6 Environment

6.0 ENVIRONMENT

6.0.1 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, however even smaller projects are subject to the same regulations as bigger projects, so a complete environmental assessment can be required for any project.

It is our intention 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 through photomontages is described in a separate chapter.

6.0.2 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;
  - o for DECIBEL/NORD2000: Noise-sensitive areas, Area Objects
  - o for SHADOW: Shadow Receptors
  - o for ZVI: Elevation data (Line or elevation grid object) and eventually Area Objects and WAsP obstacles objects.
  - o for GLARE: Solar PV areas or 3D reflectors and Glare receptors.
- ❑ From the ribbon under the tab "Environment & Visual tab", run DECIBEL/NORD2000, SHADOW, ZVI or GLARE
- ❑ View the results in reports or on the map.

6.1   **DECIBEL - Noise Calculations**

6.1.0   **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.

A few important terms:

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 neighbour 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 and the noise coming from the WTG is referred to as the source noise.

Propagation model: A propagation model is the model that converts the noise from the emission point to the immision point.

Noise code: The regulation that describes how noise impact should be calculated, maximum impact permissible and how it should be documented.

Noise guideline: An official document that describes the noise code. A guideline is advisory and complying with it is recommended practice. If a guideline is made into a law, compliance becomes compulsory.

Noise threshold: Often referred to as a "noise demand" or "noise target", this is a criterion that specifies how much noise is allowed at a receptor. It may take the form of a fixed noise level, a target function of wind speed or a target spectral distribution.

6.1.1   **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 tonality contents in the WTG noise.
- The coordinates for the noise-sensitive locations/areas.
- Maximum noise level accepted inside the noise-sensitive areas (noise threshold). Possibly with information about the ambient background noise.
- The required propagation model.
- Operational strategy (noise curtailment) of the WTGs.

A number of different propagation models have been implemented in windPRO. These models typically relate to the requirements in certain countries or regions and we advise that the user finds out which methods and requirements must 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 determines what kind of input data is required.

6.1.1.1   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.
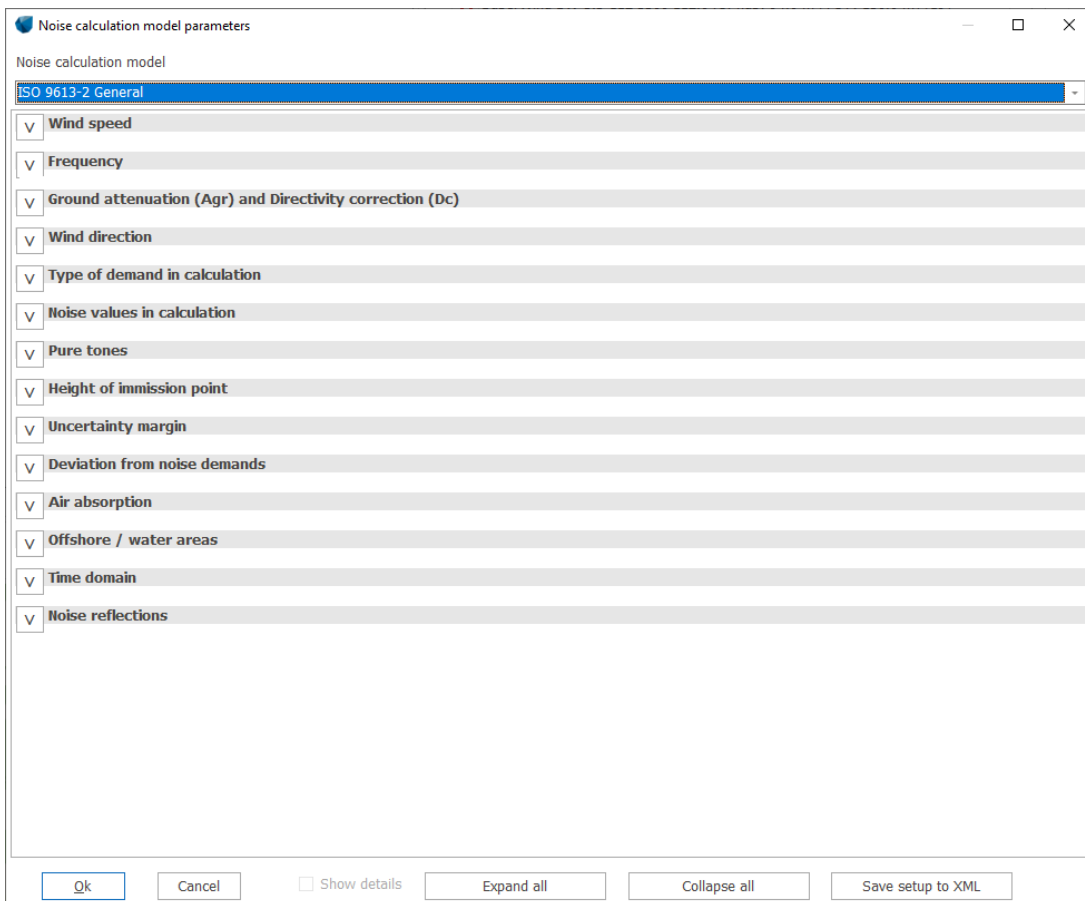
Wind speed
These are the wind speeds for which noise is calculated. Each turbine has a (or several) unique noise curves of source noise against wind speed. A calculation can refer to source noise at a specific wind speed. This wind speed would either be a reference wind speed at 10 m height or at hub height. In the wind turbine catalogue either or both can be defined (see section 6.1.2.1). If 10 m height is selected WindPRO will look for noise data in the WTG file for the specific wind speed and hub height (of the turbine) selected in the 10 m height section. If hub height is selected WindPRO will look in the hub height wind speed column for the wind speed selected. Most noise codes refer to a reference wind speed at 10 m height. If noise data for the selection is not available in the WTG file, WindPRO will notify you and may be able to suggest an alternative. All calculations are then done for 10m or hub height wind speed and refer to that in the calculation reports.

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 suggest 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 at 95% of the rated power. If no such value is available, the user will be prompted to input this. Note that 95% rated power is not a particular wind speed and windPRO cannot itself from the noise curve calculate what it may be. Instead, a specific field in the catalogue is designated **95% rated power**, typed in by the user.

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 use the loudest of the 95% rated power and the 10 m/s value. If only one of these is available, it will use that.

Highest noise value: windPRO will choose the highest noise value on the noise curve. Note that this is the highest noise value in terms of source noise dBA. Due to differences in the octave band distributions, a lower dBA source noise may actually cause higher noise impact at the receptor. If a 95% rated power value is available, this may also be considered if it is louder than fixed wind speeds available. If so, WindPRO will internally consider the wind speed 10 m/s at hub height.

Highest noise value at receptor: WindPRO will at each receptor test the use of all wind speed noise values within 1 dB of the highest dBA value and use the combination across the turbines that will give the highest noise level at the receptor. Please note that this may result in different wind speeds are used at different receptors as the focus shifts to lower frequencies at larger distances. Same clause for 95% rated power noise values as above.

Calculate entire curtailment matrix: This option is similar to the wind speed range option, but looks up the range of wind speed in the Binning file (accessible in the Noise Matrix Analyzer). This option is only valid for hub height wind speed and without Wind speed inside wind farm.

Note the info button that will call up a brief explanation of the selection options.

Wind speed inside wind farm
WindPRO can work with two different assumptions concerning the wind speed of the turbines. The classic option is that all wind turbines are experiencing the same wind speed at the same time. This is the default setting using **Uniform wind speed in wind farm (Regardless of hub height)**.

For a specific wind speed and direction situation, however, the wind speed at each turbine may be different. This may be because of terrain difference wake effect or difference in hub height. In that situation, because of the difference in wind speed, the turbines may be on a different place on the noise curve. This is important if the turbines are controlled using a noise curtailment program and it is relevant for sound measuring campaigns. The uniform wind speed situation is a hypothetical situation for ease of administration that very rarely exists in reality.

To this end, DECIBEL has a feature called **Wind speed inside wind farm** (Wiw), which is shared with the Nord2000 module. The objective is to calculate the wind speed at each turbine relative to a reference location. For the uniform case there is no need for a reference location, but if we want to calculate for 8 m/s in reality, we have to state where, at what height and from what direction, hence the reference point.

A reference point can be almost any type of object in WindPRO. Typically, it may be a particular wind turbine, a noise receptor or simply the site center object of the project. Use the two selection boxes to pick a layer (left box) and an object (right box). If a wind turbine is selected, the reference height is automatically selected as the hub height. For other types of objects, a height must be specified. The wind speed at each wind turbine will then be calculated relative to this point.
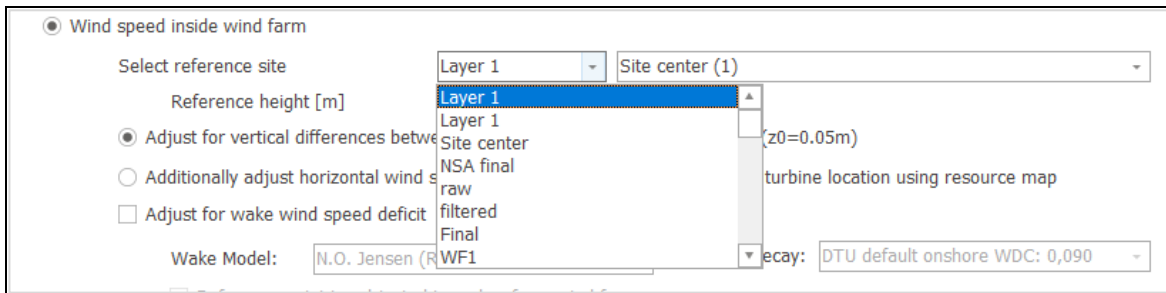
Unfortunately, the idea of a reference location is something that most noise codes and guidelines do not address, and it is therefore difficult to advice which position will be relevant for the calculation. In sound measurement campaigns it is common to reference to turbine hub height wind speed, but also a local measurement mast may be relevant. Often selection of reference location may be arbitrary as it is simply to document that for a number of wind speed intervals the wind farm will comply with noise thresholds at all receptors.

The wind speed difference with height above ground is calculated very simply using the standard IEC shear (roughness length 0.05 m), which is consistent with most regulations, but also only a good assumption when the height differences are small. It is therefore recommended that the reference point is at a representative height for the wind turbines. Wiw is restricted to work with wind speed at hub height (instead of 10 m height) for this reason.

Additionally, together with the vertical difference, the horizontal difference in wind speed can be calculated. This would be due to terrain differences across the site. The wind speed difference is defined through a wind resource map in either .rsf or .siteres format. The wind resource map must cover the height of the turbines and the reference height either as exact heights or an interval surrounding the relevant heights. DECIBEL is not interested in the absolute wind speeds but calculates a wind speed ratio between reference point and turbine locations, hence it is referred to as a gradient file. If the wind resource map is produced as a result of a noise curtailment optimization, this map will also be used in subsequent DECIBEL calculations.
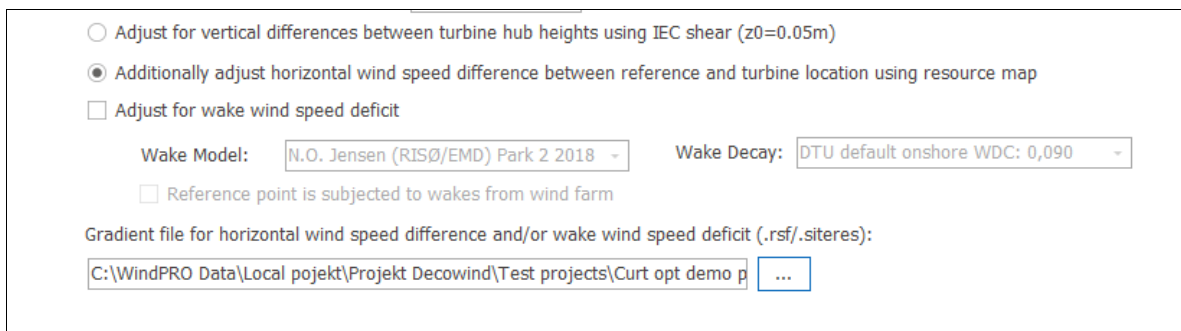
The wind speed difference due to wakes from the wind turbines can be included in the calculation. If the reference point is itself subjected to wakes, that effect can be included by hatching the checkbox. In that case, for a given wind speed at the reference point, the wake effect at the reference point is added to the wind speed and the wake effect at the turbine is deducted from the wind speed. The wake effect is calculated with the PARK2 model and at present no alternative model is allowed. Two different wake decay settings can be used: DTU standard for offshore (low turbulence) and DTU standard for onshore (high turbulence).

Frequency
This section decides how octave band distributions should be used.

Overall, a calculation can either relate to the standard range of frequencies (63 Hz to 8000 Hz) or a range of low frequencies. This choice will be model specific, and it is not possible to change this selection. The standard ISO 9613-2 model cannot be used to calculate low frequency noise as it is only defined in the standard range of frequencies.

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 dBA source noise level of the turbines. If octave data are required, but not available for the turbine, the user will be made aware of this upon starting the calculation and WindPRO can suggest values to be used (see section 6.1.3.2).

Octave data used if available: This option can be set if use of octave is optional. A specific case is when using **Alternative** ground attenuation. In that case octave band distribution is not needed to calculate the ground attenuation, but if octave band data are available these may be used to calculate the air absorption.

Octave data not used: In this case octave band data are ignored and only the dBA value is used. Note that many models and guidelines require that calculations are based on octave band distributions.

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

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 hardness (impedance) of the ground with 0 being a hard surface and 1 being a porous surface. The default value is 1. However, an individual assessment from site to site is normally needed. Please note that some guidelines advise the use of fixed ground factors irrespective of terrain.

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 have the option to use the Alternative method (see below) instead, although the optional **Valley effect** and **Topographic screening** are aimed at compensating that. These are options described in the UK guidelines and are explained in the section on the UK version of the ISO 9613-2 code.

A specific ground description can be used instead of a fixed valued by checking the **Select area with hard ground** check box. This will divide the terrain into soft terrain using the general ground factor and hard terrain with a specified ground factor (default is 0). In the calculation of each turbine – receptor pair the ground factor to each of the three zones (near receptor, middle and near turbine) are calculated as a weighting of hard and soft terrain along the line-of sight.

The terrain description is made in an area object, the purpose of which is unimportant as long as it has a layer defining hard terrain (e.g. a roughness area object with a layer defining water surfaces).

Select the Edit button next to the ground attenuation field, pick out the relevant area object and the relevant layer.
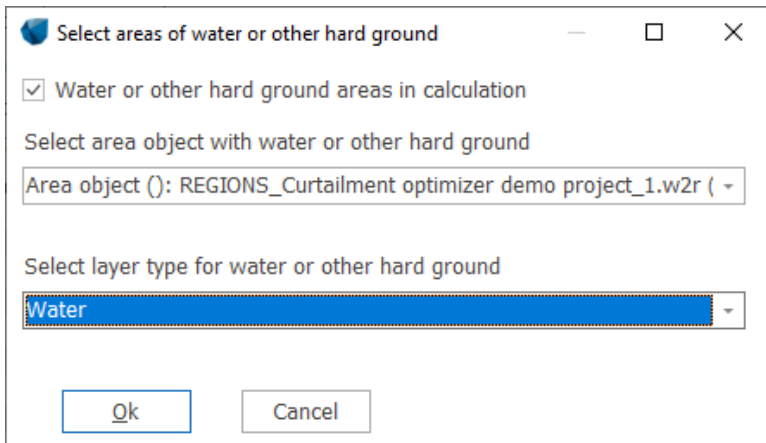
Alternative: The damping of noise due to ground attenuation follows the alternative case described by the ISO 9613-2 code. This method uses the orographic shape of the terrain to assess the ground attenuation by calculating the average vertical distance between line-of-sight from receptor to the hub 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 terrain has average porosity
- The sound does not have tonality problems

The calculation of mean height of the line-of-sight to the ground can be done in two ways:

WindPRO method: is the average vertical distance between line-of-sight and the ground. This is the standard method in windPRO.

ISO 9613 proposal; The ISO 9613-2 suggests an alternative method using the mean of height *perpendicular* to line of sight. This option is available in windPRO from version 3.2.

For receptors at normal receptor distance (>500 m) the difference between the two methods is negligible, but for very tall turbines and receptors very close to these, the two options will result in a noticeable difference.

Both the **General** and the **Alternative** methods are described further in the theoretical appendix.

Fixed values for A_{gr} and D_c. Instead of calculating General or Alternative ground attenuation, fixed values can be used. The default fixed value for ground attenuation A_{gr} is -1.5 and for directivity correction D_c 0. This is what in versions prior to windPRO 3.2 was termed **No ground attenuation**. Values for offshore ground attenuation and D_c can be selected as well. The definition of what is offshore is defined in the Offshore / water areas section. The calculation is simple in the sense that an onshore turbine will use onshore fixed ground attenuation and an offshore turbine will use offshore ground attenuation. There is no effect on a sound path that starts offshore and ends onshore. For a coastline influence the Danish or Swedish offshore models can be used.

The directivity correction D_c is set at the value 0 assuming omnidirectional emission of sound from the wind turbine. This value can be manipulated to simulate emission towards receptors at an angle to the downwind direction. Note that this refers to directivity of source noise level, not wind direction influence on sound propagation.

Wind direction
The effect of wind direction on the sound propagation is poorly described in the ISO 9613-2 standard. This references only a C_{met} value which can be changed to describe the not-downwind propagation. WindPRO versions prior to version 4.0 have only included the option to manipulate this value. There is however a general demand for appropriate ways to parcel out the sound contribution in each wind direction and WindPRO includes from version 4.0 four ways to handle wind direction.

All receptors downwind of all wind turbines (C_{met} = 0): In this scenario each turbine-receptor pair is calculated assuming downwind conditions. The calculation does look into the wind direction and directional curtailment is allowed, but we have as many wind directions in the calculation as there are turbine-receptor pairings. Wind speed inside wind farm is allowed to account for a range of wind speeds.

Fixed value for Cmet: This is the legacy option. All calculations established prior to windPRO 4.0 will use this option. Wind direction is not considered, Wiw is not allowed, and curtailments would have to be applied commonly for all direction sectors.

ISO 9613-2 directional C0 adaption: While the ISO 9613-2 standard is vague concerning wind direction effect on propagation, the LANUV NRW (LANUV NRW (2012): Empfehlungen zur Bestimmung der meteorologischen Dämpfung cmet gemäß DIN ISO 9613-2 from 26.09.2012; https://www.lanuv.nrw.de/fileadmin/lanuv/geraeusche/pdf/Cmet-Hinweise-2012.pdf, describe a method to calculate the average C_{met} value based on the directional components. In the WindPRO implementation these directional components are isolated to give the C_{met} values for each direction bin. The method is described in the technical appendix.

Directional correction based on Institute of Acoustics Good Practice Guide, 2013: The IoA describes a method to account for both directivity and wind direction as function of distance and angle to downwind. The function adopted here is for flat landscapes. The method is described in the technical appendix.

For both the C0 adaption and the IoA methods, DECIBEL offers three different calculation options:
The calculation can be done for a fixed wind speed (by entering the wind direction)
The calculation can be done for the full range of wind directions as specified by the number of sectors and by defining the mean direction of the first sector.
The calculation will look up the binning file in the curtailment matrix to define the directions to calculate. This will ensure consistency with the curtailment plan.

For both methods it is important for understand that these are engineering methods and as such has limited accuracy.

If multiple wind directions are selected, windPRO will test each wind direction for compliance and report the direction with most critical noise for each receptor.

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 (target) 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 values 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% exceedance 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.

Please note that some calculations must be performed without A-weighting. In those cases, A-weighting is removed on the receptor object (the NSA) and all units in the report are in dB, not dB(A). This is not set in the calculation setup but is controlled by the threshold setting in the receptor object.

Pure tones (Tonality)
This concerns how tonality penalties are applied in the noise calculation.

Fixed penalty added to source noise of WTGs with pure tones: In case of tonality the penalty is added to the source noise level of the turbines. The penalty is either specific to the model or specified in the wind turbine catalogue, for the noise receptor in question or user defined, in which case the user can insert the penalty at this point. Please refer to section 6.1.2.1 for how to apply tonality on the wind turbine noise. In case of the generalized ISO 9613-2 setup there are no description of a standard tonality penalty, but when applied in national codes there will typically be a specified penalty.

Pure tones penalty is subtracted from the demand: With this option the pure tone penalty is subtracted from the critical threshold of the report instead of added to the source noise of the wind turbines. The penalty may be specified in the model, the NSA individually or in the calculation as a fixed values on all receptors.

Pure tones penalty is added to total noise impact at receptors: This option adds a penalty to the calculated cumulative result at the receptors if any of the turbines used have the tonality (pure tones) box hatched in the turbine catalogue. As tonality values for different turbines may be different, it is only possible to check if turbines have tonality, but the tonality penalty cannot be derived from the individual turbines. Instead, it must be given as a fixed value or stated in the individual receptors.

Ignore pure tones setting on WTG: The tonality check box in the wind turbine catalogue is ignored.

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.

Uncertainty margin
Uncertainty can be considered in two ways:

Use uncertainty margin: This is an offset to the calculated result which is added to the calculated noise level at the receptors (NSA) and, if selected, to the noise maps. The uncertainty margin can be picked up from the NSA object or overridden by a typed value. Note that windPRO does not calculate the uncertainty of the noise calculation. If the user wants to include an uncertainty margin this must be typed in.
This method is the legacy method from versions prior to windPRO 3.5.

Add uncertainty to source noise level: This is an uncertainty added to the source noise data from the WTG before it is used in the calculation. By applying the uncertainty at this stage, all calculation results are affected by the uncertainty.

The uncertainty value may be picked up either from the turbine type info in the WTG catalogue or overwritten by a value in the WTG object. In this way an uncertainty can be type specific or unique for a particular wind turbine. Alternatively, an uncertainty can be set in the calculation setup to be used as a blanket value for all wind turbines in the calculation.

In the WTG catalogue, the uncertainty is assigned to a particular wind speed / hub height in the noise record. It may be necessary to add uncertainty to several wind speeds if for example **Highest noise value at receptor** is selected as criteria or a range of wind speeds are used.

