The experimental study of the indoor climate with the micro-environment systems

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Abstract. One of the major challenges in modern buildings is to guarantee healthy indoor air quality and excellent thermal comfort in an energy efficient manner. In this study, the performance of two micro-environment systems combined radiant panel and convective flow was designed. In one of micro-environment system of personalized ventilation and radiant panel (PVRP), two local personal air terminal devices supplied clean air directly to occupants. In the other micro-environment system, low velocity unit was installed just over the radiant panels (LVRP) and the air was supplied through those panels. The radiant panels were used to satisfy the required cooling load. The results show 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, the satisfaction on indoor climate conditions increased significantly. Furthermore, the air temperature near the workstation can be maintained at designed value with the micro-environment systems. In particularly, the vertical temperature difference did not cause thermal discomfort with the micro-environment systems near the workstation.

Keywords. Micro-environment, Personalized ventilation, Radiant cooling, Thermal comfort, Airflow pattern
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1. Introduction

Building sector accounts for about one-third of the global greenhouse gas emissions and at the same time uses about 40% of the world's energy [1]. A considerable fraction of this energy use is utilized for achieving desirable indoor climate in buildings [2]. According to the European Commission, improved energy efficiency of buildings means maintaining good indoor air quality and thermal comfort levels with less energy use than before [3]. In the European Union, policies have been stricter according to the EU 2030 goals on energy efficiency demands in buildings to meet EU's long- term 2050 greenhouse gas reductions target, which is -30% in 2030 and -80% in 2050 compared the reference year of 1990 [4].

In many cases, a good indoor environment and energy efficiency are often seen as conflicting requirements. Therefore, novel Heating, Ventilating and Air-Conditioning (HVAC) systems are required to achieve simultaneously 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.

To maintain indoor air quality, international standards or design criteria, for example, [5, 6] typically require a ventilation rate of 4–10 L/s per person of outdoor air supply to office spaces. The air inhaled by each occupant is only 0.1 L/s [7]. Thus, this inhaled air is only 1% of the supplied air. However, the required supply airflow rate is typically much higher when the ventilation is used for cooling.

In general, there is a need for a paradigm shift from uniform indoor environment to non-uniform indoor environment accommodating various individual preferences [8]. The target should be only to control local conditions when a person is at the workplace. There should be also a need to introduce more advanced systems where users can influence their own local micro-environment. An individually controlled micro-environment by providing local heating/cooling of the body and body parts has a potential to satisfy a greater number of occupants in a space compared to a centrally controlled total volume environment [9-13].

The novelty of this paper is to introduce and analyse the performance of new ventilation and cooling systems where local micro-environment is created by using personalized ventilation or low velocity unit in a double office layout. In one of micro-environment system of personalized ventilation and radiant panel (PVRP), two local personal air terminal devices supplied clean air directly to occupants. In the other micro-environment system, low velocity unit was installed just over the radiant panels (LVRP) and the air was supplied through those panels. The radiant panels were used to satisfy the required cooling load.

2. Methods

The experimental measurements were performed in the steady-state laboratory condition. The measurements were carried out in a test chamber with internal dimensions of 5.50 m (length), 3.84 m (width) and 3.20 m height from the floor up to diffuse ceiling panels. The floor area was around 21 m2. The test chamber was located inside a laboratory hall such that the outer environment was stable.

In one of the studied personalized system, 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 [14]. In the other personalized system, low velocity unit was installed just over the radiant panels and the air was supplied through those panels [15], as shown in Figure 1. Diffuse ceiling ventilation was used to provide background ventilation outside the occupied zone.

The all studied systems were measured at 60 and 80 W/m2 heat gain levels. The supplied total airflow rate was kept the same (42 l/s) with two micro-environment systems. The local airflow rates were 10 l/s and 15 l/s with the personalized ventilation or low velocity unit and the rest of the airflow rate required is released from background ventilation (DVC system) as shown in Table 1.

Tab. 1 - Two tested airflow modes supplied to each workstation with two micro-environment systems.

	Normal mode	Boost mode
Airflow rate of PV/ low velocity unit terminal (l/s)	10*2	15*2
Airflow rate at unoccupied zone (DCV) (l/s)	22	12
Total airflow rate (l/s)	42	42

