4. WindPRO Environment

4.0 ENVIRONMENT – Introduction and step-by-step guide

4.0.1 Introduction to Environmental Calculations

Environmental impact plays an increasing role in wind energy projects. With the continuing increase in project size, the environmental impact becomes a more and more decisive factor with regards to the siting of projects.

It is our intension to make it possible to calculate and document all the environmental requirements of a project using WindPRO, so that WindPRO can print the necessary documentation that the environmental authorities and neighbors might require.

Visual impact is described in a separate chapter.

4.0.2 Step-by-step guide to Environmental Calculations

- ❑ Establish a map and a proposed project (see Basis 2.0.5)
- ❑ Recommended: always establish an elevation model in line or elevation grid object – alternatively all objects must be assigned with a Z-value manually.
- ❑ Establish relevant objects; for DECIBEL: Noise-sensitive areas, for SHADOW: Shadow Receptors, for ZVI: Elevation data (Line or elevation grid object) and eventually Area Objects and WAsP obstacles objects.
- ❑ From the calculation menu, run DECIBEL, SHADOW or ZVI
- ❑ Print reports.

4.1. DECIBEL - Noise Calculations

4.1.0 Introduction to DECIBEL

DECIBEL is the name of the WindPRO program module, which calculates the noise emission and checks if the noise requirements are met at neighbors and noise-sensitive areas. It also checks if the required minimum distances from the nearest WTG to these areas are met (if this is a relevant design issue).

Furthermore, DECIBEL can calculate and plot noise level curves for the project to enable an assessment of which areas will be prevented from being used for noise-sensitive activities in the future.

One of the major advantages of WindPRO is, however, the possibility for graphic input of data concerning WTGs and noise-sensitive areas/points on a digital map directly on the screen.

Immission: Disturbing effect on the environment of emission; the arrival of pollution from a remote source of polluting substances, arriving at a target
The immission point in this text is typically called the receptor, the neighbor or the Noise-sensitive Area (NSA).

Emission: The release of substances or energy (e.g. noise, vibration, radiation, heat) into the environment from a source
The source in this text is typically the WTG.

4.1.1 The DECIBEL calculation methods

The calculation of the noise impact generated by one or more WTGs at a specific location (e.g. a neighbor) requires the following information:

- The positions of the WTGs (x, y, z coordinates).
- WTG hub height and noise emission ($L_{WA,ref}$) at one or more wind speeds, possibly at different frequencies.
- Any pure tone contents in the WTG noise.
- The coordinates for the noise-sensitive locations/areas.
- Maximum noise level accepted inside the noise-sensitive areas. Possibly with information about the ambient background noise.
- The required calculation model.

A number of different calculation models have been implemented in WindPRO. These models typically relate to the requirement in certain countries or regions and we advise that the user finds out which methods and requirements has to be met in the region of the site.

If none of the country-specific methods apply, it is possible that the general implementation of the ISO 9613-2 calculation standard can be set up to fit the requirements.

The choice of method decides what kind of input data is required.

4.1.1.1 The International standard DIN ISO 9613-2, general

The ISO 9613-2 "Attenuation of sound during propagation outdoors, Part 2. A general method of calculation" describes the calculation of damping of the noise during propagation outdoors. The theoretical background for the calculations can be found in the Appendix: Theoretical background for noise propagation models.

By choosing the general version of ISO 9613-2 the user has access to all the parameters available in WindPRO. Specific national codes available in WindPRO will restrict the choices to those relevant for the specific country as described in following chapters.

Options for the calculation
The general setup makes it possible to choose settings for a range of parameters. This makes it possible to fit it to local recommendations.

The options available are shown in the figure below.

Wind speed
Fixed wind speed: The calculation will be made for only one wind speed, selected in the field to the right.

Wind speed range: The calculation will be made for a range of wind speeds with start, end and increment selected in the fields to the right. WindPRO will require source noise data for the wind speeds selected, but can also assume values based on what is available for the turbine types selected for the calculation.

95% rated power: The calculation will be made with the noise value for the turbine for 95% of the rated power. If no such value is available the user will be prompted to input this.

95% rated power else fixed wind speed: As above, but WindPRO will itself choose a substitute noise value if no data for the 95% rated power is available. The wind speed for the substitute is selected in the field to the right. If there is no value for this wind speed either the user will be prompted for noise data.

Loudest up to 95% rated power: WindPRO will choose the highest noise level no matter the wind speed or the 95% rated power level.

Octave data required
Checking this box forces the calculation to use octave band distributions instead of the total noise value. Default is on. Octave band distributions are required if ground attenuation is selected as General. If ground attenuation is alternative the calculation can be based on either the octave band distribution or the total dB(A) source noise level of the turbines.

Spectral distribution
This allows a calculation result for each spectral band. The interval of frequencies will then have to be selected. This is used where critical noise limits are given specifically for each frequency. Default is off.

Ground Attenuation
None: No damping due to ground attenuation is used for the calculation. This approximates the very smooth surface offshore.

General: The damping of noise due to ground attenuation follows the general case described by the ISO 9613-2 code. The user is asked to select the general porosity of the ground with 0 being a hard surface and 1 being a porous surface. The default value is 1 but recent works suggest that 0 is a more appropriate value. However an individual assessment from site to site is normally needed. Octave-band source noise data for the turbines are required. If these data are not available WindPRO may suggest generic octave band distributions.
This method assumes flat terrain or terrain with a constant slope. If these conditions are not met, you are advised to use the Alternative method (see below) instead.
An interesting consequence of this method is that the ground attenuation becomes very sensitive to receiver height (height of immission point).

Alternative: The damping of noise due to ground attenuation follows the alternative case described by the ISO 9613-2 code. This method uses the orographic shape of the terrain to assess the ground attenuation by calculating the average vertical distance between line-of-sight between receptor and hub of the turbine and the terrain between the two points. A valley between the two points will cause a low attenuation whereas a hill will cause a high attenuation. If no orographic model (height contours) is given, the model assumes a terrain with a constant slope between the WTG and the NSA.
The model is valid for the case where:

- Only the A-weighted total noise level is available
- The sound predominantly spreads above porous ground
- The sound does not contain pure tones

Both methods are described further in the theoretical appendix.

Meteorological coefficient, C_0
A value for the meteorological coefficient between 0 and 5 can be selected. The meteorological coefficient is supposed to reflect damping due to special meteorological conditions (basically noise propagation in the upwind direction). EMD recommends setting this to 0 for most situations since noise is normally considered for the downwind situation.

Type of demand in calculation
WTG noise is compared to demand: The noise due to wind turbine noise only is compared to the critical demand assigned for each noise receptor. If the calculation covers several wind speeds the critical demand is either the fixed demand or a wind speed specific demand. This is the normal procedure in countries like Denmark, Germany and Sweden.

WTG plus ambient noise is compared to ambient noise plus margin: This is the scenario where the noise level at the receptors is the background noise plus the noise contribution from the turbines. This sum is compared to a noise demand that consists of the background noise plus a margin. The option is used in France among other places.

WTG noise is compared to ambient noise plus margin: Like the option above except that only the contribution from the wind turbines is considered and compared to the background noise plus the allowed margin. This option is used, for example in the UK and Australia.

Noise values in calculation
All vales are mean values (L_{WA}): This is the normal setting. Source data, background noise data and calculations are given in mean noise levels (L_{WA}).

All noise values are 90% exceedence values (L_{90}): With this special setting all noise values are considered L_{90} values. That is, the noise that will be exceeded 90% of the time. Background noise must then be entered as

L_{90} values. For the turbines the L_{WA} values will be used but 2dB will be deducted as a fair approximation of the L_{90} level. In the printouts L_{WA} is replaced by L_{90} values. This setting is used in the UK.

Pure tones
Pure and impulse tone penalty are added to WTG source noise: In case of pure tones the penalty is added to the source noise level of the turbines. The penalty is dependent on the codes used. For modern turbines pure tones is a rare phenomenon.

Pure tones penalty are added to the demand: With this option the pure tone penalty is subtracted from the critical demand of the report instead of added to the source noise of the wind turbines. The penalty can be specified in the field to the right.

Height of immission point above ground level
This allows the user to specify the calculation height for the receptor. Different codes have different recommendations for this calculation height. Typical values are 1, 4 and 5 m height above ground. If the "Allow override…" checkbox is checked, then the calculation height of the individual receptors (noise-sensitive areas) will override the model immission height, though only if a specific height is given for the NSA.

Deviation from "official" noise demands
This allows the user to introduce a special adjustment to the noise demand. If for instance the authorities require a 2dB margin to the noise demand to accommodate the uncertainty the user can set this parameter to -dB. In the printout it will then say that the demand is, for example, (45-2) = 43dB.

Air absorption
Each model in WindPRO come with their own standard settings for air absorption. Click this button to check which is selected for the model you are using. A standard set of data corresponding to 10 degree Celcius and 70% humidity is used as default.
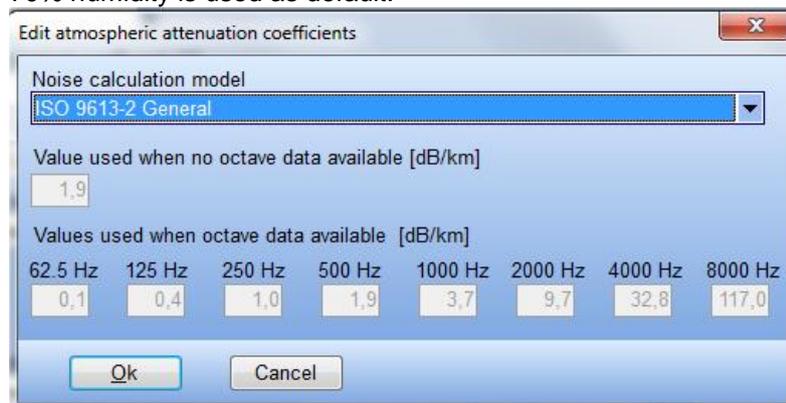
Alternative standard can be selected from the list including Custom values which allow user specific attenuation values. In case of the Alternative ground attenuation case calculations using total source noise level only is allowed. In that case the "Value used when no octave data available" value is used in the calculation.

4.1.1.2 ISO 9613-2 Germany

The ISO 9613-2 Germany calculation option is a special case of the general ISO 9613-2 code.

This option is set up to fit the usual settings used in Germany.

Calculation setup
In the figure below, the calculation setup is shown for ISO 9613-2 Germany. The fields with faded font are fixed and cannot be altered. As default they are not shown unless the "Show details" checkbox is checked. For detailed description of the fields please refer to the section on the General ISO 9613-2 codes

Wind speed
The source noise value is "Loudest up to 95% of rated power".

Ground attenuation
The alternative ground attenuation method is used.

Meteorological coefficient C_0
The meteorological coefficient can be set. The recommended maximum is 2dB.

Type of demand in calculation
Only the noise from the wind turbines is considered when compared to fixed critical demands at the receptors.

Noise value in calculation
All noise values are in L_{wa} units. This is average A-weighted noise pressure.

Pure tones
Pure tone and impulse penalties are added to the source noise values. The values come from the turbine catalogue and are typically 3 or 6dB.

Height of immission point above ground level
The height of the immission point at the receptor has been set to 5m as default, but can be changed by the user.

Deviation from official noise demand
This field is open to the user.

Octave data
Octave-band data are not required

Noise receptors

The critical noise level at the receptors must be given for each receptor. There are no requirements for background noise data.

The legal foundation for the noise problem in Germany originates from the "Bundesimmissionsschutzgesetz (BlmSchG)". The Ministry of Environment and Trade requires the buildings documented in proportion to the compatibility to environment and people according to the "TA-Lärm 1998" (Technical Guidance for Protection against Noise). The Ministry of Environmental Protection and partially The Ministries of Environment and Trade in the counties approve noise from buildings.

In the construction regulations (BauNVO, 1990) and the TA-Lärm, the construction surrounding types are decided according to a protection order with the following maximum values (at night):

- 35dB   Recreation / Exclusive residential areas
- 40dB   General residential areas
- 45dB   Rural villages, Mixed areas and Unzoned countryside areas
- 50dB   Enterprise zone

Usually the 45dB limit will apply in areas with WTG projects. The extent to which this limit is extended to includ pure tones will depend on the local authorities.

4.1.1.3 ISO 9613-2 UK

The ISO 9613-2 UK calculation option is a special case of the general ISO 9613-2 code.

This option is set up to fit the usual settings used in the UK as described by the ETSU-R-97 recommendations ("The Assessment & Rating of Noise from Wind Farms").

Calculation setup
In figure below shows the calculation setup for ISO 9613-2 UK. The fields with faded font are fixed and cannot be altered. As default they are not shown unless the "Show details" checkbox is checked. For detailed description of the fields please refer to the appendix on noise propagation models.

Wind speed
The source noise value for wind speeds between 4 and 12 m/s is used with an interval of 1 m/s. If these data are not available the user is asked for data.

Ground attenuation
The general ground attenuation method is used. A ground porosity figure must be provided by the user. In the UK a porosity of 0 is usually used.

Meteorological coefficient C_0
The meteorological coefficient can be set. The recommended maximum is 2dB.

Type of demand in calculation
The noise from the wind turbines is compared to the background noise at each individual receptor plus a margin. For recommended values on noise receptors, see below.

Noise value in calculation
All noise values are in L_{90} units. This is the noise level that will be exceeded 90% of the time. Background noise should be entered in this unit. For the turbine source noise values the conversion from L_{wa} to L_{90} is done by deducting 2dB.

Pure tones
Pure tone and impulse penalties are added to the source noise values. The values come from the turbine catalogue and are typically 3 or 5 dB.

Height of immission point above ground level
The height of the immission point at the receptor has been set to 4m.

Deviation from official noise demand
This field is open to the user.

Octave data

Octave-band data are required. If they are not available in the turbine catalogue the user is asked for data when starting the calculation.

Noise receptors

Background noise data must be entered for each wind speed from 4 to 12 m/s in L_{90} units. A margin must be set up for the noise level from the wind turbines. The standard day and night figure is 5dB. The British rules (ETSU-R-97) also defined a fixed lower limit noise from the turbines at L_{90} =35-40 dB (day time) and L_{90}=43 dB (night time) for dwellings with no financial involvement in the project. Dwellings with a defined financial involvement have a limit of 45dB, day and night. In other words, any noise level from the wind farm below these values across the wind speed range stated will be accepted. The lower fixed limit is set up in the noise receptor object, in the field "value always accepted"

4.1.1.4 ISO 9613-2 France

The French noise codes do not require a specific noise propagation model for wind turbine noise. Instead the propagation model is expected to calculate the correct noise level and provide specific result parameters. The ISO 9613-2 propagation model can be used and by selecting the special French version some parameters will be fixed in accordance with the French codes.

Wind speed

The recommended wind speed is 8 m/s at 10m height, though other wind speeds or a range of wind speeds can be used.

Octave data

There are no requirements for octave data specifically, but it can be required if the general ground attenuation is selected or if a spectral distribution is required.

Spectral distribution
Users may be required to analyze specific frequencies. In that case the frequency interval can be specified. Such an analysis will require an octave band distribution for the turbines.

Ground attenuation
There is no specific requirement to modify the calculation method for ground attenuation. As a general rule the General method be used when acoustic porosity is special (e.g. over water), while the Alternative method can be used when the terrain shape is special (e.g. hilly terrain). If a spectral distribution is required then the General method must be used.

Meteorological coefficient C_0
The meteorological coefficient can be set. The recommended maximum is 2dB.

Type of demand in calculation
The demand specification is locked to "WTG plus ambient noise is compared to ambient noise plus margin". The noise receptors must be setup accordingly.

Noise values in calculation
Locked to regular L_{WA} noise values.

Pure tones
Pure tone penalty are added to demand.

Height of immission point above ground level
The receptor height is default set to 5 m, but can be changed by the user.

Deviation from official noise demand
This field is open to the user.

Noise receptors
The noise receptors can be setup with specific settings for France. There are two types of setting: Standard and Spectral.
For the Standard calculations the ambient noise at the receptor must be stated and the allowed additional exposure is set to a fixed level. This may be for a single wind speed but can also be for a range of wind speeds. Sound level from the turbines below 30dB is always accepted.
For Standard day the allowed additional exposure is 5dB.
For Standard night the allowed additional exposure is 3dB.

In an analysis of the spectral distribution the ambient noise must be stated for individual frequencies, while the allowed additional exposure varies with frequency
The allowed additional exposure from 125 to 250Hz is 7dB, while from 500 to 4000Hz it is 5dB.

4.1.1.5 ISO 9613-2 Norway

The Norwegian noise codes are described in the document: "Veileder til Miljøverndepartementets retningslinje for behandling av støy i arealplanlegging (støyretningslinjen)", TA-2115/2005, publiced by Statens Forurensningtilsyn (SFT).

The noise codes recommend the use of either the Nordic noise model (Nord2000) or the ISO 9613-2 noise propagation model. While the ISO 9613-2 model is not able to fully comply with the requirements in the Nordic codes, choosing ISO 9613-2 will make a best approximation to the codes.

Wind speed
The Norwegian codes require a calculation based on the actual wind distribution. However when using the ISO 9613-2 model it has been generally accepted to use 8m/s at 10 m height as this is close to the maximum noise level for turbines.

Ground attenuation
It is not specified what kind of ground attenuation should be used, but instead stated that the ground attenuation should reflect the nature of the landscape. Given the nature of Norwegian landscape the alternative ground attenuation is used. This means that octave data is not required.

Meteorological coefficient, C_0
The Norwegian codes distinguish between receptors downwind from the primary wind direction and receptors in other directions. This could be represented by adjusting the meteorological coefficient, however it is not recommended.

Type of demand in calculation
Only noise from WTG's is taken into account.

Noise values in calculation
Norwegian noise values are given as L_{den} values. WindPRO will on its own present all values as L_{den} values.

Pure tones
Pure tone penalty are added to demand.

Height of immission point above ground level
The receptor height is default set to 4 m.

Deviation from official noise demand
This field is open to the user.

Edit period

The Norwegian codes operate with noise values as L_{den}, where den is an abbreviation of day-evening-night. It represents a weighted average of noise, where noise during evening and night is penalized. The conversion from L_{WA} to L_{den} is exemplified by an official spreadsheet from SFT called lden_lekv_driftstid.xls. The parameters can be seen or modified by pressing the Edit period button as seen below.

The period definition of day, evening and night can be set here, as well as the penalty due for each period. As L_{den} is an average noise the number of days in a year with noise must be stated. SFT recommends 290 days for wind turbines (to account for periods of non-operation).

A full explanation on the calculation of L^{den} can be found in the Decibel Appendix.

Level	Name	From hour	To hour	Hours	Penalty [dB]	Days per year
0	Day	7	19	12	0	290
1	Evening	19	23	4	5	290
2	Night	23	7	8	10	290

Ok   Cancel

Noise receptors

In Norway the planning authority must divide the receptors into two categories: Yellow and red zone. In yellow zone the critical noise limit is 45dB while in red zone it is 50dB. This assumes that the noise receptor is in wind shadow. The definition of wind shadow is loose and only state that 30% of the year there is less wind than at the turbine.
If the receptor is outside wind shadow 5dB can be added to the noise limit.

Noise data for WTG

As described in a separate section below an individual noise mode can be selected for the three periods as part of advanced settings of the turbine.

4.1.1.6 The German rule VDI 2714 (outdated)

Until 01.10.1998 calculations were performed from VDI-Guideline Directions "Noise emission in open air".

Wind speed
The noise calculation is made for a fixed wind speed, typically 8 m/s.

Type of demand in calculation
The noise from the turbines is compared to the demand.

Addition for pure tones (pure tone content)
Gear, generator, hydraulics to blade angle regulation etc. are all potential pure tone sources. Pure tones should be removed through construction alterations or at least reduced. It is an audible pure tone (larger than 2 dB(A)) according to VDI 2058, Section 1, if "the increased inconvenience effect results in using an addition to the calculated noise level. The addition is set for 3 or 6 dB(A) dependent on how striking the pure tone is."

Addition for impulses (Impulse tone /Impulse tone content)
Impulse tone contents can be experienced when a rotor blade passes the tower. An evaluation can be done by means of the DIN 45645 if there are impulse tone contents. If the noise source contains significant impulse noise or frequent changes in the noise level (from measurement) of several times per minute, under the VDI 2058, an additional 3 or 6 dB(A) needs to be added to the calculated noise level as described under pure tones.

Pure tone addition in practice
In the WindPRO WTG Catalogue it is possible to add information regarding possible pure tone content and whether or not an additional 3 or 6 dB(A) should be added respectively to the calculated values. If this is the case, DECIBEL will, when checking if a given noise level is met, add the given values to the calculated noise level from each source according to the VDI-standard, contrary to the Danish regulations, where you simply raise the demand (with 5dB(A)) if just one WTG has a pure tone content. If you know that there is an additional pure tone, but it is not listed in the WTG Catalogue, you can create an extra set of noise data with the addition of either 3 or 6 dB(A) yourself.

Generally, we recommend contacting the relevant authorities and/or manufacturers when having doubts about these demands.

Height of immission point above ground level
The receptor height is set to 5 m.

Deviation from official noise demand
This field is open to the user.

Noise receptors
As the VDI codes are outdated the relevant noise limits at receptors must be historic values.

4.1.1.7 The Danish Codes 1991

The former Danish rules are outlined in "Bekendtgørelse om støj fra vindmøller" (Statement from the Department of Environment) No. 304 of 14/5/91.

The propagation model is described in the Decibel appendix.

The former Danish codes require a calculation at 8 m/s at 10 m height. It is voluntary whether octave band distributions should be used, but in practice the calculations are almost always done on the total source noise level.
Noise values are compared to a critical demand (see below) and in the case of pure tones a penalty of 5dB is deducted the critical demand.

Noise receptors
The noise impact from WTGs must not exceed 45dB(A) at outdoor areas which lie in connection to neighboring settlements in the open land. The noise impact from WTGs must not exceed 40dB(A) at any outdoor recreational areas within housing zones or at any other Noise-sensitive Areas.

4.1.1.8 The Danish Codes 2007

From 2007 new noise codes for Denmark are used in Denmark based on "Bekendtgørelse nr. 1518 af 14. December 2006, Bekendtgørelse om støj fra vindmøller".

The propagation model here is changed with a separate damping for offshore wind turbines.
The revised propagation model is described in the Decibel appendix.

Wind speed
The noise impact must be calculated for two wind speeds: 6 and 8 m/s at 10 m height.

Octave band
Octave band distribution is required for the calculation.

Terrain reduction (correction)
The user must select whether the calculation is for on- or offshore turbines. This affects the ground attenuation. Note the correction is added to, not reduced from the calculated noise. The higher figure offshore thereby gives higher calculation values offshore.

Pure tones
Pure tone penalty are added to demand. Like the former Danish codes a standard of 5dB is deducted the critical noise limit of the receptors in case of pure tones.

Height of immission point above ground level
The receptor height is default set to 1.5m.

Deviation from official noise demand
This field is open to the user.

Noise receptors

The critical limits at noise receptor are defined below.

DANISH RULES FOR NOISE CALCULATION.

The calculation is based on the "Bekendtgørelse nr. 1518 af 14. dec 2006" from the Danish Environmental Agency.

The noise impact from WTGs are not allowed to exceed the following limits: (Wind speeds in 10 m height)
1) At outdoor areas maximum 15 m from neighbor settlements in the open land.
   a) 44 db(A) at wind speed 8 m/s.
   b) 42 db(A) at wind speed 6 m/s.
2) At outdoor areas in residential or recreational areas.
   a) 39 db(A) at wind speed 8 m/s in residential areas.
   b) 37 db(A) at wind speed 6 m/s in residential areas.
If a WTG has pure tones in the noise emission, a penalty of 5 dB is added.

4.1.1.9 The Danish Rules 2011

December 2011 introduced new noise codes in Denmark through "Bekendtgørelse nr. 1284 af 15.december 2011" from the Danish Ministry of the Environment (Miljøministeriet, 2011).

This code is associated with a guideline, published 16 May 2012 called "Støj fra Vindmøller, Vejledning fra Miljøstyrelsen nr. 1, 2012.
http://www.mst.dk/Publikationer/Publikationer/2012/Maj/978-87-92903-08-2.htm

A full overview of the implications of the code can be found in the article: "Experiences with the New Danish Rules for the Calculation of Low Frequency Noise from Wind Turbines", Sorensen, 2012, which is available from the WindPRO FAQ page.

The code is to a large extent based on the 2007 codes with three significant novelties:

   a. Low frequency calculation
   b. Documentation requirement
   c. 15 dB limitation

For the actual procedure of calculating the normal noise and the noise limits please refer to the 2007 codes above as these are unchanged.

Low frequency calculation

The low frequency calculation is concerned with the frequencies from 10 to 160 Hz. For this purpose a new tab is introduced in the turbine catalogue from version 2.8 containing low frequency figures. Data are entered in the tab as 1/3 octave frequencies in the same way as other data in the catalogue. Please note that if data are entered as 1/3 octave for normal noise, the form is automatically filled for low frequency noise as well. However in older versions of WindPRO the two lowest frequencies were not available so opening a turbine with 1/3 octave data from before 2.8 will leave the two lowest frequencies empty.

Noise limits

The noise limit for low frequency noise is uniformly 20 dB at any receptor (indoor) at 6 and 8 m/s at 10 m height. In the noise receptor select Danish 2011 Low frequency and this is automatically selected.

Noise calculation

When starting the calculation select as calculation type "Danish 2011 Low Frequency". The only available choice is whether to calculate for offshore turbines. If that hatch is checked, click the button Edit water areas to select an area object defining the sea. It is so that the low frequency calculation uses special dampings at sea and land and in the 200 m coastal zone makes a transition between the two calculation types. Note that the transition calculation is only for low frequency noise, not normal noise.

Documentation requirement
Due to increased documentation requirement previous practice of using the total noise figure and assuming a generic octave band distribution for existing turbines is now invalid. The noise figures used for existing turbines must be backed up by noise measurement reports for the turbine type and be available at least as 1/1 octave band distributions. If these are not available generic values provided by Miljøstyrelsen must be applied. For this reason when doing a noise calculation with Danish 2011 or Danish Low frequency WindPRO will for turbine types <=2MW use data from the generic tables from Miljøstyrelsen if data at least at 1/1 octave band level has not been selected for the turbine. EMD is gradually adding measured data to the turbine catalogue for old turbine types.

For turbine types >2MW the dB(A) value of the turbine is ignored and a generic value and distribution based on generator size is calculated. This is intended to reflect generic turbine types with unknown noise data. All other turbine typed >2MW in Denmark MUST be calculated with turbine specific octave band distributions.

In the Decibel report a remark is added to the source noise summary if insufficient data are used or if generic data from the guideline is used.

15 dB limitation
The 2011 Danish codes states that total noise at all receptors cannot exceed the noise limit. This means that noise contribution from existing turbines and new turbines must be combined and calculated for all receptors. As a practical limitation the guideline limits this by the 15 dB limitation. This means that existing turbines must be included when calculating noise for the neighbors to the new turbines if the contribution from existing turbines is higher than 15 dB below what they will get from the new turbines. It also means that noise must be calculated and comply with the present code at neighbors to existing projects if the contribution of noise from the new turbines is higher than 15 dB below what they get from existing turbines already. The practical aspects of this limitation is explained in "Experiences with the New Danish Rules for the Calculation of Low Frequency Noise from Wind Turbines", Sorensen, 2012.

4.1.1.10 The old Swedish codes

The old Swedish codes are based on the "Metod för mätning av bullerimmission kring vindkraftverk" from Statens Narturvårdsverk, Sten Ljunggren, FFAP-A-935, 1992. These follow the Danish rules except on a few points:

The maximum noise impact from WTGs at a wind speed of 8 m/s is:
- Light industrial areas: 50dB.
- Houses etc.: 40dB.
- Recreational areas: 35dB.

The damping coefficient α_a is set to 0.003dB/m instead of 0.005dB/m

4.1.1.11 Swedish, January 2002.

By the end of 2001, new guidelines for calculating noise from WTGs were released in Sweden. They are called "Ljud från Vindkraftverk", Naturvårdsverket 2001, ISBN 91-620-6241-7. They replace former calculation methods and distinguish between onshore and offshore conditions.

Naturvårdsverket has released a spreadsheet for each method and a calculation must be according to these spreadsheets in order to be approved. A verification report that documents that WindPRO fulfills these demands can be downloaded at www.emd.dk and is called "Dokumentation af WindPROs beregning af svensk støj - vers2.pdf".
At the time of preparation of this edition of the manual the Swedish codes are being changed. Until the new version is made public noise is Sweden can be calculated as maximum noise values. A document describing the procedure for maximum noise can also be found on our homepage..

Calculation setup
There are two calculation modes: land and offshore.

For the on-land codes, the user is asked to give the roughness of the surrounding land. The unit used is roughness class. This is in order to modify wind speed at hub height based on the wind shear. The wind speed difference corresponds to a source noise level difference for which the codes assume a linear relation with a slope of k.

The parameter k is fixed at k = 1, as it is unclear from the guidelines in what interval of wind speeds this factor should be derived.

Onshore calculations do not require an octave band distribution if the receptors are all closer than 1000 m to all turbines. This is however rarely the case, so for all practical purposes 1/1 octave band distributions must be available for the turbines.

If offshore codes are selected no roughness needs to be selected. Also 1/1 octave band distributions are required for all turbines.

All noise calculations are calculated for 8 m/s at 10 m height.

Swedish noise requirements
Noise limits at receptors generally follow the following rules:

Day	Light industrial locations	60 dB(A)
Day	Dwellings	50 dB(A)
Day	Recreational locations	40 dB(A)
Evening/holidays	Light industrial locations	55 dB(A)
Evening/holidays	Dwellings	45 dB(A)
Evening/holidays	Recreational locations	35 dB(A)
Night	Light industrial locations	50 dB(A)
Night	Dwellings	40 dB(A)

Night	Recreational locations	35 dB(A)

4.1.1.12 Swedish codes 2009

The Swedish codes 2009 actually represent an evolution of "Ljud från vindkraftverk", Naturvårdsverket. The latest available version is from April 2010, but the latest modifications are at the time of writing only available from Naturvårdsverkets homepage http://www.naturvardsverket.se/Stod-i-miljoarbetet/Vagledning-amnesvis/Buller/Buller-fran-vindkraft/buller-vindkraft-riktvarden/

This latest version, for ease called Swedish 2009 as the 2009 edition provided some of the most important changes, is generally based on the original "Ljud från vindkraftverk" with the following modifications:

a. Roughness correction of source noise level has been removed and replaced by the standard 0,05 m wind profile
b. Revised code for offshore calculations
c. Option of comparing with ambient noise (masking)
d. Allowing for Nord2000 calculations

Roughness correction
The elimination of the roughness correction greatly simplifies the calculation. Instead of modifying the wind speed at hub height based on a roughness specific wind profile, all calculations now assume a standard IEC profile of 0,05 m, which is used by basically all other national codes. This means that the noise figure in the wind turbine catalogue of WindPRO can be used directly without modification. Therefore the selection of roughness length has been removed. This counts for both onshore and offshore calculations.

Offshore calculation
The offshore calculation calculates similar to an onshore calculation out to 1000 from the turbine. From then a revised version of the 2002 code with different dampings are used. The noise is calculated at landfall and from then uses the land code to the dwellings. The formula in the current form is at the time of writing only available from here: http://www.naturvardsverket.se/upload/stod-i-miljoarbetet/vagledning/buller/buller-vindkraft/matning-berakning-vindkraftljud.pdf

In WindPRO DECIBEL select Swedish 2009 and select Offshore wind farm. If that hatch is checked, click the button Edit water areas to select an area object defining the sea. Any purpose of the area object will do. Any location outside the selected area type is considered on land and the boundary of the area marks the coastline.
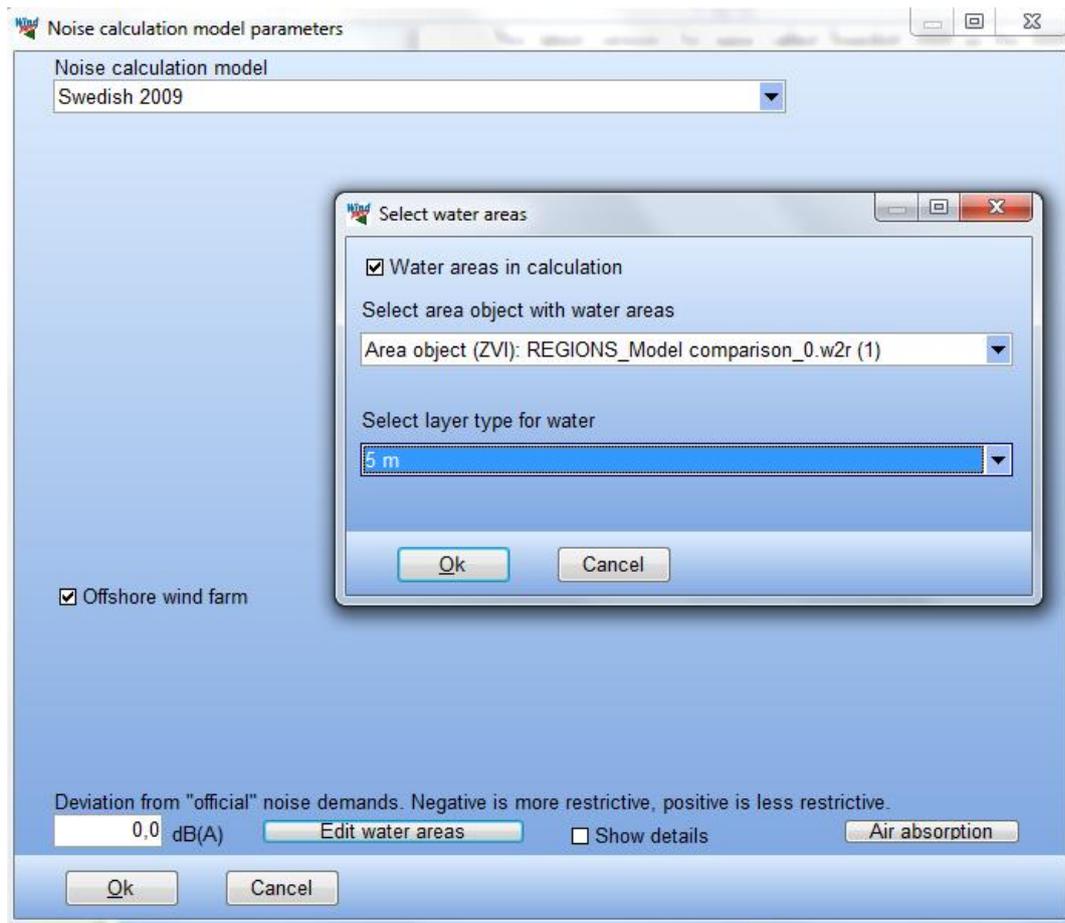
Masking of noise

From the 2009 version of "Ljud från vindkraftverk" it is possible to compare with masking from ambient noise. Depending on type of surroundings it is possible from table values to estimate the ambient noise at a dwelling. If the difference between ambient noise and calculated noise from turbines is sufficiently small the noise impact at the receptor can be disregarded. The masking element has in general not been implemented in WindPRO but it is possible to enter ambient noise in the noise receptor object.

