Report

PSO-07 F&U project no. 7389
Noise and energy optimization of wind farms

Validation of the Nord2000 propagation model for use on wind turbine noise

Final Report

Performed for Energinet.dk

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Preface

This report concludes the PSO-07 project “Noise and Energy optimization of wind farms”. The project is publicly funded by Energinet.dk with DKK 2 mill. under contract number 2007-1-7389. Supplementary funding to the project is given by DONG Energy, Statkraft Development, Vattenfall AB Vindkraft, E.ON Vind Sverige AB, Suzlon Energy and Gamesa.

The project has been carried out in cooperation between DELTA, DONG Energy and EMD International.

This report is prepared by Bo Søndergaard with Birger Plovsing, DELTA and Thomas Sørensen, EMD International A/S as contributing authors.

DELTA, 8 October 2009

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1. Summary

In wind farm planning, the noise generated by wind turbines is often an important parameter. The noise impact in the surroundings are usually described through noise prediction models like ISO 9613-2 which assumes simple propagation conditions like downwind in all directions. This leads to a concept of more or less constant noise at the neighbours independent of wind direction (and other meteorological parameters). New and more sophisticated noise prediction models, like Nord2000, include the influence of meteorology in the noise propagation. This gives the opportunity to make a more detailed planning of a wind farm layout where local meteorology is taken into account and a layout optimized with respect to noise and energy production can be defined.

In this project it has been investigated whether it is possible to use Nord2000 for noise and energy optimization of wind farm layout when combined with a flow model like WaSP developed by Risø in WindPRO developed by EMD International.

Part of the work has been to validate Nord2000 for elevated sources like wind turbines, which has been done successfully for the test cases realized in the project. It was the intention to include results from measurements made by KTH in Sweden of noise propagation over water, but the results were not available until late in the project and there were no time to work on this part.

The second part of the project was to develop a prototype software combining Nord2000 with WindPRO and to demonstrate that noise and energy optimization can be achieved. The prototype was developed and distributed within the project group. A simple version of energy optimization is included but the intended extensive optimization was found too elaborate to realize within the project. It is expected that work on the optimization procedure will continue after the project.

2. Summary in Danish

I forbindelse med planlægning af vindmølleparker er støjen fra vindmøllerne ofte en væsentlig parameter. Støjbelastningen i omgivelserne bestemmes ofte med støjberegningsmodeller som ISO 9613-2, hvor der antages simple lydudbredelsesforhold som for eksempel medvind i alle retninger. Dette fører til en antagelse om et mere eller mindre konstant støjniveau ved naboerne uafhængigt af vindretning (og andre meteorologiske parametre). Nye og mere avancerede lydudbredelsesmodeller som Nord2000 inkluderer virkningen af meteorologi i beregning af lydudbredelsen. Dette giver mulighed for en mere detaljeret planlægning af vindmølleparker, hvor lokal meteorologi kan inddrages, og parklayout kan optimeres både med hensyn til støj i omgivelserne og energiproduktion.

I dette projekt er det undersøgt, om det er muligt at anvende Nord2000 til støj og energioptimering af vindmølleparker, når modellen kombineres med strømningsmodeller som WaSP udviklet af Risø, og i WindPRO udviklet af EMD International.

En del af arbejdet har været at validere Nord2000 for højt placerede støjkilder som vindmøller. Dette er gjort med overbevisende resultater for de testsituationer, der er realiseret i projektet. Det var en intention at inkludere resultater fra målinger foretaget af KTH i Sverige af lydudbredelse over vand. Resultaterne fra disse målinger blev dog først tilgængelige sent i projektet, og der har ikke været tid til at arbejde med disse data.

Den anden del af projektet har været at udvikle en softwareprototype, der kombinerer Nord2000 med WindPRO og demonstrere, at støj og energioptimering kan opnås. Prototypen er blevet distribueret i projekt gruppen. En simpel version af optimeringen er inkluderet i prototypen, mens det blev konstateret, at en mere omfattende optimeringsrutine ikke kunne realiseres indenfor projektet. Det forventes, at der arbejdes videre med optimeringsproceduren efter projektets afslutning.

3. Aim

The aim of the project is from the project application:

- To pave the way for the global recognition and application of a single, improved sound-propagation model - the Nordic Nord2000 Model.

- To demonstrate that energy optimization can be achieved by using the Nord2000 model in the planning of wind farms.

This will be achieved through a validation of Nord2000 for noise prediction for wind turbines, making Nord2000 available for general use in WindPRO, first as a prototype later as a commercial product and subsequently communicating the results in articles and at conferences.

4. Project description

In wind farm planning, the noise generated by wind turbines is often an important parameter. Sound propagation models like ISO 9613-2 commonly used in noise predictions do not take into account the complex factors like varying surface properties of the terrain, wind velocity and weather conditions. Consequently, calculations can be subject to significant inaccuracies, resulting in errors and uncertainty for energy project stakeholders. A further consequence can be that the project fails to make optimum use of the energy.

The project comprises a validation of Nord2000 for wind turbines and a subsequent development and demonstration of a prototype program combining WindPRO and Nord2000.

The report “Nord2000. Validation of the Propagation Model” [1] sums up validation for Nord2000 for low-altitude sources at distances of up to approx. 1000 m. For that reason the validation for elevated sources like wind turbines is considered to be a supplement to existing validation rather than a full validation. More information on the Nord2000 model can be found in [2], [3], [4], and [5].

WindPRO is a commercial wind farm planning software comprises a list of relevant features like micro siting of wind turbines, analysis of meteorological measurements, modeling of wind flow, noise prediction as well as other environmental impact calculations. The project includes the construction of a prototype interface between Nord2000 and WindPRO making noise predictions with Nord2000 possible using the many features already prepared in WindPRO.

The strength of the Nord2000 model resides in the fact that it can incorporate the complex terrain, weather and wind direction conditions that influence sound propagation so radically. To make optimum use of Nord2000 it is necessary to feed data into the Nord2000 model. The data is already stored in the WindPRO modeling tool, which uses the Risø WAsP calculation model.

By linking WAsP and WindPRO with Nord2000, it will be possible to exploit the 3D-facilities in WindPRO and the wind velocity distribution from WAsP. It then becomes possible to describe the dependence of the meteorology to the noise emission - both as snapshot values, e.g. wind velocity 8 m/s, wind direction 270 deg., and as annual mean values based on wind statistics for the site in question. It will also be possible to indicate how much a given location in fact is affected by noise levels of or above a given limit value and for how much of the time the noise level is higher/lower than the limit value. The system operates with complex calculations and results.

The project's second main aim is to demonstrate that energy optimization can be achieved by using the Nord2000 model in the planning of wind farms. During this work it was found that this was an elaborate task and a simpler version of optimization is included in the prototype software.

The project divides naturally into 3 phases:

- Validation of Nord2000
- Noise and Energy optimization
- Reporting and Publishing

5. The basics of the Nord2000 model

The Nord2000 calculation principles have been described in numbers of reports [2], [3], and [4] and the method has in every detail been described in a proposal for a Nordtest standard method [5].

The limitations in the Nord2000 method are:

- The sound pressure level is predicted in one-third octave bands from 25 Hz to 10 kHz. If necessary, the method can be extended below 25 Hz.
- The Nord2000 method assumes a point source. Therefore, a complex source has to be divided into a number of incoherent point sources and a calculation has to be carried out for each point source. For wind turbines, the experience is that a single point source located at the hub is sufficient in most cases.
- The terrain shape from source to receiver has to be approximated by a number of straight line segments.
- In Nord2000 the effect of weather on propagation (refraction) is determined on basis of the vertical effective sound speed profile and Nord2000 can be used to calculate short-term noise levels for time periods where this profile is almost constant. In the Nord2000 method the profile has to be approximated by a log-lin profile between the source and receiver heights as shown in Eq. (1).

$$c(z) = A\ln(\frac{z}{z_0}+1) + Bz + c \quad (1)$$

In Eq. (1) c(z) is the effective sound speed at height z above ground, z_0 is the roughness length of the ground, and A, B, and C are constants. A and B are determined by wind speed profile, the angle between the wind direction and the direction of propagation and the air temperature profile. C is sound speed at the ground determined by the air temperature close to the ground.

In excess of the variables A, B, C, and z_0 in Eq. (1) the Nord2000 meteorological input parameters are:

- C_v^2 and C_T^2 which are structure parameters of turbulent wind speed and temperature fluctuations, respectively
- s_A and s_B which are standard deviation from short-term fluctuations of A and B in excess of what is accounted for by the turbulence parameters
- t and RH which are air temperature and relative humidity used for calculation of air absorption

In general, the log-lin approximation in the range of heights between source and receiver is sufficient for most weather cases. However, in some special weather cases (e.g. low level jets) where the approximation is less good a reduced accuracy of the Nord2000 method is expected. If the weather is changing substantially meaning that the vertical effective sound speed profile is no longer constant with minor fluctuations the method for prediction of long-term noise levels described section 7.2 has to be applied.

6. Validation of Nord2000

The validation part of the project is described in detail in [6] and only a brief description is included in this report.

Three stages of validation were planned from the beginning: loudspeaker tests, single wind turbine tests and a wind farm test.

The loudspeaker tests are considered most important as the noise source is well defined in position and in strength. As the aim of the project has been to introduce the Nord2000 in wind turbine noise prediction tests using a wind turbine as a source was planned as well. In this case the source is less well defined in both positions and in strength, and the results were expected to have a higher uncertainty. It is considered important to show that wind farm noise predictions with Nord2000 are reliable and a limited test with noise measurements and predictions for a wind farm has been included. The accuracy of this test was expected to be less than for the other two stages of validation.

6.1 Loudspeaker noise measurements

The loudspeaker measurements were made at two locations: at the Risø test site for large wind turbines Høvsøre in Denmark and at the Statkraft wind farm at Hitra in Norway. The terrain at Høvsøre was simple and flat and at Hitra the terrain was complex and hilly.

The principle behind the loudspeaker test is that a loudspeaker is placed at an elevated position (30 m and 50 m at Høvsøre and 70 m at Hitra) emitting a well defined noise signal. The noise is measured in front of the loudspeaker at a short distance to give information on the level of noise from the loudspeaker. Noise measurements were also made at various distances and heights (2 m and 5 m) for downwind and upwind conditions.

During the noise measurements meteorological data were registered synchronously. At Høvsøre it was possible to get detailed data for relevant parameters like wind speed, wind direction and temperature at several heights and relative humidity at 2 m height sampled at 10 seconds. At Hitra the main source of meteorological data was the meteorology mast at the wind farm giving data as 10 m averages.

From the noise measurements the Excess Propagation Effect can be estimated by Eq. (1) where $L(f)$ is the measured 1/3-octave band sound pressure level and $L_0(f)$ is the free field sound pressure level. The excess propagation effect determined by Eq. (1) contains the propagation effect of ground and air absorption.

$$\Delta L(f) = L(f) - L_0(f) \qquad (1)$$

The free field sound pressure level $L_0(f)$ are determined by Eq. (2) where $L_{1m}(f)$ is the sound pressure level measured approx. 1 m from the loudspeaker front. d is the distance from the loudspeaker to the receiver and d_0 is the distance from the acoustical centre of the loudspeaker to the “1m” microphone including the correction for near field effect. A value of d_0 = 1.29 m has been found to provide the best estimate.

$$L_0(f) = L_{1m}(f) - 20\log\left(\frac{d}{d_0}\right) \qquad (2)$$

6.2 Wind turbine noise measurements

The wind turbine noise measurements were following the principles of the loudspeaker measurements except the source is the wind turbine and the reference measurement position is a microphone on a board on the ground according to IEC 61400-11 [7]. The wind turbine noise measurements were only made at Hitra and due to malfunction of the measurement equipment only for the downwind direction. When comparing measurements with predictions it was assumed that the source was a point source at the hub of the wind turbine.

6.3 Wind Farm noise measurements

Noise measurements have been made at a wind farm in flat terrain in Norway. The results of these measurements are compared to noise calculations according to Nord2000 based on the prototype software developed in the project.

6.4 Results and conclusions on the validation measurements

The details of the data analysis as well as all the results can be found in [6]. The main results are given below.

6.4.1 Downwind propagation – flat terrain

Typical results for downwind propagation are shown in Figure 1 and Figure 2. The agreement between measured and predicted spectra is in general good.

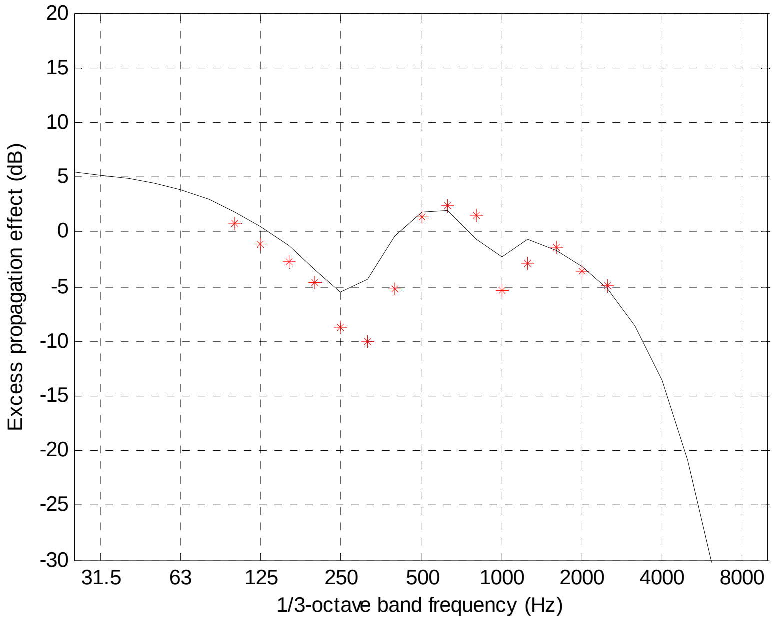

Figure 1
Measured (*) and predicted (line) excess propagation effect. Downwind, distance 500 m, source height 30 m, and receiver height 2 m.

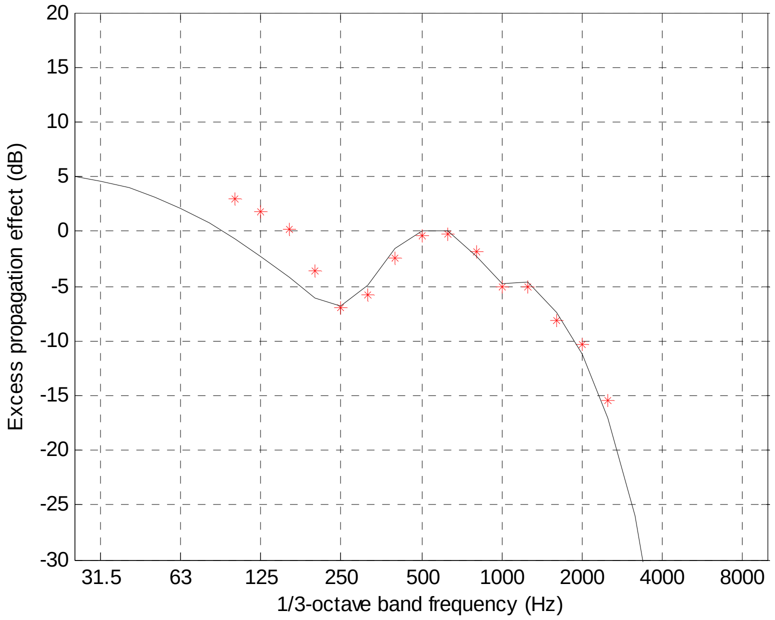

Figure 2
Measured (*) and predicted (line) excess propagation effect. Downwind, distance 1500 m, source height 50 m, and receiver height 2 m.