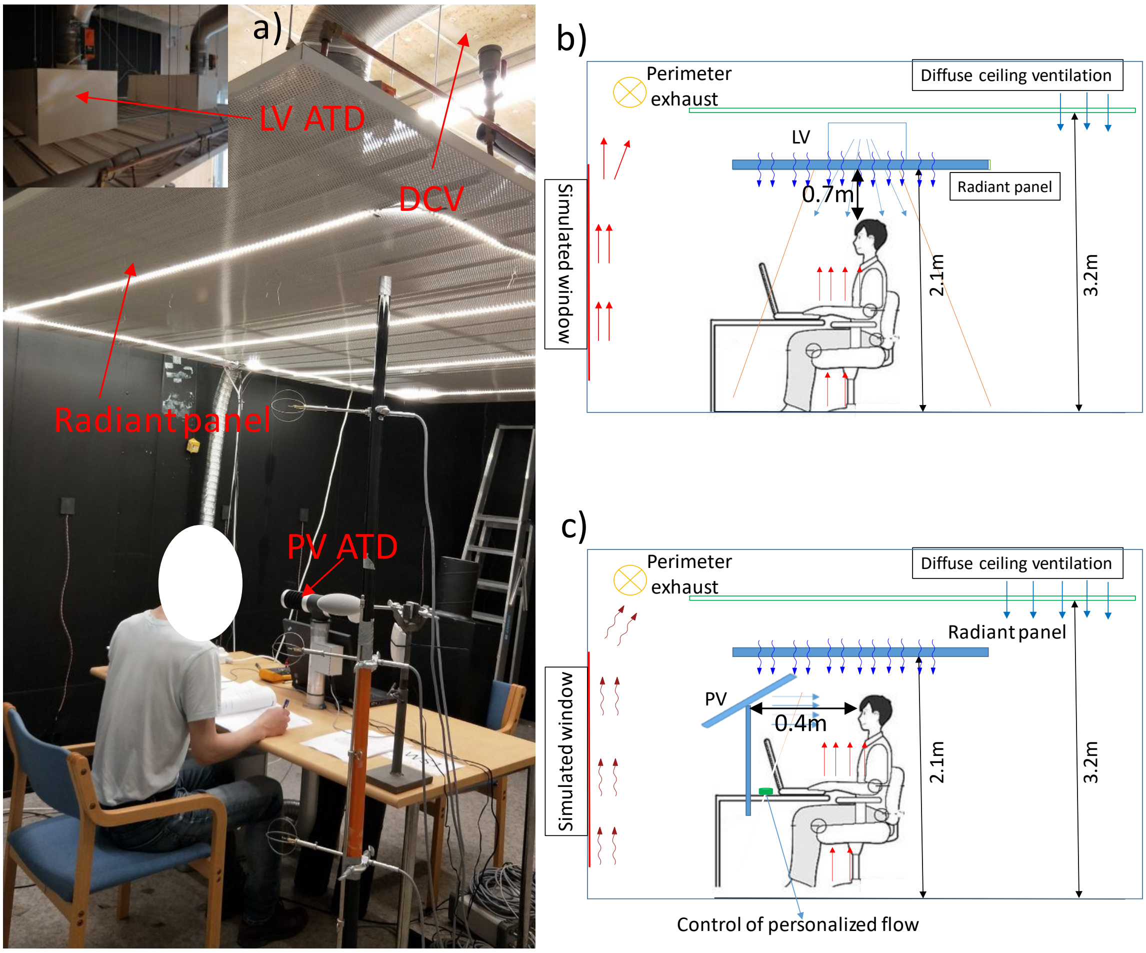

Fig. 1 - a) The set-up of low velocity unit and PV ATD at workstation. Two studied personalized systems, b) low velocity

unit and radiant panel (LVRP) and c) personalized ventilation unit and radiant panel (PVRP).

3. Results

3.1 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 increasing significantly the draught risk.

The airflow structure of the PV around the workstation was visualized by the maker smoke to assess the airflow pattern of the personalized system (Figure 3). When the personalized airflow rate was 10 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 effect of the buoyancy effect, and the jet was able to approach 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 existing the human body and cooled down the upper body.

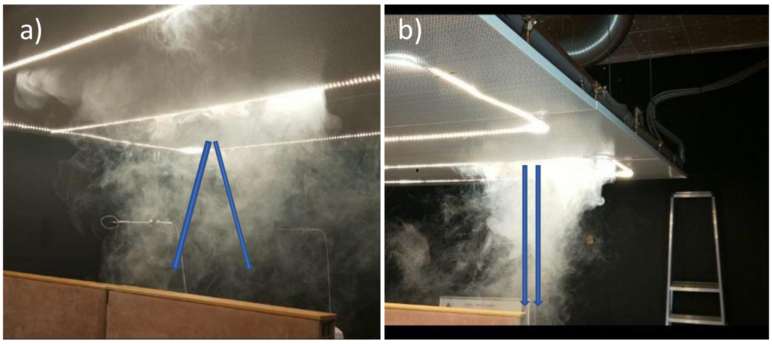

Fig. 2 - The smoke visualization of the low velocity system (LVRP) a) the local air distribution with the airflow rate of 10 l/s and b) the local air distribution with the airflow rate of 15 l/s. The blue arrows show the direction of the local airflow.

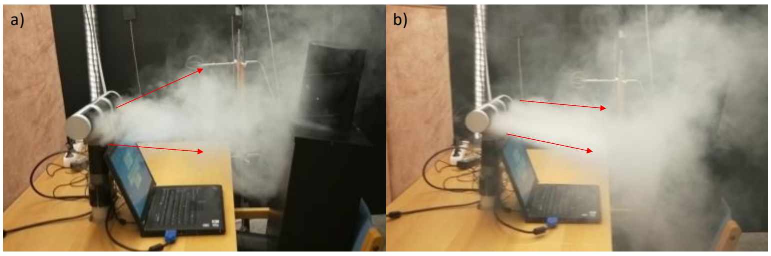

Fig. 3 - Smoke visualization of the personalized airflow pattern with PVRP system a) 10 l/s and b) 15 l/s. The red arrows mean the main direction of the air jet.

