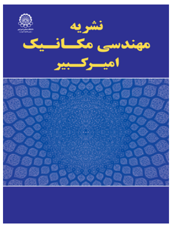

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Investigation of the Effect of Ventilation System Inlet Location on Particle Motion in a Room Using Multi Relaxation Time-Lattice Boltzmann Method

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ABSTRACT: In this work multi-relaxation time lattice Boltzmann method is used to investigate the effect of the inlet air location on particle motion in a room. The scaled modeled room is one-tenth scale of a full-size room with dimensions of 0.914 m × 0.305 m × 0.457 m. For an inlet air with dimension of 0.101 m×0.101 m, two locations (ceiling and floor) are studied. The large Eddy simulation with the standard Smagorinsky model is utilized to simulate the turbulent indoor airflow. Particles with 1 and 10 micrometer sizes are selected for investigation of particle dispersion and deposition in the room. The simulation results for number of deposited particles and those exiting the room show that when the inlet air is on the floor, the number of larger 10 µm particles leaving through the exhaust register is more than the case for inlet on the ceiling. For smaller 1 µm particles, however, no significant difference between the floor and ceiling inlet air for particles leaving the room thought the exhaust register is seen. The present results also show that the gravity significantly affects the particle deposition, and the number of deposited 10 µm particles on the floor are about 100 times that of the deposited 1 µm particles when the inlet air is at ceiling.

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1. Introduction

In the last two decades, the importance of turbulent airflow simulation in the context of indoor air pollution has increased. Therefore, various methods have been proposed to simulate airflow and particulate pollutant transport in indoor environment. In the last decade, Lattice Boltzmann Method (LBM) has received considerable attentions for simulating fluid flow, heat transfer and particle motion in complex passages [1-3].

Krafczyk et al. [4] analyzed turbulent flows using the Multiple Relaxation Time (MRT) LBM and the Large Eddy Simulation (LES) with the aid of the standard Smagorinsky model. Their results indicate that the MRT method is more stable than Single Relaxation Time (SRT). Jafari and Rahnama [5] investigated turbulent flows in a channel using the LBM and LES. They used the sheared improved Smagorinsky model to model small eddies and showed that the results of their model fit well with the direct numerical solution results.

Salmanzadeh et al. [6] studied turbulent airflow in a channel using the LES model and examined the effect of subgrid scale eddies on particle deposition velocity. They showed that the subgrid fluctuation velocities have a significant effect on small particle deposition, but their effect on large particles is not important.

Sajjadi et al. [7] investigated the turbulent indoor air flow using a hybrid model and examined the particle dispersion and deposition behavior. They compared their results with the previous experimental data and available simulations and showed that the LBM could predict the turbulent flow feature and the particle deposition and dispersion with good accuracy.

As the previous works showed, studies of particulate pollutant transport have received much attention due to its importance in human health. However, due to the complexity and extensive computational time requirement for resolving the details of turbulent flows and particle motions in a room, the analysis of these types of flow has been limited. Therefore, in this study we used the LBM as an efficient technique and predicted the turbulent airflows for various conditions in a modeled room. In addition, the trajectories of micro-particles were investigated. Particular attention was given to the influence of the inlet air location on the particle dispersion and deposition in the room.

2. Problem Statement

The geometry of the present work is shown in Fig. 1. The present geometry is a one-tenth scale of a full-size office. The dimensions of the present scaled room are 0.914 m, 0.305 m and 0.457 m, respectively, in x, z and y directions.

3. LBM-LES Model

In this study, the MRT_LBM method with D3Q19 lattice is used for the three dimensional flow simulations in the scaled

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room. In this method to evaluate the distribution function for velocity the following distribution function are used [7]:

$$f_i(x+c_i\Delta t, t+\Delta t) = f_i(x,t) - M_{ij}^{-1}.\hat{S}_{jk}.[R_k(x,t) - R_k^{eq}(x,t)] \qquad (1)$$

where fi is the velocity distribution function, Δt is the lattice time step, which was set to unity and ci is the discrete fluid particle velocity vectors are shown in Fig. 2. Mij (transformation matrixes), Sjk (diagonal matrixes of relaxation rates), Rk, Rkeq are described in reference [5].

4. Particle Motion Equation

The equation of motion for small particles is given as [8]

$$\frac{du_i^p}{dt} = \frac{1}{\tau_p}\frac{C_D Re_p}{24}(u_i - u_i^p) + (1-\frac{1}{s})g_i + n_i(t) \qquad (2)$$

:

where the first term on the right hand of the Eq. (2) is the drag force, the second term is the buoyancy force and the third term is the Brownian force.

5. Results and Discussion

A comparison of the predicted velocity profile at a section of the modeled room with the previous numerical and experimental data [9,10] is shown in Fig. 3. As it is seen that the present results are in a good agreement with the earlier experimental data and LES simulations.

The total number of deposited particles on the walls of the modeled room when the inlet air is located on the ceiling and floor are shown, respectively, in Figs. 4 and 5. It is captured that the number of deposited 10 μm particles is more than 1 μm for both locations due to gravity force.

