Leadership in Sustainable Infrastructure
Leadership en Infrastructures Durables

Vancouver, Canada
May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

MAPPING POTENTIAL OF WIND ENERGY IN NEW YORK CITY

Gholitabar, Samaneh[1,3], and Griffis, Fletcher H.[2]
[1] NYU Tandon School of Engineering, USA.
[2] NYU Tandon School of Engineering, USA.
[3] soha.gh@nyu.edu

Abstract: In this research, a methodology is employed to predict local wind levels in urban areas. A semi-analytical methodology is used to calculate local wind speed in Manhattan using regional wind speed. The model up-scales the regional wind level to the urban boundary layer; it then downscales the wind level to the average building height of urban localities through two downscaling steps. A geographic information system (GIS) framework is used to extract required input for the semi-analytical method. Using the GIS information, first aerodynamic parameters of localities in Manhattan are calculated. Next, using semi-empirical methods, wind speed at the average height of buildings in each locality are estimated. The results are presented as a wind localization index map for Manhattan that can be used to calculate local wind speed at any location in the city as a function of the regional wind level. The local wind index can be used to identify the urban localities with higher local wind speeds which can be suited for harnessing wind energy on top of high-rises.

1 INTRODUCTION

Sustainable energy is one of the major challenges in human societies. In light of adverse environmental effects of fossil fuel, there is an increasing global demand for sustainable source of energies. One viable energy resource in urban areas is wind energy, which can be captured by placing small wind turbines on top of high buildings. In this paper, a recently developed wind localization model is applied to predict local wind levels in Manhattan. It provides information for better estimation of potential wind energy in urban localities of Manhattan.

2 METHODOLOGY

The Atlas wind method, which uses the standard logarithmic wind profile was used to calculate wind speeds at a given height for a specific urban area. UK Meteorological Office used a particular version of Atlas method that was used in this study (Best et al. 2008). The graphical presentation of the method is shown in Figure.1. A summary of the model is presented in this section.

The urban boundary layer (UBL) divided into the inertial sub-layer (ISL) and the roughness sub-layer (RSL) (Raupach et al. 1991). RSL lower boundary is considered to be at the height of 2 to 5 times the height of buildings' average height *hm* for urban localities. *U* in the ISL follows the usual logarithmic law Eq. (1).

$$[1]\ U = \frac{u*}{\kappa} \ln(\frac{Z-d}{z_0})$$

Where $\kappa \approx 0.41$ is the von Karman constant, $u*$ is called frication velocity, Z is the height above the ground, Z_0 is the aerodynamic roughness length, and d is the aerodynamic zero-plane displacement, respectively. These parameters control the shape of the log profile. Therefore, it is important to estimate z0 and d as accurately as possible (Best et al. 2008; Davidson 2004; Millward-Hopkins et al. 2011; Millward-Hopkins et al. 2013).