Nord2000

From 2009 the Swedish code allows the use of Nord2000 as an alternative method. Nord2000 is not part of the DECIBEL module, but a module on its own. For further description see section 4.5.2.

4.1.1.13 Dutch, 1999.

The Dutch, 1999 method follows the guidelines described in "Handleiding meten en rekenen Industrielawaai" from Ministerie van VROM, Zoetemeer, 1999, ISBN 90 422 0232 7.

The section dealing specifically with noise from WTGs is Module C, method II.8.

Wind speed
The wind speed used for the noise calculation is a range from 3 to 12 m/s at 10 m height.
Only the total noise level is required (no need for octave band data.

Terrain reduction
The user is asked to set the terrain damping (D_{bodem}), a value between 0 and –3, where 0 is a hard surface and –3 is a very soft surface.

Height of immission point above ground level
The receptor height is default set to 5 m.

Deviation from official noise demand
This field is open to the user.

Noise receptors
The critical limits at noise receptor are defined as a function of wind speed as shown in the table below.

Wind speed, m/s	Critical noise limit, dB(A)
4	41,1
5	41,7
6	42,5
7	43,4
8	44,5
9	45,6
10	46,9
11	48,3
12	49,7

.

4.1.1.14 IL-HR-13-01 (The Netherlands)

This is the previous Dutch method for calculating noise propagation from WTGs. In WindPRO the only difference between this and the 1999 edition is that this method assumes acoustic hard terrain (B = 0).

4.1.1.15 Dutch, 2010.

The Dutch calculation method from 2011 is described in "Reken- en meetvoorschrift windturbines" from 2/2-2010. It is based on the Lden principle and use an adapted version of ISO 9613-2 as propagation model.

The calculation model is selected by choosing Dutch 2011 as Noise calculation model.
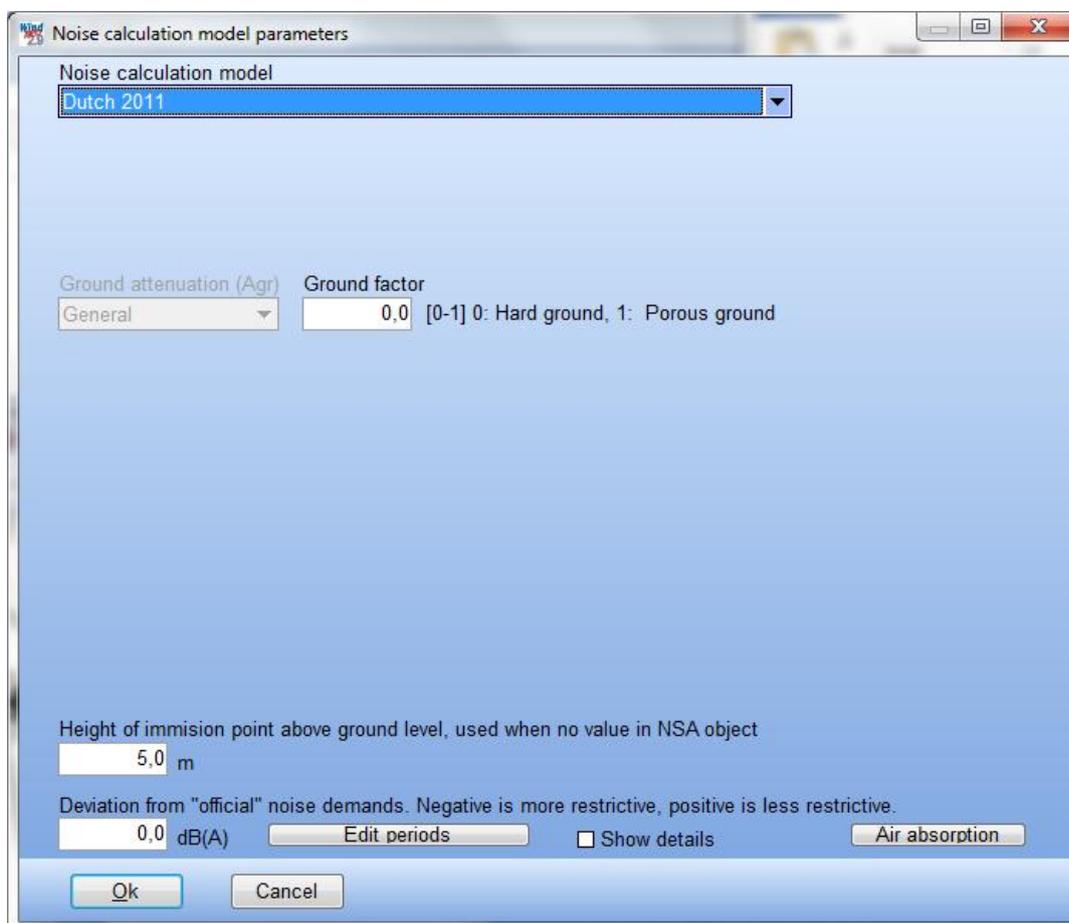
Wind speed

The Dutch 2010 code operate with average noise received day, evening and night. In order to calculate how much noise on average is emitted in each time period, an average octave band distribution is calculated. This is based on the octave band distribution at each wind speed bin from cut in to cut out weighted with the frequency of that bin.

The octave band distributions for each wind speed bin must be found in the wind turbine catalogue. It goes without saying that it requires a fairly complete set of data, something which will rarely if ever be present among the default values in the catalogue. If only a limited amount of wind speeds will be available WindPRO will interpolate between them, set noise below cut-in to 3 m/s and set the noise constant when extrapolating from the highest wind speed to cut-out. If no octave band distribution exist for a specific wind speed WindPRO

will scale the octave band distribution of the closest wind speed. If no octave band distribution exists at all WindPRO will fit a generic octave band distribution to the total noise level. This is of course insufficient for a correct calculation.

The frequency of each wind speed is found from a database provided by KNMI and found on the web site www.windenergie.nl . Based on the location of the site center of the project WindPRO looks up this location in the database and extract the frequency table for day, evening and night.

The formula for calculating the average noise for each time period is described in more detail in appendix.

Ground attenuation
The ground attenuation factor is defined for values of 0 and 1, but it is allowed to use any value in between. As with the other ISO 9613-2 calculations in WindPRO a uniform ground factor is used.

Meteorological coefficient, C_0
For distances less than 10 times hub height (actually 10 times difference in z coordinate of hub and receptor) the meteorological coefficient, C0 is 0. Beyond that distance C0 is a function of distance and direction from turbine to receptor in the way that maximum C0 is achieved downwind from the turbine.

The function for calculating C0 is described in appendix.

Type of demand in calculation
Only noise from WTG's is taken into account.

Noise values in calculation
WindPRO will on its own present all values as L_{den} values.

Pure tones
Pure tone penalty are added to demand.

Height of immission point above ground level
There is no mention in the code of receptor height. For the calculations it is set to 5 m.

Deviation from official noise demand
This field is open to the user.

Edit period
The Dutch codes operate with noise values as L_{den}, where den is an abbreviation of day-evening-night. It represents a weighted average of noise, where noise during evening and night is penalized. The parameters can be seen or modified by pressing the Edit period button as seen below.

The period definition of day, evening and night can be set here, as well as the penalty due for each period.

| Level	Name	From hour	To hour	Hours	Penalty [dB]	Days per year
0	Day	7	19	12	0	365
1	Evening	19	23	4	5	365
2	Night	23	7	8	10	365
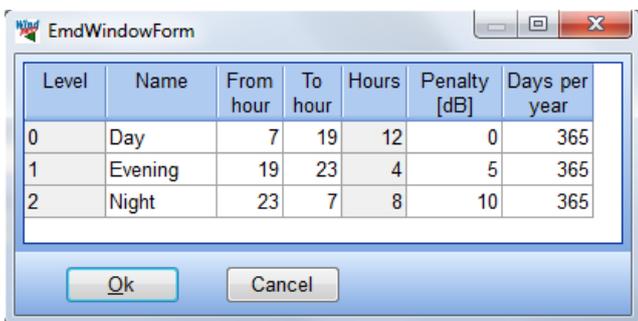
Noise receptors
The general noise limit in The Netherland is 47 dB Lden and 41 dB Lnight. The default setting for a Dutch receptor is 47 dB and this is also the noise value used on the noise ISO line report, but both Lden and Lnight can be found in the noise report.

Noise data for WTG

As described in a separate section below an individual noise mode can be selected for the three periods as part of advanced settings of the turbine.

Source noise data for the turbine is based on wind speed at hub height. If data for the turbine is only given at 10 m height they may need to be converted to hub height (section 2.6). Since a calculation is made for each integer wind speed at hub height it may be preferable to convert 10 m height wind speeds to hub height integer wind speed even though that means an interpolation of data points.
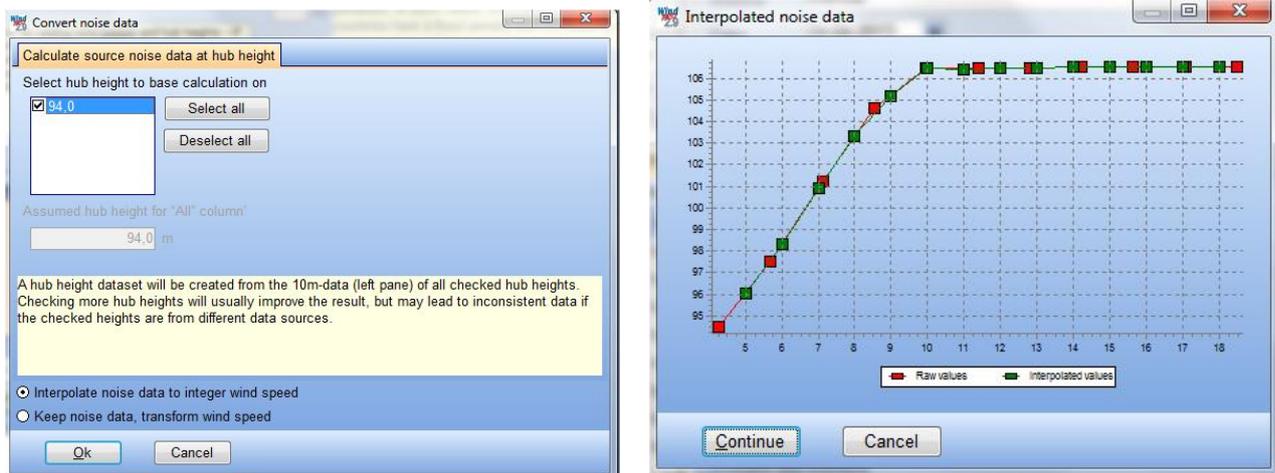
4.1.2 Entering Data for Noise and Distance in DECIBEL

A background map is required, but it can be a blank map.

If one or more maps have been linked to the project, clicking on the map icon can activate these maps. Please also refer to Chapter 2 in WindPRO BASIS for further information about the use of maps.

Please notice that when entering objects via maps, you can create a default tool by holding down the <shift> key while selecting a tool. This function will allow you to enter several objects with the same properties, (e.g. a series of noise-sensitive objects with the same requirements to distance and noise level or a number of parallel rows of WTGs of the same turbine type).

4.1.2.1 Entering WTGs

See Chapter 2 BASIS, Section 2.5.2 on entering WTGs and Section 2.6.3.2 on noise data in the WTG catalogue.

WTGs may hold different forms of noise data. Noise data may be given for different wind speeds (most common are 8 or 10 m/s) and different hub heights and the noise value may be given as either a source emission level ($L_{wa,ref}$) or as octave-divided data (or even subdivided as third octave data). The form needed in your calculation depends on the calculation method (see Section 4.1.1) and the local regulations.

WindPRO will usually detect which value is relevant for the chosen calculation type, but you can also manually select a specific noise emission level in the WTG object properties (see Section 2.5.2.1).

If the WTG type has no noise data of the type needed for your calculation, you can usually obtain it from the manufacturer.

WindPRO 2.7 includes a tab for wind speed at hub height. So this is only implemented for the Nord2000 noise calculation and for the Dutch 2011 calculation. For all other calculations in the Decibel module this tab is inactive.

Noise modes

Many turbine types come with noise reduced modes of operation. This can often be recognized from the name in the wind turbine catalogue. A noise record at Level 0 will always be standard, unreduced, while following levels often relates to successive modes of reduced noise level. A noise record with the name:

Level 3 – calculated – 103dB – 09/2009,

will represent the third reduced mode (a standard followed by three reduced modes). The type of noise data is calculated, the name of the mode from the manufacturer is 103dB (not necessarily the actual noise level) and the date of the technical specification September 2009.

Selection of noise mode
When inserting a WTG it is possible to specify the noise level by removing the check from "Always use default values". Remember that a reduced noise level must always be accompanied with similarly reduced power curve.

Advanced noise curve selection
Checking the "Adv." Box opens up advanced settings.

There are two types of advanced mode, selected on the right side: Optimize or L_{den}.

If Optimize is selected (see above) then a number of settings must be selected. These are the possible operation modes you want an optimization run to go through during noise optimization (see Chapter 8).

Press the + button to add a setting and – to remove a setting. You can move up and down through your settings with the arrow buttons.

There is a radio button called "Use" next to the setting name. The setting where this button is filled is the one which will be used in calculations.

If L_{den} is selected then the three L_{den} periods (day, evening, night) can be defined.

There are automatically three settings, which by default have the same property. It is possible to freely define which should be used for each of the period.

An L_{den} calculation is a single calculation that combines three individual noise calculations so all three noise settings are used. The energy calculation can unfortunately not be combined in a similar way so here the "Use" button still indicated which power curve is used in a production calculation.

4.1.2.2 Entering noise-sensitive areas

Graphic input of a noise-sensitive area object (NSA object): Click the icon shown to the left; double-click with the left mouse button on the map to create an NSA Object as a point.

Alternatively, when the object is selected from the icon list, click with the left mouse button on the map to define the first corner of an area, and continue to click on the map to define the other vertices of the polygon until you right-click to close the polygon.

For tab sheet Position, see BASIS Section 2.5.2.2. .

Note: The z-coordinate of a noise-sensitive area has to be entered in the same reference system as the z-coordinate of the WTGs. If the WTG(s) have been entered with the default value "0", you have to enter the z-coordinates for the noise-sensitive areas relative to the elevation of the WTG foundation, i.e. if the noise-sensitive area has a lower elevation than the WTG foundation then the z-coordinate will be negative. It is recommended to generally enter z-coordinates for all objects relative to the sea level. Here the use of automatically detected z-values from a line object is a very useful help.

Noise-sensitive areas can be entered as:

- Points
- Areas

When you enter a point, you have to enter the coordinates of the neighbor or noise-sensitive area, which, according to the actual requirements, has the highest noise impact from the WTG(s). This usually means the point nearest to the WTGs, but it may be difficult to define this point straight away. Especially if the WTGs are spread all around the neighbor or if different WTG types are sited parallel to a noise-sensitive area. Therefore, it may be relevant to enter a noise-sensitive area as a polygon, where the vertices of the polygon encircling the noise-sensitive area are entered. The program will then calculate the most critical impact point - also if this point lies between two vertices of the polygon (on a line which connects two vertices).

Demands
The tab "Demands" defines the noise receptor in term of critical noise limits (demands).

If "Define in calculation setup" is hatched a uniform description of the noise demands can defined in the calculation setup instead of individually for each receptor.

The noise receptor will automatically detect the country of the project and choose a country specific form (above) relevant for that country. This will lock the parameters to those relevant and allow manipulation in those fields where the user has to make decisions. In the example above a site located in Denmark will automatically link to the Danish 2007 codes and freeze noise demands for 6 and 8 m/s. The user has to define whether the receptor is in open land or a residential area, in which case the noise demands will reflect the critical noise limits for that type of area.

There are only country specific forms for a limited number of countries.
If not in one of these countries or if more options are needed the user can choose "Free definable form".

A distance demand and noise demand can be entered for each noise object.

The distance demand can be defined when recommendations exist or limits about the minimum distance to the dwellings have to be fulfilled. The Decibel calculation will then check if this demand is fulfilled or not. The distance demand can be shown on the map (Section 4.1.2.3) and help in the design of the layout of the wind farm, though only if a fixed distance is used and not a function of turbine size. It is can also be included in an Optimize calculation (Section 8.1.4.1).

For the default NSA, the selected calculation model decides the immission height above ground for the calculation and there is no need to enter a specific value. There may be situation however where special needs may require a different calculation height (e.g. a tower or a tall building). In that case, the checkbox can be de-selected and a specific calculation height entered.

If no demand is checked, then the requirement is not included in the calculation and will not appear in the printout. All noise values are considered L_{wa} values unless L_{90} units are selected in the calculation setup or the calculation method is locked to Lden values.

There are two types of noise demand:
- Only noise from the WTG's is considered
- Ambient noise is considered.

If "Only WTG noise…" is selected the user can type in the critical noise limit for the receptor.

If the noise demand is different for different wind speeds, then selecting "Check for more wind speeds" makes it possible to enter specific critical limits (see figure below).

Here it is also possible to define critical noise levels for specific frequencies using "Check for spectral distribution".

In some areas the background noise level is relevant for the calculation. In such cases, the ambient noise exposure (background noise level) must be entered. If the background noise is relevant for several different wind speeds, selecting "Calculate for more different wind speeds" makes it possible to type in specific noise values.

If background noise is required, it is usually because the noise demand is a function of background noise plus a margin (allowed additional exposure). The margin can be given as a fixed value, or can be dependent upon wind speed. In that case, selecting "Calculate for more different wind speeds" enables the user to input these different margins.

There may be a certain noise level from the turbines which is always accepted regardless of the background noise level. This noise level can be entered in the "WTG noise always accepted" box.

Area

If the NSA has been entered as an area rather than a point, it is possible to edit the node points of the area in the Area tab sheet. Node points can be added, edited, or deleted. If the node points need to be copied to Excel, or from Excel to WindPRO, then the entire object needs to be copied to or pasted from Excel.

When the NSA is entered as an area, WindPRO will calculate the noise level for each point at the edge of the area and give as a result the one with the highest level.

Since a polygon can only be provided with one elevation (z-coordinate), it might be relevant to enter the noise-sensitive areas as several adjacent polygons with different heights. The description for the areas could be the name of the neighbor that the noise object refers to.

4.1.2.3 Showing Distance Requirements on the map
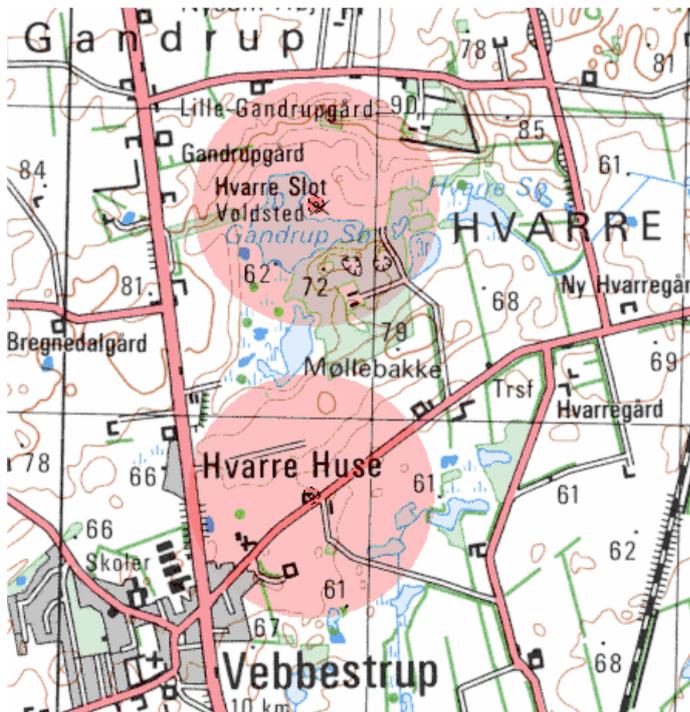
When you click with the right mouse button on an NSA object you gain access to switch the distance marker on/off. The selected mode covers all NSA objects. If the distance marker is activated, the program will produce a faded red circle, which indicates the distance requirement entered for each object (see figure).

4.1.3 DECIBEL - Calculation and printout

Click on the green arrow next to the DECIBEL heading in the calculation menu to select the calculation mode. Once the calculation mode has been selected you will be asked to complete the calculation setup.

4.1.3.1 DECIBEL - Calculation Setup

The calculation setup for the DECIBEL calculation follows the general system for calculation in WindPRO. You may find more detailed explanation of some of the general functions in other sections of the manual.

Main
The Main tab is used to set up which calculation you want AND which model to use. See in 4.1.1 how the different parameters for the different models shall be decided. Note the model choice in general must match the specifications in the Noise Sensitive Areas if such are used in the calculations.
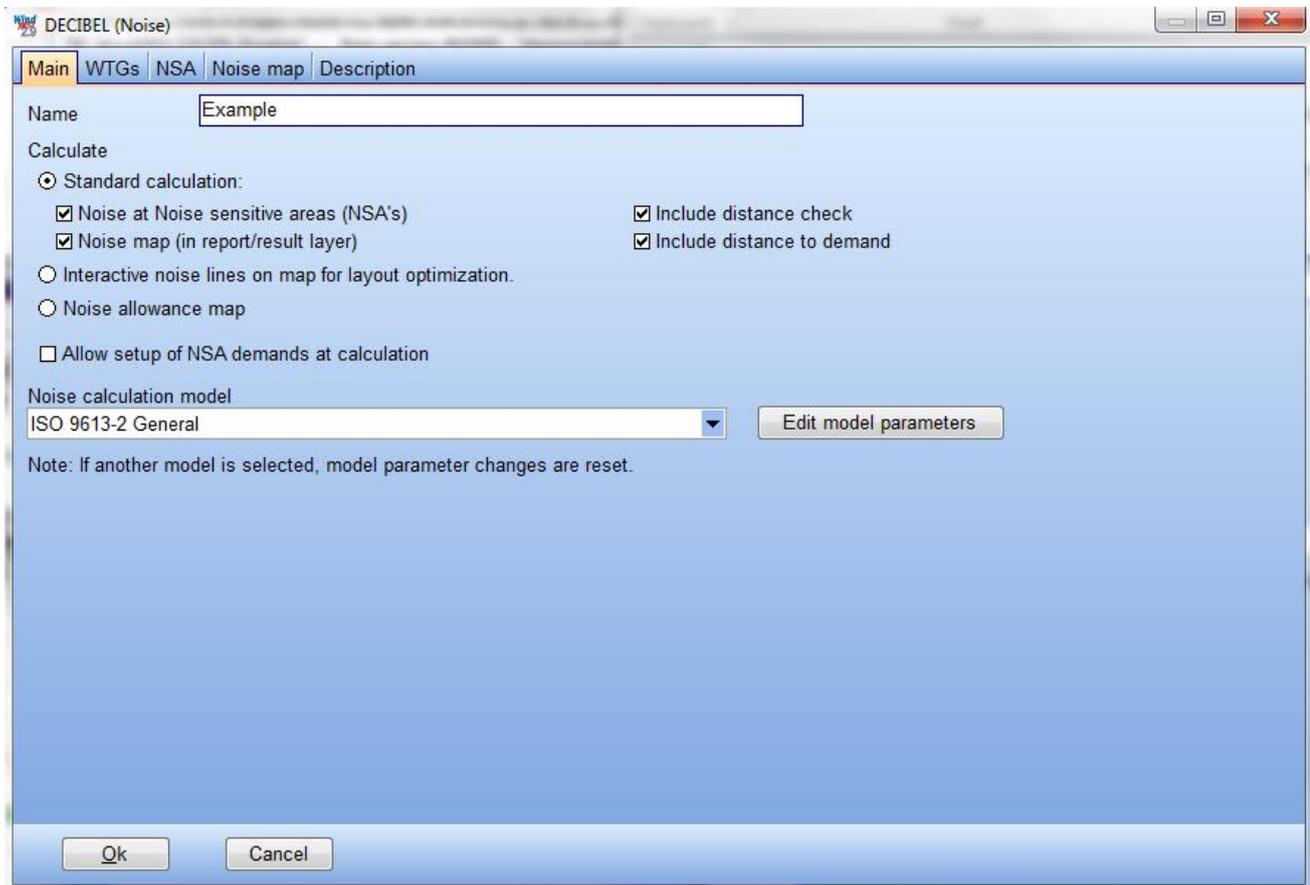
The name in the name field is the name headlining all the pages of the calculation report.

It is possible to make three types of calculations. Depending on which type of calculation is selected different tabs will become available.

The three types are:
- Standard calculation
- Interactive noise lines on map for layout optimization
- Noise allowance map

The second and third options are explained in detail in Sections 4.1.3.4 and 4.1.3.5. In this section the focus is on the standard calculation.

If standard calculation is selected it is possible to choose only to get a noise calculation for the receptors or a noise iso-line map or both.

If noise calculation for receptors is checked it is possible to include a distance check and a distance to demand calculation. A distance check is a calculation against the distance (setback) requirement entered for the receptor. Distance to demand calculates how large the margin is from the receptor to the critical noise level, basically telling you how tight you are cutting it.

Hatching "Allow setup of noise demands at calculation" introduce a new tab called "Demand" where a uniform set of noise and setback criteria can be entered.

Finally a noise calculation model must be selected. Depending on the codes selected, the calculation options for the particular code can be inspected or changed using the "Edit model parameters" button. For a description of these options please refer to the description of the appropriate model in Section 4.1.1.

WTGs
WTGs to be included in the calculation: Here you can uncheck those WTGs from the object list that you do not want to include in the calculation. A good idea is to have different layouts organized in particular layers and then select wind turbines by the layer.

NSA (Noise-sensitive areas)
Noise-sensitive objects to be included in the calculation: Again, you can uncheck those receptors from the object list that are not required in the calculation. Note that the receptors are grouped by layer. You can therefore specify receptors in one layer to for example day limits while another is night limits.
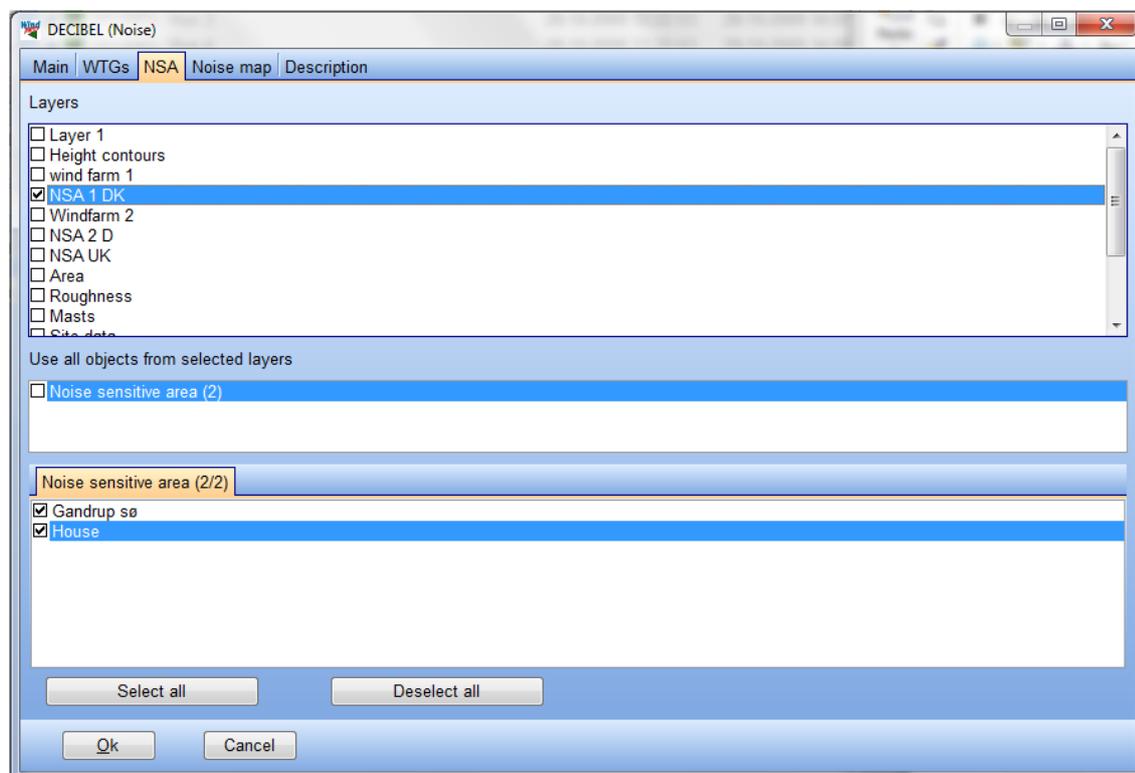
Noise map

If you have selected to calculate a noise map or Interactive noise lines you can access the Noise map tab. This is where you specify the noise iso-line maps to be included in the report.
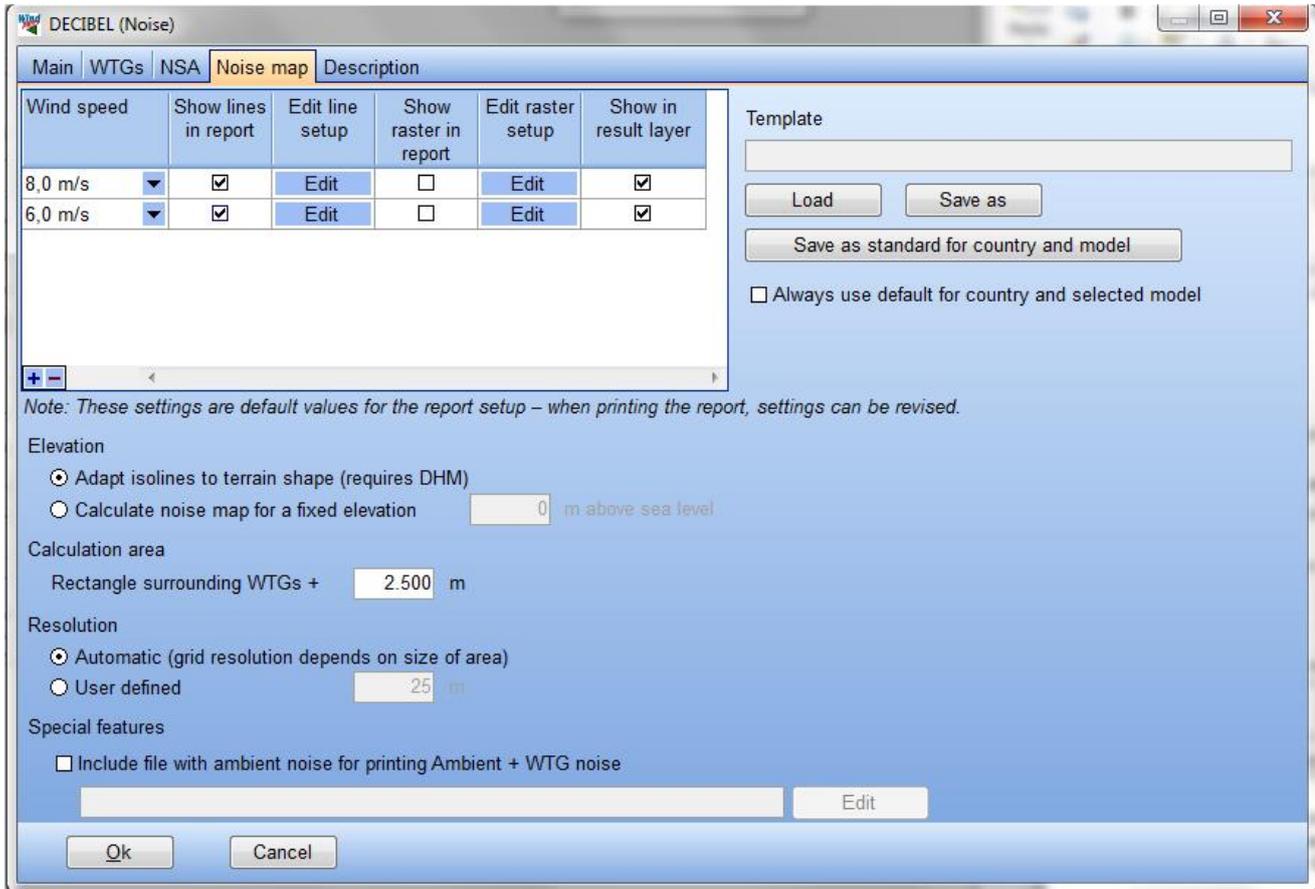
Based on the model you have selected to use one or more maps will be available. In the above example the Danish codes have been selected. The Danish codes define two wind speeds, 6 and 8 m/s, so maps for these two wind speeds have been listed.

Three kinds of map reporting are possible:
- Show lines in report, creating a page with noise iso-lines in the report
- Show raster in report, filling up the interval between lines with color
- Show in result layer, producing a result layer in Maps and Objects with noise lines and/or raster.

It is possible to select as many maps as you have wind speeds in your calculation and thus attach several maps to the report.

Pressing the edit button makes it possible to edit the lines or raster definitions for the maps.

