EVALUATION OF SOUND PROPAGATION FROM WIND FARMS

Ramani Ramakrishnan

Department of Architectural Science, Ryerson University, 350 Victoria Street, Toronto, Canada M5B2K3
e-mail: rramakri@ryerson.ca

Vipul Seharwat

Department of Mechanical and Industrial Engineering, Ryerson University, 350 Victoria Street, Toronto, Canada M5B2K3

There has been a significant increase in the installation of wind farms in Ontario. Wind farms will be a major energy supplier in Ontario due to the strong green-energy initiative of the provincial government. Noise impact of the wind turbines on nearby receptors has been a contentious issue. The current assessment procedures limit the methods to simple application of ISO-9613-Part 2. Detailed applications of terrain and weather information are beyond the scope of ISO-9613-part 2 procedures. Two improvements to the simple procedures are used to evaluate the receptor locations noise levels from a 5-turbine wind farm in southern Ontario. Comparison of the three methods is presented in this paper. The results show that only a detailed assessment using a full set of equations with accurate weather data can establish the range of noise levels possible at sensitive receptors that are located near wind farms.

1. Introduction

Wind power has been a sought after renewable energy in Ontario. Large wind farms consisting of a large number of wind turbines have been installed in many rural Ontario communities over the past ten years or so. A number of health concerns has been raised and one such concern is the noise impact at receptor locations. Wind farm noise is one of the controversial issues that wind farm developers face in Ontario.

The noise impact is determined from the actual noise levels that wind turbines can generate at receptor locations. The evaluation of noise levels has been a vexing issue for a number of reasons such as predicting the actual noise levels before the installation of the turbines and the measurement of noise levels emitted by the turbines.

Evaluation of noise levels from a wind farm is a complex issue. The current study focusses on evaluating noise levels propagating from wind farms and applies a five-turbine wind farm in the Township of West Lincoln in Ontario as a test-bed to evaluate the receptor noise levels. The application of an accurate procedure to evaluate receptor noise levels is the main focus of the current investigation. Preliminary results were presented earlier by Ramakrishnan and Sehrawat [1].

Both unattended noise monitoring, before and after installation of the five wind turbines, were conducted at four receptor locations. Attended monitoring was also conducted at two locations for a short 20-minute duration. Three methods, to be discussed in this paper, were used to calculate the noise levels.

Comparative analysis showed the three methods produced varying levels of noise at the receptor locations. The main conclusion was that the INPM method is the most reliable of the three methods.

2. Background

The determination of receptor noise levels from wind farms is set by provincial regulators. The current assessment procedures, used by the Ontario Ministry of the Environment, limit the noise evaluation methods to simple application of ISO-9613-Part 2 [2]. Simple procedures have been conventionally applied to evaluate the wind farm noise levels at nearby residential receptors [3, 4]. Many of the constraints assumed by the simple procedures are easily not complied with when such procedures are applied to wind farms. One constraint is the height of the wind turbine hub, usually in excess of 50 metres. Many of the receptors are located beyond the allowable distance of the simple procedures. Detailed applications of terrain and weather information are beyond the scope of ISO-9613-part 2 procedures.

Two improvements to the simple procedures are used to evaluate the receptor locations noise levels from a 5-turbine wind farm in southern Ontario. The two methods, exSound 2000+ and INPM code, include additional provisions that can account for some of the constraints of ISO 9613-Part 2, used by the commercial software CADNA_A [5, 6, and 7].

The five-turbine wind farm in West Lincoln was used as the test bed for the noise level evaluations.

3. Noise propagation models

3.1 CADNA_A model

CADNA_A (Computer Aided Noise Abatement) is a leading software for calculation, presentation, assessment and prediction of environmental noise [5]. The procedures of ISO9613-Part II are applied in the evaluation. All the desired sources and receiver locations, the sound power level of the source are defined by the user. The weather data is defined in terms of the humidity, temperature, wind speed, and wind direction. The Pasquill stability classes defined by CONCAWE procedures can also be applied to evaluate the noise levels [8]. The ground surface absorption coefficients, if available, can be incorporated to define the terrain between the source and receiver locations.

