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Measurement of the environmental noise at the Torseröd wind turbine site

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MEASUREMENT OF THE ENVIRONMENTAL NOISE AT THE TORSERÖD WIND TURBINE SITE

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SUMMARY

Further to complaints about the noise generated by a Micon 600 kW wind turbine, measurements of both noise immission and noise emission were performed at the Torseröd site. The measurements and analysis presented in this report were carried out by following the recommendations of the IEA documents for noise emission [1] and immission measurements [2]. It was found that the immission level, i.e. the wind turbine sound, at one of the nearest dwelling, namely Solgläntan, is 39 dB(A) for a wind speed of 8 m/s at hub height. Measurements carried out close to the turbine show that the sound power level of the turbine is 4.3 dB higher than the A-weighted level given by the supplier. Furthermore, the noise level increases more rapidly as a function of the wind speed than what it is expected from the values furnished by the manufacturer. The measurement results also show that the background noise level is unusually low at Solgläntan.

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1. Introduction

The Torseröd wind turbine site is operated by Bohus Energy AB. At the origin, this site was planned to consist of eight machines but, at the present time, only one, a Micon type M1500 600/150 kW, has been erected. However, complains on the noise were received from some of the families living close to the turbine. The unit is reported as the most annoying during West or North-West winds, which correspond to an upwind location of the dwellings relative to the turbine. This is unexpected as downwind conditions are usually considered as more detrimental. This report presents environmental noise measurements carried out at the site to analyse the situation. The measurements were performed both close to the turbine and to one of the dwellings in accordance to the documents [1] and [2].

2. Torseröd site

2.1 Topography

The immission measurements were carried out at the dwelling referred to as Solgläntan on the map in Appendix 1. This house is located to the west of the turbine at a distance of about 390 m according to our estimation (Figure 1.a). As seen from this Figure, the topography of the terrain shelters the house and the garden from West winds. Concerning the vegetation, trees and bushes surround the dwelling except the part facing the turbine (Figure 1.b). A main road (E6) with a speed limit of 90 km/hour and a railway track are situated between the house and the turbine. A 200 m wide open field separates the house from the road. On the other side of the E6, the terrain is very steep, with cliffs rising almost immediately to the 50 m high plateau where the turbine is located (Picture 1 and Figure 1.a).

2.2 Turbine

The unit is a 3 blades Micon wind turbine M1500-600/150 kW, of which the main characteristics are reported in Table 1. Figure 4 shows the power curve of the turbine as a function of the wind speed. This curve, provided by Vatenfall, was used to deduce the wind speed at hub height from electrical power measurements. Concerning the acoustical characteristics provided by the supplier, the total A-weighted sound power level should be 98.7 dB(A) re. 1pW at 8 m/s at 10 m high with an uncertainty of +/-2 dB.

The manufacturer's spectrum, given in octave band in Table 2, does not contain pure tones and the wind speed dependence should follow the linear law:

$$L_{WA}(U)=94.20+0.57U \qquad \text{in dB(A)}$$

where U is the wind speed at 10 m high.

Table 1: Description of MICON M1500-600/150

Supplier	Micon A/S, Denmark
Rotor	
Number of blades	3
Diameter	43 m
Rotational speeds	27/18 rev/min.
Tower height	46 m
Rated power reached at 14 m/s	15 m/s
Cut-in wind speed	3.5 m/s
Cut-off wind speed	25 m/s
Position of the turbine with respect to the tower	Upwind

Table 2: A-weighted octave band sound power level for M1500-600/150 at a wind speed of 8 m/s at 10 m high

Frequency (Hz)	125	250	500	1000	2000	4000
$L_{WA,ref}$ in dB(A)	86.4	92.9	94.0	91.5	88.0	86.2

3. Measurement technique

Immission and emission measurements were carried out simultaneously by following as much as possible the recommendations provided by the documents [1] and [2].

At the immission point, a 1/2" microphone plus preamplifier was taped on a (0.7mx0.5m) board fixed to the house facade (Figure 1.a, Picture 2 and Figure 2 for the exact position of the board) and directly connected to a 1/3 octave band real time analyzer. Due to the traffic, 1 mn averaging time for the measurements was unthinkable and, as an alternative, 10 s averaging was chosen. The wind speed was measured by a cup anemometer fixed on a 10 m high mast placed in the garden close to the vegetation which was the most likely to generate background noise.

