

Validations and applications of a CFD tool dedicated to wind assessment in urban areas

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1 INTRODUCTION

UrbaWind is a CFD code developed by Meteodyn especially dedicated to urban wind applications with an automatic meshing and boundary conditions set-up. The paper shows validations by comparisons with experimental data proposed by the Architectural Institute of Japan (Tominaga et al., 2008). The first selected case is a wind-tunnel experiment of wind past a group of blocks, and the second one is a field experiment inside a quarter Niigata (Japan).

Three examples of application in the outdoor comfort assessment are presented: A pool deck of Mosaic Houston (Texas), Chambéry Hospital (France), Saint-Brieuc district (France).

2 NUMERICAL METHOD

UrbaWind solves the Navier-Stokes equations with a one-equation turbulence model, where the turbulent length scale L_T varies linearly with the distance to the nearest wall (Fahssis et al., 2010). Boundary conditions are automatically generated. The vertical profile of the mean wind speed at the inlet is divided in 3 layers: logarithmic profile within the surface layer (Garratt, 1992), in the Ekman layer wind speed profile is a logarithmic function of geostrophic windspeed and windspeed at the upper limit of the surface layer and above the ABL the wind speed is constant and equal to the geostrophic windspeed. The geostrophic windspeed is a function of ABL height and the reference windspeed at 10m height in openland (roughness of 5 cm) defined at 10 m/s.

A ‘Blasius’-type ground law is implemented to model frictions (velocity components and turbulent kinetic energy) at the surfaces. The effect of porous obstacles is modeled by introducing a volume drag force in the cells lying inside the obstacle.

The equations resolution is based on a finite volume method with a rectangular multi-bloc refined mesh. A very efficient coupled multi-grid solver is used (Ferry, 2002).

3 VALIDATION CASES

3.1 *Wind tunnel experiment: group of blocks*

The site is built up of 8 blocks of 20 m of edge and an empty space in the center. The computations are done with a wind coming from the West (blue arrow) and the result points are located around the central empty space at two meters high, like shown in the Figure 1:

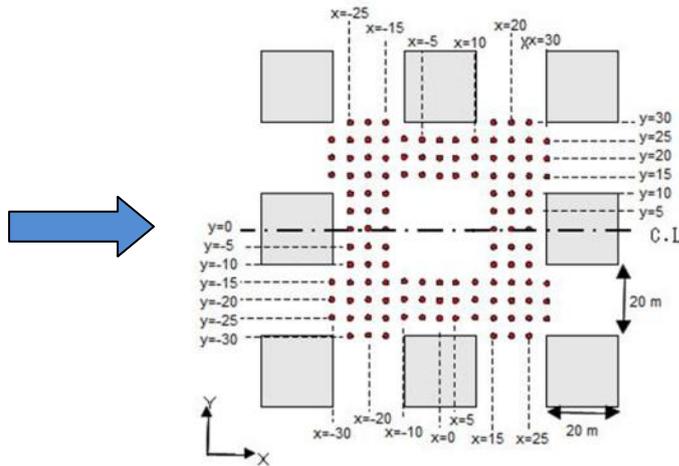


Figure 1. Results points for the group of blocks

The wind-tunnel measurement points are located around the central empty space at two meters high. The speed-up factors deduced from UrbaWind computations have been compared with the speed-up factors obtained by the experimental measures.

In the following Figure 2 (figure on the right), the computed values functions of the measured values for consistent points have been represented.