The line setup looks like below, which is similar to the setup options in the print report setup.
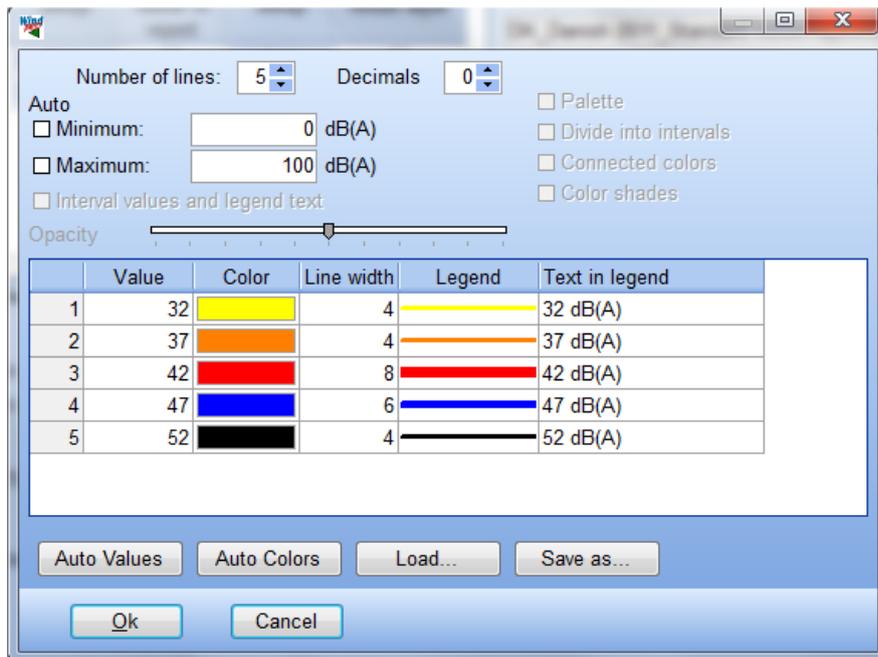
Select the number of lines wanted and then define the noise value and color for each line. With save you can save a template so you do not have to set this up every time you run the calculation. Pressing the "Load" button loads previously-saved templates. Pressing "Save" saves the current settings as a template (by default in C:\WindPRO Data\Standards.

In a similar way the raster setup can be edited.
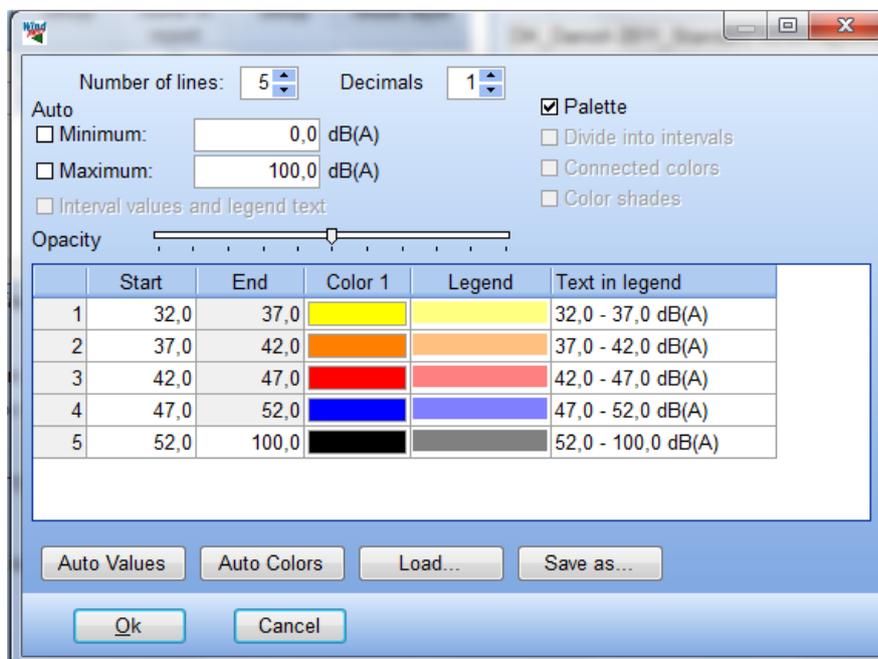
Again this is similar to the print report setup and the interface is used in several other locations in WindPRO. A typical good choice is to use the Palette format to get a single color for each interval. Then select the same number of lines as in the line definition and mark the same intervals and colors.

Back on the Noise map tab it is possible to save the entire definition as a template and even make it a standard for the country you are working in. In this way simply by making a calculation in the country WindPRO will default choose the settings saved as standard for that country.

In the Elevation part WindPRO will default choose to use the digital height model of the project when it calculated the noise map. Alternatively it is possible to choose a fixed elevation. Just be aware that WindPRO then calculates the line of sight distance from the base elevation of the turbines + hub height to the fixed height selected. In mountainous terrain this can potentially be quite wrong.

The calculation area for the noise map is default set to 2500 m around the wind farm. However with very large wind farms or when checking very low noise levels it may be necessary to extend the map further out.

The resolution is automatically selected based on the area size keeping the calculation time down by increasing the grid size when the area calculated is increased. Alternatively a fixed grid size can be selected.

If the calculation model requires a comparison to ambient noise it is possible add the ambient noise to a noise map by adding a shape file with ambient noise. Be sure to select the right coordinate system and the database column with ambient noise values.

4.1.3.2 DECIBEL - Calculation

If all required data are available for the wind turbine types being calculated, the DECIBEL calculation will commence when OK is pressed.

If some of the source noise data are missing, the window shown below will appear
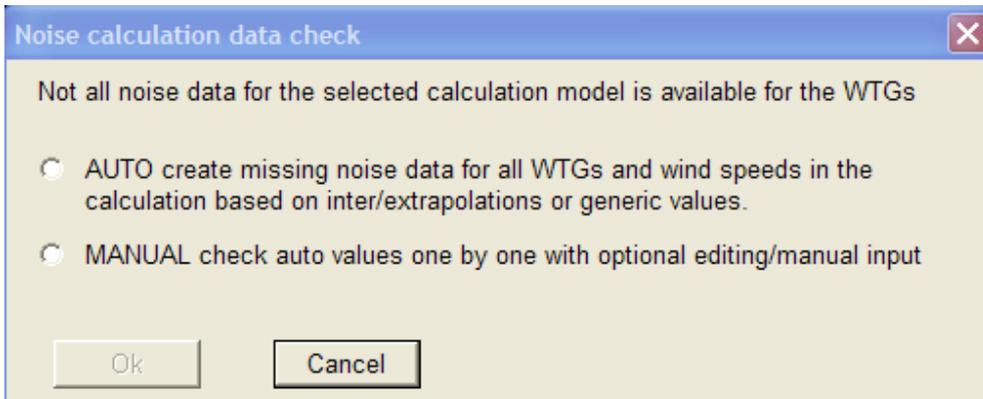
It is now possible to let WindPRO suggest some source noise values for the missing values.

It is advisable to manually review the suggestions or override them with manually-selected noise data.

Selecting the MANUAL option will open the selection window shown below.

Now noise source data must be defined for all the missing parts.

The name of the turbine type is shown in the top of the window. The noise data selected for this turbine type is shown in the window below. If anything in this window is shown with a red background, it means that the noise data record is incomplete for the selected calculation.

The available data are listed in the central field with red fields showing where data are missing. In the above example, data are missing for 60 m hub height for the 6 m/s wind speeds. The left red markings indicate that the source noise level is missing and the right red marking indicate that an octave-band distribution of the source noise is missing for both the wind speeds. WindPRO has filled in suggestions in those fields.

If the first line is highlighted you can see what WindPRO suggests.

WindPRO has extrapolated noise values from other wind speeds resulting in the suggested L$_{wa,ref}$. It also concluded that since those other wind speeds held pure tones, so must the one with missing data. Finally it suggests a generic octave band distribution that summed together will result in the total L$_{wa,ref}$.

The user can revise these values in which case you will have to press "Update list with current values", or simply accept the suggestions and move to the next turbines or start the calculation.

Please note that all these steps must be repeated if you do a re-run of your calculation. There is no way to save the input data. If you have the required noise data, the right place to input them is in the wind turbine catalogue, where you can enter user-defined noise data.

If you use generic data, the calculation report will say which data were generic.

Decision making for missing data
While it is best to have complete and correct data for the noise impact calculation it is often the case that data are missing. In those cases EMD strongly recommend to obtain the missing data from the wind turbine manufacturer and enter those value into the wind turbine catalogue. However analyses are often made at an early stage or data simply does not exist for the turbine type. For these situations WindPRO can assume generic or derived values.

Essentially noise data are required for the wind speed of the calculation, the tower height of the turbine, and in many cases the noise value must be based on a 1/1 octave band distribution.

If the proper wind speed is missing WindPRO can interpolate between the two closest wind speeds to find the noise value or extrapolate linearly using the two closest wind speeds. Extrapolated values must be used with caution as noise as a function of wind speed is not a linear function in reality.

If there is only one wind speed available WindPRO will use the Wind speed dependency value for this turbine.

If no noise value is available at all, WindPRO will look up the noise level in the noise vs. generator size experience function shown below (Møller, Aalborg University).

The figure shows a plot with y-axis labeled "dB re 1 pW" ranging from 80 to 120, and x-axis labeled "Nominel elektrisk effekt" ranging from 100 kW to 100 MW. The fitted equation shown is:

$$L_{WA} = 9.7\ dB \cdot \log_{10}(\text{nom. effekt}/1\ MW) + 100.9\ dB$$

$$R^2 = 0.75$$
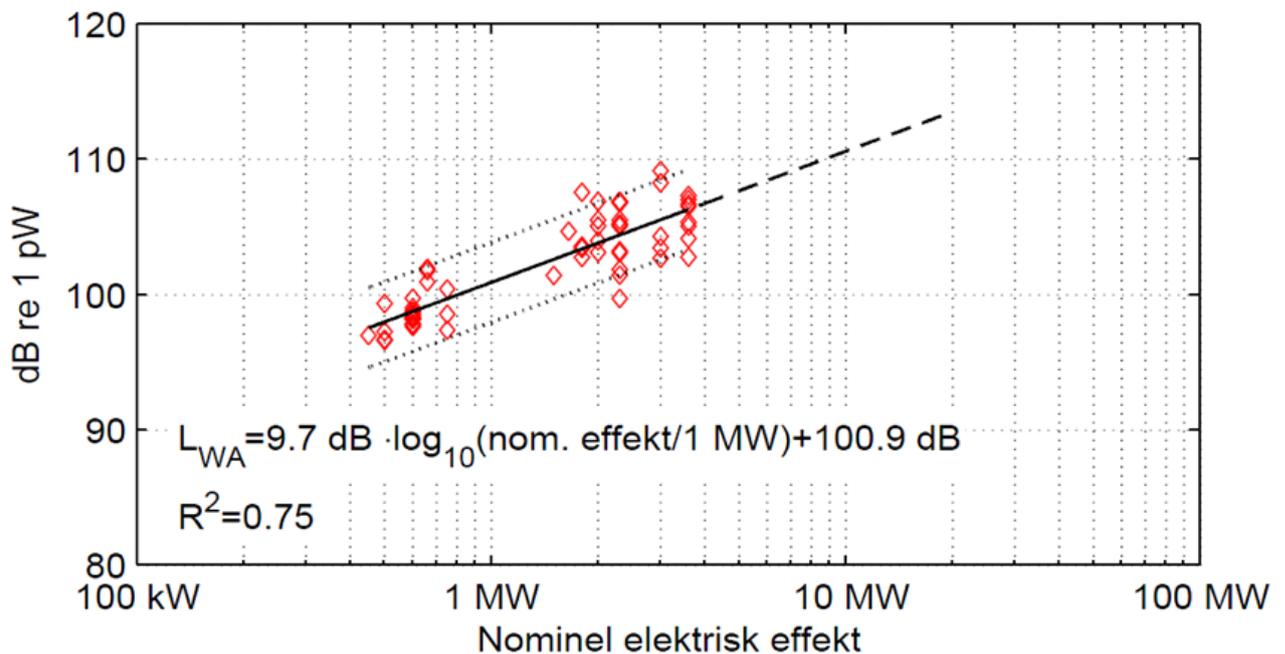
As would be noticed from the figure this is a highly uncertain approach as there is a large amount of scatter to this function.

Please note that the 95% of nominal power noise level cannot be used for extrapolation as there is no information on at which wind speed this noise level is valid.

Missing hub height
In case there are no data for the hub height selected WindPRO will interpolate between the two closest hub heights for the particular wind speed in question. If it is not possible to interpolate, the value will be found through extrapolation. In case there is only one available hub height, values from this height will automatically be used.

Only if the particular wind speed is not available from the other heights will WindPRO start the interpolation or extrapolation routines from its own height. If it is possible to interpolate or extrapolate between wind speeds in neighboring heights that will be done before using the wind speed dependency on a single wind speed for the height in question. In the same way if a single value and wind speed dependency is available for another height this will be done before looking up the above experience function to guess a noise level for the wind turbine.

Note that it is possible to define or select a hub height independent column in the wind turbine catalogue.

Octave-band distribution missing
When octave band distribution is required but missing from the data, WindPRO will suggest a distribution. Common for all suggested distributions are that they are A-weighted and when summed together they will result in the correct total noise level for that particular hub height and wind speed. The octave band distribution used as a base will be fitted by adding or deducting equally on all frequencies to achieve the wanted total noise level.

If octave band distributions are available for other wind speeds with the same hub height the closest wind speed will be used as base for the fitting.

If no octave band distribution is available for the particular hub height WindPRO will look to other heights to find the closest wind speed for a base distribution.

If that is not possible either (there simply are no octave band distributions available for this noise record) WindPRO will assume a generic distribution and fit this to the required noise level. The distribution used is a typical distribution, which by experience tends to fit many turbine types fairly well.

It must however be emphasized that while adopting a octave band distribution from a another wind speed of the same turbine will result in only marginal error, it is strongly encouraged to obtain the correct octave band distributions from the manufacturer, especially if no other distribution is available for the turbine.

Special for Denmark
When choosing the Danish 2011 codes or the Danish low frequency calculations the automatic adaption of data is disconnected. If octave data for the relevant wind speeds are not available for turbine <= 2MW a special set of official generic source noise data will be used. For turbines > 2MW generic data are used based on generator size.

4.1.3.3. DECIBEL - Printout

After the calculation has been completed, a window like the one shown below will appear which lists the available reports that can be printed.
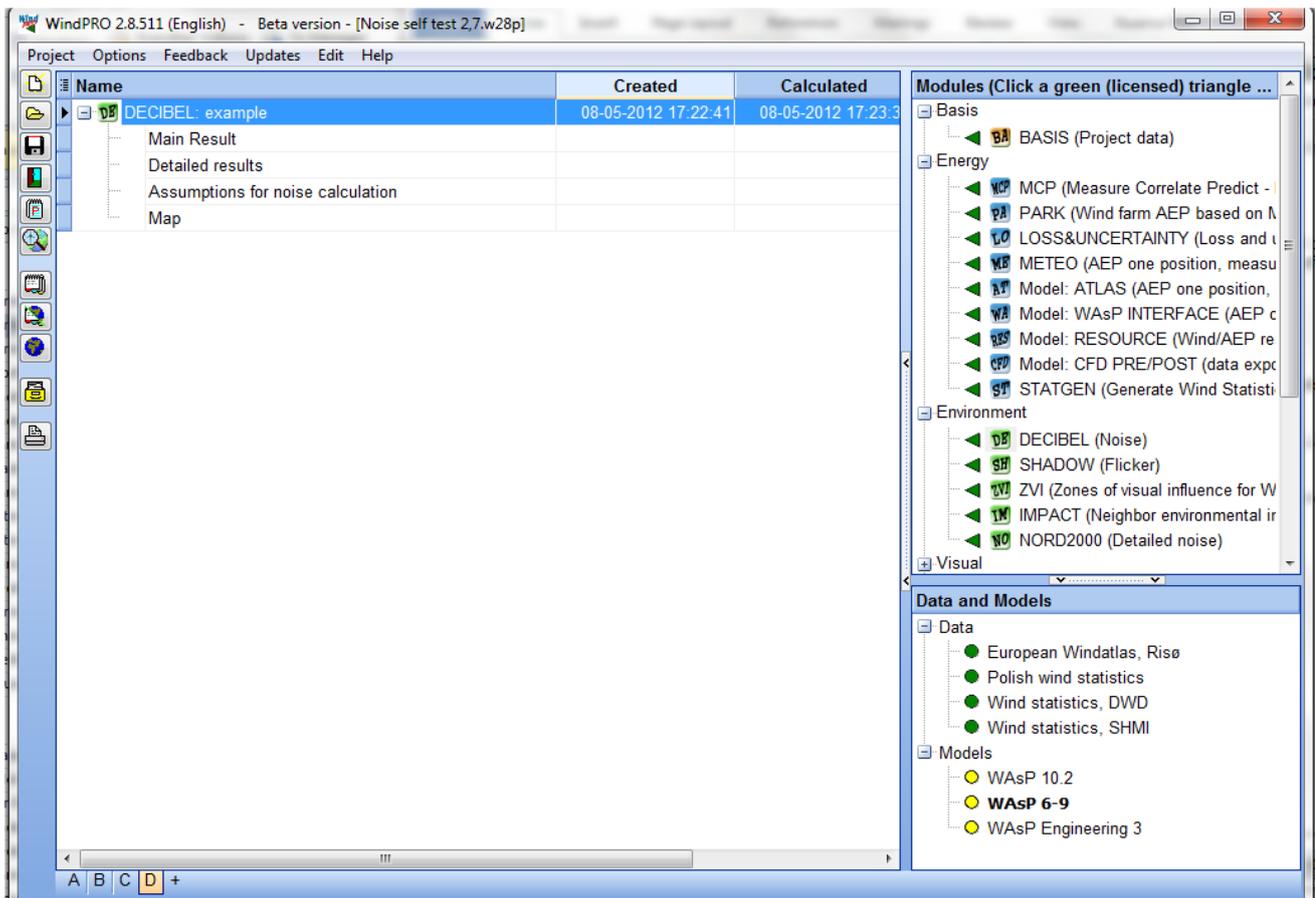
Next to the calculation name a number of properties can be selected, such as date, calculation time, etc. by right-clicking in the top bar and selecting the relevant properties.

The reports will automatically pop-up on the screen if you double-click the report page name.

If you right-click on the calculation name and select "Print", you access the Report Setup where it is possible to customize the calculation report and view all pages at the same time (see below).
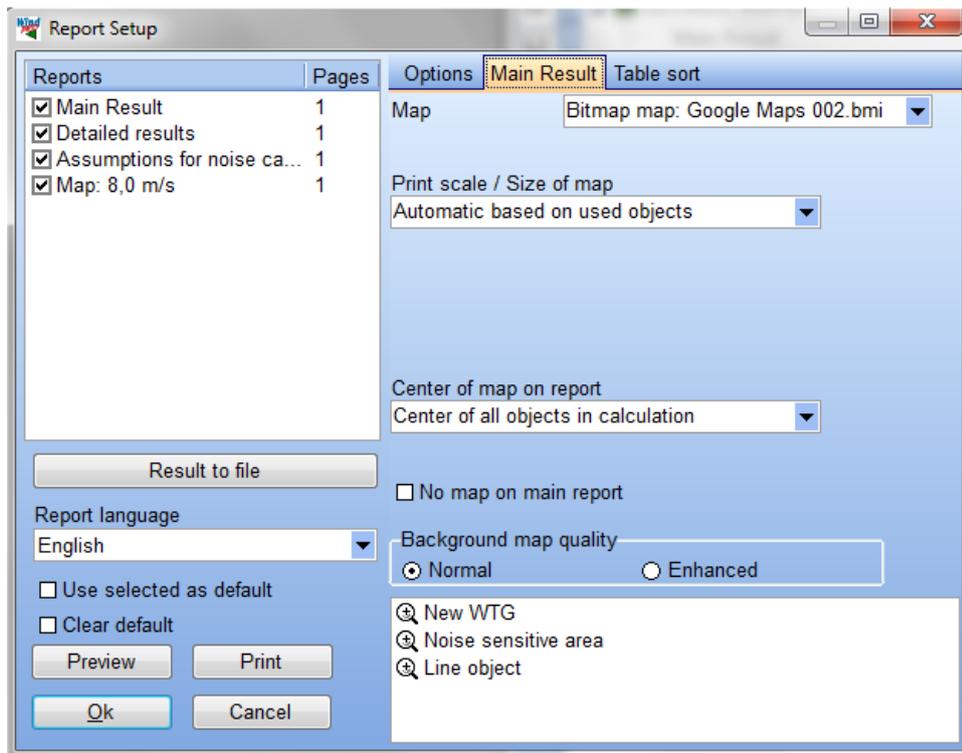
In the checkbox to the left, the individual report elements can be selected or deselected for printout. By clicking on the report name you gain access to the setup mode for the selected report in the right half of the window. Here, details regarding the individual reports can be set (e.g. the map scale which is to be used on the printout, which maps to include, etc).

Please notice the option to plot noise-level contours on the map, which can be set up individually. This works in an identical way to the calculation setup and gives you the option to reconsider your graphical settings.

Further details on printing can be found in Chapter 2 BASIS.

You will find examples of printouts from all the modules in "Module descriptions".

At this point please note that the printout is slightly different for the various codes implemented. Most different are calculations where a range of wind speeds have been chosen. Here, the main report will present the most critical wind speed results for each of the receptors. An extra report page is included showing the calculation result as a graph and in a tabular form (see below).

Farm (A)

Wind speed	Ambient noise	Demands Margin	Demands	Sound Level WTG noise	Demands fulfilled ?
[m/s]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	
4,0	28,0	5,0	33,0	32,3	Yes
5,0	29,0	5,0	34,0	33,3	Yes
6,0	30,0	5,0	35,0	34,3	Yes
7,0	32,0	5,0	37,0	35,3	Yes
8,0	34,0	5,0	39,0	36,3	Yes
9,0	36,0	5,0	41,0	37,3	Yes
10,0	37,0	5,0	42,0	38,3	Yes
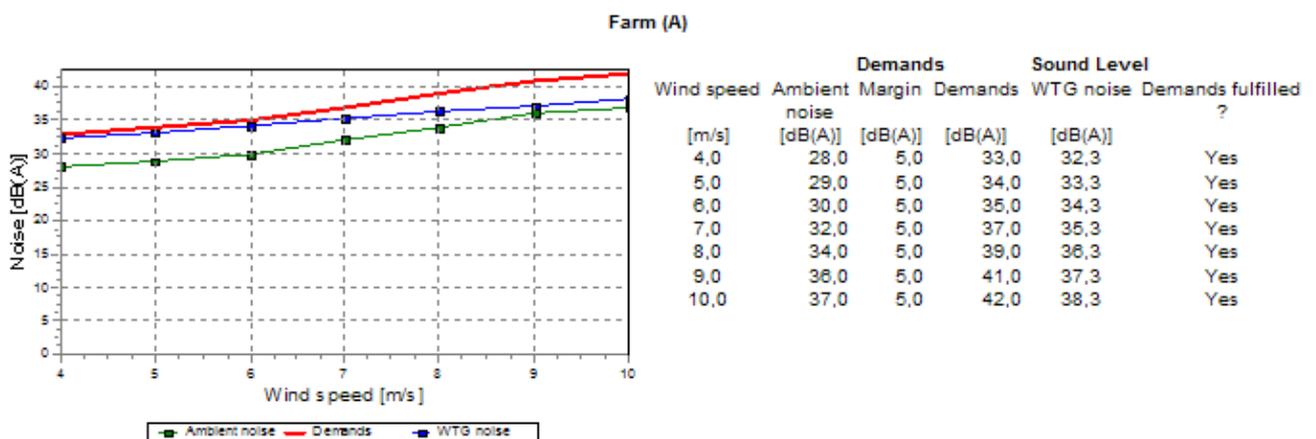
Here the ambient (background) noise level is shown. The critical level (demand) is shown as a red graph and the calculated sound level, whether it is the noise from the wind turbines or a combination of ambient and WTG noise is shown in blue. For each of the wind speeds included, the calculated noise levels are compared against the demands to determine whether or not the demands are fulfilled.

If the NSA was entered as an area, the result will give the coordinates of the point of the area with the highest noise level and the calculated level.

Result to file
Both from the print setup and by right-clicking the calculation headline it is possible to send "Result to file"
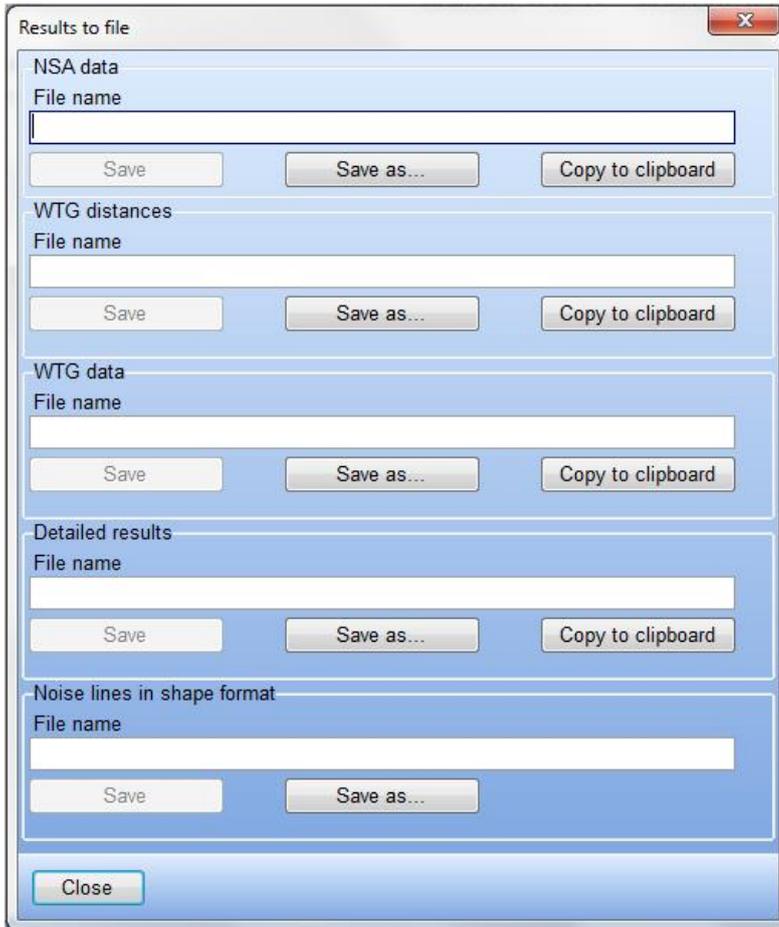
From here it is possible to either save selected data to a text or shape file or copy them to clipboard and for example paste them into Excel or similar packages.

4.1.3.4 Noise optimization using the result layer

It is possible to show the noise iso-lines on the background map and have them automatically update when the WTGs are moved. This can be a great help in finding the optimal layout with regards to noise emission.

The procedure is to perform the DECIBEL calculation as described above. On the "Main" tab "Interactive noise lines on map for layout optimization" calculation option must be selected (see below).
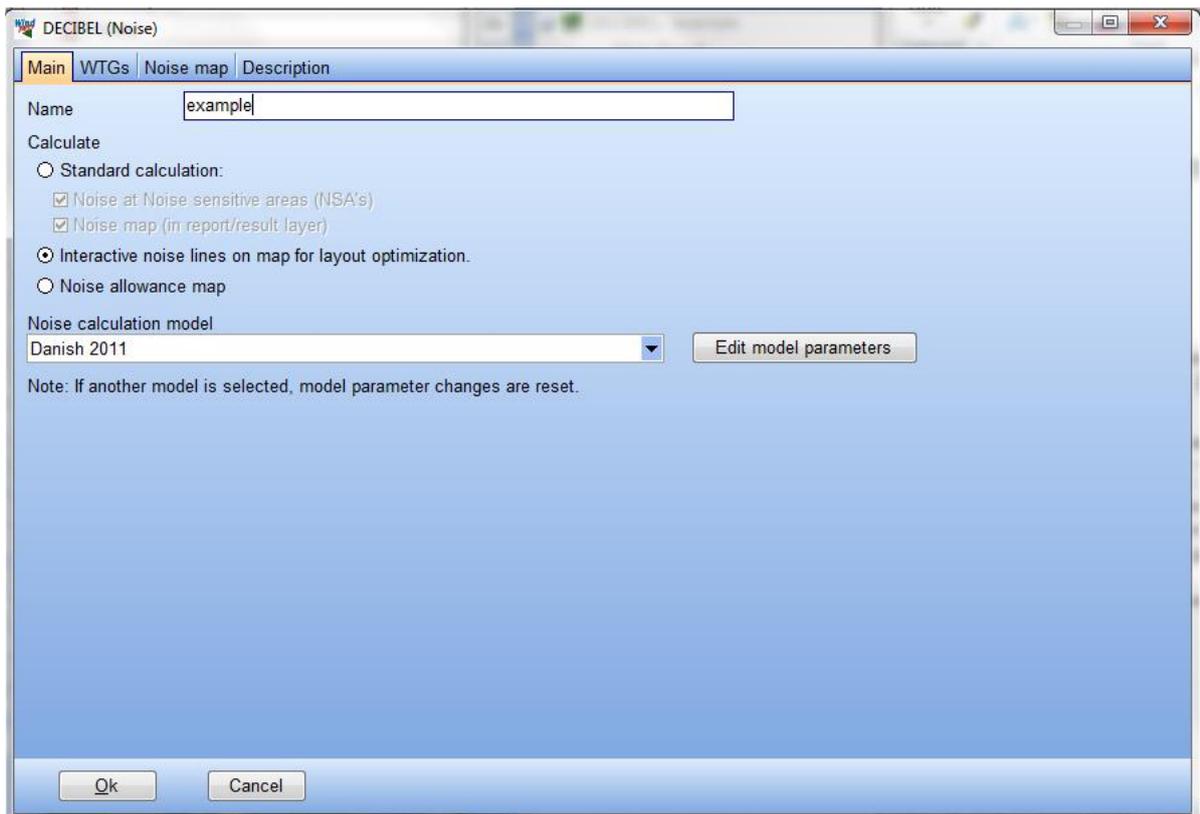
On the "Noise map" tab only one wind speed is allowed. If you have several wind speeds you will have to use the minus button to remove you excess wind speeds.

When you run the calculation WindPRO will now produce a Result layer on the maps in Maps and Objects. Where the Result layers in a standard calculation are static, this result layer is dynamic, meaning that every time a change is registered (i.e. a turbine is moved) WindPRO will update the noise lines.
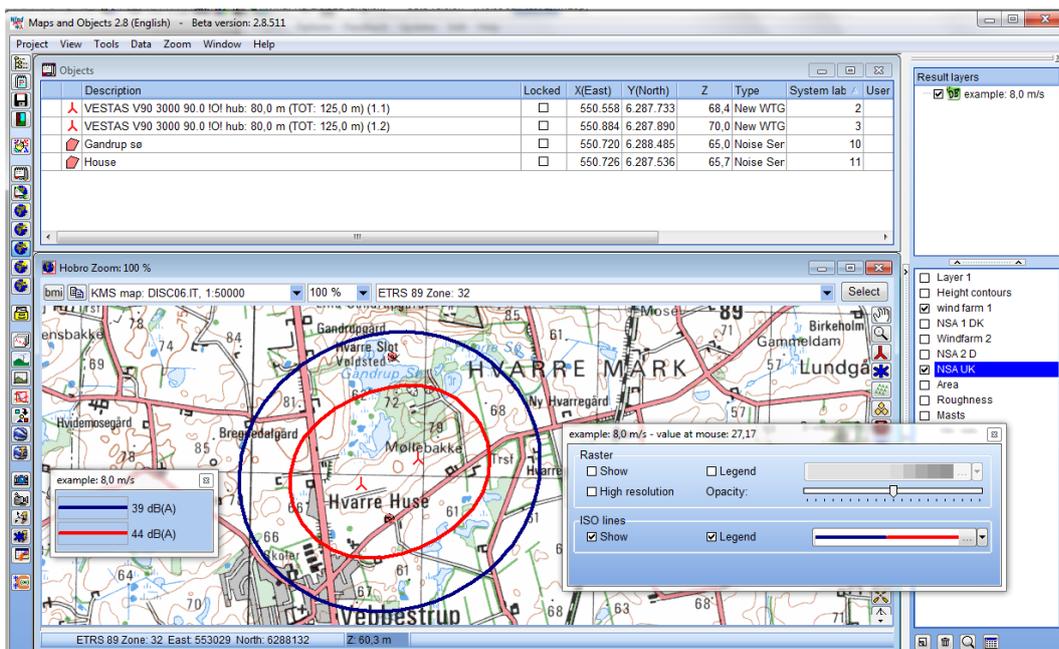
In the illustration note the result layer in the top right.

You can move the turbines, change noise settings or turbine types, remove turbines or add turbines (in the layers used for the calculation). When the turbines are deactivated (no turbines selected anymore) the update

takes place. It can therefore be a good idea to jump directly from turbine to turbine to make the changes and only then release the turbines in order to minimize update time.

The generation of the noise iso-line is faster than for the reports because the grid size is deliberately larger. However with large wind farms these updates may still run very slowly. It may therefore be useful to reduce the amount of detail by choosing a simpler code or flat terrain for the noise optimization and then re-apply the full details for the final report,

Right-clicking on the result layer gives access a few selections of the result layer. The noise lines can be switched on or off and the legend can be switched on and off.

It is also possible to enter the properties of the Result layer (see figure above).

A regular noise iso-line calculation also creates a result layer, but those are static and need a reculation to update.

When you are finished using the noise optimization it is a good idea to delete the result layer. Otherwise it will keep updating every time you manipulate you project. You can always recreate the lines by running the calculation again.