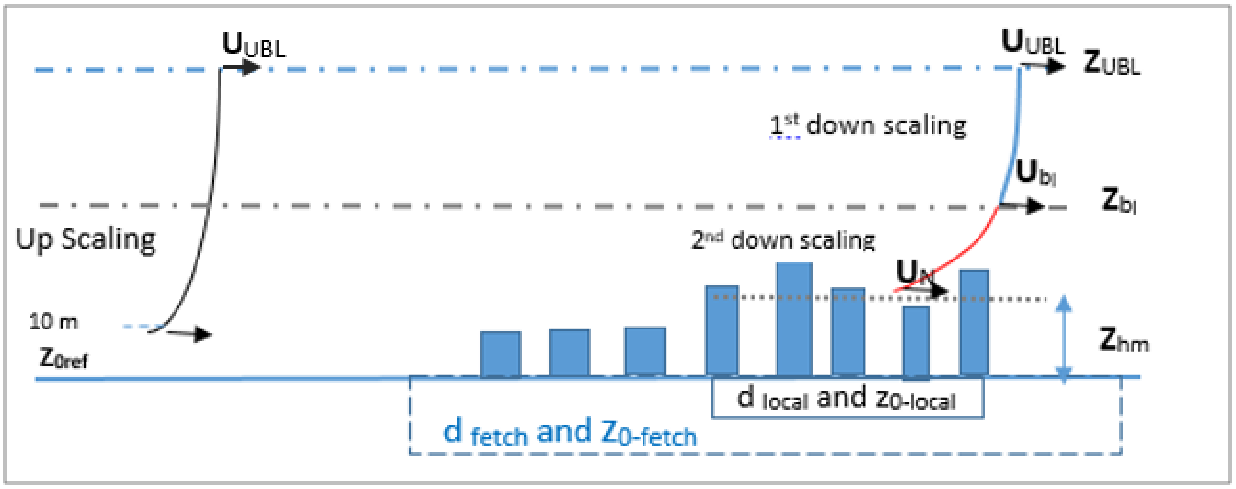

Figure 1. Schematic diagram of the methodology implemented in the current work (Adapted from Millward-Hopkins et al. 2013).

The magnitude of the turbulent shear stress, τ, is approximately constant in the inertial sublayer, and the height-gradient of wind, or wind shear, may be related to the shear stress, the height, and the density of air (ρ).

Below the RSL layer, the heterogeneous flow is predominantly controlled by the local surface geometry (Britter and Hanna 2003). This layer normally extends up to a height of about 2–5*hm* (Raupach et al. 1991). The profile in RSL can be modeled by extrapolating the ISL profile downwards with the addition of a particular correction factor for land cover effects (Millward-Hopkins et al. 2011).

The overall description of the Atlas model: (steps A (up-scaling), B and C (down-scaling)).

- **A)** In the first step, the regional wind speed (U_N) is up scaled to the top of the urban boundary layer (UBL), at height Z_{UBL} (500 meters), where the influence of the urban surface is assumed to be absent, Eq. (2). Z_{0-ref} is the roughness length related to the location of the station (urban area 1.6 m) (Millward-Hopkins et al. 2013; Elliot et al. 2008; Best et al. 2008; Raupach et al. 1991; Millward-Hopkins et al. 2013; Millward-Hopkins et al. 2012).

$$[2]\ \ U_{UBL} = U_N \frac{\ln(Z_{UBL}/Z_{0-ref})}{\ln(10/Z_{0-ref})}$$

- **B)** In the first down-scaling step Eq. (3), the wind speed at the top of the UBL is scaled down to the 'blending height' Z_{bl}. This step is to estimate the wind speed at the blending height (U_{bl}), Z_{bl} is assumed to be the top of the 'roughness sub-layer', below that level the wind profile is considered to be influenced by the local geometry of buildings. Since the layer above the blending height is influenced by upwind area of the location of interest, the aerodynamic parameters are calculated according to the description of the area upwind of the localization; this is defined as the 'fetch.' Parameters are labeled as $d_{\_fetch}$ and z_{0_fetch} for the roughness parameters of land cover maps in 5km upwind fetch. The appropriate roughness value of the fetch area considering its land cover, which is extracted from the literature (Centre for Ecology and Hydrology (CEH)) (Millward-Hopkins et al. 2012; Best et al. 2008). In the current study for Manhattan, the aerodynamic parameters of the fetch are approximately similar in all directions due to the size of Manhattan and its narrow shape.

$$[3]\ U_{bl} = U_N \frac{\ln((Z_{bl} - d_{fetch})/Z_{0-fetch})}{\ln((Z_{UBL} - d_{fetch})/Z_{0-fetch})}$$

C) In the second down-scaling step the wind speed at the average height of the buildings in the local area Z_{hm}; the elevation at buildings' average height Z_{hm} is estimated. This step needs the appropriate aerodynamic parameters z_{0_local} and $d_{\_local}$, which can be estimated given detailed data of the buildings geometry in the urban area (Eq. (4)).