The measured and predicted A-weighted excess propagation effects in the downwind experiment and the difference between predicted and measured values are shown in Table 1. The A-weighted results are determined on basis of the excess propagation effect spectra and a typical wind turbine source spectrum. The table also shows the number of signal sequences included in the average values. The average deviation is -0.1 dB with a standard deviation of 0.7 dB so the agreement is very fine. The result is presented graphically in Figure 3.

Pos.	**h_S (m)**	**h_R (m)**	**Number of seq.**	**Nord2000 (dB)**	**Measured (dB)**	**ΔL_A(c-m) (dB)**
1	30	2	15	-1.4	-2.1	0.7
1	30	5	15	0.0	1.2	-1.2
1	50	2	15	-1.1	-1.4	0.3
1	50	5	15	0.4	0.1	0.3
2	30	2	15	-3.3	-4.0	0.7
2	30	5	15	-1.3	-1.6	0.3
2	50	2	15	-2.7	-3.2	0.5
2	50	5	15	-1.0	-0.9	-0.1
3	30	2	15	-4.3	-3.2	-1.1
3	30	5	15	-2.0	-1.4	-0.6
3	50	2	13	-3.9	-3.0	-0.9
3	50	5	9	-1.6	-1.5	-0.1
Total					Average	-0.1
					Std. dev.	0.7

Table 1
Measured and predicted A-weighted excess propagation effect. Downwind propagation over flat terrain from a loudspeaker at Høvsøre.

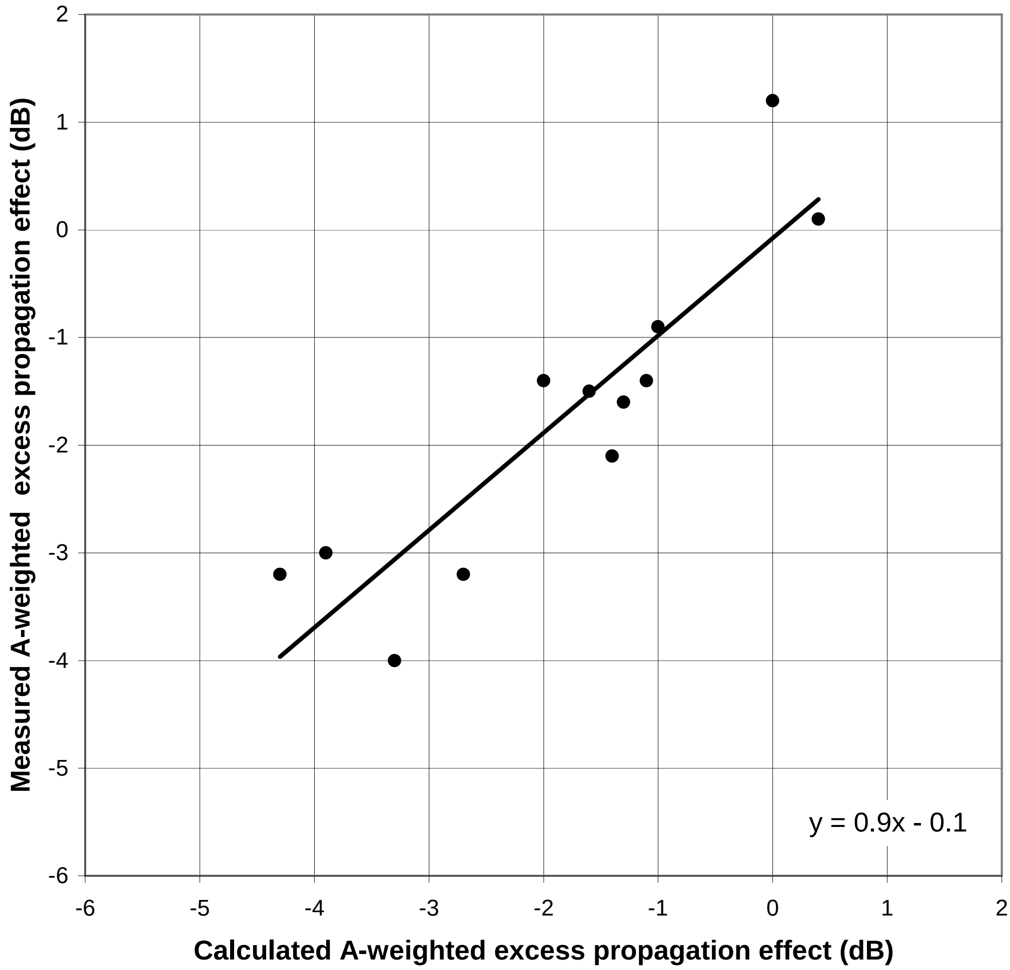

Figure 3
Measured versus predicted A-weighted excess propagation effect in the downwind experiment at Høvsøre (circles are A-weighted results, the line is a linear fit to the results given by the equation in the lower right part of the figure).

6.4.2 Upwind propagation – flat terrain

Typical results for upwind propagation are shown in Figure 4 and Figure 5. The agreement between measured and predicted spectra is in general less good than seen for downwind propagation. Figure 4 shows the result at a propagation distance of 1000 m for the lowest source position and receiver height. In this case the upwind is causing a considerable acoustically shadow zone effect with large attenuation at high frequencies. Taking into account how unstable such shadow zones are it is fairly well modelled by Nord2000. In Figure 5 where the source is at the highest position instead the measurement shows a slightly reduced attenuation compared to the low source position whereas Nord2000 predicts a much larger reduction. The general trend in the upwind measurement experiment is that measurement and prediction in some cases agree to show an effect of a shadow zone effects and in other cases agree to show no shadow zone effect. However, in a number of cases shadow zone effects are seen in the measurements but not in the predictions whereas the opposite is not seen in the experiment.

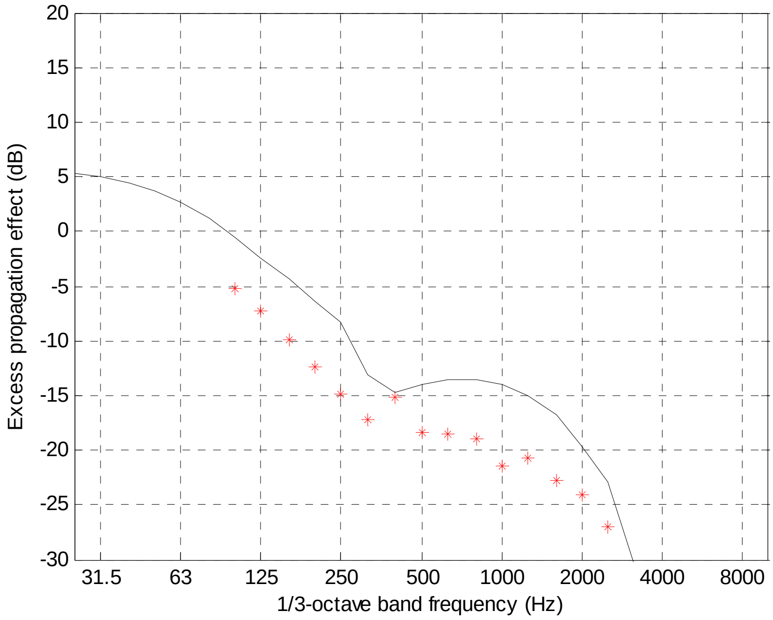

Figure 4
Measured (*) and predicted (line) excess propagation effect. Upwind, distance 1000 m, source height 30 m, and receiver height 2 m.

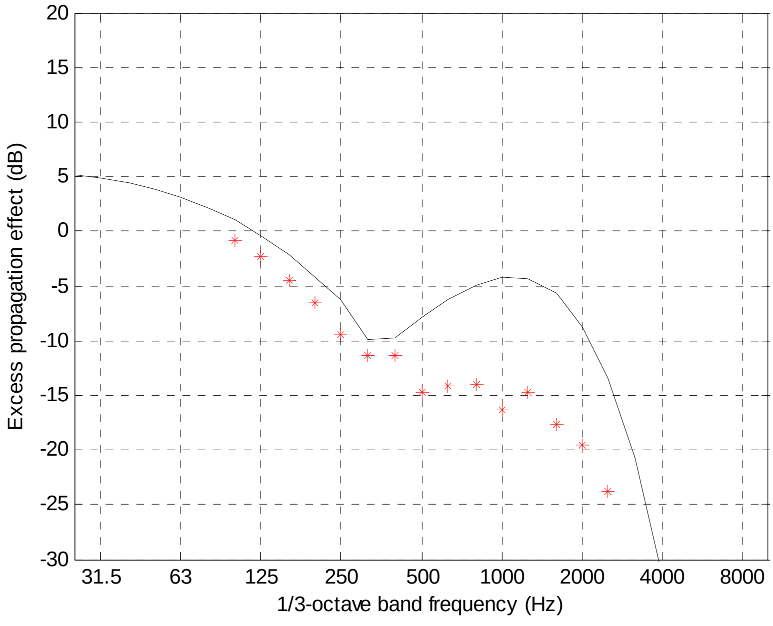

Figure 5
Measured (*) and predicted (line) excess propagation effect. Upwind, distance 1000 m, source height 50 m, and receiver height 2 m.

The measured and predicted A-weighted excess propagation effects in the upwind experiment and the difference between predicted and measured values are shown in Table 2. The table also shows the number of signal sequences included in the average values. The average deviation is 4.3 dB with a standard deviation of 1.9 dB. The result is presented graphically in Figure 6. Although the agreement is poor compared to the downwind results it is considered acceptable taking into account the well-known difficulties of making accurate prediction for an acoustical shadow zone in upwind. It is possible, that the Nord2000 method could be adjusted to decrease the average deviation in upwind but on the existing basis it is considered better to have a conservative method. An adjustment would require a much more extensive number of measurements.

Pos.	**h_S (m)**	**h_R (m)**	**Number**	**Nord2000 (dB)**	**Measured (dB)**	**ΔL_A(c-m) (dB)**
1	30	2	11	-0.8	-8.9	8.1
1	30	5	11	-0.6	-3.1	2.5
1	50	2	22	-1.2	-3.8	2.6
1	50	5	22	0.2	-2.1	2.3
2	30	2	11	-9.4	-14.6	5.2
2	30	5	11	-6.9	-11.5	4.6
2	50	2	22	-5.2	-9.5	4.3
2	50	5	22	-3.3	-8.0	4.7
Total					Average	4.3
					Std. dev.	1.9

Table 2
Measured and predicted A-weighted excess propagation effect. Upwind propagation over flat terrain from a loudspeaker at Høvsøre.

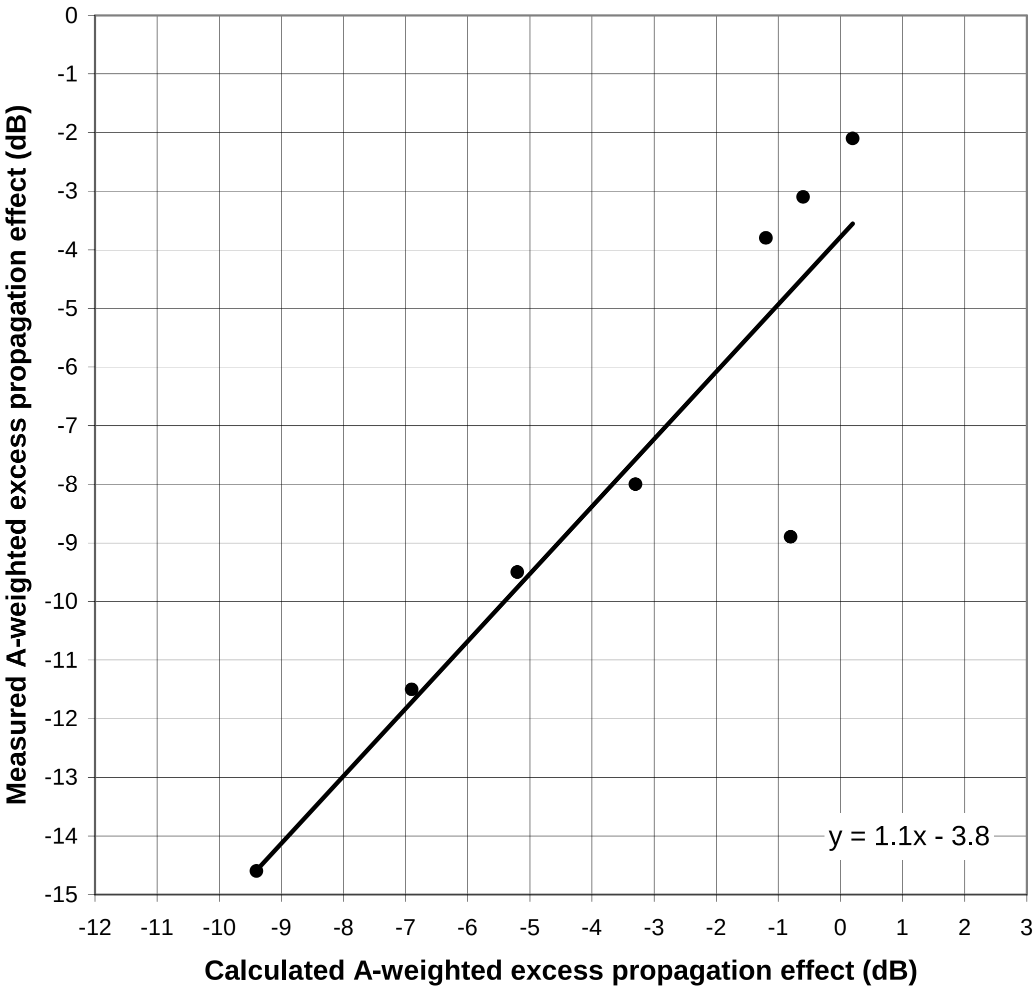

Figure 6
Measured versus predicted A-weighted excess propagation effect in the upwind experiment at Høvsøre (circles are A-weighted results, the line is a linear fit to the results given by the equation in the lower right part of the figure).

6.4.3 Results from complex terrain

Results from the downwind measurement in Pos. 1, 2, and 3 on the first day are shown in Figure 7 to Figure 9 for receiver height 2 m. The agreement between measured and predicted spectra is in general good. In Figure 7 minor irregular deviations are seen at high frequencies probably caused by the uncertainty in the loudspeaker directivity. The result shown in Figure 9 is particularly interesting because considerable attenuation is observed in most of the frequency range which is unusual in downwind propagation. This attenuation which is similar to what can be observed in upwind is interpreted as being the result of a speed-up effect on the wind speed profile. The results for downwind propagation in the cases repeated on the second measurement day agreed well with the results of the first day. Figure 10 shows a result from the upwind measurement in Pos. 1 with a receiver height of 2 m. The agreement between measured and predicted excess ground attenuation is good in this case and the result looks more like what is observed in downwind propagation which again may be explained by the speed-up effect.