In the WTG object, the uncertainty is added by hatching the **Uncertainty** box and typing the turbine specific uncertainty.
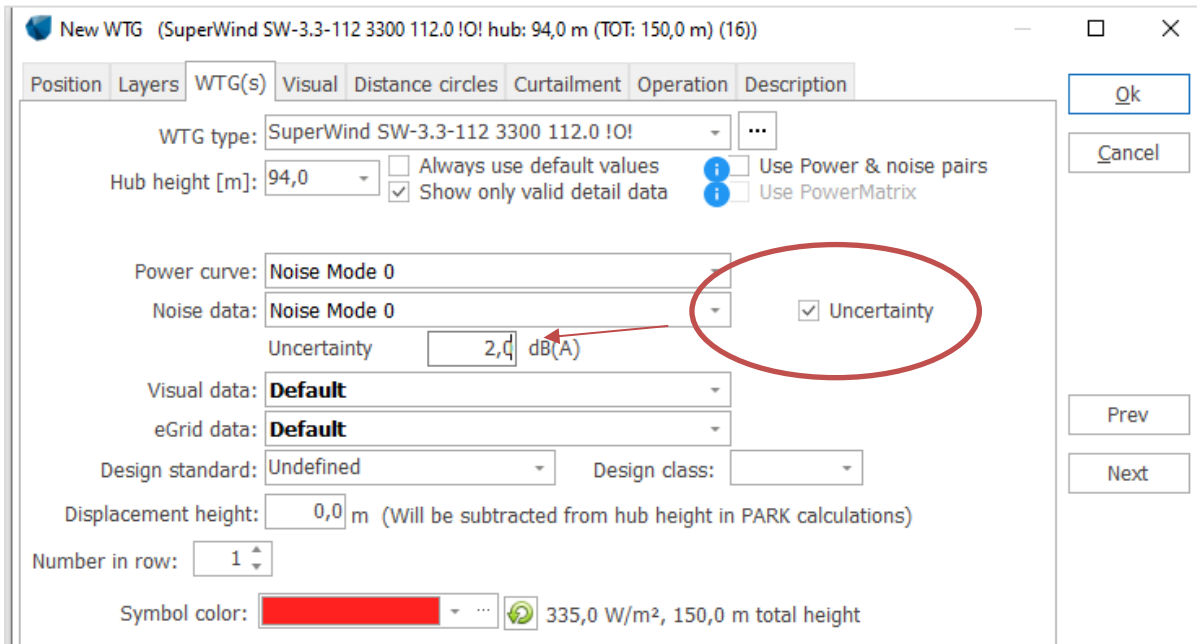
Deviation from noise demands

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

Air absorption

This is the attenuation values used for each frequency due to air absorption in dB/km.

Use fixed air absorption coefficients: Each model in windPRO comes with its own standard settings for air absorption. Click the **Edit/View** button to check which is selected for the model you are using. A standard set of data corresponding to 10 degrees Celsius and 70% humidity is used as default. If custom values are selected from the drop-down menu, specific values can be used for each frequency. 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.

This is the legacy option from versions prior to windPRO 3.5. Please note that the values for 10° C, 70% humidity has disappeared from the latest version of the ISO 9613-2 standard. For current referencing, we suggest calculating the atmospheric attenuation using the tool below.
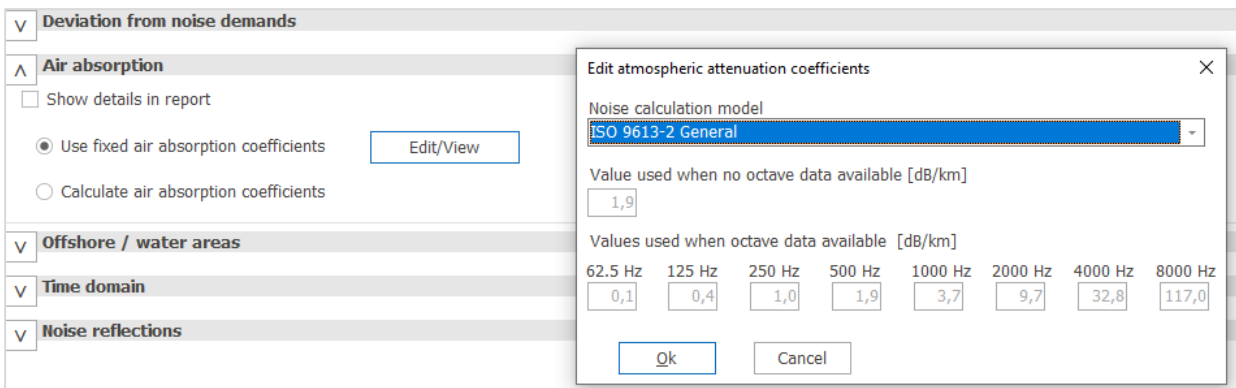
Calculate air absorption coefficients: Air absorption coefficients can be calculated based on temperature and relative humidity according to ISO 9613-1. Note that air absorption coefficients are not defined for temperatures below -20 °C and humidities below 10% in ISO 9613-1.

Air absorption is weakly dependent on atmospheric pressure and in most cases using standard atmospheric pressure is advised. This can be replaced by a custom atmospheric pressure.

DECIBEL (and Nord2000) allows for a range of temperatures and humidities to be calculated. While the standard 10˚ C, 70% humidity will almost always be the worst case scenario, it may be useful to test for compliance at other temperatures and humidities, especially if the wind turbines are curtailed according to temperature and humidity. The range of both parameters can be set using a start and a step value. The maximum allowed value sets the number of intervals. Alternatively, the bins may be defined by the binning file in the curtailment matrix.

If the Show details in report box is hatched the calculation report will include tables of the used air absorption.

The theoretical background for the calculation of atmospheric attenuation is described in the technical appendix.

Time domain
DECIBEL can provide results as a function of time, either by considering thresholds for a specific period or by calculating L_{den} values. If thresholds for specific periods should be considered, noise receptors with the necessary period settings are required. If for example calculation for day and night are to be done, the receptors must be set with both a day and night threshold, see section 6.1.2.2.

Fixed / no time dimension: This is the default setting and used as legacy for non-L_{den} calculations prior to windPRO 4.0. No time dimension should be used if periods are not defined in the noise receptors and in the time binning file. If thresholds for different time periods are set in the receptors, selecting the relevant period will test compliance with those thresholds. If the wind farm is curtailed according to time, the relevant curtailment settings will be used for that period.

Calculate full matrix resolution (all time periods): This option will test compliance against thresholds in each time period as defined in the time binning setup. The **time binning setup** can be accessed and changed at this point, but as consistency is required, please be aware that changing the setup may invalidate older calculations. Curtailment matrices already entered or produced may also be lost. It is therefore recommended to be cautious changing these settings and doing it early in the project.

In the example shown, the default Day, Evening, Night periods have been reduced to Day and Night by deleting the Evening line and adjusting the period intervals. In calculating the time matrix, the penalty and days per year values are ignored.

Lden calculation, check on combined Lden value: The calculation can be configured to calculate L_{den} noise impact at the receptor. The L_{den} (day, evening, night) noise value is a weighted average of three calculations for each of the three periods with a penalty on evening and night contributions.

WTG objects can be set with individual noise settings for day, evening and night and the calculation will then run with each of these settings. These operation settings must be set on the WTG object itself using the **den** button, see section 6.1.2.1. Noise matrix setting are ignored in an L_{den} calculation.

Using an L_{den} setup will still run the calculations at the fixed wind speed selected above. It does not use average wind speed or a wind distribution.

Note that the Norwegian and the Dutch noise codes use their own implementation of the L_{den} concept.

The L_{den} specification can be defined by pressing the **Edit den setup** button.

Noise reflections

Hatching this option includes noise reflection in the calculation as described by the ISO 9613-2 standard. It will activate a tab where obstacles can be selected, by layer or specifically. Only obstacles that are set for **Use as noise reflector** will be included. This introduces secondary noise sources to the calculations based on reflection against walls and other vertical surfaces. For more on obstacles as reflectors see section 6.1.2.4. The calculation method for reflectors is explained in Appendix: Theoretical background for noise propagation models.

6.1.1.2   ISO 9613-2 Germany

Please note that as of September 2016, the noise regulations for Germany has been modified. The modified code, called Interimsverfahren is described in section 6.1.1.3.

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 prior to the introduction of the Interimsverfahren revision.

Calculation setup
Only some parameters can be manipulated when using the ISO 9613-2 Germany. Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 codes.

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

Frequency
Standard frequency (non-octave band) is used.

Ground attenuation and Directivity correction (Dc)
The alternative ground attenuation method is used. Directivity correction is the default value from ISO 9613-2. Expanding the section gives access to the following selection:

The windPRO method is slightly more conservative, but the difference reduces with higher distances.

Wind direction
The fixed value for C_{met} is set. The default value for the meteorological coefficient is 0. 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.

Uncertainty margin
An uncertainty margin can be set by the user. This will appear on the main result report as a separate column. The allowed immission at the noise receptors will be compared to the calculated noise plus the uncertainty margin. By default, an uncertainty margin set in the noise receptor object will override the setting used here, but this can be deactivated.

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

Air absorption
Default values of the ISO 9613-2 for air absorption at 10°C and 70% relative humidity are used.

Offshore / water areas
There are no special settings for handling offshore or water areas.

Time domain
Both the fixed and matrix solution is available for ISO 9613-2 Germany as thresholds will usually come with a day and a night value.

Noise reflections
Noise reflection is not part of this model.

Noise receptors
Please see the section about noise receptors in chapter 6.1.1.3.

6.1.1.3 ISO 9613-2 German (Interimsverfahren)

The ISO 9613-2 German (Interimsverfahren) calculation option is a special case of the general ISO 9613-2 code.

Calculation setup
Only some parameters can be manipulated when using the ISO 9613-2 Germany (Interimsverfahren). Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 codes.

Wind speed
Current requirement is to use source noise data on the wind turbines at hub height wind speed. This option is therefore default with the Interimsverfahren model. WindPRO does however, allow calculations based on source noise data at 10 m wind speed, which is therefore optional and will be used in most legacy calculations.

The default wind speed setting is **Loudest**, with **Loudest at receptors** and **Loudest up to 95% of rated power** as optional settings.

Frequency
Octave data is required. If windPRO is asked to use a generic octave band when applying the ISO 9613-2 German Interimsverfahren, the so-called LAI generic octave band is used and scaled to the source sound power level of the WTG. This should only be done for existing WTGs for which no octave band data is available.
The LAI generic octave band looks like this:

Hz	63	125	250	500	1000	2000	4000	8000
dB(A)	-20,3	-11,9	-7,7	-5,5	-6,0	-8,0	-12,0	-22,9

Ground attenuation and Directivity correction (Dc)
This method uses a fixed value for Ground attenuation (-3,0 dB). Directivity correction is the default value from ISO 9613-2.

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 6 dB.

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

Uncertainty margin
An uncertainty margin can be set by the user. This will appear on the main result report as a separate column. The allowed immission at the noise receptors will be compared to the calculated noise plus the uncertainty

margin. By default, an uncertainty margin set in the noise receptor object will override the setting used here, but this can be deactivated.

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

Air absorption
Default values of the ISO 9613-2 for air absorption at 10°C and 70% relative humidity are used.

Offshore / water areas
There are no special settings for handling offshore or water areas.

Time domain
Both the fixed and matrix solution is available for ISO 9613-2 Germany (Interimsverfahren) as thresholds will usually come with a day and a night value. The default setting is **Fixed No time dimension.** If both day and night thresholds are defined in the NSA, the period should be specified. It is possible to select all periods with the full matrix resolution. In that case the **time binning setup** should be updated to reflect the periods used.

Noise reflections
The Interimsverfahren model supports noise reflection from buildings (obstacles). Hatching this option will enable the tab for selecting reflectors.

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 (BImSchG)". 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 include pure tones will depend on the local authorities.

Nighttime is defined as 22.00 to 06.00.

Receptors can be set up with time domain thresholds, using day thresholds for daytime and night thresholds for nighttime.

Curtailment optimization considerations
The ISO 9613-2 German (Interimsverfahren) only allows optimization on the time domain.

6.1.1.4   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").

In addition the UK calculation option incorporates the recommendation of "A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97 FOR THE ASSESSMENT AND RATING OF WIND TURBINE NOISE", Institute of Acoustics, May 2013.

Calculation setup
Only some parameters can be manipulated when using the ISO 9613-2 UK. Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 codes.

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.

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

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, however a value of 0.5 can be used if the source noise is warranted or is measured and includes measurement uncertainty. A value above 0.5 should never be used.

If measured source noise data are used the uncertainty has to be added manually in the wind turbine catalogue. This can be done either by adding 2 dB to the noise data or using the uncertainty σ multiplied with 1.645.

Valley effect
If calculated across a valley the noise impact is penalized with:
+3,0 dB if G=0,5
+1,5 dB if G=0,0

The criteria for a valley are:
$h_m \geq 1.5 \times (abs (h_s - h_r) /2)$
where h_m is the mean height above the ground of the direct line of sight from the receiver to the source, and h_s and h_r are the heights above local ground level of the source and receiver respectively.

Topographic screening
A reduction of 2dB is applied to the calculation of contribution if the receptor cannot see any part of the turbine Only terrain contours are used for the assessment and tip height as well as receiver height (4m) are used as input.

Wind direction
The meteorological coefficient can be set. The recommended maximum is 2dB.

The best practice recommendation from IoA (May 2013) allows for directivity adjustments. It is possible to use the method recommended by the IoA. This may include reading the curtailment matrix for derated modes by direction. However, as the Wiw calculation is not supported directly by the IoA, the calculation will assume a uniform wind speed within the wind farm. For a more detailed calculation we therefore suggest that the user instead set up an ISO 9613-2 General model with the UK settings and the addition of the Wiw model as well as the IoA wind direction / directivity model.

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 4 m.

Time domain
Both the fixed and matrix solution is available for ISO 9613-2 UK as thresholds will usually come with a day and a night value. The default setting is **Fixed No time dimension.** If both day and night thresholds are defined in the NSA, the period should be specified. It is possible to select all periods with the full matrix resolution. In that case the **time binning setup** should be updated to reflect the periods used.

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

Noise reflection
Noise reflections are not enabled for the UK ISO 9613-2 model.

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 amenity hours and night-time figure is 5dB. Amenity hours are defined as 18:00-23;00 Mon-Sun, 13:00-18:00 Sat and 07:00-18:00 Sun. Night-time hours are defined as 23:00-07:00 Mon-Sun. The British rules (ETSU-R-97) also define a fixed lower limit noise from the turbines at L_{90} =35-40 dB (amenity hours, subject to negotiation) 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"

Curtailment optimization considerations
The ISO 9613-2 UK model is locked with standard settings as suggested by the IoA. It is possible with these settings to set or optimize curtailment modes in the time domain (day and night modes), wind direction and wind speed.

6.1.1.5 **ISO 9613-2 France**

The French noise practice does 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 French practice.

Calculation setup
Only some parameters can be manipulated when using the ISO 9613-2 UK. Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 codes.

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

The wind speed inside wind farm option can be used. As the test is merely that for all wind speed and direction bins the combined noise does not exceed allowed exposure, the actual wind speed and location for that wind speed may be a minor concern. Please consult local authorities and practices for selection of reference point.

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 should 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.

Wind direction
All options are allowed. The default setting is **Fixed value for C$_{met}$** (0 dB). If wind direction is used without Wiw, the layout will be tested in each wind direction using the set directional curtailment. If the wind turbines are curtailed by wind speed, or wind direction is to be used in an optimization, the Wiw must be activated.

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 set up accordingly.

Noise values in calculation
Locked to regular L$_{WA}$ noise values.

Pure tones
Pure tone penalty is subtracted from demand.

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

Uncertainty margin
All uncertainty options are available.

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

Air absorption
All air absorption options are available, though standard 10˚C / 70% humidity is set as default.

Time domain
Both the fixed and matrix solution is available for ISO 9613-2 France as thresholds will usually come with a day and a night value. The default setting is **Fixed No time dimension.** If both day and night thresholds are defined

in the NSA, the period should be specified. It is possible to select all periods with the full matrix resolution. In that case the **time binning setup** should be updated to reflect the periods used.

Noise reflection
Noise reflections are enabled for the French ISO 9613-2 model.

Noise receptors
The noise receptors can be setup with specific settings for France. There are two types of settings: 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.

Curtailment optimization considerations
The French setting is very similar to the ISO 9613-2 General settings and therefore allow all possible curtailment optimizations.
The exception is the frequency analysis. The additional exposure can be tested by frequency, but not optimized.

6.1.1.6   ISO 9613-2 Norway (outdated)

This is an older code for Norway that refers to the ISO 9613-2 standard. The current (2018) noise code for Norway is described in section 6.1.1.20.

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.

Only some parameters can be manipulated when using the ISO 9613-2 Norway. Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 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.

Wind direction
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 is subtracted from 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.

Time domain
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

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 states 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.
Note that in the 2017/18 revision of the Norwegian noise codes a fixed limit of 45 dB in yellow zone and 55 dB in red zone is stated irrespective of wind shadow.

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.

Curtailment optimization considerations
It is not possible to use the noise matrix with L_{den} calculations and hence it is not possible to use the Norwegian model in the curtailment optimizer.

6.1.1.7 **ISO 9613-2 Finland**

The ISO 9613-2 Finland 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 Finland.

The Finish code (Ympäristöhallinnon Ohjeita 2, 2014, Modellering av buller från vindkraftverk) sets up two phases of noise calculation. During the first, the ISO 9613-2 model can be used, while during the second phase NORD2000 is required.

Calculation setup
Only some parameters can be manipulated when using the ISO 9613-2 Finland. Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 codes.

Wind speed
The source noise wind speed is selected as the one giving the highest impact at each receptor. In earlier versions of WindPRO this code used 8 m/s at 10 m height. If you are trying to reproduce earlier calculations this option can be checked.

Octave data
Octave-band data are required.

Ground attenuation
The General method should be used, preferably with terrain specific values defining land and water.
Areas defined as land use a ground factor of 0.4, while areas specified in an area object as hard terrain use a ground factor of 0 (Hard ground factor is locked).

Wind direction
The meteorological coefficient cannot be set. It is fixed at 0 dB.

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
Tonality penalty according to the Finish rules is decided at the individual receptor. If a noise measurement at the receptor shows tonality enough to trigger a tonal penalty a new calculation must be performed for this receptor adding 5 dB to the cumulative noise from turbines. Tonality is a property of the receptor (NSA), where the penalty (5 dB) can be entered manually. In a calculation only receptors with a tonal penalty will be penalized, other receptors will not. Any tonality settings on the turbines are ignored.

Height of immission point above ground level
The height of the immission point at the receptor has been set to 4m as default but can be changed by the user.

Uncertainty margin
All uncertainty options are available. The default setting is to add the uncertainty to the source noise level and to preferably pick it up from the WTG object. In this way a turbine specific uncertainty can be entered.

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

Time domain
Both the fixed and matrix solution is available for ISO 9613-2 Finland as thresholds will usually come with a day and a night value. The default setting is **Fixed No time dimension.** If both day and night thresholds are defined in the NSA, the period should be specified. It is possible to select all periods with the full matrix resolution. In that case the **time binning setup** should be updated to reflect the periods used.

Height difference penalty
If the difference in base height level between turbine and receptor is above 60 m a 2 dB penalty is applied to the source noise level.

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

The noise targets for regular noise in Finland are regulated by statutory order (Statsrådets Förordning om riktvärden för utomhusbuller från vindkraftverk, 27/8-2015). There is a general noise limit at 45 dB during day time (07:00-22:00), except for national parks where the limit is 40 dB, and a general 40 dB limit at night time (22:00-07:00).

Curtailment optimization considerations
The ISO 9613-2 Finland only allows optimization on the time domain.

Low frequency calculation
The Finish code requires a special low frequency calculation to be performed. The low frequency calculation figures as an independent calculation model in windPRO called **Finland Low frequency**.

Calculation setup
Only some parameters can be manipulated when using the ISO 9613-2 Finland Low Frequency. Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 codes.

Wind speed
The source noise wind speed is selected as the one giving the highest impact at each receptor. In earlier versions of windPRO this code used 8 m/s at 10 m height. If you are trying to reproduce earlier calculations this option can be checked.

Frequency
The low frequency calculation is concerned with the frequencies from 20 to 200 Hz. Data for the Finish low frequency calculation must therefore be available as 1/3 octave data.

Noise insulation
The Finnish codes require the calculation points to be indoors, and this therefore necessitates a description of the noise insulation damping. Unfortunately, the code does not prescribe a specific damping profile to be used

but lets the noise consultant determine how to apply a reasonable value. windPRO allows the user to type in a custom noise insulation profile, but also suggests the use of publicly available profiles.

There are three options available from Denmark: The Danish standard for the 60% fractile of Danish homes and for summer houses (light dwellings) (Danish EPA, 2019: Danish Statutory Order 135 of 7/2-2019) and the 90% fractile as published in Hoffmeyer and Jakobsen, 2010: "Sound insulation of dwellings at low frequencies", Journal of Low Frequency Noise, Vibration and Active Control.

Through contact with users in Finland we have found that ΔL noise damping values from three publications by Keränen are commonly used:
- (Keränen, J., Hakala, J., and Hongisto, V., 2017: Sound insulation of single-family houses against environmental noise at frequencies 5-5000 Hz – an infrasound study, Proceedings of Akustiikkapäivät 2017
- Keränen, J., Hakala, J., and Hongisto, V., 2018: Façade sound insulation of residental houses within 5-5000 Hz, Euronoise 2018).
- Keränen, J., Hakala, J., and Hongisto, V., 2019: The sound insulation of facades at frequencies 5-5000 Hz, Building and Environment 156, 2019).

Frequency, Hz	20	25	31,5	40	50	63	80	100	125	160	200
Finnish DL90 Keränen et.al.,2017	6	6	7	7	8	9	10	11	12	13	14
Finnish DL84 Keränen et.al, 2018	8	9	10	11	12	14	15	17	19	21	21
Finnish DL84 Keränen et.al, 2019	7,6	8,3	9,2	10,3	11,5	13	14,8	16,8	18,8	21,1	22,8

Finally, custom values can be entered for each frequency.

