Micrometeorological modeling of radiative and convective effects with a building resolving code

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Introduction

In order to simulate the urban atmosphere in non neutral stratification in dispersion and risk assessment studies, we developed a microscale three-dimensional atmospheric radiative model coupled with a Computational Fluid Dynamics (CFD) code for complex geometries. Our validation is based on the MUST [3] experiment (Mock Urban Setting Test), which is an extensive field test where the buildings are represented by an array (12 rows by 10 columns) of shipping containers carried out on a test site of the US Army in the UTAH desert in 2001. We simulated the day of September 25th 2001 from the MUST experiment, in order to study the effects of wind and radiative heat transfer in real meteorological conditions.

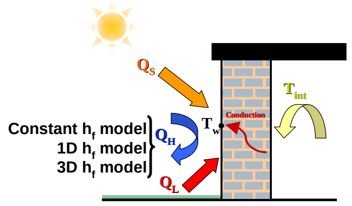


Fig.1: Schematic representation of the surface temperatures

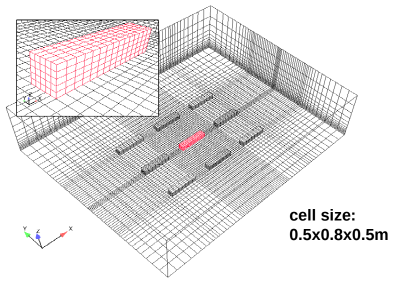


Fig.2: Model mesh for MUST simulations

Model

CFD model

- The simulations are performed with the 3D CFD model *Code_Saturne* capable to handle complex geometry.
- In this work, we use the atmospheric module, which takes into account the larger scale meteorology and the stratification of the atmosphere.
- We use the RANS approach with a k-ϵ turbulence closure and a roughness wall law.

Radiative model

Based on the Discrete Ordinate Method (DOM), a new atmospheric 3D radiative scheme was developed in *Code_Saturne* for the urban canopy [1].

- **Short and long-wave radiation**
- **Surface temperature (T_w) obtained with one of the following scheme :**

1) Force-restore scheme:

$$\frac{\partial T_w}{\partial t} = \frac{\sqrt{2\omega}}{\mu_w} Q^* - \omega (T_w - T_{g/b})$$

With ω the earth angular frequency, μ_w the thermal admittance, Q^* the total net flux and $T_{g/b}$ either deep ground or interior building temperature

2) Wall thermal scheme:

$$\frac{\lambda_w}{e_w}(T_w - T_{\text{int}}) = Q^*$$

With λ_w the thermal conductivity, e_w the thickness

- **Internal temperature obtained with one of the following options :**

1) Constant T

2) Evolution equation:

$$T^{n+1} = T^{n-1}\left(\frac{\tau - \Delta t}{\tau}\right) + \underline{T}\left(\frac{\Delta t}{\tau}\right)$$

With T^{n+1} and T^{n-1} the temperature at the future and previous time step, respectively, Δt the time step, τ is equal to 1 day, and $\underline{T}$ the average of the surface temperature

3) T from measurement

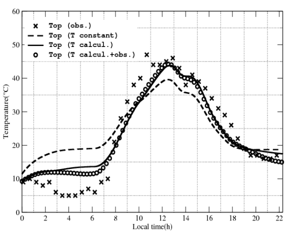


Fig.3: Comparison of the internal temperature for the 3 approaches

Results

The diurnal evolution of the surface temperatures are correctly reproduced by the coupled model with the force-restore scheme (Fig.4a - c). A large temperature difference between the coupled model and the radiative model only shows the importance of accurately modeling convective effects in microscale modeling. Assuming an isolation inside the building, using the wall thermal model can improve the simulation results (Fig.4d).

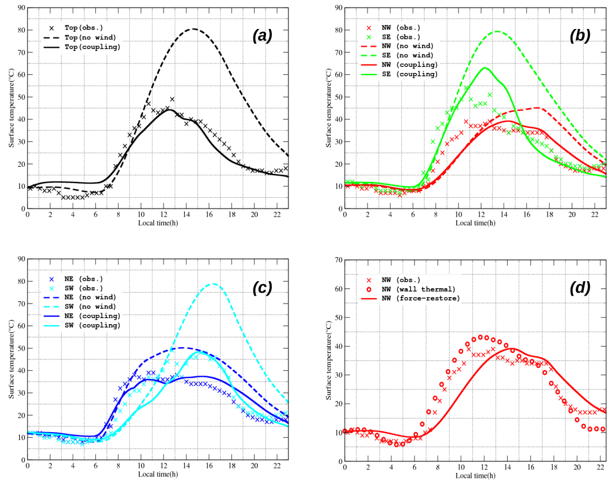


Fig.4: Diurnal evolution of surface temperatures

Discussion

The sensible flux is given by $Q_H = h_f (T_a - T_w)$

We compare 3 different approaches to compute the heat transfer coefficient:

- Assuming a constant h_f as done in the architecture simulation tools
- Modeling vertical velocity with an exponential profiles:

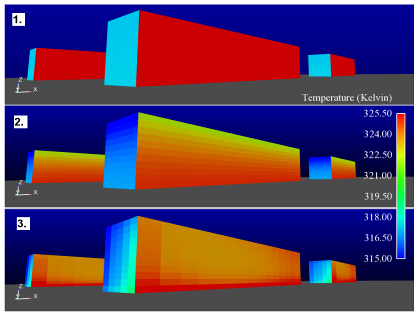
$$u(z) = u_H \exp(a(z/H - 1))$$

$$h_f = 11.8 + 4.2u(z) - 4.0$$

- Solving the 3D Navier-Stokes equations in the entire fluid domain with a roughness wall law:

$$u(z) = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right)$$

Fig.5: Comparison of three convective models with visualization of SE and NE wall temperature at 12h30:
(1) Constant h_f
(2) 1D h_f
(3) 3D h_f

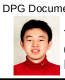


Conclusions and perspectives

- Sensitivity studies show the high dependence on initialization and parameters describing the building, especially the interior building temperature.
- There is a good agreement between the experimental data and the computations for the MUST case.
- The 3D calculation of the sensible heat fluxes allows to predict more accurately the non uniform surface temperatures.
- The perspectives of this work is to improve the thermal model.
- The coupled dynamic-radiative model will be used on a real urban area with the CAPITOUL experiment (City of Toulouse, France).

References

[1] Milliez, M., (2006) Modélisation micro-météorologique en milieu urbain: dispersion des polluants et prise en compte des effets radiatifs, Ph.D. Thesis, Ecole Nationale des Ponts et Chaussées.
[2] Oke, T.R., (1987) Boundary Layer Climates, Routledge, London.
[3] Biltoft, C.A., (2001) Customer report for Mock Urban Setting Test, DPG Document No. WDTC-FR-01-121, West Desert Test Center, U.S. Army Dugway Proving Ground, Dugway, Utah.



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