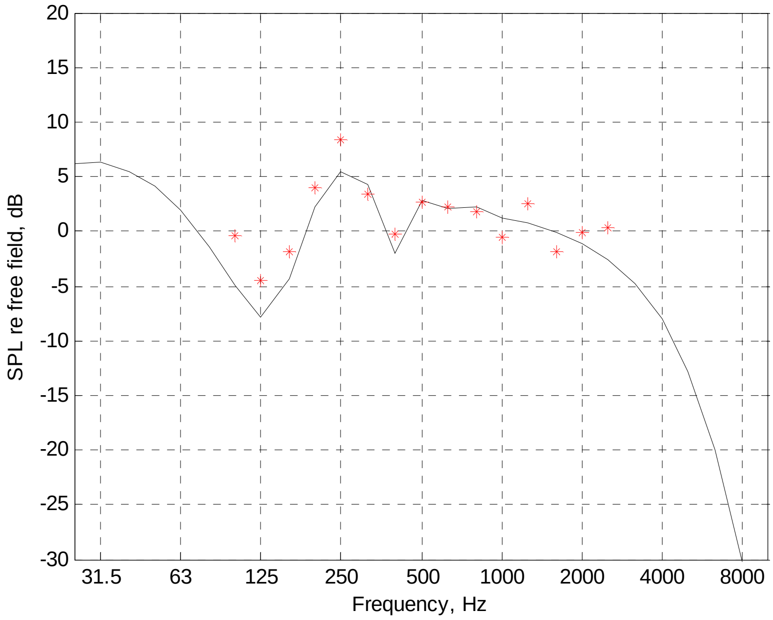

Figure 7
Downwind propagation, July 8, Pos. 1, receiver height 2 m.

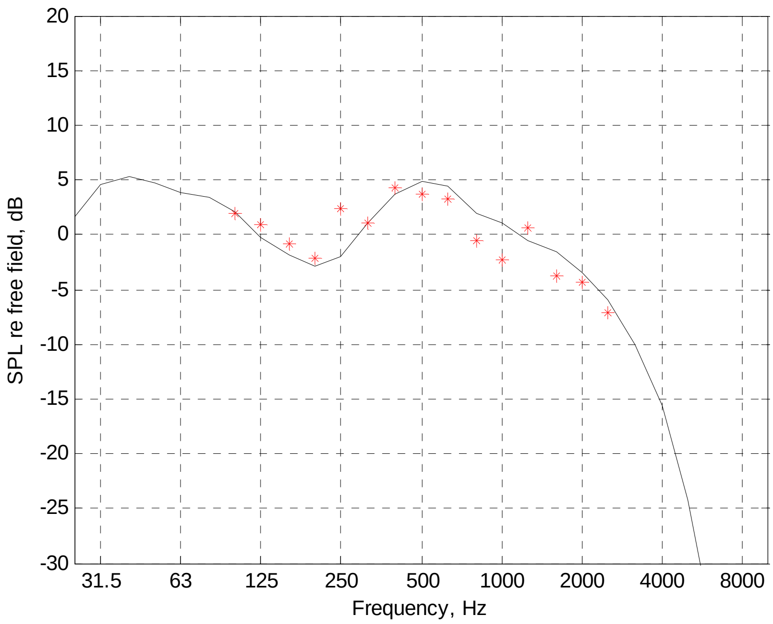

Figure 8
Downwind propagation, July 8, Pos. 2, receiver height 2 m.

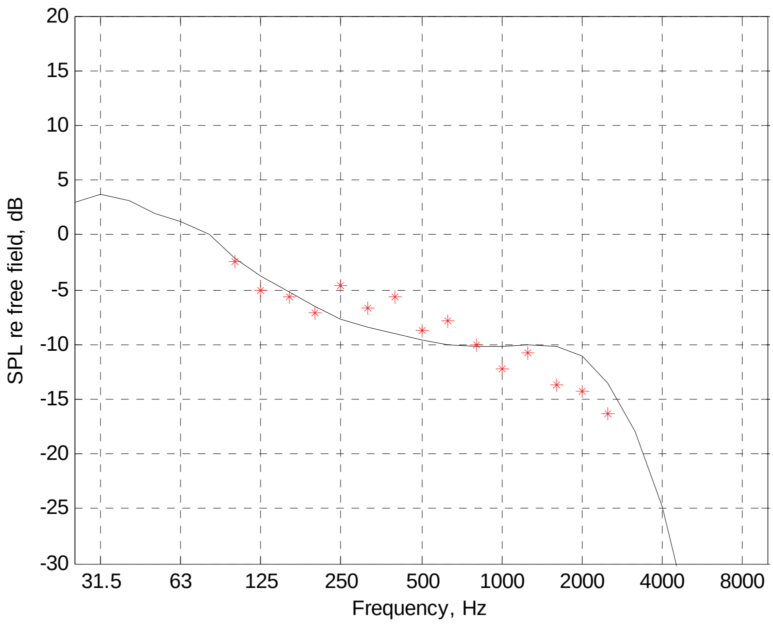

Figure 9
Downwind propagation, July 8, Pos. 3, receiver height 2 m. Typical shadow zone behaviour is observed which is unusual in downwind conditions.

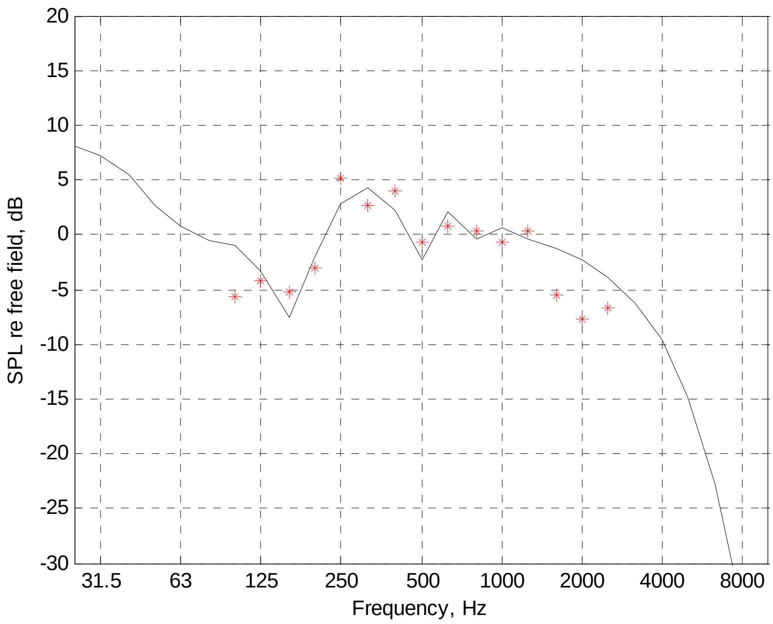

Figure 10
Upwind propagation, July 11, Pos. 1, receiver height 2 m.

The measured and predicted A-weighted excess propagation effects in the Hitra experiment and the difference between predicted and measured values are shown in Table 3 for each propagation case and measurement day. The table also shows the number of signal sequences included in the average values. The average deviation of all results is -0.5 dB with a standard deviation of 1.8 dB which is a satisfactory agreement taking into account the complexity of the propagation. The result is presented graphically in Figure 11.

Case	Pos.	h_R (m)	Number	Nord2000 (dB)	Measured (dB)	ΔL_A(c-m) (dB)	Group ΔL_A (dB)
Downwind July 8	1	2	31	2.0	3.2	-1.2	-1.6
	1	5	31	0.0	2.9	-2.9	
	2	2	31	0.8	1.8	-1.0	
	2	5	32	0.4	3.7	-3.3	
	3	2	32	-8.2	-5.6	-2.6	
	3	5	32	-2.3	-3.5	1.2	
Downwind July 11	1	2	4	2.4	1.9	0.5	0.2
	2	2	6	1.4	1.5	-0.1	
Upwind July 11	1	2	15	0.6	0.9	-0.3	0.9
	1	5	15	2.6	0.3	2.3	
	2	2	18	-5.1	-7.2	2.1	
	2	5	18	-1.7	-1.3	-0.4	
Total						Average	-0.5
						Std. dev.	1.8

Table 3
Measured and predicted A-weighted excess propagation effect from propagation over non-flat terrain from a loudspeaker at Hitra.

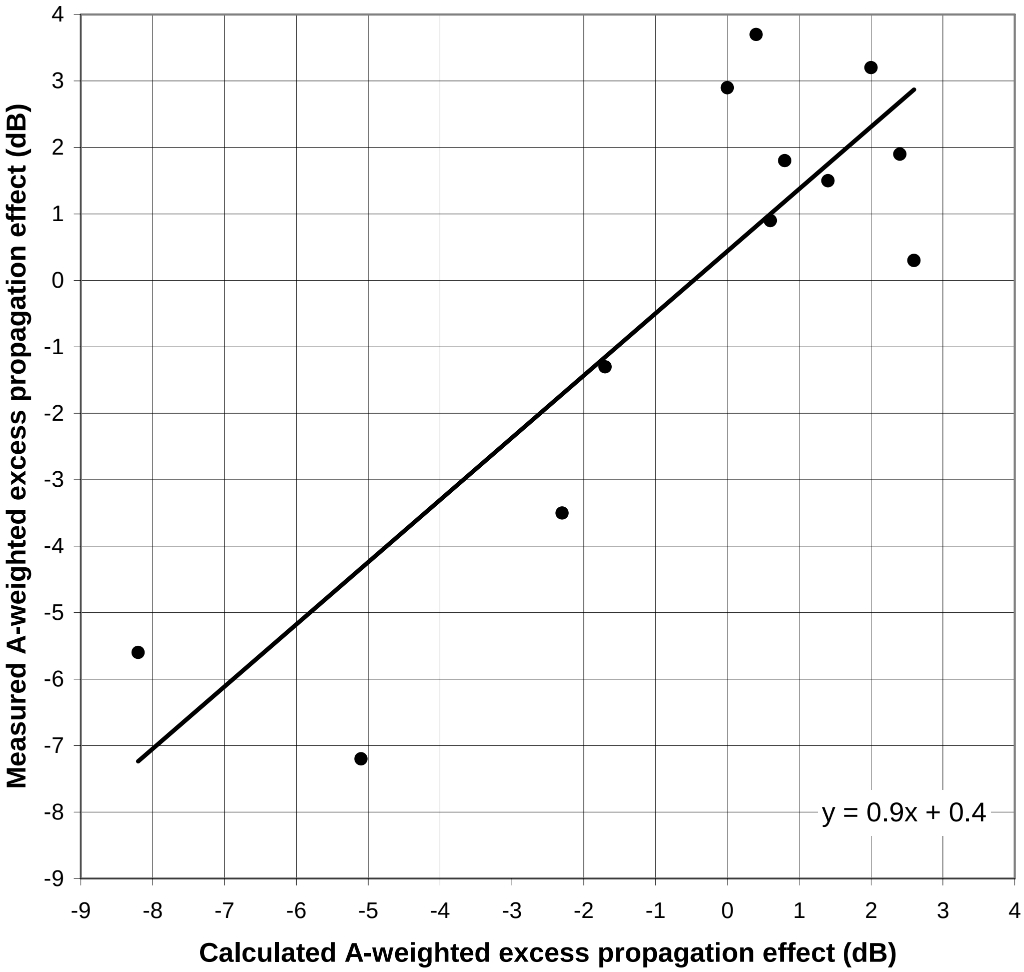

Figure 11
Measured versus predicted A-weighted excess propagation effect in the Hitra loudspeaker experiment (circles are A-weighted results, the line is a linear fit to the results given by the equation in the lower right part of the figure).

6.4.4 Result of wind turbine measurements at Hitra

As in the Høvsøre experiment measured and predicted excess propagation effect spectra *ΔL(f)* have been determined for each signal sequence and subsequently used to determine the average excess propagation effect spectra and A-weighted propagation effect for each propagation case. The propagations cases were the same as in the loudspeaker experiment but the downwind recordings in Pos. 3 were not analyzed due to too much background noise and the upwind recordings could not be used due to technical problems.

The results from the downwind measurements in Pos. 1 and 2 and receiver height 2 and 5 m are seen in Figure 12 through Figure 15.

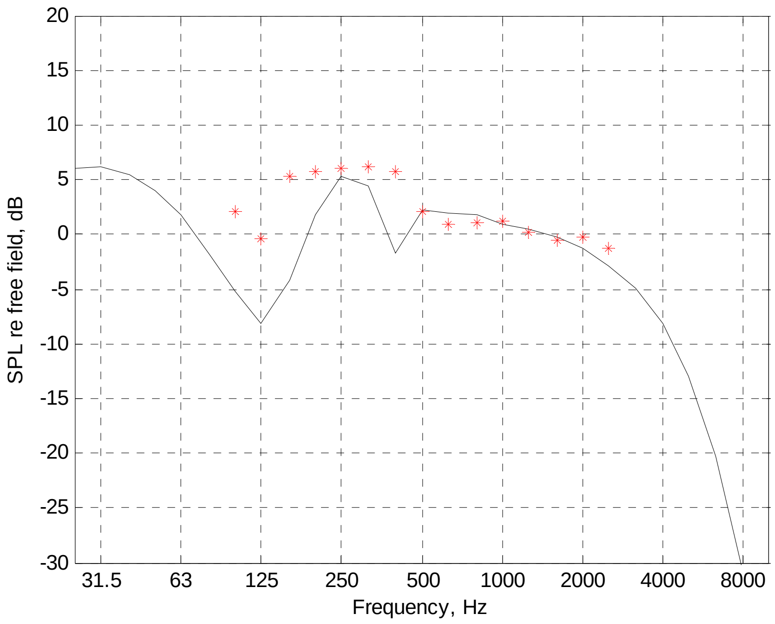

Figure 12
Downwind propagation from wind turbine, Pos. 1, receiver height 2 m

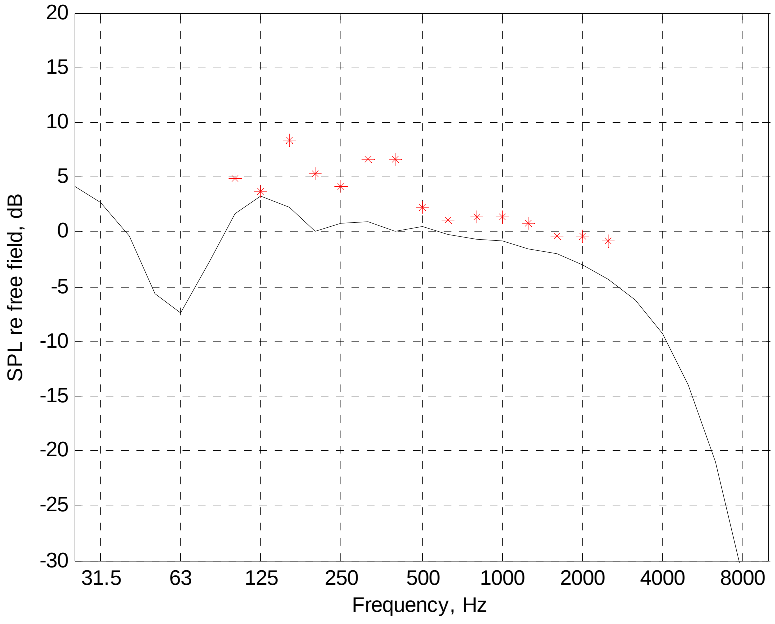

Figure 13
Downwind propagation from wind turbine, Pos. 1, receiver height 5 m.