Edit ΔLσ

Noise insulation of dwellings

Select: Finnish DL84 Keränen et.al., 2019

Frequency [Hz]	ΔLσ 60% fractile noise insulation (Danish EPA) [dB]	ΔLσ 90% fractile noise insulation (Danish EPA) [dB]	ΔLσ Summer houses (Danish EPA 2018) [dB]	Finnish DL90 Keränen et.al., 2017	Finnish DL84 Keränen et.al., 2018	Finnish DL84 Keränen et.al., 2019	Custom values [dB]
20,0	6,6	3,6	-0,2	6,0	8,0	7,6	0,0
25,0	8,4	4,6	4,8	6,0	9,0	8,3	0,0
31,5	10,8	6,7	6,2	7,0	10,0	9,2	0,0
40,0	11,4	7,6	8,4	7,0	11,0	10,3	0,0
50,0	13,0	10,3	10,5	8,0	12,0	11,5	0,0
63,0	16,6	14,2	11,9	9,0	14,0	13,0	0,0
80,0	19,7	17,5	11,9	10,0	15,0	14,8	0,0
100,0	21,2	18,4	16,0	11,0	17,0	16,8	0,0
125,0	20,2	17,5	17,5	12,0	19,0	18,8	0,0
160,0	21,2	18,6	17,9	13,0	21,0	21,1	0,0
200,0	25,0	22,4	16,6	14,0	21,0	22,8	0,0

Lσ(60%) at 200Hz is an estimated value based on the literature (Hoffmeyer and Jakobsen, 2010 and Danish Statutory order 1284, 2011)"

Jukka Keränen, Jarkko Hakala, Valtteri Hongisto: "The sound insulation of façades at frequencies 5–5000 Hz", Building and Environment 156, 2019

Ok   Cancel

Uncertainty margin

All uncertainty options are available. The default setting is to add the uncertainty to the source noise level and to preferably pick it up from the WTG object. In this way a turbine specific uncertainty can be entered.

Offshore wind farms

The only available choice is whether to assume all turbines are onshore (default) or to designate those in water as offshore turbines. If that option 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 damping 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.

Time domain

Both the fixed and matrix solution is available for ISO 9613-2 Finland as thresholds will usually come with a day and a night value. The default setting is **Fixed No time dimension.** If both day and night thresholds are defined in the NSA, the period should be specified. It is possible to select all periods with the full matrix resolution. In that case the **time binning setup** should be updated to reflect the periods used.

Noise receptors and limits

Special noise receptors must be used for a Finnish low frequency calculation. Specify specifically that the receptor is for low frequency calculation. This gives you the choice between day and night limits.

Noise limits for indoor low frequency noise is given in the Finnish Residential Health Guide (Sosiaali- ja terveysministeriön oppaita 2003: Asumisterveysohje). The noise level must at each frequency remain below the value presented in the table below. Note that the noise levels are not A-weighted. windPRO will automatically remove the A-weighting from the source noise level before processing the result.

Indoor low frequency noise limits, Sosiaali- ja terveysministeriön oppaita 2003: Asumisterveysohje											
Frequency	Hz	20	25	31,5	40	50	63	80	100	125	160	200
Night limit	Leq,1h/dB	74	64	56	49	44	42	40	38	36	34	32
Day limit	Leq,1h/dB	79	69	61	54	49	47	45	43	41	39	37

Curtailment optimization considerations

windPRO cannot optimize on the Finland low frequency mode. However, the model will use the curtailment matrix selected for the wind turbines.

6.1.1.8   **ISO 9613-2 Poland**

The ISO 9613-2 Poland 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 Poland.

Calculation setup

Only some parameters can be manipulated when using the ISO 9613-2 Poland. Other parameters are fixed and cannot be altered. As default the setting for these parameters are not shown unless the **Show details** checkbox is checked. For detailed description of the fields please refer to the relevant section on the General ISO 9613-2 codes.

Wind speed

The source noise value is **Loudest up to 95% of rated power**.

Octave data
Octave-band data are not required.

Ground attenuation
Both methods, General and Alternative, can be used. According to the ISO 9613-2 specification, **General** should be used for flat sites and **Alternative** for hilly sites, but it is advisable to contact the relevant authorities if the decision is not clear. Using "General" ground attenuation requires the source sound power level to be available as octave band data. When **Alternative** ground attenuation is selected, octave band data is not used for calculation of the ground attenuation (the calculation standard does not allow this), but octave band data can still be used for the other attenuation factors.

Wind direction
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 6 dB.

Height of immission point above ground level
The height of the immission point at the receptor has been set to 4m as default, but can be changed by the user. It should represent the highest inhabited room in a house.

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

Time domain
Both the fixed and matrix solution is available for ISO 9613-2 Poland as thresholds will usually come with a day and a night value. The default setting is **Fixed No time dimension.** If both day and night thresholds are defined in the NSA, the period should be specified. It is possible to select all periods with the full matrix resolution. In that case the **time binning setup** should be updated to reflect the periods used.

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 Poland originates from Dz.U. 2007 nr- 120 poz. 826 Rozporządzenie Ministra Środowiska z dnia 14 czerwca 2007 r. w sprawie dopuszczalnych poziomów hałasu w środowisku (Regulation of the Minister of the Environment of 14 June 2007 - On acceptable levels of environmental noise).

The immission level classes according to this regulation are:
- 45dB(A)   Night: Multi-family houses, agricultural, mixed zone
- 55dB(A)   Day: Multi-family houses, agricultural, mixed zone
- 40dB(A)   Night: Single family houses
- 50dB(A)   Day: Single family houses

6.1.1.9   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.

6.1.1.10   The Danish Codes 1991

An early Danish set of 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.

6.1.1.11   The Danish Codes 2007

From 2007 the noise codes for Denmark are 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.

Frequency
Octave band distribution is required for the calculation.

Ground attenuation
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. The selection of offshore or onshore turbines is done under Offshore / water areas (see section 6.1.1.13)

Pure tones
Pure tone penalty is added to total noise from all turbines at receptors where tonality is measured. The penalty is 5 dB. If any turbine used in the calculation has a checked tonality box for one of the relevant wind speeds, the tonality penalty is triggered for all calculated receptors.

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 thresholds 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.

6.1.1.12   The Danish Rules 2011 and 2015

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

The 2011 code was in 2015 replaced by a revised code "Bekendtgørelse nr 1736 af 21/12/2015" with the only change being that temporary refugee shelters would be permitted within the noise boundary of the turbines.

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 was 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.

It is strongly recommended to enter the full spectrum as third octave values and let WindPRO derive the low frequency values from this. This ensures consistency between low frequency and broadband calculations.

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 properties, select **Danish 2019 Low frequency**, which is valid for the 2011/2015/2019 codes. The form allows for two kinds of receptors, Regular dwellings and Cottage zones, however with the 2011/2015 codes all receptors are treated as standard dwellings.

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 option 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 damping at sea and land and in the 200 m coastal zone to make a transition between the two calculation types. Note that the transition calculation is only for low frequency noise, not normal noise.

Pure tones

Tonality penalty according to the Danish rules is decided at the individual receptor. If a noise measurement at the receptor shows tonality enough to trigger a tonality penalty a new calculation must be done for this receptor adding 5 dB to the cumulative noise from turbines. This tonality is controlled from the NSA object where the 5 dB penalty can be set for the receptor (Pure tone penalty). Tonality settings on the wind turbines are ignored and receptors without the tonality penalty will ignore the tonality.

Documentation requirements

Due to increased documentation requirements, 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 and 2015 or Danish Low frequency windPRO will for turbine types <=2MW use data from the generic tables from Miljøstyrelsen (Danish EPA) if data at least at 1/1 octave band level has not been selected for the turbine.

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 types >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.

Source Noise Project data
A specific catalogue of source noise data is provided for existing turbines in Denmark. The data are part of the Source Noise Project (Kildestøjsprojektet), and the database is documented by Grontmij in the document "Støjkatalog over ældre vindmøller i Danmark", dated June 11th 2014 (updated August 28th 2015).
The catalogue requires a special license from EMD. With this license noise records will appear in the wind turbine catalogue labeled KST. The records cannot be edited and are not visible for non-license holders. Each record holds the average 1/1 octave band distribution for the turbine type based on available measurements. In case of large scatter on the result an uncertainty is added to the frequency band.
The database is a realistic suggestion for the actual noise of old, existing turbines and has been recognized by the Danish EPA as a valid alternative to the generic values of the guideline.

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 are explained in "Experiences with the New Danish Rules for the Calculation of Low Frequency Noise from Wind Turbines", Sorensen, 2012.

6.1.1.13   **The Danish rules 2019**

From February 2019 the Danish noise code has changed to "Bekendtgørelse om støj fra vindmøller, Bekendtgørelse nr 135 af 07/02/2019", from the Danish Ministry of the Environment.

This code is associated with a guideline, published 11th February 2021 called "Støj fra Vindmøller, Vejledning fra Miljøstyrelsen nr. 51, 2021.
https://www2.mst.dk/Udgiv/publikationer/2021/02/978-87-7038-275-5.pdf

The code is almost identical to the 2011/2015 code except for the following points:
1. The low frequency calculation now differentiates between regular dwelling and dwellings in cottage zones, the latter by using a reduced noise insulation table
2. Offshore calculations, regular and low frequency, now includes multiple wakes across water.
3. Offshore calculations of regular noise now include a transition zone of 200 m on the coastline before being replaced by ground attenuation for land as in the low frequency calculation
4. Tonality penalties may cover a range of values. The fixed penalty is therefore abandoned and replaced by free selection of penalty value.

The following describes the model only where it deviates from the 2011/2015 model.

Regular noise calculation

The regular Danish 2019 noise calculation can be selected **Danish 2019**.

Pure tones
As for the 2011/2015 model the tonality penalty is added to the total impact at the receptor and is controlled by the NSA representing the receptor. A value from 0 to 6 dB is possible. The calculation will ignore any tonality settings on the WTG object.

Offshore / water areas

The calculation will either consider all wind turbines onshore or define those turbines within an area defined as **Water area** as offshore while all other wind turbines are considered onshore. The propagation model for the specific turbine is controlled by this designation. From the offshore wind turbine and until landfall an offshore ground attenuation is used. At the shoreline a transition zone of 200 m exists where the model linearly will change to onshore ground attenuation. While over water multiple reflections will add to the calculation. The longer the stretch of water the larger this component, L_m will be (see the appendix for technical documentation of calculation models). From the shoreline the multiple reflection component will not increase any further but will remain a base value in the noise impact.

Water areas are defined through an Area object, where a specific area type can be designated as water area
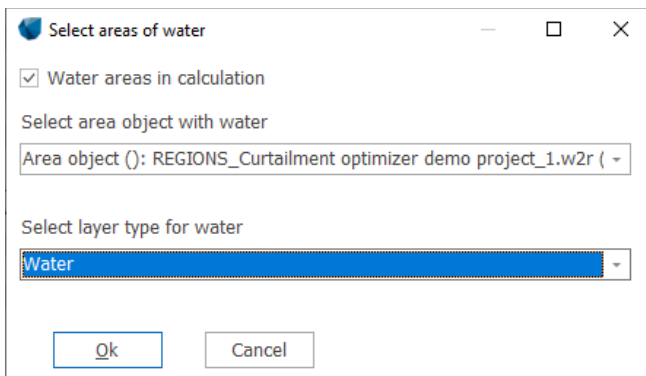
Optimization considerations
No optimization dimensions are available for Danish 2019. Only complete replacement of noise mode is allowed.

Low frequency noise calculation
The low frequency Danish 2019 noise calculation can be selected **Danish low frequency 2019**.

The procedures around pure tones and offshore calculations are identical to the regular noise calculation.

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 properties, select **Danish 2019 Low frequency.** The form allows for two kinds of receptors, Regular dwellings and Cottage zones. In the calculation a reduced noise insulation value is used cottage zones as described in the statutory order.

The calculation can handle that some receptors are regular, and some are cottage zones.

The noise insulation values can be viewed but not edited by pressing the **View** button in the **Frequency** group. The calculation will automatically select 60% fractile values for regular dwellings and summer houses respectively.

Noise sensitive area   (Noise sensitive point: User defined (35))   ✕

Position | Layers | Demands | Area | Description

☐ Define in calculation setup   ☐ Use temporal binning   View

Ok
Cancel

Insert NSA properties in

◉ Country specific form   Denmark ▾   Danish 2019 low frequency ▾
○ Freely definable form   ○ No noise demand

◉ Regular dwellings
○ Cottage zones
○ User defined

Prev

Noise demand

Noise demand

☑ Check for more wind speeds

Wind speed	Low frequency [dB(A)]
6,0 m/s	20,0
8,0 m/s	20,0

Wind speed: From, to, step
6,0   8,0   2,0

Next

Save as project default

Clear default

Distance demand

Distance demand [m]   0 + 0,0000 ∗ Rotor diameter [m] ▾

Immission height above ground level
☑ **Use standard value from calculation model**
Immission height (a.g.l.)   0,0 m

Uncertainty margin
☑ **Use default value of calculation model**
Uncertainty margin   0,0 dB

Pure tone penalty
Pure tone penalty   0 dB

Edit ΔLσ   — ☐ ✕

Noise insulation of dwellings

Select:

60% fractile noise insulation (Danish EPA) ▾

Frequency [Hz]	ΔLσ 60% fractile noise insulation (Danish EPA) [dB]	ΔLσ 90% fractile noise insulation (Danish EPA) [dB]	ΔLσ Summer houses (Danish EPA 2018) [dB]	Finnish DL90 Keränen et.al., 2017	Finnish DL84 Keränen et.al., 2018	Finnish DL84 Keränen et.al., 2019	Custom values [dB]
10,0	4,9	1,2	6,8	4,0	7,0	6,2	0,0
12,5	5,9	3,2	3,9	5,0	7,0	6,6	0,0
16,0	4,6	2,1	0,4	5,0	7,0	7,1	0,0
20,0	6,6	3,6	-0,2	6,0	8,0	7,6	0,0
25,0	8,4	4,6	4,8	6,0	9,0	8,3	0,0
31,5	10,8	6,7	6,2	7,0	10,0	9,2	0,0
40,0	11,4	7,6	8,4	7,0	11,0	10,3	0,0
50,0	13,0	10,3	10,5	8,0	12,0	11,5	0,0
63,0	16,6	14,2	11,9	9,0	14,0	13,0	0,0
80,0	19,7	17,5	11,9	10,0	15,0	14,8	0,0
100,0	21,2	18,4	16,0	11,0	17,0	16,8	0,0
125,0	20,2	17,5	17,5	12,0	19,0	18,8	0,0
160,0	21,2	18,6	17,9	13,0	21,0	21,1	0,0
200,0	25,0	22,4	16,6	14,0	21,0	22,8	0,0
250,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Lσ(60%) at 200Hz is an estimated value based on the literature (Hoffmeyer and Jakobsen, 2010 and Danish Statutory order 1284, 2011)"

Ok   Cancel

Optimization considerations
Optimization using the curtailment optimizer is not allowed. Instead, the classic optimizer can be used.

6.1.1.14   **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

6.1.1.15   **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".

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)

6.1.1.16   Swedish codes 2009

The Swedish codes 2009 actually represents an evolution of "Ljud från vindkraftverk", Naturvårdsverket. The latest available version is from 2014, but the latest modifications are at the time of writing only available from Naturvårdsverkets homepage Mätning och beräkning av ljud från vindkraft (naturvardsverket.se)

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

Naturvärdsverket has published a guideline " Vägledning om buller från vindkraftverk" vagledning-om-buller-fran-vindkraftverk.pdf (naturvardsverket.se) describing thresholds, selection of propagation models and procedures concerning verification.

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 affects both onshore and offshore calculations.

Wind speed
The source noise wind speed is selected as the one giving the highest noise level. In earlier versions of WindPRO this code used 8 m/s at 10 m height. If you are trying to reproduce earlier calculations this option can be checked.

Offshore calculation
The offshore calculation calculates similar to an onshore calculation out to 1000m from the turbine. From then a revised version of the 2002 code with different damping is 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: Mätning och beräkning av ljud från vindkraft (naturvardsverket.se)

In windPRO DECIBEL select **Swedish 2009** and select **Offshore wind farm**. If that option 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.

Important note: The Swedish authorities (Naturvårdsverket) has discontinued the use of the offshore model from landfall and inland. There is a discontinuity in the formulae and rather than correcting this, Naturvårdsverket recommends not to use the offshore model, but instead use Nord2000.

Time domain
Both the fixed and matrix solution is available for Swedish 2009 as thresholds may come with a day and a night value. The default setting is **Fixed No time dimension.** If both day and night thresholds are defined in the NSA, the period should be specified. It is possible to select all periods with the full matrix resolution. In that case the **time binning setup** should be updated to reflect the periods used.

Curtailment optimization considerations
The Swedish 2009 only allows optimization on the time domain.

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 6.5.2.

Swedish Low frequency noise
The Swedish guideline for low frequency noise as it is described by Naturvårdsverket cannot be calculated with DECIBEL. Instead Nord2000 in windPRO can be used to calculate low frequency noise.

6.1.1.17   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.

Calculation setup
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

.

6.1.1.18   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).

6.1.1.19   Dutch, 2011.

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.

Calculation setup
The calculation model is selected by choosing **Dutch 2011** as Noise calculation model.

Wind speed
The Dutch 2011 code operates 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 are 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. In WindPRO is possible to choose the currently valid database from 2018 or the pre 2018 version. The 2018 version is documented here: https://www.mp.nl/actueel/nieuwe-windgegevens-voor-het-berekenen-van-geluid-van-windturbines-beschikbaar and provides wind distribution data in a dense (2.5km) grid across The Netherlands with data at 14 height levels from 10 m to 260 m. For hub heights in between the provided elevation levels an interpolation is made. 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.

Note that because the Dutch method is linked to this database the Dutch method can only be used within the coverage of the database, meaning The Netherlands.

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 default a terrain map can be used to calculate ground factor values (see Section 6.1.1.1), but alternatively a uniform value can be used.

Wind direction
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 although sub-results present Lday, Levening and Lnight specifically.

Pure tones
Pure tone penalty is subtracted from 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 is preferable to convert 10 m height wind speeds to hub height integer wind speed even though that means an interpolation of data points.

6.1.1.20   Norwegian, 2012/2017.

The Norwegian guideline was in 2012 replaced by "Veileder til retningslinje for behandling av støy i arealplanlegging (T-1442/2012)", later replaced by a 2021 version, which is described in document M-128 – 2020 from Miljødirektoratet. The revision does not change the standard method used in WindPRO, but primarily provides a guideline for use of Nord2000.

The 2012 guideline is a combination of the Swedish guideline "Ljud från Vindkraftverk" from 2001 and the previous Norwegian guideline. It is also incompatible with the old guideline, which cannot simply be recalculated with the revised guideline.

Calculation setup
The calculation model is selected by choosing **Norwegian 2012** as Noise calculation model.

Wind speed
The Norwegian guideline describes a complex method of adjusting 10 m/s with actual roughness along the line of the older Swedish guideline, however advise as a more practical solution that calculations are done at the highest source noise level regardless of wind speed. As the typical wind profiles in Norway are governed not by roughness, but by topography only the highest source noise level option is available in windPRO.

In practice windPRO will consider the noise curve in the noise record selected for the turbine and pick the wind speed with the highest source noise level.

Octave data
Calculations within 1000 m of any turbine in the calculation can actually be calculated without octave data. However for wind farms larger than one turbine the 1000 limitation will almost certainly be exceeded and so octave band distributions are required. If the turbine noise record used does not hold octave data a generic distribution is fitted to the dBA value of the highest noise value.

Meteorological coefficient C0

Whereas the previous guideline advised an upwind reduction, the present guideline refuses this option. The meteorological coefficient should remain 0.

Offshore wind farm
In case of offshore wind farms this option is hatched. The methodology is the same as for the Swedish model and the calculation method is almost identical.

View 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 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

Because of the Lden calculation method different noise modes can be set for the turbines for day, evening and night and WindPRO will calculated the combined Lden. If all periods use the same noise mode Lden corresponds to Leq24 + 6,4dB.

Noise limits
Noise limits in Norway are governed by zoning. Dwellings receiving more than Lden = 40dB must be calculated. The noise limit of the dwelling depends on the zone in which they are situated.
The allowed noise impact is:
Yellow zone (Gul sone):   Lden 45 dB
Red zone (Rød sone):   Lden 55 dB

The relevant zone can be selected in the noise receptor.

Alternative methods
The Norwegian guideline allows for noise to be calculated using alternative methods such as Nord2000. The 2021 revision of the guideline focuses on the Nord2000 calculation. In the final assessment of noise impact in Norway it is likely that Nord2000 is required. A summary of Norwegian Nord2000 requirements is given in section 6.5.2.4.

Curtailment optimization considerations
It is not possible to use the noise matrix with L_{den} calculations and hence it is not possible to use the Norwegian model in the curtailment optimizer.

6.1.2   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 tab 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).

6.1.2.1 **Entering WTGs**

See Chapter 2 BASIS, Section 2.5.2 on entering WTGs, Section 2.6.4.3 on noise data in the WTG catalogue and Section 2.6.4.4 for the Power and noise pairs .

WTGs may hold different types 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 band divided data (or even subdivided as third octave data). The form needed in your calculation depends on the calculation method (see Section 6.1.1) 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. It is in fact recommended always to verify with the wind turbine supplier if the specifications you have on the turbine type are the latest version.

Wind turbine OEMs will often provide entire noise curves populated with 1/3 octave data for the entire spectrum. It is recommended to enter the entire data set as such data may later become useful.

Populating the noise record

If you open a noise record for a wind turbine type in the WTG catalogue, you will notice the matrix of wind speed versus hub height. That the wind turbine type has a different source noise level at different wind speed is quite understandable, but the need for different hub heights may be less intuitive. After all a wind turbine makes the same noise no matter how tall it is.

The explanation is that the actual noise curve relates to wind speed at hub height, but since many codes expect source noise data at a wind speed for the reference height 10 m above ground, the hub height wind speed is converted to the 10 m equivalent using an IEC 61400-11:2012 0.05m logarithmic wind profile (simply referred to as the IEC profile). Since wind turbines come with different hub heights, the translation of the wind speed varies. So, the noise curve is the same, but the wind speed is offset. Therefore, for a given wind speed we may have different noise values with different hub heights.

You can add wind speeds and hub heights manually by clicking the respective buttons and then type in the noise values. However typically you will want to enter the entire noise curve, maybe have more hub heights and each value as octave or 1/3 octave data. That is a lot of typing. Fortunately, there is an easier way.

