EXPERIMENTAL & NUMERICAL INVESTIGATIONS TO STUDY EFFECTS OF AIR CHANGE RATES ON VENTILATION EFFICIENCY OF UFAD VENTILATED ROOM

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ABSTRACT

Because of variable patterns of demand among users of ventilation and availability of various systems of distribution of air, HVAC engineers, worldwide, are facing challenges related to operation and design of such systems. Further, because of the concerns related to quality of indoor air and its impact on the health & productivity of workers, innovative ventilation approaches which provide cleaner indoor environment, are becoming popular indoors. Performance of various ventilation systems viz., Displacement, Mixing & Under-Floor Air Distribution systems is influenced by variables as ACH, particle sizes & location of particle sources. In this study, performance of Under-Floor Air Distribution system is evaluated for different values of ACH using efficiency of ventilation systems in occupied & breathing zones as a performance indicator. Using appropriate instrumentation, extensive experimental studies are conducted in a test room. RNG k-ε model is used for air flow simulation and a drift- flux model is used for particle movement simulation. Both experimental and simulation results are encouraging. The study helps in providing design and operational guidelines regarding use of appropriate ACH for Under-Floor Air Distribution system for obtaining better ventilation efficiency.

Keywords: **UFAD ventilation systems, Ventilation efficiency, CFD.**

1. Introduction

As people prefer to spend majority of their time indoors, maintenance of good quality of indoor air has become an important issue [1]. People's health, comfort and workplace performance is adversely affected because of air pollutants/contaminants which downgrade quality of indoor air [2] [3]. Quality of indoor air is affected because of various contaminants viz., gaseous, particulate and biological contaminants. In this paper particulate contaminants related studies are reported. Many studies have revealed that increase in PM (Particulate Matter) concentration leads to various diseases related to respiratory system. [4]. In this paper performance of Under-Floor Air Distribution system is evaluated by varying ACH. Numerical Simulation techniques can be used for assessment of indoor environment through virtual model building and testing various layouts.

An important parameter related to ventilation performance is Ventilation Efficiency [5], which is defined as the ratio of concentration of contaminants at exhaust outlet to the average concentration of contaminants in occupied/breathing zone. When the rate of ventilation is decided considering standards of industry, greater the ventilation efficiency cleaner is the ventilated air in occupied/breathing zone. The pattern of transport of the contaminants and the related ventilation efficiency are affected by number of factors. Out of various factors ACH significantly affects the ventilation performance. In this paper, results of experimental and CFD simulation studies for UFAD ventilation systems, using different ACH values, are presented. These results can be useful for HVAC engineers who are involved in design and operational aspects of ventilation systems.

2. Literature Review

A study by the Organization for Economic Development (OCED) have estimated the air pollution cost to the society in the form of treatment, rehabilitation and productivity loss at US $ 0.5 Trillion in India[5]. Standards related to acceptable quality of indoor air are provided by ASHRAE [6]. ISHRAE, in their position paper (August 2015), have identified indoor air pollution as the major killer in India [7]. Researchers Paul and others [8] have presented the effects of ventilation systems on the quality of indoor air. Yuan and his colleagues [9] conducted research on quality of indoor air considering various ventilation approaches. Austin, [10] conducted a detailed survey of literature on quality of air indoors and concluded that quality of indoor air quality is affected by variety of pollutants like volatile organic compounds (VOC), second hand smoke, asbestos fibers, biological contaminants, radon and carbon monoxide etc., ASHRAE [11] has given particulate contaminant classification based on the size and phase- which covers smokes, fogs, fumes, mists and bio-aerosols. According to studies by ISHRAE[7], major sources of solid contaminants like particulate matter(PM) in India are vehicular emissions, household cooking (especially cooking with bio-mass and frying), thermal power plants, bio-mass burning, construction work, unattended debris, fossil fuels (such as diesel) based power generators and various industrial processes. Diociaiuti, M. et al [12] conducted research for studying various particle characteristics- which included aerodynamic diameter, number distribution, mass, settling velocity. Lin, Z., et al [13] classified various ventilation systems considering positions of inlets and outlets.

