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Concerns with using simplified wind profiles in determining noise impacts of wind turbines

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ABSTRACT

The assessment of noise impact from turbines stationed in wind farms is dependent on the wind characteristics within the wind farms as well as at the receptor locations. Different procedures are usually applied by various regulatory agencies to determine the noise impact of the wind farms. The noise limits applied in the Province of Ontario are based on the ambient noise of the wind at the receptor locations. The above procedure assumes the application of IEC Standard methods to evaluate the sound power levels of the turbines within the wind farm. Based on the local topography, the noise limit can be either conservative or not stringent enough. The noise levels as well as the wind characteristics measured over a period of time, for one typical wind farm site, are analyzed. The preliminary results of the above investigations are presented in this paper.

1. INTRODUCTION

Sustainable energy development is the current buzz word and energy from wind farms using a bank of wind turbines feed into the green energy development. A Number of issues, associated with turbines in a wind farm, has prevented large scale developments of wind energy. One of the major concerns is the noise generated by the wind farm. The reaction against wind farms straddle the entire gamut of mild annoyance to serious health impacts perceived to be caused by the wind farms. Many of the noise issues associated were discussed in a special issue of the *Canadian Acoustics Journal* and can be found in References 1 thru' 8.

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The development of a wind farm can be accomplished easily as each application needs to be approved by the local authority. The regulatory noise limits applied in different jurisdiction around the world and the assessment process can found in Ramakrishnan[9]. The regulatory agency for the Province of Ontario is the Ministry of the Environment. The Ontario wind farm noise assessment and noise limits can be found in Reference 10 and the general discussion of the process was presented by Kowalewski[3].

The Ontario noise limits applies the background noise levels created by the local wind at the receptor locations as the applicable limits[10]. The Ontario guidelines are similar to the old guidelines of Netherlands as well as the ones applied in New Zealand[11]. The above guidelines, instead of fixing a single noise limit number, provide a range of limits that are a function of local wind speeds near the receptor locations. The guidelines of MOE allow extrapolation of wind speeds based on wind shear. One of the main issues raised against such an approach is the notion that the wind speed at the hub height could be much higher than the value evaluated from the 10 m high wind speed, particularly at night time based on the stability class of the local winds. The wind speeds at different night time periods were measured at a 10 unit wind farm and the results of the wind statistics are presented in this paper.

2. BACKGROUND

The assessment process of noise from wind farms includes two main sections. The first part deals with the evaluation of the noise levels at receptor locations based on the wind turbine distributions within the wind farm site as well as on the sound power level of the wind turbine themselves. The second part determines the acceptable noise limits that must be used to establish compliance.

The assessment process is quite straightforward if there are only single noise limits and one uses the maximum sound generating potential of the wind turbines, usually obtained from manufacturers' data.

The assessment process, however, gets complicated if the noise limits are based on sound levels evaluated from ambient wind speed. The establishments of the receptor location wind speeds as well as the speeds used by each turbine to evaluate the sound power levels are not that straightforward. Botha[12], quite lucidly, highlighted the complications that can arise from applying the IEC Standards 61400-11[13] procedure. The concerns arise mainly due to the way the sound power level are determined and reported when one follows the IEC methods. The manufacturers usually apply IEC method and report the sound power levels as a function of the 10 m high wind speed. As a standard reporting procedure, the IEC method is acceptable. However, as Botha has shown, due to local terrain conditions, the wind speed at hub height can be more than that calculated from simple wind profiles using the 10m high wind speed. Wind speed measurements were conducted at four sites – two (2) in New Zealand and two (2) in Australia. The measurements were conducted for a period of one year. The two Australian sites (Sites 1 and 2) were flat terrain and the two New Zealand sites (Sites 3 and 4) were complex terrain. Wind speeds were collected in 10 minutes intervals and the composite results from Reference 12 are reproduced below as Figure 1.

Five graphs were plotted for each site: Composite profile for all day data, profile for day data, profile for night data, IEC standard logarithmic profile with the shear coefficient from observed site conditions (Z_0 = 0.03) as well as the standard shear coefficient, Z_0, of 0.05. The results do indicate that for some terrains, the hub-height wind speeds can be more at night time than during day time when compared to the 10 m height wind speeds. However, the local conditions determine the meteorology and one cannot apply information from far-off sites to local conditions. Further, for the terrains in Australia, the Sound Power Levels at night time would be around 2 dBA more than predicted from standard procedures from day time profiles. It must also be highlighted that the measurements of Reference 12 clearly showed the wind profiles were nearly identical between day and night time for the complex terrains of New Zealand.

The main conclusions of this section are: a) wind shear is an important parameter that must be accounted for appropriately in any assessment; and b) the effect of meteorology is highly localized and strong conclusions cannot be easily transferred from site to site.