If you highlight a number of wind speeds and hub heights and press the **Copy selected** button (NOT CTRL-C!) and paste into a spread sheet, you can see the structure of the data. The above example will look like this:

WindSpee	HubHeigh	LwaRef	Puretones	Extra	Wind spee	OctaveDat	Aweighte	Count									1/3 octave	Count					
3	84	88,7	FALSE	0	1	TRUE	TRUE	8	73,1	80,6	82,7	82,1	81,6	78,7	75	63,2	TRUE	31	25,7	31,5	37,9	42,8	52,4
4	84	95	FALSE	0	1	TRUE	TRUE	8	77	85	88,6	89,2	88,5	85,9	81	66,9	TRUE	31	28,3	38	45,1	47,6	53
5	84	100,7	FALSE	0	1	TRUE	TRUE	8	80,2	88,4	93,2	94,7	95,7	92,2	86,4	72	TRUE	31	34,8	42,9	53	56,2	58,7
6	84	104,4	FALSE	0	1	TRUE	TRUE	8	82,5	91,6	95,6	98,3	100	96,2	90,3	76	TRUE	31	37,8	45,2	55,9	62,5	62,7
7	84	106,3	FALSE	0	1	TRUE	TRUE	8	83,8	92,8	97,1	100,4	102,2	97,7	93,1	81	TRUE	31	38,1	45,4	52,4	61,6	63,1
8	84	106,4	FALSE	0	1	TRUE	TRUE	8	84,4	93	97	100,3	102,3	98,3	93,1	80,1	TRUE	31	39,1	46,2	53,1	62,1	65
9	84	106,5	FALSE	0	1	TRUE	TRUE	8	86,5	93,8	96,4	99,5	102,1	100	93,6	77,6	TRUE	31	43,3	49,4	55,8	63,1	71,2
3	94	89	FALSE	0	1	TRUE	TRUE	8	73,3	80,8	83	82,4	81,8	79,1	75,3	63,3	TRUE	31	25,7	31,6	37,9	42,9	52,3
4	94	95,3	FALSE	0	1	TRUE	TRUE	8	77,1	85,2	88,9	89,6	89	86,3	81,3	67,1	TRUE	31	28,6	38,8	46	48	53,2
5	94	101	FALSE	0	1	TRUE	TRUE	8	80,4	88,6	93,4	95	96,1	92,6	86,8	72,3	TRUE	31	35	43,1	53,5	56,8	59
6	94	104,6	FALSE	0	1	TRUE	TRUE	8	82,8	91,9	95,8	98,5	100,3	96,4	90,6	76,4	TRUE	31	38,1	45,5	55,5	62,5	63,1
7	94	106,5	FALSE	0	1	TRUE	TRUE	8	83,8	92,7	97,2	100,6	102,4	97,8	93,4	81,5	TRUE	31	38	45,2	52,1	61,4	62,9
8	94	106,5	FALSE	0	1	TRUE	TRUE	8	84,9	93,2	97	100,2	102,3	98,6	93,2	79,7	TRUE	31	39,9	46,8	53,5	62,2	66,3
9	94	106,5	FALSE	0	1	TRUE	TRUE	8	86,5	93,8	96,3	99,4	102,1	100,1	93,5	77,4	TRUE	31	43,5	49,6	56	63,2	71,3

If there are octave band data, the "Octavedata" field is "True" and the same for the "1/3 octave band".

In order to populate the noise record simply use this format in a spread sheet, build your own list of data, copy the list and use the **Paste from Clipboard** button to paste it back into the noise record.

If your data are as 1/1 octaves you fill those columns and can ignore the LWAref column. WindPRO will itself calculate the LWAref from the octave band. The same with 1/3 octaves. If you list the 1/3 octave distribution windPRO will itself calculate the octave bands and the LWAref.

There are a few exceptions. If instead of writing the wind speed you use "-1" as wind speed, windPRO knows that the data are for "95% nominal power". "-3" as hub height tells windPRO that the data relates to wind speed at hub height, not 10 m height, and a specification of hub height is unnecessary.
An alternative approach is to set up the wind speed / hub height cells, highlight them one at a time, check **Octave** or **1/3 octave band** and paste in a frequency table.

Notice the buttons for copy and paste in the form. These should be used to copy detailed data in and out of the form. CTRL-C and CTRL-V will only copy the sum values.

The noise record is separated into a tab for 10 m height and a tab for wind speed at hub height. Clicking in either of the two areas means you are now working on that level and the buttons change color accordingly. Many calculations require noise data at hub height wind speed and the wind speed inside wind farm option requires noise data at hub height wind speed. Many other regulations require noise data at wind speed at 10 m height. However, data can be entered either at hub height wind speed or 10 m height wind speed and be converted to the other. If you receive data at hub height wind speed you must enter the noise data in this tab and, when you are done, press the convert button (Hub height > 10 m). The 10 m tab is then filled with a matrix consisting of columns with hub heights taken from the hub height list of the turbine and wind speeds converted from hub height wind speeds using an IEC 0,05m logarithmic wind profile (typically interpolated to integer wind speeds).

If several hub heights are selected, they will simply help to improve the fit of the curve.
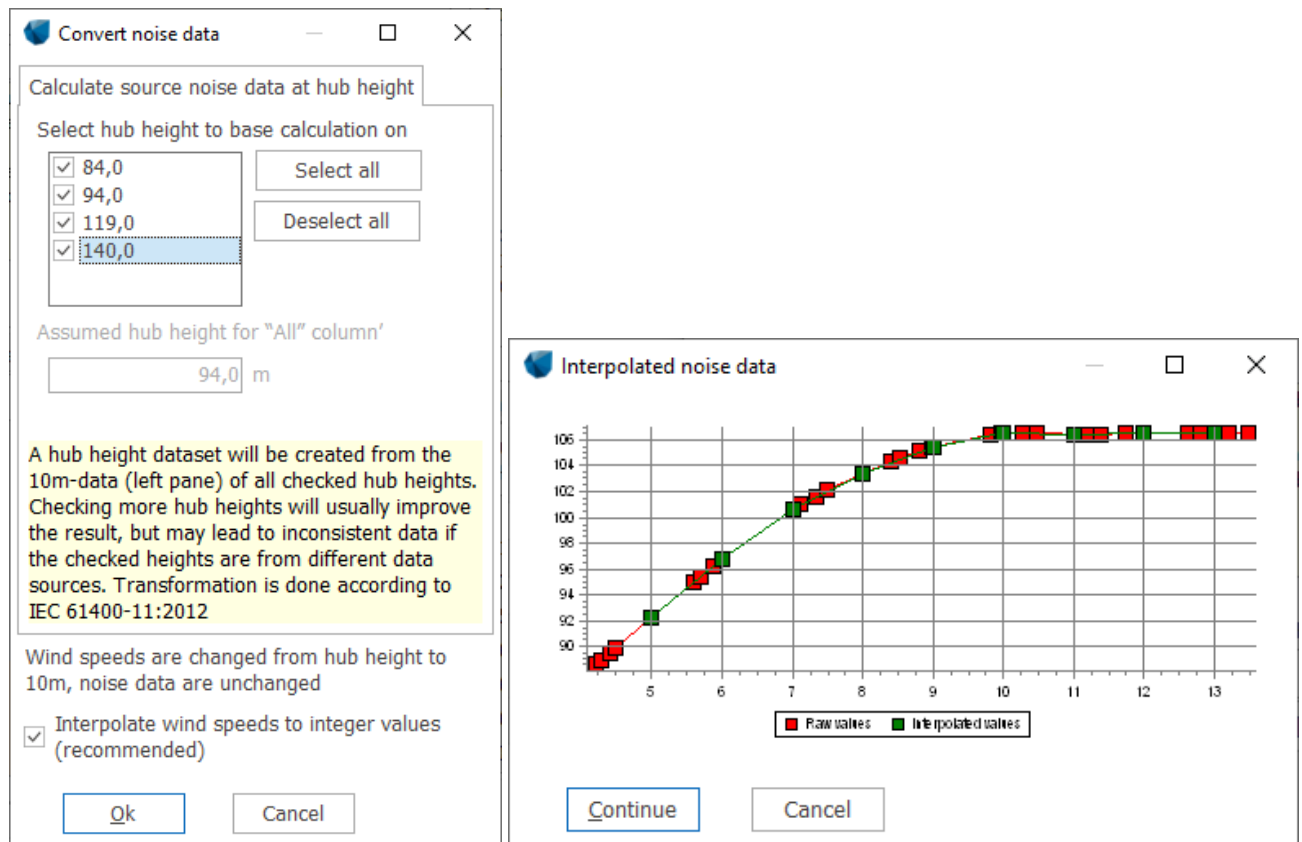
Tonality and uncertainty

Each bin in the noise record can be assigned a tonality (pure tones) penalty or an uncertainty. If you in the calculation setup selects to use tonality or uncertainty from the WTG catalogue, this is the value that will be used.

In the case of uncertainty, the value is added to the source noise level in the bin. For tonality, what to do with the value is decided by the calculation setup.

Note that the values are only assigned to the specific bin. If you need to calculate across a range of bins or with different hub heights, you may need to add tonality or uncertainty to several bins.

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 usually 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,

could represent the third reduced with a maximum noise value of 103dB. The actual labelling of the noise modes for turbines entered by EMD attempts to follow the labelling of the OEM. Often the OEM will supply a large host of operation modes to cover various markets and identifying the modes relevant in your case can be a challenge, though an important one.

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. The selected noise mode will give the noise curve being used in all noise calculations with this turbine. If the turbine is equipped with a curtailment matrix, the curtailment matrix will replace this selection.

Uncertainty

Uncertainty on the noise data can be added to the specific wind turbine at this point. Check the **Uncertainty** box and enter an uncertainty value. If selected in the noise model setup, this value will then overrule any value set in the wind turbine catalogue. It also applies to any noise record and any wind speed / hub height bin.

Power & noise pairs

It is possible to create a list of operation modes by matching power curves with noise records. These lists are called Power & noise pairs and help ensuring that power curve selection is accompanied by the correct noise curve selection. They also arrange the operation modes in progressively quieter and less performing levels and limit the operation modes to those relevant for you.

Power & noise pairs are created in the wind turbine catalogue file for the turbine on the **Details** tab.
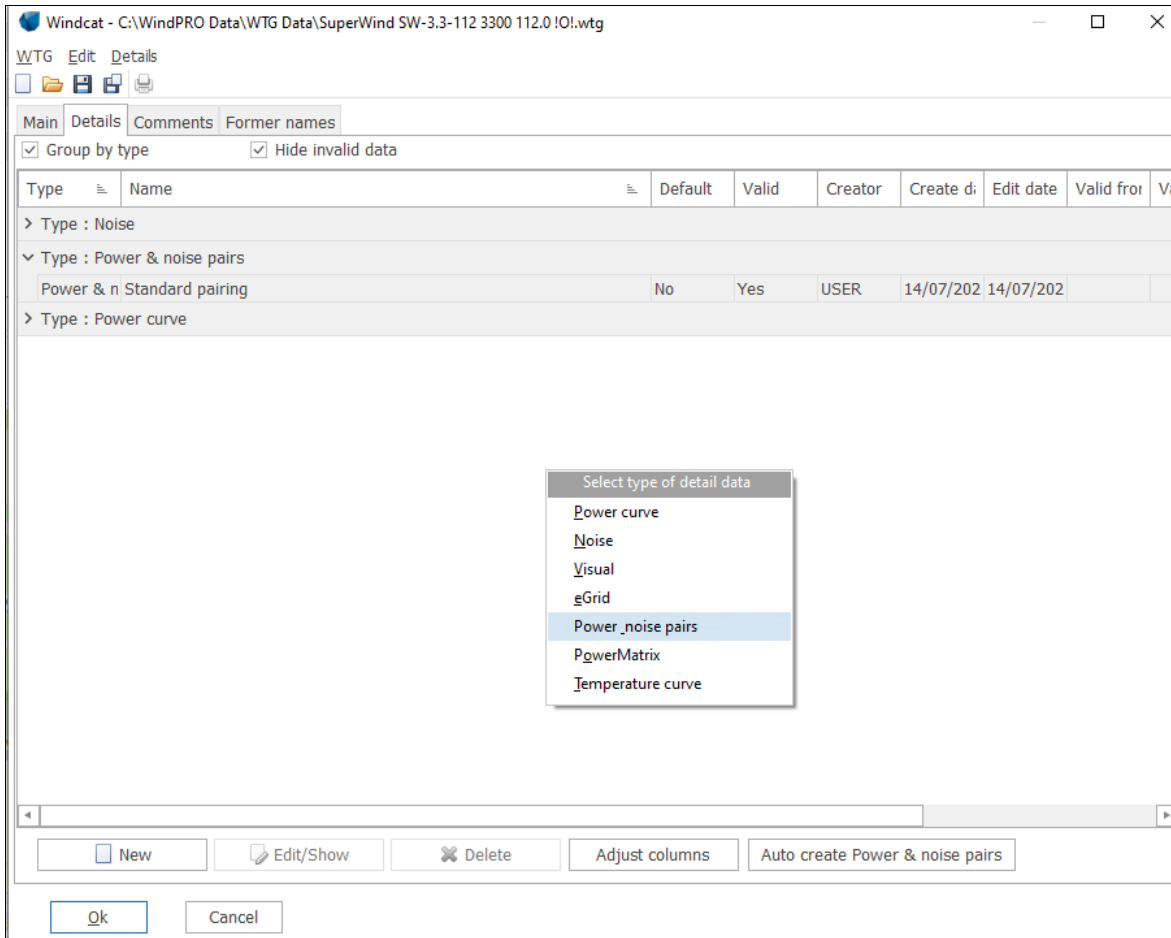
Each line in the list is an operation mode. You select from the drop-down menu which power curve and noise record to use for each mode and type a name.
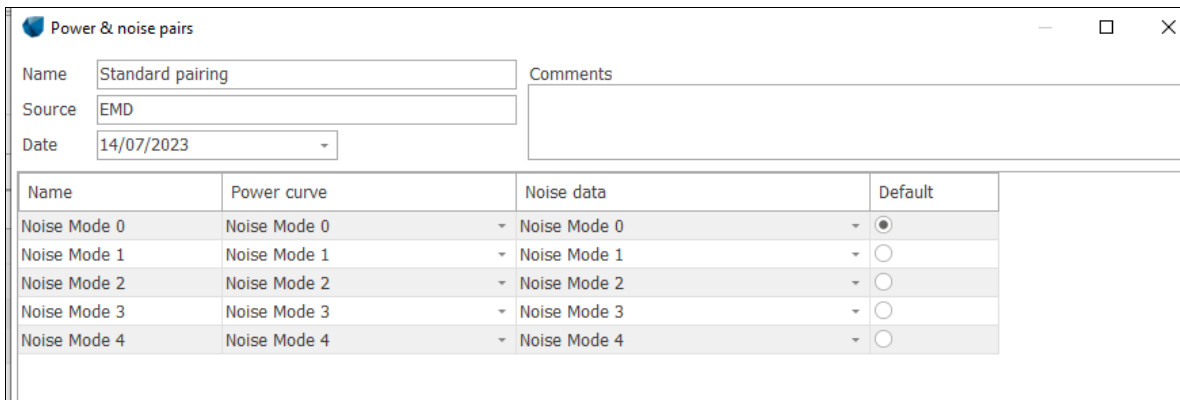
Back on the WTG property tab, when you hatch the **Use Power & noise pairs** box you get to select from your list of Power & noise pairs and from the selected list which pair you want to use.

The Power & noise pairings can be edited by clicking the three dots next to the selection.

In a noise curtailment optimization (see Chapter 8) the optimizer will use the prioritized list in the selected Power & noise pairing.

L_den selection
You can also at this place define day-evening-night settings by clicking the **den** button. Here you can select which operation mode from the Power & noise list the turbine should use in each period. Note that the day-evening-night definition can be edited either in the Decibel calculation setup or in the Park calculation setup.

Day-evening-night settings are used in yield calculations (PARK) and in Lden noise calculations (DECIBEL and Nord2000). A noise calculation that is not using Lden will simply use the day setting.

Noise matrix
The noise curtailment matrix is a definition of what conditions make the wind turbine operate in a specific operation mode. It is a curtailment rule as other curtailment rules, but different in the sense that it defines all possible situations and therefore replace the settings on the **Properties** tab of the WTG object.

If a noise curtailment matrix is assigned to the WTG object, you can see it on the **Curtailment** tab of the WTG object. A WTG object can only have one noise curtailment matrix.

Within the WTG object, the noise matrix can be viewed by clicking on it, but not edited. Editing the curtailment matrix can be done in the **Noise Matrix Analyzer** (see section 2) or by running a noise curtailment optimization (see section 8b). In the curtailment matrix, the dimensions that are defined are visible. As only two dimensions can be viewed at any one time, you may have to change the parameters in the column and row fields to get the wanted view. In the example below, only wind direction dimension is defined, resulting in a simple row. The operation mode in each bin is displayed with name and color.

When, in the DECIBEL calculation a reference is made to the binning of the matrix, windPRO will look into the curtailment matrix of the turbines to obtain the binning information.

6.1.2.2 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 must 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).

You will notice that the coordinate fields on the **Position** tab are faded. This is because the location of the noise sensitive point is managed from the **Area** tab. In case the NSA consists of just a single point, the area will be defined with a single coordinate pair.

Often noise restrictions are linked to zoning. Planners may have defined zones of particular noise restrictions and in such cases defining noise receptors as areas is very useful.

Tip: If zoning is available in shape format you can load zoning maps into an area object, using the color code to sort different kinds of zoning. Use this map as template when you define your noise sensitive areas.

Tip: Noise sensitive points are very useful when noise must be calculated for well-defined points. This is often at the corner of buildings or at the edge of property, points that may not be well defined on available maps. Use the Google map synchronization to see where you point lands and move it around to fit the required location. Google maps often reveal surprising details about property and landscape. You can combine this with a distance circle on the layer with noise sensitive points if you need to place your receptor at a certain distance of a landmark.

It is possible to change the color of the Noise Sensitive Point (or area). This is particularly useful to distinguish between dwellings of different noise thresholds.

In case many NSAs need to be entered, it may be useful to either enter them with default values or from a coordinate list and then edit them as a group using the **Edit selected objects** option in the object list. As the structure can be rather detailed, it is easier to edit them in a single operation than for each individual object. That will assign identical threshold to the NSA's. Those with different values can then be manually changed subsequently.

Demands
The tab **Demands** defines the noise receptor in term of critical noise thresholds (demands).

If **Define in calculation setup** is checked, a uniform description of the noise demands can be 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 Norway will automatically link to the Norwegian codes and freeze noise demand. The user has to define whether the receptor is in Yellow zone or Red Zone, in which case the noise demands will reflect the critical noise thresholds for that type of area.

The **No noise demand** button overrides the noise restrictions for this object, though it will still be included in the calculation. This is useful when considering exceptions (turbines owner's dwelling, potential buy-ups etc.)

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 NSA 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 requirement is fulfilled or not. The distance demand can be shown on the map (Section 6.1.2.3) 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 a Classic 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 situations 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.

Same with Uncertainty margin. If no value is given in the model, a specific value can be assigned to the receptor.

If **no noise 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 L_{den} values. For low-frequency thresholds it is possible to exclude the A-weighting.

There are two types of noise thresholds:
- 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 threshold for the receptor.

If the noise threshold is different for different wind speeds, then selecting **Check for more wind speeds** makes it possible to enter specific critical limits (see figure below). Enter from and to wind speed and step and the list of wind speeds becomes available.

Here it is also possible to define critical noise levels for specific frequencies using **Check for spectral distribution**. If that is done it is important to note if the spectral noise target is A weighted or not. In some countries the critical noise limit is a noise spectrum that you cannot exceed, and these are often not A weighted.

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 **Check for more 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.

In case of **low frequency** noise calculations, the form includes standard setups from Danish, Finnish and Swedish codes. The Danish code form test for an aggregated noise level from 10 to 160 Hz while the Finnish and Swedish both test against a predefined spectrum. In the Swedish and Finnish case, the threshold spectrum is not A-weighted, and the checkbox is therefore not hatched. A custom form can be set up using the Free definable form option for use with Nord2000.

The NSA can be set up with different thresholds for different time periods by checking the **Use temporal binning** checkbox. This will add vertical tabs to the form, each representing a different period. It is a requirement that the general structure of the form is the same for all periods, only the values are allowed to be different.

The **View** button next to the checkbox allow to see and change the temporal binning. At this point the hours of the binning is not used. Only the number of periods and their name. In the present case Day and night are defined, resulting in two vertical tabs.

Any change to the structure on any of the vertical tabs is automatically copied to the other tabs. Only the values may be different.

Area

All coordinates relating to the NSA are handled in the **Area** tab, even if it is just a single point. Here it is possible to edit the node points of the area. Node points can be added, edited, or deleted. The node points can be copied to or from Excel. The **Edit** button makes it possible to graphically edit the node points, insert new points or remove some.
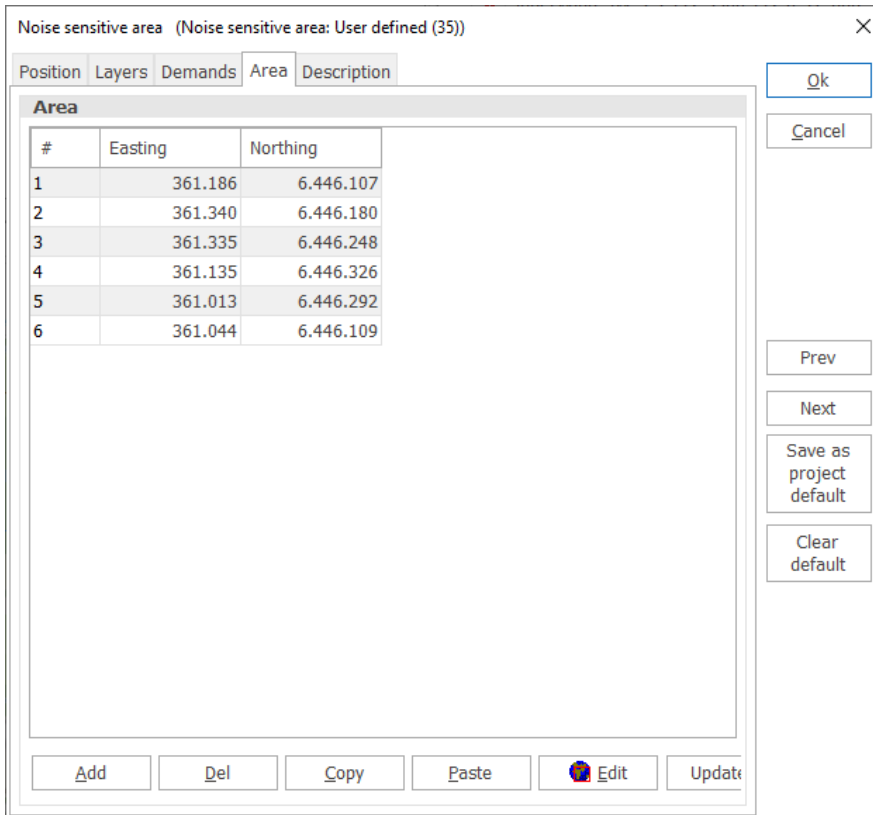
When the NSA is entered as an area, windPRO will calculate the noise level for each point at the edge of the area and give as a result the one with the highest level.