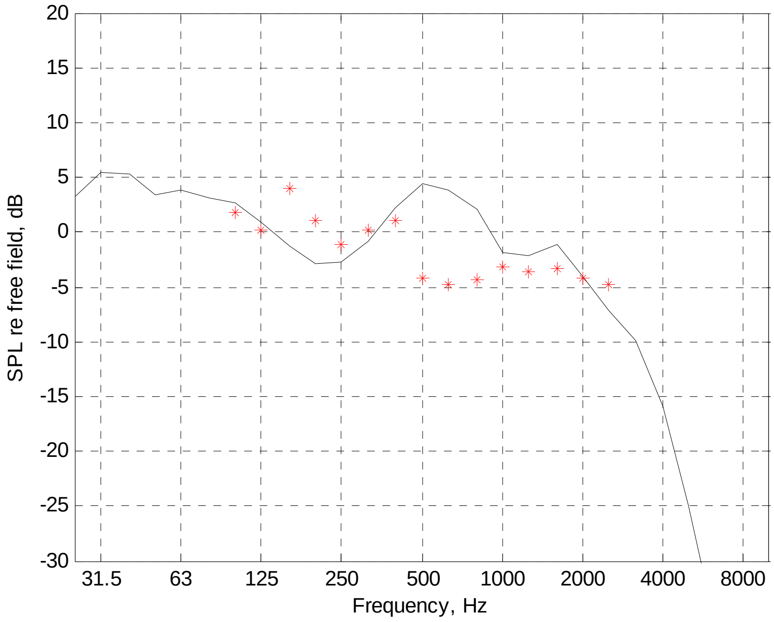

Figure 14
Downwind propagation from wind turbine, Pos. 2, receiver height 2 m. An indication of shadow zone behaviour is seen. This is most pronounced in the measurements.

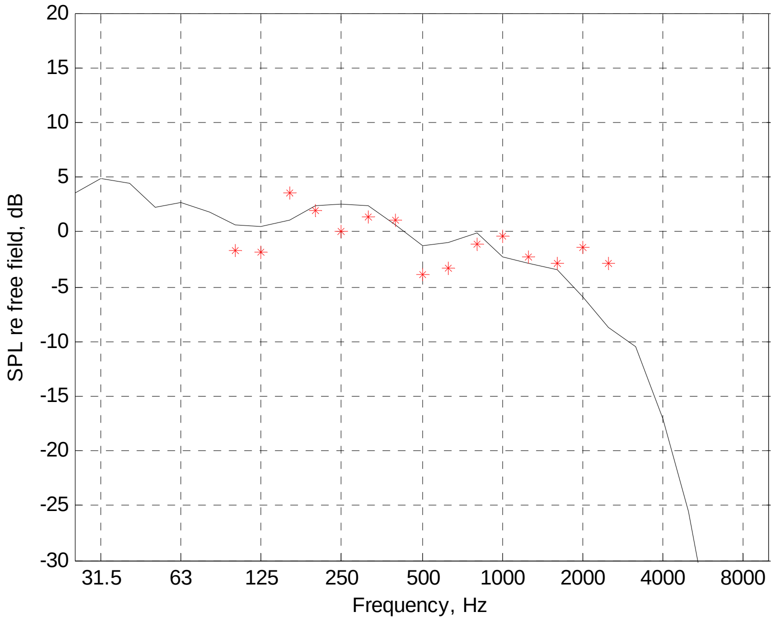

Figure 15
Downwind propagation from wind turbine, Pos. 2, receiver height 5 m.

The measured and predicted A-weighted excess propagation effects in Hitra wind turbine experiment and the difference between predicted and measured values are shown in Table 4 for each propagation case. The table also shows the time period included in the average values (number of 10 second periods times 10). The average deviation of all results is -1.0 dB with a standard deviation of 2.3 dB.

Although both the spectral results shown in the four figures and the statistics from Table 4 indicate larger deviations than seen in the loudspeaker experiment the agreement between measured and predicted is still acceptable. The determination of the sound power level of the wind turbine by the ISO method and the decrease in signal-to-noise-ratio will unavoidable reduce the accuracy in the analysis.

Pos.	h_R (m)	Duration (sec)	Nord2000 (dB)	Measured (dB)	ΔL_A(c-m) (dB)
1	2	6180	1.8	3.5	-1.7
1	5	4400	0	3.8	-3.8
2	2	2520	0.2	-1.1	1.3
2	5	2890	0.1	-0.3	0.4
Total				Average	-1.0
				Std. dev.	2.3

Table 4
Measured and predicted A-weighted excess propagation effect from propagation over non-flat terrain from a wind turbine at Hitra.

6.4.5 Comparison with ISO 9613-2

A very interesting subject is how results predicted by Nord2000 will deviate from the prediction by ISO-9613-2 which is the most commonly used method for wind turbine prediction today.

It has not been possible within this project to perform a comparison for all results but a few cases have been selected to illustrate the difference between the two prediction methods. The two selected cases are from Section 7.1.1 in [6] with downwind propagation over flat grass-covered ground at Høvsøre. Except for the high source position the ISO method is supposed to be valid in this propagation case. The results from these cases are recalculated to 1/1 octave bands and shown in Figure 16 and Figure 17 and predicted result by the ISO method has been included. The two figures show a considerable underestimation by the ISO method around 500 Hz and 1000 Hz which is a well-known experience for very high source positions. Comparison at lower frequencies is difficult due to background noise as can be seen at 63 Hz in Figure 17. Larger deviations in the prediction would of course have been observed if the ISO method had been used to predict some of the cases where the method is not valid such as the upwind cases at Høvsøre and some of the complex terrain cases at Hitra.

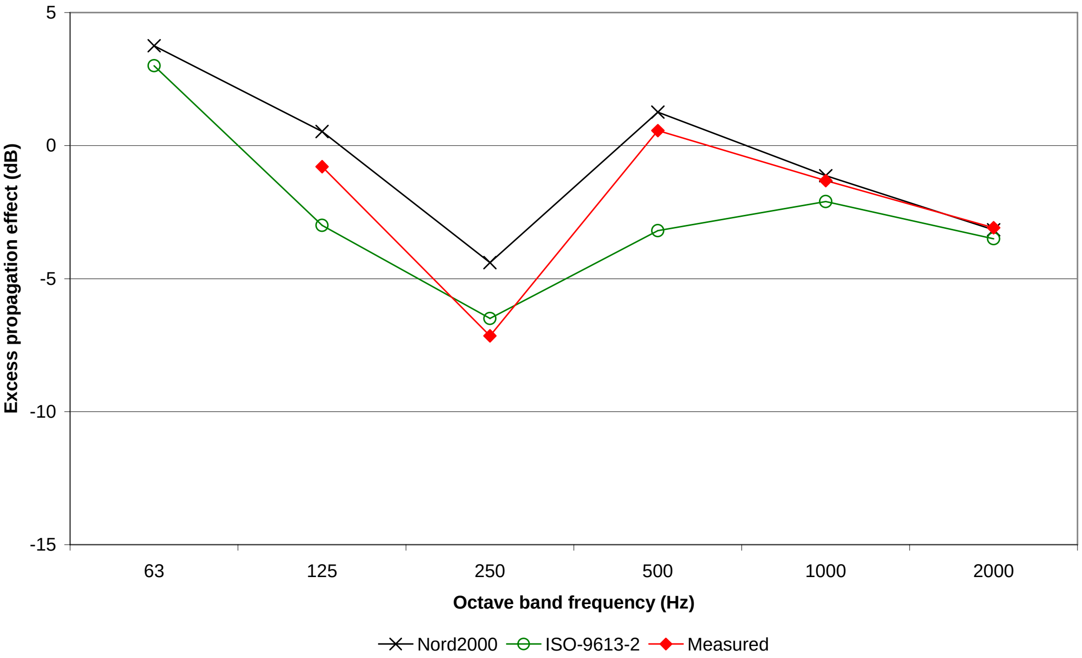

Figure 16
Measured (♦ red), predicted by ISO-9613-2 (○ green), and predicted by Nord2000 (X black) excess propagation effect. Downwind, distance 500 m, source height 30 m, and receiver height 2 m.

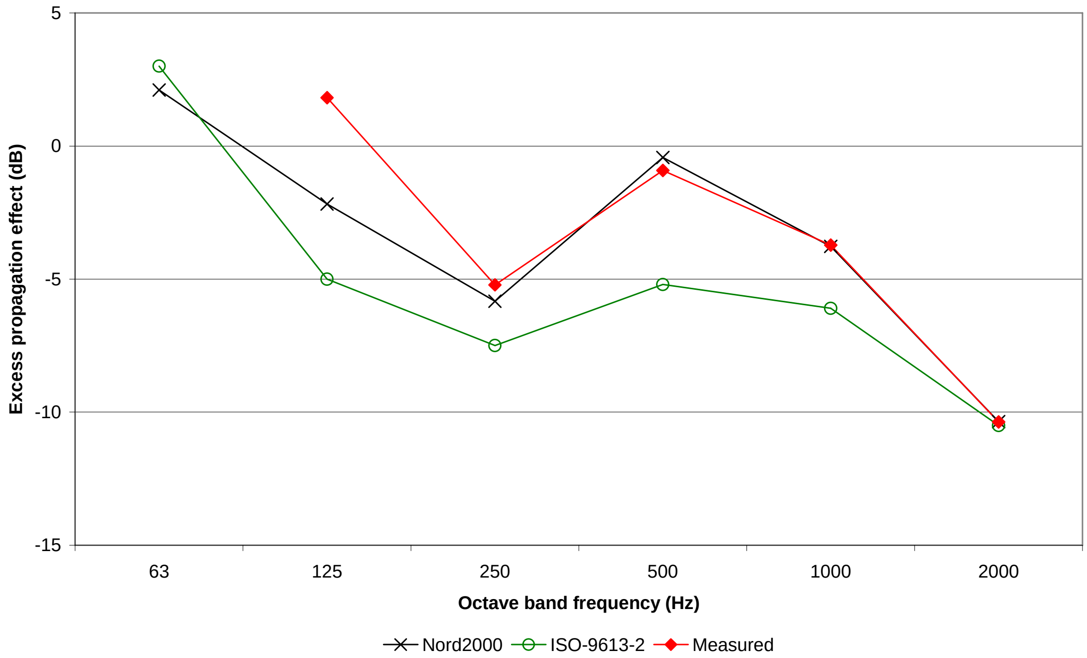

Figure 17
Measured (♦ red), predicted by ISO-9613-2 (○ green), and predicted by Nord2000 (X black) excess propagation effect. Downwind, distance 1500 m, source height 50 m, and receiver height 2 m.

6.4.6 Results from wind farm validation

Measurements have been made at 3 positions downwind from a wind farm with around 70 wind turbines in flat terrain. Meteorology data is received from the meteorology mast at the wind farm. The wind speeds were measured at several heights, the temperature and pressure were measured at one height. Detailed information on the terrain was available as elevations lines in digital format. The ground conditions were a mix of soft ground, rocks and water.

The size of the wind farm was 4.5 times 4 km and the measurement positions were 4 km, 3 km and 2.5 km from the nearest wind turbine. Measurement position 1 and 2 are lying in the same direction at different distances while position 3 is in another direction. Noise predictions are made with Nord2000 for conditions corresponding to the measurement situation. Noise emission measurements were made on 2 of the wind turbines at the site according to IEC 61400-11 and these data are used in the noise predictions. The results are shown in Figure 18 to Figure 20. There is a good agreement at the lower frequencies, but at higher frequencies the background noise is dominating. Above 1 kHz only background noise is present in the measurements.

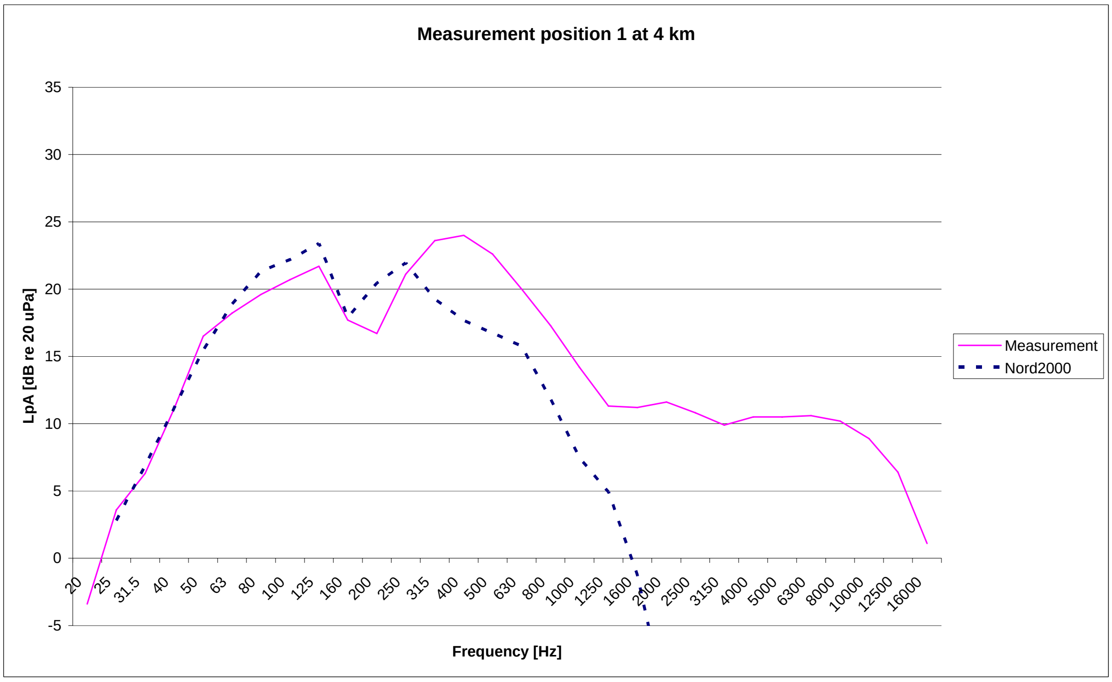

Figure 18
Downwind propagation from a wind farm. 4 km, receiver height 1.8 m.

