Indoor climate in a simulated office room with personalized micro-environment and fully mixed ventilation systems

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One of the major challenges in modern buildings is to guarantee indoor air quality and thermal comfort in an energy-efficient manner. To fulfill both energy and indoor climate demands simultaneously, there is a need to introduce more advanced systems where users can influence their own local micro-environment.

Keywords: Personalized ventilation, Micro-environment system, Radiant panel cooling, Diffuse ceiling system, Indoor climate

In many cases, a good indoor environment and energy efficiency are seen as conflicting requirements. Therefore, novel heating, ventilating & air-conditioning (HVAC) systems are required to simultaneously achieve indoor climate and energy efficiency requirements. For that reason, more concerns have been focused on the novel solutions e.g. micro-environment of occupants to optimize energy usage and trade-off energy conservation and indoor comfort, where the main challenge is to supply clean air to the breathing zone and maintain thermal conditions.

In general, there is a need for a paradigm shift from a uniform indoor environment to a non-uniform indoor environment accommodating various individual preferences. The target should be to control local conditions when a person is at the workplace. There is also a need to introduce more advanced systems where users can influence their own local micro-environment.

Two concepts for micro-environment control

The current norm of having comfort conditioning systems that are designed for an average person, where the thermal comfort and indoor air quality conditions of individuals are deemed to be impossible to fulfill, is changing fast. The development of more advanced smart systems should be, and is being, introduced to improve indoor climate conditions for all the occupants of a space, not just the mythical average person.

Smart micro-environment systems refer to the capability of a building to sense, interpret, and respond to changing conditions, which are introduced by requirements of occupants to indoor climate, operation of technical building systems and demands of intelligent energy systems. Possibility to adapt in response to the perception of the occupants and further engage end-users makes it possible to enhance users' satisfaction to indoor climate. The main benefits of the novel system are that the controllability of indoor climate is enhanced in an energy-efficient manner, and that users' perception on the indoor climate is improved.

In literature, different personalized ventilation and micro-environment control systems are proposed. This paper introduces the results of two systems where radiant and convective cooling are utilized for micro-environment control (**Figure 1**).

In one of the studied personalized system PVRP, a PV (personalized ventilation) air terminal device (ATD) was installed on the desk at a distance of 40 cm from the dummy to supply fresh air directly to the breathing zone [1]. In the other personalized system LVRP, a low velocity unit was installed just over the radiant panels and the air was supplied through those panels [2].