3.2 NORD 2000

The NORD2000 method is designed for predicting noise level generated from a stationary source, infinite straight road or rail track sources [6]. The model is based on geometric ray theory and diffraction. The calculations are carried out in one-third octave bands. The sound power level of the source for various frequencies is defined along with the height of the source. Terrain profile is defined by the distance from the source, height, and ground type and roughness. Also, any scattering zone in the terrain can be categorized as forest area or housing area. The weather data is defined in terms of wind speed, wind direction, turbulence strength, standard deviation of wind speed, temperature, temperature gradient, standard deviation of temperature gradient and turbulence strength.

3.3 Parabolic equation solver

The INPM noise model was developed by JASCO Applied Sciences, originally for use by the Canadian Department of National Defence as an environmental impact assessment and forecasting tool [7]. The INPM propagation modelling algorithm involves numerical computation of the parabolic form of the acoustic wave equation in vertical planes, thus providing a full description of the

sound pressure in the air column along a radial line from the source. The model takes fully into consideration the physical properties of the propagation media resulting in the complex structure of sound distribution.

INPM accounts for the acoustic influence of vertical profiles of atmospheric parameters - temperature, pressure, and humidity and is able to account for the influence of atmospheric turbulence. The model inputs the ground elevation and terrain type or cover (from which acoustic ground impedance is computed) from geo-referenced files to account for the local influence of these parameters on sound waves as they interact with the terrain. Sound propagation in each frequency band is computed independently and the results are summed to provide broadband estimates. Planar maps of noise footprints are obtained from multiple runs of the model along a fan of propagation radials from a source, a process that can be further expanded to multiple sources; the sound intensity is estimated at a standard receiver height above ground.

4. The wind farm

The wind farm under investigation is located in the Town of West Lincoln, near Hamilton, Ontario. The layout in West Lincoln is shown in Figure 1. The wind farm and the five turbines became operational in May of last year.