The result layers have so additional features besides being useful for presenting the results. One very useful feature is that they can be exported to numerous formats. Right click on the result layer and select export.
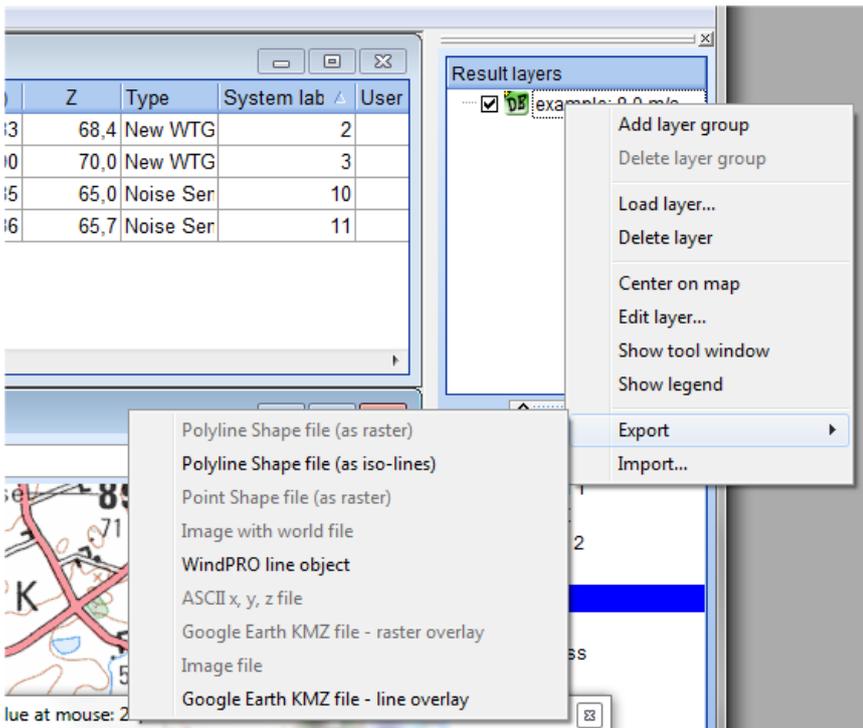
4.1.3.5 Noise allowance map

A third calculation option from the Decibel calculation is to generate a map that shows the maximum allowed noise. This map considers the area available for turbines and the noise sensitive points and areas surrounding the site and can be used to find out if there is room for wind turbines on the site.

A prerequisite for the calculation is a WTG area object. WTG area objects are described in detail in Section 8.1.2.1. The area needed for this calculation only need to contain the boundaries of the site. There is no need to define turbine numbers and spacing, nor exclusion zones etc.
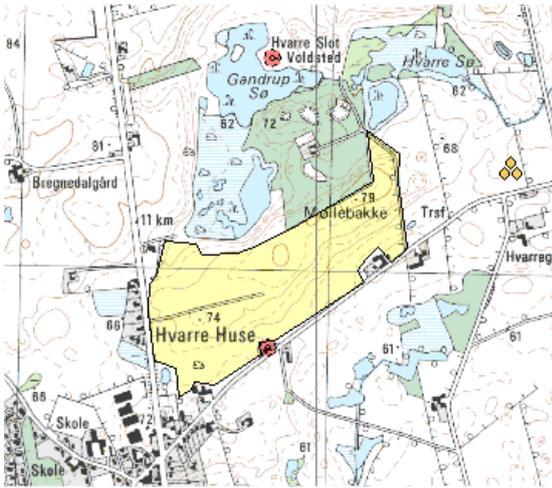
The Noise allowance map calculation is selected on the main tab when running a Decibel calculation.

Note that the calculation model is disabled.

The tabs now available are the NSA and the Noise allowance map tabs.

On the NSA tab the noise receptors limiting the site are selected by layer.

The selections on the Noise allowance map tab relate to map to be created. The WTG areas defining the area are selected in the top part. Below this it is possible to select the grid size (resolution) of the map. The smaller the grid size the slower the calculation. Calculation hub height defines the height of the noise source.

If you want the resulting map displayed on the map in Maps and Objects you can hatch the box for "Show result in a result layer on the working map". Otherwise the map will only be shown in the calculation report.
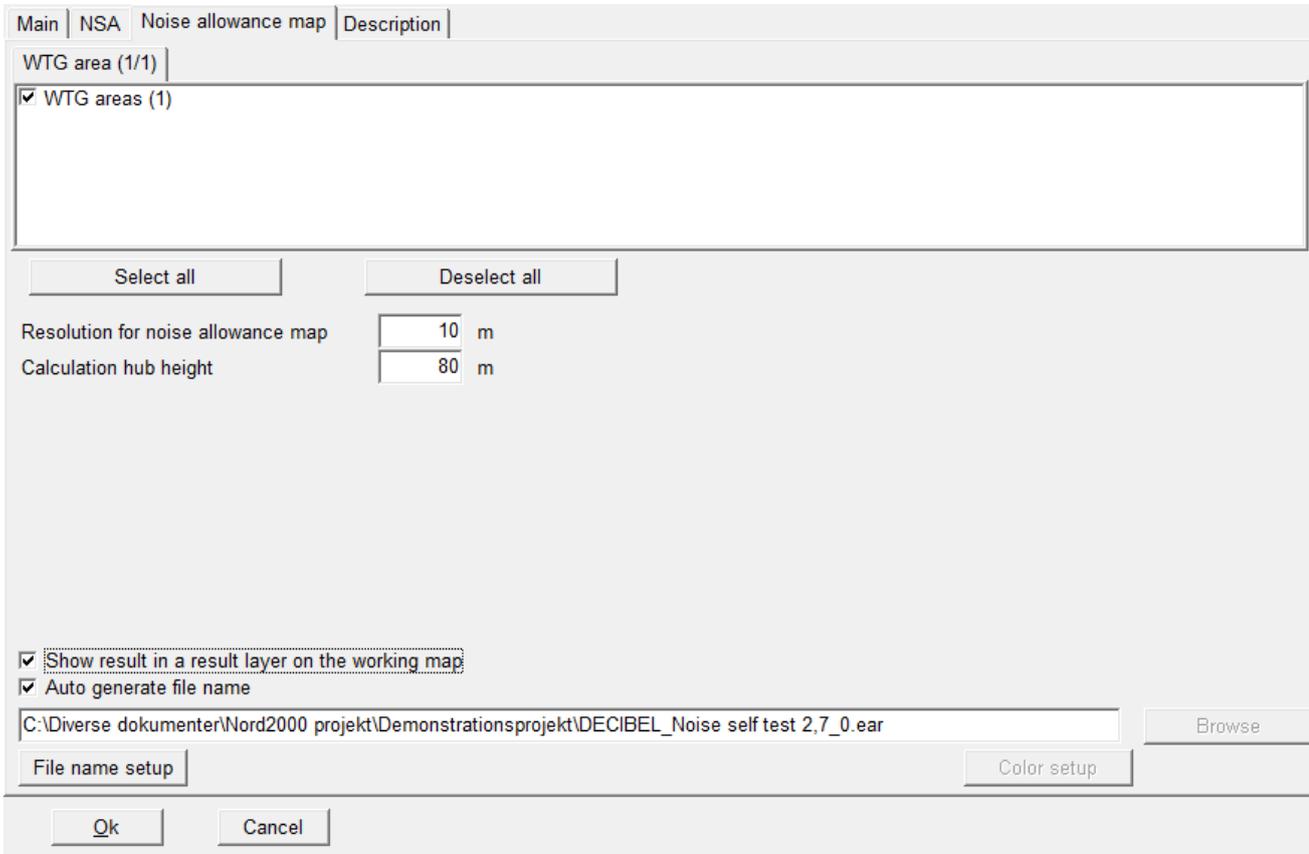
The resulting map is shown below in Maps and Objects. Right-clicking on the Result layer gives access to a legend.
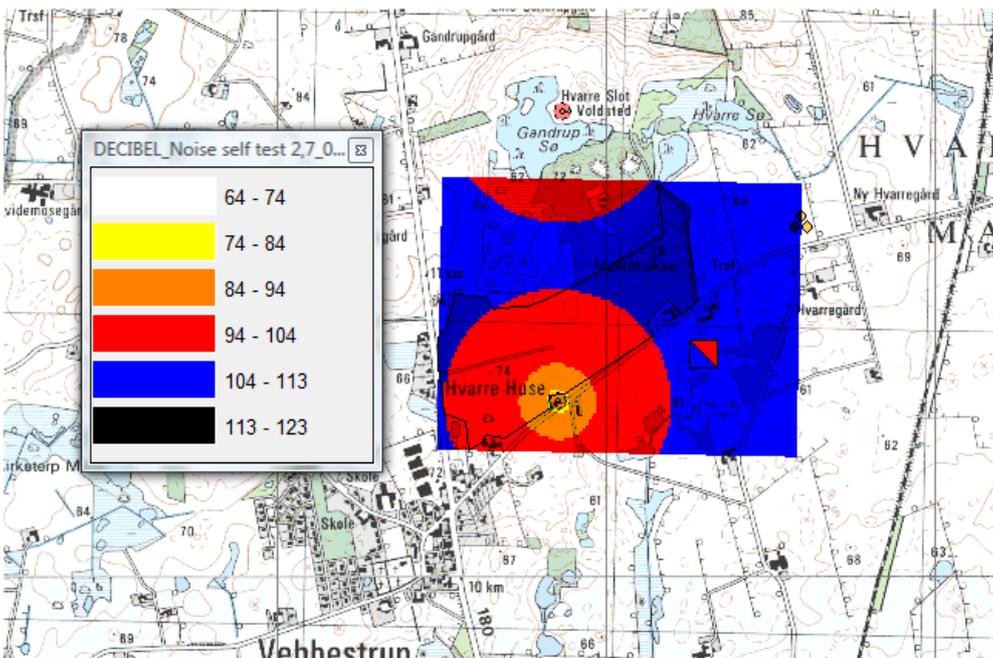
The map shows in a color code how much noise (L_{WA}) a turbine will be allowed to make depending on location.

4.1.4 Appendix. Theoretical background for noise propagation models

4.1.4.1 The International rule DIN ISO 9613-2, general

The ISO 9613-2 "Attenuation of sound during propagation outdoors, Part 2. A general method of calculation" describes the calculation of damping of the noise during propagation outdoors.
This text describes the theoretical basis of the ISO 9613-2 as implemented in WindPRO.

Calculation formulas if octave data are not available

Normally, the A-weighted noise source (without octave division/classification) is determined for one WTG type through measurements. The damping values at 500 Hz are used to determine the resulting damping of noise emission. The general method for calculation of ground attenuation cannot be used. The resulting noise level from each source is thereafter calculated from the ISO 9613-2 as follows:

$$L_{AT}(DW) = L_{WA} + D_C - A - C_{met} \qquad (1)$$

L_{WA}: Source noise, A-weighted.

D_c: Directional correction for noise source without directional effect (0dB), but taking the reflection from the terrain into consideration, D_Ω (Needed because the alternative method for calculating ground attenuation, Agr is used)

$$D_C = D_\Omega - 0 \qquad (2)$$

D_Ω is calculated as:

$$D_\Omega = 10 \lg\{1 + [d_p^2 + (h_s - h_r)^2] / [d_p^2 + (h_s + h_r)^2]\} \qquad (3)$$

Where:
h_s: Noise source height above terrain (hub height)
h_r: Noise receptors height above terrain (usually 5m, but can be set individually in the calculation setup)
d_p: Distance between noise source and recipient projected on level terrain

The distance is determined by the (x,y) coordinates for sources (index s) and recipient (index r).
$$d_p = \sqrt{[(x_s - x_r)^2 + (y_s - y_r)^2]} \qquad (4)$$

A: Damping between the noise source (WTG-Nacelle) and the noise critical point:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \qquad (5)$$

A_{div}: Damping due to geometry

$$A_{div} = 20 \lg(d/1m) + 11 \text{ dB} \qquad (6)$$

d: Distance between noise source and recipient
A_{atm}: Damping due to air absorption

$$A_{atm} = \alpha_{500} \, d / 1000 \qquad (7)$$

α_{500}: Air absorptions coefficient (= 1,9 dB/km)
The value for α_{500} is based on the most optimal noise emission conditions (temperature 10 Gr. C and 70% relative atmospheric humidity)

A_{gr}: Terrain damping:

$$A_{gr} = 4,8 - (2h_m / d)[17 + (300 / d)] \qquad (8)$$
$$\text{IF } A_{gr} < 0 \text{ then is } A_{gr} = 0$$

h_m: Average height above terrain (in meters) for noise emission
If there is no orography for the site:

hm = (hs + hr) /2   (9a)

If there is a DHM in the area between line of sight and the terrain surface between the WTG and the immission point, it will be calculated based on a grid (grid size set in the calculation setup) with a calculation for each grid point the line of sight passes through. The medium height is calculated by:

h_m = F/d   (9b)

F: Integrated area from emission point to receptor (immission point)
$F = F_1 + F_2 + … + F_{100}$
d: distance from emission point to receptor (immission point)

A_{bar} :   Damping due to shielding (noise protection) normally no
shielding protection: A_{bar} =0.
A_{misc}:   Damping due to different other effects (vegetation, buildings, industry). Usually these effects are not included in the calculation. A_{misc} =0.

C_{met}:   Meteorological correction which is determined by means of the equation:
C_{met} = 0 for dp < 10 (h_s+h_r)
C_{met} = C0 $[1-10(h_s+h_r)/dp]$ for dp > 10,
d_p: Distance between noise source and recipient projected on level terrain.

where the factor C0, dependent on weather conditions, can be between 0 and 5 dB. In exceptional cases, values over 2 dB may occur. In WindPRO, C0 can be defined individually for each noise calculation.

Calculation method with octave-divided noise data

Using the ISO 9613-2 it is possible to calculate according to octave-divided noise figures for a WTG. If such data are available and entered into the WindPRO WTG catalogue, they will automatically be used in calculations. Using octave-band data also makes it possible to use the general ground attenuation method. In the following formula is only demonstrated the difference from calculation with 500 Hz frequency as average value. The resulting noise is calculated as follows:

L_{AT} (DW) = $10lg[10^{0,1LAfT(63)} + 10^{0,1LAfT(125)} + 10^{0,1LAfT(250)} + 10^{0,1LAfT(500)} + 10^{0,1LAfT(1k)} + 10^{0,1LAfT(2k)} + 10^{0,1LAfT(4k)} + 10^{0,1LAfT(8k)})$ (10)

where:

L_{AfT}:   A-weighted noise source for each noise sources at different frequencies (63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz)

The A-weighted noise source L_{AfT} at average frequencies for each noise source is calculated from:

L_{AfT} (DW) = $(L_W + A_f) + D_C - A$ (11)

where:

L_W: Octave noise source for non A-weighted point source. LW + Af constitute the A-weighted octave-divided noise source LWA according to IEC 651

A_f: standardized A-weighted from IEC 651. WindPRO calculates the A-weighted values for the noise source according to this.

D_c: Directional correction for noise source without directional effect (0dB), but taking the reflection from the terrain into consideration. If general ground attenuation is used $D_\Omega = 0$, which means $D_c = 0$. If alternative method is used D_c is calculated as in the non-octave band case.

A: Octave damping, damping between point source and recipient which is determined as described above by the following damping types:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \qquad (12)$$

A_{div}: Damping due to geometry (= VDI 2714 Distance figure Ds)
A_{atm}: Damping due to air absorption, frequency dependent (=VDI 2714 air absorption figure DL)
A_{gr}: Terrain damping:(=VDI 2714 Terrain and meteorological damping figures DBM)
A_{bar}: Damping due to shielding (noise protection), worst case, no noise protection $A_{bar} = 0$
A_{misc}: Damping due to different other effects (growth, housing, industry). Worst case $A_{misc} = 0$

At octave-divided noise emissions, the damping due to air absorption depends on the frequency due to the air absorption:

$$A_{atm} = \alpha_f \, d / 1000 \qquad (13)$$

where:

α_f: absorption coefficient for each frequency band.

The air-damping coefficient depends strongly on the noise frequency, surrounding temperature and the relative atmospheric humidity. The adverse conditions are at 10 degree Celsius and 70% relative atmospheric humidity. The following values are:

Band, mean frequency, [Hz]	63	125	250	500	1000	2000	4000	8000
α_f, [dB/km]	0.1	0.4	1	1.9	3.7	9.7	32.8	117

For the terrain damping there is two methods available for calculation the ground attenuation, A_{gr}. The alternative method is as described for the non-octave band case above. The general method is calculated as:

$$A_{gr} = A_s + A_r + A_m \qquad (14)$$

Where

A_s: The attenuation for the source region spanning $30h_s$, though max d_p. This region is described by the ground factor G_s, which gives the porosity of the surface, a value between 0 (hard surface) and 1 (porous surface).
A_r: The attenuation for the receiver region spanning $30h_r$ from the receiver. This region is described by the ground factor G_r.
A_m: The attenuation for the middle region. If the source and receiver region overlaps, then there is no middle region. This region is described by the ground factor G_r.

In WindPRO only one parameter for G (porosity) is used

$$G = G_s = G_r = G_m \qquad (15)$$

The porosity is set in the calculation setup.

The below extract from the ISO 9613-2 document explains how the three ground attenuations are calculated.

Nominal midband frequency	A_s or A_r[1)]	A_m
Hz	dB	dB
63	− 1,5	− 3q [2)]
125	− 1,5 + G × a′(h)	
250	− 1,5 + G × b′(h)	
500	− 1,5 + G × c′(h)	
1 000	− 1,5 + G × d(h)	− 3q(1 − G_m)
2 000	− 1,5(1 − G)	
4 000	− 1,5(1 − G)	
8 000	− 1,5(1 − G)	

NOTES

$$a'(h) = 1,5 + 3,0 \times e^{-0,12(h-5)^2}\left(1 - e^{-d_p/50}\right) + 5,7 \times e^{-0,09h^2}\left(1 - e^{-2,8 \times 10^{-6} \times d_p^2}\right)$$

$$b'(h) = 1,5 + 8,6 \times e^{-0,09h^2}\left(1 - e^{-d_p/50}\right)$$

$$c'(h) = 1,5 + 14,0 \times e^{-0,46h^2}\left(1 - e^{-d_p/50}\right)$$

$$d'(h) = 1,5 + 5,0 \times e^{-0,9h^2}\left(1 - e^{-d_p/50}\right)$$

1) For calculating A_s, take $G = G_s$ and $h = h_s$. For calculating A_r, take $G = G_r$ and $h = h_r$. See 7.3.1 for values of G for various ground surfaces.

2) $q = 0$ when $d_p \leq 30(h_s + h_r)$

$$q = 1 - \frac{30(h_s + h_r)}{d_p} \quad \text{when } d_p > 30(h_s + h_r)$$

where d_p is the source-to-receiver distance, in metres, projected onto the ground planes.

Long-term average noise level (resulting noise level)

Noise source figures and distances to noise critical points will be overlaid (superimposed) if the calculation contains n noise sources (wind farm). The resulting noise L_{AT} is calculated according to following:

$$L_{AT}(LT) = 10 \cdot \lg \sum_{i=1}^{n} 10^{0,1(L_{ATi} - C_{met} + K_{Ti} + K_{Ii})} \qquad (14)$$

L_{AT}:   Resulting noise at noise critical points
L_{ATi}:   Noise at noise critical point from noise source i
i: Index for all noise sources from 1-n
K_{Ti}:   Addition for pure tone content for a noise source i, depends on the local rules
K_{Ii}:   Addition for impulse tone content for a noise source i, depends on the local rules
C_{met}:   Meteorological correction which is determined by means of the equation:
$C_{met} = 0$ for dp < 10 $(h_s + h_r)$
$C_{met} = C0 [1 - 10(h_s + h_r)/dp]$ for dp > 10,
d_p: Distance between noise source and recipient projected on level terrain.

where the factor C0, dependent on weather conditions, can be between 0 and 5 dB. In exceptional cases values over 2 dB may occur. In WindPRO the C0 can be defined individually for each noise calculation.

4.1.4.2 Calculation of Lden (Norway)

L_{den} is a weighted average of the noise over a period of time. The den label refers to day-evening-night and means that the noise is calculated independently for each period with special penalties for evening and night. The noise for each period is calculated as L_{eq24}, which corresponds to the standard L_{WA} noise calculated normally in WindPRO. The formula for converting L_{eq24} noise to L_{den} is given in the formula below, adapted from Statens Forurensningstilsyn's spreadsheet lden_lekv_driftstid.xls.

$$L_{den} = 10 * \log\left(\frac{10^{\frac{L_{day,y}}{10}} * t_{day} + 10^{\frac{L_{eve,y}+P_{eve}}{10}} * t_{eve} + 10^{\frac{L_{night,y}+P_{night}}{10}} * t_{night}}{24}\right)$$

Where t gives the number of hours in the periods day, evening and night respectively. Typical values are 12, 4 and 8 hours
P is the penalty for evening and night respectively. Typical values are 5 and 10 dB.
$L_{day,y}$ is the annual average of daytime noise given as:

$$L_{day,y} = 10 * \log\left(\frac{10^{\frac{L_{day,d}}{10}} * O_y}{365}\right)$$

Where O_y is the operation days per year. This value is typically set to 290 days.
$L_{day,d}$ is the daily average of noise. Typically this will the same as L_{eq24} or L_{WA}. If the turbine is stopped parts of the day $L_{day,d}$ can be calculated as:

$$L_{day,d} = 10 * \log\left(\frac{10^{\frac{L_{eq24,day}}{10}} * t_{day}}{12}\right)$$

L_{eve} and L_{night} are calculated the same way.

$$L_{eve,y} = 10 * \log\left(\frac{10^{\frac{L_{eve,d}}{10}} * O_y}{365}\right)$$

$$L_{night,y} = 10 * \log\left(\frac{10^{\frac{L_{night,d}}{10}} * O_y}{365}\right)$$

$$L_{eve,d} = 10 * \log\left(\frac{10^{\frac{L_{eq24,eve}}{10}} * t_{eve}}{4}\right)$$

$$L_{night,d} = 10 * \log\left(\frac{10^{\frac{L_{eq24,night}}{10}} * t_{night}}{8}\right)$$

4.1.4.3 The German rule VDI 2714 (outdated)

Until 01.10.1998 calculations were performed from VDI-Guideline Directions "Noise emission in open air". The starting point for the calculation is a simple A-weighted noise emission. The formula below is the calculation formula for noise level at the distance S between the WTG and the noise-sensitive point:

LS = LW + DI + KO - DS - DL - DBM - DD - DG   in dB(A)

LS   : Calculated noise level in distance S
LW   : Noise emission for the WTG
DI   : Directional impact figure (= 0)
KO   : Solid angle figure (= 3 dB)
DS   : Distance figure DS=10 log(4 π S2)
DL   : Air absorption figure DL=α_L S
            α_L = 0.00209 dB/m

DBM   :Terrain and meteorological damping figure

DBM = Max(0, 4.8 - (hq+hA)/S(17+300/S))
       hq hub height
       hA Noise critical point height above terrain IP (= 5m)
DD   : Vegetation damping figure (= 0)
DG   : Build up damping figure (= 0)

Default values are shown in brackets. These are the so-called "worst case" values, which WindPRO uses. For instance, vegetation damping will normally always be >0 and therefore the measured noise should be below the value calculated.
If the noise originates from several sources (e.g. a wind farm) then each individual noise source contribution is add up and the resulting noise at noise critical points is calculated from there..

4.1.4.4 Danish noise codes

Danish codes 1991

The Danish rules are outlined in "Bekendtgørelse om støj fra vindmøller" (Statement from the Department of Environment) No. 304 of 14/5/91.
The key equation is:
$L_{pA} = L_{WA,ref}$ - 10 x log(l^2+ h^2) - 8dB - ΔL_a
Where
l is the distance between the WTG and the neighbor
h is the height difference between the nacelle and the neighbor (normally = hub height) and
ΔL_a is the air absorption.

ΔL_a is calculated as $\alpha_a \overline{\sqrt{(l^2+ h^2)}}$

Where α_a is the damping coefficient (0.005 dB/m or from the table below).
Octave Band Damping Coefficient:

Center freq. (Hz)≤	125	250	500	1000	2000	4000	8000
α_a (dB/m)	0	0	0.002	0.004	0.007	0.017	0.06

If the noise emission from the WTG is given for each octave band (see Chapter 2, section 5 "WTG Catalogue" under WindPRO BASIS), the damping coefficient will be more correctly included in the calculations, but this is not a requirement.

Danish codes 2007

From 2007 new noise codes for Denmark are used in Denmark based on "Bekendtgørelse nr. 1518 af 14. December 2006, Bekendtgørelse om støj fra vindmøller".
The propagation model here is changed with a separate damping for offshore wind turbines.
The central equation for is:
$L_{pA} = L_{WA,ref}$ - 10 x log(l^2+ h^2) - 11dB + ΔL_g - ΔL_a
Compared to the former Danish codes the difference is in the damping.
The ground attenuation ΔL_g is 1,5 dB for onshore turbines and 3 dB for offshore wind turbines.
The air absorption ΔL_a is calculated as above but with revised damping coefficient as follows:

Center freq. (Hz)≤	63	125	250	500	1000	2000	4000	8000
α_a (dB/m)	0.0001	0.0004	0.001	0.002	0.0036	0.0088	0.029	0.1045

The noise must be calculated using 1/1 octaves.

The noise level from groups of turbines are added together using the formula:

$$L_{total} = 10 * \log \left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{P2}}{10}} + \cdots \right)$$

4.1.4.5 Swedish noise codes, 2002.

By the end of 2001, new guidelines for calculating noise from WTGs were released in Sweden. They are called "Ljud från Vindkraftverk", Naturvårdsverket 2001, ISBN 91-620-6641-7. They replace former calculation methods and distinguish between onshore and offshore conditions.

Swedish, Jan 2002, Land.

For distances from the WTG up to 1000 m, the following formula is used:

$$L_A = L_{WA,corr} – 8 – 20 * log(r) – 0,005*r$$

where r is the distance from the receptor to the hub of the WTG.

$L_{WA,corr}$ is a corrected source emission value, which depends on the roughness of the terrain and noise as a function of wind speed.

$$L_{WA,corr} = L_{WA,measured} + k*\Delta v_h$$

Where $L_{WA,measured}$ is the measured, A-weighted noise emission level at hub height and 8 m/s at 10 m height.

k is the rate of change of noise with wind speed. In WindPRO k is set to 1 dB/(m/s).

Δv_h is the difference in wind speed at hub height compared to 10 m height and is calculated as:

$$\Delta v_h = v_h([ln(H/z_0)/ln(h/z_0)]*[ln(h/0,05)/ln(H/0,05)]-1)$$

where H is the hub height, h is 10 m and z_0 is the roughness length corresponding to a roughness class (see Chapter 3). In WindPRO, a general roughness class must be chosen for the calculation site.

If the distance between the receptor and the WTG is more than 1000 m, a different method is employed using octave-divided noise data. The noise level at the receptor is then calculated as:

$$L_A = L_{WA,corr} – 10 – 20*log(r) - \Delta L_a$$

Here the damping ΔL_a is calculated as:

$$\Delta L_a = 10*log(\Sigma 10^{(Li+Ai)/10}) – 10*log(\Sigma 10^{(Li+Ai-r*ai)/10})$$

where Li is the measured octave-band value and Ai is the A-weighting at the appropriate frequency.

r is the distance from the receptor to the WTG.

If no octave-divided data exists for the WTG, the calculation yields no result. This is true both for noise receptors and for the noise iso-line map.

Swedish, Jan 2002, Water

For the calculation of noise propagation over water surfaces, the Swedish guidelines recommends using a different formula.

$$L_A = L_{WA,corr} – 8 – 20*log(r) - \Delta L_a + 10*log(r/200)$$

where:

$$\Delta L_a = 10*log(\Sigma 10^{(Li+Ai)/10}) – 10*log(\Sigma 10^{(Li+Ai-r*ai)/10})$$

Thus octave-divided data is also required for calculation of noise emissions over water surfaces.

If no octave-divided data exists for the WTG, this calculation cannot be used (returns no values).

4.1.4.6 Dutch, 1999.

The Dutch, 1999 method follows the guidelines described in "Handleiding meten en rekenen Industrielawaai" from Ministerie van VROM, Zoetemeer, 1999, ISBN 90 422 0232 7.

The section dealing specifically with noise from WTGs is Module C, method II.8.

Theoretical background

The basic formula is:

$$L_i = L_{WR} - \Sigma D$$

Where L_i is the noise level at the receptor

L_{WR} is the noise level at the WTG

And ΣD is:

$$\Sigma D = D_{geo} + D_{lucht} + D_{refl} + D_{scherm} + D_{veg} + D_{terrein} + D_{boden} + D_{huis}$$

Which are the different damping elements.

In this method octave-divided values are used. Where these are not available, a source noise emission value is used.

In WindPRO the following assumptions are made:
- The noise receptor point is 5 m above ground
- No shelter effects or reflection of noise
- No significant noise levels at low frequencies (31,5 and 63 Hz)

- The distance between the receptor point and the WTG exceeds 1,5 times the rotor diameter.

D_{geo} is the geometrical damping and is calculated as:

$$D_{geo} = 20*\log(d)+11$$

where d is the distance from the WTG to the receptor.

D_{lucht} is the damping due to air absorption. When using octave-divided data, a specific air absorption coefficient is used for each frequency. If only a source emission value is used, D_{lucht} is calculated as:

$$D_{lucht} = 0,002*d$$

D_{refl} is the damping from reflection. This is set to 0 in WindPRO.

D_{scherm} is damping from shielding. This is set to 0 in WindPRO.

D_{veg} is damping from vegetation. This is set to 0 in WindPRO.

$D_{terrein}$ is damping from industrial terrain. This is set to 0 in WindPRO.

D_{bodem} is damping from hardness (or softness) of the ground. It is possible in WindPRO to set the acoustic hardness B of the terrain with a value from 0 (hard terrain) to –3 (soft terrain, farmland with some trees). D_{bodem} is then calculated as:

$$D_{bodem} = -2 - B$$

D_{huis} is special case damping from houses. This is set to 0 in WindPRO

4.1.4.7 Dutch, 2011

The 2011 Dutch noise code is described in "Reken- en meetvoorscrift Windturbines, 2/2-2010"

The Dutch codes require the calculation of an Lden value for each receptor.
The Lden value has the formula

$$L_{den} = 10 \lg \left(\frac{12}{24} 10^{\frac{L_{dag}}{10}} + \frac{4}{24} 10^{\frac{L_{avond}+5}{10}} + \frac{8}{24} 10^{\frac{L_{nacht}+10}{10}} \right)$$

The Leq noise value is calculated independently for the three situations: day, evening and night (L_{dag}, L_{avond}, L_{nacht}). In each case the formula is:

$$L_{eq} = 10 \lg \sum_{i=1}^{9} \sum_{n=1}^{N} 10^{L_{eq,i,n}/10}$$

"I" is the 8 octave bands,
"n" is the number of turbines.

The noise at each octave band is calculated as:

$$L_{eq,i,n} = L_E - D_{geo} - D_{lucht} - D_{ref} - D_{scherm} - D_{veg} - D_{terrein} - D_{bodem} - C_{meteo}, \text{ met}$$

Dref, Dscherm, Dveg and Dterrein can all be ignored.

Le
Le is the source noise emission. This is different from most other codes.
The Le is the average noise emission from the turbine. The formula is the below:

$$L_E = 10 \lg \left(\sum_{j=V_{ci}}^{V_{co}} (\frac{U_j}{100} 10^{L_{w,i,j}/10}) \right) + \Delta L$$

The summation is done for each wind speed bin from V_{ci} (cut-in) to V_{co} (cut-out). At rated power it is assumed that the noise level does not change.

U_j is the frequency of the particular wind speed.
ΔL is a direction component, which is usually not available and is therefore set to 0.
From this it is clear that a weibull distribution is required at hub height for each turbine. This is done automatically with reference to http://www.mp.nl/rekentool/ . The codes recommend to use this resource.

Dgeo
This is the geometric damping. It is identical to the ISO 9613-2 standard.

$$D_{geo} = 10 \lg(4\pi r_i^2) = 20 \lg r_i + 11,$$

"r" is distance from turbine to receptor.

Dlucht
This is the air absorption. The formula is the same as in ISO 9613-2 but the damping's are different.

$$D_{lucht} = a_{lu}(f)\, r_i$$

middenfrequentie octaafbanden [Hz]	31,5	63	125	250	500	1000	2000	4000	8000
a_{lu} [dB/m]	2.10^{-5}	7.10^{-5}	$2{,}5.10^{-4}$	$7{,}6.10^{-4}$	$1{,}6.10^{-3}$	$2{,}9.10^{-3}$	$6{,}2.10^{-3}$	$1{,}9.10^{-2}$	$6{,}7.10^{-2}$

Dbodem
This is the ground absorption. This is similar to the general ground attenuation of the ISO standard.
The regions are defined in the same way:
Near area:

$$r_b = 30\, h_b \qquad \text{als } r_i \geq h_b$$

$$r_b = r_i \qquad \text{als } r_i < 30\, h_b$$

Remote area:

$$r_o = 30\, h_o \qquad \text{als } r_i \geq h_o$$

$$r_o = r_i \qquad \text{als } r_i < 30\, h_o$$

Middle area:
Everything in between.

B is the ground porosity: B=1 absorbing, B=0 hard.
In WindPRO a universal ground porosity is selected by the user to cover all three regions for all turbine receptor couples.
The three components are added:

$$D_{bodem} = D_{b,br} + D_{b,ont} + D_{b,mid}$$

Unfortunately the dampings in each frequency is different from ISO 9613-2.

Middenfrequentie octaafband [Hz]	$D_{b,tr}$ of $D_{b,ont}$ [dB]
31,5	-3
63	-3
125	$-1 + B_b (a(h) + 1)$
250	$-1 + B_b (b(h) + 1)$
500	$-1 + B_b (c(h) + 1)$
1000	$-1 + B_b (d(h) + 1)$
2000	$-1 + B_b$
4000	$-1 + B_b$
8000	$-1 + B_b$
met	$a(h) = 3{,}0e^{-0{,}12(h-5)^2}(1 - e^{-r_i/50}) + 5{,}7e^{-0{,}09h^2}(1 - e^{-2{,}810^{-6}r_i^2})$
	$b(h) = 8{,}6e^{-0{,}09h^2}(1 - e^{-r_i/50})$
	$c(h) = 14{,}0e^{-0{,}46h^2}(1 - e^{-r_i/50})$
	$d(h) = 5{,}0e^{-0{,}90h^2}(1 - e^{-r_i/50})$

h is hub height.

The D_{mid} is calculated as

Middenfrequentie octaafband [Hz]	$D_{b,mid}$ [dB]
31,5 en 63	$-3\,m$
125 en hoger	$+3\,m\,(B_m - 1)$
met: $m = 0$	als $r_i \leq 30\,(h_b + h_o)$
$m = 1 - 30\,(h_b + h_o)/r_i$	als $r_i > 30\,(h_b + h_o)$

Cmeteo
C_{met} is defined as

$$C_{meteo} = 0 \qquad\qquad\qquad\qquad\qquad\qquad \text{voor } r \leq 10(h_b + h_o)$$

$$C_{meteo} = 5\left[1 - 10\left(\frac{h_b + h_o}{r}\right)\right]\left[1 - \frac{1}{2}\cos(\beta - 45°)\right] \qquad \text{voor } r > 10(h_b + h_o), \text{ met}$$

h_b is hub height, h_o is receptor height.
Beta is the angle from downwind from turbine to receptor.

