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ENERGY SAVING POTENTIAL OF A VENTILATED SEAT CUSHION

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SUMMARY

Local exhaust ventilation method called Ventilated Seat Cushion (VSC) has been developed and proven to be efficient method for minimizing the spread of body released contaminants in the breathing zone of occupants. In this study, the VSC was assessed for its potential to save energy in mechanically ventilated buildings. The energy saving potential of the VSC was assessed by means of dynamic computer simulations. IDA ICE energy simulation program was used to calculate the energy use of a call-centre, which was air-conditioned with fourteen chairs each equipped with a VSC, variable air volume (VAV) room mechanical ventilation and radiant ceiling. The estimated annual energy use for the call-centre using the VSCs combined with VAV and radiant ceiling was compared to the annual energy use when the VSCs were not in operation. The obtained results show that combining the VSC with background VAV ventilation and radiant ceiling panels for cooling reduced the annual energy use by 7% compared to a system with only VAV ventilation.

Keywords: local exhaust ventilation, indoor air quality, local body cooling, energy saving

1 INTRODUCTION

Studies have shown that localized exhaust ventilation methods are more efficient to minimize the spread of contaminants in the breathing zone of occupants than the conventional mechanical ventilation of the entire room volume (Bolashikov et al., 2015; Melikov, 2011; Melikov and Dzhartov, 2013; Yang et al., 2014). These previous studies, however, have mainly focused on controlling and preventing the airborne transmission of infectious diseases due to human expiratory activities or reducing exposure to room pollution. Recently, experimental studies (Bivolarova et al. 2016, 2017) investigated the effectiveness of using local exhaust ventilation to remove body generated bio-effluents while a person is seated on a chair and thus to reduce the indoor exposure to those pollutants. Ventilated Seat Cushion (VSC) was used as local exhaust ventilation. It was found that the VSC could remove bio-effluents released from the human body before the pollutants mixed with the room air (Bivolarova et al. 2016).

Studies have reported that ventilated office chairs may provide thermal comfort to occupants at elevated ambient temperatures (Kogawa et al., 2007; Watanabe et al., 2009). As a result, the room air temperature can be elevated above the limits recommended in the standards. This suggests that such method has potential for energy savings. It has been reported that the air movement caused by the VSC's exhaust flow rate provides also local body cooling (Bivolarova, 2017). As already discussed the potential of the ventilated seat cushion to improve occupants' inhaled air quality has been documented as well. However, its performance with regard to energy saving is unknown and needs to be explored.

The specific objective of this study was to identify the energy saving potential of the VSC in buildings with mechanical ventilation.

2 METHODS

2.1 Simulation tool

The energy simulations were carried out using the building energy performance simulation software IDA ICE 4.7 (EQUA Simulation, IDA Indoor Climate and Energy).

2.2 Simulation model

The simulated model in IDA ICE was a call-centre. The model was selected because call-centre operators usually perform seated work for long periods of time. The number of operators on duty, room size and time of operation (time spend by the desk) and building location were adopted by a field study of Wargocki et al. (2004). The study investigated the indoor air quality and work-performance in a call-centre located in Copenhagen, Denmark. The call-centre room was planned as an open-space office with a floor area of 154 m² (17.5 m x 8.8 m x 2.9 m, L x W x H). There were no internal partitions in the model. The external construction of the call-centre consisted of a brick wall (U-value = 0.26 W/m²K), roof (wooden construction with U-value = 0.10 W/m²K), internal lightweight concrete wall (U-value = 0.54 W/m²K) and internal floor (concrete slab with U-value = 2.9 W/m²K). The roof and two of the walls were considered external. The external walls were facing east and west. On each external wall there were seven windows (Figure 1). Each window had an area of 2.25 m² (in total 31.5 m²) and a window-to-floor surface ratio of 20%. The windows were composed of three layers of 4 mm panes with two layers of 12 mm air gap in between. The overall U-value was 1.1 W/m²K, a g-value (solar heat gain coefficient) equal to 0.68, and a light transmittance equal to 0.74. All windows of the call-centre had integrated blinds between the window panes. The blinds were descended when the incident light exceeded 100 W/m² on the inside of the glass.

Figure 1. IDA ICE model of the call center with external facade facing east.

2.3 Air-conditioning systems

The call-centre was air-conditioned with variable air volume (VAV) system, water radiator and in some cases chilled ceiling to remove the excess heat. All HVAC systems for the call-centre were running one hour before the occupancy started and one hour after the occupancy ended resulting in the following schedules: Monday to Friday 6:00 to 24:00, Saturday 6:00 to 16:00, and Sunday 13:00 to 22:00. It was assumed a 70% of the total ceiling area to be covered with radiant heating and cooling panels in order to avoid radiant asymmetry. The radiant ceiling was dimensioned to keep the necessary thermal conditions in the models without causing water condensation on the panels. Condensation on the panels was avoided by limiting the supply water temperature to be above the indoor dew-point temperature. The input parameters of the radiant ceiling installed in the model are listed in Table 1.

