Wind Engineering Joint Usage/Research Center
FY2017 Research Result Report

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Research Theme:
Fast prediction of pollutant dispersion for human-walking induced indoor environment

Representative Researcher:
Shi-Jie Cao; Weirong Zhang; Yelin Deng; Dong-dong Ceng;Yu Zhou
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*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
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1. Research Aim

Particle dispersion can be influenced by human activities' inducing effect, which may not be allowed in high-demanded cleanness environment, such as operation room. The application of dynamic mesh simulation method has been widely applied for objects moving, which is not CPU-friendly in calculation as well as complex meshing required. Thus, we proposed a new method of momentum theory to investigate human motion induced effects on indoor environments (i.e., momentum source implemented into Navier-Stokes equations to simulate human/objects moving).

2. Research Method

This work aims to investigate the feasibility of momentum theory method to simulate human moving as well as its impacts on indoor environment. Experimental method of small-scale chamber and CFD simulation were employed in the current work. We first carried out a series experiments to validate simulation. During simulations, both methods of dynamic mesh and momentum theory were applied for human motion effects on airflow. Next, momentum theory method was employed to study a case for particles decaying in a test chamber.

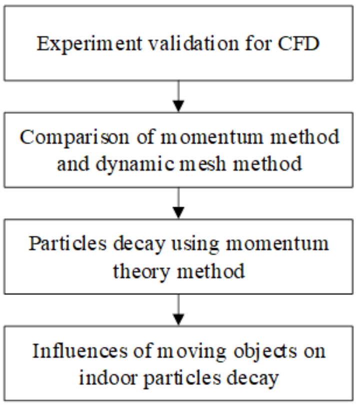

Fig. 1 The structure and Methods of this work

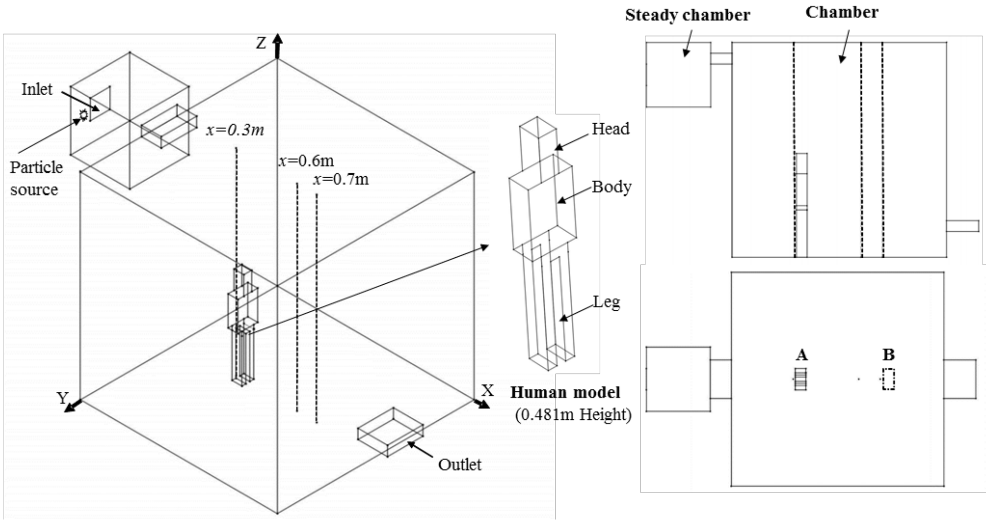

Fig. 2 The schematic of the experimental chamber

Momentum theory method implementation in NS equations:

$$\frac{\partial \overline{\boldsymbol{u}}_i}{\partial t}+\frac{\partial}{\partial x_i}(\overline{\boldsymbol{u}}_i\,\overline{\boldsymbol{u}}_j)=-\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i}+\frac{\partial}{\partial x_j}((\nu+\nu_t)\frac{\partial \overline{\boldsymbol{u}}_i}{\partial x_j})+\boldsymbol{F}_i \tag{1}$$

$$F=1/2\times\rho\times v_b^{\,2}\times A \tag{2}$$

Fi in Eq. 1 is the momentum source. Based on momentum theory, the magnitude of momentum force F (which has the same direction with objects moving with shear effects neglected) can be calculated by the product of dynamic pressure of the front area of the human body, and v is the average velocity of the human body, A is the front area of the human body (box-shaped objects) that generates the movement.