4.2. SHADOW – Flickering

4.2.0 Introduction to SHADOW

SHADOW is the WindPRO calculation module that calculates how often and in which intervals a specific neighbor or area will be affected by shadows generated by one or more WTGs. These calculations are worst-case scenarios (astronomical maximum shadow, i.e. calculations which are solely based on the positions of the sun relative to the WTG). Shadow impact may occur when the blades of a WTG pass through the sun's rays seen from a specific spot (e.g. a window in an adjacent settlement). If the weather is overcast or calm, or if the wind direction forces the rotor plane of the WTG to stand parallel with the line between the sun and the neighbor, the WTG will not produce shadow impacts, but the impact will still appear in the calculations. In other words, the calculation is a worst-case scenario, which represents the maximum potential risk of shadow impact. A calendar can be printed for any specific point of observation, which indicates the exact days, and time periods where shadow impact may occur.

Apart from calculating the potential shadow impact at a given neighbor, a map rendering the iso-lines of the shadow impact can also be printed. This printout will render the amount of shadow impact for any spot within the project area.

At present, only Germany has detailed guidelines on limits and conditions for calculating shadow impact. These are found in "Hinweise zur Ermittlung und Beurteilung der optischen Immissionen von Windenergianlagen" (WEA-Shattenwurf-Hinweise).

According to the German guidelines, the limit of the shadow is set by two factors:
- The angle of the sun over the horizon must be at least 3 degrees
- The blade of the WTG must cover at least 20% of the sun.

The maximum shadow impact for a neighbor to a wind farm according to the German guidelines is:
- Maximum 30 hours per year of astronomical maximum shadow (worst case)
- Maximum 30 minutes worst day of astronomical maximum shadow (worst case)
- If automatic regulation is used, the real shadow impact must be limited to 8 hours per year.

In Sweden and Denmark there are no official guidelines as yet on shadow flickering, but for practical purposes, 10 hours (Denmark) and 8 hours (Sweden) real case (weather-dependent) shadow impact is used as the limit. In the UK, no official limits are in force, however an assessment must be made at all dwellings within ten rotor diameters of the turbine locations (PPS22 for England, TAN8 for Wales). In Ireland, a worst-case 30 hours per year, 30 minutes per day limit has been set.

The time of the day for which shadow impact is critical and the definition of a shadow receptor for which shadow impact is calculated are less rigidly defined by the guides and is often something which should be evaluated in each individual case.

As an example, a factory or office building would not be affected if all the shadow impact occurred after business hours, whereas it would be more acceptable for private homes to experience shadow impact during working hours, when the family members are likely to be at work/school anyway.

Also, it is sometimes questionable whether the shadow impact should be calculated for a window, the façade of a house or the full outdoor curtilage. Should a shadow in one end of the garden be added to a shadow in the other end of the garden?

Finally, the actual amount of shadow impact as a fraction of the calculated potential risk will depend heavily on the geographic location in question. In areas with high rates of overcast weather the problem would obviously decrease, and during potential hours of shadow impact in the summer the WTG may often be stopped due to lack of wind.

Statistics regarding the wind conditions and number of hours with clear sky can also be taken into account.

As in the other WindPRO modules, input of data can be based solely on entering coordinates and characteristics for the individual WTG and shadow receptor objects manually.

A significant strength in the WindPRO system is the option of direct graphic on-screen input of WTGs and shadow receptors on a map.

4.2.1 The SHADOW calculation method

The calculation of the potential shadow impact at a given shadow receptor is carried out simulating the situation. The position of the sun relative to the WTG rotor disk and the resulting shadow is calculated in steps of 1 minute throughout a complete year. If the shadow of the rotor disk (which in the calculation is assumed solid) at any time casts a shadow reflection on the window, which has been defined as a shadow receptor object, then this step will be registered as 1 minute of potential shadow impact. The following information is required:

- The position of the WTGs (x, y, z coordinates)
- The hub height and rotor diameter of the WTGs
- The position of the shadow receptor object (x, y, z coordinates)
- The size of the window and its orientation, both directional (relative to south) and tilt (angle of window plane to the horizontal).
- The geographic position (latitude and longitude) together with time zone and daylight saving time information.
- A simulation model, which holds information about the earth's orbit and rotation relative to the sun.
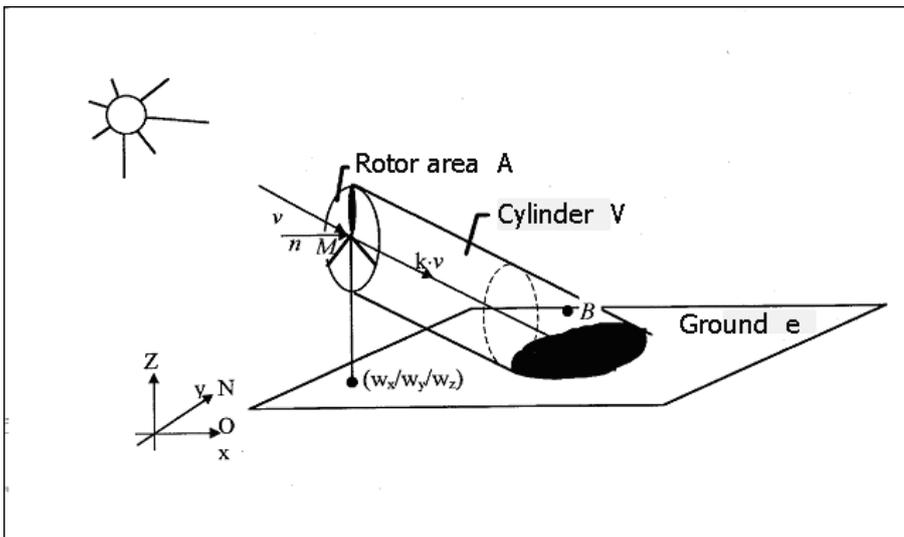
4.2.1.1 The SHADOW calculation model

In the shadow calculation model used by WindPRO the following parameters defines the shadow propagation angle behind the rotor disk

- The diameter of the sun, D: 1,390,000 km
- The distance to the sun, d: 150,000,000 km
- Angle of attack: 0.531 degrees

Theoretically, this would lead to shadow impacts in up to 4.8 km behind a 45 m diameter rotor disk. In reality, however, the shadows never reach the theoretical maximum due to the optical characteristics of the atmosphere. When the sun gets too low on the horizon and the distance becomes too long, the shadow dissipates before it reaches the ground (or the receptor). How far away from the WTG the shadow will be visible is not well documented and so far only the German guidelines have set limits for this (see Section 4.2.0). The default distance in WindPRO is 2 km or coverage of 20% of the sun disk, whichever is the shortest,

and the default minimum angle is 3 degrees above the horizon. If the German guidelines are used, the maximum distance from each WTG can be calculated using the formula

Max. distance = (5*w*d) / 1,097,780

where w is the average width of the blade. The value of 1,097,780 is derived from the diameter of the sun, reduced by a compensation factor for the fact that the sun disk is a circle and not a square.
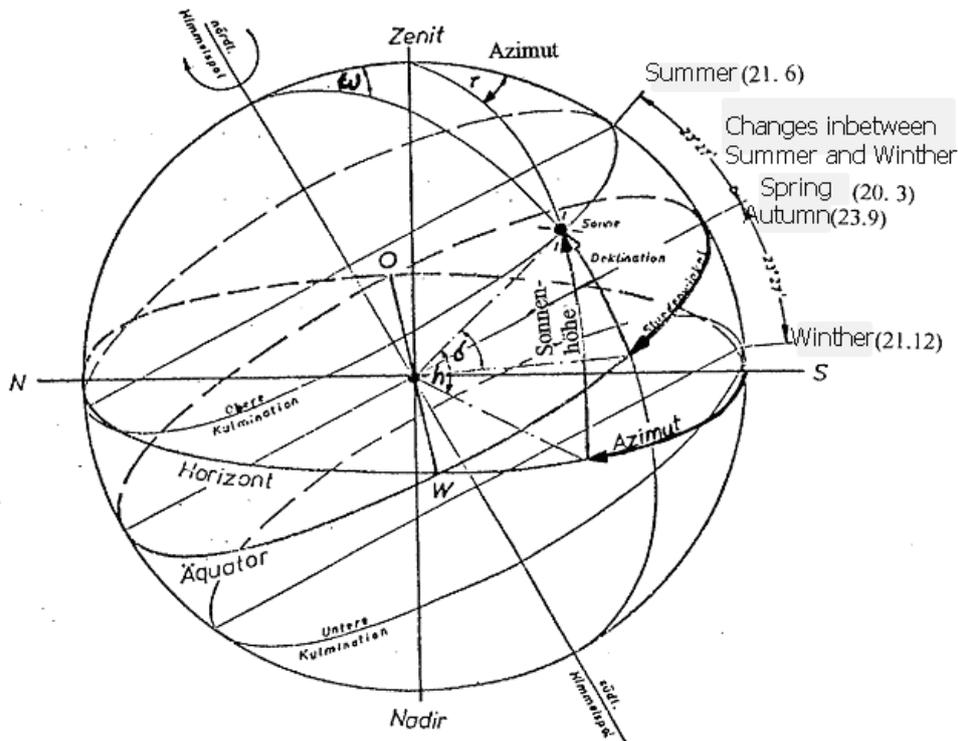
4.2.2 Entering data for Shadow Impact calculation

First of all, a background map is required, although a blank map can be used.
If one or more maps have been assigned to the project, click on the map icon to open one or all of them. Please refer to Chapter 2, WindPRO BASIS, for further information about the use of maps.

Please notice that, when entering objects via maps, you can create a default tool by holding down the <shift> key while selecting a tool. This function will allow you to enter multiple objects with the same properties (e.g. shadow receptors).

4.2.2.1 Entering WTGs

(See section Chapter 2. BASIS, Section 2.5.2)

4.2.2.2 Entering Shadow Receptors

Shadow Receptors are objects for which the potential risk of shadow impact is calculated.

Input a shadow receptor by selecting the icon shown to the left and place it on the map.

When you have selected the object with the mouse from the tool bar it is placed on the map with a click on the left mouse button.

After entering information on the receptor size and name, you can activate the shadow receptor again to align it. This is done by clicking on the icon, holding the stick and rotating it to align it towards the WTGs or along the side of the relevant house on your map. The shadow is thrown into the "bowl", so the stick gives the direction of the window.
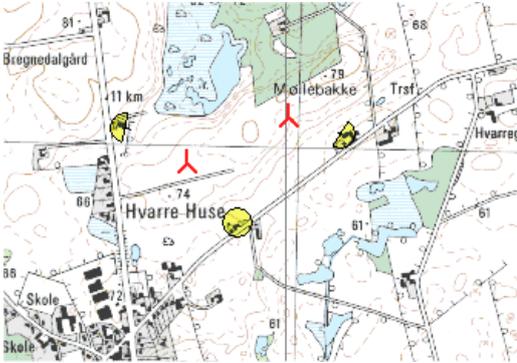
For Tab sheet Position, see Chapter 2.5.2.2. Basis.

Note: The z-coordinate of a shadow receptor must be entered in the same reference system as the z-coordinate of the WTGs. If the WTGs have been entered with the default value "0", you have to enter the z-coordinates for the shadow receptors relative to the elevation of the WTG foundation, i.e. if the shadow receptors have a lower elevation than the WTG foundation, then the z-coordinate will be negative. It is recommended to enter z-coordinates for all objects relative to the sea level.

The shadow receptors are described by the following information:

- The position of the "window" above ground level and its size (height and width).
- The tilt of the "window" relative to horizontal (you can choose between vertical, horizontal and roof window [45°]).
- The directional orientation of the window relative to south (in degrees, positive, westwards)

The default parameters are good as a standard description of typical windows.

Alternatively "Green house" mode can be selected. Then the receptor will not face any particular direction, but instead will face all directions. This is useful if the actual properties of the receptor are unknown or if there are wind turbines on more sides of the house that will contribute to the flickering impact.

The figure shows the data input sheet for the above information.

4.2.3 Calculation and printout from SHADOW

Click on the green arrow beside the SHADOW heading to activate the calculation module (if the arrow is yellow you do not have a registration license for the module - please contact EMD). After having selected the calculation, you are given some options for setting up the calculation.

4.2.3.1 SHADOW - Calculation Setup

Main: The name of the calculation: Enter a unique descriptive name so that different calculations in the same project can be separated.

This is the tab where the type of calculation is selected.

It is possible to choose two types of calculation:
- Shadow flicker at the shadow receptors
- A shadow flicker map

The two calculations are not mutually exclusive. It is possible to calculate one or the other or both.

There is an "Advanced settings" box on the lower part of the main tab. If this is checked it is possible to modify the maximum distance for shadow flicker and the lower limit of the Sun above the horizon to include in the calculation.

According to the German guidelines described in Sections 4.2.0 and 4.2.1.1., flickering is only an issue when at least 20% of the sun disk is covered by the blade. Checking this box lets WindPRO use the blade width information from the wind turbine catalogue to calculate the maximum distance from the turbine where flickering must be calculated. Beyond this distance, the turbine will not contribute to the flickering impact. The calculation requires that the blade width at 90% radius and at the maximum blade width has been entered in the catalogue for the particular turbine type.

As an alternative, or if there are no data for the specific WTG, the maximum distance can either be given by typing a fixed maximum distance (default 2000 m), choosing no limit, or using an individual distance for each wind turbine. The individual settings offer to use one of the WTG distance circles (see Chapter 2 Section 2.5.2.5).

The minimum angle of the sun above the horizon can also be set (default is 3.0 degrees). When the sun angle gets very low, the light has to pass through more of the atmosphere and becomes too diffuse to form a coherent shadow.

The reference year field makes it possible to specify a specific year. This will make the calendar use the daylight saving time dates correctly as well as the number of days in the year. The default year used is 1981.

Flicker at receptors
The theory for calculating flicker at the receptors is explained in Section 4.2.0.

The default selection is the worst case calculation, assuming no clouds, wind direction aligned with direction from turbine to receptor and always operation as described in Section 4.2.0.

It is also possible to calculate using "Real" case limitations in respect to the above parameters (see section below) and as an experimental option "Real case based on time series".

WTGs

Here you can define a sub-range of WTGs to be included. By default all visible WTGs (in all visible layers) are selected. Layers as well as individual WTGs can be checked or unchecked.

Receptors

On this tab the receptors being calculated are selected by selecting the layers in which the receptors are located. Alternatively the receptors can be selected individually.

ZVI

WindPRO will combine the ZVI and the Shadow calculation and thus exclude contributions from wind turbines that cannot be seen from the receptors. This is so also true for the shadow map, where only turbines visible from each calculation grid point will be included.

In order to perform the ZVI calculation, there must be a height model available in the form of a line object with height contours. Area objects defining blocking elements like forests or villages and obstacles can also be included.

The height above ground for the observer is set as the Eye height. The grid resolution for the ZVI calculation can be defined.

For more information on the ZVI calculation see Chapter 4.3.

When a receptor is shadowed from the sun by the topography (deep valley, cliffs…) it will not receive any flicker impact. The option **Use topographic shadow** can be selected to take this phenomenon into account. In that case WindPRO will check if there is a line of sight between the receptor and the sun. If none, the result of the shadow flicker from the turbine will be zero. See explanation in graphics below.
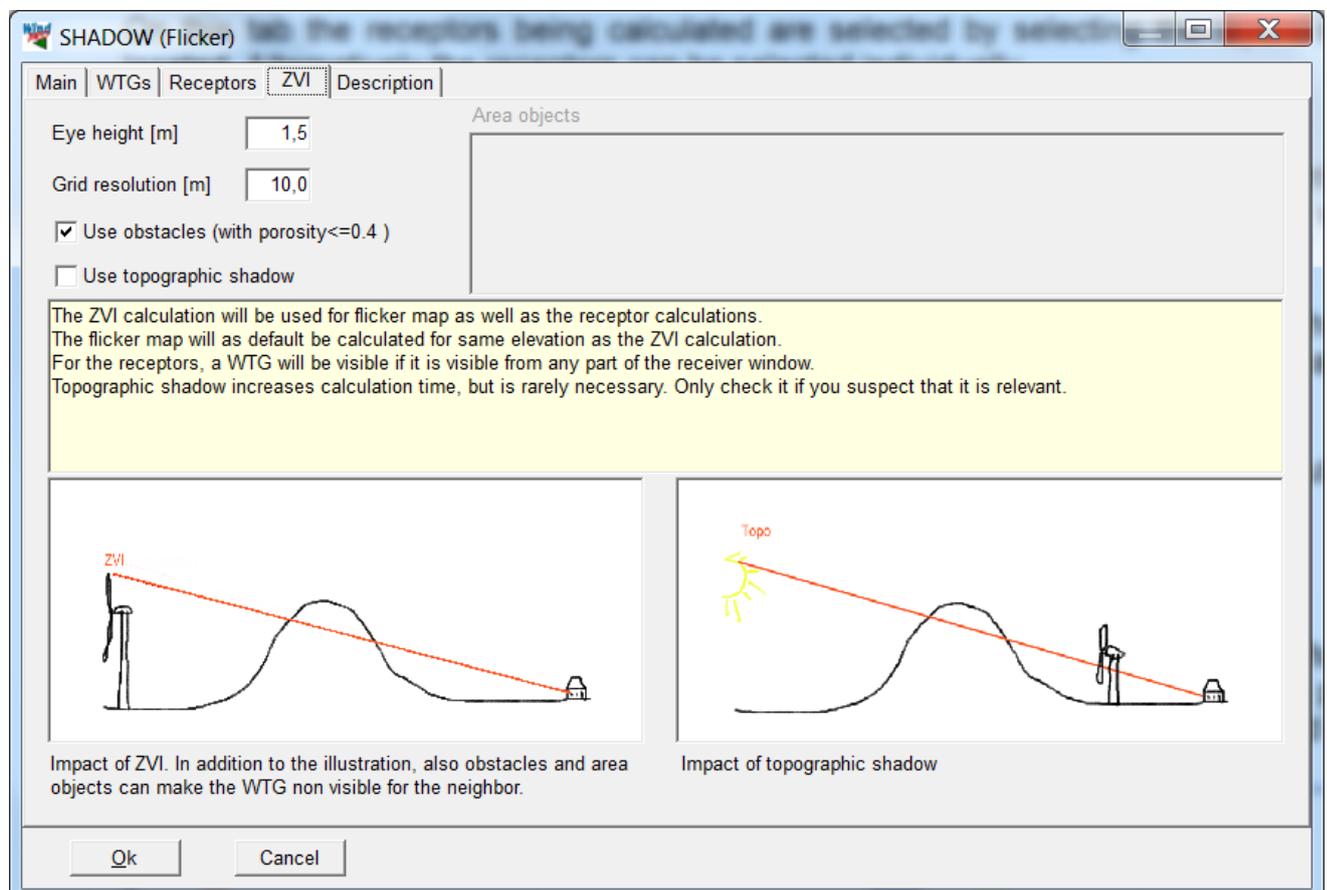
Real case based on statistics

It is possible to add a real case calculation to the shadow flicker calculation. This gives access to the additional tab: Real case statistics.

The Real case statistics tab is split in two parts: Operational hours and Monthly sunshine probabilities.

Operational hours statistics. This is the period that the WTG will be in operation from the different wind directions during the year. If an energy calculation has been prepared in the same project, this can be linked to the calculation. It is possible to link to a site data object set for WAsP calculation or a Meteo object with wind speed and direction data. Then a WAsP or a METEO calculation respectively will be performed at the beginning of the calculation, giving the probable hours of operation for each wind-direction sector. The operational hours statistics can also be typed manually or loaded from a template. Demonstration templates are available from Denmark and Germany.

If the turbine rotor starts rotating before cut-in (idling) the "User defined idle start wind speed" box can be checked and the start wind speed for idling can be entered.

Monthly sunshine probabilities. This is the percentage of daytime hour with sun for each month. This can be given as sun hours / possible sun hours or as the number of average sunshine hours per day. While it is possible to type in custom values or loading a previously made template, the default setting is to look up a data base value. Contained within WindPRO is a database with approximately 721 metrological stations worldwide. WindPRO selects the closest one to the project site by default, but it is also possible to press the "Select" button and manually pick another station.
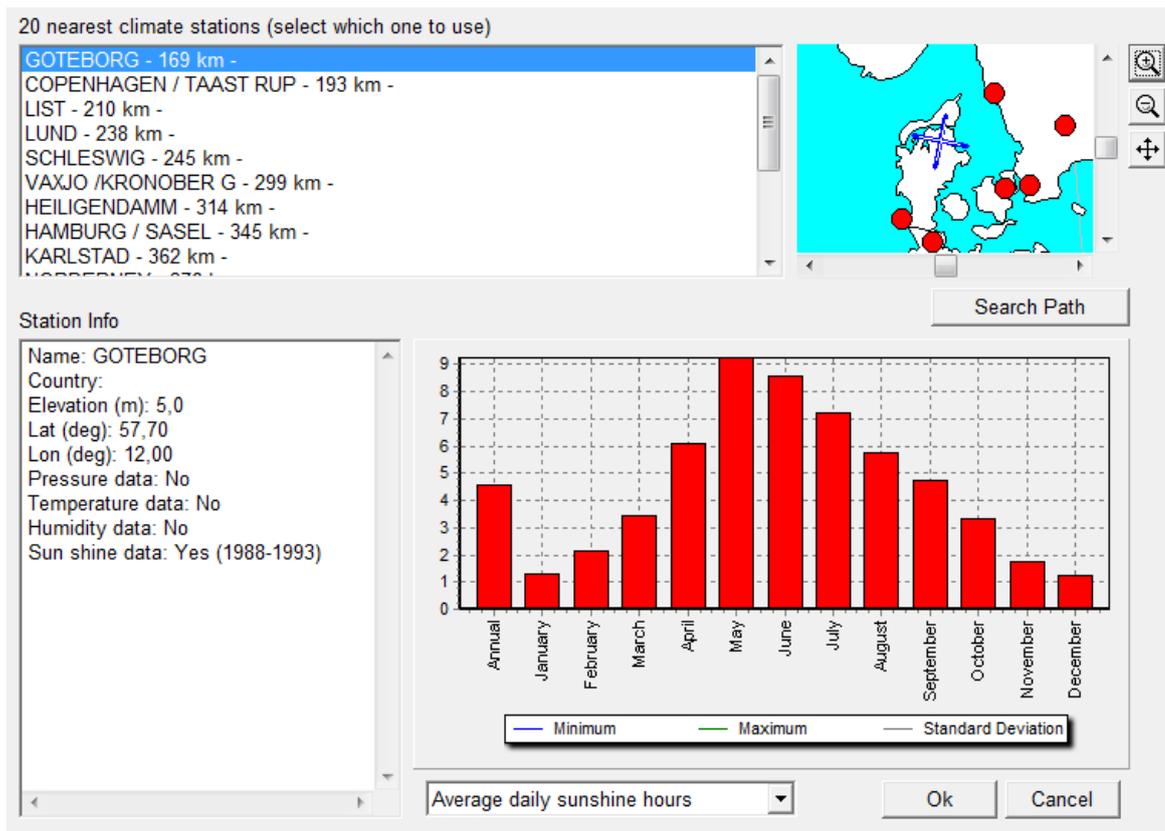
The station can be selected either from the list on the left or by selecting one of the red dots on the map to the right. It is a requirement that the station holds sun shine data. The sunshine statistics are displayed graphically in the lower diagram.

Real case based on time series
It is possible to use actual observed sunshine and wind condition observations to calculate how many shadow flicker hours the receptors have really experienced during the reference year.

This option is selected by adding the calculation option "Real case based on time series" from the Main tab. This option is currently only for experimental use.

Selecting this calculation option enables a new tab called "Real case time series"

The actual data set used must be selecting in the top of the tab.

If a .wti file has been created (see Section 3.3.3.4) the daily and monthly distributions can be read from this file. Otherwise an actual time series from a Meteo object can be used. Here the different heights in the Meteo objects of the project can be selected. For more information on the Meteo object see Section 3.32. The meteo object must also contain sunshine or cloud cover information. If you are uncertain whether your time series is sufficient for the calculation you can press the "View" button. This will show you the content and some statistics on the file including an evaluation of the suitability of the data.

Having selected the data source a filter must be setup to read the measurements.

Start date is by default the beginning of the time series.

Signal used for sunshine is the channel of the meteo object or .wti file holding the parameter that tells if the sun is shining. In the screen dump below, "Cloud Cover" has been selected, but it could also have been sunshine radiation level or other user-defined parameters.

"Sun shines when signal value" sets up a rule for the parameter. The sun shines when the parameter is either larger or smaller than the value given in the "Threshold value" box.

The .wti file and the meteo object time series give the relative variation in wind speed throughout the period analysed. In order to get the correct absolute values, the relative values must be scaled with the mean wind speed of the wind turbines. This mean wind speed is set in the "Mean wind speed in hub height for all WTGs" field.

Idling time can also be defined, see explanation above.

Main | WTGs | Receptors | Real case time series | ZVI | Description |

○ Use generic time variation data (*.WTI)   [   ] Browse   [View]
● Use time series from Meteo object   [cloud - 10,00 m   ▼]

Start date   Signal used for sun shine   Sun shines when signal value   Threshold value
[01-01-2008 ▼]   [Cloud cover   ▼]   [less than threshold value   ▼]   [2,00]

Mean wind speed in hub height for all WTGs
[7,0]

□ User defined idle start wind speed   [0,0] m/s   Default is cut in wind speed from power curve

[Ok]   [Cancel]

Flicker map
The second main type of calculation is a shadow flicker map.

The shadow flicker map calculates the shadow flickering in the grid across the site. The shadow receptor here is a horizontal 1x1m square at an elevation above the ground given by the eye height in the ZVI tab at the center of the grid cell. Since a site may hold a lot of grid cells the calculation resolution is reduced. There may therefore be small deviations between the result of a shadow map and the result for an actually defined receptor in that cell. The shadow map is used to visualize the extent of shadow flickering in the surroundings of the site.

The flicker map can be calculated either as a worst case calculation or as a real case calculation. If real case is selected the real case statistics must be defined as described above.

Selecting the Flicker map option enables the flicker map tab.

In the upper part of the tab sheet, a shadow flicker map can be chosen and defined. An area for the calculation can be selected through the globe icon directly on the map or with the four fields that gives the distance in each direction from the site center. For the height model for the calculation, the choice is either a fixed elevation (z-level, which should then be the average height of the ground level of the surrounding area) or elevations from a line object (plus eye height from ZVI tab). The latter is more correct, and should always be used if the heights vary more than approximately 5-10 m.

The shadow map calculation can be very time consuming. A simulation of an entire year is carried out for each node in a rectangular grid, which is then used to print the iso-lines. The resolution can be set to Coarse, Normal or Fine. A calculation using the coarse setting will usually take minutes. The fine calculation may take hours. By selecting Edit, the parameters of the different settings can be inspected or modified.

The lower part of the tab defines the maps includes in the report. It is only possible to include one report. The report options are either for a worst case calculation or for a real case calculation. The type selected on the Main tab is shown as white and it is possible to select and edit those options.

The three maps available are Hours per year, Shadow days per year and Max minutes per shadow day.

Three kinds of map reporting is possible:

- Show lines in report, creating a page with noise iso-lines in the report
- Show raster in report, filling up the interval between lines with color
- Show raster in result layer, producing a result layer in Maps and objects with noise intervals filled with color.

Pressing the edit button makes it possible to edit the lines or raster definitions for the maps.

The line setup looks like below, which is similar to the setup options in the print report setup.

Select the number of lines wanted and then define the noise value and color for each line. With "Save" you can save a template so you do not have to set this up every time you run the calculation. "Load" loads templates.

In a similar way the raster setup can be edited.

Again this is similar to the print report setup and the interface is used in several other locations in WindPRO. A typical good choice is to use the Palette format to get a single color for each interval. Then select the same number of lines as in the line definition and mark the same intervals and colors.

Back on the Flicker map tab it is possible to save the entire definition as a template.

It the last column is hatched WindPRO will produce a Result layer object in Maps and Objects.

4.2.3.2 SHADOW - Calculation

The calculation starts automatically when you press OK in the calculation setup. Please notice that the calculation may take some time depending on the setup parameters.

If a real case calculation is selected the user may have to either accept the selection of terrain and wind data in the site data object or the shear values used in a Meteo calculation.

4.2.3.3 SHADOW - Printout
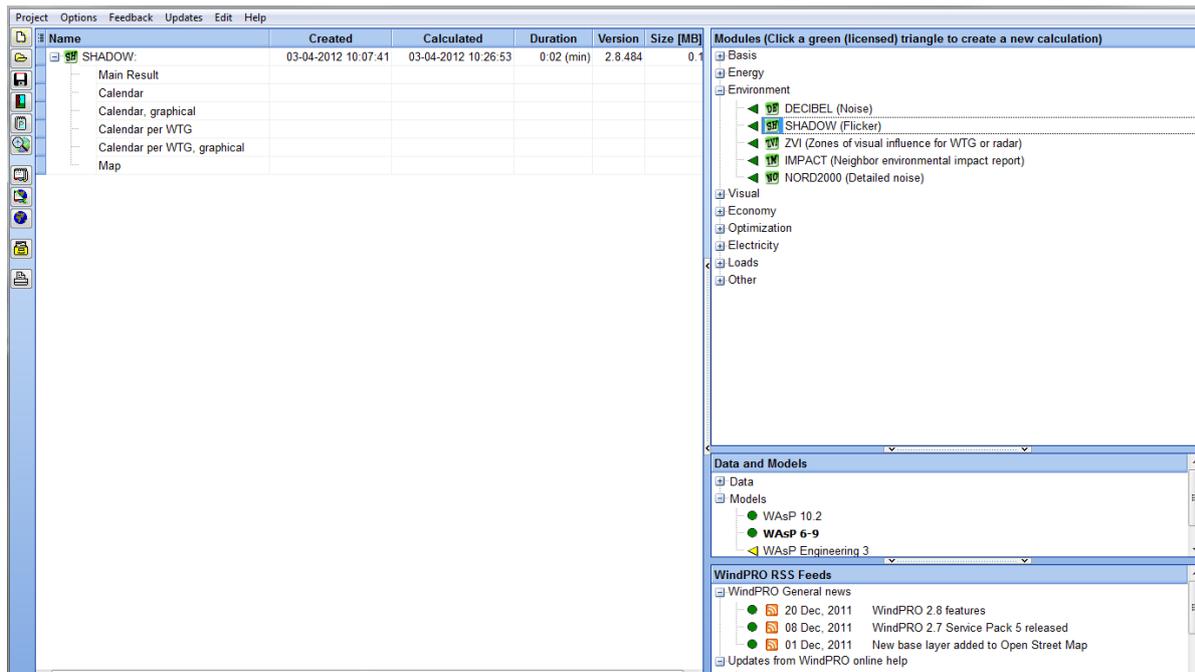
When the calculation has finished, a list with all the reports that can be printed will appear on the screen (see above).

SHADOW can produce the following six report types:

1. Main result

This shows the hours of astronomical maximum shadow (Worst case) or statistical real shadow impact at each shadow receptor (and the number of minutes on the "worst day"). Also results are generated for each turbine indicating how many hours per day that each of the turbines is causing shadows, both for the real and worst cases.

2. Calendar

This presents a calendar for each shadow receptor which contains the following information:

Timetable for sunrise and sunset for each day of the year in local time (i.e. corrected for time zone and daylight saving time)
Table for when shadow impact may occur for each day of the year, the total amount of hours of impact for the day in question and moment of beginning and end of the shadow impact (please notice that the time between beginning and end of shadow impact may last longer than the total hours of impact if the shadow impact is generated from more than one WTG).
The number of the WTGs, which cause the shadow impact at the moment of beginning and end respectively.
The total amount of hours of potential impact month by month.
Reductions due to sunshine statistics and statistics of operational hours.

3. Graphic calendar.

Showing when (hours and months) and from which WTGs flickering problems CAN occur (worst case). You can decide whether you want a full-page print per receptor, or up to 6 receptors per page.

4. Calendar per WTG.

This is similar to the regular calendar, but is instead for the individual turbines, telling when the flickering it may cause begins and ends. The purpose of this calendar is to help set up stop periods for the turbines to avoid flickering problems.

5. Calendar per WTG, Graphical

Like the graphical calendar for the receptors, this shows when the turbines may cause flickering.

6. Map

A map which renders the WTGs, the shadow receptors AND, if the calculation has been set up for it, a map rendering the iso-lines or raster grid of the shadow impact for the area in question. The settings for the iso-lines and the raster map were set in the calculation, but can be revised in the report setup using the same interface.

7. WTG data to file. Finally data from the calculation can be printed, the calendar results as .txt files for other presentation or further calculations (imported into a spreadsheet), the shadow map iso-lines as .shp (shape) files for use in GIS systems.

WTG data
File name

| Save | Save as... | Copy to clipboard |

WTG distances
File name

| Save | Save as... | Copy to clipboard |

Shadow receptor data
File name

| Save | Save as... | Copy to clipboard |

Shadow calendar
File name

| Save | Save as... | Copy to clipboard |

Shadow calendar per WTG
File name

| Save | Save as... | Copy to clipboard |

Time series details
File name

| Save | Save as... | Copy to clipboard |

Shadow lines in shape format
File name

| Save | Save as... |

Shadow details
File name

| Save | Save as... | Copy to clipboard |

Close

The status shows how many pages will be printed if the full report is to be printed.

Please notice that a report will automatically pop up on the screen if you double click on the report name.

When you click with the right mouse button on the calculation header or one of the calculation reports, you gain access to the following features; recalculation, editing the assumptions for the calculation, change of printer setup or preview of the report on the screen.