6. Conclusions

In this paper, the MRT-LBM in conjunction with the LES model was used to solve the turbulent indoor airflow in a

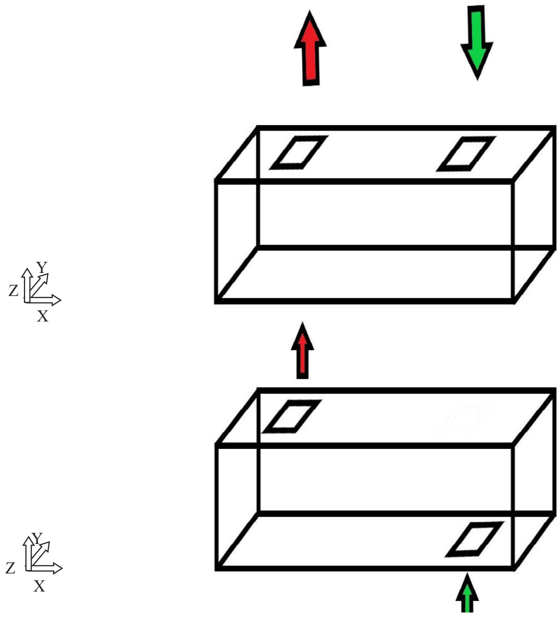

Fig. 1. Geometry of the scaled room studied.

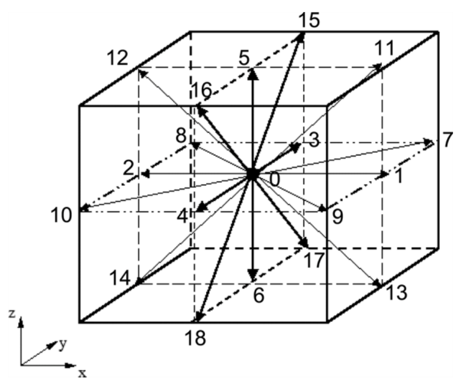

Fig. 2. Discrete velocity vectors for D3Q19.

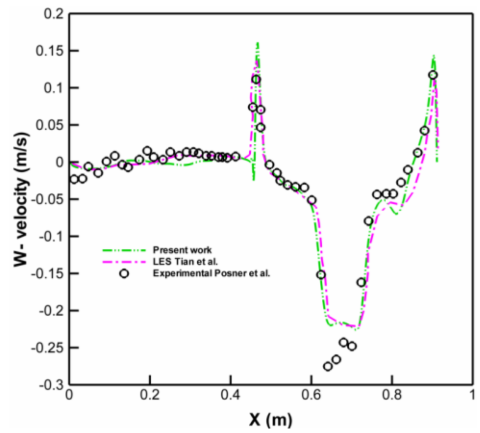

Fig. 3. Vertical velocity along the horizontal line at mid-partition height from the left wall to the right wall

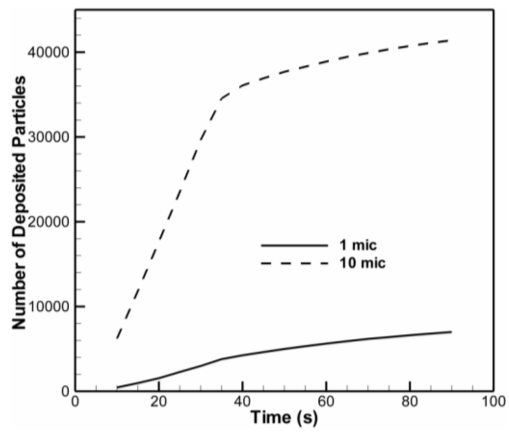

Fig. 4. Number of deposited particles on the various surfaces for the inlet air register on the ceiling.

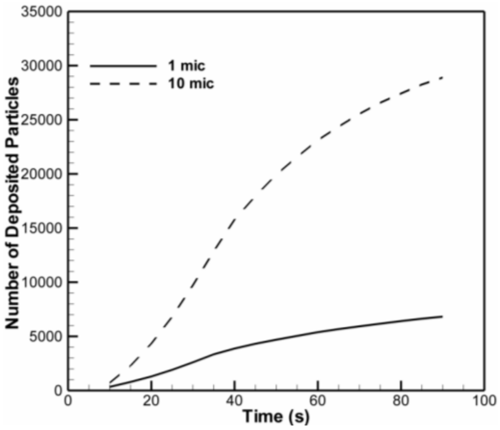

Fig. 5. Number of deposited particles on the various surfaces for inlet air location on the floor.

scaled room. In order to investigate the effect of the inlet air location on the particles behavior, two different positions for inlet air were considered. Motions of 1 and 10 µm particles are simulated for different cases the simulation results showed that when the inlet air location was on the floor, the number of 10 µm particles that exited the room was larger than the case that the inlet was that on the ceiling. For the 1 µm particle, however, the simulation results are almost the same both cases. The number of deposited 10 µm particles was much more than the 1 µm particles for both configurations.

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