ESTIMATION OF SURFACE ROUGHNESS LENGTH FOR URBAN LAND: A REVIEW

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***Abstract*— Urbanization and development in developing countries have led to growth of urban area in all the directions. To accommodate this huge population urban areas have seen abrupt increase in the number of high rise structures which are affect the flow of wind inside the urban area. Wind flow inside an urban area is a key microclimatic phenomenon as it counters the effect of Urban Heat Island affect and also disperses the accumulated pollution. To model and simulate the behaviour of urban winds inside the urban area knowledge of urban roughness plays a significant role. Urban roughness constitutes of land use and land cover elements that introduce turbulence in the flow of wind. Roughness Length (z_0) and Zero Plane Displacement Height (z_d) are two key parameters that are used to designate urban roughness. Many Air Pollution dispersion models are depend upon surface roughness values. To Accurate predictions of air quality and atmospheric dispersion at high spatial resolution rely on surface roughness parameters. Thus, Computation of these parameters is complex and is usually done using Micrometeorological methods and Morphometric methods. Micrometeorological methods are expensive and require complex set up to be installed and hence are not feasible to be used in urban areas. This paper gives a detail description about surface roughness and different type of estimation of surface roughness.**

***Index Terms*— Surface roughness length, Zero plane displacement height, Morphometric methods, Micrometeorological methods**

I. INTRODUCTION

Urban roughness mapping is most important for sustainable development and for providing better living condition to the inhabitants of urban area. Urban roughness constitutes of elements of an urban area which introduce turbulence to the flow of wind. Urban roughness is defined by the set of attributes that are derived using the morphology of the urban area. Urban roughness is an aggregation of various parameters that include building plan area fraction (λP), zero plane displacement height (zd), roughness length(zo), frontal area density(λf), building area density(ap(z)), rooftop area density(ar(z)), complete aspect ratio(λC), height to width ratio(λS). Roughness length (z0) and displacement height (zd) are considered the most vital parameters to designate urban roughness. Frontal area one of the key building geometric parameter is required as an input parameter to compute zo and zd. The estimation of urban roughness parameters is required in the areas of wind modelling, dispersion modelling, urban climatic studies and detection of ventilation paths. The surface roughness is often quantified in terms of the roughness length or the bulk drag coefficient and these values are strongly related to the size, shape and layout (morphology) of buildings in a neighbourhood. The morphology of the surface can be described quantitatively in terms of the building plan area index (λP) and frontal area index (λF). Accurate knowledge of the aerodynamic characteristics of cities is vital to describe, model and forecast the behaviour of urban winds, turbulence and the dispersion of pollutants at all scales. Broadly, the urban roughness mapping methods can be classified into following categories:

- Micrometeorological methods
- Morphometric methods

To approaches used to compute urban roughness and other required morphometric parameters have evolved drastically, however, the application of the computed parameters plays a key role in selection of the approach used. Micrometeorological methods are considered as most accurate and efficient, as they completely depend on the in-situ measurements. But the site installation and operation are difficult and expensive. Also meteorological methods are not found suitable to model near surface wind flow. Morphometric methods on the other hand are less expensive and easy to operate. These methods are also identified suitable to understand wind flow near surface and inside the urban canyon.

II. SURFACE ROUGHNESS LENGTH

A. *Introduction*

Roughness length is defined as the height above the surface at which the horizontal component of the wind speed approaches zero, measured logarithmically downward from the gradient wind level where the free flowing winds are an energy source free of surface influences. Roughness length is thus some fraction of the thickness of the obstructed surface boundary layer in the lower troposphere. Below the gradient wind level in the lower troposphere is the planetary boundary layer or region where the atmospheric flow is directly influenced by the nature of the surface. The outer part of the boundary layer, known as the Ekman spiral layer, is characterized by winds that change in direction and speed as height above the surface decreases in reaction to increasing shear stress and increasing frictional drag. Energy transmitted downward through the spiral layer interacts directly with the underlying terrain, and the momentum flux toward the surface varies with the roughness of the surface.

B. Effect of Surface Roughness on Model Prediction

Surface roughness is a factor affecting the wind flow and hence loading on structures, dispersion of pollutants, and other atmospheric boundary phenomena. An estimate of roughness length is required by some atmospheric models and is also used in the logarithmic profile to determine the increase of wind speed with height under neutral conditions. The choice of technique for estimating roughness lengths is generally constrained by the available input data. In most of the air pollution models, Surface roughness length use for friction velocity scale(u^*) and convective velocity scale(w^*) which are determine monin obukhov length (L). This monin obukhov length determine stability class and ultimately stability class affect the predicted emission concentration.

