Interactive thermal comfort assessment simulations

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Introduction

In modern design and planning processes of large buildings, thermal comfort assessment is mandatory.
On the one hand, there is the indoor assessment related to the comfort of people staying inside buildings, on the other hand there is the outdoor assessment related to the impact of heat and pollutant emissions of buildings to the environment. Both assessments should be done in very early design stages as economic savings have the highest potential in this phase due to the possibility of changing design steps easily. Necessary simulations have to be carried out on very different scales (from very small, i.e. local, to very large, i.e. global, effects) and, thus, entail an enormous demand for computing performance as provided by the world's largest supercomputers.

Furthermore, there is strong need for interactive computing or computational steering, i.e. carrying out the simulations in real-time and allowing users interactively to visualise the simulation results and manipulate the scenario/setup, in order to optimise the design process and minimise the costs. Unfortunately, interactive computing and high-performance computing are still a contradiction and, thus, demand for special approaches and sophisticated methodologies in order to bridge the gap between computational steering and supercomputing.

Results

For performing thermal comfort assessment, we apply computational-fluid dynamics simulations on varying scales using the Lattice-Boltzmann method. Unlike the classical method using the Navier-Stokes equations, the Lattice-Boltzmann method (LBM) is based on concepts of statistical physics. For the LBM code developed by our group, we use a first order finite difference approach in space and time resulting in a quite simple scheme regarding implementation and parallelisation. For additional numerical stability of the method, a multiple-relaxation-time model based on d'Humières [1] was used and the simulation of convective airflows was achieved by using the hybrid thermal model proposed by Lallemand and Luo [2].

As input data for this LBM code, a voxel-based structure containing information about boundary conditions is necessary. Based on a hierarchical representation, we benefit from the spatial decomposition of an octree structure for the discretisation of the corresponding domain and all included geometric information – ranging from whole buildings down to small details or the interior of single rooms (furniture) – as any desired level-of-detail is easily to be achieved. Due to the necessity that our code requires an equidistant discretisation, all voxels have to be refined until a certain mesh width. An analysis regarding the parallel performance of our code and the influence of different discretisation widths can be found in [3]. Figures 2a, 2b show the results of simulation runs for a highly detailed power plant model (Fig. 1) on different scales.

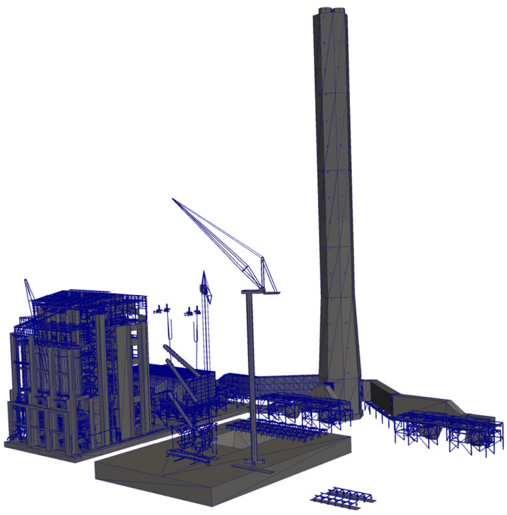

Figure 1: BREP geometry of a power plant containing more than 12 million triangles

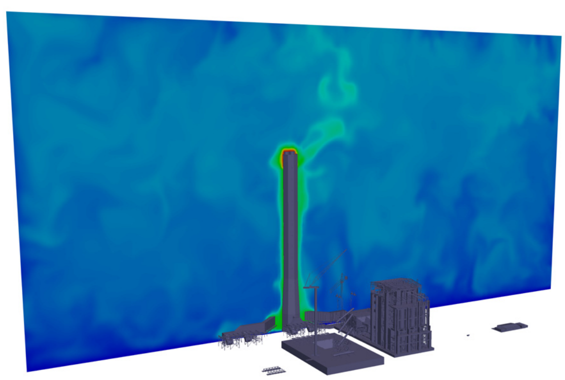

Figure 2a: simulation results on a large scale of the power plant model in order to investigate pollutant emissions to the surrounding environment