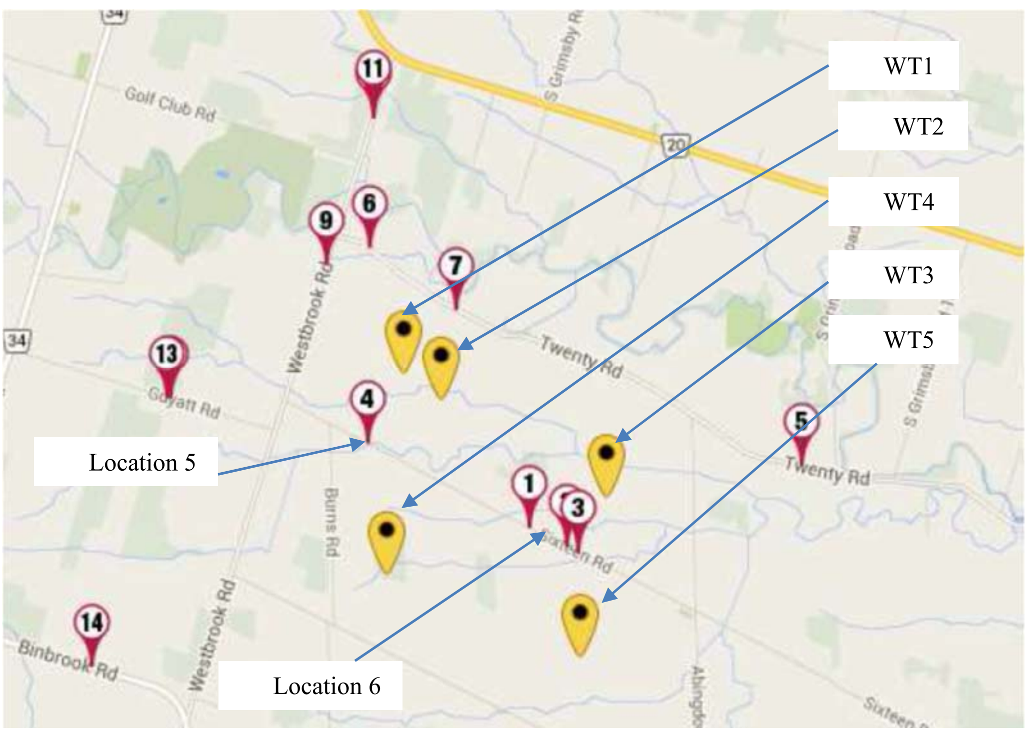

Figure 1. Wind turbines (arrows - WT) and nearby receptors, West Lincoln, Ontario, Canada.

The distances from each turbine to each of the four receivers are shown in Table 1. The four receptors were chosen for noise evaluations, since sleep disturbance tests were conducted on these residents by other researchers.

The ID numbers shown in Table 1 refer to the receptor numbers shown in Figure 1. SENES Consultants of Markham, Ontario evaluated the detailed weather data for three days for the month of June. Wind speed profiles evaluated by SENES Consultants at the four receiver locations are shown in Figure 2 for 8.30 at night.

Table 1. Distances between wind turbines and receptors, metres.

Turbine Number	Receiver 1 ID - 1	Receiver 2 ID - 11	Receiver 3 ID - 5	Receiver 4 ID - 14
WT1	1780	2080	3080	3190
WT2	1310	2420	2800	3010
WT3	620	3110	1440	4040
WT4	1600	3310	3450	2080
WT5	960	4440	2150	3710

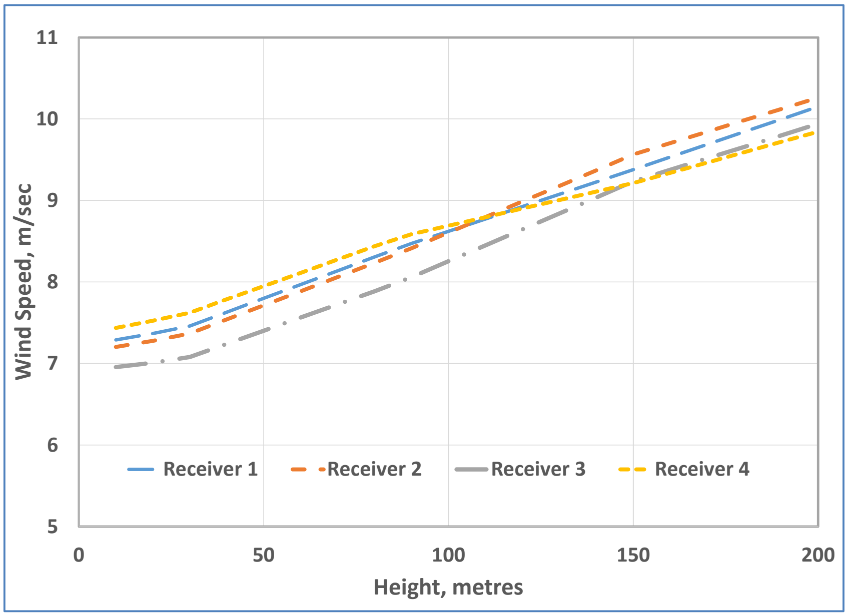

Figure 2. Wind Speed Profile at the four receptors.

The three propagation models were applied for a particular time on 5 June 2014 and the sound levels were evaluated in dBA. The results of the evaluation are shown in Table 2 below.

Table 2. Summary of receptor sound levels for 5 June 2014, dBA.

