The Effects of Air Change Rate and Indoor Particle Generation on Indoor Particulate Concentration Based on Numerical Simulation

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Abstract. The influences of air change rates and particle generation on indoor particulate concentrations in a cleanroom were studied by eight numerical simulation cases. Results show that the influence of ACH on indoor particulate concentration is very significant than that of particle generated concentration when ACH great than 4.0 h⁻¹. And ACH = 4.0 h⁻¹ seems a suitable value for central air conditioning (AC) systems in residential buildings and public buildings.

Keywords: ACH, Particle Generation, Indoor Particulate Concentration, Numerical Simulation.

1. Introduction

The effects of particulate matter on human health are getting more attentions in the past decades. People spend 80% of their lives in buildings [1, 2]. The indoor particulate concentration had a great influence on indoor human health [3]. There are many factors would influence the indoor particulate concentration such as outdoor particulate concentration, air leakage of building, indoor particle generation and form of ventilation or air conditioning system [4–8].

To analyze those factors. The outdoor particulate concentration depended on outdoor environment which is very difficult to control. The air leakage of building depended on the construction level and the gaps of doors and windows. In most cases, the gaps of buildings was very hard to control and have different penetration results [9–11]. The particle generated in the room will affect the indoor particulate concentration directly. The central air conditioning system was installed in most residential buildings and public buildings. There was a medium efficiency filter installed in the air handling unit which would filter the most particles of outdoor air. And the number of particle of air through ventilation or air conditioning system would be little. This meant air supplied through the filter had a low number particle and would dilute the indoor air and reduce the indoor particulate concentration. For this reason the air volume (or air change rate (ACH)) through the filter had a great impact on indoor particulate concentration [12].

Compared with other factors, air change rate and particle generation concentration are two important factors which have research value. In order to study their effects on indoor particulate concentration, this paper carries out an simulation research in a cleanroom with good air tightness. The dimension of cleanroom was 4.445m×3.2m×2.1m. The air change rate of air through filters in simulational and
The simulation was from 2.5 to 6.9 h\(^{-1}\) and the number of particle (≥0.3μm) of indoor particle generation was from 140,000 to 300,000 pc/(ft\(^{3}\)•min).

2. Simulation setup

For the sake of avoid the impact from building envelope, a full-scale cleanroom with dimensions of 4.445 m(length) × 3.2 m (width) × 2.1 m (height), equipped with 14 units of fan filter units (FFUs) with high efficiency particulate air filter(H14) was utilized and 1 unit FFU was used in this study.

![Figure 1. The schematic of the cleanroom.](image)

The releasing points of challenging particles (P01 and P02) and the test points in the cleanroom (S01~S06). Note: OA = Outside Air. MAU = Make-up Air Unit. RA = Return Air. SA = Supply Air. Fig 1 shows the schematic of cleanroom model. The air supplied from one FFU. And the return air grilles are on the side wall.

A combination of eight simulation cases with varied testing condition was evaluated as shown in Table 1. Four different ACHs (2.5, 4.0, 5.6 and 6.9 h\(^{-1}\)) and two varied particle generated concentrations (140,000 and 310,000 counts/ft\(^{3}\) (for 0.3μm particles)) were evaluated. The selection of ACH ranges are based on the design parameter of central air conditioning (AC) systems in residential buildings and public buildings.

| ACH (h\(^{-1}\)) | 6.9 | 5.6 | 4.0 | 2.5 |
|------------------|-----|-----|-----|-----|
| Particle generated concentration (counts/ft\(^{3}\)) | 140,000 | Case 1 | Case 2 | Case 3 | Case 4 |
| 310,000 | Case 5 | Case 6 | Case 7 | Case 8 |

The 0.3μm PSLs (polystyrene latex spheres) particles were generated at two locations (P01 to P02 at the 1.8m height from the raised-floor, as shown in Fig. 1(b). The generation rate was 23±10% L/min. The total concentration of particles at two source locations was about 140,000 & 310,000 counts/ft\(^{3}\) (for 0.3μm particles). The particle concentration at six sampling points will be used(S01 to S06 at the height of working level i.e. 0.8 m from the floor, as shown in Fig. 1(b). The sampling time on each point was 60s and repeated 3 times (omitting the data of first sampling). The cleanroom was maintained to a cleanliness level of ISO class 5 for all particle sizes, before 0.3μm PSLs particles were introduced.

3. Results and discussion

Through the measured raw data, one trend can be observed that the particle counts was similar at each test point for different cases. I.e. the indoor particulate concentration decreases as the room ACH was increased at a given particle generated concentration. And when the concentration of particles at the

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The above text is a sample of the content from the document. It is a part of a larger document discussing the simulation of indoor particulate concentration in a cleanroom. The text outlines the setup of the simulation, the cases studied, and the results and discussion section. The document provides a detailed explanation of the methodology, including the cleanroom dimensions, the particulate generation rates, and the measurement setup. The results show a decrease in particulate concentration with an increase in air change rate (ACH), which is a significant finding for understanding indoor air quality in cleanrooms.
source points was increased at a given room ACH, the concentrations decrease especially for low ACH cases i.e. Case 1 and 5.