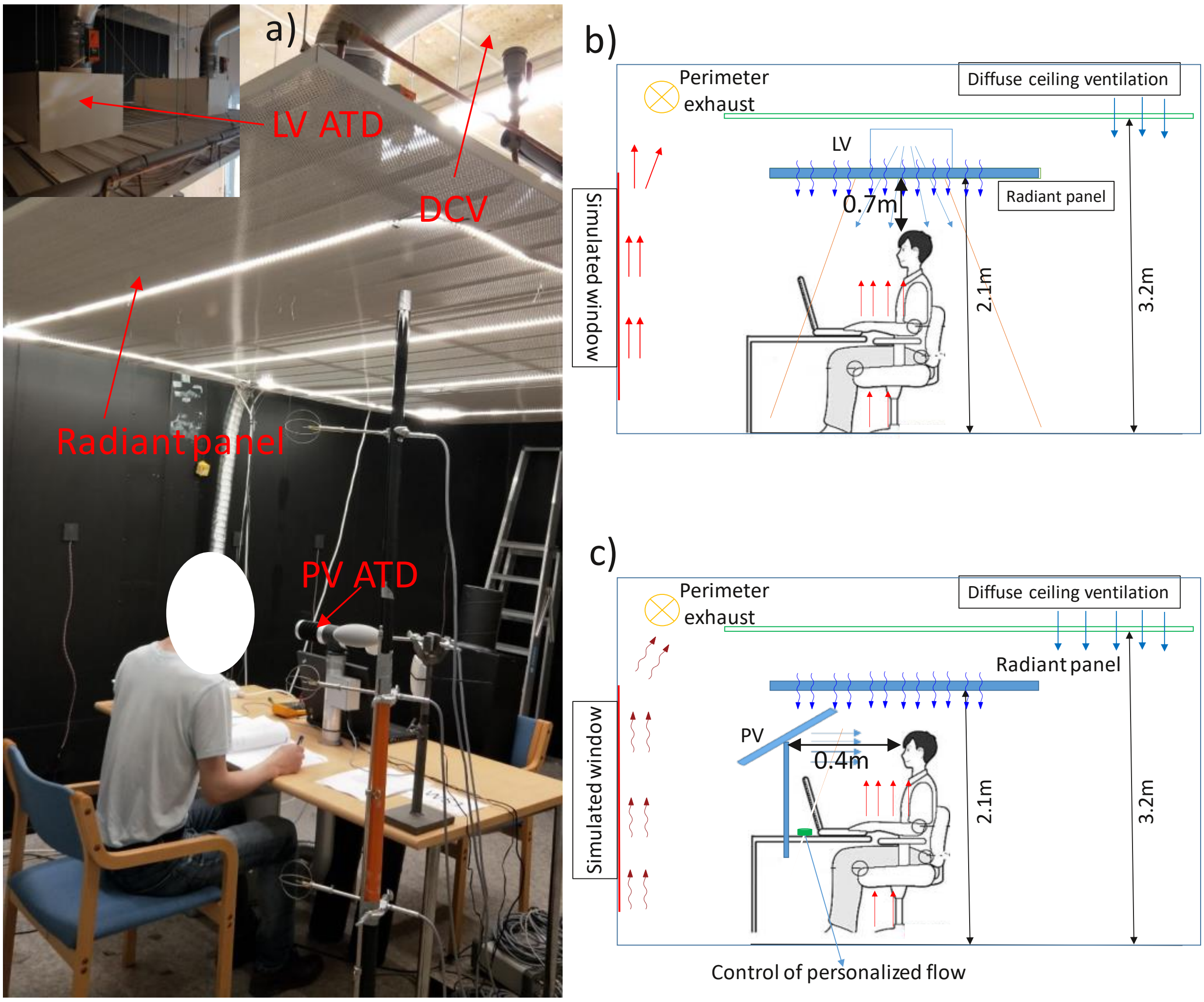

Figure 1. a) The set-up of low velocity unit and PV ATD at workstation. Two studied personalized systems b) low velocity unit and radiant panel (LVRP) and c) personalized ventilation unit and radiant panel (PVRP).

Diffuse ceiling ventilation was used to provide background ventilation outside the occupied zone. To evaluate the performance of the personalized system, it was compared with the all-air system- diffuse ceiling ventilation (DCV) in the same set-up condition.

The personalized systems were measured at 40, 60 and 80 W/m² heat gain levels. With the low velocity unit (in the LVRP system), the supply air flow rates were 10 ℓ/s and 15 ℓ/s. With the PVRP system, the supplied total airflow rate was kept the same (42 ℓ/s) with 60 W/m² and 80 W/m². The designed supply airflow rates were 7 ℓ/s, 10 ℓ/s or 15 ℓ/s from each PV air terminal device, and the rest of the required airflow is released from background ventilation (DCV system in this case). The room air temperature was kept constant at 23.5°C at the low heat gain of 40 W/m² and 26°C at high heat gains of 60 W/m² and 80 W/m². The total airflow rates used with the reference diffused ceiling system (DCV) were 78, 118 and 153 ℓ/s with 40 W/m², 60 W/m² and 80 W/m², respectively.

Smoke visualization of air distribution

Figure 2 shows the air movement with a 10 ℓ/s local air flow rate over the workstation. Smoke visualization indicates that the momentum flux of the jet was not strong enough to reach the dummy. When the local airflow rate was increased to 15 ℓ/s, the airflow from the low velocity unit was just strong enough to reach the level of the top of the dummy. This smoke visualization confirmed that the airflow rate of 15 ℓ/s could be used for local micro-environment control without significantly increasing the draught risk.

The airflow structure of the PV around the workstation was visualized by the marker smoke to assess the airflow pattern of the personalized system (**Figure 3**).

