Mean Wind Velocity Distribution at Near-ground Level Obtained Through Field Measurements

Jiading Zhong, Jianlin Liu*, and Guoming Liang
College of Environmental Science and Engineering, Donghua University, Shanghai, P.R. China

Abstract. Mean wind velocity profiles enable researchers to conduct efficient and accurate analyses of a wide variety of urban microclimatic problems, such as pollution dispersion, heat island effect and pedestrian wind comfort. However, due to the heterogeneity in the complex urban context, the wind profile at near-ground level within the real urban context remains insufficiently investigated. The present study aims to measure the near-ground level mean wind profiles in an industrial park. To this practical end, a sonic anemometer was equipped to a height adjustable bar on a mobile measurement platform. Through adjusting the sonic anemometer’s height, the mean wind velocities at different heights of the near-ground level were measured. Results indicate that the mean wind velocities’ variation along the near-ground heights measured at the site exposed to open and flat upwind areas can be reasonably captured by the power-law profile, while the other two conventional profiles, i.e. the log-law and the exponential profiles, show different levels of inaccuracy.

1 Introduction

Enlarged industrial productions have made the production activities one of the major sources of air pollutants in cities. To study the wind-driven dispersion process of the air pollutants from the industrial production sites to the other areas in the cities, it is vital to understand the wind profile especially at the near-ground level where pedestrians are exposed to. The common wind profile assumptions include the log-law, the power-law, and the exponential wind profiles. However, each of the assumptions has its drawbacks. For applications in urban context especially at the near-ground level, the log-law wind profile’s validity is dubious, as the roughness of urban areas would significantly alter the atmospheric boundary layer’s (ABL) layered structure which makes the log-law wind profile less accurate [1, 2]. The power-law wind profile is an empirical assumption that describes the ground surface roughness’s influence on the wind profile, of which the validity in describing the near-ground wind profile is also dubious. The exponential wind profile originates from wind tunnel tests of sub-roof level wind velocities, and thus provides a seemingly valid assumption for the near-ground wind profile. However, a recent review points out that the exponential assumption is based on inadequate proofs and thus might be erroneous [3]. This study aims to test the validity of the aforementioned three different assumptions in describing the near-ground wind profile in industrial park, using horizontal mean wind velocity time series obtained from field measurements.

2 Methodology

The field measurements were conducted using a portable measurement platform that was equipped with a 3D ultrasonic anemometer (0–30m/s, ±1%, ±0.05m/s). The anemometer was mounted to a height adjustable bar, and the measurements were conducted at the heights of 2.55m, 3.55m, 4.55m, and 5.55m. At each of the height, the anemometer measures the wind velocity components along the cardinal directions for 59min, and then 1min is spent adjusting the measuring height. The anemometer was configured to sample each of the wind velocity components 32 times per second, and the components are u, v, and w that align to the east-west direction, the north-south direction, and the vertical direction, respectively. The measurements obtained instantaneous wind velocity time series, which contained wind fluctuations. In order to remove the wind fluctuations and get the mean wind velocity time series, the nonstationary model was applied. The nonstationary model is based on taking time-varying averages of the instantaneous wind velocity, and in comparison with the stationary model that takes the time averages, it was more suitable for removing the wind fluctuations from the nonstationary natural wind data [4].

3 Results and discussion

The field measurements in an industrial park in the southwestern Shanghai conducted on October 27th, 2021 are presented, and for simplicity only the lower
heights of 2.55m and 3.55m are presented. As shown by the measurement results, the primary wind direction measured at the near-ground level is East-Northeast wind (ENE), and the average wind velocities are 1.95m/s and 1.96m/s at heights of 2.55m and 3.55m respectively (see Figure 1-a and -b). Illustrations of the time series for the velocity component u at the two near-ground level heights show both the variations that happen in longer time periods (see Figure 2-a and c)) and the high-frequency fluctuations (see Figure 2-b) and -d)).

**Fig. 1.** Wind roses, based on instantaneous wind velocities at the lower heights: a) 2.55m; b) 3.55m.

The removal of the wind fluctuations from the instantaneous wind velocity time series for the velocity component u is achieved using the nonstationary model. Comparisons are made between the removals done by the nonstationary model and the stationary model for the heights of 2.55m and 3.55m. At both 2.55m and 3.55m, the nonstationary model produces wind fluctuations that pose less skewness and agree better with their normal distribution curves, compared to the stationary model (see Figure 3-a) and -b)). After removing the wind fluctuations, the mean wind velocity time series are compared with the near-ground wind profiles assumed by the three different wind profile assumptions, as shown in Figure 4. Note that the values are normalized using the reference wind velocity recorded by the meteorological observatory on the same day, which is $u_{ref}=2.2$ m/s.

**Fig. 2.** Time series for the wind velocity component u: a) and c) instantaneous wind velocities (IWV) and time-varying averages (TVA) at heights 2.55m and 3.55m; b) and d) removed wind fluctuations at heights 2.55m and 3.55m.

**Fig. 3.** The removed wind fluctuations derived from the nonstationary model (which produces time-varying averages, TVA) and the stationary model (which produces time averages, TVA-ND).

![Wind roses](image1)

![Time series](image2)

![Velocity](image3)
TA), and their normal distribution curves (ND): a) 2.55m; b) 3.55m.

Fig. 4. Comparisons between the three assumed near-ground wind profiles and the mean wind velocity time series.

Mean wind velocities can be used to construct wind profiles. In this study the mean wind velocities are the time series produced by the nonstationary model. The model’s appropriateness is checked in Figure 3, where the removed wind fluctuations are compared with their normal distribution curves. According to a previous study [5], the wind fluctuations are stochastic processes and thus their distributions should observe the normal distribution. The comparisons shown in Figure 3 indicate that the removals using the nonstationary model are effective. Then, in Figure 4, the comparisons between the assumed near-ground wind profiles and the mean wind velocity time series’ variation along heights indicate that the power-law assumption is the valid one. However, the near-ground wind profile assumption examined in this study only corresponds to the scenarios when the site is exposed to open and flat upwind areas. To make comprehensive examinations of the near-ground wind profile assumptions, it is worth further research efforts to examine the validity of the wind profile assumptions under different exposure conditions.

4 Conclusions

This study measures the instantaneous wind velocities at near-ground level using a portable measurement platform for an industrial park in Shanghai. Further analyses reveal that the nonstationary model is a suitable approach for removing wind fluctuations from instantaneous wind velocities to obtain mean wind velocity time series at the near-ground level. Besides, for the areas in industrial parks that have open and flat upwind areas the power-law assumption is valid for the near-ground wind profile.

The work described in this paper was supported by the National Natural Science Foundation of China (No. 52008079).

References

1. Y.K. Ho, C.H. Liu, Theor. Appl. Climatol. 130, 305-320 (2017)
2. Z.W. Mo, C.H. Liu, Y.K. Ho, Build. Environ. 188, 107463 (2021)
3. I.P. Castro, Bound.-Layer Meteor. 164, 337-351 (2017)
4. J.W. Zou, Y.C. Yu, J.L. Liu, J.L. Niu, K. Chauhan, C.W. Lei, Build. Environ. 194, 107713 (2021)
5. Y.L. Xu, J. Chen, J. Struct. Eng. 130, 912-920 (2004)