Energy and Buildings 127 (2016) 648–657

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Effect of supply/exhaust diffuser configurations on the contaminant distribution in ultra clean environments: Eulerian and Lagrangian approaches

Jaber Eslami[a], Abbas Abbassi[a,*], Mohammad H. Saidi[b], Majid Bahrami[c]

[a] Mechanical Engineering Department, Amirkabir University of Technology, 424 Hafez Ave., P.O. Box 15916-34311, Tehran, Iran
[b] Center of Excellence in Energy Conversion (CEEC), School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran
[c] Mechatronic Systems Engineering Department, Simon Fraser University, Surrey, Canada

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form 8 June 2016
Accepted 9 June 2016
Available online 11 June 2016

Keywords:
Cleanroom
Eulerian approach
Lagrangian approach
Particle
Supply/exhaust configurations

ABSTRACT

In this research, the airflow pattern and particle dispersion in a contaminated full-scale cleanroom are investigated numerically using both Eulerian and Lagrangian approaches. Three different supply diffuser configurations namely (1) central, (2) horizontal and (3) vertical and three different exhaust grille configurations namely (4) vertical symmetric, (5) asymmetric and (6) horizontal symmetric are selected for the analysis. The presented results reveal that the supply/exhaust openings arrangement has a significant influence on the particulate contaminant dispersion in the cleanrooms. The comparison of the above different supply diffuser configurations shows that the vertical and horizontal supply diffuser configurations lead to a more escaped particles and less deposited particles on the room walls and installed working table in the room than the central one. It is also found that for different exhaust grille arrangements, the performance of the ventilation system in the horizontal symmetric case is higher than asymmetric and vertical symmetric ones. At the same time, it is observed that the variations of contaminant concentration in both Eulerian and Lagrangian approaches are almost the same. The results of the velocity and particle concentration show good agreement with the available experimental data in the literature.

1. Introduction

Indoor air quality (IAQ) is crucial for both human health and manufacturing processes. In many industries such as pharmaceutical, food processing, biotech, aerospace, optics, microelectronics and operating rooms, particulate contamination has a significant effect on IAQ. In recent decades, cleanrooms have been extensively used to decrease particulate contamination, as well as to control other environmental parameters such as temperature, humidity and pressure to provide an appropriate comfort level [1,2]. Better dilution of dispersed contaminant from cleanrooms is a fundamental factor for the cleanroom ventilation system design. The dispersion of the contaminant directly depends on the type of airborne particles and the airflow pattern within the cleanrooms. The airborne particles are transported with a large volume of air that enters from supply diffusers and away from critical zones such as working table. The airflow pattern and the turbulence can be the most efficacious factor on particle transportation [3]. Therefore, based on the cleanroom flow field, the investigation of airborne contaminant concentration and developing a new method to reduce this effect is essential.

Since the 90s, with significant improvement in the computational capacity, computational fluid dynamics (CFD) has become a powerful and efficient tool to study engineering problems including airflow and airborne contaminant distribution in enclosures. It is known that there are two main particle transport approaches in CFD simulations: (1) the Eulerian-Eulerian (E-E), and (2) the Eulerian-Lagrangian (E-L) approach. Considering computational cost, the E-L approach is more suitable for particle concentration modeling for transient state whereas for steady state, the E-E approach simulates concentration in less computational time than E-L approach [4]. Several investigations have been made to explore the effect of different factors that influence the contaminant concentration in cleanrooms with two aforementioned approaches. The main factors such as airflow pattern, particle characteristics, the location of obstacles [5], contaminant source location [4–6], supply/exhaust openings arrangement [7–9] are reported in the literature.