3. Methodology

3.1 Experimental and numerical study details

3.1.1 Experimental Study Details

A test room was used to carry out experimental study for measurement of room air and distribution of contaminant particles. The ETR had the dimensions (4.4m(L) x 4.0m(W) x 3.2m(H). The air and particle supply unit was connected to this room(figure 3.1).

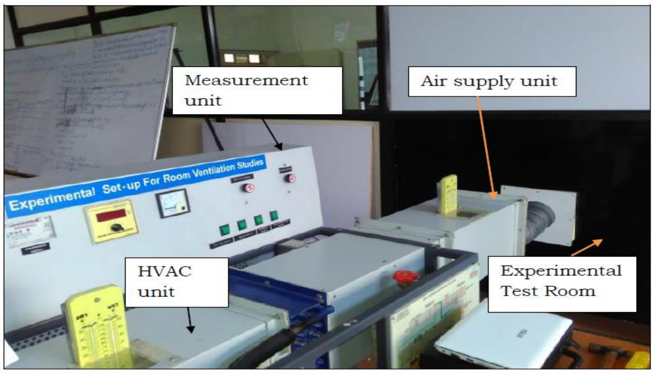


Figure 3.1 Experimental Set-up

The supply air unit was provided with HEPA filters, fan unit, cooling coil, heating coil, moisture unit and particulate supply unit. The interior walls of test room were made of aluminum section sections and detachable particle boards. The flooring of the room was suitably designed to accommodate UFAD unit. The test room is made air tight to reduce leakages and infiltration.

The particle concentration was measured at inlet, exhaust and 54 measurement points spread across the test room. Air Particle Counter (AEROCET 531S, Met One, Beckman-Coulter) was used for measurement of particle concentration. All the measuring instruments were calibrated periodically. In these investigations, ventilation efficiency in occupied zone(ε_{oz}) and breathing zone(ε_{bz}) was evaluated using ACH values of 3.6, 6.0 and 8.4.

3.1.2 Numerical Study Details

Geometric details of the test room were used for developing a numerical model. Airflow was predicted using RANS equations along-with the RNG k- ε turbulence model. The generalized form of the governing equations are-

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho.u) = 0 \qquad (1)$$

Momentum Equation

$$\frac{\partial (\rho U)}{\partial t} + \nabla.(\rho U \otimes U) = -\nabla.p + \nabla\tau + S_m \qquad (2)$$

Thermal Energy Equation

$$\frac{\partial (\rho.e)}{\partial t} + \nabla.(\rho.Ue) = \nabla.(\lambda T) + p\nabla.U + \tau:\nabla U + S_E \qquad (3)$$

For particle concentration prediction the drift-flux model (Eq. (4)) is used.

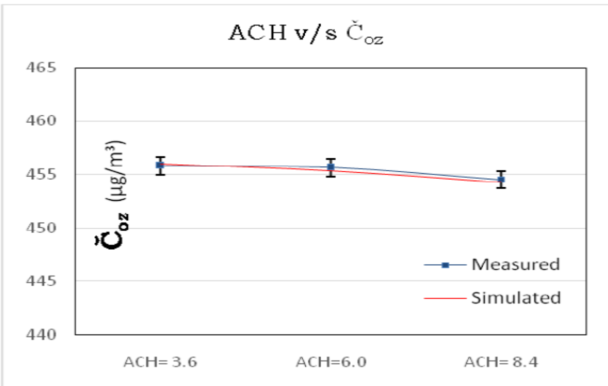
$$\nabla.(\rho\,(\vec{u}_a + \vec{v_s})c) = \nabla.\left(\frac{M_{eff}}{\rho_c}\,\nabla c\right) + s_c \qquad (4)$$

The second order upwind scheme was used for discretization for all the variables except the pressure term. SIMPLE algorithm is used for pressure-velocity coupling. Efficiency of ventilation in occupied/breathing zones is used as a performance indicator for various values of ACH.