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.

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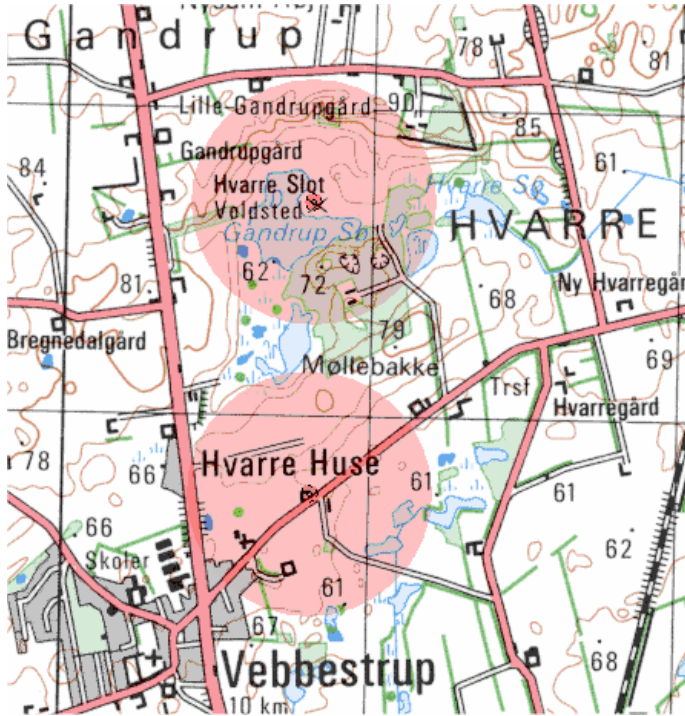
When you click with the right mouse button on an NSA object you gain access to switch the distance marker on/off. The selected mode covers all NSA objects. If the distance marker is activated, the program will produce a faded red circle, which indicates the distance requirement entered for each object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

Alternatively, double click a layer in the Object Layers list and press **Distance circles for objects on layer**. Here you can set a distance around all objects in the layer. If the layer consists only of noise receptors you will effectively get a line with a fixed distance around the receptors.

6.1.2.4   Using obstacles for reflection

It is possible to include noise reflections from vertical surfaces in the noise calculation. At this point this has been implemented in the general ISO 9613-2 method and in the Interimsverfahren method.

Reflectors are described using obstacles. The side of an obstacle will describe a vertical wall on which the sound will bounce off and continue towards the receptor from this secondary source.
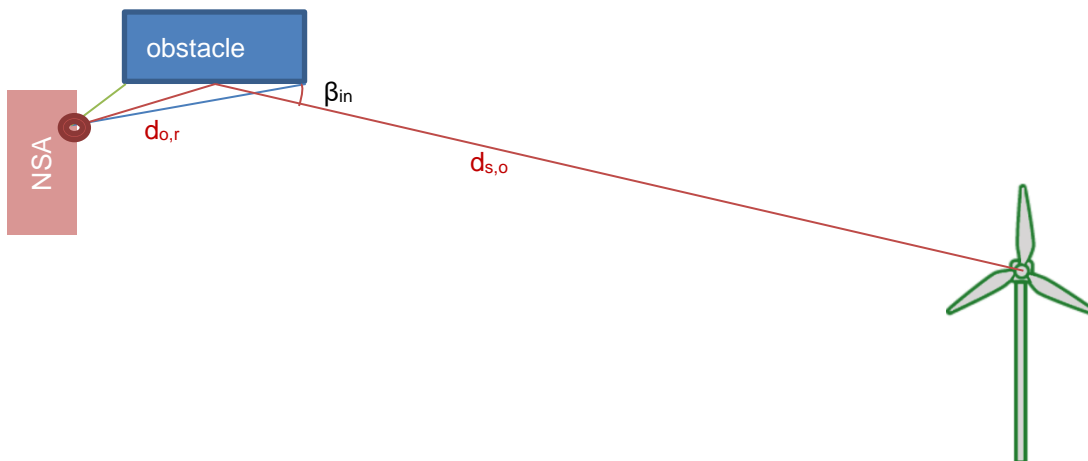

The obstacle is a standard WindPRO object that is already used in yield assessment and for photomontages and ZVI calculations. To insert the obstacle, select it from the list of object icons, point out on corner of house

on the map and drag until the obstacle fit the wall. It is not necessary to match the entire building, only the reflective wall needs to be described.
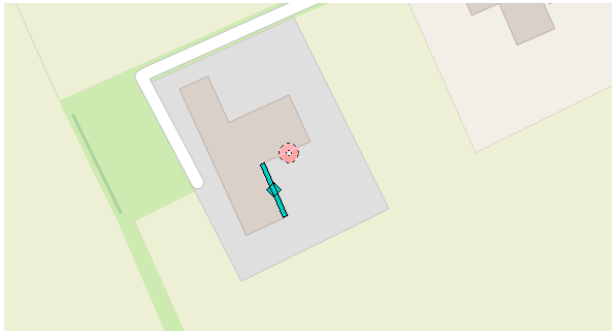
Only include the closest wall in any direction. A wall behind the first wall will create a reflection that ignores the first wall which is incorrect.
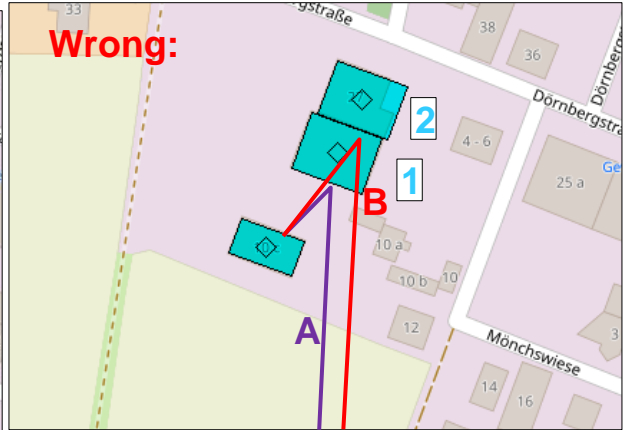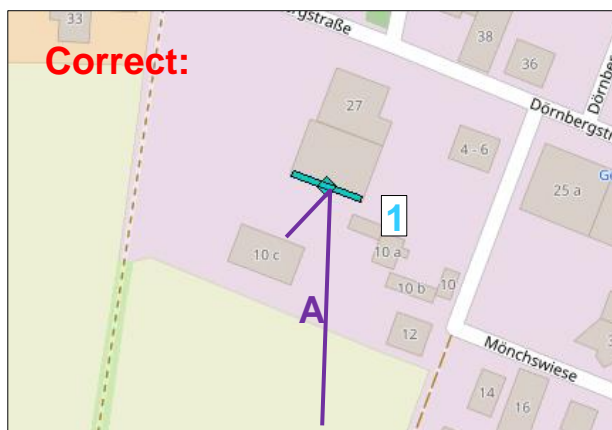

The dimensions of the obstacle are managed from the **Obstacle** tab. The height must be entered manually, keeping in mind that the reflection only is relevant on a vertical surface. A sloping roof will bounce off the reflected sound in a different direction and not toward the receptor.

On the **Noise reflection** tab, a check box can be found, **Use as noise reflector**. If this is hatched the obstacle will be considered in a DECIBEL calculation if reflection is activated in the calculation setup.

The reflective property of the reflector / obstacle is the Sound reflection coefficient, ρ. These coefficients are defined in the ISO 9613-2 standard and on the **Noise reflection** tab the various types of Sound reflection coefficients can be selected.
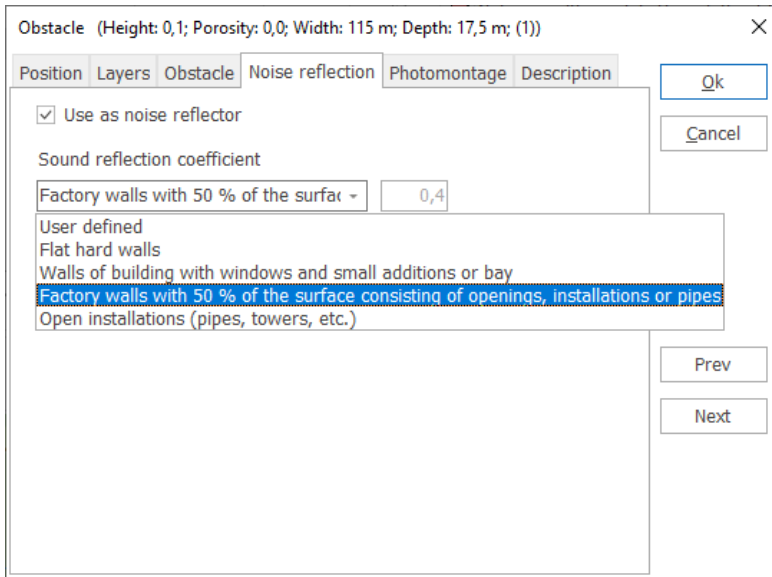

In the actual calculation, each noise reflection obstacles are considered against each receptor. In order to reflect the noise, the reflecting surface must be large enough, given the angle of the surface, in each frequency band. It is therefore possible that the wall will reflect noise in only some frequencies. For this reason, it is important to describe the wall with a single obstacle object if at all possible, rather than patching it up from small pieces.

Noise reflection, if included in the calculation will generate extra pages in the report printout (see section 6.1.3.3).

The noise reflection calculation is described in detail in the technical appendix.

6.1.3   DECIBEL - Calculation and printout

The DECIBEL calculation can be started from the Environment & Visual tab of the ribbon.
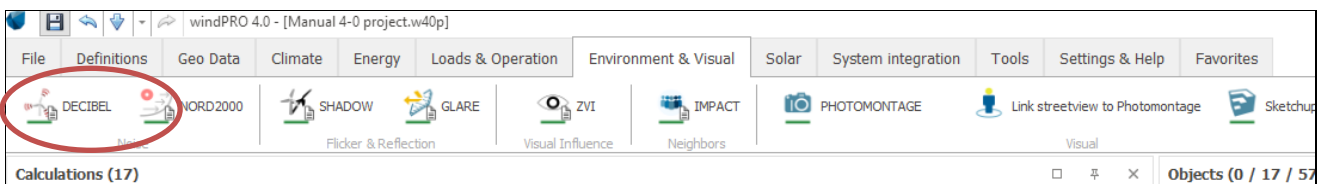
If the bar below the icon is green, it is possible to perform a calculation. If it is yellow, license for the module is needed.

6.1.3.1   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 6.1.1 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 6.1.3.4 and 6.1.3.5. 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. The calculation is based on the noise map, so the option is removed if no noise map is calculated.

You can also setup the number of decimals to present in the main result. The actual calculation uses many decimals, but for presentation purpose it is useful to limit this.

At this place it is also possible to check whether or not to include a check against the critical noise thresholds in the noise receptors and if this check should be based on rounded values. Example: if you have a critical noise limit of 40 dB and the result is 39.97 dB you will be presented with a result of 40.0 dB if you are using 1 decimal place. If you have unchecked the rounded values box this will result in a fail because 39.97 is less than 40, while checking the box will result in a pass as 40.0 just complies with the threshold.

Checking **Allow setup of noise demands at calculation** introduces 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 6.1.1.

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 layers.
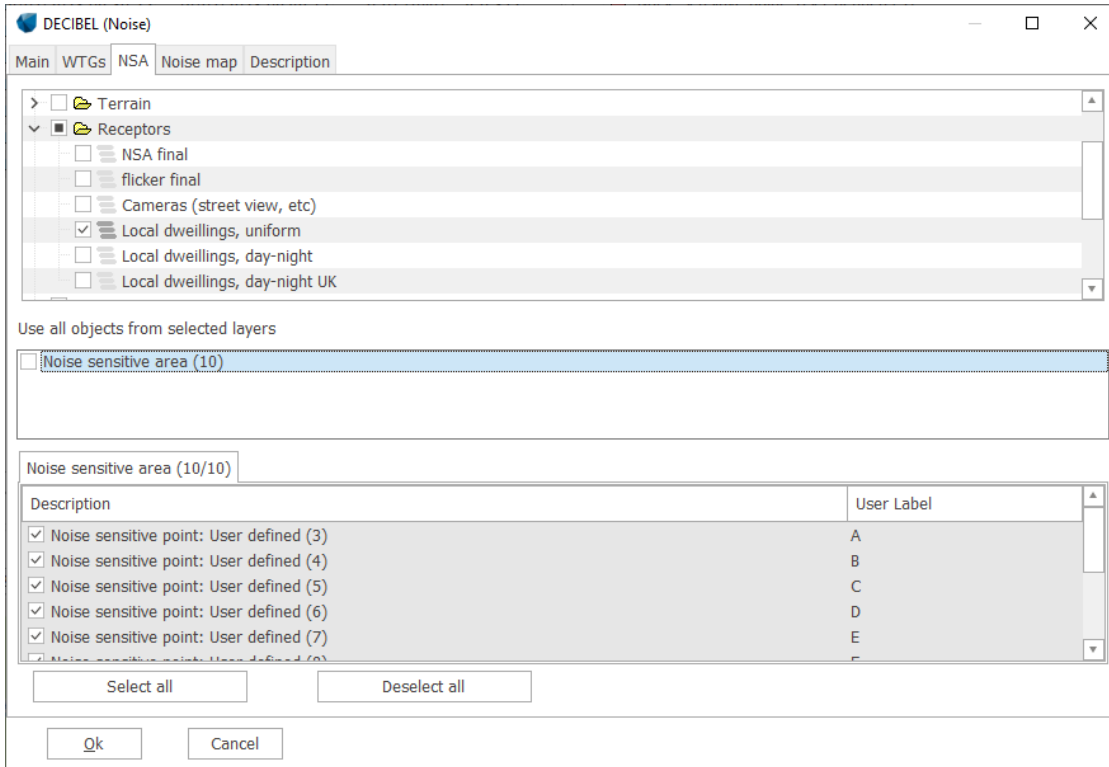

Obstacles

If Noise reflection is activated in the model setup a new tab will have appeared: **Obstacles**. On this tab the layer with the obstacles relevant for the calculation can be selected. All other obstacles are ignored.
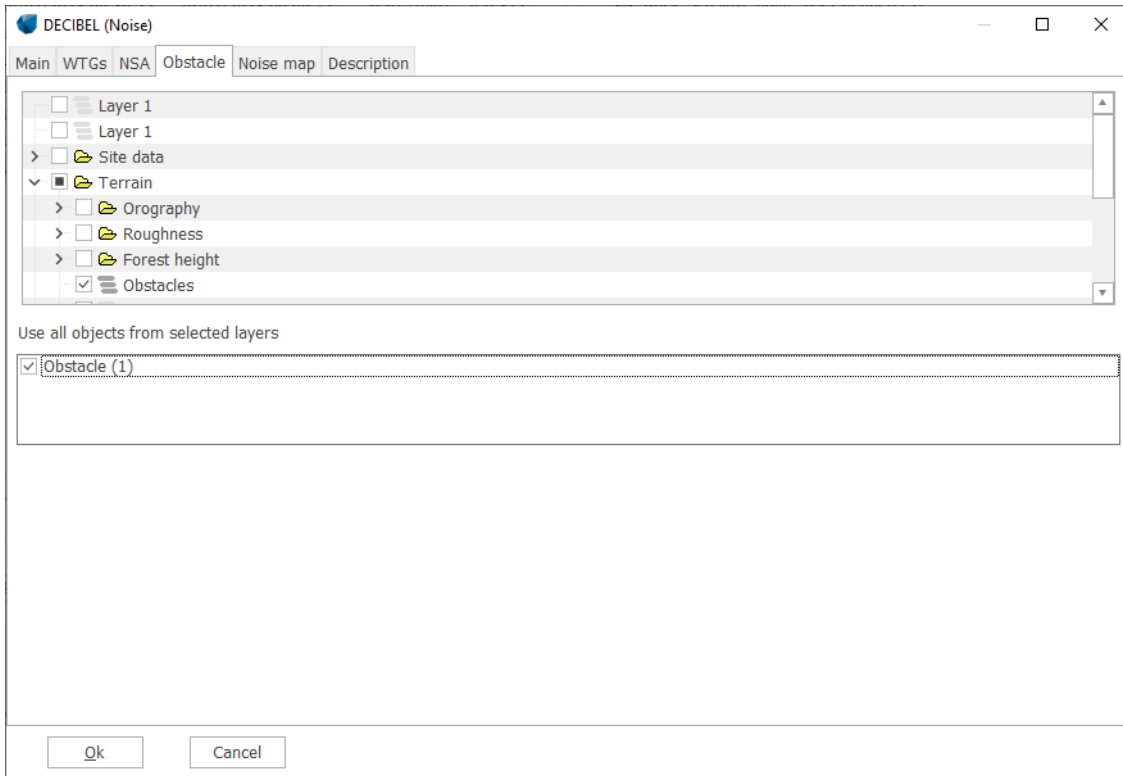
Noise map

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.
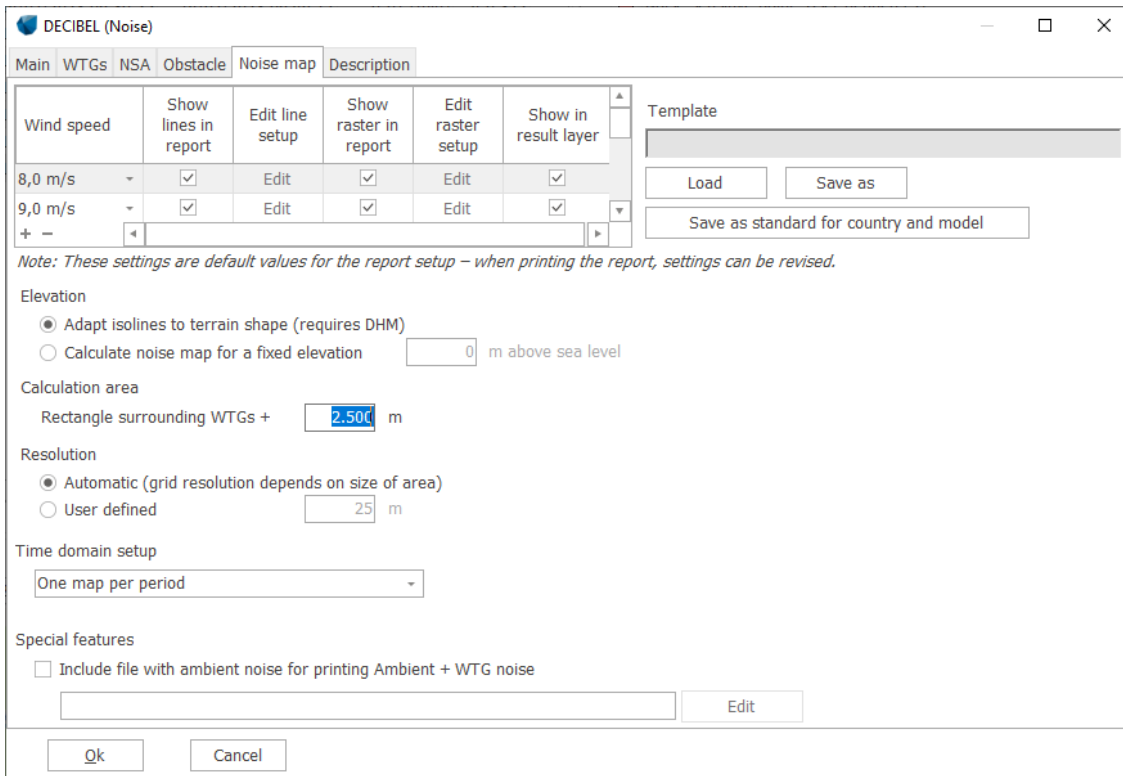
The **Noise map** tab depends on the selections in the noise model. Changing the noise model will also change the appearance of this tab.

The calculation wind speed will also be the wind speed for the map. This might not be a specific wind speed but could be the highest noise level wind speed or the 95% nominal power wind speed. If the model includes a range of wind speeds, the full range will be listed on the tab. If the calculation is an L_{den} calculation, there will be a line for the combined L_{den} value and on for each of the periods.

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.

The little "+" and "-" below the noise map list allows addition or removal of maps. WindPRO wind always try to setup the right number of maps, but this may result in an excessive number of maps. It is possible to reduce the number of maps, but adding maps is only possible if they correspond to a calculation scenario. An 11 m/s line can therefore only be added if there is a calculation for 11 m/s.

Whether the wind speed indicated are for 10m height or hub height depends on the calculation model setup.

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. The form follows standard windPRO conventions. 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.

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.

The calculation model may allow for several time periods to be tested in the calculation. If that is the case, a decision on the **Time domain setup** has to be made.

The default option is **Loudest across periods**. This is an aggregate map that compares the noise from the wind farm across all periods in each calculation point and selects the highest value. This is therefore the highest noise value to be expected at any time.

Alternatively, a map can be produced for a **specific period** (day, evening or night) and simply a map for each period. Beware that with multiple wind speeds and multiple periods, this may amount to a lot of maps.

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.

6.1.3.2 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 posts.

It is advisable to manually review the suggestions or override them with manually selected noise data. Det difference between **MANUAL check auto values…** and **MANUAL input of missing…** is that in the former you get to review all the wind turbines, also those with sufficient data, while with the latter you will only get to review those turbines that lack data.