3. Research Result

1) It was found that momentum theory method is sufficiently fine when compared to dynamic mesh (flow and particle deviation within 15% and 5% respectively).
2) Momentum theory method was then employed to investigate the decay process of particle concentration influenced by human walking in a chamber, which could save up to 90% of the calculation time compared to dynamic mesh method.
3) The results also indicated that particles decay would be delayed in the presence of object moving. Human motion has strong impacts on surrounding airflows, i.e., disturbing local velocity field. Further it influenced the dispersion of particle concentration. The higher the walking speeds, the longer particles decay delayed. For instance, it would take about 14 and 12.5 minutes for particles concentration decreased to 10%, corresponding to walking speeds 0.2 m/s and 0 m/s respectively.

4) During the decaying process in the chamber, decay speed is highly depending on the location/region of the chamber. More specifically, decay rate is relatively higher in the region of close to walking zone.

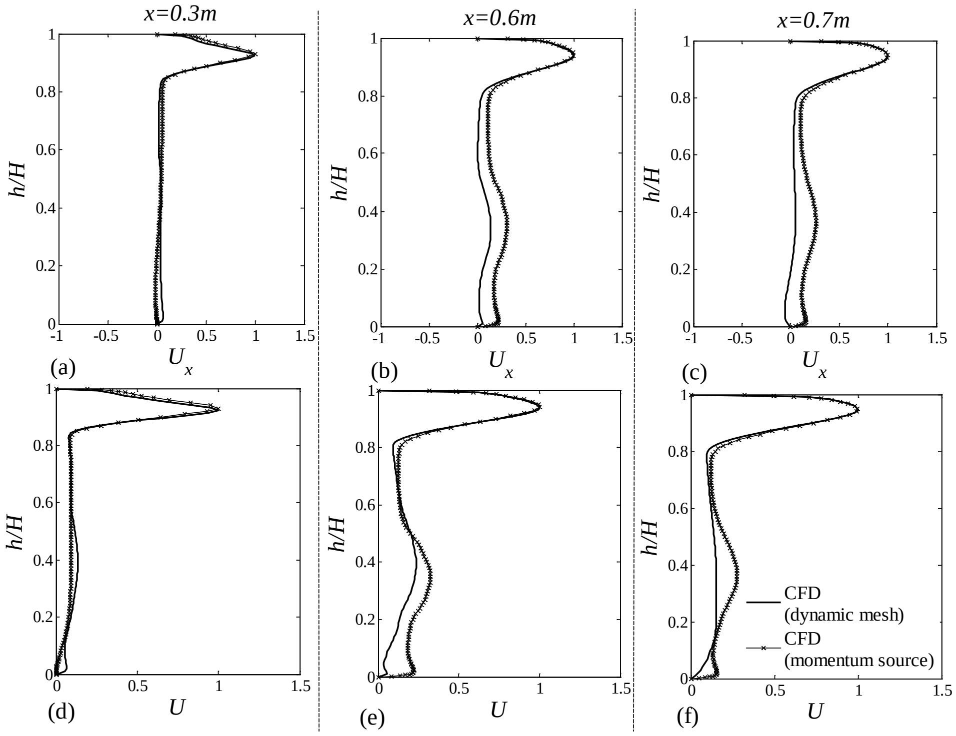

Fig. 3 Normalized air flow velocities in x-direction and air flow magnitudes comparison of momentum theory and dynamic mesh method at t=2s [air supply conditions: 0.5m/s, human walking speed: 0.1m/s, row 1 and row 2 mean x-direction and magnitude velocities, respectively (U=u/us, u is the local air flow velocity, us is the maximum airflow velocity along this line)]