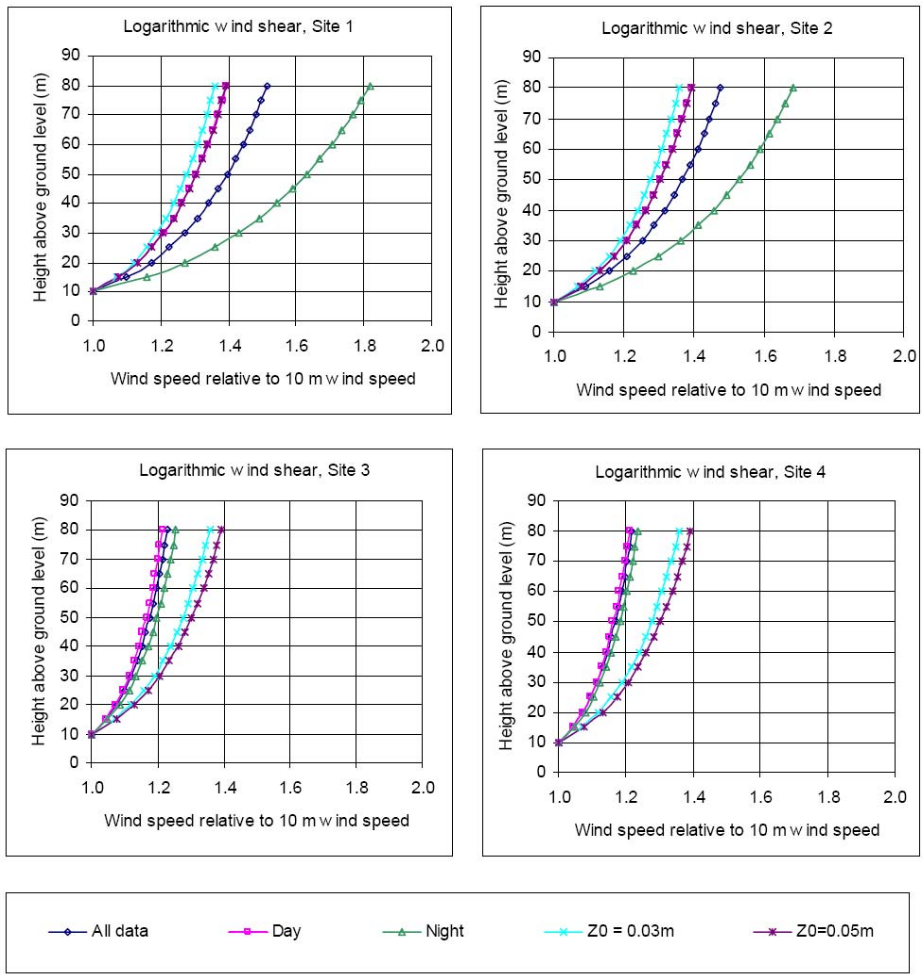


Figure 1: Wind speed profiles at 4 different sites (From Reference 12).

3. WIND STATISTICS

The background to the issue of site specific conditions described in Section 2 is highlighted in this section through an example from a wind farm in Ontario, Canada. A part of the wind farm covers an area of four sq. km with ten wind turbines. The area includes a number of residences as shown in Figure 2. The noise levels and 10 m high wind speeds were measured at a residential location. In addition, the 80 m hub height wind speed at the nearby turbine was also measured. The data was collected over four nights. The measured results are summarized in this section. The measurement locations are also shown in Figure 2 below.

The main focus of this analysis is the measurement of wind speeds during night time. It was postulated that the main noise impact of a wind farm is during night time periods when the atmospheric class can be classified as stable or very stable as per Pasquill class descriptions.

According to the anti-wind farm groups, the noise levels are under-predicted during the stable and very stable wind conditions. However, the research of Botha[12] has shown that such blanket statements are not accurate and conditions must be evaluated for each wind farm site individually. The collected data over a few hours was analyzed in 10 minute intervals similar to the data presented by Botha.