Results & Discussions

The effects due to variations of ACH on average contaminant particle concentration in occupied and breathing zones can be clearly seen in figure 4.1 & figure 4.2. The occupied zone concentration gradually decreases with increase in air change rate and concentration in breathing zone increases steeply with increase in ACH.

The effects due to variations of ACH on efficiency of ventilation in occupied & breathing zones can be seen in figure 4.3 & figure 4.4. The efficiency of ventilation in the occupied zone marginally increases with the increase in air change rate (ACH) and the breathing zone ventilation efficiency shows decreasing trend with increase in the air change rate (ACH).



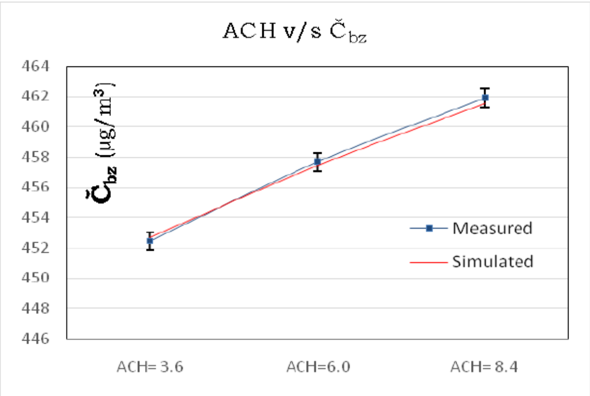
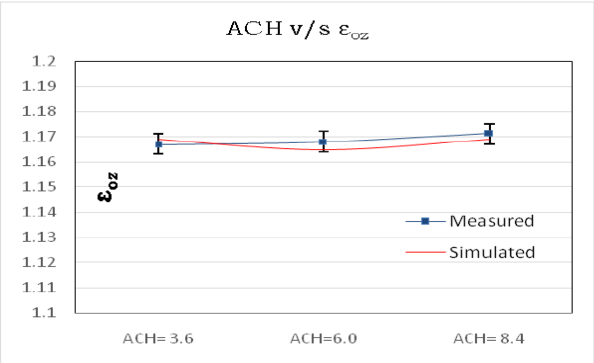


Figure 4.1 ACH v/s C_{oz}
Figure 4.2 ACH v/s C_{bz}



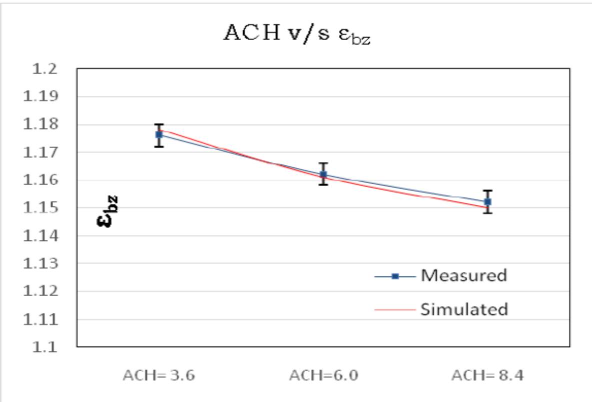


Figure 4.3 ACH v/s ε_{oz}
Figure 4.4 ACH v/s ε_{bz}

4. Conclusions

From the studies, using experimental and numerical simulation techniques for Under Floor Air Distribution (UFAD) ventilation system by changing the ACH, following useful conclusions are drawn.

(i) CFD simulations can be effectively used for studying behavior of UFAD ventilation systems as there is good agreement in numerical & experimental results.
(ii) For a UFAD ventilated room if lower concentrations within occupied zone is the objective then it is recommended to use higher ACH.
(iii) If lower concentrations within breathing zone is the requirement then it is advisable to use lower ACH.
(iv) If higher efficiency of ventilation within the occupied zone is the objective it is recommended to use higher ACH.
(v) If higher efficiency of ventilation within the breathing zone is the objective it is recommended to use lower ACH.

5. References

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