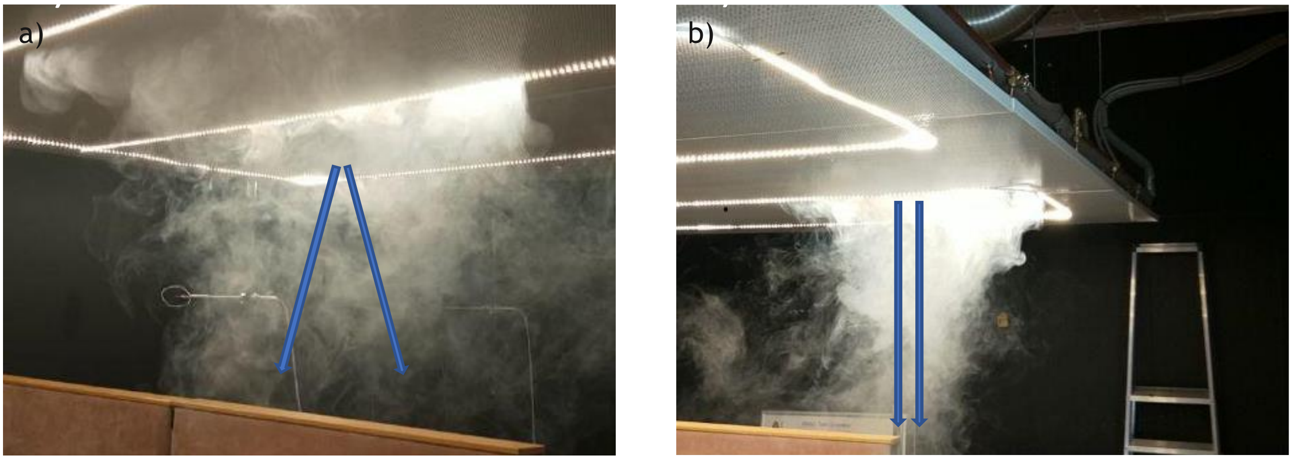

Figure 2. The smoke visualization of the low velocity system (LVRP) a) the local air distribution with the airflow rate of 10 ℓ/s and b) the local air distribution with the airflow rate of 15 ℓ/s. The blue arrows show the direction of the local airflow.

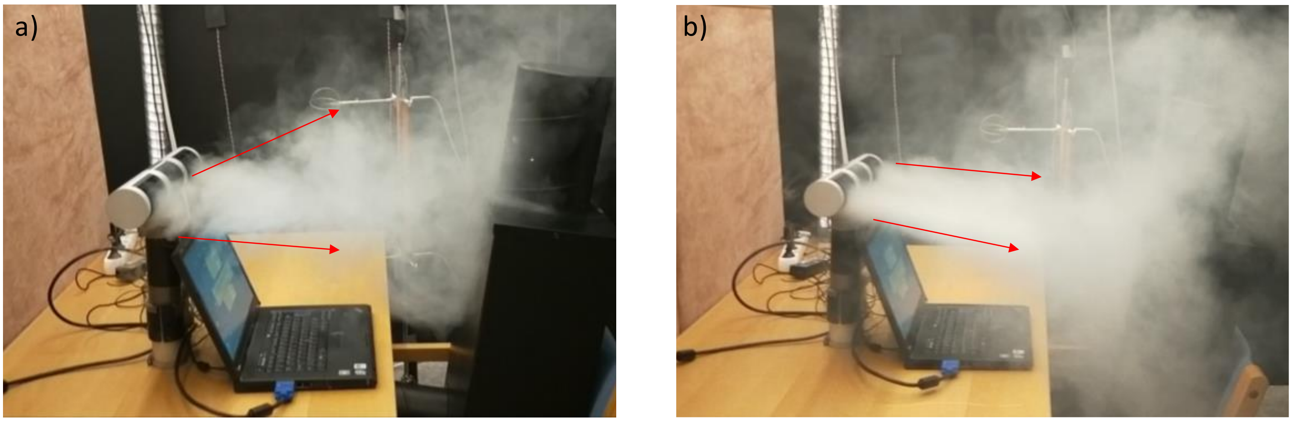

Figure 3. Smoke visualization of the personalized airflow pattern with PVRP system a) 7 ℓ/s and b) 15 ℓ/s. The red arrows show the main direction of the air jet.

When the personalized airflow rate was at the minimum setting (7 ℓ/s), the air jet turned slightly upward because of the combined buoyancy flow of the computers and dummy. However, the jet still reached the breathing zone. The momentum flux of the jet overcame the buoyancy effect, and the jet was able to reach the dummy when the personalized airflow rate was increased to 15 ℓ/s. The central axis of the jet was aligned with the level of the subject's chest, and after the jet collided with the dummy, it turned both downwards and upwards along the body. Hence, the personalized airflow entrained the convective boundary layer around the human body, and cooled down the upper body.