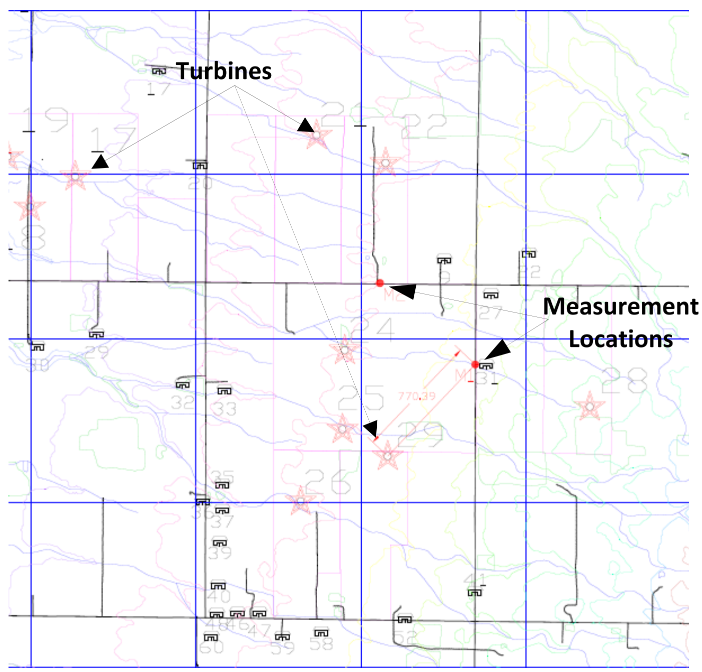


Figure 2: Aerial map of a ten turbine wind farm site.

4. RESULTS

The noise levels and wind speeds were collected over four nights. The noise levels and 10 m high wind speeds were measured at one residential location. The 80 m hub-height wind speed was also measured simultaneously at a nearby turbine. The nearest turbine was located at a distance of 760 m from the residences. The remaining nine turbines were spread over the four sq. km area at distances of between 1 and 3 km from the residential location.

The data reduction consisted of: a) The wind speeds collected in one-minute intervals were averaged over a period 10 minutes; b) The measured sound levels at the residential location were integrated over the 10-minute interval to produce the L_{EQ} values in A-weighted levels (dBA). The measured noise levels include all contributing sources such as the local wind, noise from 10 turbines and other local sources such as a garbage truck or passing cars.

A sample subset of 18 intervals is presented in Table 1 below. Each row contains the values averaged or integrated over a 10-minute period. The first row shows the noise level of 55.1 dBA which includes two car pass-bys during the 10 minute duration. If one removes the noise values of the two cars, the 10 minute L_{EQ} reduces to 44.6 dBA. The above exercise simply shows the sensitivity noise levels due to any extraneous activities other than the noise from the wind turbines. The data also shows the gusty activities on the evening of 5 November 2007.

The eighteen samples were used to evaluate the relationships between the wind speeds at the two heights, i.e., determine wind shear factors so as to establish the wind profile. The 10-unit wind farm is basically a flat terrain and is more than a kilometer away from any major bodies of water. Two wind profiles are usually discussed in determining the wind speed patterns and they are shown in Equations 1 and 2. The Vs are velocities at the two heights h_2 and h_1, the exponent 'm' is the shear factor and z_0 is the roughness coefficient. The accepted values of 'm' for stable and very stable stability classes are 0.37 and 0.41 respectively. The standard roughness coefficient applied in IEC Methods[13] is 0.05 and the roughness coefficient for flat terrains is 0.03.

$$V_{h2} / V_{h1} = (h_2/h_1)^m \quad (1)$$

$$V_{h2\ log} / V_{h1} = \log(h_2/z_0) / \log(h_1/z_0) \quad (2)$$

The 10 meter high wind speeds for the 18 samples were used to estimate the speed at the hub height by using Equations (1) and (2) and the results are shown in Table 2. Table 2 results provide very interesting observations. For most cases of the 18 samples, the wind shear equation (1) grossly over-predicts the 80-m high wind speeds. The logarithmic wind profiles of Equation (2) under-predicts the wind speed at 80 m below 7m/s (10m wind speed) and over-predicts beyond that. The average of the eighteen samples for the 10m high wind speed was then used to estimate the hub height wind speed and the results are also shown in Table 2. Interestingly, the logarithmic wind profile seems to estimate the hub height with reasonable accuracy, once the average over a longer duration is evaluated.

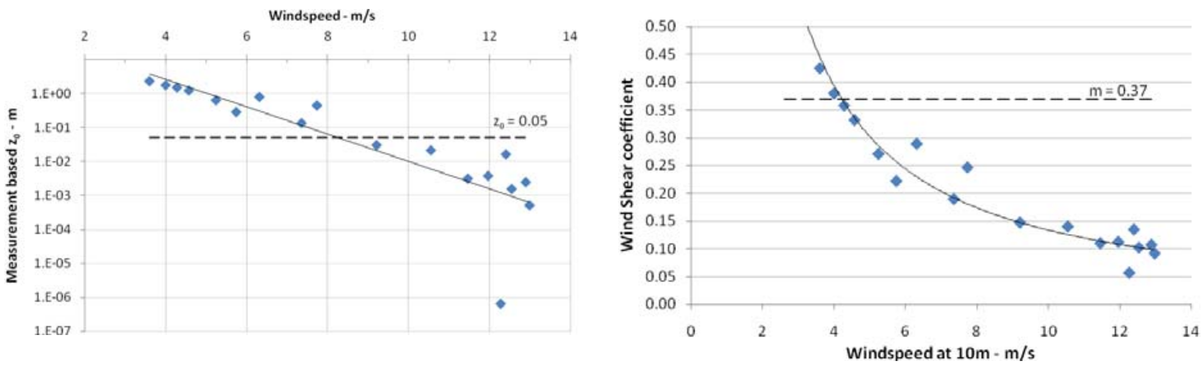
Table 1: Wind speed and noise data.