3.2 temperature profile

The temperature at the reference location as well as the exhaust air temperature with the two micro-environment systems were summarized in Table 2. Air temperature, operative temperature and mean radiant temperature all decreased with the increasing local airflow rate. The average temperature difference between the exhaust air and room air at the reference point was rather significant (from 0.7°C to 1.9°C), especially with a higher local airflow rate. Also, this difference was bigger with a higher heat gain level. Therefore, better thermal comfort can also be achieved in the micro-environment near the workstation at the higher heat gain level.

Tab. 2 - The average thermal conditions in different test cases.

	LVRP 60 W/m^2		LVRP 80 W/m^2		PVRP 60 W/m^2		PVRP 80 W/m^2	
Measurement results at occupied zone	10 L/s	15 L/s	10 L/s	15 L/s	10 L/s	15 L/s	10 L/s	15 L/s
Air temperature (°C)	25.9	25.9	26.1	25.9	25.9	25.6	26.5	25.9
Exhaust temperature (°C)	26.3	26.9	26.9	27.4	26.1	25.9	26.2	25.9
Operative temperature (°C)	26	25.8	26	25.8	26.3	25.9	26.2	26
Mean radiant temperature (°C)	26.1	25.9	26	25.9	26.1	25.9	26.7	26.5
Average difference between room air at the reference point and operative temperature (°C)	-0.07	0.08	0.1	0.11	-0.17	0.06	0.05	-0.13
Average difference between exhaust-room air temperature at the reference point (°C)	0.99	1.63	1.22	1.92	0.24	0.31	0.25	0.57

3.3 Draught risk

Figure 4 shows the vertical distribution of draught rate of all studied systems in the occupied zone with 80 W/m^2. With the LVRP system, the draught risk was quite small, less than 10%. With PVRP system, the draught risk (DR) was relatively low. 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 to18 % at the 1.1 m level at 80W/m2.

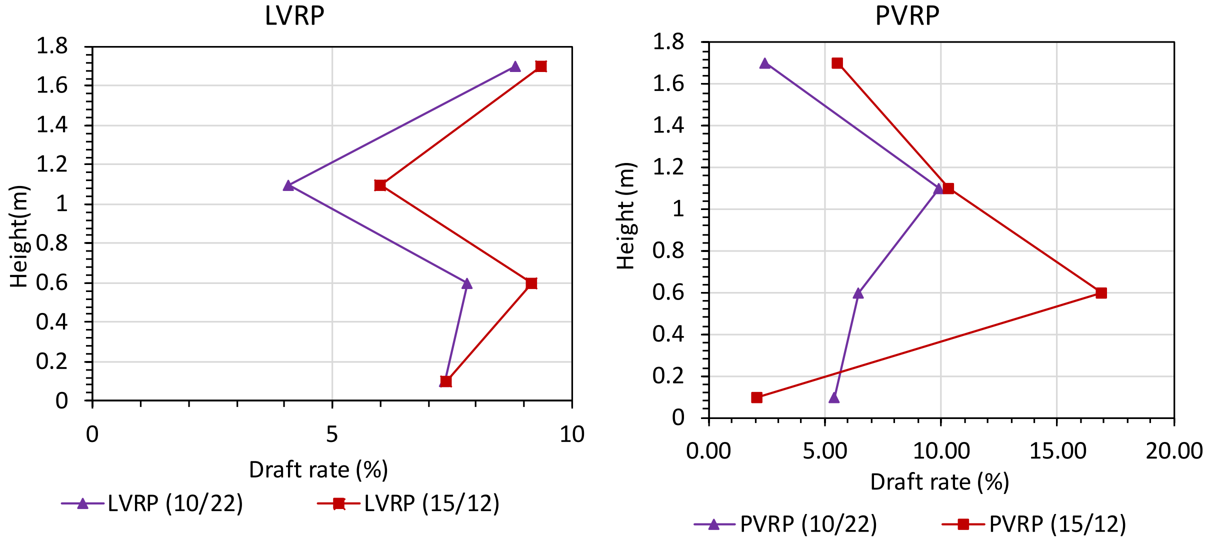

Fig. 4 - The vertical distribution of draught rate in the occupied zone with heat gains of 80 W/m2.

4. Conclusion

This study analysed the performance of the micro-environment control systems by experimental studies. 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, the satisfaction on indoor climate conditions increased significantly. The smoke visualization showed that the PV or low velocity unit supplied the fresh air directly to the occupants and created a micro-environment around the dummy. The mean temperature in the micro-environment at the workstation can keep at design 26°C. Also, the draught rate was between 5-20 % in most of the cases. With a higher local airflow rate, the draught risk at 0.1 m can remain at a reasonable value without discomfort.

5. Acknowledgement

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