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Coupled indoor/outdoor airflow simulation comparing ANSYS Fluent with a GPU-based lattice Boltzmann model for urban environments

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SUMMARY
A lattice-Boltzmann method model with large eddy simulation model deployed on the graphics card was used to represent cross-flow ventilation in a cubical building in isolation and in an array format. Results are compared against wind-tunnel experiment and Ansys Fluent. Accuracy is comparable and speedup is two orders of magnitude.

KEYWORDS
real-time CFD simulation; lattice-Boltzmann method; cross-flow ventilation

1 INTRODUCTION

This study benchmarks computational fluid dynamics package Ansys Fluent 16.2 and an in-house novel graphics card lattice-Boltzmann method (LBM) code against wind-tunnel experimental results for coupling internal and external building flows. Both codes employ the large eddy simulation (LES) with a Smagorinsky sub-grid turbulence model. Cross-flow through a window is investigated in a cubical building in isolation and in a regular array format. The main objective of this study is to: Assess the validity and accuracy of the LBM code for representative urban environments.

2 METHODS

A 0.2mx0.16mx0.2m surface mounted hollow cube with windows was modelled both in an isolated scenario and in a nine cube irregular array. Local internal anemometry data (Tominaga and Blocken 2015) are used for experimental comparison.

The LBM approach is a microscopically inspired method designed to solve macroscopic fluid dynamics problems. The movement of a fluid are described by particle distribution functions from which velocities can be recovered (Delbosc et al. 2014). The LBM has several advantages over traditional CFD, such as numerical stability and accuracy and the capacity to handle complex geometries which we run on the graphics processing units (GPU). A large eddy simulation turbulence model was used in both Fluent and LBM on a hexahedral grid. The atmospheric boundary layer was modelled logarithmically and turbulence quantities extracted directly from experiment. ANSYS Fluent 16.2 used a PISO discretisation scheme with 25iterations per 0.001s time-step.

3 RESULTS

Figure 1 a-c) show time-averaged normalised velocity plots inside the cube for both LBM and Fluent codes respectively at three vertical lines (x/D=0.125, 0.5 and 0.875, where D is the horizontal length of the cube) for the isolated cube case. Flow dips as it enters the window and discharges towards the ground, which is represented by the decay in streamwise velocity along u direction.

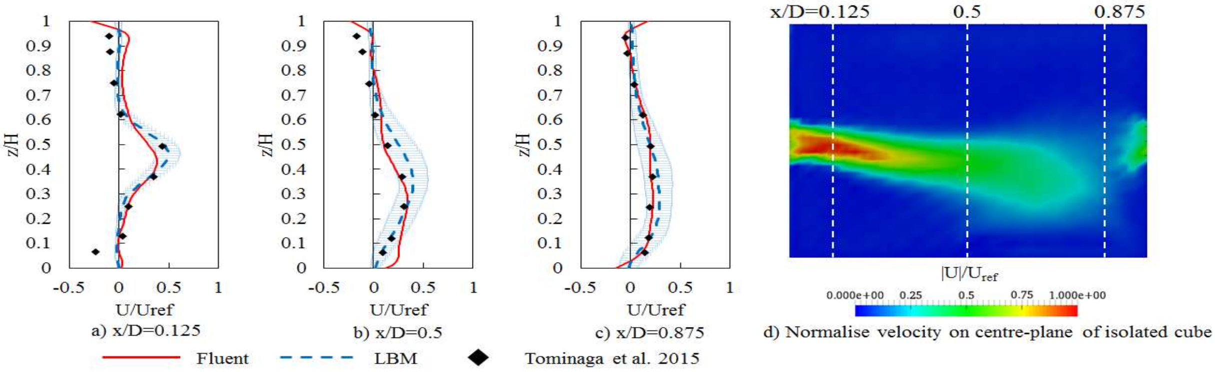

Figure 1 U/Uref for the isolated cube with under perpendicular flow (0°). Errorbars represent one standard deviation from the mean. Contours show LBM prediction.

Simulated ventilation rates compare well with experimental values, with LBM tending to give more conservative estimates and with lower levels of variation than Fluent. When the cube was surrounded by other cubes (packing density=25%), simulations suggest that vortex shedding from up-wind buildings provides pulsating ventilation, whereby improving airflow ingress in the parallel cases.

Results are encouraging, capturing the transient nature of natural ventilation but also highlighting poor mixing as can be seen in Figure 1. The LBM code is able to capture indoor flow features in real time that alternate between impinging jets and turbulent mixing whereby potentially providing a tool for an improved understanding of indoor air quality. In addition, the LBM code calculated the flow 700 times faster than Fluent.

4 DISCUSSION

The LBM code tends to overestimate the velocity in the peak regions, whereas Fluent is more conservative. Discrepancies with respect to experimental values (Tominaga and Blocken 2015) are seen in both codes close to the wall. It is acknowledged that the cubical structures tested with large openings are not fully representative of buildings. It does however allow a simplification of the urban environment which allows for individual parameter sensitivity analysis.

5 CONCLUSIONS

The LBM code running on one GPU was several orders of magnitude faster than Fluent with similar accuracy. The current validation study shows that the code is capable of predicting internal and external flow acceptably well. Full parallelization of the LBM code could create real-time airflow simulations comparable in accuracy to traditional CFD, with far reaching implications for building designers, risk analysts and emergency responders.

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6 REFERENCES

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