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Comparison of Removal Effectiveness of Mixed versus Displacement Ventilation during Vacuuming Session

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Abstract

In indoor environments, floor surfaces are sinks of particles that might re-suspend in air. If not removed by the ventilation configuration, particles carrying bacteria and viruses constitute a threat for occupant's health. In this work, a typical office space was considered with the option of varying the ventilation configuration by considering a mixing ventilation (MV) system, displacement ventilation (DV) system, and reversed displacement ventilation (RDV) system. The effectiveness of these systems in removing re-suspended particles from the indoor space during vacuuming sessions was studied. For this reason, a transient 3D computational fluid dynamics (CFD) model was developed and was validated experimentally in a climatic chamber equipped with both MV and DV systems. The parametric study conducted showed that the reversed DV configuration insured the best particle removal performance by resulting in an effective suction effect at the floor level. The worst performance was provided by the conventional DV system due to the upward DV airflow transporting the re-suspended particles from the floor levels to the upper breathing levels spreading contaminants. From here the RDV configuration was suggested for operation of ventilation system during vacuuming session.

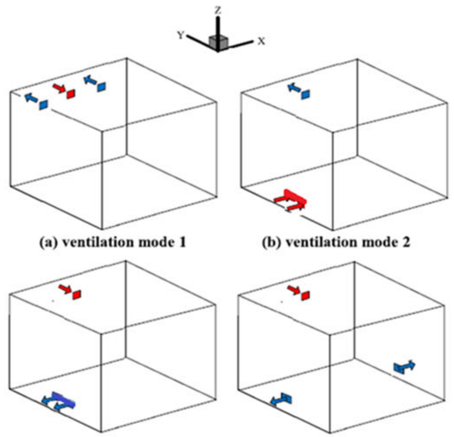
Introduction

Floor vacuuming is frequently used as a mechanism to remove indoor particles. However, it was not found to be a very effective cleaning process. For instance, vacuuming has been identified to be a significant source of airborne particulate matter, with an average dust removal efficiency of 50% – 60% for a typical household vacuum cleaner. Several researchers observed elevated concentrations of dust particles in air during and shortly after vacuuming activities in indoor spaces. In fact, the floor constitutes a large reservoir for dust and contagious particles requiring frequent cleaning by vacuuming. Unfortunately, only a portion will be taken by the vacuuming machine while the other portion will be suspended into the space air volume. Depending on the air distribution system and the size of the particles, these particles might stay a long time in the space air before settling again into the floor or being escaped by the air distribution system. Therefore, assisting vacuuming by proper airflow distribution is important to enhance the removal efficiency. In fact, if not removed, suspended particles that may carry viruses and bacteria represent high risk of contaminating occupants. This threat to human health can be decreased by controlling the airflow pattern during vacuuming. Since the ventilation system plays a major role in particle distribution and removal from the occupied space, the heating ventilation and air conditioning (HVAC) during the vacuuming session should be carefully selected.

Aims

- Compare effectiveness in particle removal during vacuuming session for MV, DV and RDV configurations
- Enhance particle removal performance in indoor spaces during vacuuming.
- Recommend ventilation systems' operational conditions during vacuuming.

Ventilation Modes



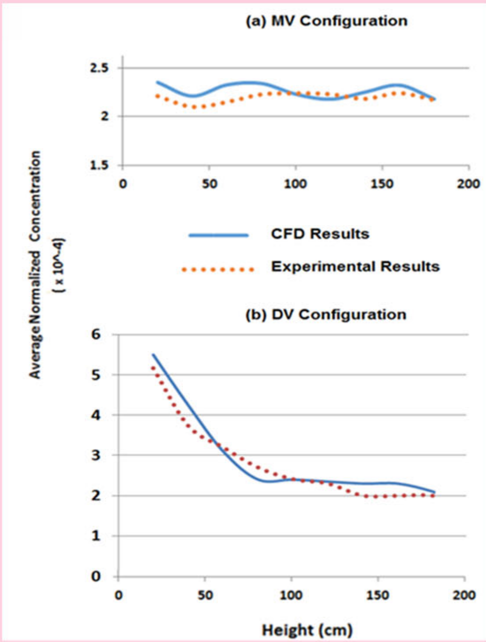
CFD model

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 realizable 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 SIMPLE algorithm was adopted for the coupling between pressure and velocity fields. To study particles' behavior, the Lagrangian tracking technique which is a discrete trajectory method was used in the CFD model. The Lagrangian method is based on the second law of Newton involving variable forces affecting particle behavior as gravitational, lift and drag forces.

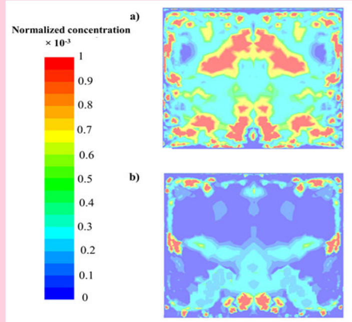
The effect of local turbulence intensities on particles' trajectories was considered using the discrete random walk model (DRW) which adopts a stochastic approach to compute particles' paths. The particle source in-cell (PSI-C) scheme was adopted for computing the resulting concentrations within the indoor space.

Experimental Validation

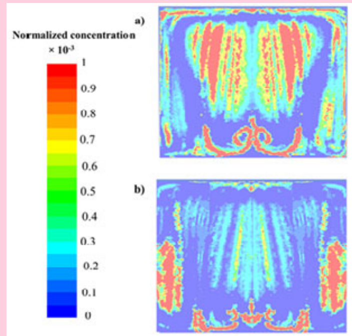


CFD Results

Normalized concentration contours at the breathing level (height 1.1 m for seated occupant) for MV and RDV (mode 4) configurations



Normalized concentration contours at the floor level (height 0.2 m) for MV and RDV (mode 4) configurations



Conclusion

A CFD model was developed and validated experimentally to compare the effectiveness of MV and DV in the removal of re-suspended particles from floor level.

Bad performance is provided by DV compared to conventional MV leading to higher normalized concentrations within the space. This can be explained by the upward transport of particles generated at floor level by the supply DV jet and distribution within the indoor space without effective removal from exhaust at ceiling level due to the large distance separating floor generation from ceiling exhaust location. Hence, during a vacuuming session in a DV room, it is suggested to reverse the flow pattern by supplying air from ceiling and exhausting from ground level creating a suction effect at floor level contributing to particle removal and thus reducing health risks.

Increased flow rate enhanced particle removal performance for all configurations. A large enhancement is provided by RDV (mode 4) compared to MV resulting in much lower concentrations in the two critical planes illustrated. This is due to the positive suction effect created by symmetric exhausts at floor level in this configuration where two exhausts were placed opposing each other resulting in a suction effect covering the majority of the floor area.