Progress in Computational Fluid Dynamics (CFD) methods allows advance in natural resource assessment for wind energy production in complex urban terrain by modeling wind circulation around different urban obstacles. Compared to rural open spaces, the geometry in urban areas is more complex and has intricate influence on wind flow on micro-meteorological scale. The effects of the buildings on wind flow, such as vortices at the foot of the towers, Vector effects or Wise effects, make the modeling of urban flows considerably more difficult. We simulate these effects with UrbaWind CFD model by solving the equations of Fluid Mechanics with a specific method which allows representation of the turbulence and the wakes around buildings.

The software model has been used to evaluate the wind energy potential on the campus of the Massachusetts Institute of Technology in Cambridge (MA) for the installation of a free standing small wind turbine. The wind resource assessment has been performed by using long-term observations nearby the site to integrate the local climatology. In order to validate the results, two met masts have been installed on-site. Comparisons between the measurements and the predicted wind speeds allowed validation of the software results by offering a minor error margin on the wind speed prediction. This analysis provides an improved understanding of the micro-climate of wind resource on MIT campus and will facilitate the optimal siting of the turbine on campus.

The aim of this study is to assess wind energy resource on MIT campus for optimization of installation of small wind turbine. The procedure of resource assessment includes prediction of average wind energy available for energy production on campus and identification of optimal location for turbine installation. We study the local micro-meteorological features of wind flow and the effects of the complex urban topography. Localization of zones of re-circulation and turbulent wakes is important for both - high energy production and protection of the turbines from excessive gusts load by avoiding installation in a high turbulent area.

Because the fine resolution of the computational grid can lead to a large number of cells in urban areas, the typical size of the sites calculated with UrbaWind is around 1 mile by 1 mile. The Logan airport being located 4.8 miles away from the site, another tool is used to transpose the local long-term climatology from the airport to the site. The fine urban effects are then included in the simulations, the computational grid is Designated as 250 cells in the vertical direction and 20 cells in the horizontal direction (resulting in approx. 50,000 cells depending on wind direction) was used to model wind flow over the site in 18 sectors every 20 synthetic degrees.

A resolution of 1 x 1 m has been applied near the areas of interest resulting in a total of 4 million cells. The calculations are performed on 14 directional computations with a refinement around the prevailing wind direction 280°.

To help visualize the roughness and topography maps (35 x 5.5 miles)

The results of these calculations will be compared to a met tower on-site to validate the accuracy of this method. The picture below shows the wind rose at the airport and the wind rose 100m above the site.

This analysis allows for a more complete understanding of the micro-climate of wind resource on MIT campus and for a more accurate assessment of the wind energy resource available on the site.

As a first approach, the met tower data for the two sites on campus were processed according to the criteria set for wind resource assessment techniques and normalized using a set of techniques with the measure-statistic-predict framework. The data for the second test site over the first during the three winter months of data collection. However, post-normalization, the performance statistics of the two sites for wind speed and power density tends to converge. Details on the normalization will be made available in a future publication.

The wind rose calculated on-site shows the effects of the topography between the site and the airport and particularly the river on the wind. It shows clearly that the main wind direction on campus is 280°.

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Figure 1: Domain of analysis – West Campus MIT

Moreover, this study aims to evaluate the methodology for site calibration in urban environment using CFD numerical methods for transfer-long term measurements from a remote station rather than installing a met tower on-site.

Figure 2: Visualization of the roughness and topography maps (35 x 5.5 miles)

CFD Climatological Transformation

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Figure 3: Wind speed averages based off of raw data and statistical MCP techniques

Figure 4: Measuring grid used for the calculation in the direction 280°

A resolution of 1 x 1 m has been applied near the areas of interest resulting in a total of 4 million cells. The calculations are performed on 14 directional computations with a refinement around the prevailing wind direction 280°.

UrbaWind uses the solver MIGAL [5] with a DGMRES-type preconditioner to improve the robustness and a multi-grid procedure to accelerate the convergence. It completely solves 3D equations for fluid dynamics (RANS method). MIGAL employs a Galerkin’s projection method for generating the equations on the coarse grid. This technique, so-called “Additive Correction Multi-grid” consists in generating the equation of the coarse mesh as the sum of the equations of each corresponding fine cell. Once the solution is obtained on the coarse grid, it is introduced by correcting the values calculated previously on the fine grid with the calculated error.

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Figure 5: Scheme of the agglomeration method used by MIGAL - UNS5 in UrbaWind

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Figure 6: Spatial analysis of wind resource: CFD site map with directional wind statistics

The wind rose calculated with TopoWind at 100m above the site is used as input data in UrbaWind to define the reference local climatology.

UrbaWind solves the equations of Fluid Mechanics, i.e. the averaged equations of mass and momentum conservation (Navier-Stokes equations). As the wind is steady and the fluid incompressible, these equations become:

\[ \frac{\partial}{\partial x} \left[ \frac{u}{v} \right] = 0 \]

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The turbulent fluxes are parameterized by using the so-called turbulent viscosity. This viscosity is considered as the product of a length scale by a speed scale which are both characteristic lengths of the turbulent fluctuations. Boundary conditions are automatically generated. The vertical profile of the mean wind speed at the computation domain inlet is given by the logarithmic law in the surface layer, and by the BLau’s law function [3]. A Blau’s law type ground law is implemented to model friction (velocity components and turbulent kinetic energy) at the surfaces (ground and buildings). The effect of porous obstacles is modeled by introducing a sink term in the cells lying inside the obstacle [4].

\[ \frac{\partial}{\partial x} \left[ \frac{u}{v} \right] = 0 \]

Where \( C_f \) is a volumetric coefficient of frictions, which is proportional to the porous obstacle density, and \( V \) is the volume of the considered cell.

The turbulence characteristics are given by the standard deviation of the velocity fluctuations, which is globally estimated by the ratio between the square root of the turbulent kinetic energy and the mean wind speed. The wind rose calculated on-site shows the effects of the topography between the site and the airport and particularly the river on the wind. It shows clearly that the main wind direction on campus is 280°.

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Figure 7: Directional calculation of urban wind isolation factors, shown for the prevailing wind direction

Conclusions

We demonstrate application of CFD analysis for wind power resource assessment in complex urban environment of MIT campus. Meteorological data directly measured at the site is examined and compared to the results of CFD simulations. Qualitative comparison of the results exhibits satisfactory agreement. Detailed quantitative analysis is underway and will be reported in the future.

We show how CFD model is integrated in resource assessment procedure. The extensive available observations from a nearby airport can be transferred several miles to the area of interest. Next, calculations of the local speed-up factors with UrbaWind CFD model allow to estimate the mean wind speeds and the energy production at the site. A map of wind resource can be produced to identify the most productive areas and low turbulence zones.

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References


Figure 8: Spatial analysis of wind resource: CFD site map with directional wind statistics

Figure 9: Spatial analysis of wind resource: CFD site map with directional wind statistics

Figure 10: Spatial analysis of wind resource: CFD site map with directional wind statistics