Table 1. Comparison Computations vs. Measurements for the group of blocks

	Error	R ²
For all points	8.5%	0.70
For the consistent points	5.8%	0.71

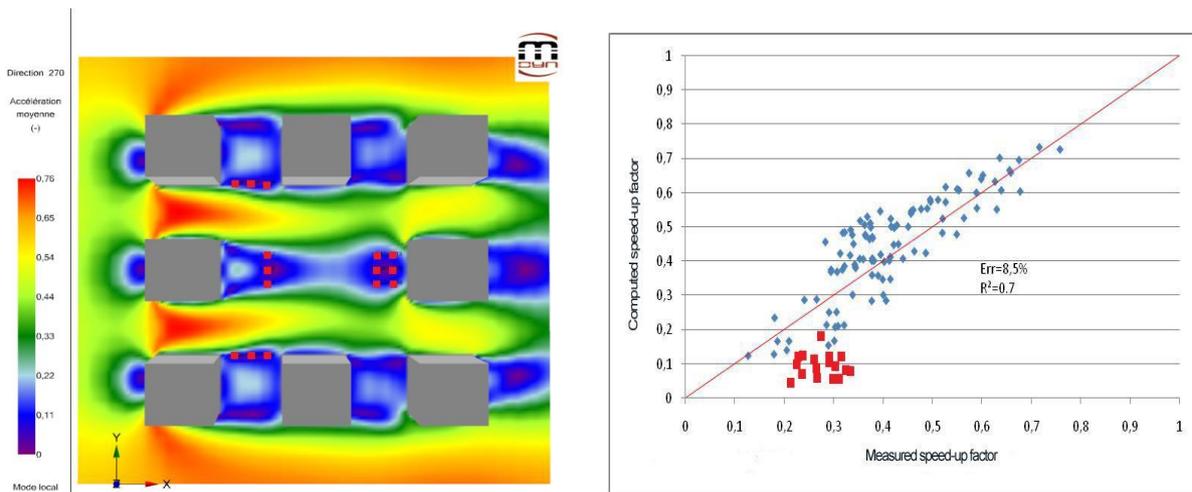


Figure 2. Wind flow around the blocks (wind from left to right) and computed vs measured normalized wind speeds.

The error on the speed-up factor for the mean windspeed is 5.8% when averaged on all points excluding the red points. 80% of points have an error less than 10%. The main errors come from low winds points or in area of large gradients (close to the corners in particular see Fig. 2). We can notice that the less consistent points are the points located in the areas where the mean acceleration is near zero. As all the CFD models, it is in the area near the joining distance that the results are the most difficult to reproduce.

3.2 Field experiment: Niigata district (Japan)

The field study has been conducted in a district of the Japanese city of Niigata. The wind is coming in the direction of 225° (blue arrow) and results points are placed in several random locations at two meters high.



Figure 3. Results Points Niigata (Japan)

The speed-up factors of the computation have been compared to the speed-up factors obtained by the experimental measurements. In the following Figure 4 (figure on the right), the computed values functions of the measured values for consistent points have been represented.

Table 2. Comparison Computations vs. Measurements for the city of Niigata

	Error	R^2
For all points	5.9%	0.75
For the consistent points	5.4%	0.79

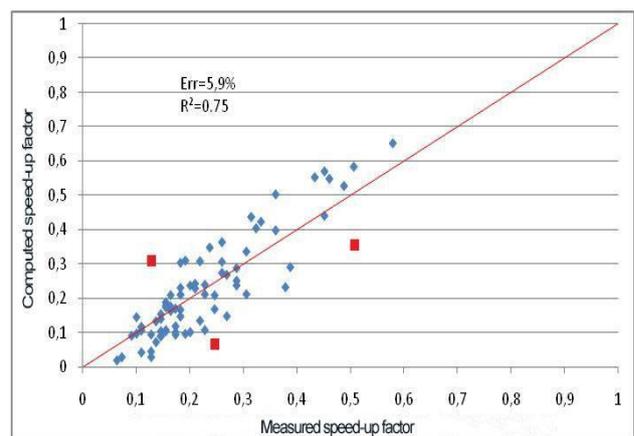
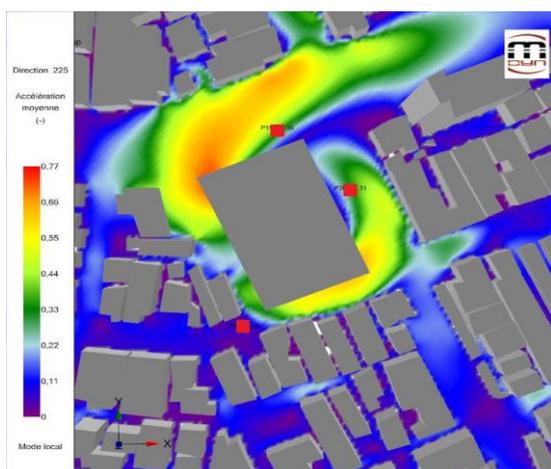


Figure 4. Computed wind flow inside the Niigata district and computed vs measured normalized wind speeds

The points where the computed value of the speed-up factor is far from the measured value are represented. One can observe (Fig. 4) that the worst points correspond either to low-speed areas, or to areas where a small change of location can lead to an important speed variation.