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

Data in Windcat not complete for selected noise calculation mode

WTG: SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0

Noise data: Noise Mode 0

Available data, partly generic: (select a data set to EDIT or press Start calculation)

Lwa,ref	Wind speed	Hub height	Data type	Pure tones	Penalty	Octave data	Wind speed dependency
106,5	8,0	94,0	From Windcat	No	0	Yes	1,0
106,5	9,0	94,0	From Windcat	No	0	Yes	1,0
106,5	10,0	94,0	Extrapolated	No	0	Yes	1,0
106,8	11,0	94,0	Extrapolated	No	0	Yes	1,0
106,6	12,0	94,0	Extrapolated	No	0	Yes	1,0

L90 (Based on entered octave data) [____] dB(A)   Pure tone penalty [__] dB   Wind speed dependency [__] dB(A)/m/s

Octave data

☐ Calculate generic values   ☑ Octave data already A-weighted

62.5 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Update list with current values ⇧

<< Previous WTG	Next WTG >>
Start calculation	Cancel calculation

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 the right red marking indicate that data for 10, 11 and 12 m/s are missing. windPRO has filled in suggestions in those fields.

If the problem line is highlighted, you can see what windPRO suggests.

Data in Windcat not complete for selected noise calculation mode

WTG: SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0

Noise data: Noise Mode 0

Available data, partly generic: (select a data set to EDIT or press Start calculation)

Lwa,ref	Wind speed	Hub height	Data type	Pure tones	Penalty	Octave data	Wind speed dependency
106,5	8,0	94,0	From Windcat	No	0	Yes	1,0
106,5	9,0	94,0	From Windcat	No	0	Yes	1,0
106,5	10,0	94,0	Extrapolated	No	0	Yes	1,0
106,8	11,0	94,0	Extrapolated	No	0	Yes	1,0
106,6	12,0	94,0	Extrapolated	No	0	Yes	1,0

Data generated by windPRO based on simple inter/extrapolations

L90 (Based on entered octave data) [106,5] dB(A)   Pure tone penalty [0,0] dB   Wind speed dependency [1,0] dB(A)/m/s

Octave data

☐ Calculate generic values   ☑ Octave data already A-weighted

62.5 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
85,0	93,2	97,0	100,3	102,3	98,7	93,3	79,8

Update list with current values ⬆

<< Previous WTG	Next WTG >>
Start calculation	Cancel calculation

windPRO suggests to extrapolate the source noise data from other wind speeds in the above case, keeping the octave band distribution.

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 obtaining 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).

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

$$R^2=0.75$$
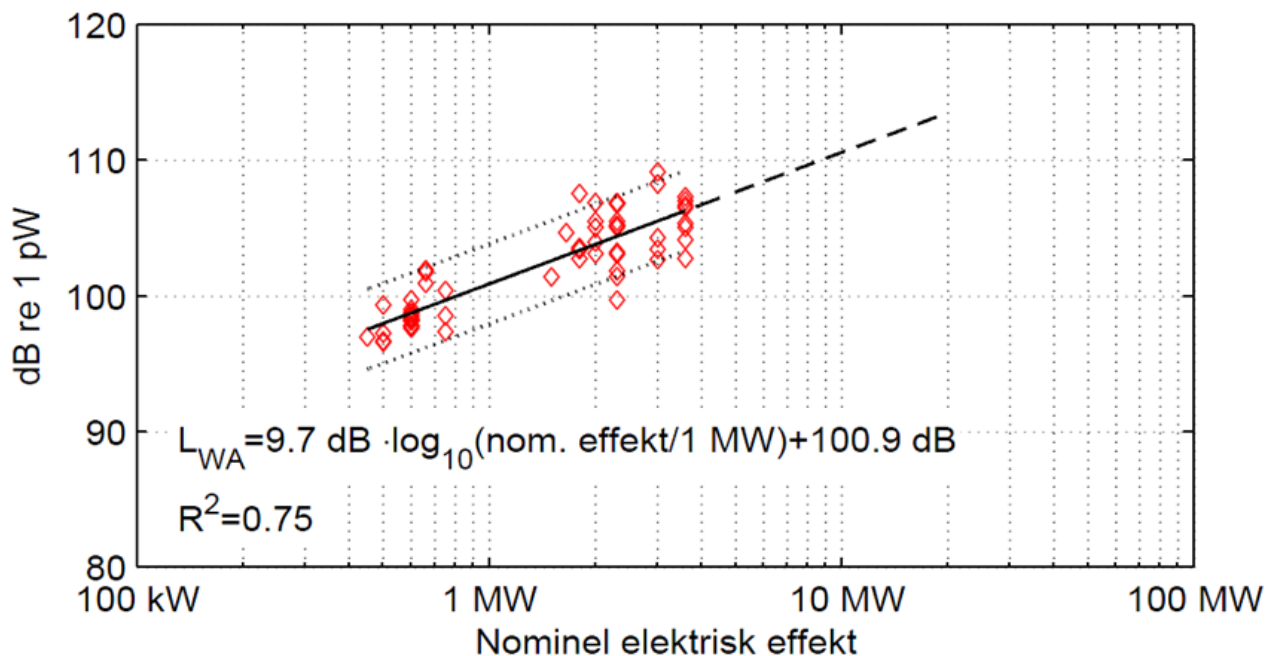
As would be noticed from the figure this is a highly uncertain approach as there is a large amount of scatter to this function. More recent publications have shown a disconnect between source noise level and generator size, which emphasizes the need for actual data rather than using generic data ("Evolution of sound production of onshore wind turbines", van den Berg et.al., 10th International Conference on Wind Turbine Noise). Notice that use of generic data will in the report be accompanied by a note saying that the data are highly uncertain.

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. The generic octave band distribution used to scale the distribution is presented below. Note that a different distribution is used for ISO 9613-2 Interimsverfahren, see section 6.1.1.3.

It must however be emphasized that while adopting an octave band distribution from 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.

Hz	63	125	250	500	1000	2000	4000	8000
dB(A)	-18,4	-11,4	-8,0	-5,4	-5,6	-8,5	-13,3	-22,8

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.

6.1.3.3   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/viewed.

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 checkboxes to the left, the individual report pages can be selected or deselected for printout. By clicking on the report page 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.

The various calculation options have a lot of influence on what the report looks like. Some of those variations are discussed below

Main Result
The Main Result page is intended as a summary page for the calculation results.

The top part summarizes the calculation settings, which will be very much based on the calculation model used. Ground attenuation for example will be listed if selecting ground attenuation is part of the calculation setup but not if it is inherent in the model.

The map displayed gives an overview of the calculation with the wind turbines and the receptors used. As default the scale is adjusted to include all objects in the calculation, but map and scale can be specified in the calculation setup (See general section on report printouts in windPRO).

There is a list of wind turbines involved in the calculation. Each turbine gets a line of its own with the relevant specifications. Of special concern is the name of the noise record, which may indicate noise reduced operation or to identify the noise data used. The sound level at the reference wind speed is listed as well as whether or not the turbine type has a tonality penalty.

WTGs

	Easting	Northing	Z [m]	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Noise data Creator	Name	Wind speed [m/s]	LwA,ref [dB(A)]	Pure tones
1	360.811	6.445.575	90,7	SuperWind SW-3.3-112 ...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Noise Mode 0	8,0	106,5	No
2	360.753	6.446.054	112,6	SuperWind SW-3.3-112 ...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Noise Mode 0	8,0	106,5	No
3	360.696	6.446.534	130,0	SuperWind SW-3.3-112 ...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Noise Mode 0	8,0	106,5	No
4	360.638	6.447.014	151,4	SuperWind SW-3.3-112 ...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Noise Mode 0	8,0	106,5	No
5	360.581	6.447.494	134,4	SuperWind SW-3.3-112 ...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Noise Mode 0	8,0	106,5	No
6	360.523	6.447.974	130,0	SuperWind SW-3.3-112 ...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Noise Mode 0	8,0	106,5	No

In case the calculation model has two wind speed levels (The Danish codes), both wind speeds are listed. If there are more wind speeds, such as the UK noise curve, the lowest and highest wind speed is listed. For Lden calculation there will be a line each for day, evening and night with a fixed wind speed or highest wind speed. In case the wind turbines are using a curtailment matrix, the list will show the name of the Power & Noise list and the value of the top mode in that list. The actual source noise level of the turbine will then be variable and can be found in the curtailment pages of the report.

WTGs

	Easting	Northing	Z [m]	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Noise data Creator	Name	Wind speed [m/s]	LwA,ref [dB(A)]	Pure tones
1	360.811	6.445.575	90,7	SuperWind SW-3.3-1...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Standard pairing	10,0	106,5	No
2	360.753	6.446.054	112,6	SuperWind SW-3.3-1...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Standard pairing	10,0	106,5	No
3	360.696	6.446.534	130,0	SuperWind SW-3.3-1...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Standard pairing	10,0	106,5	No
4	360.638	6.447.014	151,4	SuperWind SW-3.3-1...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Standard pairing	10,0	106,5	No
5	360.581	6.447.494	134,4	SuperWind SW-3.3-1...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Standard pairing	10,0	106,5	No
6	360.523	6.447.974	130,0	SuperWind SW-3.3-1...	Yes	SuperWind	SW-3.3-112-3.300	3.300	112,0	94,0	USER	Standard pairing	10,0	106,5	No

Pay special attention to any notes to the wind turbines. To the very left a note may appear if there is a caveat to the data. An explanation will then follow just beneath the wind turbine list.

"a" – No noise data available. Generic data has been used based on the generator size (see section 6.1.3.2)
"b" – No noise data available or the data does not include octave band distribution. Generic data from the Danish EPA is used instead. This is a special requirement in Denmark and applies to turbines <=2 MW.
"f" – Noise data from another hub height has been used.
"g" – Noise data was not available for the selected wind speed. Instead, noise data has been calculated from other wind speeds. As this is done as a simple, linear extrapolation of the noise curve, this number is highly uncertain
"h" – The calculation required an octave band distribution, but only the dB(A) value was available. Instead, a generic distribution was fitted the dBA value.
"k" – The WTG has a noise matrix assigned, the noise curve used is governed by the noise matrix.

WTGs

	Easting	Northing	Z	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Noise data Creator	Name	Wind speed	Status	LwA,ref	Pure tones
			[m]					[kW]	[m]	[m]			[m/s]		[dB(A)]	
1	553.666	6.284.269	74,0	SuperWind SW-3.0-112 3075 11...Yes		SuperWind	SW-3.0-112-3.075	3.075	112,0	100,0	USER	Level 0 - warranted - M1 - 2014-05	8,0	From other hub height	106,5	No f
2	553.353	6.284.441	85,0	SuperWind SW-3.0-112 3075 11...Yes		SuperWind	SW-3.0-112-3.075	3.075	112,0	94,0	USER	Level 0 - warranted - M1 - 2014-05	8,0		106,5	No f
3	553.041	6.284.614	85,3	SuperWind SW-3.0-112 3075 11...Yes		SuperWind	SW-3.0-112-3.075	3.075	112,0	94,0	USER	Level 0 - warranted - M1 - 2014-05	8,0		106,5	No f

f) From other hub height

Below the wind turbine list is the calculation result.

Each dwelling is listed. The sorting is decided in the calculation setup where an alternative sorting can be selected, such as by User label.
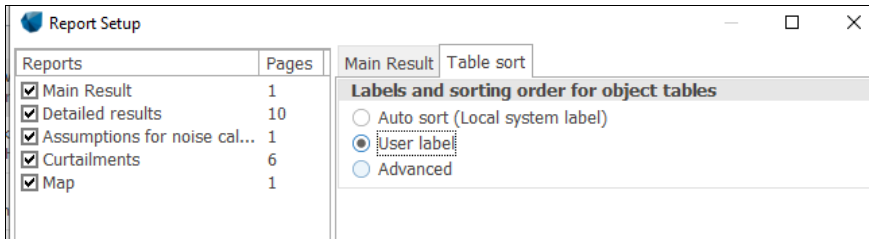
Exactly what is included in the result depends on the calculation type. The key word is that for each receptor, the most critical result is displayed. Sometimes multiple wind speeds, wind directions or frequencies are tested and WindPRO will list the highest noise level relative to the threshold, i.e. the most critical event.

In the most basic form, the result line presents the noise threshold (Demand), the calculated sound level from the turbines and Yes/No on whether or not the sound level is within the noise target.

Calculation Results

Sound level

	Noise sensitive area					Demands	Sound level	Demands fulfilled ?
No.	Name	Easting	Northing	Z	Immission height	Noise	From WTGs	Noise
				[m]	[m]	[dB(A)]	[dB(A)]	
A	Noise sensitive point: User defined (3)	360.402	6.445.315	90,0	1,5	40,0	37,7	Yes
B	Noise sensitive point: User defined (4)	360.344	6.445.801	80,0	1,5	40,0	39,8	Yes
C	Noise sensitive point: User defined (5)	360.267	6.446.113	100,0	1,5	40,0	39,9	Yes
D	Noise sensitive point: User defined (6)	360.172	6.446.426	93,1	1,5	40,0	39,9	Yes
E	Noise sensitive point: User defined (7)	360.140	6.448.018	68,3	1,5	40,0	39,5	Yes
F	Noise sensitive point: User defined (8)	360.186	6.448.058	68,9	1,5	40,0	39,8	Yes
G	Noise sensitive point: User defined (9)	360.508	6.448.347	100,0	1,5	40,0	38,5	Yes
H	Noise sensitive point: User defined (10)	361.218	6.445.866	91,2	1,5	40,0	39,7	Yes
I	Noise sensitive point: User defined (11)	361.290	6.445.651	69,3	1,5	40,0	38,4	Yes
J	Noise sensitive point: User defined (12)	360.715	6.444.988	80,0	1,5	40,0	35,5	Yes

If noise is calculated for two wind speed (Danish codes), two lines will appear for each receptor. In the case of Lden, a line will appear for each period and in case a range of wind speeds are calculated, the most critical wind speed is presented. This could be combined with an ambient noise level and then critical noise is not merely a critical noise level but how large or how close to exceedance the noise level is at the most critical wind speed, see example below. Here the most critical exceedance at receptor B is at 7 m/s where the sound level is 6.1 dB higher than allowed.

Calculation Results

Sound level

	Noise sensitive area					Most critical demand		Predicted sound level		Demands fulfilled ?
No.	Name	Easting	Northing	Z	Immission height	Wind speed	Demand	WTG noise	Max exceedance	Noise
				[m]	[m]	[m/s]	[dB(A)]	[dB(A)]	[dB(A)]	
A	Noise sensitive point: British - British (35)	360.402	6.445.315	90,0	4,0	7,0	35,0	39,0	4,0	No
B	Noise sensitive point: British - British (36)	360.344	6.445.801	80,0	4,0	7,0	35,0	41,1	6,1	No
C	Noise sensitive point: British - British (37)	360.277	6.446.121	100,0	4,0	7,0	35,0	41,4	6,4	No
D	Noise sensitive point: British - British (38)	360.172	6.446.426	93,1	4,0	7,0	35,0	41,0	6,0	No
E	Noise sensitive point: British - British (39)	360.140	6.448.018	68,3	4,0	7,0	35,0	40,7	5,7	No
F	Noise sensitive point: British - British (40)	360.186	6.448.058	68,9	4,0	7,0	35,0	41,0	6,0	No
G	Noise sensitive point: British - British (41)	360.508	6.448.347	100,0	4,0	7,0	35,0	39,7	4,7	No
H	Noise sensitive point: British - British (42)	361.218	6.445.866	91,2	4,0	7,0	35,0	40,9	5,9	No
I	Noise sensitive point: British - British (43)	361.290	6.445.651	69,3	4,0	7,0	35,0	39,5	4,5	No
J	Noise sensitive point: British - British (44)	360.715	6.444.988	80,0	4,0	7,0	35,0	36,8	1,8	No

Time domain results can be shown in case several periods have been calculated (day/night or day/evening/night).

Calculation Results

Sound level

No.	Time	Name	Easting	Northing	Z [m]	Immission height [m]	Demands Noise [dB(A)]	Sound level From WTGs [dB(A)]	Demands fulfilled ? Noise
A	Day	Noise sensitive point: User defined (45)	360.402	6.445.315	90,0	5,0	60,0	44,2	Yes
A	Night						42,0	38,6	
B	Day	Noise sensitive point: User defined (46)	360.344	6.445.801	80,0	5,0	60,0	46,1	Yes
B	Night						42,0	40,9	
C	Day	Noise sensitive point: User defined (47)	360.277	6.446.121	100,0	5,0	60,0	46,1	Yes
C	Night						42,0	41,6	
D	Day	Noise sensitive point: User defined (48)	360.172	6.446.426	93,1	5,0	60,0	45,2	Yes
D	Night						42,0	41,4	
E	Day	Noise sensitive point: User defined (49)	360.140	6.448.018	68,3	5,0	60,0	45,9	Yes
E	Night						42,0	40,0	
F	Day	Noise sensitive point: User defined (50)	360.186	6.448.058	68,9	5,0	60,0	46,5	Yes
F	Night						42,0	40,6	
G	Day	Noise sensitive point: User defined (51)	360.508	6.448.347	100,0	5,0	60,0	45,8	Yes
G	Night						42,0	39,8	
H	Day	Noise sensitive point: User defined (52)	361.218	6.445.866	91,2	5,0	60,0	46,1	Yes
H	Night						42,0	40,7	
I	Day	Noise sensitive point: User defined (53)	361.290	6.445.651	69,3	5,0	60,0	44,8	Yes
I	Night						42,0	39,3	
J	Day	Noise sensitive point: User defined (54)	360.715	6.444.988	80,0	5,0	60,0	41,9	Yes
J	Night						42,0	36,4	

In case the noise target is a frequency distribution, such as Finnish low frequency noise, the result table will not present a calculated sound level, but merely tell if the calculation complies with the noise target. In that case the Detailed results will present the results.

If it has been selected to calculate the distance to the noise demand at the time of calculation, the table will include such a number. WindPRO will use the noise isoline map to calculate the distance from the receptor to the point where the noise target is met. If the number is positive the critical point is somewhere between the wind farm and the receptor. If it is negative, then the receptor is receiving too much noise and the critical point is further away from the wind farm. This number is helpful for micrositing, to give an idea of how much space is available. Note that this number cannot be calculated if the noise map is not calculated.

Finally, a distance matrix is presented. These are the distances between each wind turbine and each receptor. If a distance requirement was entered for any of the receptors, those combinations where the receptor and turbine are too close to each other will be presented in bold. Note that the distance is the horizontal distance component, not the sound distance.

Detailed results

The Detailed results pages are a breakdown of the calculation. Here the contribution that each turbine make to each receptor can be found, as well as the source noise level and the attenuations.

Noise sensitive area: A Dwelling 1

Wind speed: 8,0 m/s

WTG

No.	Distance [m]	Sound distance [m]	Calculated [dB(A)]	LwA,ref [dB(A)]	Dc [dB]	Adiv [dB]	Aatm [dB]	Agr [dB]	Abar [dB]	Amisc [dB]	A [dB]
1	1.353	1.356	**25,80**	106,5	0,00	73,65	-	-	0,00	0,00	-
2	996	1.001	**29,39**	106,5	0,00	71,01	-	-	0,00	0,00	-
3	640	647	**34,39**	106,5	0,00	67,22	-	-	0,00	0,00	-
Sum			**36,02**								

- Data undefined due to calculation with octave data

Some attenuations are frequency specific and so cannot be listed in a table as above. However, if in the report setup the **Show frequency details** box is hatched, the Detailed results report will be expanded to include also each frequency. Alternatively use the Results to file option to dump the frequency based results.

Report Setup

Reports	Pages
☑ Main Result	1
☑ Detailed results	10
☑ Assumptions for noise cal...	1
☑ Curtailments	6
☑ Map	1

☐ Watermark | DRAFT

Report language

English

Preview	Settings...
PDF file	Print setup
Print	Result to file

Ok	Cancel

Table sort | **Select NSA objects**

☑ Show frequency details in report

Period selection: Worst period   ▾

Select NSA objects

☑ A - Noise sensitive point: User defined (45)
☑ B - Noise sensitive point: User defined (46)
☑ C - Noise sensitive point: User defined (47)
☑ D - Noise sensitive point: User defined (48)
☑ E - Noise sensitive point: User defined (49)
☑ F - Noise sensitive point: User defined (50)
☑ G - Noise sensitive point: User defined (51)
☑ H - Noise sensitive point: User defined (52)
☑ I - Noise sensitive point: User defined (53)
☑ J - Noise sensitive point: User defined (54)

Set All	Clear All

Noise sensitive area: A Dwelling 1

Wind speed: 8,0 m/s

WTG

No.	Distance [m]	Sound distance [m]	Frequency [Hz]	Calculated [dB(A)]	LwA,ref [dB(A)]	Dc [dB]	Adiv [dB]	Aatm [dB]	Agr [dB]	Abar [dB]	Amisc [dB]	A [dB]
1	1.353	1.356		25,80	106,5	0,00	73,65	-	-	0,00	0,00	-
1			63	17,74	88,5			0,14	-3,00			70,78
1			125	16,03	95,5			0,54	5,32			79,51
1			250	15,85	97,9			1,36	7,02			82,03
1			500	18,84	100,0			2,58	4,97			81,20
1			1000	21,73	101,1			5,02	0,66			79,32
1			2000	12,32	99,1			13,16	0,00			86,80
1			4000	-23,64	94,5			44,48	0,00			118,13
1			8000	-146,37	86,0			158,68	0,00			232,32
2	996	1.001		29,39	106,5	0,00	71,01	-	-	0,00	0,00	-
2			63	20,41	88,5			0,10	-3,00			68,11
2			125	19,07	95,5			0,40	5,06			76,47
2			250	18,84	97,9			1,00	7,02			79,04
2			500	22,15	100,0			1,90	4,97			77,89
2			1000	25,67	101,1			3,70	0,66			75,38
2			2000	18,40	99,1			9,71	0,00			80,72
2			4000	-9,37	94,5			32,84	0,00			103,86
2			8000	-102,22	86,0			117,16	0,00			188,17
3	640	647		34,39	106,5	0,00	67,22	-	-	0,00	0,00	-
3			63	24,24	88,5			0,06	-3,00			64,29
3			125	24,20	95,5			0,26	3,86			71,34
3			250	22,98	97,9			0,65	7,02			74,89
3			500	26,61	100,0			1,23	4,97			73,42
3			1000	30,78	101,1			2,39	0,66			70,28
3			2000	25,63	99,1			6,28	0,00			73,50
3			4000	6,04	94,5			21,23	0,00			88,45
3			8000	-56,99	86,0			75,72	0,00			142,94
Sum				36,02								
Sum			63	52,58								
Sum			125	41,94								
Sum			250	33,57								
Sum			500	31,64								
Sum			1000	32,34								
Sum			2000	25,35								
Sum			4000	5,17								
Sum			8000	-55,89								

The above tab in the report setup can also be used to select which time period to display in the Detailed results. As default the worst period is shown for each receptor, meaning that for each receptor WindPRO will decide whether to show results for day or night (or evening) depending on which result is most critical. Alternatively, all calculated periods can be listed.