Prediction method	Receiver 1 ID - 1	Receiver 2 ID - 11	Receiver 3 ID - 5	Receiver 4 ID - 14
CADNA_A (without CONCAWE)	38.1	26.3	20.1	22.5
Nord2000	41.8	27.5	24.6	29.4
INPM	44.3	34.2	30.3	30.7

The results shown in Table 2 assumed that all five wind turbines were operating, at the speed evaluated from Figure 2 at the hub height of 95 m. The manufacturer's rated sound power levels were used to evaluate the receptor sound levels. The main finding of the simulation is that results of CADNA_A and NORD2000 are seen to agree within engineering accuracy for shorter distances between the turbines and the receptors. The differences between CADNA_A and NORD2000 increase between 4 to 7 dB as the distances between turbines and receivers increase. In addition, the above evaluations show that INPM results are higher than CADNA_A and NORD2000. The differences between INPM and the other two methods are between 3 dB and 10 dB. It must be pointed out that CADNA_A simulation did not apply any stability class corrections to the evaluated noise levels.

Exact modelling of the meteorological data was undertaken by INPM simulation alone. It can be concluded that controlled simulations with field measurements are necessary to determine the best evaluation method.

5. Results and discussion

The preliminary results presented in Sec 4 clearly showed varying levels of predicted sound levels from wind farms, resulting in a high level of uncertainty. It is obvious that a strong correlation between prediction and experimental validation alone would alleviate the uncertainties.

5.1 Unattended monitoring

Sound levels were monitored at the four locations with a simple integrating sound level meter. One-hour L_{EQ} (Equivalent energy sound levels) in dBA were recorded from the unattended monitoring. Forty-eight hours of data was collected at each location before and after the turbines became operational. The results of the unattended monitoring are summarized in Table 3.

Table 3. Summary of recorded data for wind farm sound levels at receptor locations.

Turbine Number	Receiver 1 ID - 1	Receiver 2 ID - 11	Receiver 3 ID - 5	Receiver 4 ID - 14
Sound Levels, before Turbines, dBA	40.3	42.9	40.9	44.6
Sound Levels, after Turbines, dBA	39.3	38.3	38.4	41.9

The sound levels before the turbines became operational ranged between 40 – 45 dBA. The sound levels aftr the turbines became operational ranged between 38 – 42 dBA. It can be inferred that it is impossible to parse the results to identify the wind turbine generated noise levels from the unattended monitoring.

5.2 Attended monitoring

Unattended monitoring didn't produce any reliable results and hence many attempts were made to isolate the noise generated by the five wind turbines. Due to logistical difficulties and strong opposition from the community, only two 20-minute data set was obtained on 28 August 2014 at two locations, Location 5 and Location 6, shown in Figure 1. The weather was clear, sunny with 18º C with occasional bouts of wind gusts. The weather data was measured by a monitoring system. The wind speed and Pasquill stability class are presented in Table 4 below. The temperature and wind speed profiles are shown in Figure 3 below. The weather data (see Fig 3 and Table 4) showed that only mildly unstable conditions existed with insignificant gradients with respect to height.

The weather data was modelled in INPM with all the details whereas only salient data points were used in NORD2000 evaluations. CADNA_A was evaluated with average ground absorption and appropriate Pasquill class. The sound power levels were obtained from the manufacturer's data at hub-height wind speed of 5 m/sec.

The 20 minute measurements consisted of instant dBA values at one sec intervals as well as overall L_{EQ} level in dBA over the 20 minute duration. Local farm equipment, road traffic noise and wind gusts interfered during the measurements. Careful monitoring showed that wind turbine noise level ranged between *44 dBA* to *47 dBA* at Location 5 and the wind turbine noise level was *41 dBA* at Location 6.

Table 4. Location 5 weather Information for 28 August 2014.