Table 1. Parameters for the radiant cooling panels in the call-centre.

Maximum indoor air temperature	26°C	28°C
Parameters	-	-
Panel width [m]	1	1
Panel length [m]	8	8
Panel area [m^2]	8	8
Capacity per panel [W]	641	525
Number of panels [m]	9	9
Total capacity [W]	4724	5767
dT(room operative-mean water) [°C]	7.9	9.2
dT(outlet water-inlet water) [°C]	6.3	7.6

2.4 Heat gains and occupancy schedule

The room was occupied by 14 phone operators with activity level set to 1.2 met, which corresponds to 70 W/m^2. The operators were present in the call-centre from Monday to Friday, from 7:00 to 23:00 including no breaks. On Saturday, the operators were present from 7:00 to 15:00 and on Sunday 14:00 to 22:00 including no breaks either of the days. It was assumed that all operators were coming to the centre at the same time. No holidays were included in the simulations. The heat gain from general lighting was estimated to be 5 W/m^2. The heat load from equipment (14 desk lamps, 6 wall monitors, and 28 personal monitors) was 1450 W in total. The use of lighting and other equipment followed the schedule of the occupants (they were turned off when the occupants were not present). IDA-ICE takes into account the emitted from the occupants sensible and latent heat.

2.5 Simulated conditions

The energy simulations were carried out with the VSC operating together with reduced background mixing ventilation (MV) and radiant ceiling panels used for cooling. The results were compared to MV alone at airflow rate based on the air quality requirements defined in the standard EN 15251 2007 for category II, very low polluting buildings. According to this category, the standard requires 7 L/s per occupant (q_{occ}). In the simulations, it was assumed that the 7 L/s could be decreased by 53%, 81% and 89% when the VSC exhaust flow rate was 1.5, 3 and 5 L/s, respectively. This assumption was based on the exhaust efficiency of the VSC to reduce bio-effluents from the body shown in the study by Bivolarova et al (2016). Therefore, when exhausting 1.5, 3 and 5 L/s through the VSC, the supply background ventilation rate per occupant was reduced to 3.2, 1.3 and 0.8 L/s, respectively. The ventilation rate for building emissions (q_b) was selected to be 0.35 L/s.m^2, which corresponds to the standard criteria of very low polluting buildings (EN 15251, 2007). Finally, the total airflow rate (q_{tot}) was calculated for each case as follows:

$$q_{tot} = A \cdot qb + q_{occ} \cdot n + q_{vsc} \cdot n \qquad (1)$$

Where:

q_{tot} - Total volume ventilation rate of the room [L/s],

A – Room floor area [m^2],

q_b - Ventilation rate for emissions from buildings [L/s]

q_{occ} - Ventilation rate per person from the MV [L/s],

n - Number of persons in the room,

q_{vsc} - Ventilation rate per person from the VSC [L/s].

Since, VAV ventilation was used in the call-centre, the estimated q_{tot} was the maximum possible supply ventilation rate. The VAV system adapted the airflow rate needed to keep the required CO_2 level and operative temperature limits. The supply air temperature was kept constant for all simulations and it was set to 16°C. The lower limit of the indoor operative temperature set-point was always 20°C and the upper limit was either 26°C or 28°C. The design indoor operative temperature range of 20-26°C complies with recommendations for thermal comfort conditions for category II in the EN 15251 (2007). The maximum allowed room temperature was expanded from 26°C to 28°C in order to study the importance of using the VSC cooling effect for possible energy-savings. The maximum CO_2 level was set to 900 ppm (500 ppm above outdoors) which complies with category II in the EN 15251 (2007).The minimum airflow rate was set to 0.35 L/s.m^2 (corresponding to airflow rate due to pollution from the building). For the reference case of MV alone, the VAV system's maximum supply airflow rate was calculated based on the total heat load in the call-centre for supply air temperature of 16°C and room temperature of 24°C. The total heat load due to occupants, equipment and solar gain was calculated to be 4044 W. The maximum supply airflow rates for the simulated cases are listed in Table 2.

Table 2. Maximum supply airflow rates from the VAV system in the call-centre for different VSC exhaust flow rates and air-conditioning systems.

VSC flow rate	System	Maximum total air flow rate
VSC: 0 L/s	MV	421 L/s
VSC: 0 L/s	MV/RC*	152 L/s
VSC: 1.5 L/s	MV/RC/VSC**	120 L/s
VSC: 3 L/s	MV/RC/VSC	114 L/s
VSC: 5 L/s	MV/RC/VSC	135 L/s

*Mixing ventilation combined with radiant ceiling
**Mixing ventilation combined with radiant ceiling and ventilated seat cushion

Infiltration due to wind driven flow was taken into account and it was equal to 0.5 ACH at a pressure difference of 50 Pa.

