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Value of on-site wind measurements to close the building design loop

Rubina Ramponi [1], Viet Le [2], Melissa Burton [3]

[1]*Arup, Dublin, Ireland, rubina.ramponi@arup.com*
[2]*Arup, New York, USA, viet.le@arup.com*
[3]*Arup, Toronto, Canada, melissa.burton@arup.com*

SUMMARY:
Different wind assessment techniques are used to support design and operational decisions at various stages of a Masterplan's lifespan. Predictive detailed studies are often carried out using wind tunnel facilities or Computational Fluid Dynamics (CFD) simulations during the design process to assess the building performance in its final design state. However, scenarios may emerge during operation that result in unexpected wind issues. The paper examines a case study where on-site measurements and CFD simulations were used to complement the insights from wind tunnel testing at design stage and provide feedback on the wind conditions experienced on site. The measurements were carried out at up to 20 key pedestrian locations using an ultrasonic anemometer and a cup anemometer and were repeated throughout a 1-month period. The records were then correlated to the results of 3D steady RANS CFD simulations and wind tunnel testing using meteorological data from the closest weather station to the site. The study provides insights on the use of these tools at different stages of the building design life and discusses how the synergy between monitoring data and predictive tools can aid designers and specialists in closing the design loop.

Keywords: Urban wind flow, Wind measurements, CFD

1. GENERAL INSTRUCTIONS

Wind is an important environmental factor affecting a building's performance throughout its design life. Different assessment methods are used during the design stages to provide insights on the wind conditions expected on site. These typically include wind tunnel experiments carried out with a reduced-scale model or numerical simulations using computational fluid dynamics (CFD). The knowledge acquired through these studies is used to predict and minimize the impact of wind on the usability of a building and comfort of the outdoor spaces.

Detailed studies using either wind tunnel testing or CFD simulations are often carried out during the stages of design and reflect the initial and final site conditions. However, several different intermediate scenarios emerge throughout project construction and operation, for which limited attention is spent on acquiring data to continue these wind assessments. These situations can result in a missing link in the design loop, creating uncertainty in the wind conditions experienced on site. In the worst cases, some spaces are affected more severely by the wind in an unpredicted manner and need temporary mitigations to improve the user experiences. Incorporating site measurements as part of the wind assessment methodology is one way to close the gap in the design loop. Site measurements can provide additional, user-centric perspectives on the actual wind conditions at different stages of a development's lifespan and identify residual wind impacts. CFD simulations can then be used to approximate the real conditions and explore temporary or permanent mitigation options.

The paper examines a case study where on-site measurements and CFD simulations have been used to complement the results of early wind tunnel testing of a high-rise Masterplan and further inform the actual wind conditions on site during construction. Some insights are provided on the use of these tools at different stages of the building design life, including construction and operation. Measurements taken at critical pedestrian areas have been used to get feedback on the current wind conditions on site and inform a site wide CFD model to test mitigation solutions that can improve the spaces in the future. The results of this study demonstrate how the synergy between monitoring data and predictive tools can aid designers and specialists in closing the design loop and improve the quality of urban environments.

2. CASE STUDY

The study area consists of a cluster of high-rise buildings ranging from 270m to 390m tall surrounded by a public realm. The buildings are surrounded by a high-density urban area from the north to the southwest and some low-rise buildings to the west and northwest. At the time of the site measurement campaign, the area included buildings within the Masterplan which were already operational and some buildings under construction.

3. WIND ASSESSMENT METHODOLOGY

3.1 Climate characteristics

A wind climate analysis was carried out using historical weather data recorded at the nearest airport weather station (17 km to the southwest) to the site and acquired through the NOAA database (NOAA, 2001). The wind data were transposed to site using the upstream terrain assessment methodology described in ESDU (2010).

3.2 Physical modelling

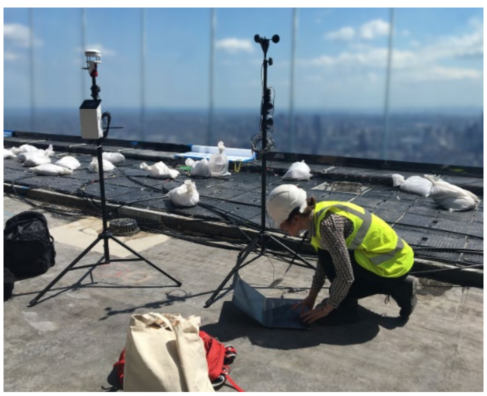
Wind tunnel testing of the development was carried out during the design stages. The tests were performed in an atmospheric boundary layer wind tunnel on a reduced-scale model, and the wind speed at an equivalent full-scale height of 1.5m from ground was measured at selected pedestrian location using Irwin probes. More information on the wind tunnel testing will be provided in the full paper.

3.3 Numerical modelling

The computational model and domain used for the CFD simulations was defined to include the target buildings and central open space and all surroundings within a radius of about 600 m. A structured computational grid with predominantly hexahedral cells of identical size and shape within the refined areas of interest was developed using the meshing utility snappyHexMesh in the OpenFOAM software library. The areas of interest were near the ground where resolution of the cells was increased to adequately capture pedestrian level wind effects. Cell non-orthogonality, skewness and aspect ratio were all well within acceptable limits (Ferziger and Perić, 1996). The boundary conditions consist of an atmospheric boundary layer profile at the inlet that replicate the effects of the upstream terrain. Zero pressure outlet and slip conditions were defined at the sides and top of the domain. The simulations were conducted using OpenFOAM. The 3D steady RANS equations were solved with the k-ω SST turbulence model for closure.