Fig. 2 shows the test results based on four different room air change rates (2.5, 4.0, 5.6 and 6.9 h⁻¹). It can be found that the relationship of these parameters is not linear but logarithmic, so the regression analysis was applied in order to determine the correlation between the ACH, particle generated concentration and indoor particulate concentration.

**Figure 2.** Regression analysis for indoor particulate concentration based on four different ACH

It is noted that the influence of ACH on indoor particulate concentration is very significant than that of particle generated concentration when ACH great than 4.0 h⁻¹. In the low ACH ranges, the change of particle generated concentration influence indoor particulate concentration greatly. Especially the indoor particulate concentration when ACH is 2.5 h⁻¹ were higher than those in other cases. This is more evidently shown in Fig. 3.

**Figure 3.** Regression analysis for indoor particulate concentration based on two particle generated concentration

Fig 3 shows the profiles of regression analysis for particle concentrations based on two different particle generated concentration cases (140,000 & 310,000 counts/ft³) under ACH in ranges of 2.5, 4.0,
5.6 and 6.9 h\(^{-1}\). Similar to those in Fig. 2, profiles of regression analysis in Fig. 3 show that particle generated concentration greatly influences the indoor particulate concentration values at a low ACH case i.e. ACH = 2.5 h\(^{-1}\). Besides, it is observed that the indoor particulate concentration is comparable for case 4 (ACH = 2.5 h\(^{-1}\) and particle generated concentration = 140,000 counts/ft\(^3\)) and case 7 (ACH = 4 h\(^{-1}\) and particle generated concentration = 310,000 counts/ft\(^3\)). Concerning reduction in the operating cost and capital cost, the ACH = 4.0 h\(^{-1}\) is a suitable value for central air conditioning (AC) systems in residential buildings and public buildings.

4. Conclusions
This study focuses on the influences of air change rates and particle generation on indoor particulate concentrations in a cleanroom, challenged at two distinct locations with total number of 0.3μm particles about 140,000 counts/ft\(^3\) & 310,000 counts/ft\(^3\). Based on the results and discussion, the following conclusions are drawn:
1. The simulation data in this study shows the relationship of these parameters is not linear but logarithmic. The indoor particulate concentration decreases as the room ACH was increased and the concentration of particles at the source points was decreased.
2. The influence of ACH on indoor particulate concentration is very significant than that of particle generated concentration when ACH great than 4.0 h\(^{-1}\). In the low ACH ranges, the change of particle generated concentration influence indoor particulate concentration greatly.
3. Although the increase of ACH will decrease the indoor particulate concentration, the operating cost and capital cost will rise accordingly. Based on the values of ACH increase from 4.0 h\(^{-1}\) to 5.6 h\(^{-1}\), the indoor particulate concentration decrease 38–52% in simulations. It means the air volume will rise 40% and the cost of fan will increase 274% theoretically. So ACH = 4.0 h\(^{-1}\) seems a suitable value for central air conditioning (AC) systems in residential buildings and public buildings.

References
[1] P.L. Jenkins, T.J. Phillipa, E.J. Mulberg, et al., Activity patterns of Californians: use of and proximity to indoor pollutant sources, Atmos. Environ. Part A Gen. Top. 26 (12) (1992) 2141–2148.
[2] J. Robinson, W.C. Nelson, National Human Activity Pattern Survey Data Base, USEPA, Research Triangle Park, NC, 1995.
[3] C.A. Pope, R.T. Burnett, M.J. Thun, et al., Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution, J. Am. Med. Assoc. 287 (9) (2002) 1132–1141.
[4] Matson U. Comparison of the modeling and the simulational results on concentrations of ultra-fine particles indoors. Building and Environment, 2005, 40(7): 996-1002.
[5] Zhao B, Zhang Y, Li X T, et al. Comparison of indoor aerosol particle concentration and deposition in different ventilated rooms by numerical method. Building and Environment, 2004, 39(1): 1-8.
[6] W. Sun, J. Liu, John M. K. Flyzik, et al. Development of cleanroom required airflow rate model based on establishment of theoretical basis and lab validation. Ashrae transactions, 2010, 116(1):87-97.
[7] W. Whyte, W. M. Whyte, T. Eaton. The application of the ventilation equations to cleanrooms. Clean Air and Containment Review, 2012, (12): 4-8.
[8] Nazaroff, Cass G. Mathematical modeling of indoor aerosol dynamics. Environment Science and Technology, 1989, 23(2):157-165.
[9] Mosley R B, Greenwell D J, Sparks L E, et al. Penetration of ambient fine particles into the indoor environment. Aerosol Science & Technology, 2001, 34: 127-136.
[10] Abt E, Suh H H, Catalano P J, et al. Relative contribution of outdoor and indoor particle sources to indoor concentrations. Environment Science and Technology, 2000, 34: 3579-3587.
[11] Zhu Y, Hinds William C, Margaret Krudysz, et al. Penetration of freeway ultrafine particles into indoor environments. Journal of Aerosol Science, 2005, 36(3): 303-322.

[12] Yang Lv, Haifeng Wang, Shanshan Wei. The transmission characteristics of indoor particles under two ventilation modes. Energy and Buildings. 2018, 163: 1-9.