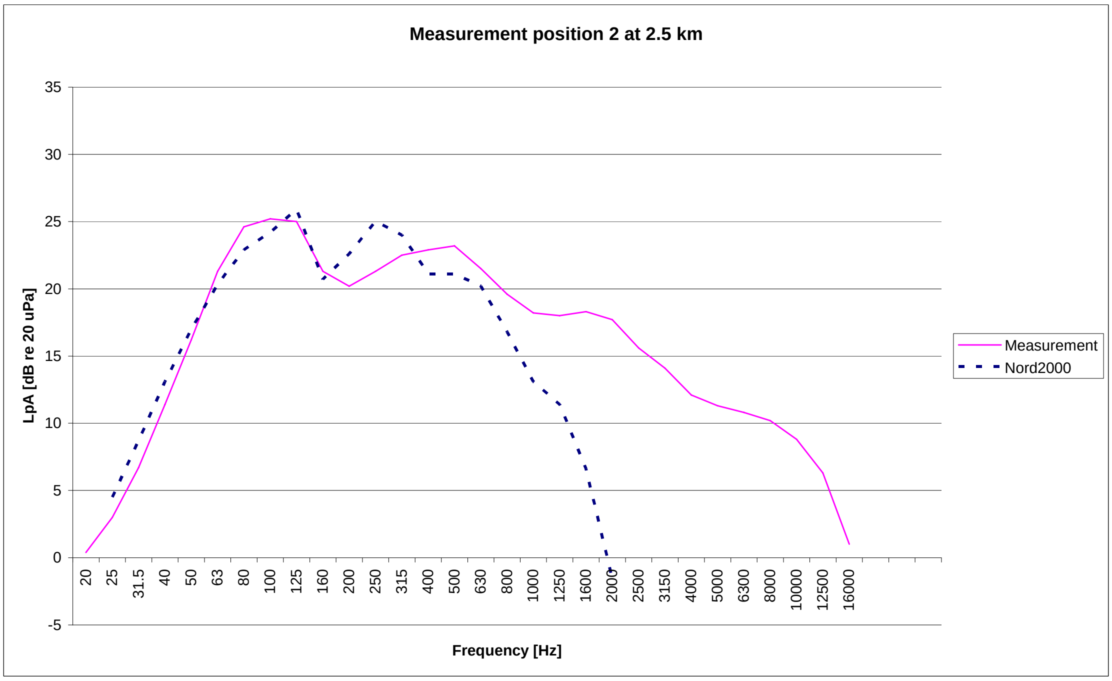

Figure 19
Downwind propagation from a wind farm, 2.5 km, receiver height 1.8 m.

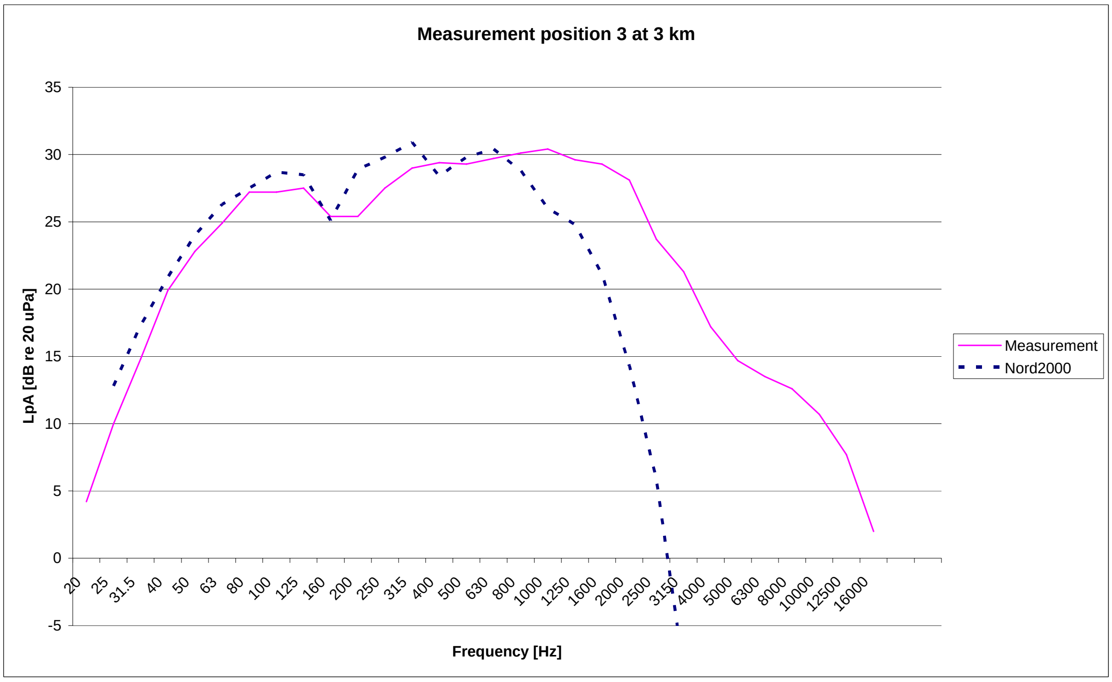

Figure 20
Downwind propagation from a wind farm, 3 km, receiver height 1.8 m.

6.5 Conclusion on validation

The validation measurements for downwind propagation from a loudspeaker over flat grass-covered ground show a fine agreement between measurements and predictions by the Nord2000 method in the considered range of propagation distances (up to 1500 m). The average difference in A-weighted levels is 0.1 dB with a standard deviation of 0.7 dB which is very fine. Also, the agreement between measured and predicted spectra is good.

The validation measurements for upwind propagation from a loudspeaker over flat grass-covered ground show a less good but still acceptable agreement between measurements and predictions by the Nord2000 method considering the well-known problem of making accurate prediction in long-distance upwind cases. On average the predicted A-weighted noise levels are 4 dB higher than the measured levels with standard deviation of 1.9 dB. In principle, the Nord2000 method could be adjusted to give a better fit to the validation measurements but it would be dubious to change the method based on only one experiment. Furthermore, noise levels in an acoustical shadow zone caused by upwind are in general low and very unstable. Therefore, it is can be considered an advantage that the shadow zone effect predictions are conservative.

The validation measurements for downwind and upwind propagation from a loudspeaker over non-flat terrain show that predictions by Nord2000 are producing A-weighted noise levels which on average are within 0.5 dB of the measured values with a standard deviation of 1.9 dB. This is considered a good agreement taking into account the complexity of the terrain and the meteorological conditions. In downwind pos. 3 at a distance of approx. 1000 m the measured spectra show attenuation at high frequencies which most likely is to the result of an moderate acoustical shadow zone normally seen during upwind propagation. The most likely explanation is that the effect is caused by a wind speed-up effect over the hill-shaped terrain. This is supported by the wind speed measurements showing a lower wind speed at the height 70 m than at 10 m and 29 m. This complex situation is predicted well with Nord2000.

The validation measurements with a wind turbine as a source show good agreement with Nord2000 predictions as well. On the average the A-weighted levels are within 1 dB with a standard deviation of 2.3 dB. The spectra for the excess propagation effect are not showing the same agreement as for the loud speaker measurements. This can in part be due to measurement distance for the sound power level which is considerably larger than for the loudspeaker measurements, the lower noise emission of the wind turbine making intermittent background noise a parameter and possibly the fact that the source may in reality be a distributed source rather than a point source. It was tested whether a distributed source would give better agreement in the predictions but no significant change was seen in the results.

For the wind farm measurement a good agreement was seen for spectra as well as for the A-weighted levels. This validation is slightly different from the other parts as the results are given as noise levels rather than the excess propagation effect.

Generally the conclusion on validation is that for the tested situations Nord2000 shows a fine agreement with noise measurements for simple flat terrain with simple meteorology and for complex terrain with complex meteorology. When compared to ISO 9613-2 the Nord2000 model is an improvement especially for the complex situations.

7. Noise and energy optimization

The noise and energy optimization part of the project includes the use of WindPRO for optimization and Nord2000 for the noise predictions. WindPRO is already a fully integrated software package with a series of features while the Nord2000 model exists only in few implementations of which none is very well suited for use on wind farms.

At DELTA a stand-alone program has been developed for wind turbine noise predictions according to Nord2000. In work with the prototype it was decided not to reprogram or otherwise to integrate Nord2000 into WindPRO but create an interface between the two programs.

7.1 Design concept

Nord2000 is inferred as a separate module in WindPRO and is started by running the Nord2000 calculation from the main menu of WindPRO. It requires a Nord2000 program provided by DELTA and delivered together with WindPRO 2.7, similar to the way the Risø software WAsP is called by WindPRO. This means that all access to Nord2000 predictions is through WindPRO using all the well-known features for setting up the geometry for a wind farm and using the catalogue of wind turbines already implemented. This should make the use of Nord2000 predictions in planning easier for experienced users of WindPRO.

There are three fundamental calculation types in the Nord2000 module:

- Point calculation, meaning a calculation for one specific climatic and terrain condition.
- Speed/direction analysis, which calculates a range of wind speed and wind directions for one climatic situation.
- Aggregated, in which calculations are made through a time period for which statistics can be made.

Nord2000 calculates the noise propagation for specific climatic and terrain situations, which makes it possible to calculate rather precisely, but also means that the result will only be valid for those specific situations. If national codes require a specific meteorological situation it is possible to set the parameters accordingly in which case the result can be compared to results from the models used by national codes.

Details on the parts of WindPRO that are changed to be able to handle the extra information on meteorology, terrain etc. are shown in annex A.

7.1.1 Data communication

As the Nord2000 model is running outside WindPRO, data exchange between the two programs had to be established. It was decided to handle the data exchange in xml-file format as this format can be read in a text editor and the different parameters can be identified by a header making it easy to check and change the structure in the development phase.

All the necessary data for every noise calculation in Nord2000 are prepared in WindPRO and communicated to the Nord2000 program through this xml-file format.

7.1.2 Optimization

Existing optimization algorithms in WindPRO are focused on finding the most optimum positions of a wind turbine with respect to energy production. It was found that including noise criteria in the optimization is very time consuming and thus found unrealistic at the moment.

Within the project a tool for optimization is developed which for a given layout (e.g. production optimized) can optimize according to the noise criteria.

The principle in this optimization is, that the wind turbines contributing the most are reduced in operation (and noise) until the noise criteria are met. If this does not solve the problem the most noisy wind turbine is removed and the process starts over again.

If a given site has some predominant meteorological conditions (like a dominant wind direction) this procedure can be applied for the different meteorological conditions and result in a wind farm where all the wind turbines are operated at optimum production most of the time and for certain meteorological conditions some of the wind turbines are operated in a reduced mode.

The Nord2000 model can predict these meteorological situations with low noise impact in the surroundings.

7.2 Prediction of long term noise levels

A major benefit of the Nord2000 model is that it is possible to predict long term noise levels like annual average of L_{Aeq} and L_{den}, statistical distributions of the noise and maximum and minimum levels. Depending on the available meteorological data these parameters can be given as a function of wind directions, month of the year or time of day.

When predicting long-term noise levels the weather conditions are divided into a number of meteorological classes. Each weather class covers a variety of meteorological conditions with almost the same sound propagation. The method used for calculating long-term noise levels is a European method proposed in [8] and later adopted by the Nordic countries [9]. Each class is defined by A and B in the log-lin sound speed profile (5 values of A and B symmetrically distributed around A=0 and B=0). If the occurrence p_i of each meteo-class is known together with the average air temperature t_i and relative humidity RH_i the long-term noise level can be predicted according to eq. (3), where L_i is noise level in the meteo-class i.

$$L_{long-term} = 10\log\left(\sum_{i=1}^{25} p_i\, 10^{L_i/10}\right) \quad (3)$$

The statistical weights p_i and average temperature t_i and relative humidity RH_i needed for the calculation according to eq. (3) are obtained from normal weather statistics as described in [8] or [9]. For each observation at a synoptic weather station (typically for each hour) the meteorological class given by A and B are determined on basis on wind speed and direction at 10 m and cloud cover in octas and time of the day (day/night). This statistics are obtained for the period of interest (e.g. one year or ten years). Statistics shall be determined each direction of propagation (in 10° intervals according to [8] or [9] but for wind turbines data are typically available in 30° sectors).

The experience from creating statistics for calculations of the yearly average noise level L_{den} is that there are no occurrences in almost half of the 25 meteorological classes at selected weather stations in the Nordic countries. Furthermore, in few classes the percentage is so small that it can be moved to a neighbouring class. In practice the number of classes is therefore no more than 9-10 classes which means that the calculation time can be substantially reduced compared to doing a calculation for each hour in e.g. a one year period.

8. Reporting and publishing

During the project period a total of 4 reference group meetings with participation of representatives from the project partners, Energinet.dk, the funding companies and the Danish Energy Agency have been held. At these meetings results have been presented and important feedback has been received for the remaining work.

8.1 Publications and presentations

The project and the results of the project have been presented at various conferences and seminars in connection with other wind turbine noise issues or as results from the project alone.

The following presentations include project and/or project results.

- Implementation of the Nord2000 model for wind turbines: New possibilities for calculating noise impact
  Thomas Sørensen, EMD et.al.
  Paper at Wind Turbine Noise 2009 in Aalborg; 2009.
- Prediction of noise from wind farms with Nord2000. Part 1
  Bo Søndergaard, Birger Plovsing, DELTA
  Paper at Wind Turbine Noise 2009 in Aalborg; 2009.
- Prediction of noise from wind farms with Nord2000. Part 2
  Birger Plovsing and Bo Søndergaard, DELTA
  Paper at Wind Turbine Noise 2009 in Aalborg; 2009.
- Poster presentation of the Nord2000 project at the European Wind Energy Conference & Exhibition; EWEC 2008 in Brussels.
- 58th IEA Topical Expert Meeting “Noise Prediction Models and Validation” Stockholm 2009. Presentation.

Furthermore DELTA has been asked to write an article to Noise and Control Engineering Journal based on the presentation made at WTN 09 in Aalborg.

9. References

[1] B. Plovsing and J. Kragh, *Nord2000. Validation of the Propagation Model* DELTA Acoustics and Electronics. Report AV1117/06, 2006.

[2] J. Kragh, B. Plovsing, S. Å. Storeheier, G. Taraldsen, H. G. Jonasson: *Nordic Environmental Noise Prediction Methods, Nord2000 Summary Report. General Nordic Sound Propagation Model and Applications in Source-Related Prediction Methods,* DELTA Acoustics & Vibration Report AV 1719/01, 2002.

[3] B. Plovsing and J. Kragh, *Nord2000. Comprehensive Outdoor Sound Propapagtion Model. Part 1: Propagation in an Atmosphere without Significant Refraction,* DELTA Acoustics & Vibration, Report AV 1849/00, 2001.

[4] B. Plovsing and J. Kragh, *Nord2000. Comprehensive Outdoor Sound Propapagtion Model. Part 2: Propagation in an Atmosphere with Refraction,* DELTA Acoustics & Vibration, Report AV 1851/00, 2001.

[5] B. Plovsing, *Proposal for a Nordtest Method: Nord2000 – Prediction of Outdoor Sound Propagation*, DELTA Acoustics Report AV 1106/07, 2007.

[6] B. Søndergaard, Plovsing B. *Noise and Energy Optimization of wind farms - Validation of Nord2000,* DELTA Acoustics Report AV 1236/09, 2009.

[7] IEC 61400-11:2002 edition 2.1 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques.

[8] R. Nota, R. Barelds and D. van Maercke: *Harmonoise WP3 Engineering method for road traffic and railway noise after validation and fine-tuning*, Technical Report HAR32TR-040922-DGMR20 (2005).

[9] R. Eurasto: *NORD2000 for road traffic noise prediction. Weather classes and statistics*, Research Report VTT-R-02530-06 (2006).