Globally 90% of the points have an error value lower than 12% on the gust value and the mean error is lower than 5.9% for all points and 5.4% when selecting only the consistent points.

4 WIND COMFORT ANALYSIS

4.1 Wind comfort criteria

In UrbaWind, the wind comfort is expressed in terms of rates of windspeeds threshold exceedance as recommended by Delpech et al. (2005). If we consider for instance the CSTB criteria, we consider the frequency of the “gust speed” exceeds 3.6 m/s. In this case the “gust speed” is defined as the sum of the 10 min mean wind speed and its standard deviation.

According to CSTB criteria, the limit of comfort is 5% exceedance for a steady position, 10% for a walking pedestrian, and 20% for a brisk walking.

Table 3. Discomfort frequency

	Transitory motion	Recreational motion	Short Stationary	Long Stationary
France (CSTB)	$F(V > 3.6) < 20\%$	$F(V > 3.6) < 10\%$	$F(V > 3.6) < 5\%$	$F(V > 3.6) < 5\%$
Netherlands	$F(V > 5) < 20\%$	$F(V > 5) < 10\%$	$F(V > 5) < 5\%$	$F(V > 5) < 5\%$
Denmark (DMI)	$F(V > 5) < 50\%$	$F(V > 5) < 34\%$	$F(V > 5) < 15\%$	$F(V > 5) < 15\%$
Montreal (Winter)	$F(V > 4) < 25\%$	$F(V > 4) < 15\%$	$F(V > 4) < 10\%$	$F(V > 4) < 10\%$
Montreal (Summer)	$F(V > 6) < 25\%$	$F(V > 6) < 15\%$	$F(V > 6) < 10\%$	$F(V > 6) < 10\%$
United Kingdom	$F(V > 11) < 2\%$	$F(V > 8) < 4\%$	$F(V > 5) < 6\%$	$F(V > 5) < 1\%$

Safety : $F(V > 15) > 0.05\%$: risky site

$F(V > 15) > 0.3\%$: dangerous site

Notation: $F(V > 3.6)$ = frequency of the winds faster than 3.6 m/s

4.2 Examples of applications to comfort assessment

We present here 3 cases of applications for which UrbaWind was used and allowed to propose solutions for wind evaluation with possibility of wind protection.

The first case deals with the wind comfort of a swimming-pool at the top of a building, between two high towers (Fig. 5), located in Houston (Texas). Prevailing winds are closed to the symmetrical plan (y0z on Fig. 5). Consequently, comfort wind can be considered “poor” with high frequency of occurrence of the event wind gust than 5 m/s (US criteria) reaching 50%. Windbreaks are required to improve wind comfort on the pool deck.

Thanks to Windbreak design, wind comfort will be enhanced. Gust speed is going to go from 6 m/s to 4 m/s on the pool deck and frequency of discomfort decreases from 50% to 30%.

Computations have shown that porous screens of height 4 m were necessary to ensure an acceptable comfort level (Fig. 6).