To estimate the annual use of primary energy delivered to the call-centre, several assumptions were made regarding the generation and transformation of the energy. District cooling with a COP value of 4 was used to supply cold water to the air handling unit's (AHU's) cooling coil and the chilled ceiling. District heating with a primary energy factor equal to 0.6 was used to supply heat to the AHU's heating coil and the radiators, and electricity with a primary energy factor equal to 1.8 was supplied to the electrical systems such as fans, circulation pumps and lighting. The selected COP and primary energy factor values complied with low energy class 2020 building according to the Danish Building Regulations 2015 (BR 15, 2015).

3 RESULTS AND DISCUSSION

The results of the energy simulations presented in Figure 2 show that energy savings can be achieved when applying sustainable heat removal, i.e. radiant ceiling panels for cooling (also known as chilled ceiling) combined with MV. In the MV/RC case and room operative temperature within $20 - 26°C$, the use of the chilled ceiling (without the VSC) decreased the energy use with approximately 7% compared to the case with only MV. For this temperature set-points, 20/26°C, the results show that applying the VSC combined with reduced background ventilation (MV) and RC (i.e. case MV/RC/VSC) did not lead to further energy savings compared to the case MV/RC. However, neither the energy use increased in this case. Thus, removal of human body bio-effluents by means of the VSC (i.e. increase of air quality)

can be achieved without the need to increase the energy use. The VSC operating at the three different airflow rates kept the energy use constant at 52 kWh/m^2 and at 50 kWh/m^2 for the temperature set-points 20/26°C and 20/28°C, respectively. These results indicate that the increased airflow rate from the VSC, namely from 1.5 L/s to 3 L/s and 5 L/s, applied on the 14 workstations does not increase the energy use. This can be explained with the principle of the VAV control. Therefore, the supplied airflow rate was automatically reduced when the designed q_{tot} (the maximum airflow rate) was not required to sustain the CO_2 and the temperature set-points. If the ventilation system in the simulation model had been designed as a constant air volume (CAV) system, the increase in the energy use would have been proportional to the increase of the supply flow rate. A CAV system in general is more energy consuming compared to a VAV system and consequently the yearly energy use would be higher for all simulation cases. Further studies on energy saving potential may therefore comprise other control set-points of the HVAC systems for CO_2 in order to improve the demands for maximum airflow rates. As expected, when the set-points for the room operative temperature were expanded in the MV/RC/VSC cases (20/28°C) the energy use was decreased with about 10% compared to MV alone and with 4% compared to the MV/RC operating at set-points 20/26°C. This was because extended upper temperature set-point was achieved at reduced background ventilation rate (q_{tot} reduced from 421 L/s in MV to 152 L/s in MV/RC and to the range 114-135 L/s in the conditions with MV/RC/VSC). At elevated room temperature thermal comfort can be improved by the local cooling provided by the ventilated seat cushion.
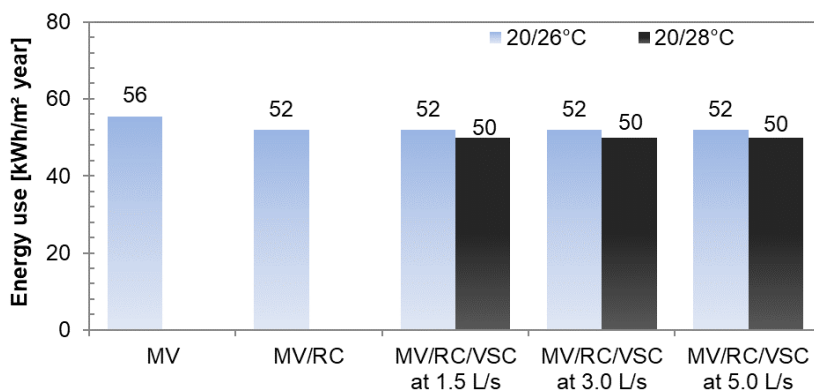

Figure 2. Yearly primary energy use for all cases with room temperature set-points of 20/26 °C and 20/28 °C.

The findings from the performed dynamic energy simulations have important implications for improving the methods for delivery of conditioned air with regard to energy use in indoor environments, where people spend considerable amount of time sitting. However, these findings need to be interpreted with caution as they are specifically valid for the current simulated model comprising a specific room type, room temperature set-points, cooling and heating methods, equipment, etc. More realistic results on the energy performance of the VSC might be obtained by conducting human subject experiments during which individual control of the flow rate through the cushion is provided. As a result, energy calculations can be performed based on a more realistic energy use pattern that would be identified from such experiments.

4 CONCLUSIONS

The results of the performed energy simulations show that the ventilated cushion combined with background mixing ventilation and radiant ceiling panels has potential for energy saving by about 7%

compared to a system with only mixing ventilation. Furthermore, increasing the maximum allowed room operative temperature and maintaining occupants' thermal comfort due to the local cooling provided by the ventilated cushion is an effective energy-saving strategy.

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