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Topic A5: Indoor transport phenomena

A LATTICE BOLTZMANN BASED REAL-TIME COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATION OF MOVEMENT-INDUCED INDOOR CONTAMINANT TRANSPORT

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INTRODUCTION

Indoor air quality (IAQ) and thermal comfort are fundamental for the wellbeing of humans inside buildings, as we spend more than 90% of our time indoors. It is therefore crucial to control IAQ in order to protect humans from health hazards such as air borne infections in hospitals and to mitigate exposure during accidental or deliberate release of contaminants. Furthermore, transient events such as human or doorway motion can have significant effects during building evacuation scenarios or containment failure in clean or isolation rooms. CFD can predict the dynamic nature of contaminant transport and distribution in great detail and accuracy but the computational time is prohibitive for its usage as a management or control tool. Hence the aim of our work is to present an investigation into the development and implementation of a novel real-time or faster than real-time CFD based simulation tool, to predict the effect of transient activity or events on contaminant transport, and thereby transforming the traditional CFD based IAQ analysis into a viable tool for indoor environment management and control.

METHODOLOGIES

In this work we use a non-traditional CFD method with an integrated visualisation tool to simulate interactively in real-time the behaviour of indoor air flow and contaminant transport. In order to achieve both real-time compute and visualisation capabilities while maintaining good physical accuracy, lattice Boltzmann method (LBM) (Chen and Doolen, 1998) was chosen. The LBM algorithm is based on threefold discretisation of the Boltzmann equation in phase space, involving space, time and velocities. The movement and distributions of a fluid are described by particle distribution functions residing at the sites of a regular grid or lattice of points which encompasses the entire indoor environment i.e. a room for example. The particle distribution functions represent the probability of particle presence with a given velocity at each lattice site. The macroscopic quantities of the fluid like the density ρ or the velocity $\mathbf{v}$ can be recovered from these distribution functions. The LBM has several advantages over traditional CFD, such as its numerical stability and accuracy, the capacity to efficiently handle complex geometries and the data-parallel nature of its algorithm. It has the advantage of being easy to implement and is especially well suited for massively parallel machines like graphics processing units (GPU) (Obrecht et al., 2012).

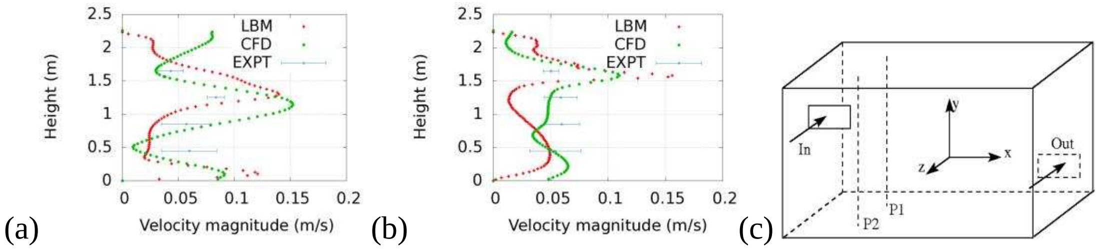

Figure 1. Comparison of the mean velocity profile inside the test chamber at positions (a) P1(x=1m, z=1.1m) and (b) P2(x=1m, z=2.36m) respectively, computed from real time LBM simulation, traditional CFD and experiments. The ventilation rate in the chamber (c) of dimensions 4.2m x 2.26m x 3.36m is held fixed at 5 air changes per hour (King et al., 2013).

RESULTS AND DISCUSSION

A common labelling for lattices used in LBM is **DdQq**; where **d** is the space dimension and **q** the number of microscopic velocities. There are several possible nodes for 3D lattices, such as D3Q13, D3Q15, D3Q19, and D3Q27. The D3Q19 model, was chosen because it has a minimum number of velocities while maintaining good isotropy of the lattice. Simulation of a turbulent velocity field is carried out on such a D3Q19 lattice with Smagorinsky sub-grid model to resolve large Reynolds number flow fields (Delbosc et al., 2014). Our results of the 3D LBM simulation running on a single GPU in real time are in good agreement with the benchmark results found in the literature (Delbosc et al., 2014). Furthermore qualitatively good agreement between LBM and traditional CFD based Reynolds averaged (RANS) simulations are obtained for turbulent air flow in a 32m^3 bio-chamber (see Fig. 1(c)). The simulated room is based on a real Class II bio-aerosol chamber built in the School of Civil Engineering at the University of Leeds. Work is currently ongoing regarding the improvement of the LBM model and obtaining high resolution experimental data from the chamber.

CONCLUSIONS

A novel LBM based interactive real-time CFD technique with integrated visualisation method has been implemented on the GPU. Real-time simulation of airborne pollutant transport is achievable, thereby enabling a smart and intelligent response to movement-induced spread of contaminants in indoor environments.

REFERENCES

S. Chen, G. D. Doolen (1998), Lattice Boltzmann method for fluid flows, Annu. Rev. Fluid. Mech. **30** 329-364.

N. Delbosc, J. Summers, A. I. Khan, N. Kapur, C. J. Noakes (2014), Optimized implementation of the Lattice Boltzmann Method on a graphics processing unit towards real-time fluid simulation, Computers & Mathematics with Applications. **67** 462–475.

M. F. King, C. J. Noakes, P. A. Sleigh, M. A. Camargo-Valero (2013), Bioaerosol deposition in single and two-bed hospital rooms: A numerical and experimental study, Building and Environment. **59** 436-447.

C. Obrecht, F. Kuznik, B. Tourancheau, J. Roux (2012), The TheLMA project: A thermal lattice Boltzmann solver for the GPU, Computers & Fluids. **54** 118-126.