During the measurements, the house was always upwind the turbine but the complex terrain (see Figure 1) made impossible to locate the emission point between the turbine and the house. Instead, the emission point was located at the R_o-distance (67 m) downwind the turbine (Figure 1.a). At that point, a 1/2" microphone, taped on a ground board (1 m x 1 m) (Picture 3 and Figure 3), was connected to a sound level meter, itself connected to a tape recorder. In the laboratory, the tape was replayed and monitored on a loudspeaker and selected period without disturbances were analyzed by the 1/3 octave band analyzer.

The background noise should be measured with the turbine parked immediately before or after the measurement of the turbine noise at the measurements points. It will be seen that this recommendation could not be followed. Actually, only few values of the background noise level have been obtained. Nevertheless, they should be sufficient to provide reliable assessment of the background noise level.

Calibrations of the measurement chains were made at 1000 Hz before the recording. The microphones were sheltered by hemispherical 10 cm diameter foam balls. The characteristics of the instrumentation are listed in Table 3.

Table 3: Instrumentation (provided by Ingemansson Technology AB)

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Instrument	Manufacturer	Type	Serial number	Latest calibration
Calibrator	B&K	4231 / KU 39	1790922	98-04-03
Anemometer	Thies	cup anemometer / Ö 64	4.340.450.000	97-10-15
Microphone 1	B&K	4188 / M 155	185 7843	98-04-03
Pre-amplifier	B&K	2671 / MK 63	185 4116	98-04-03
Signal Analyser	HP	3569A / AL 73	3405A00278	98-04-03
Sound Lev. Meter	B&K	2221 / LM 34	1282289	98-05-05
Sound Lev. Meter	Norsonic	NL-18 / LM 57	960357	96-10-28
DAT recorder	Sony	TCD-D8 / B 54	1722-0291	97-02-18

4. Measurement results

The measurements were carried out by the author and Mr Johan Lindroos, Ingemansson Technology AB. They went on from the 19th of May at noon until 01:00 o'clock in the morning the 20th of May. Three periods of measurements have been carried out during the time intervals [12:00-13:30], [19:15-20:45] and [23:20-01:00]. The first two ones were too disturbed by the intense traffic and no reliable immission value could be measured, in spite of the use of a reduced averaging time of 10 s. Thus only the third period results are presented and analyzed in this report.

4.1 Meteorological conditions during the measurements

The wind speed at the turbine hub height was determined from the electric power output generated by the turbine. After correction for the temperature and the air pressure, the wind velocity was derived from the power curve (Fig. 4). This method enables the determination of the horizontal component of the wind speed. Nevertheless, due to the complex shape of the terrain (Figure 1.a), it might be expected that the vertical component of the wind speed should not be negligible at the turbine. The wind speed and direction at the hub, the air temperature and the relative humidity prevailing during the third period are reported in Table 4.

At the immission point, the wind was almost absent due to the sheltering provided by the terrain topography during west winds. Thus, there is no point to report the local wind speed.

Table 4: Meteorological conditions during the third period

	wind speed m/s	wind direction °	air temperature °C	rel. humidity %
period 3	5.5-10	310	10	60

4.2 Emission measurements

The board was placed on a large rock (Picture 3) at a distance of 67 m from the turbine. As the background noise level was more then 10 dB(A) lower than the levels obtained with the turbine in operation, no correction has been added to the measured levels before determinating the A-weighted sound power level of the turbine.

The apparent A-weighted sound power level, L_{WA}, is calculated from the emission value, $L_{A,eq}$, by using the following expression [1]:

$$L_{WA}=L_{A,eq}+10\log(4\pi R^2)-6 \qquad \text{in dB(A)}$$

where $R=\sqrt{R_0^2+H^2}$, with R_0 the Ro-distance (67 m) and H the nacelle height (46 m). The deduced values are reported on Figure 5 and it is seen that they increases approximately linearly with the wind speed. The law is given by the equation:

$$L_{WA}=92.0+1.30U \qquad \text{in dB(A)}$$

where U is the wind speed measured at the hub of the turbine.

The power spectrum of the turbine might be deduced from the spectra measured at the emission point by using the same equation as for the total power. Table 5 and Figure 6 show the sound power levels per octave band obtained from the emission measurement results and provided by Micon.

