the personalised ventilation system is not as efficient as it could be and in the next research we should focus on creating a diffuser more adapted on the different temperature and A more stabilised environment could have better results on both the side of the thermal comfort impact and the ventilation efficiency.

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