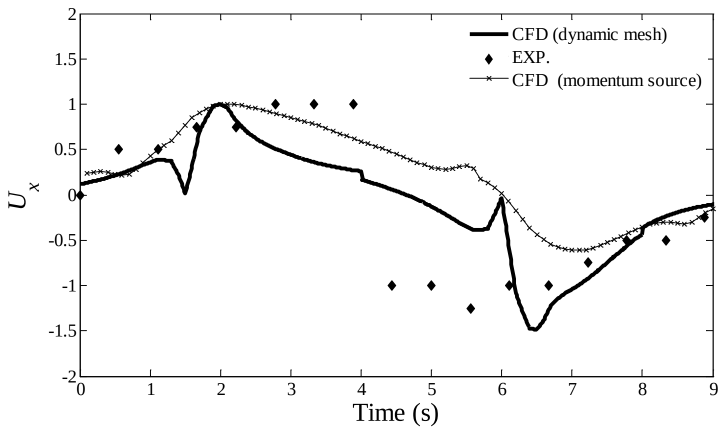

Fig. 4 Comparison of normalized air velocity in x-direction at the monitoring point (set at the location of (x, y, z)=(0.5 m, 0.6m, 0.48m)) induced by human's walking with velocity of 0.1 m/s [experiment, dynamic mesh and momentum source; air supply velocity of 0.5m/s; U=u/us, u is the local airflow velocity, us is the maximum airflow velocity]

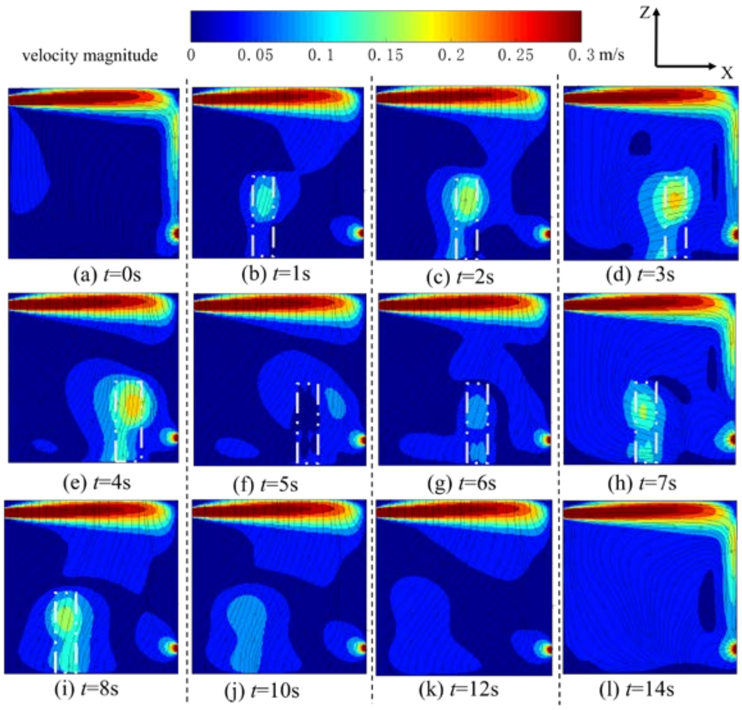

Fig. 5 Air flow distributions effected by human walking using momentum theory method [supplied air velocity of 0.5m/s, module moving speed of 0.1 m/s; the rectangle represents the wireframe of human module]