Table 5: Apparent A-weighted sound power level per octave

Frequency, Hz	63	125	250	500	1000	2000	4000	total
$L_{WA,ref}$ in dB(A) Micon (8 m/s at 10 m high)	/	86.4	92.9	94.0	91.5	88.0	86.2	98.7
$L_{WA,ref}$ in dB(A) Measurements (8 m/s at hub height)	77.4	86.0	95.8	98.1	95.1	92.9	86.7	102.1

4.3 Immission measurements

Even with a 10 s averaging time, it proved to be very difficult to find periods free from traffic noise during the afternoon and the evening at the immission point. Instead, the most reliable results have been obtained during the third period, i.e. around midnight.

4.3.1 Background noise level

Unfortunately, the background noise level was not measured during the night as it was not possible to park the wind turbine then. Nevertheless, due to the low wind conditions which are prevailing around the house for west winds, independence of the background noise to the wind speed might be assumed, at least up to very high wind speeds. Thus it is reasonable to use the values measured with parked turbine during the day. Unlike the measurements with the turbine in operation, the background levels obtained during the day should be reliable. Indeed, when the turbine was in operation, it was difficult to discern if some approaching vehicles influence the measurement. But, for background noise measurements, the selection was much easier and the measurement results show that the background noise level was about 34 dB(A).

4.3.2 Turbine in operation

During the third period, 95 immission levels were obtained. Nevertheless, as the wind speed values obtained from the turbine were 1 min averages, the noise levels belonging to the same minute have also been averaged. This lead to 21 immission levels as a function of the wind speed. These values have then be corrected with respect to the background noise of 34 dB(A) and to the reflection by the facade according to [2]:

$$L_{Aeq,corr} = 10\log(10^{(L_{Aeq,measured}-6)/10} - 10^{L_{Aeq,background}/10}) \quad \text{in dB(A)}$$

where

$L_{Aeq,corr}$ is the sound level of the wind turbine alone,
$L_{Aeq,measured}$ is the combined level of the wind turbine sound and the background noise,
$L_{Aeq,background}$ is the level of the background noise,
the -6 dB(A) added to $L_{Aeq,measured}$ corresponds to the correction for the reflection by the house facade.

Figure 7 shows the corrected immission levels as a function of the wind speed at hub height. It is seen that they follow a linear law given by the following regression line:

$$L_{aeq,corr} = 24.75 + 1.70U \qquad \text{in dB(A)}$$

where U is the wind speed at hub height.

5. Discussion of the results

Calculations of the immission level have been performed by using a program called *wituprop.exe* developed within the frame of the EU project JOR3-CT95-0065 [3]. Table 6 shows the value of the parameters used for the calculations. For a wind speed of 8 m/s at hub height, the calculated levels were 38.7 dB(A), respectively 35.5 dB(A), by using the sound power level spectrum deduced from the present emission measurements (see Table 5), respectively the values from Micon. No correction has been made to take into consideration the difference of between a wind speed of 8 m/s at hub height and at 10 m height. Finally, the measured level after correction is 38.3 dB(A) which agrees very well with the calculated result.

Table 6: parameters used for the calculation

Source-receiver distance (m)	source height (m)	receiver height (m)	temperature (°C)	relative humidity (%)
390	96	4	10	60

Flow resistivity ($kNsm^{-4}$)	wind speed at 96. 0 m (m/s)	wind direction (°)	temperature gradient (°C/m)
100	8	180	0

From the analysis of the measurement results, the following conclusions might be drawn:

- the measured sound power level of the turbine is 102.1 dB(A) at 8 m/s at hub height. For this wind speed, the corresponding speed at 10 m high is 6.4 m/s if a logarithmic wind profile together with a roughness length of 0.02 m are used. According to the supplier's data, the turbine should have a sound power level of 97.8 dB(A) at this wind speed. Thus, the turbine exhibits a higher sound power level than the one given by the supplier and the difference between the measured and the given levels is 4.3 dB(A) for a wind speed of 8 m/s at hub height.

- the corrected immission level at the dwelling Solgläntan is 39 dB(A) at a wind speed of 8 m/s at hub height. Nevertheless, as the wind profile at the wind turbine should be roughly uniform in the present case due to the presence of the cliff, a wind speed of 8 m/s at hub height should correspond to a wind speed of 8 m/s at 10 m high.