Turbine Number	Day	Afternoon	Evening
Wind Speed at 10 m, m/sec	2.1	2.2	2.1
Pasquill Class	B	B	C

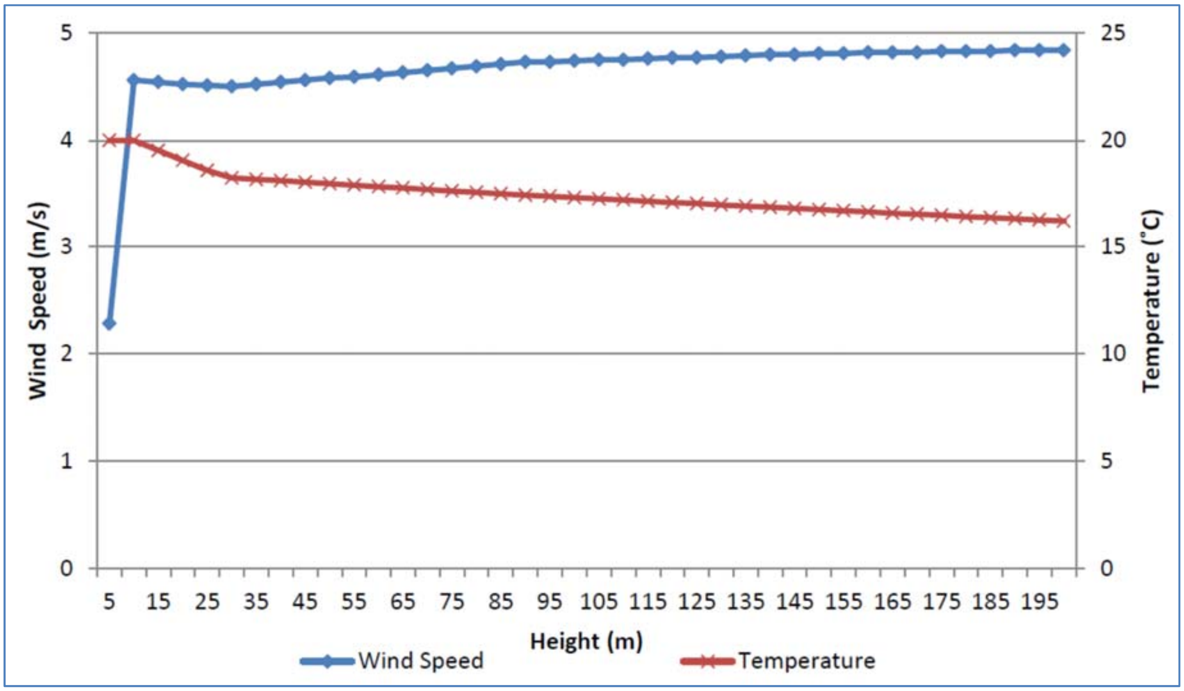

Figure 3. Wind speed and temperature profiles at Location 5 around 11 am.

Finally, the spectrum of the clean wind turbine signal was measured with a two-channel real-time analyser connected to a GRAS low-frequency microphone. The spectrum, from 4 Hz to 200 Hz is shown in Figure 4 below.

