Direct Numerical Simulation of a paradigmatic Urban Heat Island

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In the last decades the urban population has increased a lot making cities objects of different studies. In this context, urban climate is an expanding research field and understanding the main features of the urban heat island effect (UHI) is one of the challenges. As suggested by Masson et al.[1] , and confirmed by numerous examples in literature, a discrete number of neighborhoods has been object of study for this climate effect with growing interest in recent years, especially focusing on heat mitigation. Despite this, there is a lack of knowledge due to the complex nature of the problem given by the multi-physics involved, the multiple parameters that govern it and above all, the complexity of the city's geometries that lack generality.

In this respect, and to keep results applicable in a broader context, this work proposes an innovative approach to studying urban heat island effects, providing a unique framework for understanding the interaction between urban geometry and heat transport dynamics while addressing the complexities of urban configurations with an innovative and systematic approach. In particular, the city is represented as a rough surface of simplified hexahedral buildings arranged in a circular domain of radius R. The urban layout is characterized by four key non-dimensional parameters: the reference coverage frequency KC^{ref}, the reference density coverage ρ^{ref}, the reference aspect ratio of the planform area AR_{π}^{ref}, and the reference aspect ratio of the building heights AR_z^{ref} along with α, a coefficient describing the radial variation of the city shape. These parameters effectively capture the main statistical features of cities and enable a generalized modeling approach. In this paradigmatic context, the urban heat island is studied by considering only pure convection conditions without external wind.

Flow physics and heat transport properties of this setup are investigated via direct numerical simulation (DNS) at fixed $Ra = 10^8$ and $Pr = 0.7$ in a domain dimensions of $(L_x, L_y, L_z) = (8R, 8R, 1R)$, discretized with $(n_x, n_y, n_z) = (1600, 1600, 263)$. This simulation is performed by using the massively-parallel open-source code CaNS[2] which employs a staggered second-order finite difference scheme for spatial discretization. Integration in time is performed using a third order accurate Runge-Kutta method with a condition of $CFL = 0.6$. Coupled with an Immersed Boundary Method (IBM) that employs a masking technique, this approach enables the accurate resolution of flow dynamics and heat transport around the complex urban layout. The methodology and results of this study will be presented during the conference.

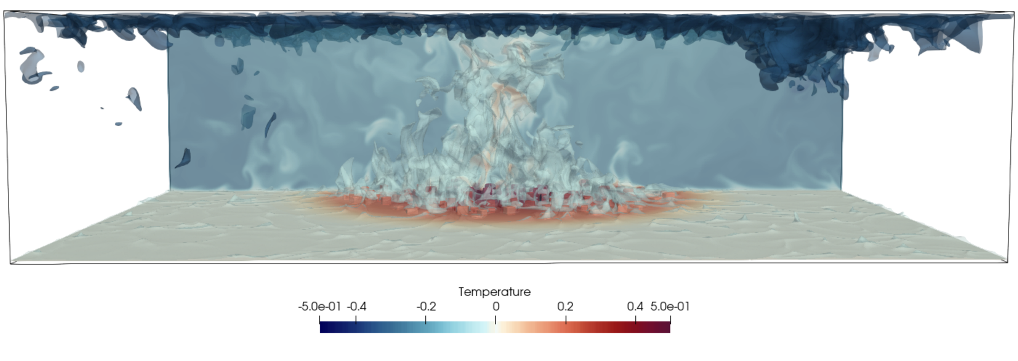

Figure 1: Instantaneous visualization of the urban configuration with contours of temperature fields

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[1] Masson et al. (2020). *Urban climates and climate change*. Annual Review of Environment and Resources **45**, 411–444.

[2] P. Costa. (2018) *A FFT-based finite-difference solver for massively-parallel direct numerical simulations of turbulent flows*. Computers & Mathematics with Applications **76**, 1853-1862