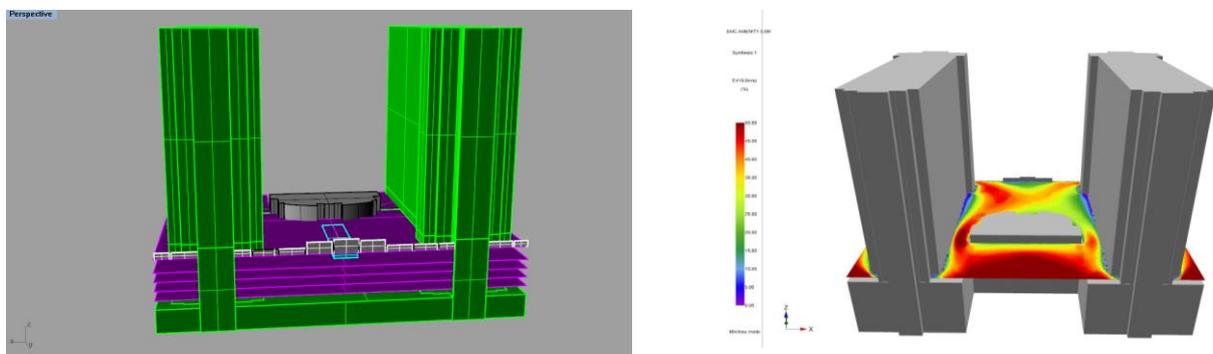


Figure 5. Original windbreak design and wind comfort index at the pool level

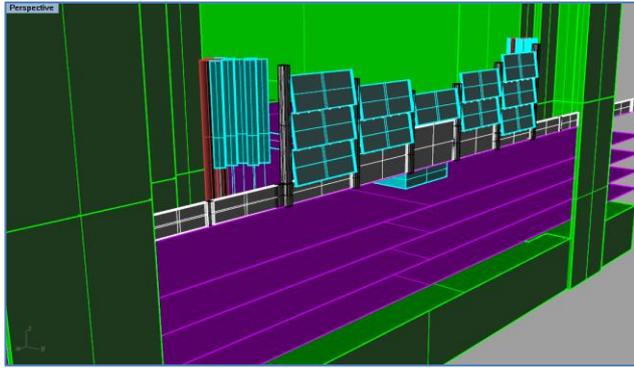


Figure 6. Original windbreak design and wind comfort index at the pool level

The second case, at a larger scale aimed at enhancing outdoor environment of the Chambéry Hospital (France).

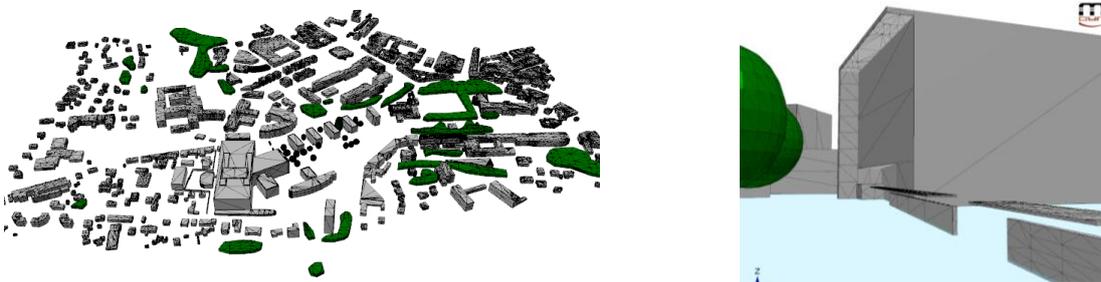


Figure 7. CAD of the Chambéry Hospital (Left: Overview. Right: Entrance of the Hospital)

Wind comfort at the hospital entrance, most sensitive area, is suited for long stationary. Locations of vegetal screens were determined in order to enhance wind comfort.

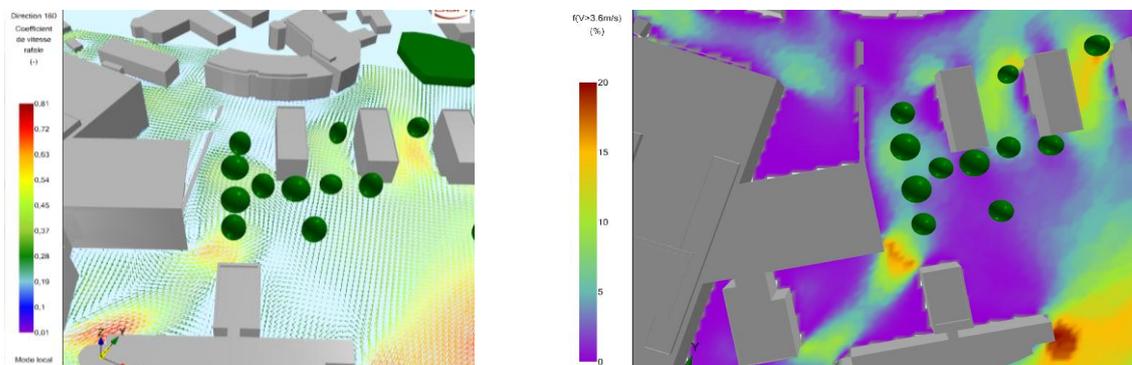


Figure 8. Left: Wind speed distribution at the entrance hospital. Right: Wind comfort at the entrance hospital

The third case at an urban scale (4 km x 4 km) aimed at checking that the renewal of 3 districts in St-Brieuc (France) did not lead to undesirable effects.