Annex A -WindPRO 2.7 – Nord2000 beta version

Thomas Sørensen, EMD International A/S, 20/7-2009

Contents

A1. Introduction

This is a brief explanation of the WindPRO 2.7 – Nord2000 beta version, which is sent out to the group associated with the Nord2000 project July 2009. It is not a complete manual. The interface is likely to be modified and there will be changes in the future to a number of the calculation routines. However the basic elements will not be changes unless serious unexpected issues occur.

A2. WindPRO 2.7 access

The version of 2.7 in which the Nord2000 is implemented is close to the beta release for external testing. It is therefore not recommended to do general calculations in this version. For that we advice using version 2.6. For that reason only a few modules are unlocked for the Nord2000 beta tester. Beside the Nord2000 module itself, it is the Meteo, Park, Resource and WAsP interface module as these are called or required by the Nord2000 module. The new features of these modules are not explained by this text. In order to register the 2.7 version use the .erf file you received by email or contact EMD.

A3. Overall structure

Nord2000 is a module in itself and is started by running the Nord2000 calculation from the main menu. It requires a Nord2000 .dll provided by Delta and delivered together with WindPRO 2.7, a bit like WAsP is called by WindPRO.

There are three fundamental calculation types in the Nord2000 module:

- Point calculation, meaning a calculation for one specific climatic and terrain condition.
- Speed/direction analysis, which calculates a range of wind speed and wind directions for one climatic situation.
- Aggregated, in which calculations are made through a time period for which statistics can be made.

Nord2000 calculates the noise propagation for a very specific climatic and terrain situation, which makes it possible to calculate rather precisely, but also means that the result will only be valid for those specific situations. If national codes require a specific meteorological situation it can be recommended to set those parameters in which case the result can be compared to results from the models used by national codes.

A4. Limitations in the current version of WindPRO 2.7 - Nord2000

As the version is only a beta version a number of known issues are as yet unresolved causing some limitations of the model.

A4.1. Shear issues

The current version does not adjust the source noise level for shear. This means that the IEC shear of 0.05 m (roughness class 1.5) is assumed. Similarly this shear is not adjusted for meteorological stability meaning that while the propagation model take the shear into account, the transformation of wind speed between two heights for the source noise level is assuming neutral stratification.

In practice this means that a calculation based on wind speed at 10 m height will simply look up the source noise level from the wind turbine catalogue and use that, irrespective of local shear and stability.

It is possible to bypass this problem by using wind speed at hub height. Then the source noise level will be looked up in the catalogue data at hub height. If the wind speed at hub height is found individual for each turbine using WAsP model then the transformation of wind conditions around the site is based on neutral stratification, which if the reference height is near hub height may have very little influence, but may have major influence if reference height is low (eg. 10 m). Most national codes assume neutral stratification.

A4.2. Aggregation model issues

The aggregation model is based on 25 climate classes. As wind direction is a component in defining the climate class the various turbines in a wind farm may have different climate class and therefore different damping. We are aware that there is an error in transferring the climate class between turbines and recommend not to use the aggregation model.

The report output of the aggregated model is as yet incomplete.

A5. Background data for the calculation

A5.1. Source noise data

In the turbine catalogue the turbines can now be equipped with a tabulated noise curve at hub height. It is arranged as a separate tab next to a normal 10 m tab (Figure 21).

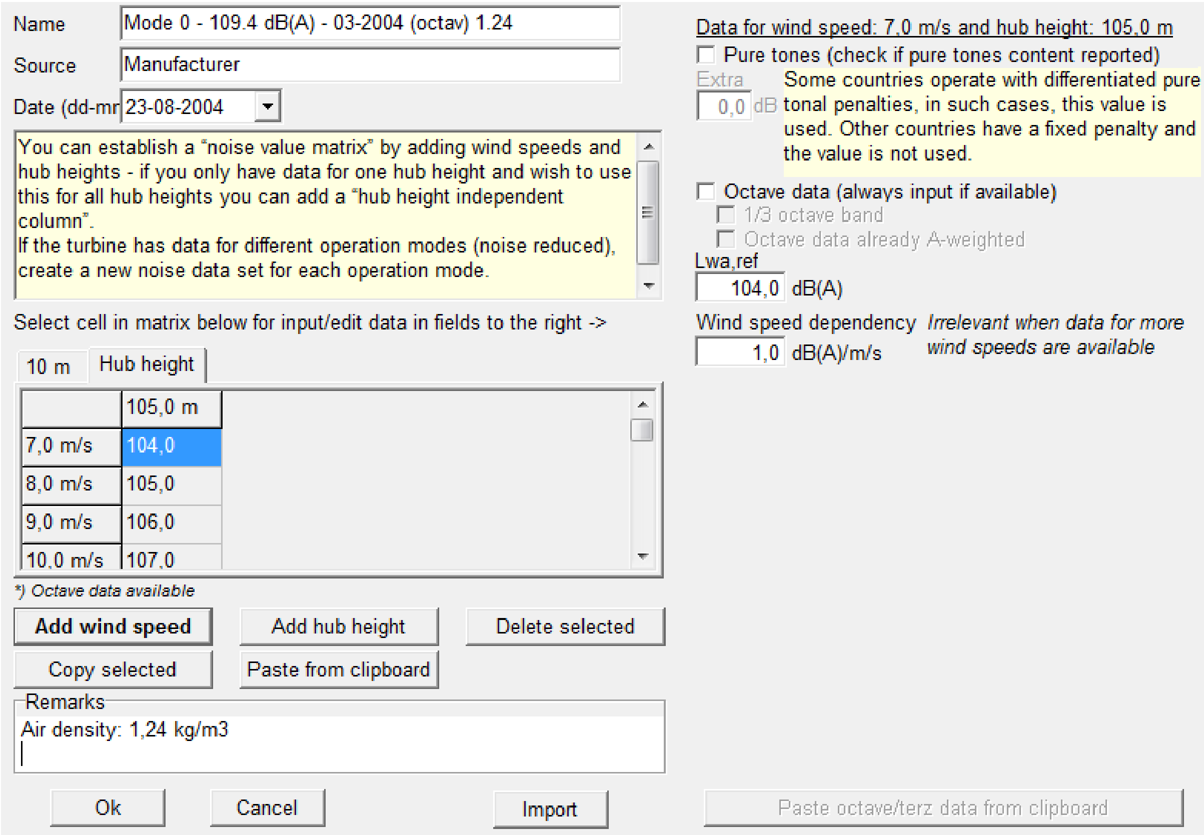

Figure 21
A noise curve at hub height can be inserted as a separate tab in the turbine catalogue.

A5.2. Area object data

Area types in the area object now have a new Nord2000 property. If Nord2000 is selected as purpose then the area types will get a terrain type property where terrain hardness can be selected as function of month. The hardness values are translated into terrain types, so that a qualitative assessment is possible.

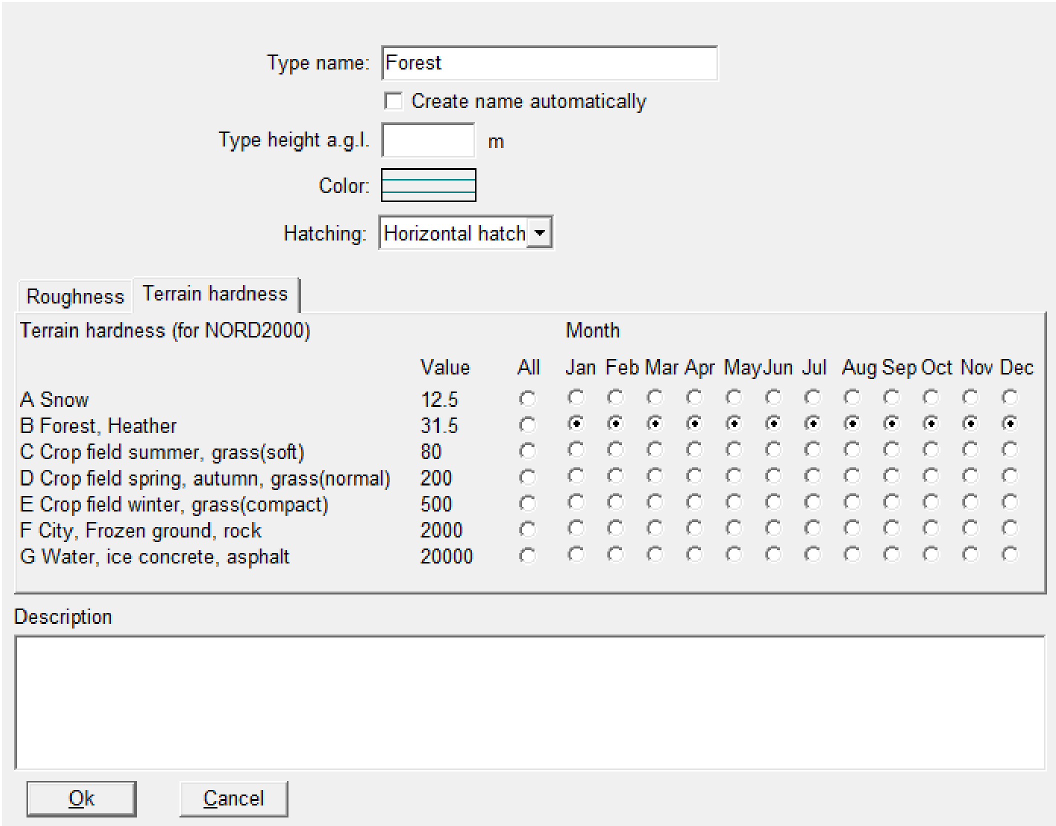

Figure 22
New area type property: terrain hardness.

A general 2.7 feature is that background properties have been moved to the Area types tab and are given properties similarly to the other area types.

A5.3. Meteo data

In the Meteo object it is now possible to define columns with Cloud cover (in 1/8's) and relative humidity. A time series with mean wind speed, wind direction, cloud cover, relative humidity and temperature is required for the Aggregated calculation.

A6. Point calculation

The purpose of a point calculation is to calculate the noise impact for a very specific situation at the receptors defined as NSA as in a normal Decibel calculation.

A6.1. Main

In the Main tab Point is selected.

A6.2. WTGs

The WTGs tab, like elsewhere in WindPRO selects the turbines for the calculation.

A6.3. Noise sensitive areas

The noise sensitive areas are selected as in a normal Decibel calculation.

A6.4. Terrain

The terrain used for the noise propagation model is defined in this tab.

For elevation data a fixed base height or elevations from a line object can be selected.

The roughness can be defined as roughness length or roughness class or it can be read from an area or a line object

Terrain type hardness can be selected as uniform for the entire site or defined by an area object. By selecting a date the relevant hardness is selected if differentiated by month.

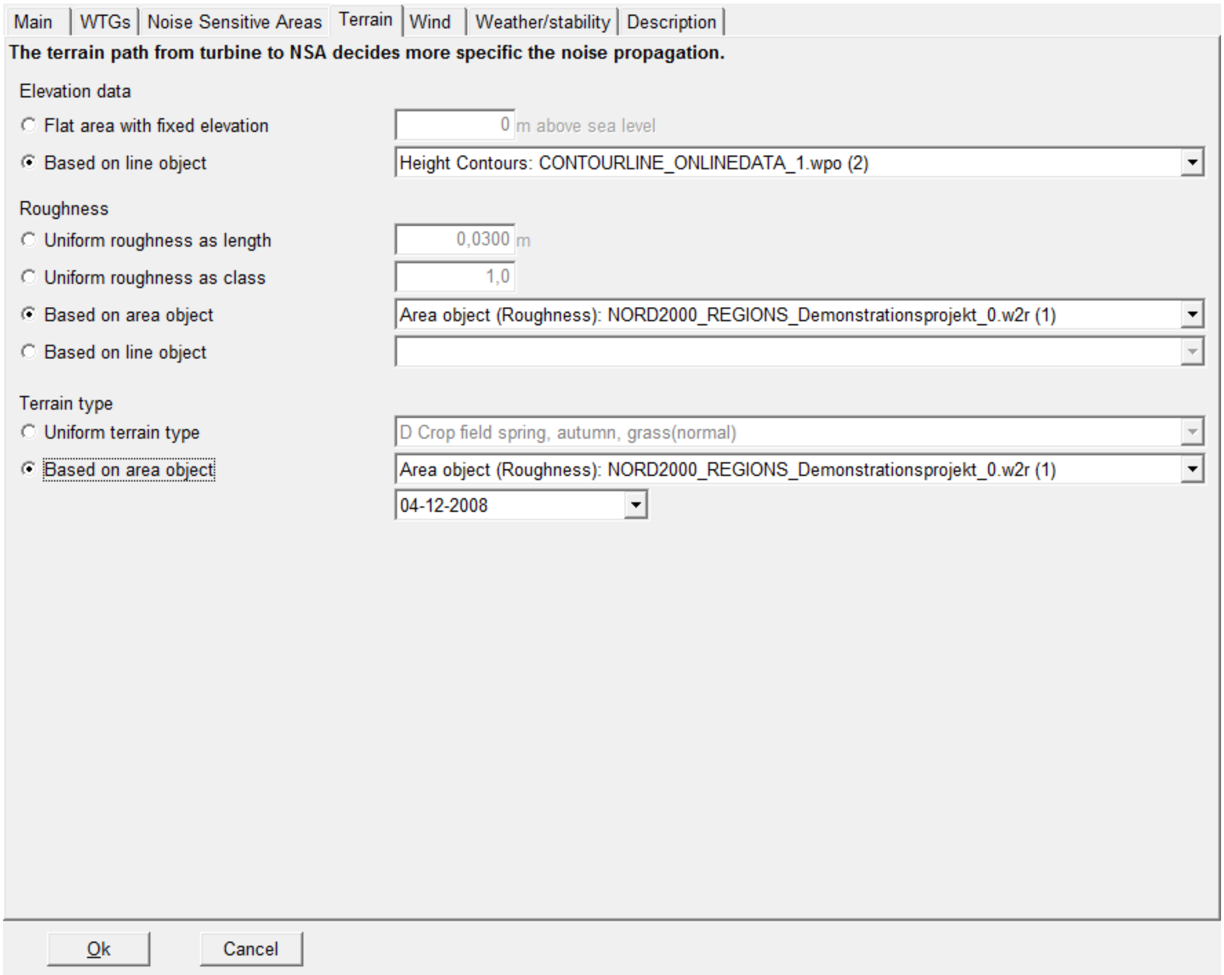

Figure 23
Terrain definition for the Nord2000 calculation. In this example all data are defined by line and area objects.

A6.5. Wind

There are mainly three ways to define the wind speeds at the wind turbines and thus the source noise level.

