Comparison of Chilled ceiling and Mixing ventilation assisted by intermittent personalized ventilation: Thermal comfort and Energy savings

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Abstract

The integration of intermittent personalized ventilation units (PVU) in office spaces equipped with chilled ceiling and mixing ventilation has been proven to enhance comfort and provide energy savings. However, the performance of the intermittent personalized ventilation has not been compared between both systems. This is important to see under which system the intermittent personalized ventilation performs best. In this work, two office spaces equipped with a chilled ceiling/mixing ventilation coupled with intermittent personalized ventilation were modelled using validated CFD models. The intermittent jet was supplied towards an infected occupant at an average flow rate of 7.5 L/s. The frequency of the intermittent PVU was varied in each case. It was found that the intermittent PVU provided better thermal comfort in the case of chilled ceiling under neural to warm conditions (14% increase compared to MV systems). However, twice as much energy savings were obtained in the case of mixing ventilation than chilled ceilings. Therefore, it is better off to operate intermittent PVU under MV systems.

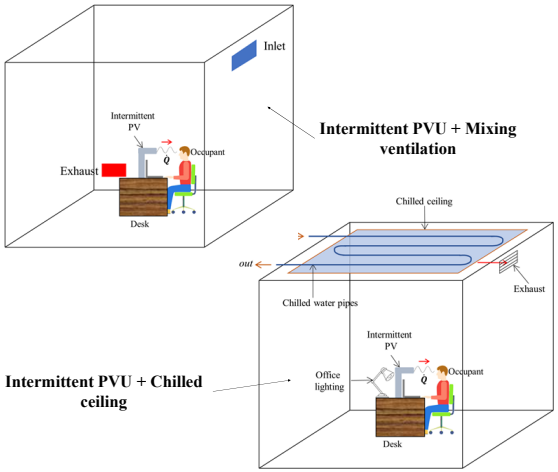
Introduction

In recent HVAC applications, the cool fresh air supplied by the PVU was modified by fluctuating the supply flow rate between a minimum and a maximum at a certain characteristic frequency.. The intermittency of the PVU system was found to improve thermal comfort compared to steady flow rates. Furthermore, providing airflow intermittently can help decrease PVU energy costs even further by reducing the amount of fresh air to be cooled by the system and lowering the fans' power consumption. The intermittent PVU was coupled with MV and CC and it was proven that comfort was enhanced and that energy savings can be achieved compared to a steady PVU. Moreover, it was found that under specific intermittent PVU operating conditions, acceptable inhaled air quality. However, the performance of intermittent PVU was not compared between the systems. This comparison is made possible by the fact that they have similar microclimate characteristics: well mixed conditions with uniform conditions of temperature and contaminants' concentration.

Aims

- Compare the performance of intermittent PVU when assisting an office space equipped with mixing ventilation or chilled ceiling systems.
- Determine the intermittent PVU operating frequency for comfort and air quality
- Determine the energy savings of the system.

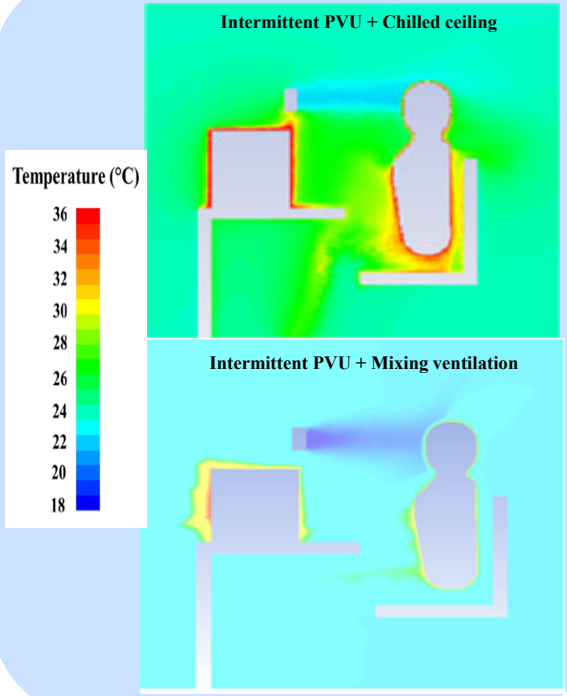
Office space configuration



CFD model

To CFD modeling constitute a viable tool in assessing the performance of indoor ventilation systems. CFD has shown high efficiency in literature in terms of computing airflow velocity and temperature profiles and distribution of particles of variable diameters and densities in indoor spaces. For this reason, CFD modeling was used in this work to investigate the performance of different ventilation configurations in particle removal during a vacuuming session.
A detailed CFD model was developed to predict the airflow and concentration fields using the commercial software ANSYS FLUENT. Modeling of the different flow physics insures robust CFD results.
The Eulerian approach was selected to simulate the indoor room air since it can be assumed as a continuous fluid. Furthermore, the interaction between air and particles was modeled as one way coupling since the discrete phase volume is negligible compared to the indoor space volume. For turbulence modeling, the RNG k-ε model was adopted since it presents a high accuracy in the prediction of flow behavior involving recirculation in indoor spaces. The energy, momentum k and ε equations were solved by a second-order upwind discretization scheme. The "PRESTO!" staggered scheme was used to compute the pressure field while the PISO algorithm was adopted for the coupling between pressure and velocity fields as it is suitable for transient applications. The solver was set to transient with a time step of 0.05 s in order to capture the smallest chronological changes in the solution. Convergence was reached when the scaled residuals reached 10^{-6} for the different variables and 10^{-3} for the continuity.

Intermittent PVU + Chilled ceiling / Mixing ventilation



Thermal comfort

T_a =26°C, PV jet T_{PV} = 22°C, RH = 50%

PV frequency (Hz)	MV system	CC system
0.3	0.341	0.386
0.5	0.4966	0.578
1	1.015	1.181

Energy savings

In order to calculate the energy savings of the intermittent PVU+CC/MV system, the fan power consumption as well as the cooling capacity of an intermittent PVU should be calculated and compared to a steady case. The reference steady state condition in the case of MV is a steady PVU flow rate of 9 L/s and in the case of CC, a PVU flow rate of 7.5 L/s that provides similar comfort.

$$P_{fan} = P_{ref}\left(\frac{\dot{m}_{fan}}{\dot{m}_{fan,ref}}\right)^3$$

To account for time variation, the power was averaged over one period. It was found that a transient fan operation (2 W) was slightly higher than a steady case (1.62 W). However, the decrease in cooling capacity was more significant than the increase in fan power consumption between transient and steady state PVU operation. Therefore, a transient PVU system operating at an average flow rate of 7.5 L/s provided energy savings of 16.1% and 7.5% in the case of MV and CC respectively.

Conclusion

A transient validated 3D CFD model was simulated to conduct a study on intermittent PVU assisting conventional CC and MV systems. It was found that increasing frequency enhanced thermal comfort in the case of CC and MV systems. Note that 14% better comfort was obtained in the case of CC compared to MV due to smaller turbulence levels in the CC space. This was favorable in warm ambient conditions due to increased heat losses. However, twice as much energy savings were obtained in the case of MV systems. Therefore, it is better off to operate the intermittent PVU with MV systems, since it provides comparable levels of comfort to CC systems while assuring higher energy savings