3.4 Full-scale experiments

Site measurements were carried out over the course of a month during moderately windy days from the prevailing wind directions (Northeast, Northwest and Southwest). The measurements were conducted using a cup anemometer and an ultrasonic anemometer. The ATMOS 22 ultrasonic anemometer was equipped with a ZL6 datalogger at typical pedestrian level height (1.5 m) and was carried around the site to measure the wind speed and direction at different locations (Figure 1(a)). Wind speeds and directions were collected in one-minute intervals. A separate anemometer operating via rotating cups was placed at an unobstructed location as a reference and recorded wind speeds every ten seconds (Figure 1(a)). The measurements were carried out at up to 20 locations across the site (Figure 1(b)) and approximated to an hourly mean wind speed using the methodology in Durst (1960).



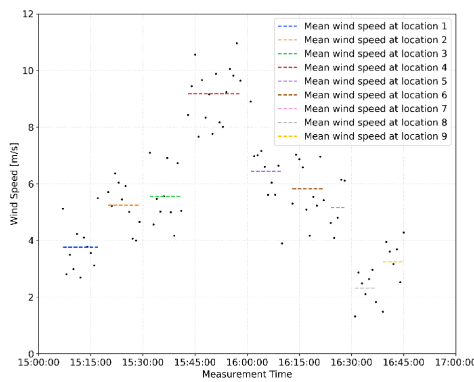


Figure 1. (a) Ultrasonic anemometer (left) and cup anemometer (right) used for the site measurements; (b) sample of recorded data for different locations with averaging time.

4. RESULTS AND DISCUSSION

Figure 2 overlays the wind speed measured on site to the results of the CFD simulations for two different wind direction. The measurements were taken at up to nine locations over a 2 to 3-hour period during two different wind events: (a) northwesterly (310 - 330° from North) winds with speeds of 7-11 m/s, and (b) northeasterly (30 - 40° from North) winds with speeds of 5-6.5 m/s recorded at the airport. An example of the wind speeds measured from the northwesterly wind event is shown in Figure 2. Each location exhibited varying wind conditions which were averaged over the measuring period and converted to approximate hourly means to compare against the CFD simulation results. The CFD model captures some typical flow features such as the acceleration and recirculation zones around the corners of upstream buildings and tend to reproduce well the wind direction observed on site. However, the wind speeds are largely overestimated in the large open areas. This is partially due to the simplified representation of the development in the computational model, and the lack of small features near the ground, either permanent or temporary, that are characteristics of sites in operation and under construction. Some examples, as shown in Figure 3 are construction elements, or hard and soft landscaping.

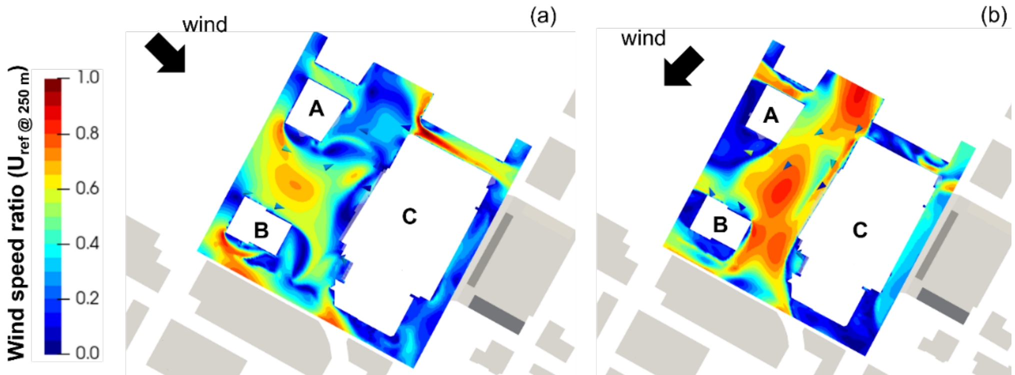


Figure 2. Wind speed ratio obtained from the on-site measurements and CFD simulations for (a) northwesterly and (b) northeasterly winds.

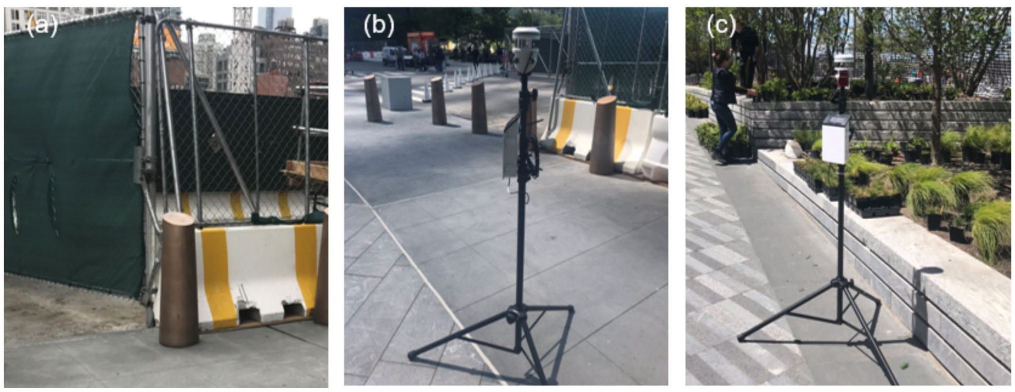


Figure 3. Small scale feature that may obstruct the wind on site: (a, b) construction elements, (c) landscaping.

7. CONCLUSIONS

The paper discusses the use of different modelling and measurement tools to predict the wind conditions on site and ultimately improve building operations and pedestrian experience of the public realm. While detailed analysis with CFD and wind tunnel testing provide valuable insights to drive design decisions, the use of site measurements offers an opportunity to record the wind conditions during operation, and highlight relevant design elements that may not have been captured otherwise. When coupled with a CFD model, the on-site measurements can help specialists and designers to close the design loop and to test wind mitigations to be implemented on site.

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