- at the immission point, respectively the emission point, the slope of the noise level as a function of the wind speed, is 1.7, respectively 1.3. These values are much higher than the slope predicted by the manufacturer, i.e. 0.57.

- the values provided by the manufacturer apply for a flat terrain with a logarithmic wind profile. In the present case, the steep slope of the terrain in front of the turbine during West wind conditions should affect considerably both the wind speed profile and the angle of attack with respect to the turbine rotor. This might be a possible explanation of the discrepancies observed between the present measurement results and the values provided by the manufacturer. Indeed, no complain has been reported for East wind conditions, i.e. with the house downwind the turbine. This might of course be the result of a higher background noise at Solgläntan but also it is possible that the sound power level of the turbine is lower then. It would be very interesting to check this hypothesis by carrying out emission measurements during East winds to see if the wind direction, i.e. the angle of attack of the wind, affects the turbine sound power level.

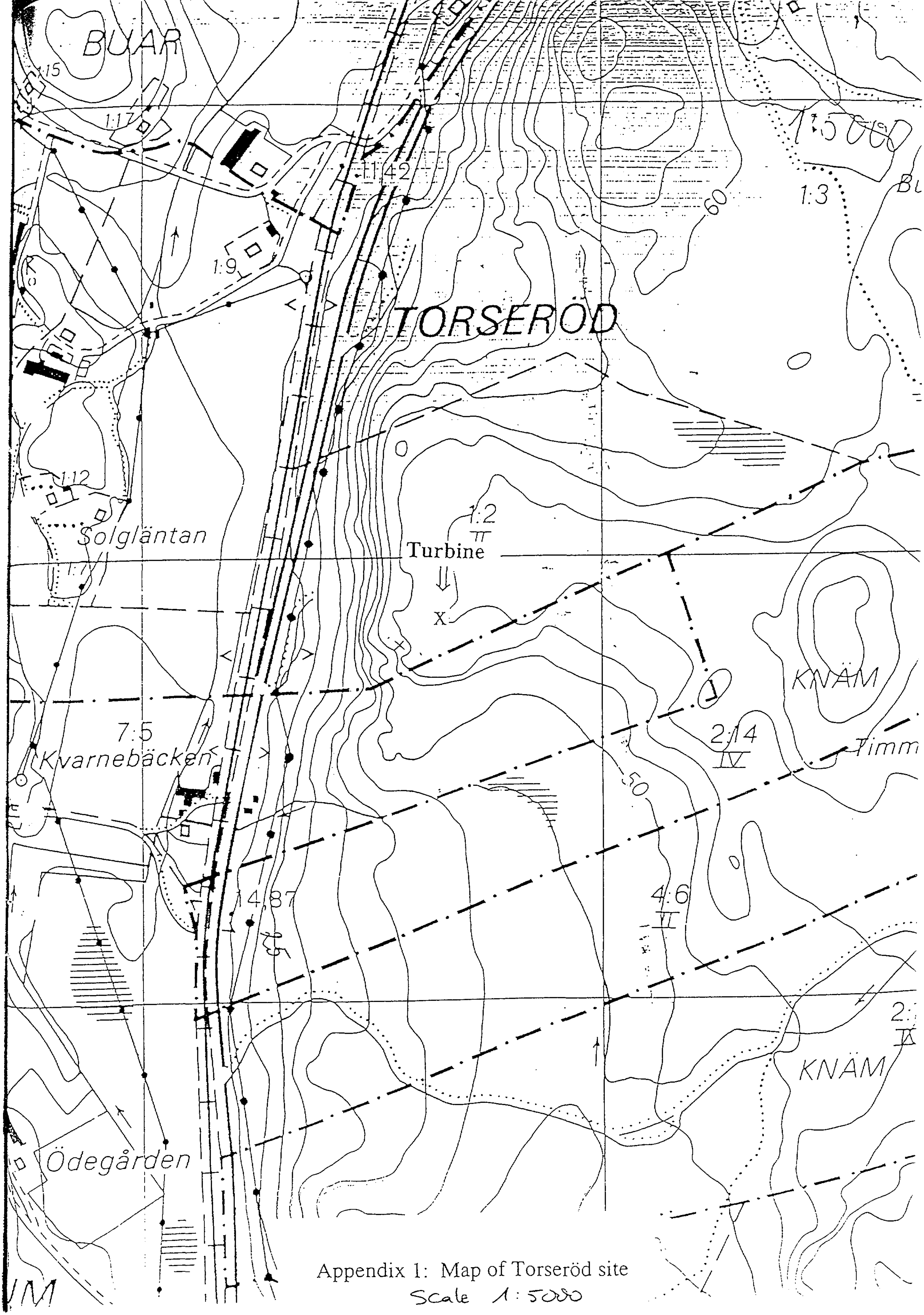
- the annoyance is enhanced by the exceptionally low background noise prevailing around the house during west wind conditions as the terrain forms then a natural sheltering to the house.