In case reflection is included in the calculation the Detailed results will include the contributions from the secondary sources of the reflectors. Added to the primary noise, a secondary source for each relevant receptor is listed below the turbine. In the figure below Dwelling 1 is receiving noise from the secondary source obstacle A, the map showing the layout and with black lines the sound paths being reflected.

Calculation Results

Noise sensitive area: B Noise sensitive point: German TA Lärm - Unzoned countryside areas (16)

Loudest up to 95% rated power
WTG

No.	Reflection obstacle	Distance [m]	Sound distance [m]	Calculated [dB(A)]	LwA,ref [dB(A)]	Dc [dB]	Adiv [dB]	Aatm [dB]	Agr [dB]	Abar [dB]	Amisc [dB]	A [dB]
1		612	618	**39,66**	106,5	0,00	66,82	3,05	-3,00	0,00	0,00	66,87
1	A		713	**36,5**								
2		870	875	**35,86**	106,5	0,00	69,84	3,83	-3,00	0,00	0,00	70,67
2	A		949	**31,0**								
3		1.180	1.184	**32,43**	106,5	0,00	72,47	4,63	-3,00	0,00	0,00	74,10
3	A		1.243	**18,9**								
Sum				**43,16**								

Scale 1:20.000

人 New WTG   ⬟ Noise sensitive area

© Kort & matrikelstyrelsen
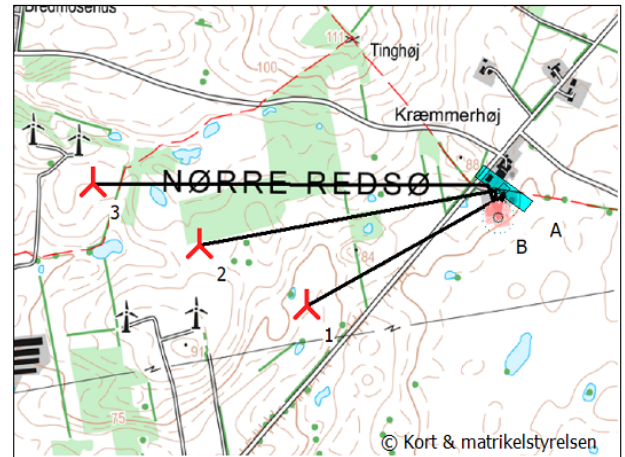
In case of Lden calculations, the Detailed results specify the day, evening and night contributions that make up the Lden for each turbine.

Noise sensitive area: A Noise sensitive point: Dutch - Dutch Lden (1)

Aggregated
WTG

No.	Distance [m]	Sound distance [m]	Lden(year) Calculated [dB]	Day [dB]	Wind speed [m/s]	Evening [dB]	Wind speed [m/s]	Night [dB]	Wind speed [m/s]	Cmet [dB]
1	355	365	**43,69**	38,64	7,5	37,72	7,5	36,98	7,7	0,00
2	611	617	**38,53**	33,47	7,5	32,56	7,5	31,82	7,7	0,00
3	1.024	1.027	**32,91**	27,83	7,5	26,93	7,5	26,21	7,7	0,39

Detailed results, graphics

For some calculation types a **Detailed results, graphics** section is added. This is done if either a range of parameters such as wind speed, wind direction, temperature or humidity are calculated or if a frequency spectrum is used as threshold. In the table the relevant parameters are listed with those wind speeds where the target is exceeded in bold.

The standard view will present graph with sound as a function of wind speed at the top, a graph of sound as a function of wind direction in the middle and in the bottom a graphic showing each wind speed and direction bin with the value of impacted noise level from the wind farm. Green color means the noise level complies with threshold in that bin, red color means threshold is exceeded.

If threshold is a function of ambient noise, the ambient noise curve as entered into the NSA is displayed in the top graph.

Period: Night
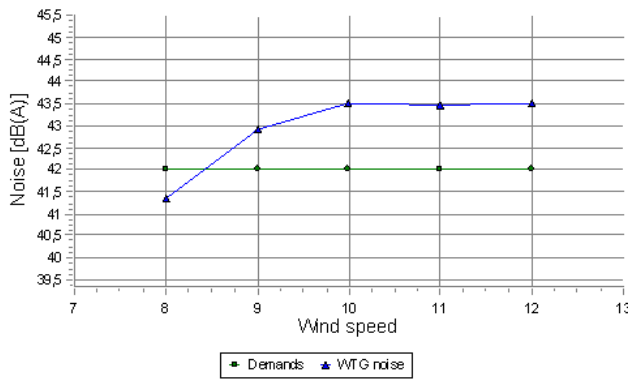
Sound level, Max impact Wind direction: 330 [°]

Wind speed [m/s]	Demands [dB(A)]	WTG noise [dB(A)]	Demands fulfilled ?
8,0	42,0	41,3	Yes
9,0	42,0	**42,9**	**No**
10,0	42,0	**43,5**	**No**
11,0	42,0	**43,5**	**No**
12,0	42,0	**43,5**	**No**

Calculated Noise vs direction and wind speed
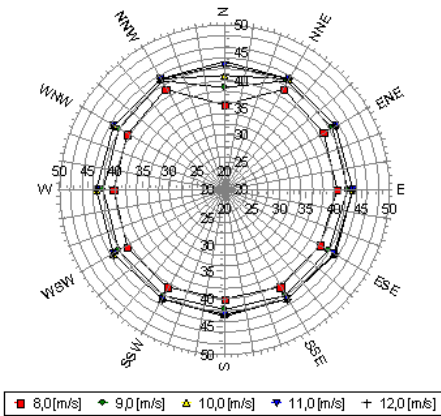
Sound level, Max impact Wind speed: 10,0 [m/s]

Wind direction [°]	Demands [dB(A)]	WTG noise [dB(A)]	Demands fulfilled ?
0	42,0	**43,5**	**No**
30	42,0	**43,5**	**No**
60	42,0	**43,5**	**No**
90	42,0	**43,4**	**No**
120	42,0	**43,2**	**No**
150	42,0	**43,0**	**No**
180	42,0	**42,9**	**No**
210	42,0	**43,0**	**No**
240	42,0	**43,3**	**No**
270	42,0	**43,4**	**No**
300	42,0	**43,5**	**No**
330	42,0	**43,5**	**No**

Calculated noise [dB(A)]

Wind speed [m/s]	\ Wind direction [°] 0	30	60	90	120	150	180	210	240	270	300	330
8,0	35,6	41,3	40,9	40,4	40,1	40,5	39,8	40,5	40,6	40,2	40,5	41,2
9,0	38,5	42,9	42,7	42,3	42,0	42,2	41,7	42,2	42,3	42,2	42,4	42,9
10,0	40,9	43,5	43,5	43,4	43,1	43,0	42,7	43,0	43,3	43,3	43,4	43,5
11,0	42,6	43,5	43,4	43,3	43,1	42,9	42,9	43,0	43,2	43,4	43,4	43,5
12,0	43,5	43,5	43,5	43,4	43,2	43,0	42,9	43,0	43,2	43,4	43,5	43,5

It is possible to add an extra page for each receptor with dimensions of your choice, as long as it was included in the calculation. This is done in the report setup tab for **Detailed result, graphic**.
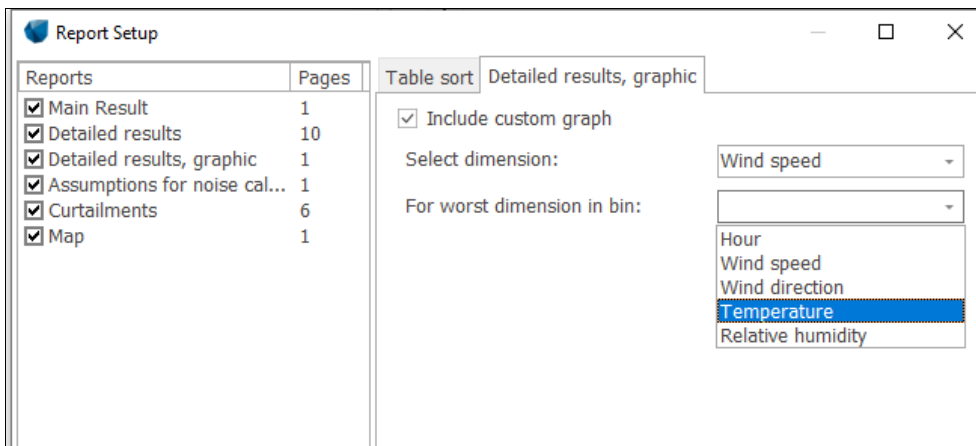
Below is shown a graph that includes ambient noise and the threshold as a combination of margin to ambient noise and an always accepted noise level (here 35 dB).

Noise sensitive point: British - British (5) (B)

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	27,0	5,0	35,0	30,1	Yes
5,0	28,0	5,0	35,0	33,8	Yes
6,0	29,0	5,0	35,0	37,3	**No**
7,0	30,0	5,0	35,0	39,1	**No**
8,0	31,0	5,0	36,0	38,7	**No**
9,0	32,0	5,0	37,0	38,3	**No**
10,0	33,0	5,0	38,0	38,0	Yes
11,0	34,0	5,0	39,0	38,0	Yes
12,0	35,0	5,0	40,0	38,0	Yes
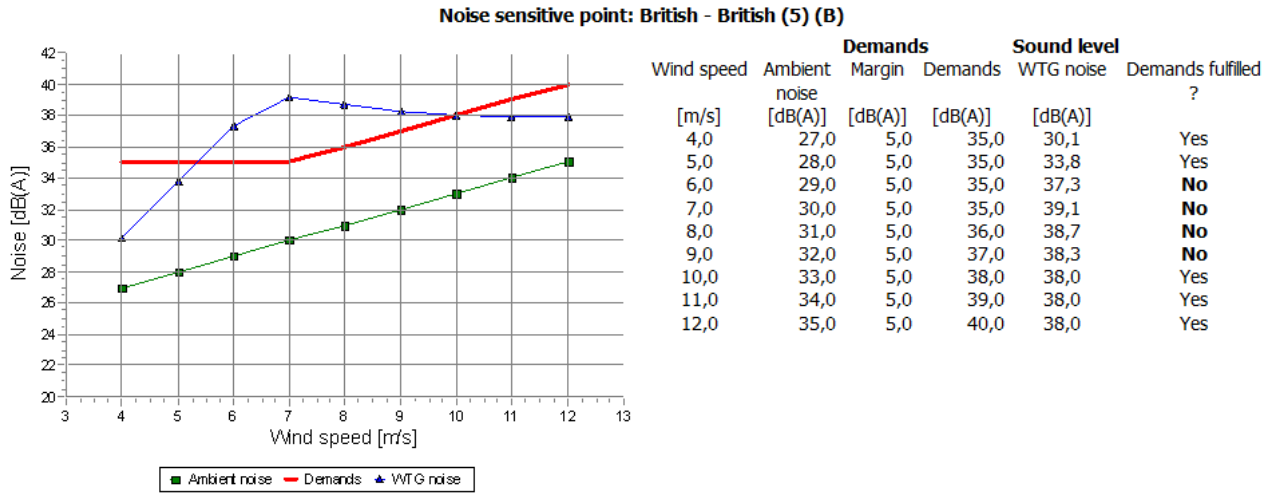
If the threshold is on the spectrum values, only the spectrum table is shown.

Below is an example with Finnish low frequency noise. Here the calculated result in green is compared to the target in blue.

B Noise sensitive point: Finnish low frequency - Residential health guide 2003, indoor - day (10)

Frequency	Sound level Demands	WTG noise	Demands fulfilled ?
[Hz]	[dB]	[dB]	
20,0	79,0	50,5	Yes
25,0	69,0	46,9	Yes
31,5	61,0	41,1	Yes
40,0	54,0	40,4	Yes
50,0	49,0	37,3	Yes
63,0	47,0	32,5	Yes
80,0	45,0	28,2	Yes
100,0	43,0	24,8	Yes
125,0	41,0	25,3	Yes
160,0	39,0	18,3	Yes
200,0	37,0	12,0	Yes
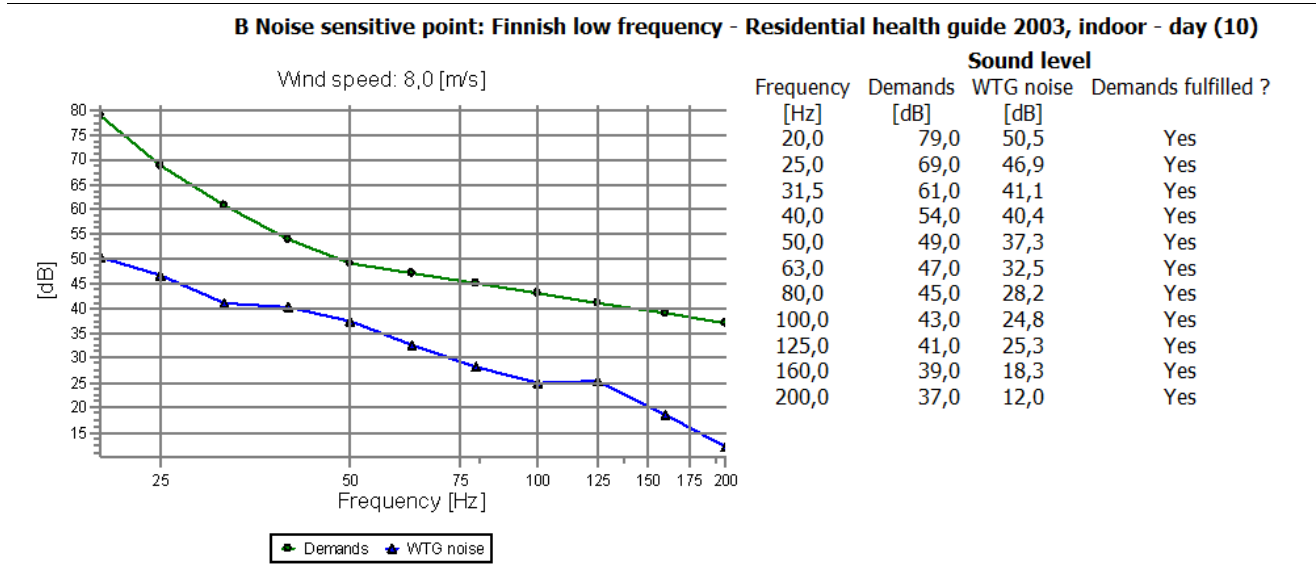
Assumptions for noise calculation
The Assumptions page will give a breakdown of the assumptions for the calculation. It is divided into three sections, the calculation parameters, the wind turbine parameters and the receptor parameters.

The calculation parameters lists all the parameters specific for the calculation such as air absorption values, ground attenuation parameters, noise insulation values, wind speed(s) etc.

For the wind turbines the source noise data are listed for each wind speed used. If octave band distributions are required, these are listed as well. This will include any notes from the wind turbine catalogue so if document references from measurement reports etc. is listed in the noted, they will appear on the on the Assumptions page.

In case of the Dutch Lden calculation the frequency of occurrence of each wind speed is listed in the table.

For the receptors, the noise target for each receptor is listed along with any other information relevant to the receptors.

Reflections details

If reflections were included in the calculation a Reflections details page is added. This lists all the obstacles / reflectors in the calculation with their dimensions and a calculation for each frequency to test if there will be a reflection contribution at that frequency. In the example below there is reflection from WTG 1 to NSA B via obstacle A in the frequency range 500 – 8000 Hz.

Noise sensitive area: B Noise sensitive point: German TA Lärm - Unzoned countryside areas (16)

From WTG: 1 via Obstacle: A

Frequency [Hz]	Reflection point Easting	Northing	lmin [m]	$\hat{I}^2$ [°]	ds,o [m]	do,r [m]	Check value	1/lambda	Used	rho
Common	554.229	6.284.593	10,0	24,78	650,4	62,6	1,39			1,00
63								0,18	No	
125								0,37	No	
250								0,74	No	
500								1,47	Yes	
1000								2,94	Yes	
2000								5,88	Yes	
4000								11,76	Yes	
8000								23,53	Yes	

Curtailments

If any of the wind turbines are equipped with a curtailment matrix, a curtailment section will be added. There will be a page for each turbine for each period.

The top section lists the relevant operation modes being used. Each are identified with a number. The octave distribution and information about uncertainty and tonality for these modes can be found on the Assumptions page. Mode -1 will always signify shut-down of the turbine.

Below is shown a wind speed vs. direction table. In each bin the operation mode is indicated by the identifier number of the operation mode and a color. If more than two dimensions are used, there may be more operation modes in use within the bin. In that case the highest and the lowest mode in the bin is listed. The color refers to the lowest, most curtailed, mode in the bin.

On the **Curtailment** tab in the report setup, it is possible to add a second table to get a different view of the operation modes of the turbine. The dimensions of both tables can be selected freely.

Report Setup

Reports	Pages
☑ Main Result	1
☑ Detailed results	10
☑ Detailed results, graphic	1
☑ Assumptions for noise cal...	1
☑ Curtailments	6
☑ Map	1

Curtailment

Turbines

☑ 1 - SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0 m (TOT: 15
☑ 2 - SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0 m (TOT: 15
☑ 3 - SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0 m (TOT: 15
☑ 4 - SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0 m (TOT: 15
☑ 5 - SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0 m (TOT: 15
☑ 6 - SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0 m (TOT: 15

[Select all] [Deselect all]

Select parameters for operation mode tables:

☑ First table:

Rows: Wind speed

Columns: Wind direction

☑ Second table:

Rows: Temperature

Columns: Relative humidity

☐ Watermark DRAFT

Report language

English

[Preview] [Settings...]
[PDF file] [Print setup]
[Print] [Result to file]

[Ok] [Cancel]

DECIBEL - Curtailments

Calculation: Site: 3 - Strategy: 1

Period: Night

Curtailment details for: SuperWind SW-3.3-112 3300 112.0 !O! hub: 94,0 m (TOT: 150,0 m) (16)

Operation modes used for curtailment

ID	Name	Remark
-1:	Shut down	
0:	Noise Mode 0	Noise curve based on hub height wind speeds
1:	Noise Mode 1	Noise curve based on hub height wind speeds
2:	Noise Mode 2	Noise curve based on hub height wind speeds
3:	Noise Mode 3	Noise curve based on hub height wind speeds
4:	Noise Mode 4	Noise curve based on hub height wind speeds

Each cell in the operation mode table(s) below denotes the least and most restrictive noise mode across all bins. The listed wind speeds are at hub height.

Wind speed

Wind direction [°]

[m/s]	0	30	60	90	120	150	180	210	240	270	300	330
7,0	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2
8,0	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2
9,0	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 2	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3
10,0	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3
11,0	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3
12,0	0	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3
13,0	0	0	0	0	0	0	0	0	0	0	0	0

Temperature

Relative humidity [%]

[°C]	10	20	30	40	50	60	70	80	90	100
-20	0 - 3	0 - 2	0 - 2	0 - 2	0 - 1	0 - 1	0 - 1	0 - 1	0 - 1	0 - 2
-10	0 - 2	0 - 1	0 - 1	0 - 1	0 - 1	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2
0	0 - 1	0 - 1	0 - 1	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2
10	0	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2
20	0 - 1	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2
30	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2
40	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2	0 - 2

Map

One or more maps will be included to display the extend of the noise from the wind farm. See section 6.1.3.1. Note that some calculation models cannot produce a map, such as the Finnish low frequency model.

Result to file
Both from the **print setup** and by right-clicking the calculation headline it is possible to select **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. Note Noise detail with frequency data. This will give a complete breakdown of the calculation by frequency and is very convenient for postprocessing the results of the calculation.

The curtailment result-to-file produces the files the **Noise Matrix Analyzer** can read as a curtailment plan.

6.1.3.4   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 your excess wind speeds. You will also only be able to use a single time period or the Loudest across periods option.

When you run the calculation windPRO will now produce a Result layer on the maps in Maps and Objects. Whereas 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.
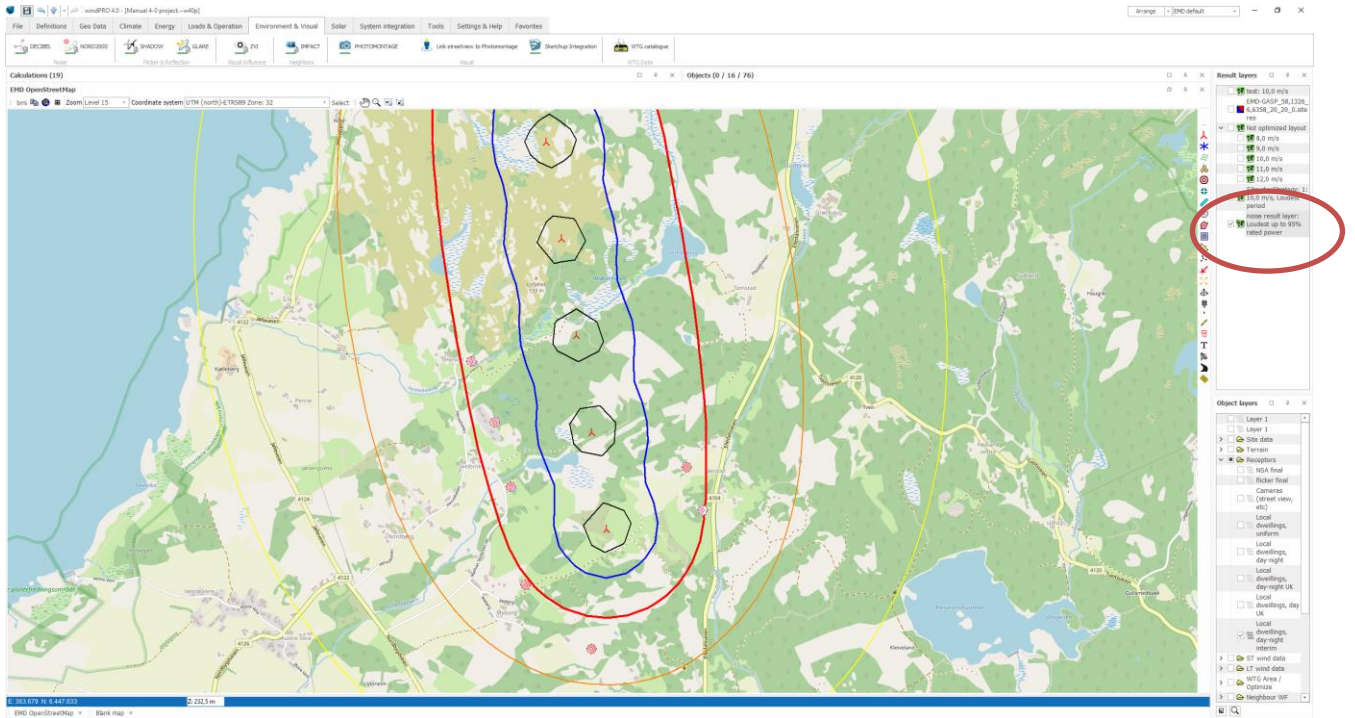
In the illustration note the result layer in the top right.