Air change efficiency

The air change efficiency (ACE) was between 60% and 70% with the personalized system (PVRP) depending on personalized airflow rate. ACE was higher than with the reference mixing system (DCV) system (less than 50%), as shown in **Figure 4**. With the personalized system, a higher ACE can be achieved despite supplying less outdoor air than with the DCV. Because the heat gain was distributed asymmetrically, the air was not fully mixed in the whole space. That led to an ACE of less than 50% with the DCV.

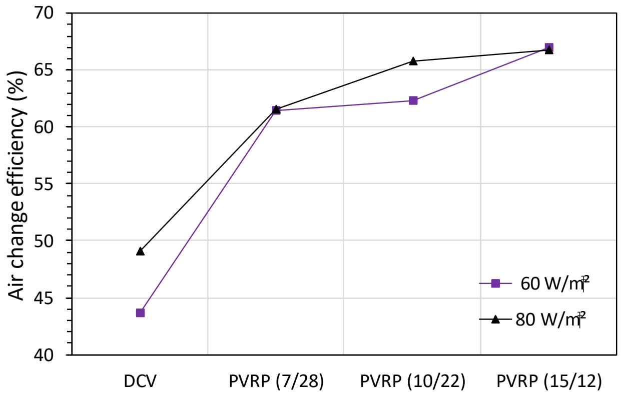

Figure 4. Air change efficiency with the personalized system (PVRP) and the reference mixing system (DCV).

The air change efficiency with LVRP was between 70% and 80%, with different conditions being higher than with the DCV (44%–49%) (**Figure 5**). Thus, the performance of the LVRP system was much better than that of the fully mixing ventilation which had an air change efficiency of 50%. This indicates that the LVRP system can achieve a higher ventilation effectiveness even with a lower airflow rate (42 ℓ/s) as compared to the DCV system (78–153 ℓ/s).

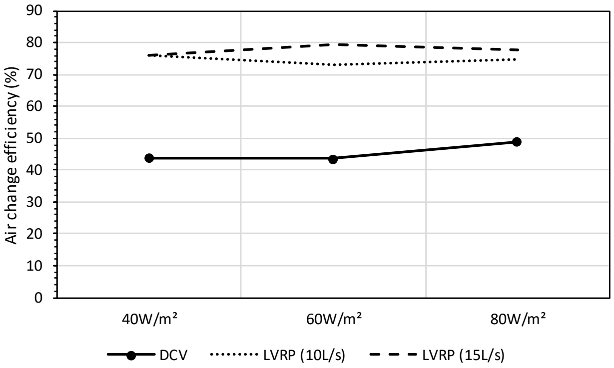

Figure 5. Air change efficiency with the personalized systems (LVRP) and the reference mixing system (DCV).

Draught risk

Figure 6 shows the vertical distribution of draught rate of LVRP system in the occupied zone with different heat gains and airflow rates. In all cases, the draught risk was quite small. Also, it shows that the average draught rates were 5.8% and 7.0% with the LVRP and DCV system from 0.1 m to 1.1 m at a heat gain of 40 W/m^2. The corresponding draught rate were 7% and 10% under LVRP and DCV with the heat gain of 80 W/m^2, respectively. With the DCV system, the draught risk at the 1.1 m height was also low (6%). However, the draught risk at ankle level (0.1 m) was much higher with the DCV (10%) than with the PVRP (less than 5%). The reason for the high draught risk of the DCV at the floor level was the return flow created from the corridor by the convection flows.

With the PVRP system, the draught risk (DR) was relatively low (**Figure 7**). The highest DR happened at the heights of 0.6–1.1 m. With the lower personalized airflow rate, DR was below 10% with PVRP system. When the personalized flow rate was increased to 15 ℓ/s, the draught risk increased to 12% and 18% at the 1.1 m level at 60 W/m^2 and 80 W/m^2, respectively.

Conclusion

The study shows that that it is possible to enhance system performance with micro-environment control systems, where users are able to control their own set points for room air temperature and indoor air quality, increasing the satisfaction on indoor climate conditions significantly.