REFERENCES

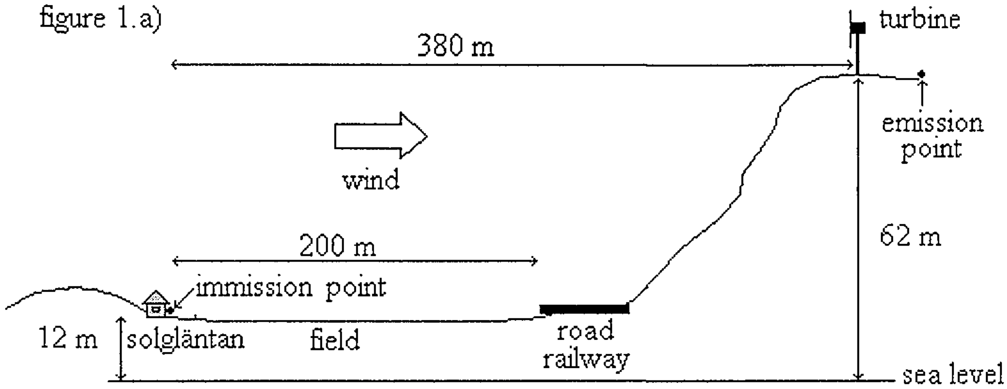
[1] Expert IEA Group (editor S. Ljunggren). IEA recommended practices for wind turbine testing and evaluation. *4. Acoustics Measurement of Noise Emission from Wind Turbines,* 3rd edition, 1994.

[2] Expert IEA Group (editor S. Ljunggren). IEA recommended practices for wind turbine testing and evaluation: *10. Acoustics: measurement of noise immission from wind turbines at noise receptor locations*, 1st edition, 1997.

[3] Jorgen Kragh. Noise Immission from Wind Turbines: *Final Report on Project JOR-CT95-0065*, 1998.