S. Wagner, A. Bode, H. Satzger, M. Brehm (Eds.), High Performance Computing in Science and Engineering Garching/
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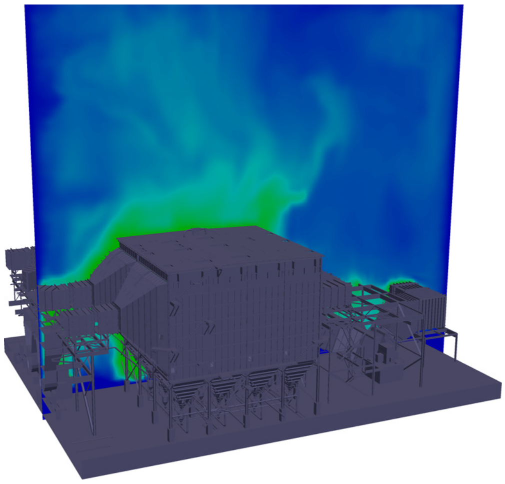

Figure 2b: simulation results on a small scale of the power plant model using the same resolution (i.e. amount of degrees of freedom) as on the large scale in order to investigate physical properties in detail

To evaluate the efficiency of the code, several scalability studies have been performed on the HLRB2. Figure 3 summarises a strong speedup analysis for different discretisation sizes of the above geometry. Small sizes obviously result to a bad CCR and, thus, hinder good scalability values.

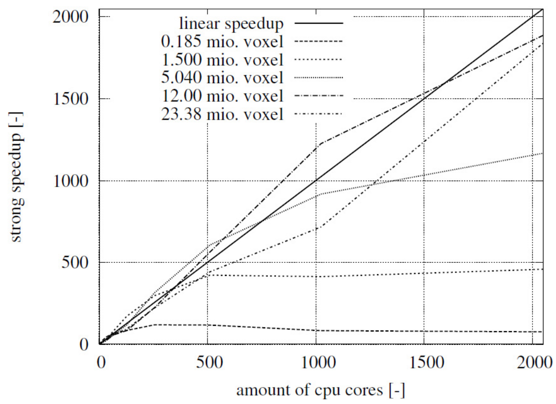

Figure 3: strong speedup analysis for different domain sizes performed on the HLRB2 (see [3])

In order to assess the thermal comfort on a local scale, such as in a room e.g., one approach is to apply empirical relations stated in norms. In Fig. 4, local surrounding temperatures resulting from the LBM code are mapped to a dummy's surface (i.e. numerical manikin) and thermal comfort can directly be assessed by applying well established relations. A more complicated but far more accurate approach would be to couple the LBM code to a human thermoregulation model such as Fiala's model [4]. Due to a bidirectional coupling, boundary conditions from the room influence the manikin and the manikin delivers new boundary conditions for the thermal solver.

Here, computational steering can help to identify setups with better comfort behaviour (small scale) or less impact on surroundings (large scale) on-the-fly, i.e. without separate batch computing and visual post-processing. Users can manipulate the scenario (geometry and boundary conditions) during runtime in order to get an immediate feedback by the running simulation; hence there is a direct relation between cause and effect. Nevertheless, this requires the simulation to run in an interactive instead in batch mode, which is not always supported by supercomputer systems. One possibility though to combine interactive computing and HPC is to run 'small' simulations, i.e. with reduced accuracy, on small interactive cluster systems for a quantitative analysis, before any promising setup figured out by the user is then (automatically) launched as batch job with high accuracy for a qualitative analysis on a supercomputing system as proposed in [5].

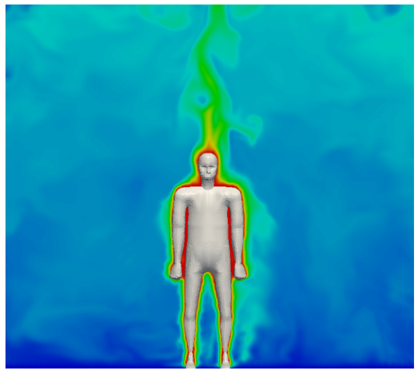

Figure 4: numerical manikin simulation in an enclosed room – the LBM code computes the domain under natural convection boundary conditions with the manikin as heat source; a thermal analysis can now be coupled to this simulation assessing the thermal comfort in the room

On-going Research / Outlook

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