This study compared the performance of the micro-environment control systems to that of a diffuse ceiling

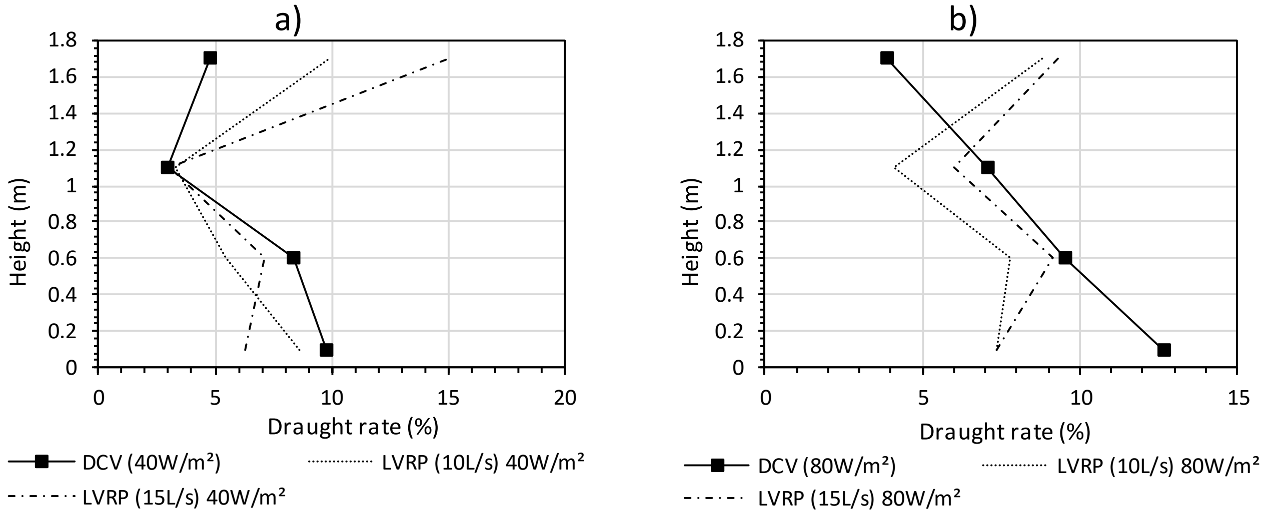

Figure 6. The vertical distribution of draught rate in the occupied zone under the DCV and LVRP system with heat gains of a) 40 W/m^2 and b) 80 W/m^2.

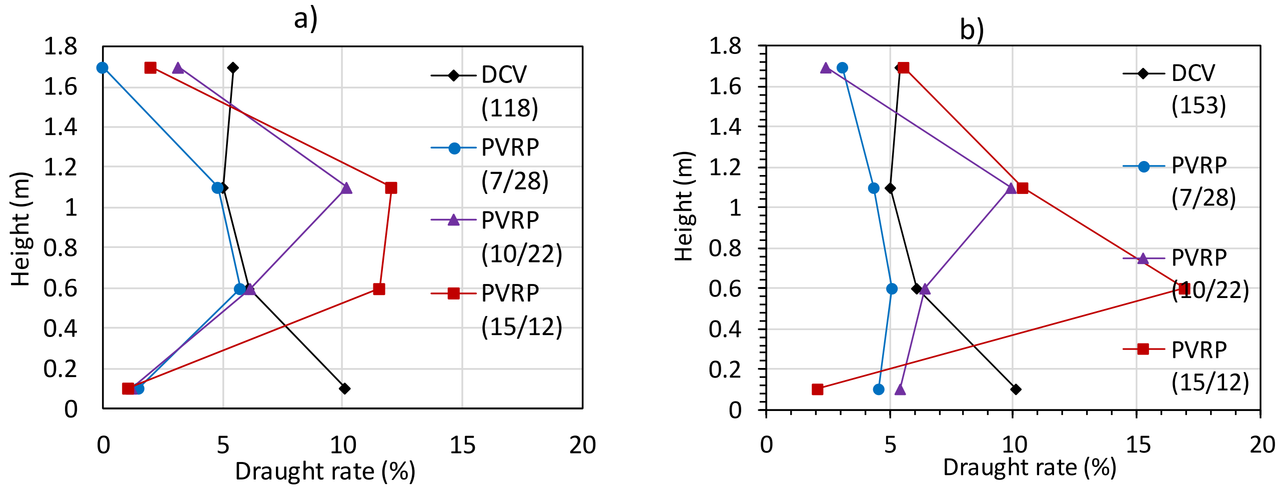

Figure 7. Draught risk under the PVRP and DCV systems at a) 60 W/m^2 and b) 80 W/m^2.

ventilation system (DCV) by experimental methods. The air change efficiency was over 60% which was better than the fully mixed flow (50%). The draught rate was between 10–15% in most of the cases. ■

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