When you click with the right mouse button on the report header under the printout setup menu, you can choose which pages to print. Also, the layout can be defined (see the example in the below figure).
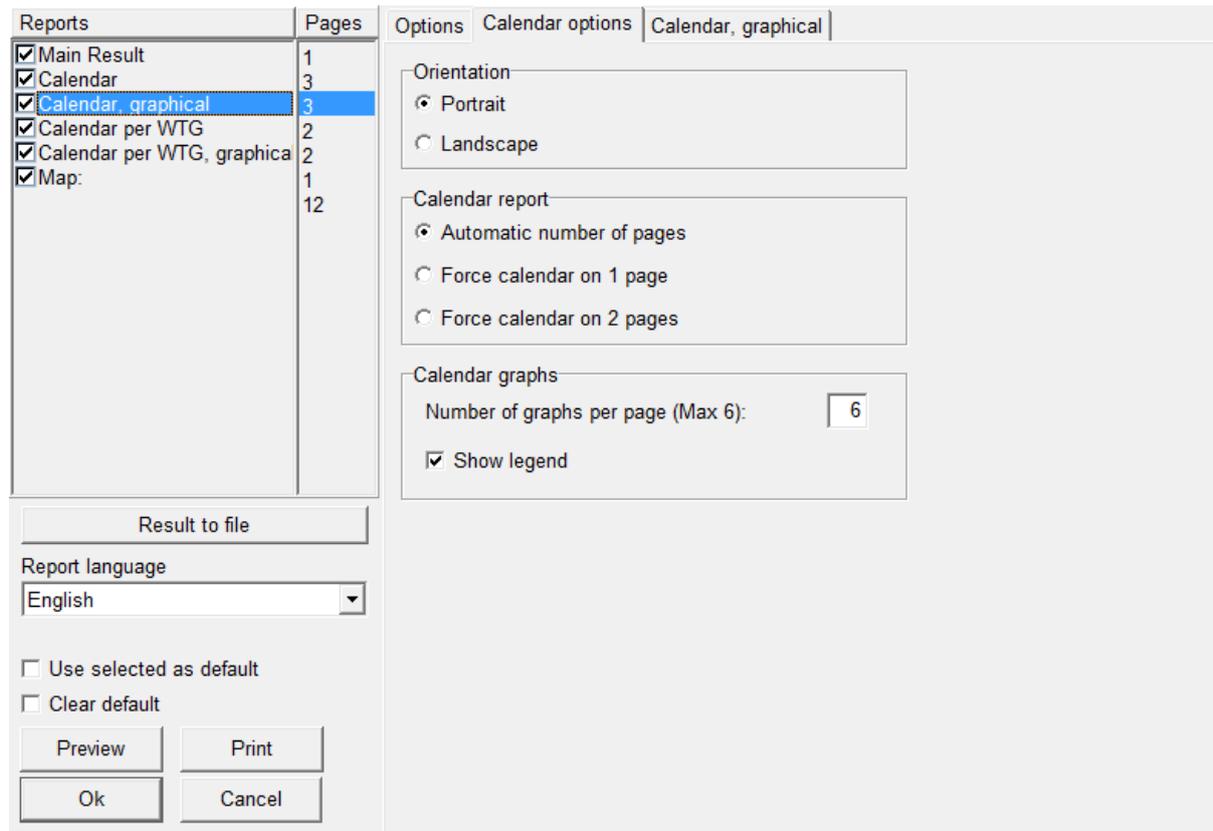
Click on the check box to the left of each object to select/deselect that object. By clicking on the report name you gain access to the setup window for the selected report. Here, you can enter details about the selected report, e.g. the shadow receptors for which a calendar printout is needed, the map scale which is to be used on printouts, what to include on maps, which maps to include, etc.

Regarding printing iso-lines and raster maps on the Map page: Click on the [...] button for setup, and check the box to activate, see below. Using this feature, you can create a map which shows, hours per year, max. minutes per day or days per year as lines and similar as a raster map.

An example of a shadow flicker map is shown above.

4.3 ZVI – Zones of Visual Influence

4.3.0 ZVI - Introduction

ZVI is a WindPRO module that calculates and documents the visual impact (a ZVI is also known as a ZTV – a zone of theoretical visibility) of WTGs on the landscape, i.e. identifying the spots from where you will be able to see one or more WTGs. For example, the program calculates the percentage of a given area from where a given number of WTGs can be seen. A ZVI calculation can handle the cumulative impact of several wind farms (see Section 4.3.4).

In general, there are no acceptance criteria regarding the maximum allowable visibility of WTGs and indeed, it would be very difficult to make operational definitions on the matter.

ZVI calculations are often used in discussions regarding local and regional planning for new WTGs. For specific projects, the ZVI analysis can form part of the background material used for an environmental impact assessment of the project.

The ZVI analysis is particularly useful when assessing alternative projects or WTG planning proposals.

The ZVI module can also be used to calculate the visibility of wind turbines from radar locations. In some countries the impact of the wind turbines on the radar signals can indeed be problematic. With a ZVI calculation it is possible to perform a Line of Sight analysis which can point out whether the WTGs are visible from one or more radars (see Section 4.3.5).

4.3.1 ZVI - Calculation method

The calculations are based on a digital 3D model of the landscape established from digital height contours. Furthermore, local obstacles and surfaces (e.g. forest areas) can be included. In short, a ray is sent from the point of calculation towards each WTG top and it is checked whether the ray is interrupted by the landscape, a surface (with a defined height) or a local obstacle. The number of uninterrupted rays is then counted. The earth's curvature is also taken into account in the calculation. In radar mode the earth curvature is adjusted by a refraction constant k in order to compensate for the bending of radar signals in the atmosphere (see Section 4.3.5).The following information is needed:

- The position coordinates of the WTGs (x,y,z)
- Hub height and rotor diameter of the WTGs
- A digital height contour map (through the line object – see Chapter 2.8)
- Local obstacles (WAsP format - only obstacles with a porosity lower than 0.3 are included)
- Surface objects (forests, cities) with defined elevations above the terrain, defined in the area object
- The position coordinates and antenna height of the radars (x,y,z) if relevant.

4.3.2 ZVI - Input for the calculation

First of all a background map is needed – although it can be a blank map.

If one or more maps have been assigned to the project, click on the map icon to open one or all of them. Please refer to Chapter 2, WindPRO BASIS for further information about the use of maps.

Please notice that, when entering objects via maps, you can create a default tool by holding down the <shift> key while selecting a tool. This function will allow you to enter several objects with the same properties.

4.3.2.1 Input of WTGs

(See Chapter 2. BASIS, Section 2.5.2)

4.3.2.2 Input of digital height contours

Digital height contours are entered in a line object by loading a data file containing the contour lines in an appropriate format or by digitizing the curves directly on-screen with the mouse.

See Section 2.8 in WindPRO BASIS for detailed guidance.

4.3.2.3 Input of Area object

The procedure follows the one for input of height contour lines, the only difference being that surfaces in the area object have to be entered as closed polygons.

See Section 2.9 in WindPRO BASIS for detailed guidance. Notice that the area object has to be checked for use in ZVI calculation to take effect here.

4.3.2.4 Input of local obstacles

Local obstacles are entered graphically on-screen using the WAsP obstacles button. The dimensions are defined by dragging the object (click and drag first corner to set the length of the obstacle, then click and drag the next corner to set the width and finally click once more to finish the input).

Once the object has been positioned, the following window pops up for setting the height and porosity:
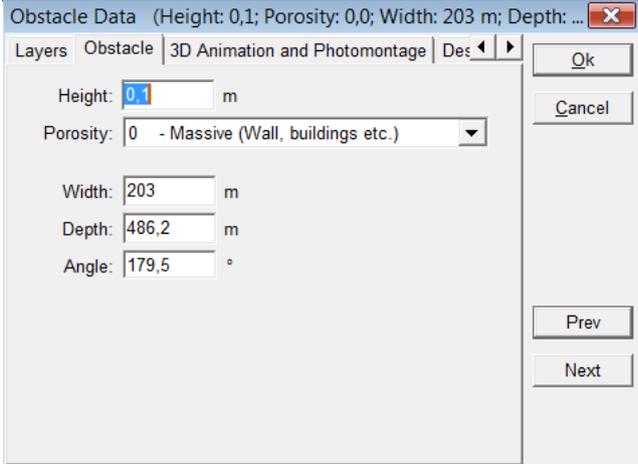
Note: We have chosen a minimum porosity of 0.3 for an obstacle to be included in the calculations as a "solid" that will interrupt the line of sight to the WTG. For higher porosities the obstacle will be treated as transparent, i.e. the WTG will be visible through the obstacle.

4.3.2.5 Input of Radars

When needed, Radars are entered with this icon [icon]. The effective (antenna) height of the radar above the ground shall be defined. It is the radar radiation centre above the ground level. The coordinates of the radar can be entered on the Position Tab.
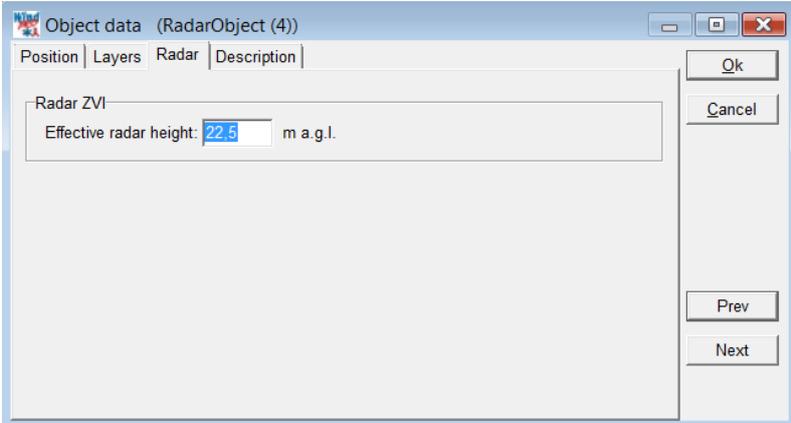
4.3.3 ZVI - Calculation and printout

The calculation menu is invoked by clicking the green arrow beside ZVI (if this arrow is yellow you do not have a registered license to the model - please contact EMD). In the calculation menu you can set different parameters for the calculation.

4.3.3.1 ZVI – Setup and calculation
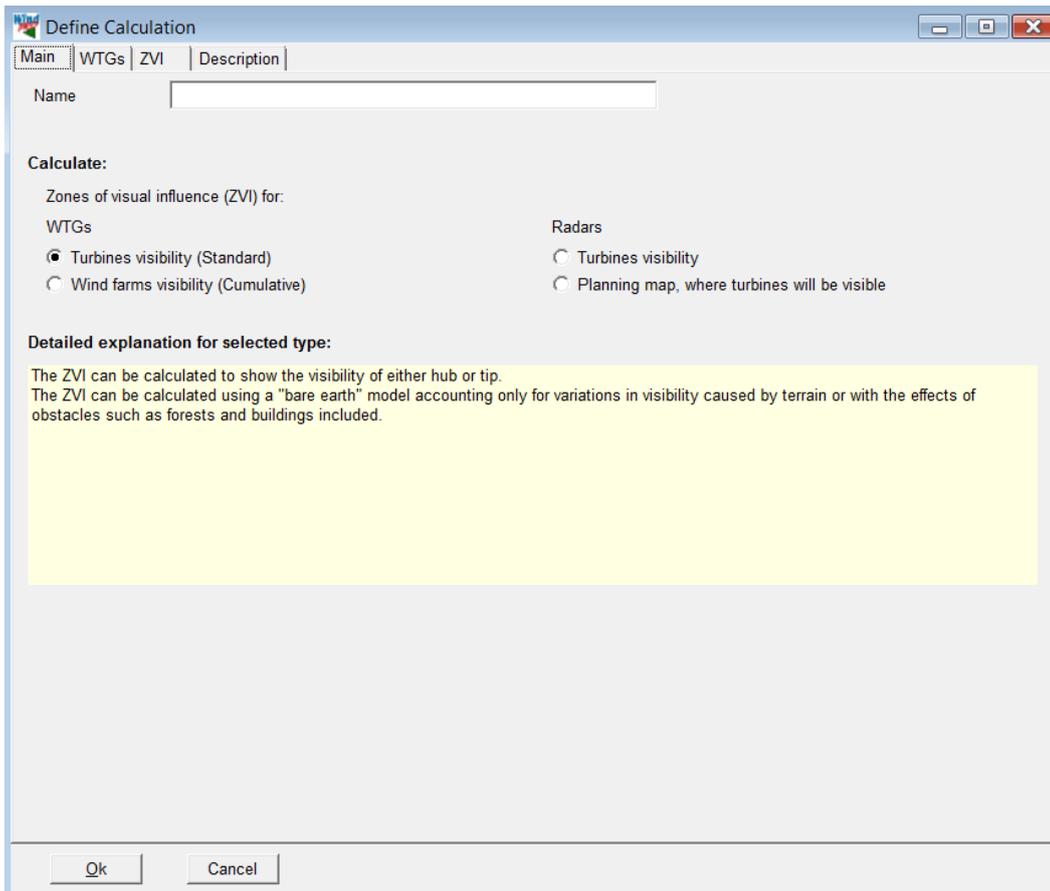
Figure 1 At the Main tab, the type of calculation is chosen.

Name of calculation: Here a name can be entered for the calculation to help you recognize it when there are more calculations in the same project.

The type of ZVI calculation is then selected from:
- **WTGs/Turbines visibility**: calculates and shows on a map the number of wind turbines which are visible within an area;
- **WTGs/Wind Farms visibility**: calculates the cumulative visibility of several wind farms (see Section 4.3.4);
- **Radars/Turbines visibility**: calculates whether the WTGs are visible from one or more radars (see Section 4.3.5);
- **Radars/Planning map**: calculates a map showing the areas where a specific WTG type could be installed without being seen by the radar(s) (see Section 4.3.5).

On the WTGs tab you can choose to leave out certain WTGs in the calculation if you only want the calculation to be carried out for selected WTGs.

The ZVI parameters for the calculation are defined in the following window:
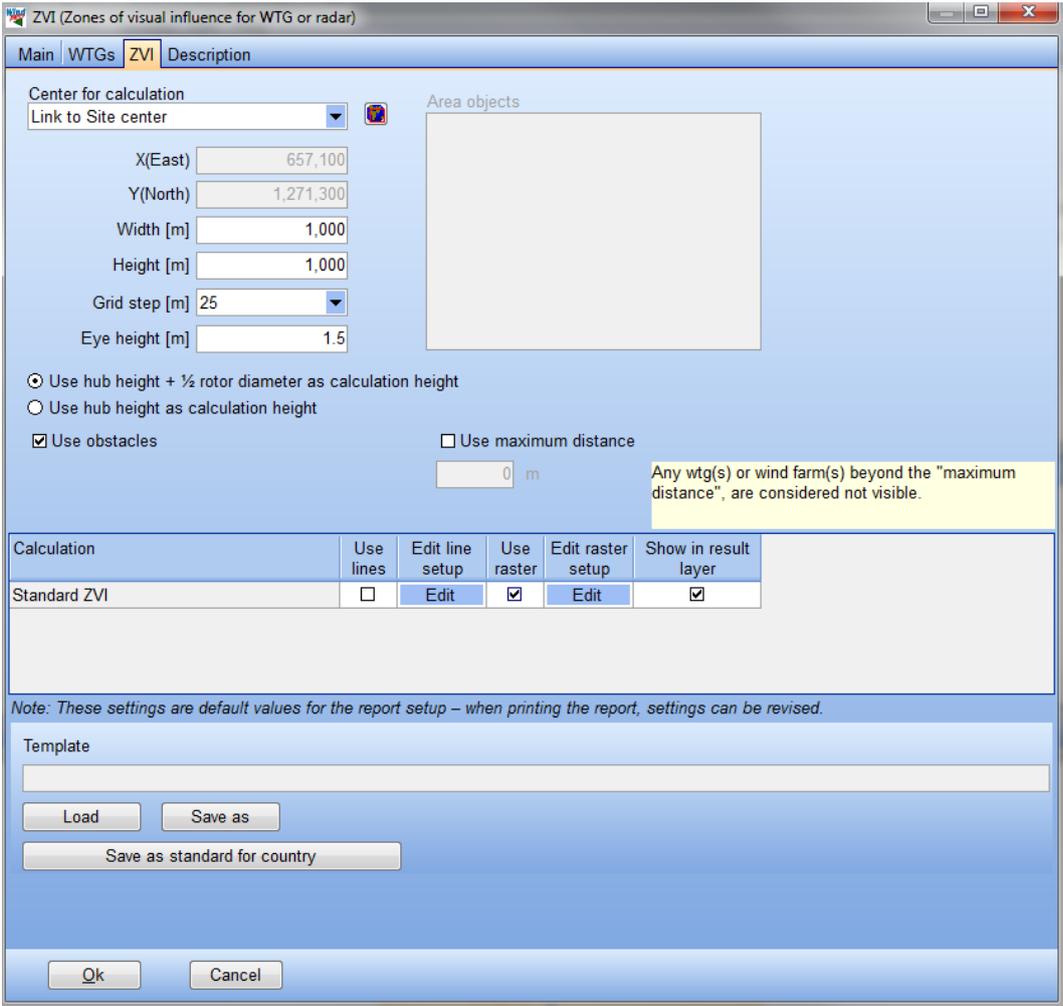
You have the following setup possibilities for a ZVI calculation:

Manual definition of the calculation area: The area selection for the ZVI calculation can be done with a center and an extent for the calculation. Here the site center can be a useful anchor point, but it is also possible to type a coordinate point as the center of the calculation.

Graphical definition of the calculation area: Clicking on the globe icon sends you temporarily back to "Maps and Objects", where you are given a rectangle, with which you can define the extents of the calculation.

It is difficult to give general recommendations for the selection of a relevant area. It could be an area of special environmental interest that you want to protect against the visual impact from too many WTGs or it could cover a whole county to identify the areas where a given number of WTGs would be visible. It could also be the local area around the WTGs for which an impact study is needed. In other words, the area has to be defined in a dialogue between the developer and the relevant authorities.

Grid steps: This sets the grid size/resolution for the calculation. A resolution of 25 m would be a reasonable choice for a smaller area (up to 5 x 5 km) whereas a larger area as a whole county would probably call for a resolution of around 100 m.

Eye height of observer: A height of 2 m would correspond to a "maximum" height of a walking person. For observations from a car, a height of 1 m would be more realistic. A number of 1.5 m seems to be a fair compromise.

Height of WTG: It is possible to choose whether the WTG is visible when you can see just the very top of the WTG blades or if you should be able to at least see the hub. While the top position of a blade tip would cover

the full range of visibility, the hub height should be chosen where the zones of significant visibility are searched.

Local obstacles: This enables you to include obstacles with a maximum porosity of 0.3. If a local obstacle is specifically established because of the possible reduction of the visual impact it should be included in the calculation. Obstacles created solely for energy production calculations should not necessarily be included in the ZVI calculations since the obstacle could, for example, be a row of deciduous trees through which WTGs might be visible during the wintertime.

Area objects: This shows you which area objects are included in the calculation. If there are objects such as forests or villages in the investigated area, they should be digitized into an area object. The areas with a height will be added on top of the height contour lines and thereby provide important information on visibility. Notice that "inside" an area with a height larger than the observer, it is always assumed that all WTGs are invisible. (this might not be true from inside a village). If very detailed calculations are desired, the village must be defined in greater detail, e.g. every house and tree must be defined as local obstacles or small area parts in an area object.

Use maximum distance: Used for excluding WTGs in project at large distances in calculation report.

Map set up: You can choose a legend setup for the map before starting the calculation, but it can always be changed later on in the result layer properties (See 2.11) and/or in the report setup). Select Show in result layer in order to see the maps in maps and objects.

Template: this where predefined legend can be loaded or saved.

4.3.3.2 ZVI - Calculation

When you press OK to accept the calculation definition you can choose to start the calculation or save it for later. The calculation is rather fast and only for very large areas will it take more than a few minutes.

4.3.3.3 ZVI - Printout

When the calculations are completed, a list of available reports that can be printed is shown.
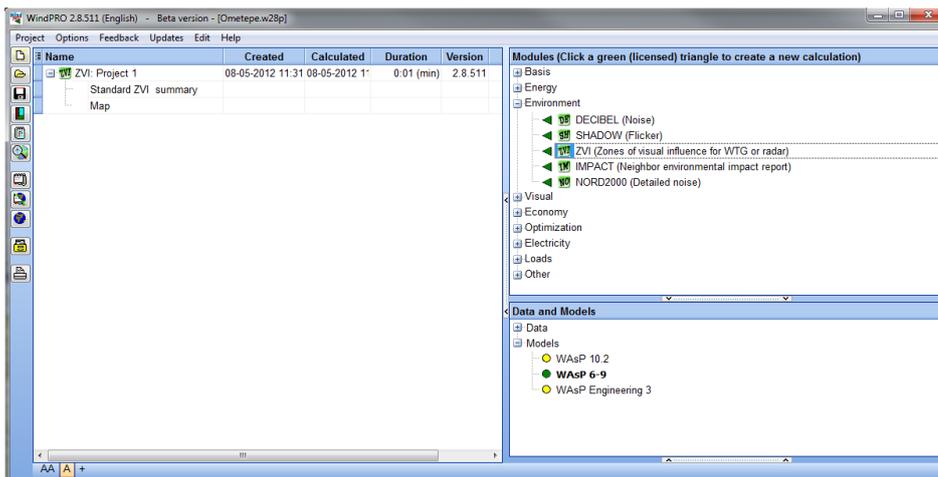
In the ZVI calculation module there are two different reports available:

1. A summary report that gives the assumptions for the calculation together with the resulting areas of visual impact divided into areas of different number of visible WTGs. This information can be useful when assessing the visibility for different micro-siting alternatives.

2. A map with the WTG locations and a raster graphic that shows the impact area and the number of visible WTGs at a given location inside the impact area.

Note: A double-click on a report name automatically shows a preview of the report on the screen.

By right-clicking the calculation header or one of the calculation reports you can either recalculate, change the calculation assumptions, change the printer setup or see a preview of the report on the screen.

By right-clicking the report header you can specify which pages are to be printed as well as the layout. See the general description of "Results - layer object", Chapter 2 in BASIS, Section 10.

4.3.3.4 ZVI presentation in the result layer

It is possible to display the resulting ZVI map in Maps and Objects using the result layer. In this case the resulting .ear file must be selected in the browser of the Result layer. See Chapter 2 Section 2.10.

4.3.4 Cumulative ZVI

The cumulative ZVI can be used to compare the visual impact of a number of windfarms located in the same area. This may be the case if a new project is planned next to an existing one or if several projects are competing in the same area.
The cumulative ZVI calculation is performed on the wind farm(s) as a whole, not on the individual turbines within the wind farm(s) (i.e. the result is a quantification of whether any turbine from a project can be seen at the given grid node rather than the number of turbines visible).

4.3.4.1 Cumulative ZVI - Setup

Each wind farm has to be defined on a separate layer, where the name of the layer becomes the name of the wind farm. By default the wind turbines on one layer are considered as one wind farm for the purposes of cumulative impact.

Although it is theoretically possible to do the calculation with a large number of wind farms and this may make sense for special calculation tasks (see last paragraph), the calculation will generally be easier to interpret so long as there are no more than three wind farms chosen. If you have more wind farms in the area, it may be necessary to group wind farms onto layers so that you only have three layers with which to perform the calculation.

In ZVI calculation, the ZVI for "Wind farms visibility (Cumulative)" should be selected.

4.3.4.2 Cumulative ZVI – Printout

The output is the map result showing the zone of visibility of the different wind farms.

Compared to a standard ZVI calculation, the legend of the map is not showing the *number* of visible wind turbines but *which* wind farms are visible. For example it can be shown the areas of visibility of a wind farm A alone, then the areas of visibility of the wind farms A and B or A and C, etc…

The legend categories show all possible combinations of the different wind farms visibility. For *n* number of wind farms, the number of combination is then 2^n, i.e. for three wind farms, there would be eight categories in the legend.
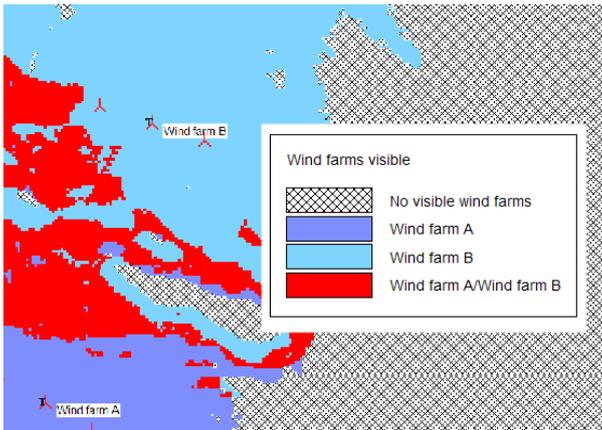
In addition, the display can be manipulated to add or remove colours from any of the legend entries. If you want to see only those areas where wind farm A adds to the visibility of wind farms in the area, then you can set all other colours to white (i.e. not shown on the map) and you will be left with only those areas you wanted to display. Similarly, if you want to show only the areas where all wind farms are visible, then you can set all legend combinations to white apart from the last one.

4.3.5 Radar ZVI

Two types of Radar ZVI calculations can be performed. The first one "Turbines visibility" calculates whether the WTGs are visible from one or more defined radar(s). The clearance height which is the distance between the intersection of the line of sight of the radar and the tip height (cf below) is also calculated. The second calculation "Planning map" calculates a map showing the areas where a WTG with specific dimensions could be installed and would not be seen by the radar(s). In the areas where the WTG is seen, the maximum clearance height is also given by the map.
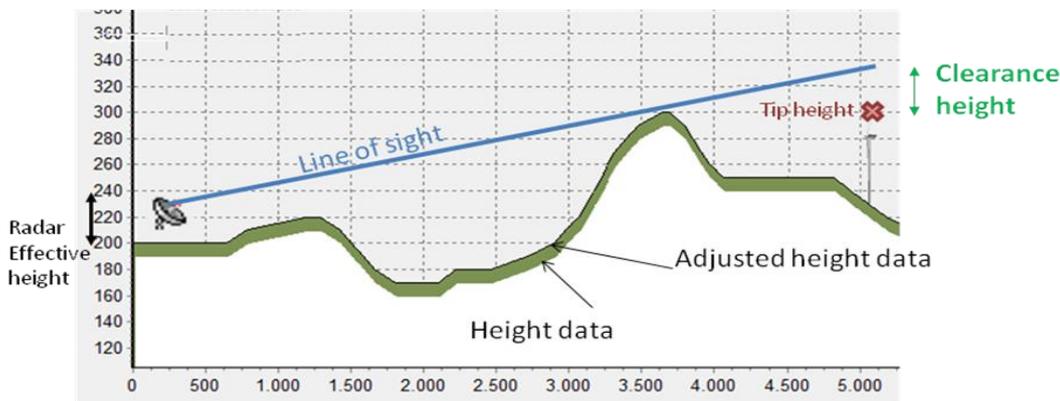
Definition of the clearance height in a Radar ZVI calculation

4.3.5.1 Radar ZVI - Setup

Turbines visibility calculation

In the Radar ZVI calculation, "Turbines visibility" should be selected.
For the input of wind turbines and radar(s) see Section 4.3.2.
The option "Grid step" sets the grid size/resolution for the calculation.
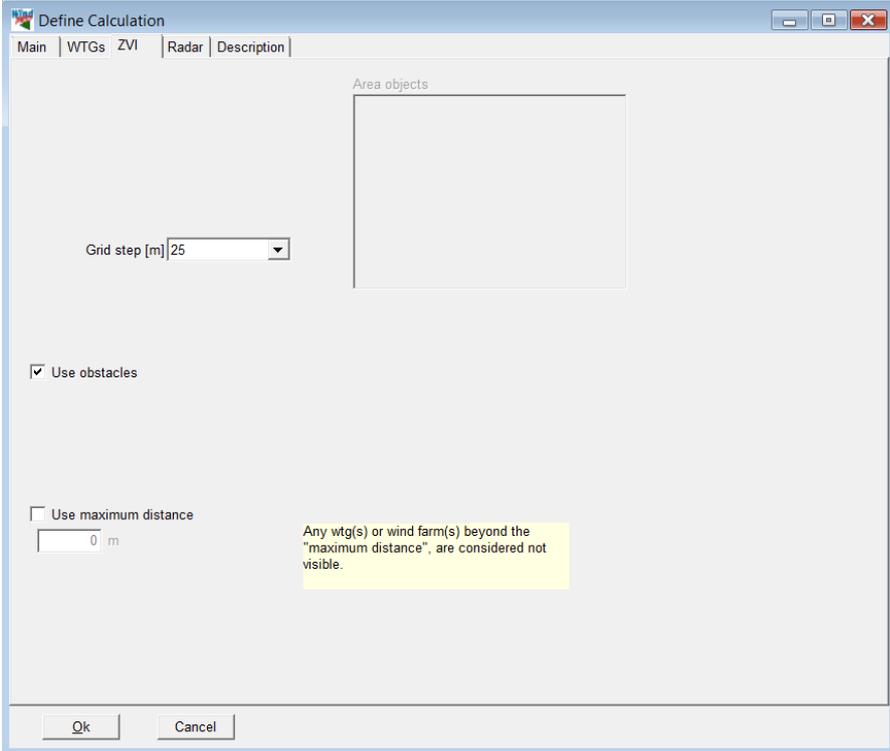
On the Radar tab, the radar(s) to be considered can be selected.

The Refraction Constant k modifies the Earth Curvature used in the ZVI calculation.
Variations in the atmosphere cause bending of radar signals, which as a result extends the effective radar range beyond the visible horizon. This is commonly compensated for by using a larger effective Earth Curvature in the calculations (i.e. flattening the Earth). This compensation allows radar signals to be treated as straight lines. The Earth Radius is multiplied by a refraction constant k to give an increased effective Earth curvature. The standard figure used for k is 1.33 (4/3). In the USA k is between 1.25 and 1.90.
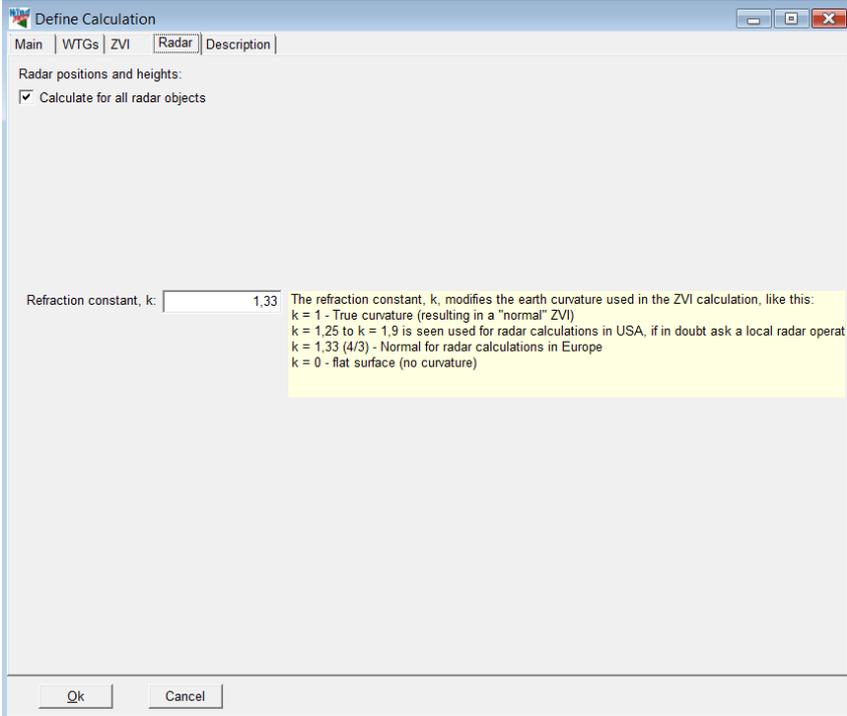
Planning map calculation

In the Radar ZVI calculation, "Planning Map" should be selected.

For the input of wind turbines and radar(s) see Chapter 4.3.2.

Definition of the calculation area: the area can be selected for the ZVI calculation with a center and an extent for the calculation. Here the site center can be a useful anchor point, but it is also possible to type a coordinate point as the center of the calculation. For a graphical definition of the calculation area: clicking on the globe icon sends you temporarily back to "Maps and Objects", where you are given a rectangle, with which you can define the extents of the calculation.

The option Grid steps sets the grid size/resolution for the calculation.
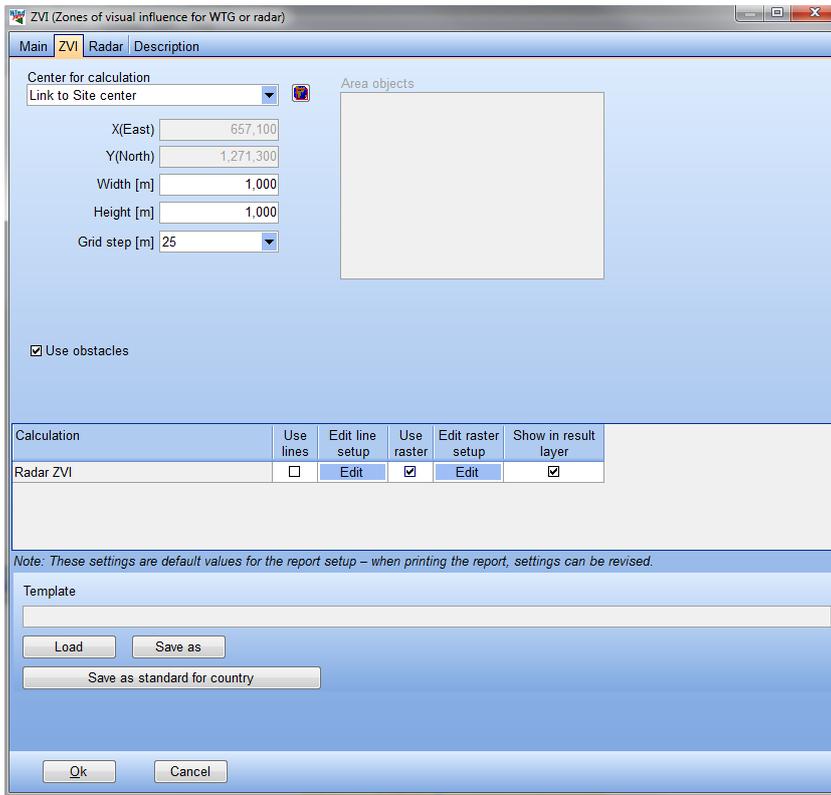
The WTG type is selected on the Radar tab.