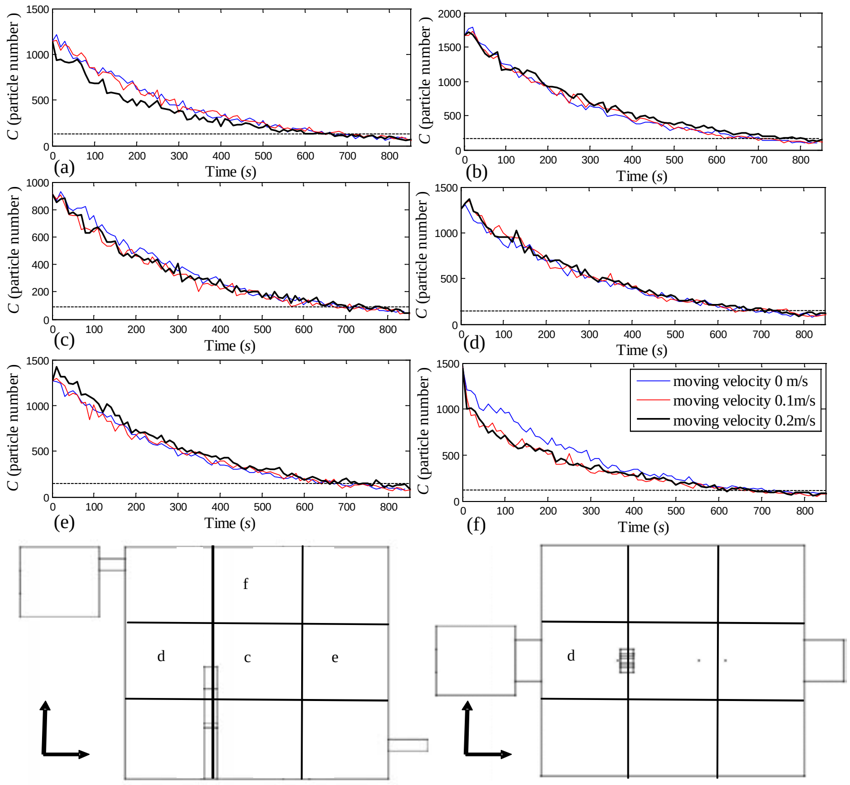

Fig.6 The decay of particle concentration in different zones at air supply velocity of 0.5 m/s. (C is the total particle number in local zone).

4. Published Paper etc.
[Underline the representative researcher and collaborate researchers]
[Published papers]

Cao, S.-J.*, Cen,D., Zhang,W., Feng Z. (2017), Study on the impacts of human walking on indoor particles dispersion using momentum theory method, Building and Environment,V(126), pp.(195-206) .
https://www.sciencedirect.com/science/article/pii/S036013231730450X

[Presentations at academic societies]

Cen, D., Feng Z., Zhang W., Cao, S.-J.* (2017),Numerical study on the influence of human walking on indoor contaminant transport using momentum theory method. ISHVAC 2017: International Symposium on Heating, Ventilating and Air-Conditioning. Jinan, P.R.China,19 - 22 October 2013.

5. Research Group
1. Representative Researcher

1. Shi-Jie Cao, Civil and Environmental Engineering, Soochow University, Associate professor
2. Weirong Zhang, Faculty of Engineering, Tokyo Polytechnic University, Associate professor
3. Dongdong Ceng, Civil and Environmental Engineering, Soochow University, Master Student

2. Collaborate Researchers

1. Yu Zhou, Civil and Environmental Engineering, Soochow University, Master Student
2. Yelin Deng, Civil and Environmental Engineering, Soochow University, Associate professor

6. Abstract (half page)

Research Theme
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Summary

Particle dispersion can be influenced by human activities' inducing effect, which may not be allowed in high-demanded cleanness environment, such as operation room. The application of dynamic mesh simulation method has been widely applied for objects moving, which is not CPU-friendly in calculation as well as complex meshing required. Thus, we proposed a new method of momentum theory to investigate human motion induced effects on indoor environments (i.e., momentum source implemented into Navier-Stokes equations to simulate human/objects moving). Experiments were conducted for validation. RNG k-ε model was adopted for turbulence modeling. Both methods of dynamic mesh and momentum theory were used to investigate the impacts of human induced motion on indoor environments of airflow distributions and particles dispersion. It was found that momentum theory method is sufficiently fine when compared to dynamic mesh (flow and particle deviation within 15% and 5% respectively). Momentum theory method was then employed to investigate the decay process of particle concentration influenced by human walking in a chamber, which could save 90% of the calculation time compared to dynamic mesh method. The results also indicated that particles decay would be delayed in the

presence of object moving. Particle concentration in different zones of the chamber was also discussed. We found that particle decay effected by human motion (human speed was 0.2m/s) was 19.6% faster than that without human motion in the region with larger background airflow speeds.