Appendix 1: Map of Torseröd site
Scale 1:5000



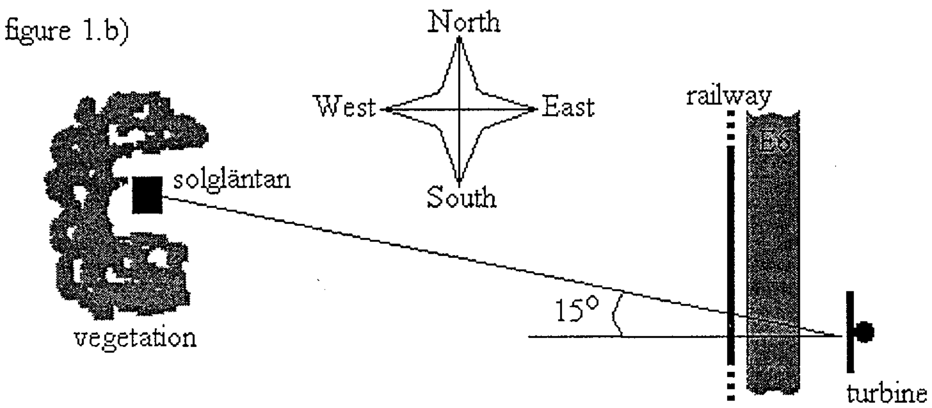


Fig. 1.a and 1.b: Description of the site

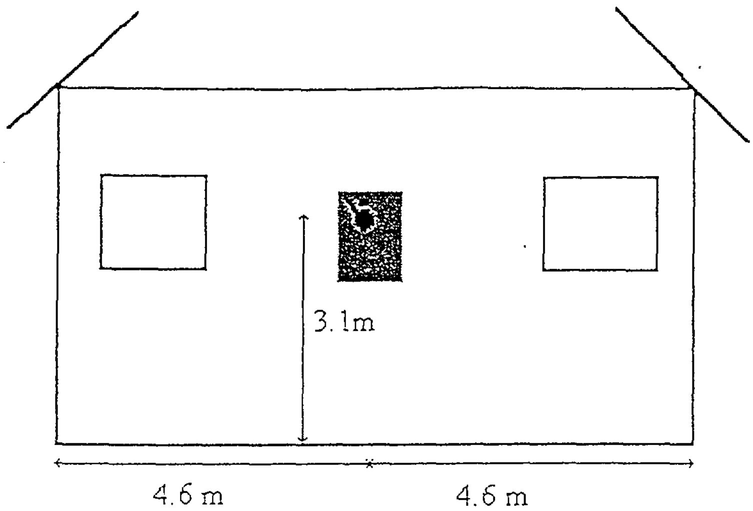


Fig. 2. position of the microphone on the house facade

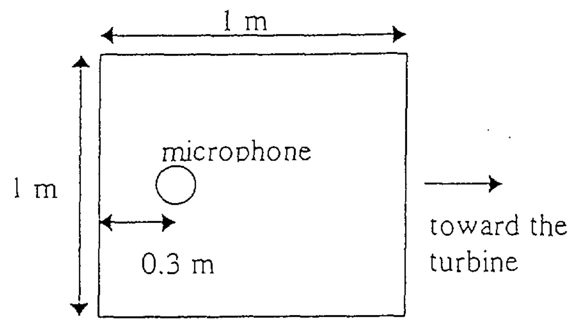


Fig. 3: Position of the microphone on the ground board

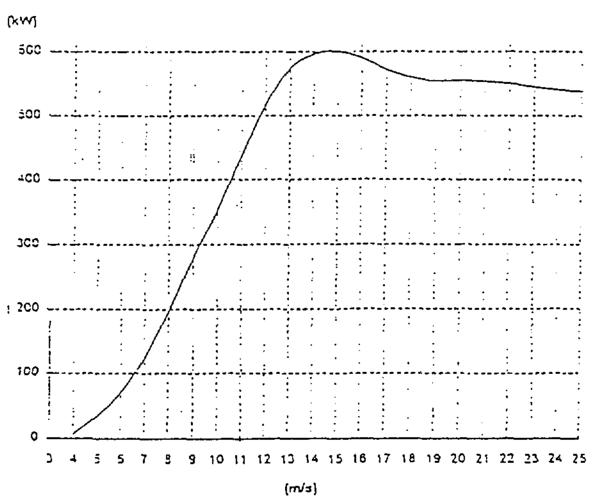


Fig. 4: Measured electrical power curve for M1500 600/150 kW
(source : Vatenfall)

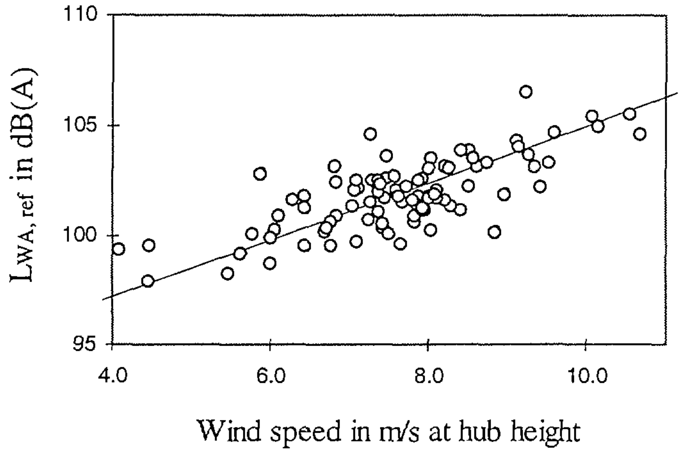


Fig. 5: Apparent A-weighted sound power level as a function of the wind speed at hub height