The following line diagram shows how surface roughness length affect the emission concentration.

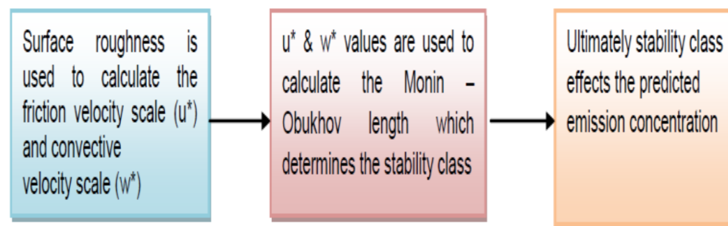

Fig.1 Line diagram effect of surface roughness on predicted emission concentration

III. LITERATURE REVIEW

Urban roughness parameters are estimated to study the effects of urban structures on the movement of wind. Several methods and parameters have been suggested for overall estimation of urban roughness: Zero-Plane Displacement Height (*zd*) and the Roughness Length (zo) (Lettau, 1969) Plan Area Density (λp), Frontal Area Index (λf) (Grimmond and Oke, 1999; Burian et al., 2002, Wong et al., 2010)**,** Frontal Area Density (Yaun et al., 2014), Depth of the Roughness Sub-layer (*zr*) (Bottema, 1997; Grimmond and Oke. 1999) and the Effective Height (*heff*) (Matzarakis and Mayer, 2008) etc. One of the important parameter is Frontal Area Index and this is said to have parameter has strong relationship with Surface Roughness (*zo*). Frontal area index is suggested as a good indicator for mesoscale meteorological and urban dispersions models (Burian et al., 2002).

i. Micrometeorological Methods

Micrometeorological methods depend on extensive in-situ data which includes observations of wind direction and speed at different heights. Later this field data is used for computations using log-law on which micrometeorological methods usually depend.

Micrometeorological (or anemometric) methods that use field observations of wind or turbulence to solve for aerodynamic parameters included in theoretical relations derived from the logarithmic wind profile.

Log Law: $\frac{u(z)}{u} = \frac{1}{k} ln \frac{Z-Z_0}{Z_0}$ (1)

Where u(z) is averaged wind speed at height z, u is frictional velocity, k is Von Karman's constant and zd and zo are zero-plane displacement height and roughness length respectively. For this equation a lot of field data is required for a particular direction from at least one height well above the surface for which towers need to be installed (Gal and Z. Sumeghy, 2007).

To take field observations many approaches were used using Eiffel tower (Taylor, 1918), meteorological towers (Shiotani and Yamamoto, 1950), TV towers (Soma, 1964; Arakawa and Tsutsumi, 1967), using hot air balloons (Angel et al. 1974) and helicopters (McCormick and Kurfis, 1966; Taylor 1918). The first documented measurement of urban turbulence was probably performed in October 1946 from the tower of central meteorological observatory, Tokyo (Roth, 2000). These early studies focused on the upper atmosphere and used hot wire anemometers followed by Grill propeller anemometers and finally sonic anemometers during the 1990's (Roth, 2000). Jones et al. (1971) used a captive balloon to take measurements 1000 ft. above two urban areas. Using the measurements of average wind speeds and temperature, he established a relationship between velocity profile index and lapse rate. In this study Jones and Wilson (1971) also computed adiabatic profile index and compared it with the earlier values. With this comparison authors concluded conditions for dry adiabatic lapse rate of 0.21 which gave the confirmation of slow growth rate.

Marullaz (1975) conducted a study in Nantes, France. Propeller anemometer was used at four different heights on each mast. The measurements were used in Davenport (1963) empirical law to determine variation of mean wind Speed. The roughness values computed were very high.

$$\frac{u(z)}{u(z_1)} = \left(\frac{z}{z_1}\right) \alpha \qquad (2)$$

Where u(z) is mean wind speed at z altitude and u(z1) is mean wind speed at z1 altitude and α is roughness.