Number	**Date**	**Time (hh:mm)**	**10m Average Wind Speed, m/sec**	**10m Max Wind Speed m/sec**	**Hub (80m) Wind Speed, m/sec**	**L_{EQ} dBA**
1	Evening 1	21:39	3.6	5.4	8.7	55.1 (44.6)**
2	Evening 1	21:49	4.0	5.8	8.8	43.5
3	Evening 1	23:20	4.57	6.7	9.1	44.1
4	Evening 1	23:30	4.28	6.7	9	43.5
5	Evening 2	21:28	5.24	8.9	9.2	45.1
6	Evening 2	21:38	5.74	8.9	9.1	45.2
7	Evening 3	21:37	12.97	19.2	15.7	68.1
8	Evening 3	21:47	12.53	17.9	15.5	69.5
9	Evening 3	21:57	12.39	18.3	16.4	68.6
10	Evening 3	22:07	11.45	16.5	14.4	67.2
11	Evening 3	22:18	11.95	16.1	15.1	66.7
12	Evening 3	22:28	10.54	14.8	14.1	66.8
13	Evening 3	23:33	12.88	18.3	16.1	68.3
14	Evening 3	23:41	12.26	17.9	13.8	68.5
15	Evening 4	19:25	7.35	12.1	10.9	54.4
16	Evening 4	19:33	9.2	12.1	12.5	59.7
17	Evening 4	20:15	6.31	9.4	11.5	53.4
18	Evening 4	20:25	7.73	11.2	12.9	58.4

Table 2: Hub Height Wind speed data.

		Hub Height wind speed (@80 m), m/sec				
Number	**10 m High wind speed, m/sec**	**m =0.37**	**m =0.41**	**z_0 =0.03**	**z_0 =0.05**	**Measured**
1	3.6	7.68	8.35	4.83	4.96	8.7
2	4.0	8.66	9.41	5.45	5.58	8.8
3	4.57	9.86	10.72	6.21	6.36	9.1
4	4.28	9.24	10.04	5.81	5.96	9
5	5.24	11.31	12.29	7.12	7.30	9.2
6	5.74	12.39	13.46	7.79	7.99	9.1
7	12.97	28.00	30.42	17.61	18.06	15.7
8	12.53	27.05	29.39	17.02	17.45	15.5
9	12.39	26.74	29.06	16.83	17.25	16.4
10	11.45	24.71	26.86	15.55	15.94	14.4
11	11.95	25.79	28.03	16.23	16.64	15.1
12	10.54	22.75	24.72	14.31	14.68	14.1
13	12.88	27.80	30.21	17.49	17.94	16.1
14	12.26	26.46	28.76	16.65	17.07	13.8
15	7.35	15.86	17.24	9.98	10.23	10.9
16	9.2	19.86	21.58	12.49	12.81	12.5
17	6.31	13.62	14.80	8.57	8.79	11.5
18	7.73	16.68	18.13	10.50	10.76	12.9
Average	8.6	18.58	20.19	11.69	11.99	12.4

Furthermore, if one evaluates the wind shear coefficient m and the roughness length z_0 for each set of data, an interesting trend emerges. The variation in these coefficients based on measurements is presented in Figure 3 below. It is worthy to note the relatively regular change in both indices with respect to ground level wind speed.



(a) (b)

Figure 3: Variation in wind profile indices with ground level wind speed. (a) Roughness length z_0 varies exponentially with 10 meter wind speed; (b) Wind shear coefficient *m* seems to vary as a power of 10m wind speed

Given that currently, wind farm noise assessments use wind turbine noise data gathered using the IEC stnadard[13] methods to estimate noise levels at receptor locations, the above analysis shows some potential vulnerabilities that may arise when a simplified (and constant) wind profile model is used. The main conclusion of the preliminary investigation is that local wind speeds may not follow those presumed in standard practices and one cannot assume that stable and very stable wind classes will produce higher than predicted noise levels.

5. CONCLUSIONS

One of the main aspects of noise from turbines in a wind farm is the wind speeds at a number of different locations. The results of a preliminary investigation of wind statistics were presented in this paper. The major conclusion is that wind speed characteristics are highly localized and meaningful relationships can be established only from local monitoring of wind speeds over a longer period of time.

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