With a WTG height of 0m, the clearance height corresponds to the maximum height of a wind turbine that can be planned without been seen by the radar(s).
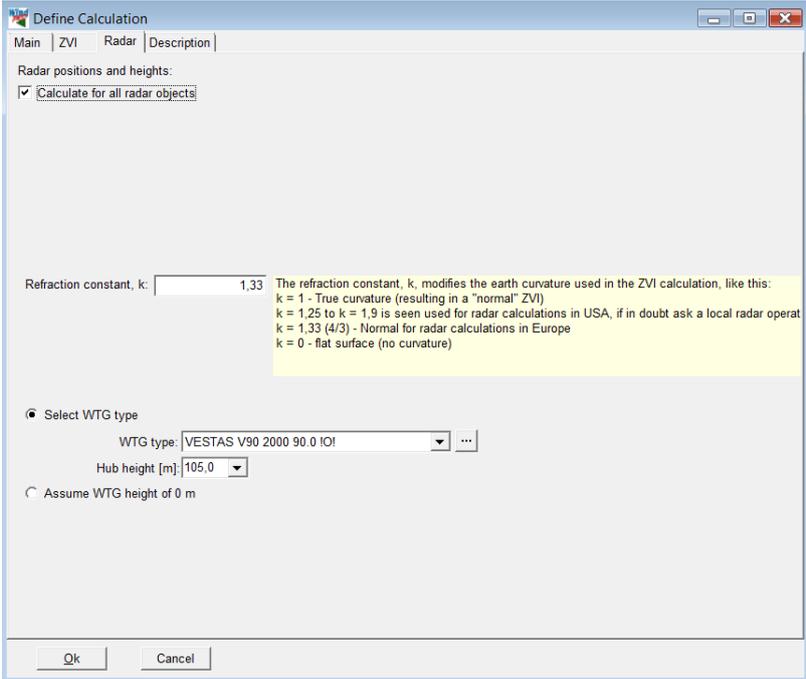
4.3.5.2 Radar ZVI - Printout

Turbines visibility calculation

The clearance height between each wind turbine and radar is given in a table. The clearance height specifies the space between the WTG and the line of site of a radar; negative value indicates that the height of the WTG is above the limit.

		Clearance height [m]
		R1
wtg1	GE WIND ENERGY 2500 kW (182)	-121,3
wtg2	GE WIND ENERGY 2500 kW (183)	-76,1
wtg3	GE WIND ENERGY 2500 kW (184)	-131,7
wtg4	GE WIND ENERGY 2500 kW (185)	-114,3
wtg5	GE WIND ENERGY 2500 kW (186)	-66,2
wtg6	GE WIND ENERGY 2500 kW (187)	-92,0
wtg7	GE WIND ENERGY 2500 kW (188)	-120,4
wtg8	GE WIND ENERGY 2500 kW (189)	-135,0
wtg9	GE WIND ENERGY 2500 kW (190)	-68,1
wtg10	GE WIND ENERGY 2500 kW (191)	-7,6
wtg11	GE WIND ENERGY 2500 kW (192)	-54,2
wtg12	GE WIND ENERGY 2500 kW (193)	-127,0

Clearance height table

Planning map calculation

The output shows the distribution of clearance height values over the area of calculation in a table and on a map.
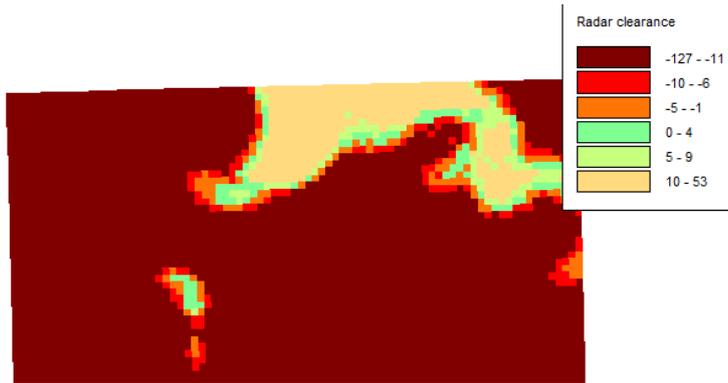
Map of clearance height for a 125m high turbine (total height)

4.4. IMPACT - Calculation of Neighbor Nuisance

4.4.0 IMPACT - Introduction

Impact is the name of the calculation of the aggregated environmental impact at each neighbor in a planned wind energy project.

The following can be calculated and reported for each specific neighbor, with one page per neighbor:

- Noise
- Shadow flicker
- Zones of Visual Influence (ZVI)
- Photomontage

The Photomontage can be free defined, and could e.g. hold a photo of the house seen from wind farm area.

Apart from the calculation results the printout will also include an explanation of the individual types of impact (effect) and governing limits where legislation is in force.

4.4.1 IMPACT - Calculation method and setup

The calculation follows the descriptions found in Sections 4.1 (Decibel), 4.2 (Shadow) and 4.3 (ZVI) of this chapter.

What is unique about this calculation module is that all environmental impact calculation results are included on one single printout per neighbor.

Both the noise and the shadow calculation setup are the same as for the DECIBEL and SHADOW calculation

In the ZVI calculation, the same point is used as for the noise calculation.
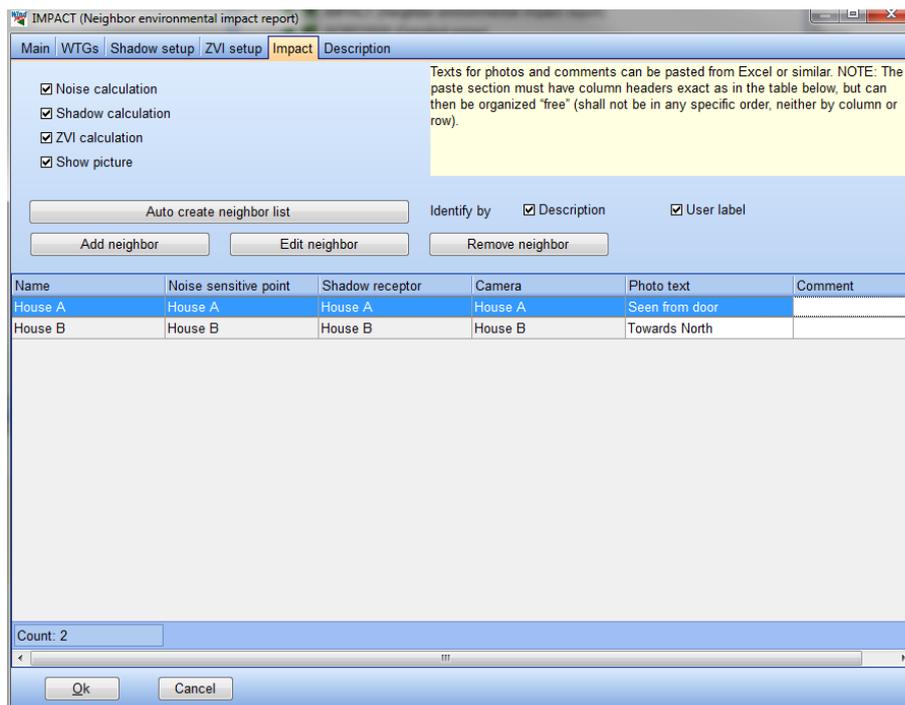
The only "special" operation in this calculation is the pairing of objects for each neighbor. This is done in the window shown below. If you have assigned the same object name (typically a neighbor address or name) to a noise-sensitive area, a shadow receptor and a camera, the "Auto create neighbor list" button will pair these automatically. Alternatively, neighbors can be added individually and paired manually using the form shown below. Here it is also possible to write a caption for the picture and a comment for the page. This could be your evaluation of the total environmental impact for the neighbor.

The calculation provides a page for each neighbor included and a map showing the positions of the WTGs, the neighbors and the cameras.

An example of the printout can be seen in the Module Description.

4.5 NORD2000 – Advanced noise calculations

4.5.1 NORD2000 – Introduction and step-by-step guide

4.5.1.1 Introduction to NORD2000 Calculations

NORD2000 is an advanced calculation engine for noise calculation. It was developed for traffic noise (Plovsing 2010) and has in later years been validated for calculation of wind turbine noise (Plovsing and Søndergaard, 2009).

A calculation with NORD2000 is an attempt at calculating the real noise experienced at a receptor. There are many factors influencing the noise impact and therefore there are many parameters in a NORD2000 calculation. Importantly many of these parameters are variable in time and so a standard NORD2000 calculation calculates the noise for a specific situation that may be present for only a short while.

Most official noise codes define specific conditions during which the noise from the wind turbines must comply with a critical noise impact level. Often these are hard-coded into specific noise propagation models, which must be used. Such models are implemented in the DECIBEL module. At other times specific conditions are required, but not a specific noise propagation model. In those situations the NORD2000 model can be used to simulate those situations.

In other situations the noise codes simply state that noise from turbines cannot exceed a certain noise level. Those cases are more problematic because the noise impact varies with time as a function of wind direction, wind speed, turbulence, thermic stability, humidity and changes in landscape texture between summer and winter. In those cases the object might be to find a worst case noise. Worst case however is quite extreme and a maybe more realistic objective is the average noise or maybe the noise exceeded in only 10% of the time. For this purpose the NORD2000 calculation can calculate for a range of wind speeds and wind directions to give the worst case impact or for a more advanced analysis combine the calculation with wind measurements to find how often different noise levels occur at the noise receptor.

Maybe a more obvious use of NORD2000 is for problem sites where there are doubts whether a wind farm will comply with noise limits under very specific conditions. Will a lake in front of the house be a problem? What happens on a dry clear night at the receptor? In those cases NORD2000 can give that specific analysis that answers those questions.

But most value the user will get if the country/region allow for flexible noise reductions of the turbines, like e.g. direction dependent noise reduction, which can save noise reduction losses and still keep the neighbors on the safe side of the noise limits. Just gaining few percent more energy production by less noise reduction can by todays large projects mean millions of Euros gained.

4.5.1.2 Step-by-step guide to NORD2000 Calculations
- ❑ Establish a map and a proposed project (see Basis 2.0.5)
- ❑ Establish relevant objects; Noise-sensitive areas, Elevation data in Line Objects OR elevation grid object, Area Objects with terrain characteristics, Meteo object (if required) and a Site data object if WAsP is used.
- ❑ From the calculation menu, run NORD2000, set up calculation parameters.
- ❑ Print reports.

4.5.2 NORD2000 calculations

4.5.2.0 Background on the NORD2000 calculations

The NORD2000 noise model was originally developed for traffic noise by an international workgroup. The original model and project is described in (Plovsing, 2010).

In 2007 a workgroup consisting of representatives from DELTA, EMD, and DONG Energy began the process of validating the NORD2000 noise model for wind turbines and implanting the model in a commercial software package (WindPRO). The project was called "Noise and energy optimization of wind farms" and was funded by Energinet.dk.

As a result of the project the NORD2000 model was successfully validated on test sites with elevated loudspeakers (Denmark) and operating wind turbines (Norway). The results were presented at the Wind turbine noise 2009 conference (Sondergaard, Plovsing, 2009).

The implementation of the noise model required a number of considerations not, or to a lesser degree addressed by the original traffic noise project. These include the relationship between wind speed and source noise level, Climatic situations and their relation to source noise level and the general application of an aggregated model. Some of these considerations were presented at the Wind turbine noise 2009 conference (Sorensen, et.al. 2009).

The NORD2000 implementation in WindPRO is the result of this work and is released for common use first time in WindPRO version 2.8. It consists of a calculation engine produced by DELTA and a user interface produced by EMD.

Principles of calculation

The basic NORD2000 calculation calculates the noise propagation from a wind turbine to a receptor (neighbor) given the specific terrain, wind and climatic condition.

The first task is to find the source noise level of the turbine (section 2.6.3.2). This is a function of wind speed at the turbine and the turbine specifications. The source noise level is divided into 8 octaves or 24 third octaves.

This task may be complicated by the fact that turbines in a wind farm rarely experience the same wind speed at the same time and that the reference wind speed location is often undefined.

The second task is to define the terrain. The terrain itself causes terrain attenuation. This is calculated as a function of the terrain shape (height contours) and the terrain acoustic hardness. Hard terrain like water or a parking lot may attenuate very little noise, while soft ground like natural or agricultural land my attenuate the noise well.

The terrain will also influence the wind profile in the form of a terrain roughness (roughness length), which affect the atmospheric attenuation.

This will also depend on a number of climatic parameters. These are:

- Wind direction
- Wind speed
- Humidity
- Temperature
- Turbulence strength (wind)
- Turbulence strength (temperature)
- Standard deviation of wind fluctuations
- Inverse Monin Obukov length

- Temperature scale T*

The last five of these parameters are rather exotic and have for ease of calculation been reduced to standard settings for day and night, clear sky and clouded.

Finally the height above ground level for the receptor is set.

With these settings for source noise level, terrain and atmosphere the data is sent to the NORD2000 calculation engine, which return the resulting noise level at the receptor from the turbine calculated.

The calculation is repeated for the other turbines in the wind farm and the noise is added together.

Please note that the noise calculated is the outdoor noise. It is not possible to include any damping from being inside or behind noise reducing structures.

Overview of calculations (Main).

When a NORD2000 calculation is started it is possible to select what type of calculation to do.
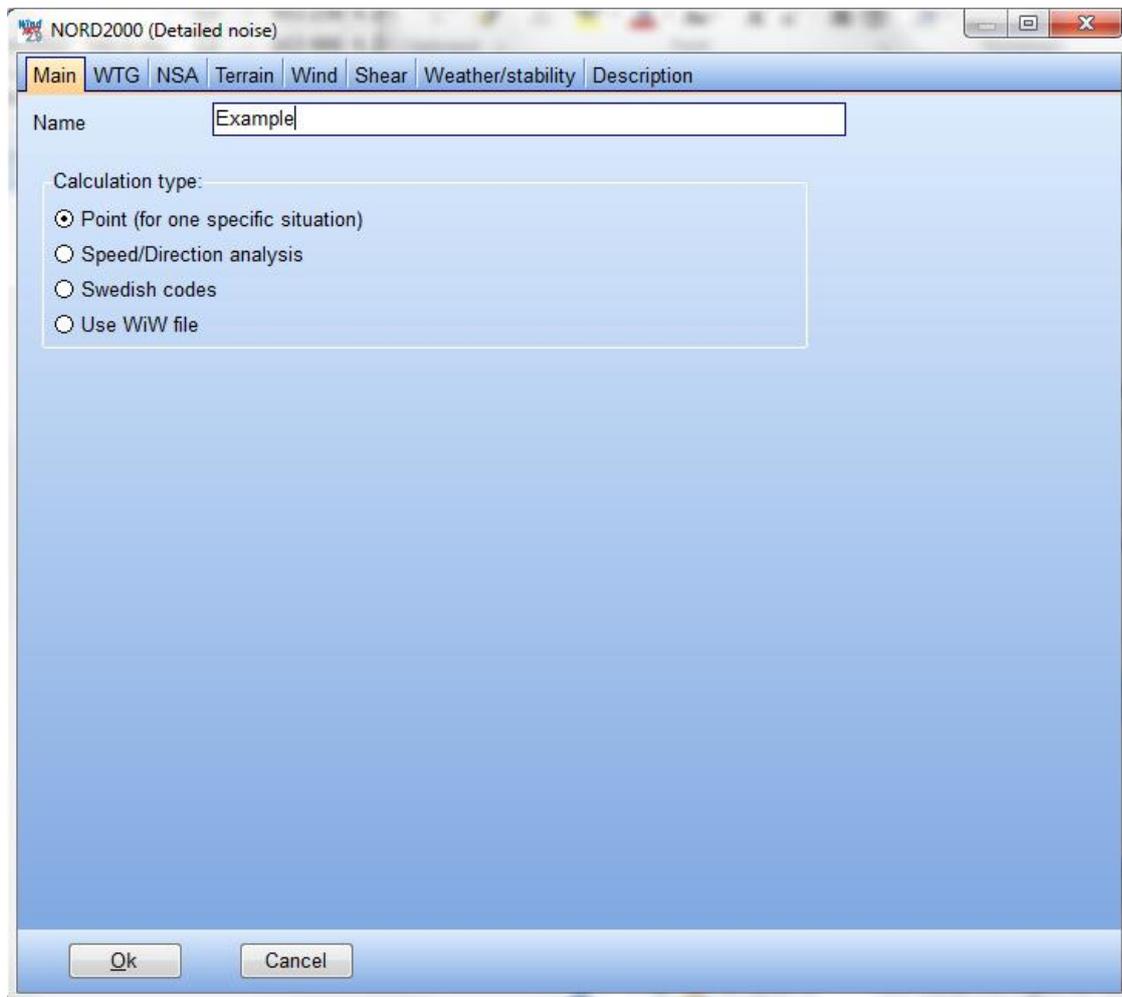
The **Point** calculation is a calculation of the noise from a wind farm at a group of receptors for a very specific set of conditions. It is valid for that brief moment where these conditions are present. This means a specific wind speed, wind direction, temperature humidity, terrain etc.

The **Speed/directional analysis** (or Range) calculation calculates a range of wind speeds and directions. Most noise codes refer to the downwind noise level. By going through a range of directions it is possible to find

the worst case (most downwind) situation at each receptor, since what is downwind of one turbine may be upwind from another.

The **Swedish codes** lock the settings in the NORD2000 calculation to settings described in "Ljud Från Vindkraftverk" (Noise from wind turbines), Naturvårdsverket, April 2010, in so far as the parameters are described.

Use WIW file is a special setting where the wind speed at each wind turbine is calculated through a "Wind speed Inside Wind farm" calculation. This has the advantage of including the wind speed reduction due to wake losses. This calculation option requires that a "Wind speed inside Wind farm" calculation (from a PARK calculation, see section 3.4.1.4) has been made before the NORD2000 calculation is run.

The following description of the calculation settings is based on the Point calculation. Later, the differences caused by the other calculation options are described.

4.5.2.1 Point calculation

Wind farm selection

The WTG tab lets the user select the wind farm to be used is the calculation. The tab is identical to similar tabs in other calculations in WindPRO (see section 4.1.3.1).
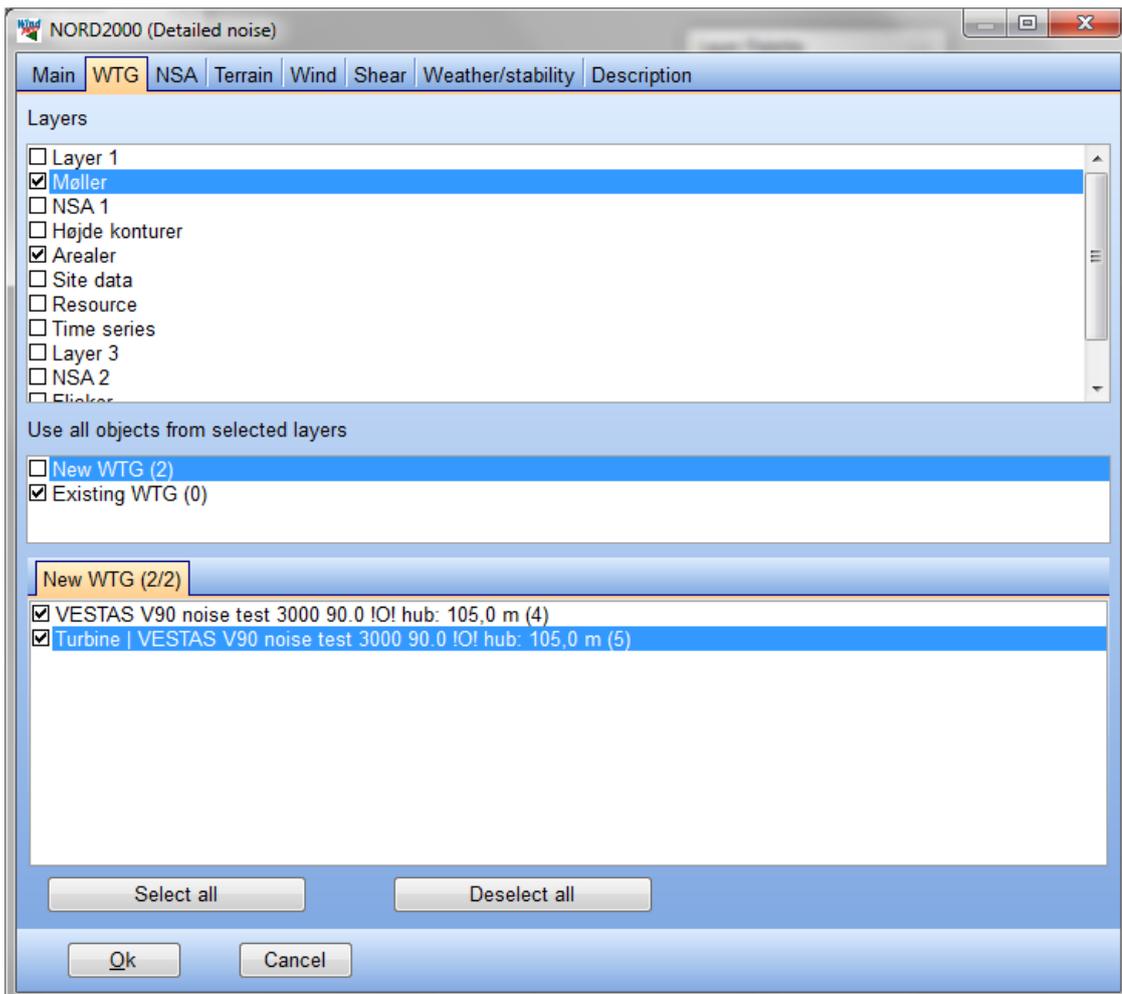
The top section is a list of layers in the WindPRO project. The layers visible when starting the calculation is automatically selected (hatched). Additional layers can be selected or deselected at this point. It is a good idea to organize the project so that each layout suggestion gets its own layer.

In the section below is listed how many new and existing turbines have been selected. Hatching the box to the left of the text includes all these turbines.

If the boxes are not hatched the bottom field appears where the turbines in the selected layers can be selected individually.

Of the turbines themselves a good calculation requires a rather complete data set.

This means that the turbine noise dataset should include noise levels at multiple wind speeds, typically in steps of 1 m/s from 4 to 12 m/s. Also an octave band distribution is required. The description of how to enter noise data can be found in section 2.6.3.2.

WindPRO will interpolate linearly between wind speeds and extrapolate using the closest two wind speeds.

If octave band distribution is not available for all wind speeds the closest wind speed octave band distribution is used and extrapolated to the total noise level at the wind speed in question.

From WindPRO 2.8 the wind turbine catalogue hold noise level both at 10 m above ground and hub height. The user can select where to input the noise data and WindPRO will convert to the other. If multiple hub heights are given the first in the list is used for the conversion. This is important as the NORD2000 model uses the noise level at hub height for its calculations.

Noise sensitive areas

The NSA (Noise Sensitive Area) tab is where the noise sensitive areas are selected.

The procedure is described in section 4.1.3.1 and follows the same principles as for selection of wind turbines.

The noise sensitive areas are fully described in the DECIBEL manual (section 4.1.2.2). There are no special NORD2000 settings.

The NORD2000 calculation is at the present stage only set up to calculate the noise from the turbines and so ambient noise it not handled by the model. The NSA should therefore only set critical noise limit on noise from the turbines themselves.

Terrain

On the **Terrain** tab, the terrain used in the calculation is defined. This is the Elevation data, Roughness data and Terrain type (hardness).
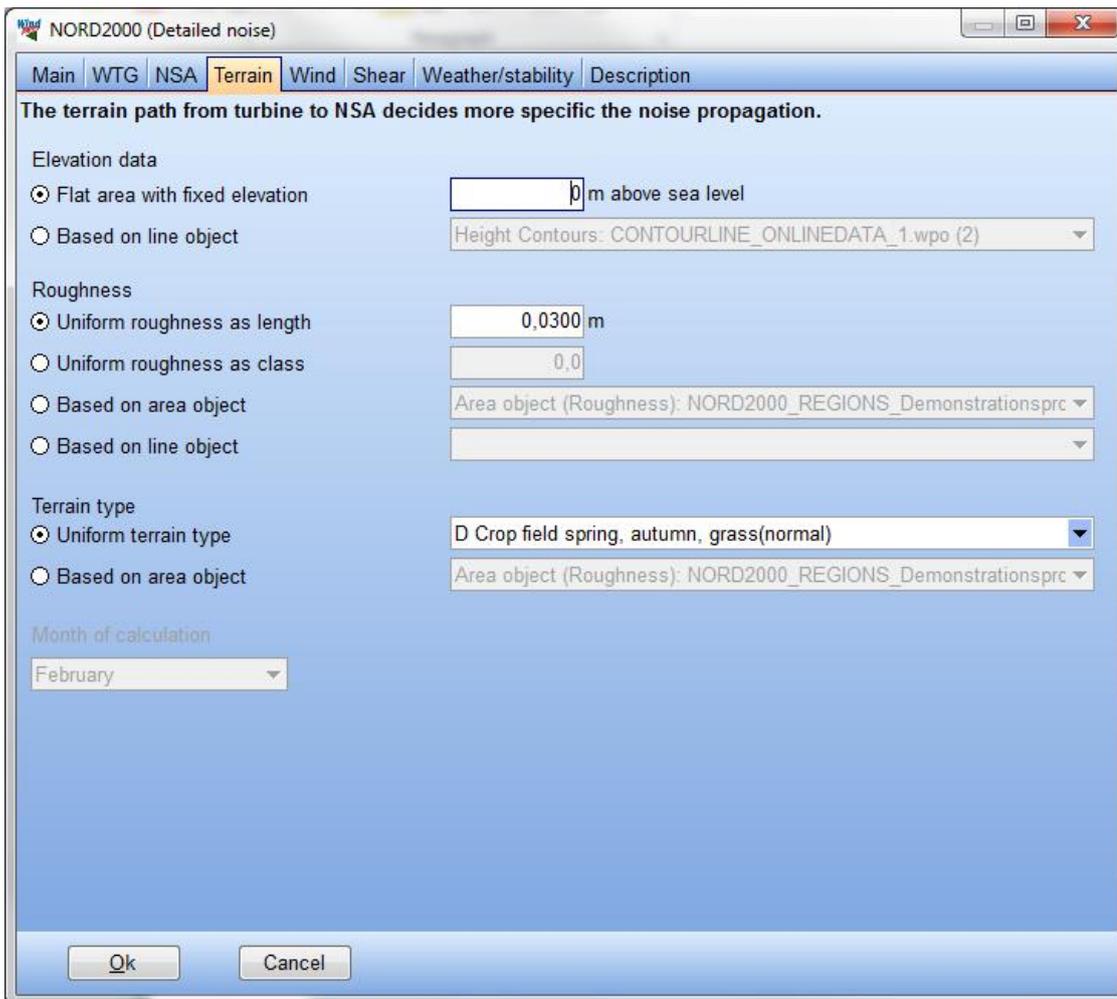
- ***The elevation data***

The elevation data is the height model used.

There are two options:

1. Using flat terrain where the fixed height level is set in the box. Beware that if the turbines or the receptors already have a z value this may be different from the value typed and cause a wrong calculation result.
2. Link to a line object. In this case you link to a line object holding the elevation model (contours or grid) of the project. This elevation model is used to calculate the terrain between turbine and receptor and not to find the base height of the objects. In order to secure consistency it is strongly recommended to use the same height model as is used for the TIN. For more on elevation models see section 2.8).

NORD2000 uses the elevation model to create a cross section from the turbine to the receptor. In general the larger the difference between line of sight and the terrain the less the terrain attenuation. However the model also uses the slope angles to calculate the noise propagation.

- ***The roughness data***

The roughness is the surface texture properties that identify the drag the terrain exert on the wind. The higher the roughness, the faster wind speed increase with height. A full description of the concept of roughness can be found in section 3.2.1.3.

There are the following possibilities:

1. **Uniform roughness as length**. The entire calculation area is considered to have the same roughness given as roughness length, z0.

2. **Uniform roughness as class**. The entire calculation area is considered to have the same roughness given as roughness class.
3. **Based on area object**. Choosing this links to an area object set for roughness areas. For more on area objects see section 2.9.
4. **Based on line object**. Choosing this links to a line object with roughness lines. Such a roughness line object would typically be used also in a production calculation. For more on line objects see section 2.8.

The roughness description is used to calculate the wind profile through which the noise propagate. It is not used to calculate the hub height wind speed of the turbines.

- ***Terrain type***

The terrain type is the acoustic hardness of the terrain, basically how well noise gets absorbed by the ground.

There are two options:
1. **Uniform terrain type**. In this case the terrain type is chosen from the list and is uniform for the entire site.
2. **Based on area object**. Choosing this links to an area object with NORD2000 properties.

The acoustic hardness is an important property of the ground. In WindPRO we use 7 categories of terrain each corresponding to a hardness value (Plovsing, 2010). These types are shown below.

Terrain hardness (for NORD2000)	Value
A Snow	12.5
B Forest, Heather	31.5
C Crop field summer, grass(soft)	80
D Crop field spring, autumn, grass(normal)	200
E Crop field winter, grass(compact)	500
F City, Frozen ground, rock	2000
G Water, ice concrete, asphalt	20000

Throughout a site the acoustic hardness can vary a lot. Lakes, farmland and forests are often mixed. Therefore it is useful to map such areas so the right values are chosen for the calculation. This can be done with the Area object.

From WindPRO 2.8 the Area object come with a new property, NORD2000 Terrain hardness.
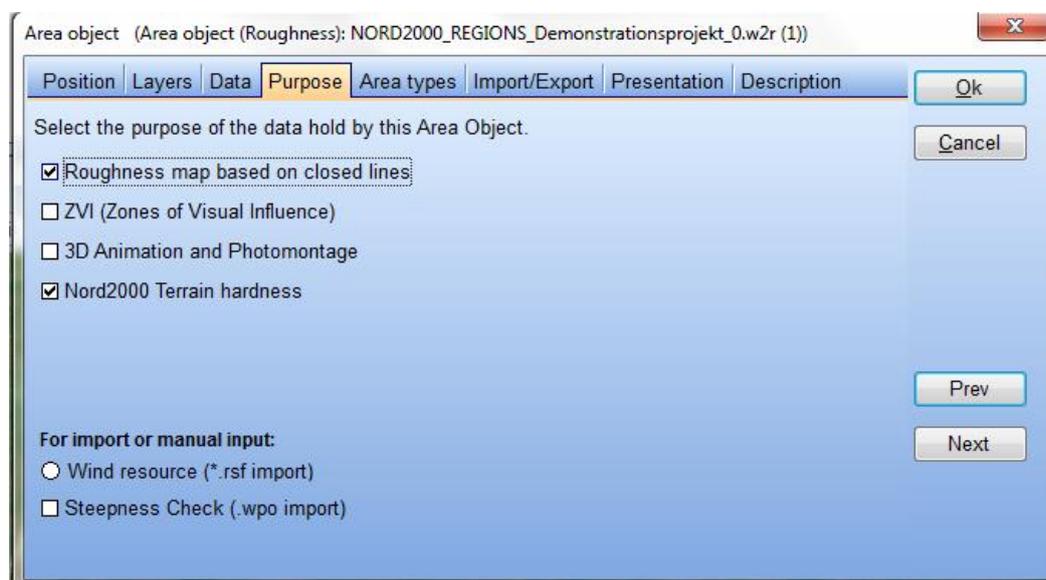
It is useful to use the same area object for both roughness and acoustic hardness.
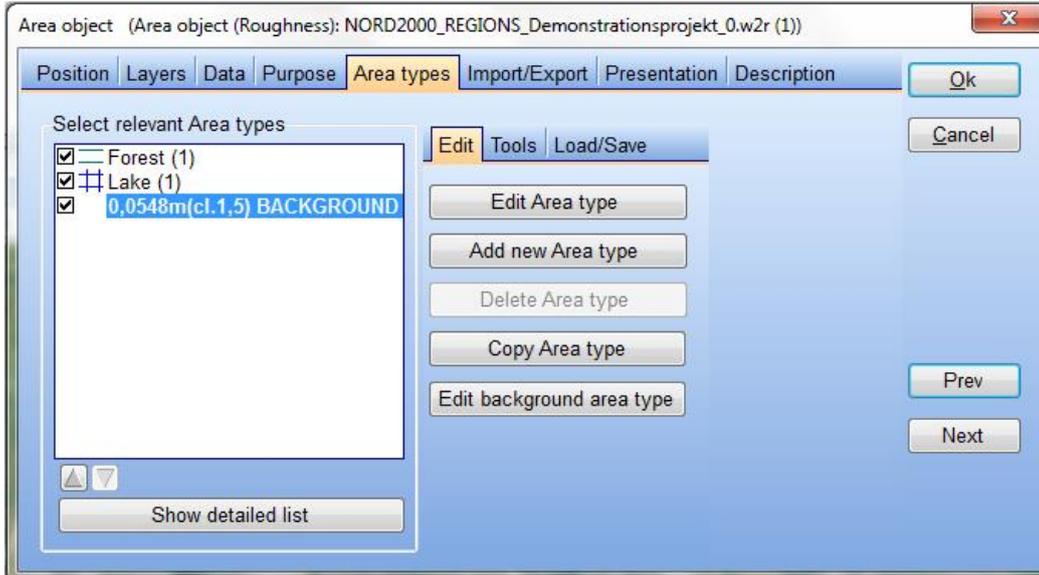
A number of area types need to be defined including a background. This follow the standard procedure for area objects as described in section 2.9.