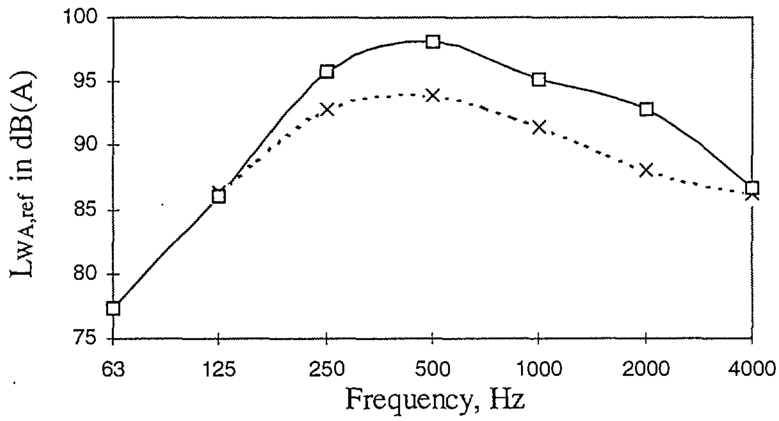


Fig. 6: Apparent A-weighted sound power level per octave
(—□) measured values at 8 m/s at hub height
(---×) Micon values at 8 m/s at 10 m high

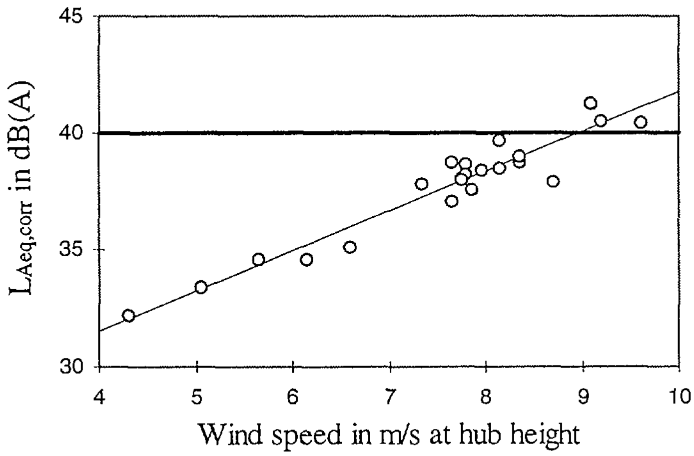
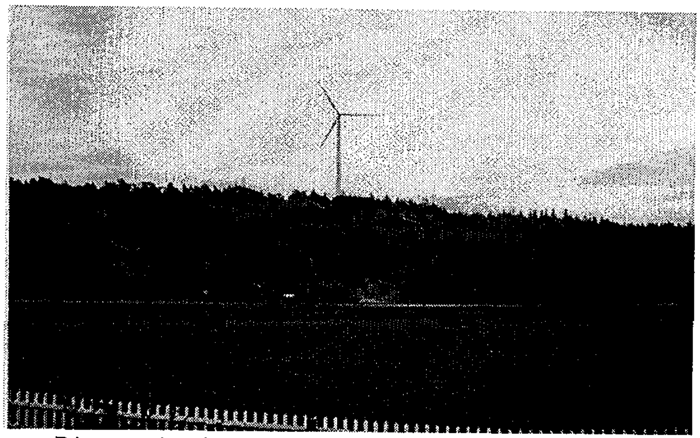
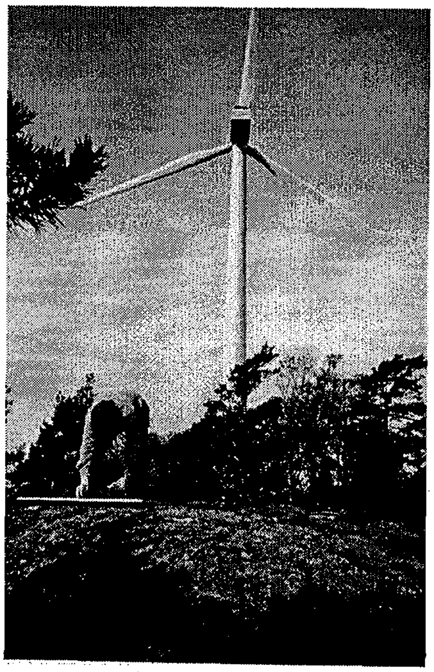


Fig. 7: Corrected A-weighted immission levels as a function of the wind speed at hub height.


Picture 1: view of the turbine from Solgläntan


Picture 2: location of the board on the house facade (immission point)


Piccture 3: view of the emission point