For example, in one district major modifications were towers and building demolition, creation of building and house:

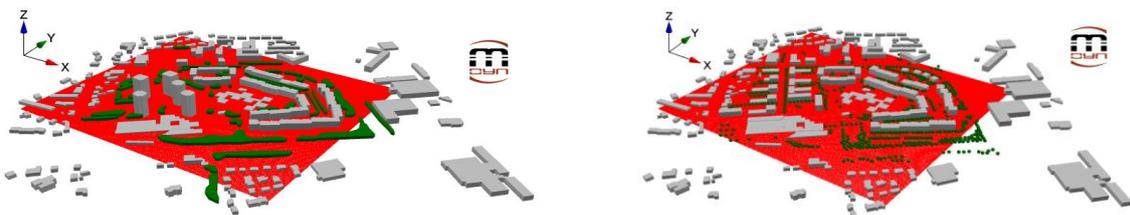


Figure 9. District Area of the present configuration (left) and new configuration (right)

The frequency of occurrence of the event wind gust > 3.6 m/s is compared here.

It appears that the urban planning has a significant positive impact on wind comfort.

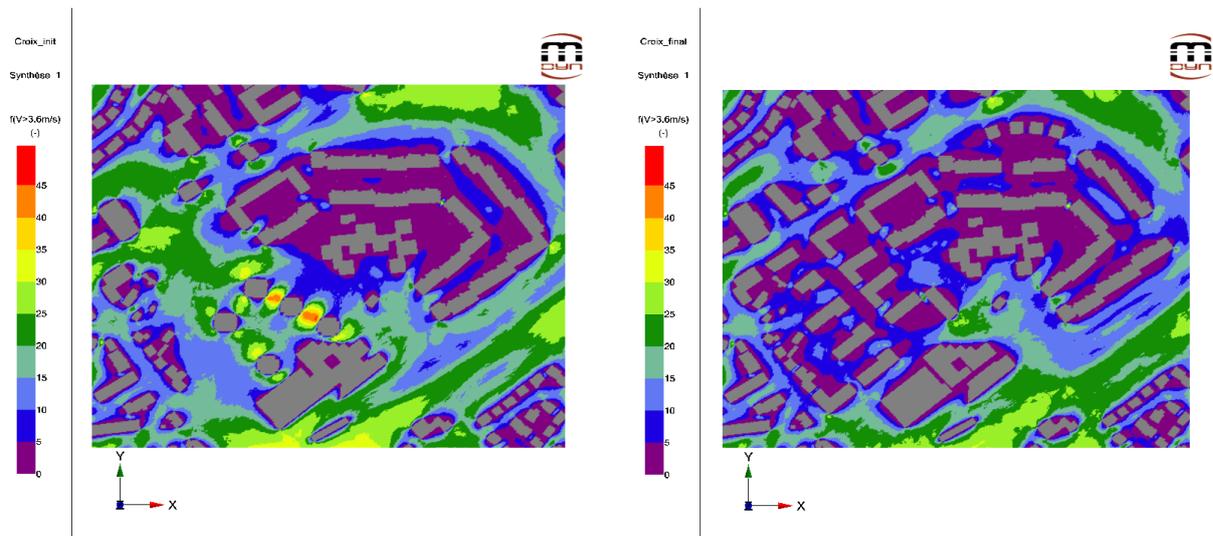


Figure 10. Wind comfort comparison

5 REFERENCES

- Delpech P., Baker C.J., Blackmore P.A., Koss H., Sanz-Andres A., Stathopoulos T. Willemsen E., 2005. Pedestrian wind comfort assessment criteria: A comparative case study, Proc. 4th European & African Conference on Wind Engineering, 11-15 July 2005, Prague
- Fahssis K., Dupont G., Leyronnas P., 2010. UrbaWind, a Computational Fluid Dynamics tool to predict wind resource in urban area, International Conference of Applied Energy, Conference paper, April 2010, Singapore
- Ferry M., 2002. New features of the MIGAL solver, in: Proceedings. Phoenics Users International Conference, Moscow, Sept 2002
- Garratt J.R., 1992, The atmospheric boundary layer, Cambridge Atmospheric and space sciences series.
- Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M., Shirasawa, T., 2008. AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. Journal of Wind Engineering and Industrial Aerodynamics, 96, 1749-1761