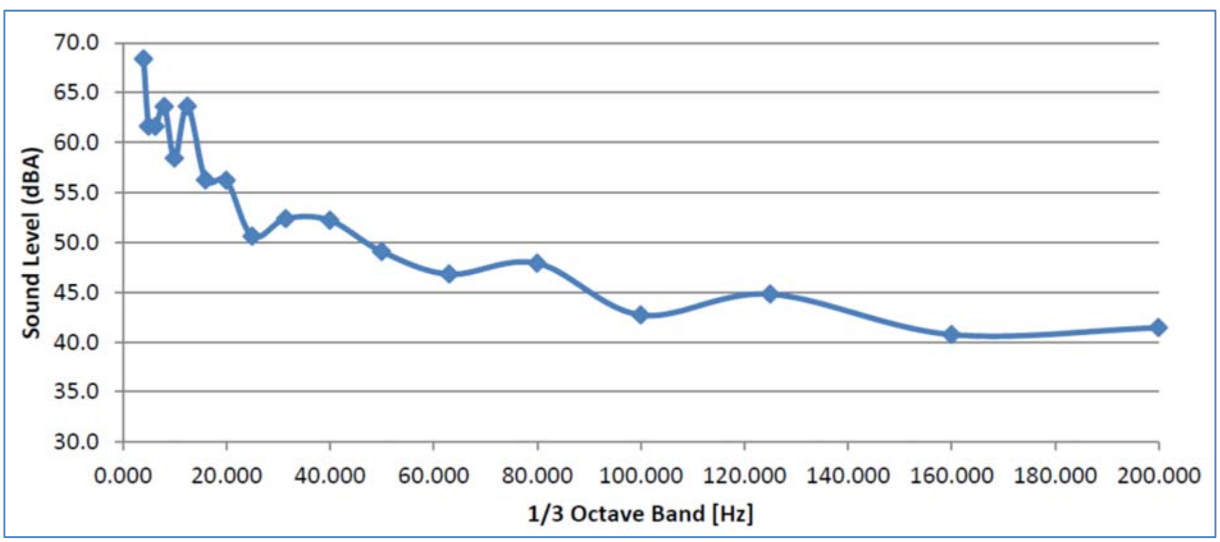

Figure 4. Spectrum of wind turbine noise at Location 5.

It can be seen that there are low frequency components generated by the turbines. However, the levels are quite low. When converted to the dBG scale, the level is 71.4 dBG well below the 85 dBG criterion [9, 10, and 11].

5.3 Comparisons

The 28th August information was used to compare the predicted values evaluated by the three methods. First, the variation within the CADNA_A method (ISO9613-Part2) is highlighted by using the appropriate CONCAWE's stability classes. The results are shown in Table 5 below.

Table 5. Sound levels of CADNA_A with stability classes.

Date	CONCAWE	R-1	R-2	R- 3	R-4	Loc- 5	Loc- 6
5 June 2014	NO	38.1	26.3	20.1	22.5	-	-
	YES	41.3	23.7	25.2	16.6	-	-
6 June 2014	NO	37.9	26.0	19.7	22.1	-	-
	YES	40.5	20.6	21	13.8	-	-
28 August 2014	NO	41	26.6	17.9	18.8	47.7	34
	YES	40.4	20.6	20.7	13.8	48.3	38.6

It is seen that the precise information about the stability classes is critical for the CADNA_A method. On an average the differences are within 3 dB, but a spread as high as 6 dB can result in the receptor location noise levels. Since the noise impact for a proposed wind farm with hundreds of wind turbines is dependent on the predicted noise levels at sensitive receptors, approval of the proposal can be in jeopardy.

Finally, the predicted noise levels for 28 August 2014 results are shown in Table 6 below. The measured data is also included in Table 6. It must be pointed out that only a short period, about a minute within the 20-minute measurement duration, could be parsed as the noise generated by the turbines for the two data set. And hence, the current results are the first step in our investigations and a larger data set would be required for conclusive proof.

Table 6. Wind turbine noise levels for 28 August 2014.

Condition	Location 5, SPL dBA	Location 6, SPL dBA
Experiment	44-47	41
CADNA_A (with CONCAWE)	48.3	38.6
NORD2000	48.6	39.8
INPM	45.5	43.3

As the results show, there is a strong variation in the comparison data. INPM is the sole method that uses both terrain and weather data with appropriate profiles for speed, temperature and humidity. INPM's predictions are within 1-2 dB of the measured value. Even though the prediction by the NORD2000 method is seen to be closer for Location 6, the process does not include detailed metrological information. CADNA_A and NORD2000 methods still have inherent uncertainties.

6. Conclusions

The difficult task of predicting noise levels at sensitive receptor locations from wind farm with tall turbines was investigated. A 5-turbine wind farm in the Township of West Lincoln, Ontario was used as a test-bed for the investigation. Three methods were used for the evaluation of noise levels propagating from the wind farm. Unattended monitoring showed that it was impossible to parse the turbine data from the measured results. The sound power levels from manufacturer's data was used in the evaluation methods. Two 20-minute attended measurements were conducted at two locations within 500 meters of the turbines. The measured data was compared to the predictions by the three

methods. The results, based on two short duration data-set, showed that the INPM method that used realistic meteorological and terrain data predicted the most reliable noise levels.

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