---

* Corresponding author.
E-mail addresses: abbassi@aut.ac.ir, abbassi3410@gmail.com (A. Abbassi).

http://dx.doi.org/10.1016/j.enbuild.2016.06.028
0378-7788/

Nomenclature

Abbreviations

CFD	Computational fluid dynamics
DRW	Discrete random walk
E-E	Eulerian-Eulerian
E-L	Eulerian-Lagrangian
IAQ	Indoor air quality
RANS	Reynolds averaged Navier–Stokes
RNG	Renormalization group
UDF	User defined function

Greek symbols

ε	Energy dissipation rate
ρ	Density of the fluid
ρ_p	Density of the particle
μ_{eff}	Air effective viscosity
μ_l	Laminar viscosity
μ_t	Turbulent viscosity
τ	Particle relaxation time
τ^*	Dimensionless time
τ_c	Particle eddy crossing time
τ_e	Lifetime of the turbulent energy
λ	Mean free path
η	Ratio of turbulent to mean strain time scale
$\sigma_k, \sigma_\varepsilon$	Model constants in the RNG k-ε model
β	Volumetric expansion coefficient

Subscripts

i, j	Spatial coordinates
in	Inlet
L	Lagrangian
P	Particle

Latin symbols

A_{in}	Inlet area
C_c	Cunningham slip correction factor
$C_{1\varepsilon}, C_{2\varepsilon}$	Model constants in the RNG k-ε model
C_μ	Model constant in the RNG k-ε model
c	Contaminant concentration
c_j	Mean particle concentration in a cell
D	Molecular diffusion rate
d_p	Particle diameter
$dt_{(i,j)}$	Particle residence time
F_a	Additional forces
G	Gaussian random number
g_i	Gravitational constant in i direction
k	Turbulent kinetic energy
Kn	Knudsen number
L_e	Eddy length scale
$\dot{M}$	Flow rate
P	Turbulent energy production rate
p	Pressure
S	Particle to fluid density ratio
Sc_t	Schmidt number
T_L	Turbulent lagrangian time scale
t	Time
U_{in}	Inlet velocity
u_i	Fluid mean velocity components
u_i^p	Particles velocity components
u_i'	Turbulent fluctuating velocity components
V	Cleanroom volume
V_j	Volume of a computational cell
x, y, z	Rectilinear orthogonal coordinates

One of the main parameters which may impact the contaminant concentration, especially in ultra-clean environments, is the configurations of supply and exhaust diffusers [10]. Zhao et al. [11] numerically studied the aerosol particle concentration and deposition in displacement and mixing ventilation rooms. Their results showed that a displacement-ventilated room had a lower particle deposition rate and larger escaped particle mass than the mixing one, while the average particle concentration of displacement case was higher than the mixing case. Sadrizadeh et al. [12] investigated the effectiveness of vertical and horizontal ventilation system on the particle distribution in the surgical zone. They found that the preferred selection between vertical and horizontal ventilation scenario in an operating room was highly dependent on internal constellation of obstacles, work practice, and the supply airflow rate.

Although, some researchers have studied the particle movement, deposition and distribution in indoor airflow, few investigations have been found in the literature to explore the effectiveness of different supply/exhaust configurations in reducing contaminant in the cleanroom.

In the present paper, the effect of supply diffuser and exhaust grille configurations on the contaminant transport in cleanrooms is studied numerically using both E-E and E-L approaches. To compare the contaminant distribution, particles are supposed to be uniformly distributed in the model cleanroom and the ventilation system removes contaminant from the model room. The following questions will be investigated:

1) What is the effect of different supply/exhaust opening arrangements on the contaminant distribution in a model cleanroom?
2) Which configuration has better effectiveness to discharge contaminant from the cleanroom? Is there any significant difference between the percentages of escaped and deposited particles for different configurations?
3) Is there difference between E-E and E-L approaches to predict the contaminant concentration distribution for a model cleanroom?

The goal of this study is to provide detailed knowledge and engineering guidelines for better design in future cleanrooms.

2. Analysis of numerical method

This investigation compares the two modeling approaches with an emphasis on their performance of predicting particle concentration distributions in ventilated spaces. Both the E-E and E-L models under examination are performed based on the same airflow field calculated by solving the Reynolds Averaged Navier–Stokes (RANS) equations with the Renormalization Group (RNG) $k-\varepsilon$ turbulence model.

2.1. Flow model

2.1.1. Governing equations

As the contaminant concentration in cleanrooms is very low, the airflow hydrodynamics is not affected by the contaminant phase. Therefore the interaction between continuous airflow phase and particle discrete phase are treated as one-way coupling [4]. Considering Boussinesq's turbulent viscosity hypothesis [13], the flow governing equations are as follows [14]:

Continuity equation:

$$u_{i,i} = 0 \tag{1}$$

where u_i are the mean velocity components.