$$[4]\ U_{hm} = U_{bl} \frac{\ln((Z_{hm} - d_{local})/Z_{0-local})}{\ln((Z_{bl} - d_{local})/Z_{0-local})}$$

2.1 Semi-empirical Methods for Aerodynamic Parameters (Step C):

Previous studies, related aerodynamic parameters (z_0 and d) to the geometrical parameters of buildings in the locality. Area densities λp and frontal area densities λf was considered as the two main geometrical parameters to find the aerodynamic parameters. λp is defined as the ratio of buildings' plan area to ground surface area and λf is defined as the ratio of buildings' frontal area to ground surface area. (Grimmond & Oke; 1999; Millward-Hopkins et al. 2011; Best et al. 2008).

According to these earlier studies, the shape and height of the buildings are two of the most significant factors influencing aerodynamic parameters. Geometrical data for all the buildings in Manhattan was accessible in GIS platform (Figure 2). Therefore the available semi-empirical methods which are based on wind tunnel tests and drag force analysis was used to estimate the local wind speed in Manhattan localities. Millward-Hopkins et al (MH) presented a semi-empirical method based on uniform arrays which is implemented in this study (the elaboration of the method is in Millward-Hopkins et al. 2011).

3 IMPLEMENTING THE METHOD ON NYC (MANHATTAN)

Detailed three-dimensional building data and semi-empirical morphometric methods were used to estimate the aerodynamic parameters of Manhattan. New York City map was divided into a relatively consistent geometry with ArcGIS (census tract boundary for 2011).

Figure 2: Shape of buildings, their plan view and CT boundaries (maps created with ArcGIS from New York City PLUTO data).

Next, the geometric parameters required by the MH methods were calculated from the building's detailed data for each locality. Building geometry was extracted from the Pluto file[1]. Then morphometric parameters (e.g. $\lambda p, \lambda f$) was calculated. Z_{hm} was calculated by weighted average based on buildings' plan area in each locality. Finally, the semi-empirical equations were used for the calculation of the aerodynamic parameters ($d_{\_fetch}$ and z_{0_fetch}). Using the local aerodynamic parameters in step C of the Atlas model. The localized wind at the average height of buildings in each of the Manhattan localities was calculated.

4 RESULTS

Local wind index (U_{hm}/U_N) is shown in Figure 3. Local wind index (LWI) can be used to estimate the localized wind speed of Manhattan. LWI is the ratio of local wind speed at the average height of buildings in each of locality to the regional wind speed at the height of 10 meters above ground (U_N). Higher local wind index represents the higher potential of wind energy on high-rise buildings of the locality.