Site characteristics need to be considered for micrometeorological studies for roughness value estimation. These site characteristics can be best adapted from the works of Wieringa (1992) and Bottema (1997), which are briefly stated: flat terrain, tower construction should be slender and open enough to avoid wake interferences, instruments must be equipped to accurately measure wind and turbulence measurements, measurement height must be above roughness sublayer but low enough to be in an adjusted boundary layer. At least three levels for measurements, should allow sampling into mean values over a period of time, should be neutral to or should be atmospherically stable and there should be inclusion of zero plane displacement. Different methods were used to determine the range of values that could be estimated using commonly accepted methods for estimating surface roughness length. Along with surface roughness length, the displacement height (d) was also estimated. What most of the early studies lacked was no inclusion of displacement length (zd) which led to large values of z0. This was very effectively proved by Hanna (1969) in the reanalysis of Ariel and Kliwchnikova (1960). Grimmond and Oke (1999) applied the criteria's adapted from Wieringa (1992) and Bottema (1997) to 60 field studies and surprisingly only 9 could pass the test. Majority of studies failed due to non-inclusion of zd and high value of z0. For aerodynamically rough atmospheric flows in the "constant stress" layer, the following form of the logarithmic law is most often used to describe the mean velocity profile (Lyles and Allison, 1979):

$$\bar{u}_z = \frac{u^*}{k}\left[ln\left(\frac{Z-D}{Z_0}\right)\Phi_z\right] \qquad (3)$$

Karman's constant (0.4), D is effective height of roughness, Z is roughness element and Φz is diabitic influence function.

Micrometeorological methods require an exhaustive site preparation which includes installation of towers for taking wind measurements. The application of these methods for estimation of roughness values for an urban area is limited. The urban areas are often not suitable for installing towers and urban areas also requires under canopy realization of wind dynamics. No method can achieve the accuracy with which the estimations are computed by micrometeorological measurements but due to the constraints of execution, this method is not feasible in urban areas.

ii. Morphometric Methods

Morphometric (or geometric) methods that use algorithms that relate aerodynamic parameters to measures of surface morphometry.

Morphological methods have the advantage that the values can be determined from the database of the distribution of roughness elements. A commonly used rule of thumb estimate for surface roughness length (Z_0) is *0.75H* (Gardner 2004). McDonald et al. (1998) has reviewed empirical methods for estimating the surface roughness before providing their own improved method derived from basic principles of fluid dynamics.

The roughness parameters were calculated as functions of secondary parameters derived from shape, size and density of roughness elements. For this study, cubes and rectangular prisms of height H were used as roughness elements, where:

H = Average height of obstacles
Af = frontal area of obstacles, λf = frontal area ratio = *Af / Ad*
Ap = planar area of obstacles , λp = planar area ratio = *Ap / Ad*
Ad = total lot area covered by obstacles.

The roughness models are summarized in Table 1 below. The first two methods did not provide formulas for calculating displacement height. For a terrain with high density of obstacles of uniform height, a phenomenon known as "skimming flow" occurs, where the wind is effectively displaced by the averaged height of obstacles, while the roughness length goes down to zero.

The Lettau (1969) and Counihan (1971) model disregarded this effect, hence their use is limited to low area densities usually not more than 30%. Peak values of *z0* occur roughly at an area density ratio of 20% (McDonald 1998).

Table 1: Summary of models used for calculating roughness parameters

Model	Published	Z_0 / H	*d/H*
Lettau	1969	0.5 λf	None
Counihan	1971	1.8 λf - 0.08	None
Theurer	1993	1.6 λf (1 - 1.67 λp)	1.67 λp
McDonald	1997	(1 - d/H) exp (-(0.5 * Cd/k2 * (1 - d/H) * λf)-0.5)	1 + A-λ(λ-

The Lettau (1969) relationship has been used for almost three decades by meteorologists and wind-tunnel engineers to estimate surface roughness from the geometry of regular arrays of roughness elements. Lettau (1969) in his study discussed various problems that micrometeorological applications deal with. Like the masts used for measurements were itself acting like a roughness element. The determination of roughness values using wind profile measurements is troublesome as the instrumental errors need to be eliminated and major problem arises when the true reference point log law is not known in prior, making determination of Z_d in addition to Z_0.

IV CONCLUSION

From the research it is concluded that surface roughness length play a significant role in areas of wind modeling, dispersion modelling, urban climatic studies and prediction of ground level concentration in AERMOD model. Micrometeorological methods are based on instrument and field observation of field work but, sometimes error may be arise due to instrumental error. To overcome this problem morphometric methods are useful to determine surface roughness length in urban land by using building dimensions.

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