When adding a new area type or editing an existing area type the acoustic property can be set according to the list above. In addition it is possible to vary the acoustic hardness over time by hatching the relevant months. In the calculation it is possible to select a month and thus pick the correct hardness values for the terrain.
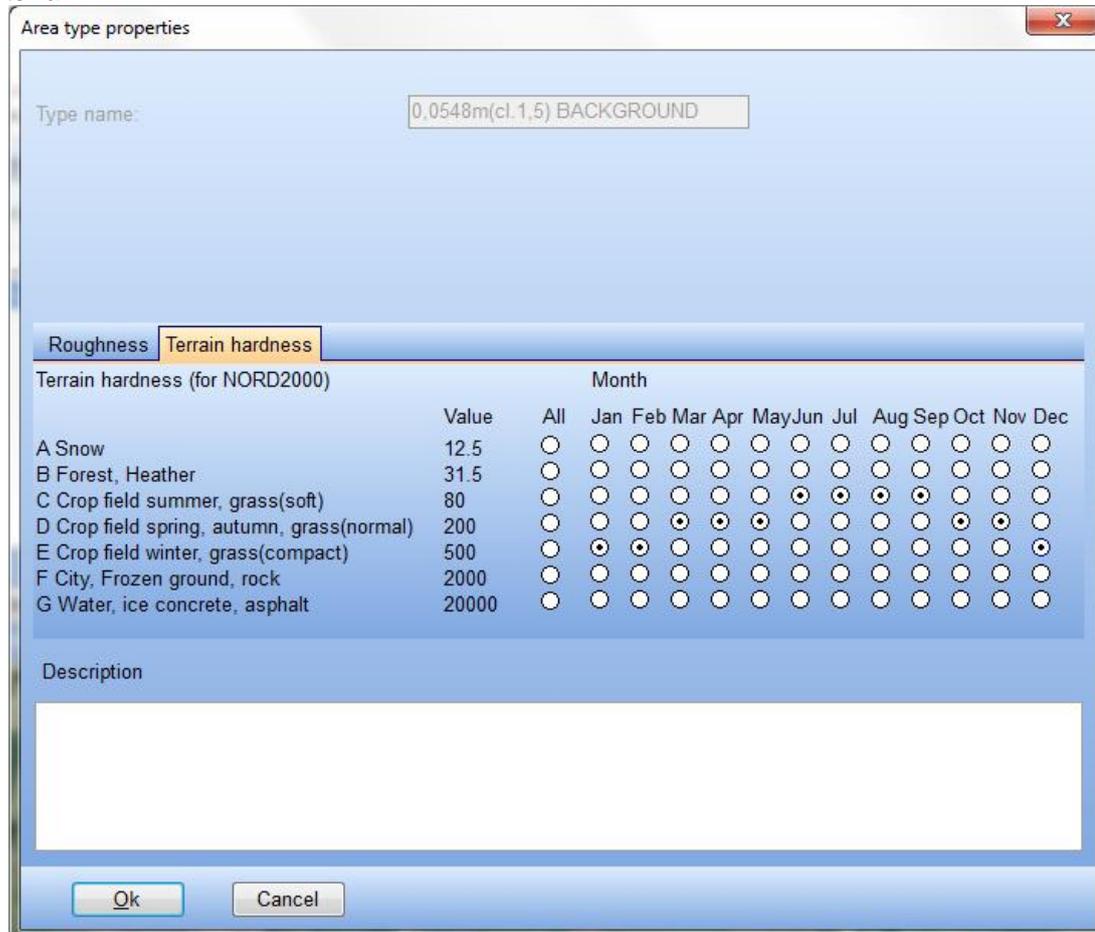
Wind

The Wind tab is where the wind speed and direction for the calculation is entered. It is also here where the source noise levels for the turbines are calculated.

The default setting is **Uniform wind speed in wind farm**. With this setting all turbines are set to have the same wind speed in hub height and therefore same source noise level.

The wind speed and direction is typed into the relevant boxes together with the height for the wind speed.

Most noise codes refer to source noise level at a reference wind speed at 10 m height above ground. The question is of course what wind speed that corresponds to at hub height. This question is dealt with on the Shear tab.

On more complex locations the wind turbines will not have the same wind speed at the same time. There may be different wind speed and this may in turn be a function of wind direction. This raises also the question where the reference location is. If noise must be calculated at 8 m/s at 10 m height, is that at turbine 1, turbine 2, receptor 1, receptor 2 or maybe the location of a site meteorological mast?

For this purpose it is possible to select to use a WAsP model to calculate the wind speed in the wind farm. WAsP will calculate the wind speed difference between the reference site and height and the hub height of each turbine for each wind direction and thus give an individual wind speed for each turbine.

Select the second radio button, **Use calculated wind speed differences in wind farm**. This activates all the WAsP related details.

In the **Reference site** field an object must be selected to be used as reference location. This can be any object in the project. The wind speed direction and height above ground refers to this location.

The method for calculating the wind speed and direction difference at each location is WAsP. WAsP requires three things:
1. A WAsP license
2. A license for the MODEL module in WindPRO
3. A Site data object set for Statgen, where height contours and roughness lines for use in the calculation are indicated. For more on Site data objects see section 3.3.1.

The wind speed at hub height at each turbine location is used to find the source noise level.

A fully documented noise record will have noise levels at different wind speed and WindPRO interpolate between the two closest wind speeds.

Please note:
1. Wind speed reduction due to wake loss is not included. To include that you need to run the WIW option (see section 4.1.12). Whether wakes decrease (due to less wind speed) or increase (due to turbulence) the source noise level of turbines is still being debated (Madsen, et.al, 2011) and the WIW is there for experimental purpose.
2. Directivity of turbine noise is not included. All source noise levels are considered downwind. At other angles to wind direction the source noise level has been reported to be less. However this is poorly or not at all documented for most turbine types.

At the bottom of the Wind tab the **Height above ground level** for the receptors can be written. This is also the height for which wind speed at receptor is calculated.

Shear

The tab shear is used to calculate the relation between wind speed at reference height and wind speed at hub height. This is in order to pick up the correct source noise level for the turbines.
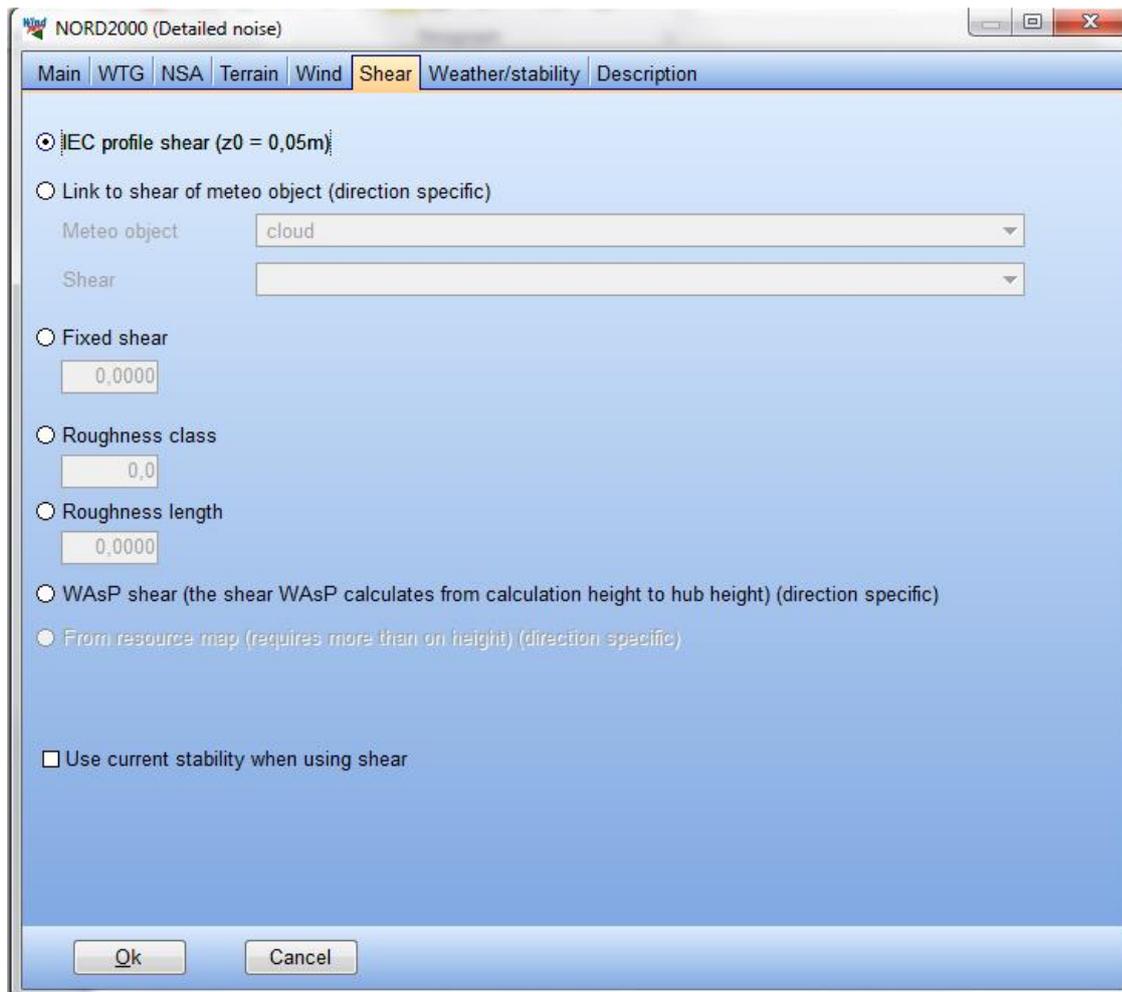
Default setting is to use the **IEC profile**. This is the standard profile assumed according to the IEC standard when using 10 m reference wind speed to identify the wind speed of noise measurements. This is incidentally why many turbines have different source noise levels at different hub height. The wind speed at hub height changes with hub height and the turbine have different source noise level at different wind speeds.

The IEC profile corresponds to a roughness length of 0,05 m.

The second option is to use the observed shear on site. This is done with **Link to shear of meteo object**. The observed shear on a site is a more objective relation between wind speed at reference height and wind speed at hub height. It is thus possible to link to a meteo object and a particular shear from this meteo object. The shear values are given for the direction sectors specified in the meteo object. For details on meteo objects see section 3.3.2.
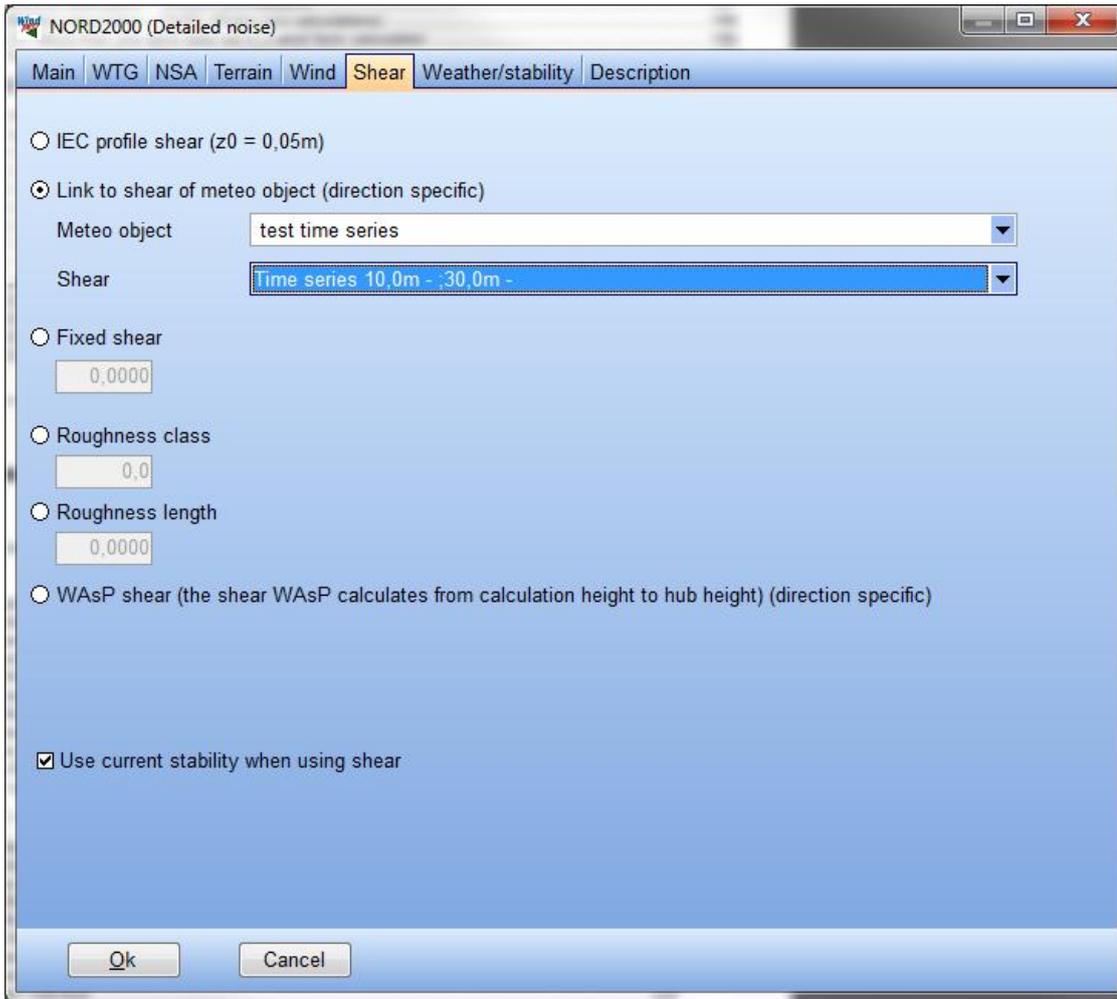
Fixed shear means that a particular typed shear exponent is used uniformly for the entire site.

Roughness class means that a particular typed roughness class is used uniformly for the entire site.

Roughness length means that a particular typed roughness length is used uniformly for the entire site.

WAsP shear would be the obvious choice if the wind speed at hub height on the Wind tab was found using WAsP. If WAsP was selected on the Wind tab and another shear option is selected on the Shear tab, WAsP is used for the horizontal extrapolation and the shear selection for the vertical extrapolation.

The last option **Use current stability when using shear** can be checked in addition to the above options. This modifies the selected shear with a stability correction based on the stability parameters given on the Weather/stability tab. Stable and unstable conditions can create extreme shear that makes a much higher or lower source noise level of the turbines.

Weather/stability
The **Weather/stability** tab is where the climatic condition of the calculation is described.

Relative humidity is the humidity of the air in percentage

Temperature is the temperature at a specified height above ground in degrees Celsius.

The stability parameters are more complex. They consist of several exotic parameters where the most important is the Monin Obukov length and temperature scale T*. They become visible by hatching Show advanced options.

Turbulence strength (wind) (or turbulence intensity) is the standard deviation on wind speed divided by mean wind speed in a 10 minute interval and is well described in section 3. It is given in percentage.

Turbulence strength (temperature) is the same but for temperature.

StDev Wind fluctuations is the standard deviation of the wind speed, likewise a parameter described in section 3 on the meteo mast.

Inverse Monin Obukov length is a stability length scale (1/m). A negative value means unstable conditions with high degree of mixing and low shear and a positive value means stable conditions with low degree of mixing and high shear.

Temperature scale T* is the slope of the temperature profile.

While these parameters are quite exotic and can be hard to get for a site, for simplicity four standard situations have been preset, so by selecting one of those the exotic parameters is set at representative values.

These are **Day** and **Night**, **Clear sky** and **Clouded.**

Hatching **Input advanced options manually** aborts the preset settings and allow for a manual setting of the parameters.

All these climatic settings influence the propagation of the noise from the turbine to the receptor. Obviously they are fluctuating parameters and you will only have the specific situation for a very short period of time. For

a more meaningful calculation one can have a specific setup as a "standard" situation, which will often be described in the relevant noise codes.

4.5.2.2 Speed/directional (range) analysis

The Speed/directional analysis calculation allows for a calculation for a range of wind speeds and wind directions in one calculation. Besides the simple efficiency of covering more calculation in one operation it also makes it possible to cover the worst case situation of down wind noise.

A wind direction which is downwind from one turbine to one receptor may be upwind or side wind for another turbine – receptor pairing, which means that there is no single wind direction which is the ultimate downwind situation for a wind farm consisting of more than one turbine and one receptor. However by calculating for, say, 12 different wind directions and selecting the highest noise level for each receptor it is possible to present in one calculation the worst case noise i.e. most downwind noise situation.

A speed direction analysis is started by selecting **Speed directional analysis** on the **Main tab**.
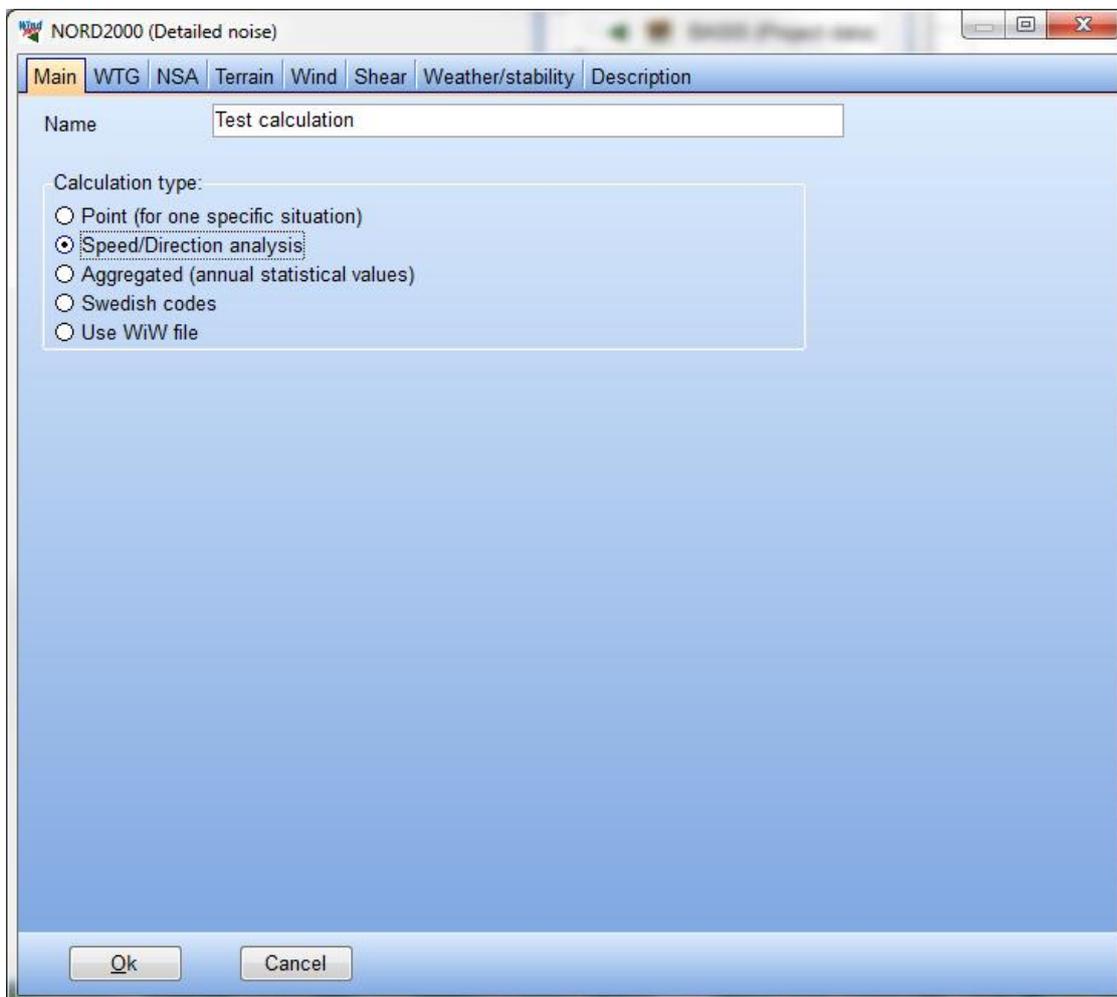
The following text describes the difference on the individual tabs from doing a Point calculation. If nothing is commented the calculation setting options are the same as for the Point calculation.

Wind (speed and directional analysis)

The only difference from a Point calculation is on the Wind tab.

Instead of choosing just one wind speed and one direction you can choose a range of wind speeds and directions.

Enter a **from** and **to** wind speed and direction and the **step** size of the interval between the wind speeds and directions and WindPRO calculate how many calculations this amounts to.

Note for directions that if a full circle is required not to end with the same direction as you began. That direction would then be calculated twice which is unnecessary (see example above).

The wind speed and direction range refers as before to the height and position of the reference point.

4.5.2.3 Swedish codes

The Swedish noise codes are described in "Ljud från vindkraftverk" from Naturvärdsverket. In the edition from April 20th 2010 is described the possibility to calculate the wind turbine noise using NORD2000.

Unfortunately a methodology for using NORD2000 is not described, but must be assumed to follow the general noise codes for Sweden.

The Swedish codes option in the NORD2000 calculation in WindPRO locks the settings to the values and configurations described in "Ljud från vindkraftverk" and leaves open a number of options not described in the codes.

Wind (Swedish codes)

The Swedish codes requires a calculation downwind from the turbines. Therefore will the Swedish setting automatically run a range (speed/directional analysis) calculation in each sector and select the noisiest result for each receptor.

The source noise level is based on 8 m/s at 10 m height and scaled to hub height using the IEC profile (roughness length = 0,05m).

For these two reasons the Wind tab only show the selected parameters and the shear tab is unavailable.

"Ljud från vindkraftverk" does not permit that the source noise level is found individually at each tubine such as with WAsP.

Receptor height is automatically set to 1,5m.

Weather/stability (Swedish codes)

The climate settings are not specified in "Ljud från vindkraftverk" so the options are as described in 4.1.8.

Using WiW file

The Use WiW file option is an experimental option that allows the user to adjust the wind speed at the turbine hub height - and thus the source noise level - with wake losses.

This calculation requires as input a Wind speed inside Wind farm (WiW) file. This is done in a PARK calculation (see section 3.4.1.4). Hatch the **Advanced** box, select a **wake model** other than N.O.Jensen (RISØ/EMD) and hatch **Reduced wind speed inside wind farm**.

Otherwise the turbine layout and wind model is selected as for a standard PARK calculation.

When the calculation is done, right click on the calculation header and select **Result to file**. In the list that appears find Wind speeds inside wind farm. Select Save as and you get the WiW window from which you can select the wind speed and wind directions to use later on in NORD2000.
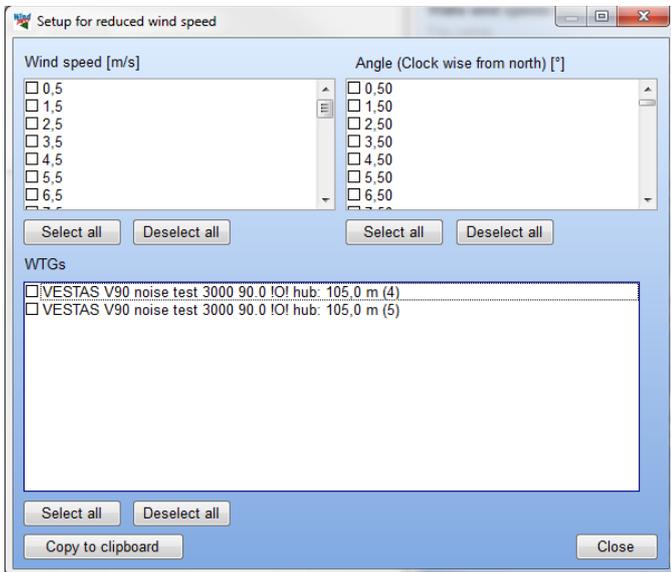
These are the conditions that must be calculated by NORD2000. This is like the speed/direction calculation where the parameters for wind speed and direction are given in a file instead. The wind speed is the free wind speed at hub height. WindPRO will thus reduce the wind speed with the wake loss fir each turbine and each selected wind direction based on the wake model. Note that this calculation is not doing a WAsP calculation and so the same free wind speed is assumed at all turbines.

The NORD2000 WiW option is started from the NORD2000 main menu by selecting the WiW calculation.

The Wind tab is obsolete as all the wind speeds and directions for the calculations are given in the WiW file.

4.5.3 NORD2000 - Printout

The reports from NORD2000 are in principal similar to a Decibel calculation report. That means that there is a main page with a summary of the results followed by a list of assumptions, a page(s) with details on the calculations and finally a map. In the current edition the map does not include noise iso-lines like the Decibel calculation.

In the following, the report from a NORD2000 point calculation is firstly described. The differences to this report are then presented for the other calculation options.

4.5.3 1 Point calculation

The main result
The Main result is similar in structure to most other WindPRO calculations.

At the top of the printout is a section with the calculation setup.

Assumptions

Weather stability	
Relative humidity	50,0 %
Air temperature	15,0 °C
Height for air temperature	2,0 m
Stability parameters	Night;Clouded
Inverse Monin Obukov lenght	0,0000
Temperature scale T*	0,0000
Terrain	
Flat area with fixed elevation	0,0 m above sea level
Roughness based on area object	
Area object (Roughness): NORD2000_REGIONS_Demonstrationsprojekt_0.w2r (1)	
Terrain type based on area object	
Area object (Roughness): NORD2000_REGIONS_Demonstrationsprojekt_0.w2r (1)	
Month for calculation	January
Wind speed criteria	
Wind speed at 10 m agl. at location	
Reference location	
(UTM (north)-WGS84 Zone: 32 East: 550.729 North: 6.287.826)	
Wind speed	8,0 m/s
Wind direction	180,0 Deg
Height above ground level for receiver	1,5 m
Wind speed has been extrapolated to calculation height using	
WAsP	
Use stability correction	

Weather stability lists the climate parameters selected for the calculation including the two most important stability parameters T* and the inverse Monin Obukov length (see section 4.1.8).

Terrain lists the terrain settings used or the file/object used to describe the terrain.

Wind Speed criteria lists the wind speed and direction settings for the current calculation. It is listed at what height a specific wind speed and wind direction is used. If WAsP is used to calculate the hub height wind speed at each turbine, then the location used as reference is mentioned. The method used to scale the wind speed to the hub height is mentioned and whether this extrapolation is corrected for the stability settings of the calculation.

Below the calculation settings is a list of the turbines involved.

WTGs

	UTM (north)-WGS84 Zone: : 32				WTG type						Noise data			Wind	LwA,ref
	East	North	Z	Row data/Description	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Creator	Name		speed [m/s]	[dB(A)]
	UTM (north)-WGS84 Zone: : 32		[m]												
1	551.021	6.288.035	70,0		Yes	VESTAS	V90 noise test-3.000	3.000	90,0	105,0	USER	Mode 0 - 109.4 dB(A) - 03-2004 (octav) 1.225		10,6	108,9
2	550.724	6.287.831	70,0		Yes	VESTAS	V90 noise test-3.000	3.000	90,0	105,0	USER	Mode 0 - 109.4 dB(A) - 03-2004 (octav) 1.225		10,6	108,9

For each turbine the wind speed at hub height is calculated and the source noise level at that wind speed is stated. Note that the turbine used in the example is a generic turbine with artificial data.

Finally the list of the calculation results is shown.

Calculation Results

Sound Level

Noise sensitive area		UTM (north)-WGS84 Zone: 32					Sound Level
No.	Name	East	North	Z [m]	Imission height [m]	Wind speed [m/s]	From WTGs [dB(A)]
A	Voldsted	550.718	6.288.479	65,0	1,5	8,0	44,4
B	House	551.228	6.287.866	65,0	1,5	8,0	50,3

Here each receptor and their location is listed. The wind speed mentioned is the wind speed at the reference location, not necessarily at the receptor itself. The Sound level is the resulting noise level for the receptor.

Assumptions

The assumptions page repeats the calculation settings presented on the main result page.

Below this the details for the turbines involved is presented. This includes the name of the noise record used, the source and date and the comments written to the record in the turbine catalogue. This will often include reference details on the technical specification or noise measurement report that the data originate from.

The data are presented as a matrix where each line is a wind speed at hub height, the first column is the total noise level and each column after that is the noise level of each octave.

Finally there is a list of each noise receptor in the calculation.

Details

The Details page gives detailed results for each calculated receptor.

Calculation Results																								
Noise sensitive area: A Voldsted																								
WTG No.	Distance	Wind speed	Wind direction	Wind speed at hub height	Sound level	Octave data 63	125	250	500	1000	2000	4000	8000	Source noise LwA,ref	Octave data 63	125	250	500	1000	2000	4000	8000	
	[m]	[m/s]	[°]	[m/s]	[dB(A)]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB(A)]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	
1	538	8,0	270,0	10,6	**42,05**	32,9	30,7	31,4	37,6	36,9	29,3	13,0	-27,5	108,88	95,7	97,5	101,4	102,2	103,8	99,9	95,1	86,5	
2	648	8,0	270,0	10,6	**40,62**	32,5	31,7	30,3	35,6	35,0	26,7	8,9	-36,1	108,91	95,7	97,6	101,4	102,2	103,9	99,9	95,2	86,6	
Sum					**44,41**																		

Each receptor has its own table. In the above example the results for the receptor called Voldsted are presented.

Each line in the table represents a turbine. The numbering refers to the list on the Main result page. The distance to the turbine is presented in the second column.

The first wind speed column gives the wind speed at the reference point and the wind direction for the calculation. The second wind speed column is the wind speed at turbine hub height. Note that while the first wind speed column will be the same for all turbines, the second might be different if a separate wind speed calculation is made or if the turbines have different hub height.

The column in bold is the total noise from each turbine and these noise levels are added together in the sum line.

To the right of the resulting noise are two groups of octave data. The right one is the input data from the turbine. This will usually be an interpolation from the source noise level table on the assumptions page and if the wind speed at hub height is different for the involved turbines the source noise level may also be different. The table to the left is the resulting octave band distribution at the receptor from each turbine.

Map

The final page is a map page giving the location of turbines and receptors.

Note that NORD2000 does not calculate noise iso-lines.

4.5.3.2 Speed/direction analysis report

Main result

In a range calculation it is not possible to state in the settings exactly what wind speed and direction is used as a range of wind speeds and wind directions are used.

The calculation result table looks a slightly different from the Point calculation.

Calculation Results

Sound Level

No.	Name	East	North	Z [m]	Imission height [m]	Wind speed [m/s]	Sound Level From WTGs [dB(A)]
	A Voldsted	550.718	6.288.479	65,0	1,5	6,0	41,1
	A					8,0	44,8
	B House	551.228	6.287.866	65,0	1,5	6,0	47,1
	B					8,0	50,5

Noise sensitive area   UTM (north)-WGS84 Zone: 32

Sound Level

Noise sensitive area   UTM (north)-WGS84 Zone: 32

No.	Name	East	North	Z [m]	Imission height [m]	Wind speed [m/s]	Dir [°]	Sound Level From WTGs [dB(A)]
	A Voldsted	550.718	6.288.479	65,0	1,5	6,0	0,0	40,9
	A					6,0	30,0	41,0
	A					6,0	60,0	40,9
	A					6,0	90,0	40,8
	A					6,0	120,0	40,3
	A					6,0	150,0	40,4
	A					6,0	180,0	40,4
	A					6,0	210,0	41,1
	A					6,0	240,0	41,0
	A					6,0	270,0	40,2
	A					6,0	300,0	40,1
	A					6,0	330,0	39,8
	A					8,0	0,0	44,5
	A					8,0	30,0	44,6
	A					8,0	60,0	44,7
	A					8,0	90,0	44,7
	A					8,0	120,0	44,6
	A					8,0	150,0	44,7
	A					8,0	180,0	44,7
	A					8,0	210,0	44,8

At the top of the list a summary of the result is presented. Here is for each wind speed the highest noise level calculated among the tested wind directions. In other words the worst case or most downwind result.

Below is a list of results for each receptor, wind speed and direction. The example above is just a fraction of this potentially very long list of results.

Details
The list of detailed results on the Details page is now very long as many calculations are made for each receptor. Also in the case of the range calculation it is not meaningful in this list to calculate the sum of noise.

Speed/directional analysis
The Speed/directional analysis page is special for the range calculation option.
The analysis is made for each receptor.
A table summarizing the results for the receptor is presented at first

Direction	Wind speed	
	6,0	8,0
Degrees	[m/s]	[m/s]
0,0	40,9	44,5
30,0	41,0	44,6
60,0	40,9	44,7
90,0	40,8	44,7
120,0	40,3	44,6
150,0	40,4	44,7
180,0	40,4	44,7
210,0	41,1	44,8
240,0	41,0	44,7
270,0	40,2	44,4
300,0	40,1	44,3
330,0	39,8	44,2

It is a matrix of all the wind speed and direction combinations.

Below this, two graphs are shown illustrating the influence of wind speed and wind direction.
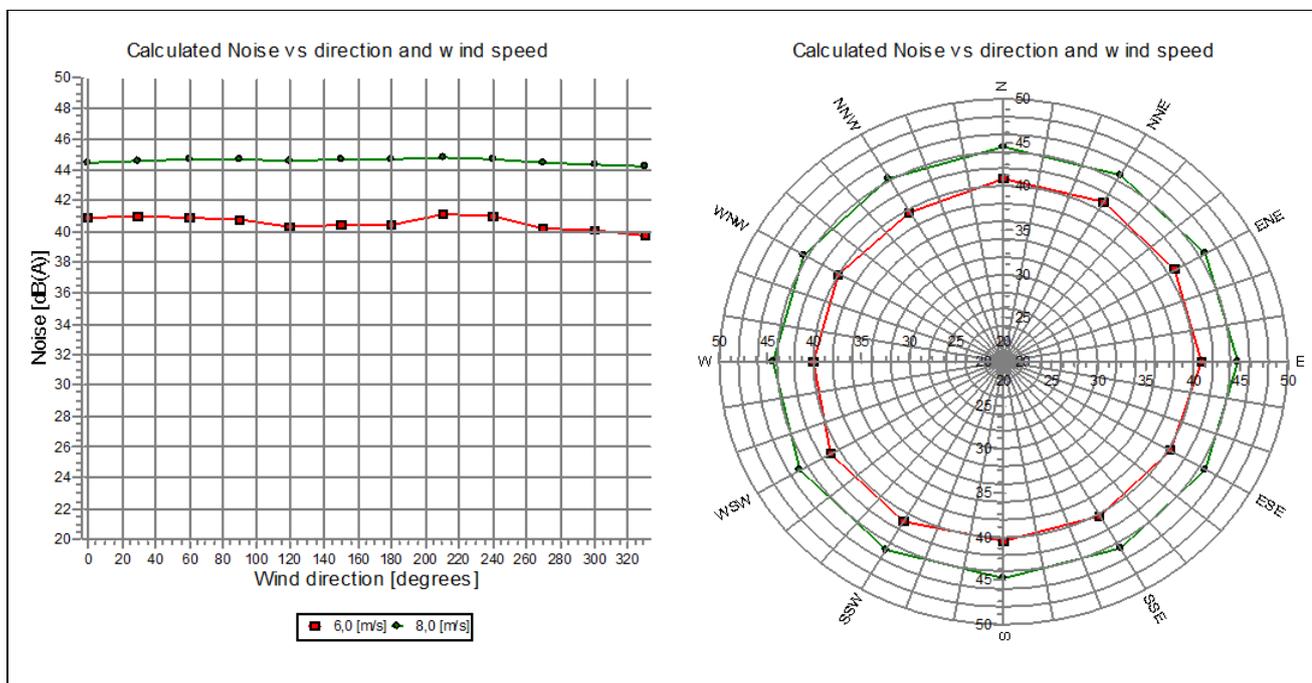
4.5.4 References

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