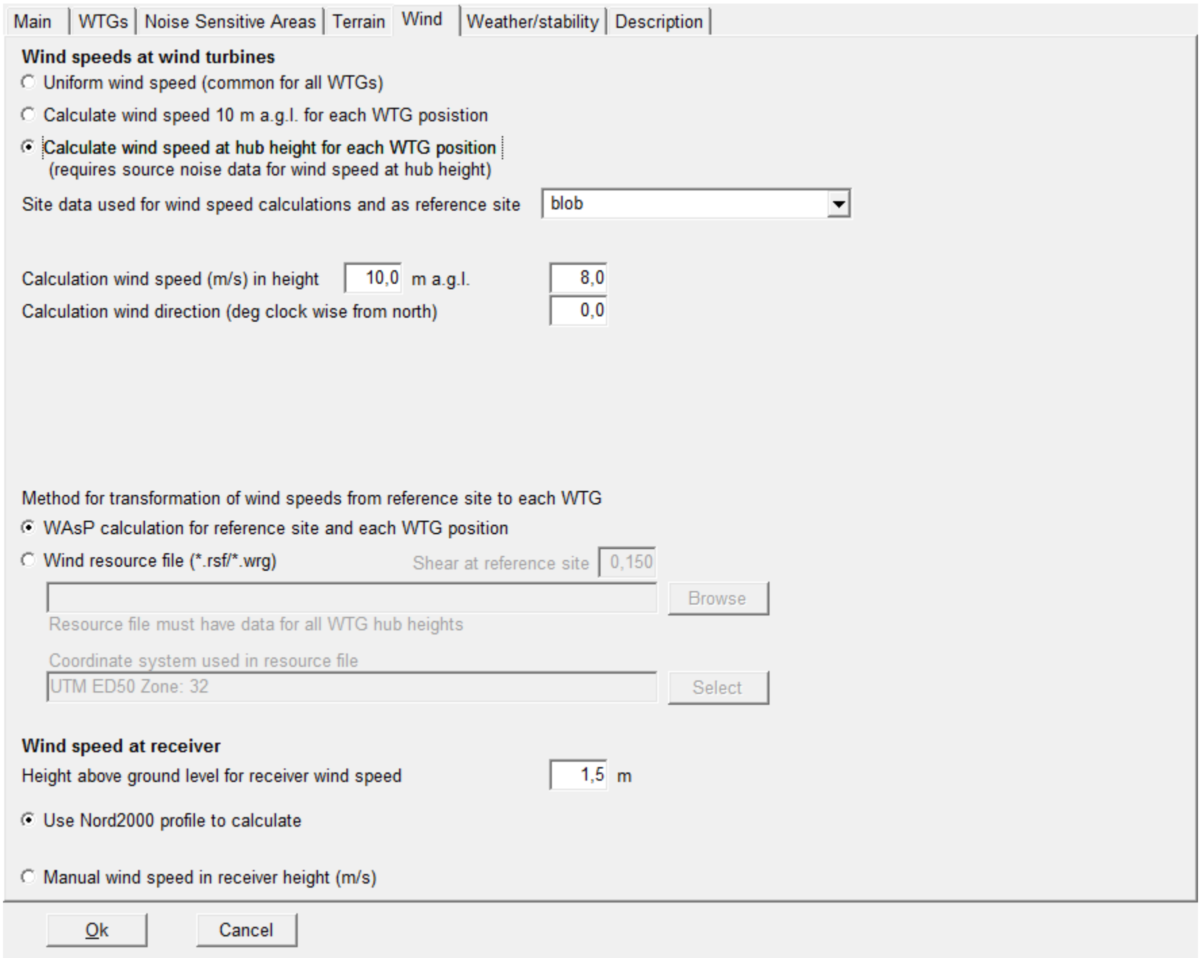

Figure 24
The selection of the wind model to find the source noise level for the WTG's.

A6.5.1. Uniform wind speed

This means that all wind turbines will have the same wind speed. This wind speed can be defined for either 10 m above ground level or hub height. The wind speed and the wind direction (where the wind is coming from) must then be defined.

The source noise level is looked up in the wind turbine catalogue and requires that noise levels for the selected wind speeds are available. Preferably as octave band data, though WindPRO can fit an octave band distribution based on other wind speed noise data or simply use a default distribution fitted to the stated noise level as in the regular Decibel calculation.

Note that the shear information on the weather/stability tab is currently not used to revise the source noise level.

A6.5.2. Calculate wind speed at 10 m a.g.l. for each WTG position

Selecting this means that the source noise level is still 10 m height, but calculated individually from turbine to turbine. This requires that a reference location is defined for example the first turbine or the location of a specific receptor where the wind speed is defined. The reference location is defined by a site data object.

The model used to calculate the wind speed at each turbine location is either a standard WAsP model as defined through the selected Site data object, or a wind resource map that can be created by WAsP or a CFD model.

A6.5.3. Calculate wind speed at hub height for each WTG position

This works exactly like the 10 m option except that it is the hub height wind speed which is being calculated. This requires a source noise curve at hub height for the turbines.

Again a reference point and height is defined by the location of a Site data object and the stated height. If for example 10 m is selected the model will use the terrain information to calculate the wind speed at hub height, but this will only be for the neutral atmosphere. If wind speed at hub height is selected the calculation is less sensitive to stratification.

If a resource map is used the resource map must be calculated for both reference height and every hub height or a common shear value must be defined, which is then used to extrapolate the wind speed.

A6.5.4. Wind speed at receiver

The Nord2000 model requires a wind speed and height above ground level for the receivers. This is usually a very low height, so low that it is outside valid operation range of the WAsP model. Instead a fixed wind speed can be used or the Nord2000 profile defined on the next tab can be used to extrapolate the wind speed down to the selected height.

A6.6. Weather/stability

The information in this tab is used to calculate the propagation of noise with the Nord2000 model.

The upper half is basic information while the lower half (if Show advanced options is checked) gives the advanced information. The quantitative impact on the qualitative stability settings in the upper part is shown in the lower part.

Relative humidity and temperature for the calculation situation is selected.

Stability can be set to either Day or Night and Clear or Clouded or overridden in the advanced settings.

Wind shear can be set manually or defined by a roughness class. These last shear values are adjusted by the stability parameters.

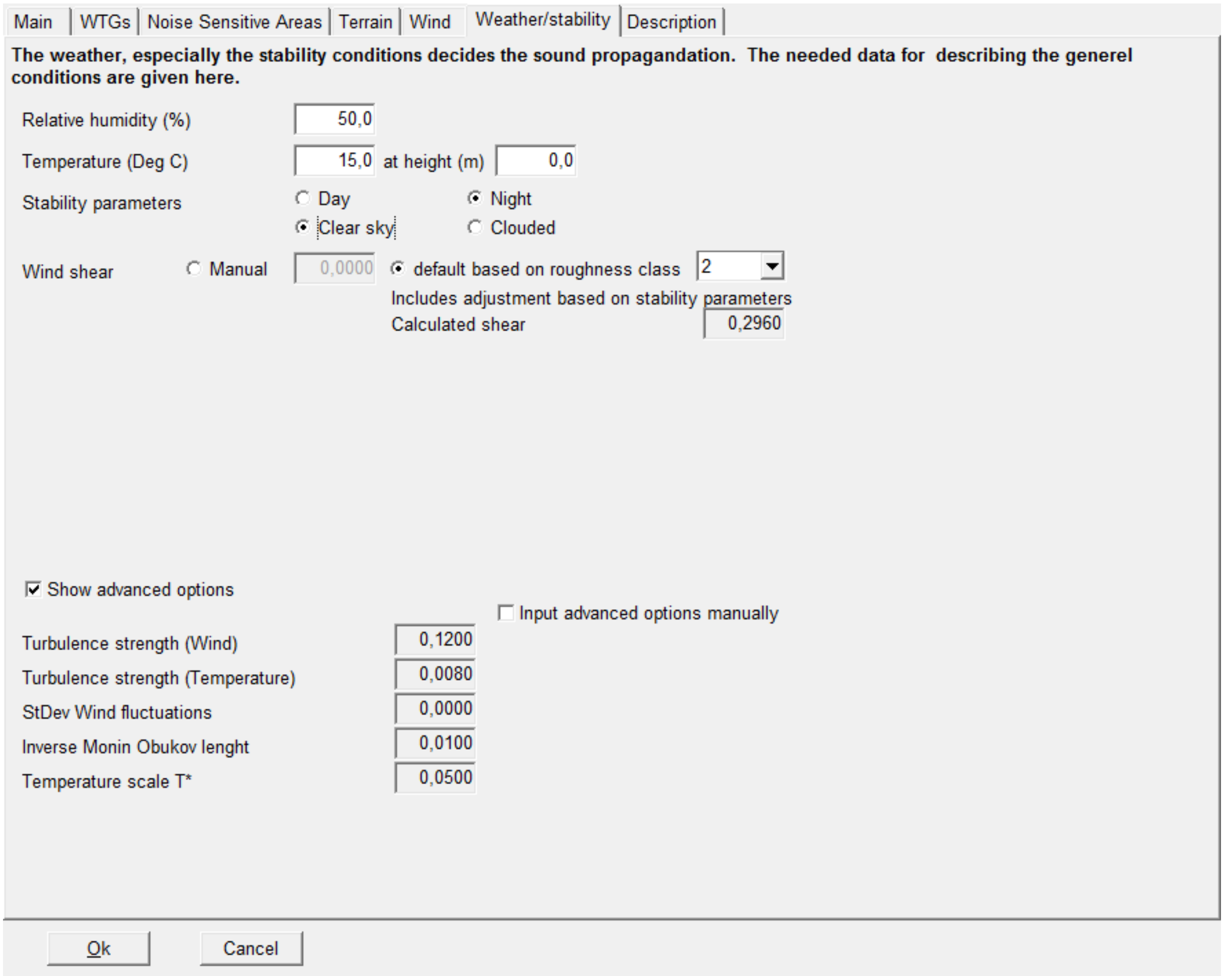

Figure 25
The Weather and stability tab defines the climatic conditions for the Nord2000 propagation model.

A7. Speed/Direction analysis

A7.1. Main

Selecting the Speed/Direction analysis allows the calculation of noise at a range of wind speeds and directions for a specific climatic situation.

A7.2. WTG's

Like the Point calculation.

A7.3. Noise sensitive areas

Like the Point calculation.

A7.4. Terrain

Like the Point calculation.

A7.5. Wind

Instead of just calculating for a specific wind speed and direction, a range of wind speeds and directions can be calculated. The interval is defined in From and To and the Step defines the step between values.

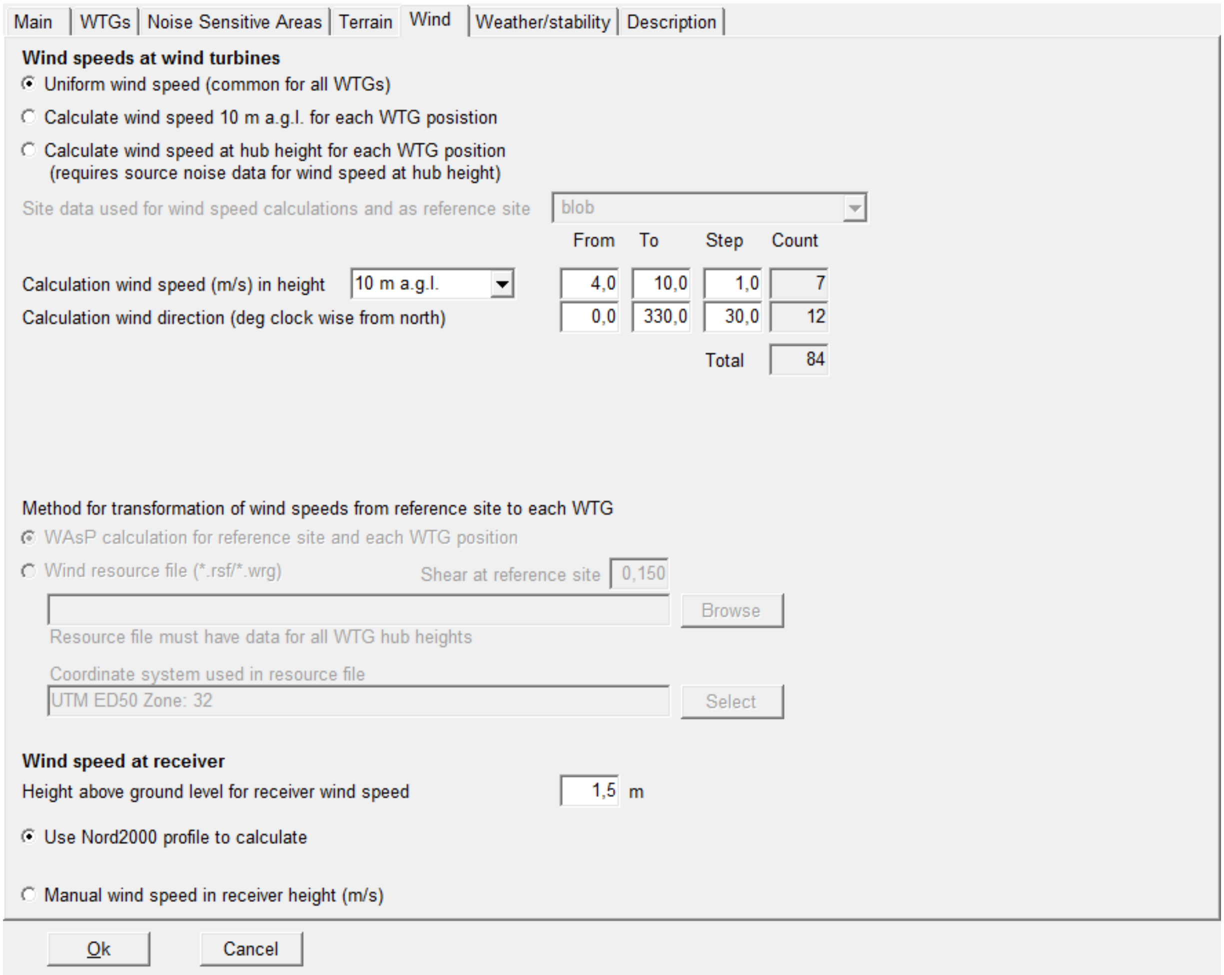

Figure 26
In a Speed/Direction analysis it is possible to define a calculation range.

A7.6. Weather/stability

Like the Point calculation.

A8. Aggregated calculation

A8.1. Main

By selecting the Aggregated option on the Main page a period is analyzed in order to obtain the noise variation over that time.

Please note that both the shear problem and the transfer of climate class problem render this calculation invalid for the moment.

A8.2. WTG's

Like the Point calculation.

A8.3. Noise sensitive areas

Like the Point calculation.

A8.4. Terrain

The date is only used if the data used in the calculation does not give information on the date and time (eg. a Weibull distribution).

A8.5. Wind

With the aggregated model the Wind tab works a bit different from the other two calculation modes.

Choosing Uniform wind speed means that all turbines will have the same wind speed, which is the wind speed recorded in the wind data assigned on the Weather/stability page. By selecting a wind speed height the wind data is transformed to this height using simple shear.

Calculate wind speed at 10 m height at each WTG position uses WAsP or a resource file to calculate the relation between the reference location and the turbine locations and transfers the data from the measurements out to these locations.

Calculate wind speed at hub height does the same but for hub height of the turbine locations.

The calculation wind speed height is used to describe the reference location, but the wind speed and direction are not used.

A8.6. Weather/stability

Two new components appear in the Weather/stability tab when choosing the Aggregated model.