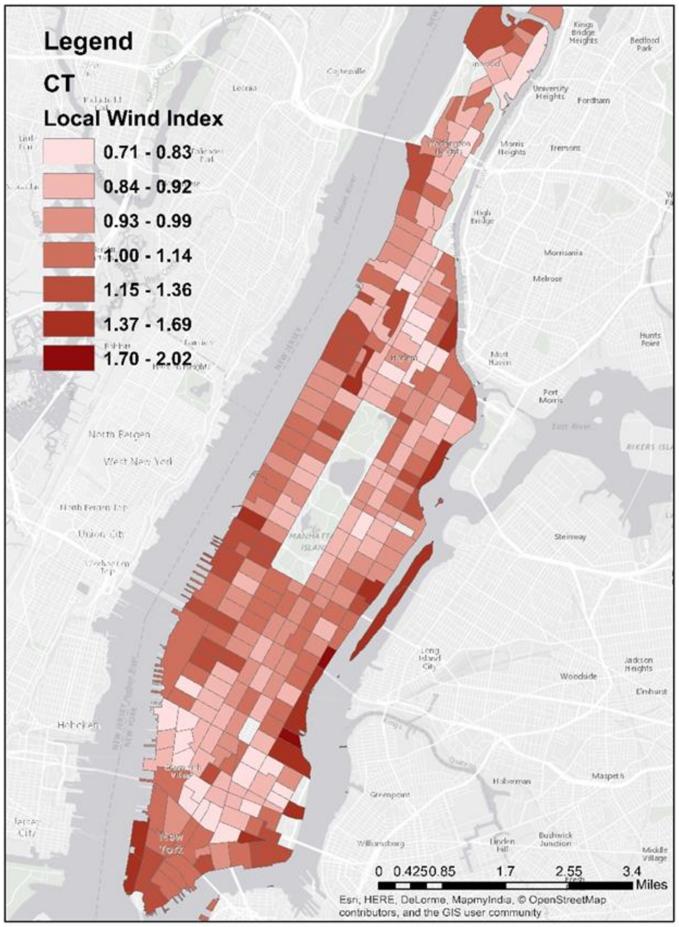

Figure 3: Local wind index, (U_{hm}/U_N) in each locality (CT) in Manhattan-local wind speed at average height of the buildings to the regional wind speed at the height of 10 meters above ground (regional wind U_N).

---

[1] http://www1.nyc.gov/site/planning/data-maps/open-data/dwn-pluto-mappluto-request.page

5 CONCLUSION

Semi-empirical methods can provide higher resolution of wind patterns in urban areas compare to national wind maps. In this study, the recently developed semi-empirical method of Millward-Hopkins et al. (2012) was implemented and adjusted for use in a GIS framework. The borough of Manhattan in New York City was used as a case study. The approach can provide highly resolved estimates about wind level at the average height of each locality. However, a better understanding of the vortex and canyon effects requires computational fluid dynamic analyses (CFD). The results can be used in energy planning and also construction management industry in preparation for the effect of high winds in the storm preparations and disaster management.

6 References

Best, M., Brown, A., Clark, P., Hollis, D., Middleton, D., Rooney, G.,Wilson, C. (2008). Small-scale wind energy–Technical Report. *UK Meteorological Office*.

Millward-Hopkins, J. T., Tomlin, A. S., Ma, L., Ingham, D. B., Pourkashanian, M. (2013). Mapping the wind resource over UK cities. *Renewable energy*, 55, 202-211.

Raupach, M.R., Antonia R.A., Rajagopalan S. (1991). Rough-Wall Turbulent Boundary Layers. *Applied, Mechanics Reviews*; 44:1-25.

Davidson, P.A. (2004). Turbulence: an introduction for scientists and engineers. *Oxford University Press, Oxford*, 655 pp.

Millward-Hopkins, J. T., Tomlin, A. S., Ma, L., Ingham, D., Pourkashanian, M. (2011). Estimating aerodynamic parameters of urban-like surfaces with heterogeneous building heights. *Boundary-layer meteorology*, 141(3), 443-465.

Millward-Hopkins, J. T., Tomlin, A. S., Ma, L., Ingham, D. B., Pourkashanian, M. (2013). Assessing the potential of urban wind energy in a major UK city using an analytical model. *Renewable energy*, 60, 701-710.

Britter, R.E., Hanna, S.R. (2003). Flow and dispersion in urban areas. *Annual Review of Fluid Mechanics*, 35:469–496.

Millward-Hopkins, J. T., Tomlin, A. S., Pourkashanian, M., Ingham, D., Ma, L. (2012). Mapping the urban wind resource over UK cities using an analytical downscaling method*. In Proceedings of the EWEA Annual Conference.*

Elliott, W. P. (1958). The growth of the atmospheric internal boundary layer. Eos, *Transactions American Geophysical Union*, 39(6), 1048-1054.

Grimmond, C. S. B., Oke, T. R. (1999). Aerodynamic properties of urban areas derived from analysis of surface form. *Journal of applied meteorology*, 38(9), 1262-1292.

Raupach, M. (1992). Drag and drag partition on rough surfaces. *Boundary-Layer Meteorology*, 60(4), 375-395.