Proposal for a PhD thesis :

Urban environments and advanced modeling: Radiative coupling and analysis of the effects of radiation / atmosphere interactions on urban microclimates

Keywords : Urban micro-meteorology, Thermal and areaulic conditions, Computational fluid mechanics, Radiative transfers, Lattice Boltzmann method.

Supervising team *:*

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  Modeling of atmospheric radiative transfers, coupled heat transfers
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  Building and Urban physics, Computational fluid dynamics, Architecture and Urban planning
- *Mathieu Galtier – Associate professor CETHIL / INSA Lyon*
  Modeling of radiative transfers, Statistical methods

Location :
Centre for energy and thermal sciences of Lyon, Campus de la Doua, INSA de Lyon, 69100 Villeurbanne, France (http://cethil.insa-lyon.fr/)

Subject :

Context :

In the context of climate change and urban densification, urban overheating (resulting from the conjunction of heat wave and urban heat island effect) becomes critical for contemporary urban development, with major social, health, economic, environment and energy consequences. However, urban micro-meteorological conditions are very variable in time and space. These conditions result from complex multi-physical (radiative, thermal, aeraulic, latent transfers) and multi-scale (from the small scale of turbulence to that of heatwaves) interactions, which develop within an even complex open, 3D, built and inhabited urban system. These interactions notably explain the importance of the urban heat island effect, which results from:

- Morphological factors: the 3D geometry of cities forms obstacles to wind and traps solar and infrared radiations within it
- Material and surface factors: mineral materials used in constructions absorb and store heat, while having a low evapo(traspi)ration potential
- Anthropogenic factors: Human activities and the use of active systems generally constitute heat sources

Therefore, tackling the problem of urban overheating requires developing knowledge about the micro-meteorological system, with the purpose of both diagnosis and designing suitable cooling solutions. To do this, different complementary approaches can be implemented, such as experimental approaches based on measurements, surveys or numerical modeling and simulation. Although this last approach necessarily involves some mathematical, physical and numerical assumptions, it has the advantage of allowing the realization of objective, three-dimensional, parametric and more or less detailed studies to evaluate the effects of different modes of heat transfers in cities, with respect to their dependence on the urban structure and atmospheric conditions on larger scales.

Problem and objectives :

Numerical approaches currently used to study urban microclimates are generally based on (very) simplified descriptions of the urban structure and physical phenomena. This is explained by the complexity of the coupled processes developing in urban environments, the detailed simulation of which requires important computational resources. Although they are in practice necessary, these simplifications can have a significant impact on the physical representativeness of simulation results, which limits the quality of predictions, as uncertainties are often unknown. These simplifications can also make it difficult to understand the developing physical processes and, thus, our capacity to extract useful information and suggest relevant solutions. In addition, model validation generally remains an issue because of the difficulty to produce and use reliable, relevant and suitable reference data in terms of representativeness and physical complexity.

In order to provide some answers to this problem, innovative techniques are emerging. They particularly aim at studying urban airflows in details but computationally efficiently (large eddy simulation, based on the lattice Boltzmann method – LBM-LES). These methods, coming from the aeronautic sector and adapted for urban applications, are able to solve the most important scales of turbulence considering complex geometries and were validated against reference high-resolution experimental data. First studies showed how beneficial the development of such detailed approaches is to highlight the different mechanisms that contribute to generate urban environmental conditions, in particular for applications to pedestrian wind comfort and pollutant dispersion. Thus, in complement to these aerodynamic aspects**, the present project aims at developing a radiative heat transfer model, coupled with the computational fluid mechanics model, allowing the analysis of the physical processes that develop in urban environments in order to study precisely the issues linked with urban micro-meteorology**.

The radiative transfer model will use the same solver as the aerodynamic solver (LBM), thus allowing to use a single code. Indeed, the use of LBM for radiative computation is formally equivalent to apply the discrete ordinates method, as the radiative transfer equation is a Boltzmann equation for photons. The main difference between the two formulations is the disappearance of the unsteady term of the Boltzmann equation as radiation propagates with the speed of light. This aspect of the subject (to solve the ETR using a LBM solver) is original and innovative both in the radiative community and for urban physicists. In addition, it will be possible to validate the approach by comparison with Monte-Carlo-type reference solutions (existing radiative code at the CETHIL) and with experimental data measured on the Greater Lyon area. This double comparison will allow assessing the reliability and relevance of the developed methodology and defining some boundary conditions for the modeling.

Compared to usual radiative methods used in urban microclimatic tools, the developed high-resolution model will allow considering non-transparent atmospheres (integration of absorption by gases and aerosols for example) and non-uniform properties of surfaces (specular reflexions). Therefore, the model will enable the urban radiative heat fluxes and energy budgets to be better estimated. Additionally to the better representativeness of urban environmental conditions, and thus the better characterization of the citizens exposure to heat stress depending on the properties of their close built environment, the developed approach will also enable different transversalities to be developed, e.g. with air quality (interaction radiation/pollution) or biodiversity (links between solar loads, ecosystems and photosynthesis for example). Hence, the coupled micro-meteorological model will make it possible to link science, engineering and urban planning by proposing a detailed approach aiming to better understand the impact of the different modes of heat transfers as well as their coupling – phenomena conditioning the energy behavior of buildings and the comfort and health of citizens- on urban environments. It can also be used as a reference model to derive simpler operational models for applications to the definition of architectural or urban planning cooling solutions.

Collaborations :

This work will be carried out in close collaboration with the M2P2 UMR 7340 laboratory in Marseille, France, and more particularly with P. Sagaut's team, which develops the LBM LES code used. For several years, this collaboration shares high-level skills in numerical modeling of complex turbulent flows, initially applied to aeronautic and automobile issues, civil engineering / building physics and architecture/urban planning. The present project will develop and strengthen the scientific collaborative activities thanks to the integration of a new expertise in thermal radiation.

Internationally, the present project will also benefit from the partnerships set up at the CETHIL with Brigham Young University (Utah, USA), with which the CETHIL collaborates on radiation topics for several years as well. Recent joint works showed the possibility of extending the ''combustion type'' models to cold atmospheres such as those encountered in cities. A stay of several months abroad is planned.

Prerequisites :

Good knowledge of heat transfers and good modeling skills. Bases in building physics and fluid mechanics. Good level of English and good communication skills.

Skills or interest in architecture, urban planning or the humanities and social sciences will be very appreciated.

Required background: engineer's or master's degree in energetics or civil engineering

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Funding: This project will apply for a Lyon Urban School doctoral grant (https://ecoleurbainedelyon.universite-lyon.fr/formation/financements-de-these-par-l-ecole-urbaine-de-lyon-29472.kjsp)

Duration of the work: 3 years, beginning on 01/10/2019

Application process: Send by e-mail, your curriculum, your cover letter, as well as references to contact to lucie.merlier[at]insa-lyon.fr **before the 23/04/2019**