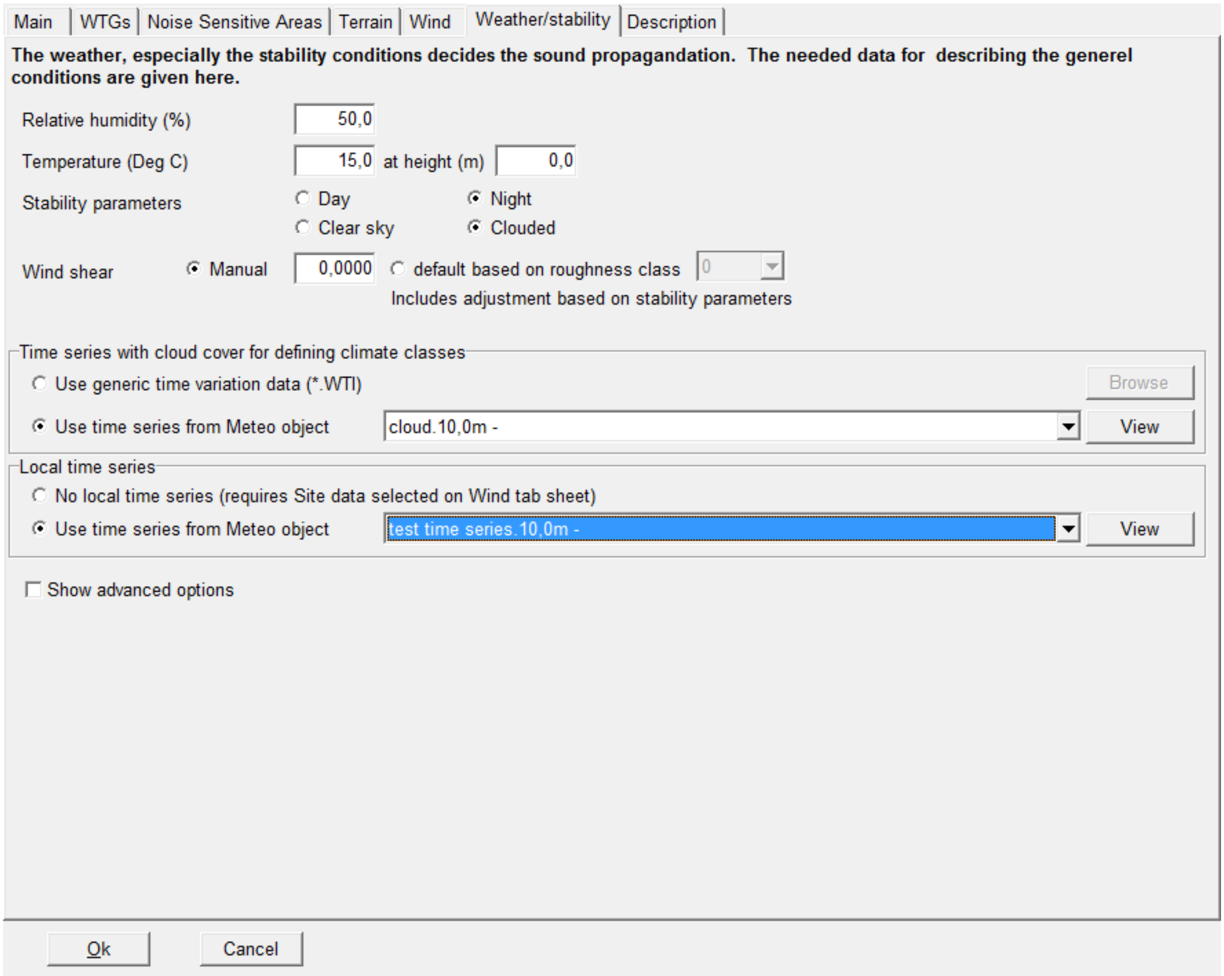

Figure 27
Two new selections appear on the Weather/stability tab when doing the aggregated calculation.

A8.6.1. Time series with cloud cover for defining climate classes

In the aggregated model the many possible climatic combinations are reduced to 25 climate classes so that for each receptor only 25 Nord2000 calculations need to be calculated (Sørensen et.al., 2009). The climatic classes are defined by a time series of climatic information. The time series must contain date, time, wind speed, wind direction, temperature, relative humidity and cloud coverage (in 1/8th). It is possible to link to a meteo object with this information (recommended) or load a time variation (.wti) file.

The location of the meteo object with climate data is unimportant. It may not even be necessary to have data near the site as the distribution of climatic conditions may be similar over a large region.

A8.6.2. Local time series

The local time series gives the wind distribution on site and is basically the data set which is used to find the distribution of noise impact from the turbines. It is therefore vital that the data are representative for the site.

The data can be a local meteo object on the site (recommended) with date, time, wind speed and wind direction. This can be used to create a matrix of noise output at different wind speed bins in hourly and monthly bins (Sørensen et.al., 2009).

Instead it is possible to use the site data object selected on the Wind tab and thus use a Weibull distribution. This will also give a distribution of noise impact binned with wind speed, but it is not possible to make the hour/monthly binning.

The climate class information overrules any settings for the various climatic parameters on the page, except if the .wti file is selected.

A9. Report

At the current stage the reports are not finalized, but does at this point contain the essential results.

A9.1. Point calculation report

The Point calculation report is the simplest of the reports. It is in generally similar to the standard Decibel calculation.

The first page gives the calculation settings followed by a list of terrain data files used and the turbines in the calculation. In the bottom is given a result for each receptor with the calculated noise level.

The last page gives the usual map.

A9.2. Speed/Direction report

The first page gives a summary of the results. First with a list of the maximum noise level for each turbine at each selected wind speed. This is followed by a complete list of results listing through all the selected directions for each wind speed and each receptor.

Calculation Results

Sound Level

Noise sensitive area No.	Name	UTM ED50 Zone: 32 East	North	Z [m]	Imission height [m]	Month	Hour	Wind speed [m/s]	Sound Level From WTGs [dB(A)]
A	Voldsted	550.801	6.288.685	65,0	1,5			4,0	41,2
A								5,0	46,0
A								6,0	49,8
A								7,0	52,7
A								8,0	53,7
A								9,0	51,4
A								10,0	50,6

Sound Level

Noise sensitive area No.	Name	UTM ED50 Zone: 32 East	North	Z [m]	Imission height [m]	Month	Hour	Wind speed [m/s]	Dir [°]	Sound Level From WTGs [dB(A)]
A	Voldsted	550.801	6.288.685	65,0	1,5			4,0	0,0	41,1
A								4,0	30,0	41,1
A								4,0	60,0	41,1
A								4,0	90,0	41,1
A								4,0	120,0	41,1
A								4,0	150,0	41,1
A								4,0	180,0	41,1
A								4,0	210,0	41,2
A								4,0	240,0	41,2
A								4,0	270,0	41,1
A								4,0	300,0	41,1
A								4,0	330,0	41,1
A								5,0	0,0	45,9
A								5,0	30,0	45,8

To be continued on next page...

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Figure 28
Calculation of a range of wind speed and direction. First a summary of maximum values, then the full list of results.

For each noise sensitive area is now created a detailed result with a matrix of wind speed and direction, a graphic showing noise impact as a function of wind direction and a radar diagram also showing noise impact as a function of direction.

NORD2000 - Speed/Directional analysis

Calculation: Copy of **NSA:** A - Voldsted

Direction	Wind speed						
	4,0	5,0	6,0	7,0	8,0	9,0	10,0
Degrees	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]
0	36,4	41,1	44,8	47,6	48,6	46,2	45,5
30	36,6	41,3	45,0	48,0	49,0	46,6	45,9
60	36,6	41,4	45,2	48,3	49,3	46,9	46,3
90	36,7	41,5	45,2	48,4	49,4	47,0	46,4
120	36,7	41,5	45,3	48,4	49,5	47,1	46,4
150	36,7	41,5	45,3	48,4	49,5	47,1	46,4
180	36,6	41,4	45,2	48,4	49,4	47,0	46,4
210	36,6	41,4	45,1	48,2	49,3	46,8	46,2
240	36,5	41,3	45,0	48,1	49,1	46,6	46,0
270	36,5	41,2	44,9	47,9	48,8	46,2	45,4
300	36,4	41,0	44,4	47,4	48,2	45,7	45,0
330	36,3	40,9	44,4	47,3	48,3	46,0	45,2

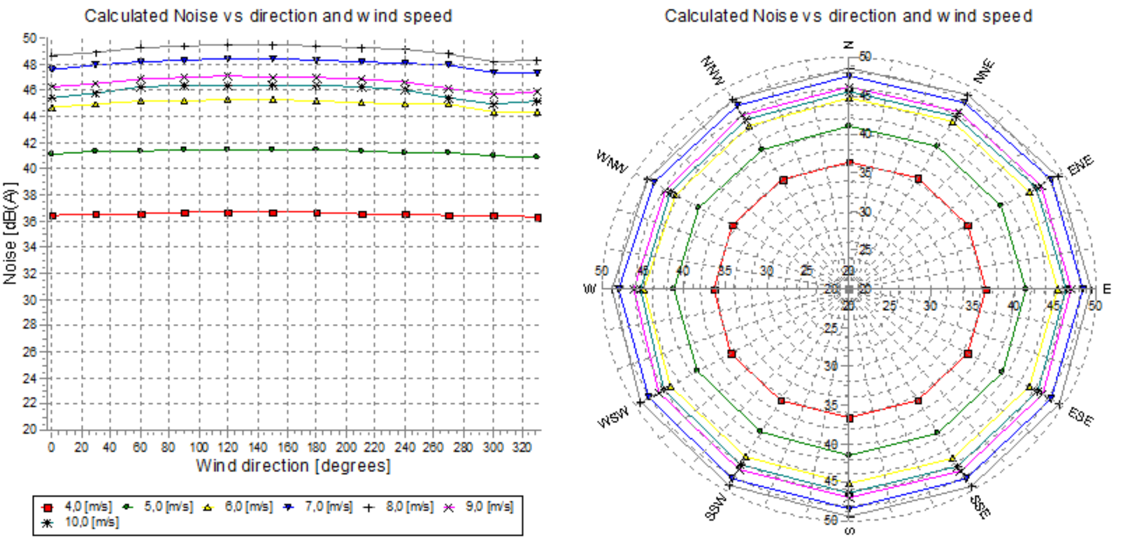

Figure 29
Detailed presentation of a speed and direction analysis.

A9.3. Aggregated report

During the calculation of the Aggregated calculation it is possible to dump the climatic class tables and the time series of noise impact results for further processing in spread sheet.

In the report setup of the aggregated calculation report the settings for the report must be selected. This is done in the Aggregated result tab of the Main result (see below figure). Here it is possible to select a template with pre-set settings (so far none are provided, but it is the intension that national codes should be selectable). With the save button in the bottom of the page it is possible to save the current settings as a template.

The wind speed for the presentation can be selected as:

- Specific wind speeds, where the wind speed bins to be displayed is specified using From, To and Step.
- A wind speed interval that gives one display of all data within this interval
- All data, which simply presents all the wind speeds registered in the selected time series.

The period of the day for the presentation can be selected as:

- All, meaning no specification of particular periods.
- Day - Night, separating the results into day and night, where the hours of day and night needs to be specified.
- Day – evening - night, as above but including evening as period. If this selection is chosen an L_{den} calculation is made including the relevant penalties for evening and night noise impact.
- Specific hours allow the selection of specific hours for analysis.

The period of months for the presentation can be selected as:

- All, meaning no specification of particular months.
- Seasons, where the four seasons of the year must be specified by their month number.
- Monthly, giving a result for each month.
- Specify allows the specification of particular months.

The parameters to be calculated in the report must be selected. A hatching in the Report column means that the parameter will be presented in the report, while the selected Critical parameter is the one used to test against the critical noise limit in the noise sensitive areas. Lx is in that respect special as it enables the calculation of the noise impact which is exceeded a specified percentage of the time. For example L_{10} means the noise level is exceeded 10 % of the time.

The graphical presentation can either be made as a frequency distribution or as a cumulative distribution.

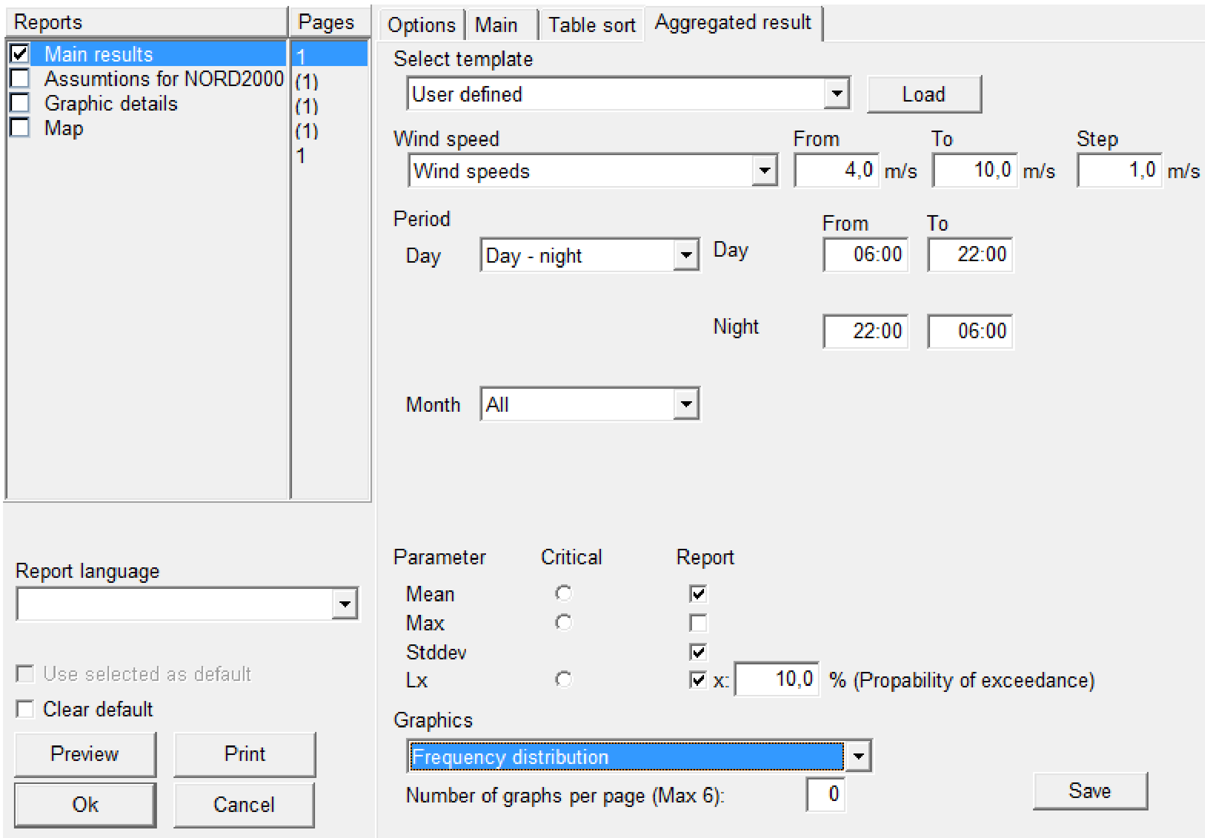

Figure 30
The selection of the Aggregated calculation result parameters in the report setup.

A9.3.1. Main Result

The main result page gives the summary of the noise impact calculation including the parameters selected in the report setup.

A9.3.2. Detailed result

Here the frequency table of the noise calculation is shown.

This feature is currently not enabled.