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 recalculation 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 some 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.
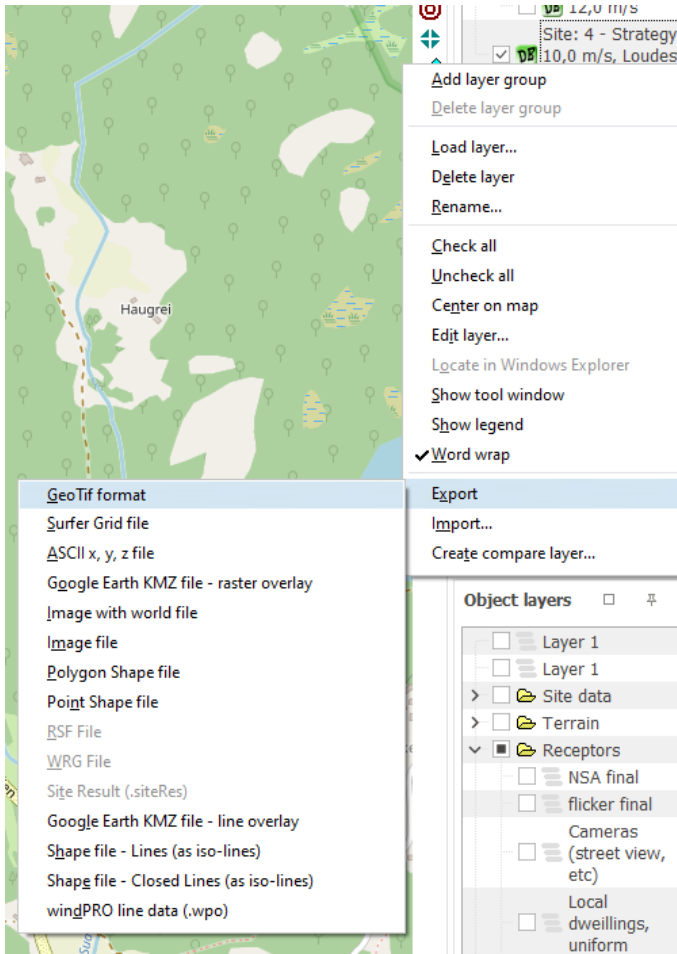
6.1.3.5 Noise allowance map

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.
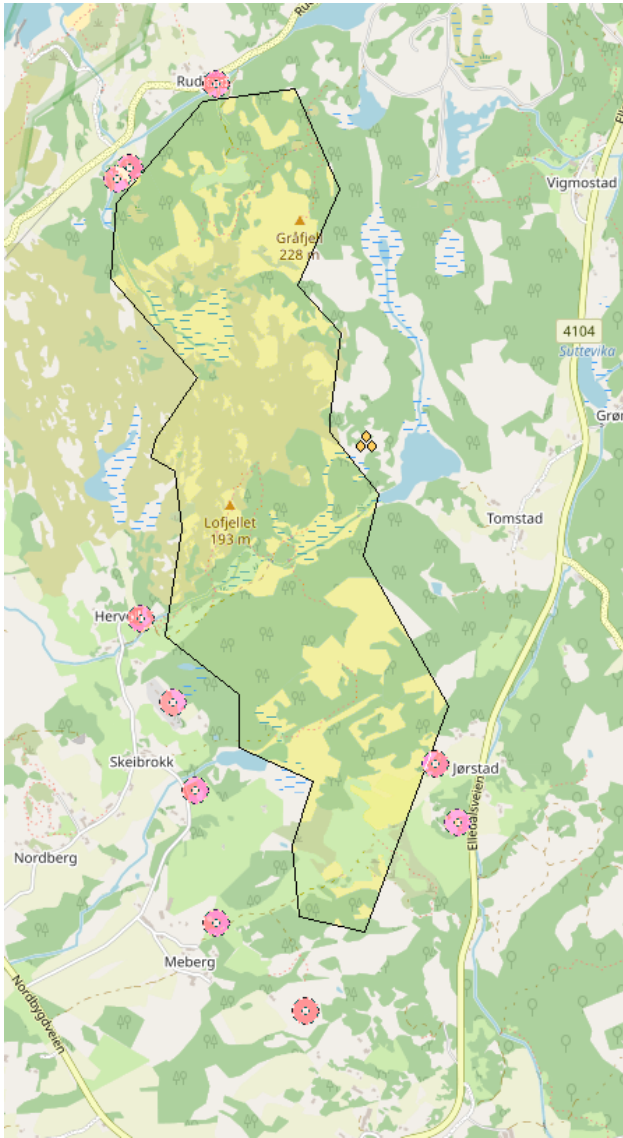
The Noise allowance map calculation is selected on the main tab when running a Decibel calculation.
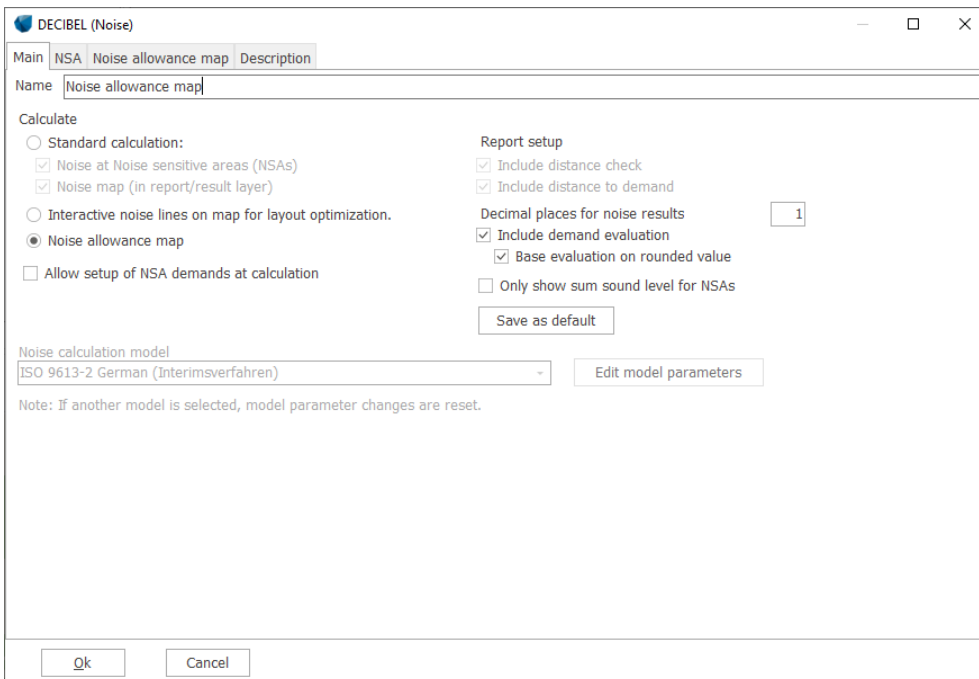
Note that the calculation model is disabled.

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 check the box for **Show result in a result layer on the working map**. Otherwise the map will only be shown in the calculation report.
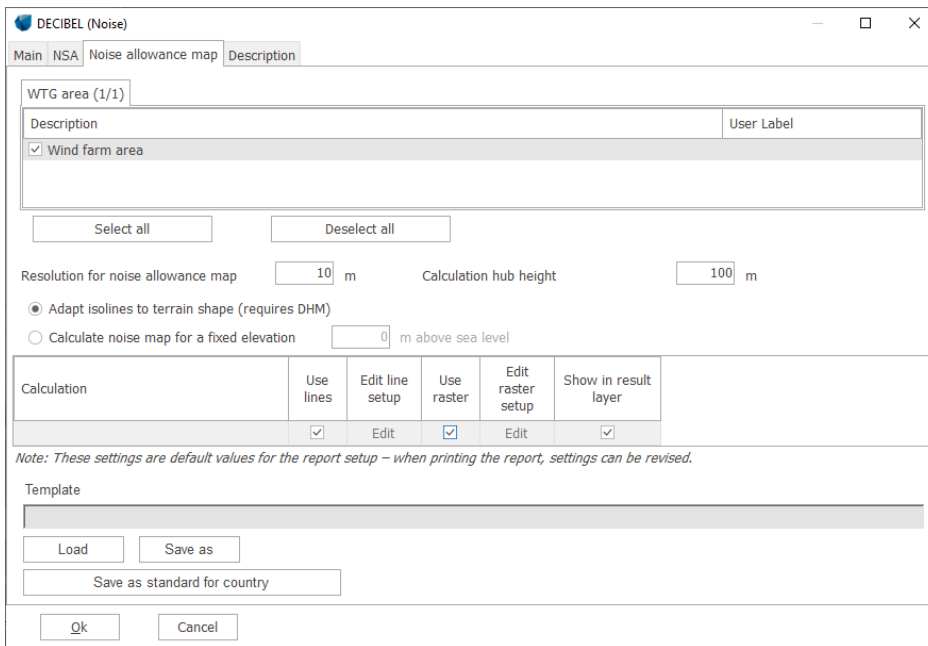
The resulting map is shown below in Maps and Objects. Right-clicking on the Result layer gives access to a legend.
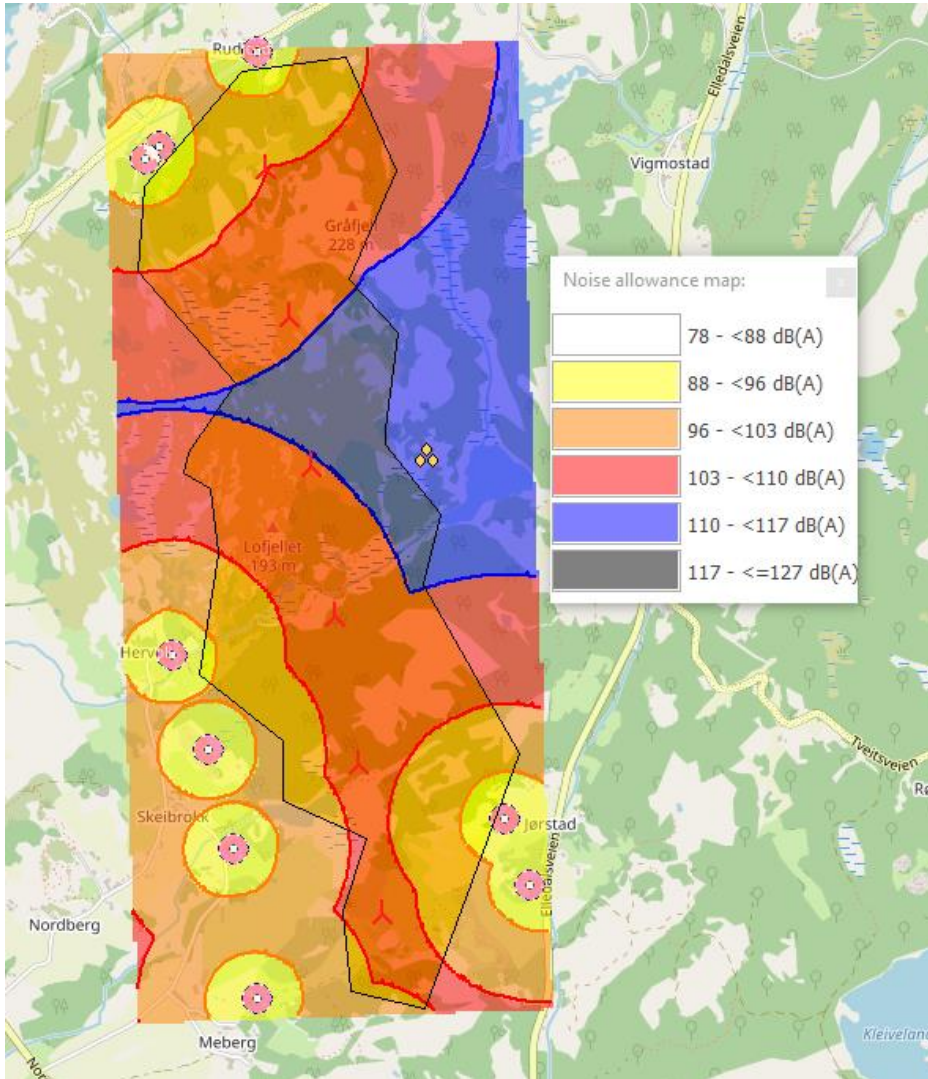
The map shows in a color code how much noise (L$_{WA}$) a turbine will be allowed to make depending on location.

6.2 SHADOW – Flickering

6.2.0 Introduction to SHADOW

SHADOW is the windPRO calculation module that calculates how often and at which times of day 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 position of the Sun relative to the WTGs). Shadow impact may occur when the blades of a WTG interrupt the Sun's rays seen from a specific location (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 be 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 presenting the iso-lines of the shadow impact can also be printed. This printout will render the amount of shadow impact for any location within the affected 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.

As suggested in the guidelines, the atmospheric refraction is not considered in the calculation of flicker impact.

The limits of shadow impact for a neighbor to a wind farm according to the German guidelines are:
- a maximum of 30 hours per year of astronomical maximum shadow (worst case);
- a maximum of 30 minutes per 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 (PPG for England, TAN8 for Wales, SPP for Scotland). In both the Republic of Ireland and Northern Ireland (PPS18), a worst-case limit of 30 hours per year, 30 minutes per day 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 on an individual basis.

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

When the maximum allowed or recommended shadow flicker time at a dwelling is exceeded, a curtailment strategy is generally defined to decrease the shadow impact. This curtailment can be taken into account in the calculation of the shadow flicker time.

As with 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.

Finally, besides the SHADOW module, note that SketchUp Integration module allows to easily export the wind turbine layout and simulate an animation of the shadow flickering in SketchUp software. For more details, see Section 7.3 and this tutorial video:
https://www.youtube.com/watch?v=fhO1gj3xwpg&list=PL6zroSoHTqaNZw8Pd7749w8cZSKYshOxY&index=10

6.2.1   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.
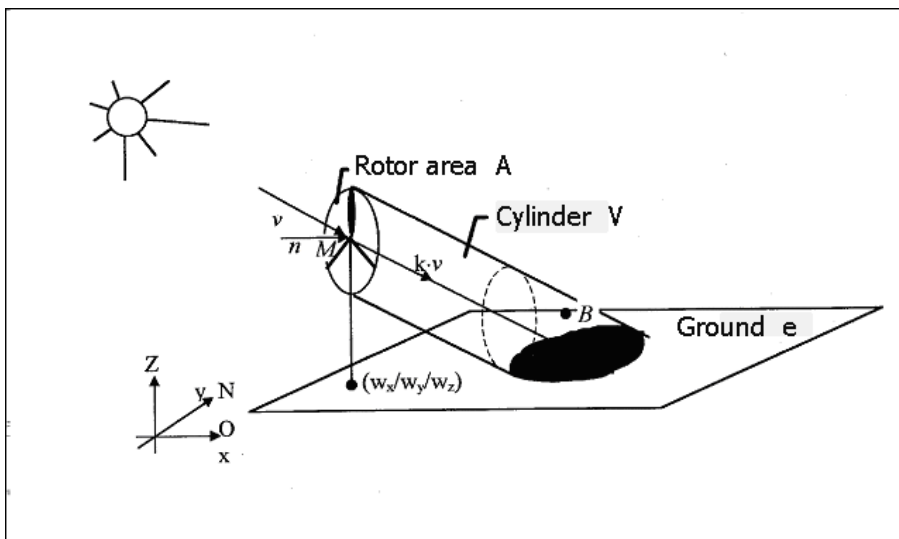
6.2.1.1   The SHADOW Calculation Model

In the shadow calculation model used by windPRO the following parameters define 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 6.2.0). The default distance in windPRO is 2,5 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 (calculated as the average between the blade width at 90% radius and the maximum blade width). 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.
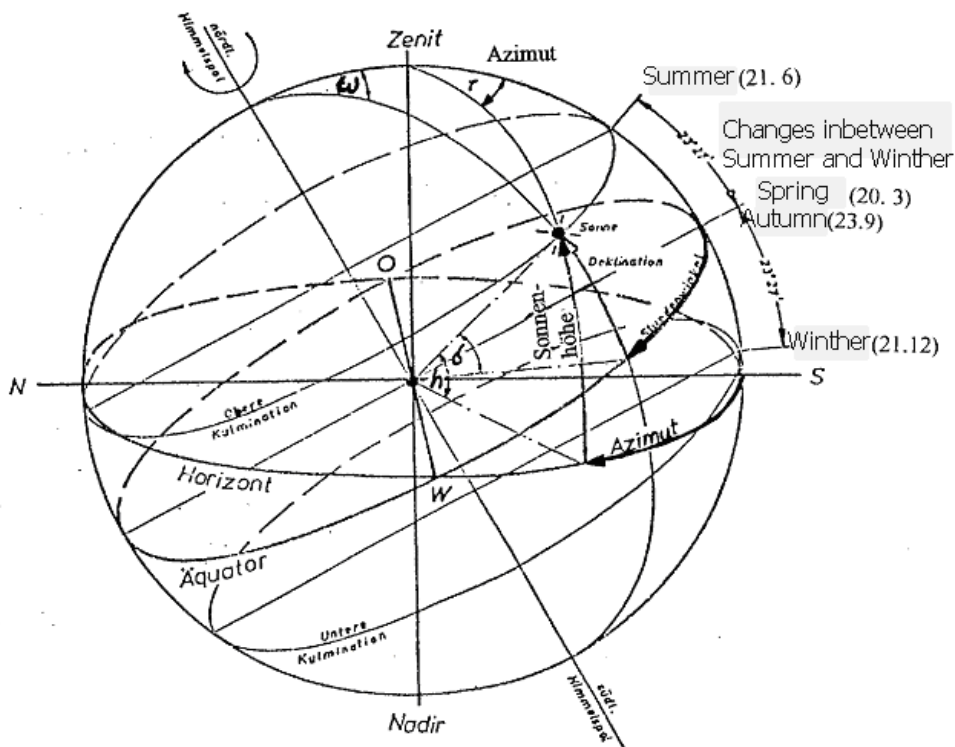
6.2.2 Entering Data for Shadow Flickering Impact Calculation

First of all, a background map is required, although a blank map can be used.
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 object by holding down the <shift> key while selecting an object. This function will allow you to enter multiple objects with the same properties (e.g. shadow receptors).

6.2.2.1 Entering WTGs

(See Chapter 2. BASIS, Section 2.5.2)

6.2.2.2 Entering Shadow Receptors

Shadow Receptors are objects for which the potential time of shadow flickering 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. The object opens on the Window tab, where all the input specific to shadow receptor can be defined. A shadow object can also be used for a PV Glare calculation (see 6.6.3.2).

Shadow/Glare receptor (Shadow Receptor: 1.0 × 1.0 Azimuth: 0.0° Slope: 0.0° (2))

Position | Layers | **Shadow** | Glare | Description

☑ Use for Shadow Calculation

Flicker receptor input
- ◉ Defined from center
- ○ Defined from one or more corners
- ○ Defined from the map (flat area only)

☐ "Green house" mode, window is perpendicular to all WTGs

		☑ Synchronize Shadow and Glare angles
Degrees from south clockwise	0.0 °	
Height of window	1.0 m	
Width of window	1.0 m	
Bottom line height above ground	1.0 m	
Slope of window	90 Vertical (Normal window) ▾	
User defined slope	0.0 °	

Ok | Cancel | Prev | Next | Save as default | Clear default

A Shadow receptor is represented as a surface such as a window, a garden …The main parameters are:

- The directional orientation relative to south (in degrees, positive, westwards)
- The shape and size of the surface (**height** and **width**, or polygon)
- The **bottom line height above the ground** which is the height of the "window" or surface above the ground level
- The tilt or slope of the window relative to horizontal (you can choose between vertical, flat, roof window [45°] or any user defined value).

The surface can be defined from its center, from one or more corners or from hand digitalization on the map (for flat areas only).

Shadow/Flicker receptor **defined from the center** applies to rectangular surfaces, the center of which refers to the coordinates of the object. The coordinates of the shadow object are defined on the Position tab or manually on the map.
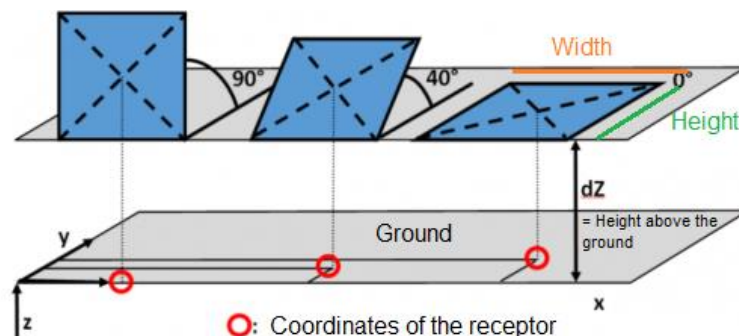
Coordinate of the receptor for different inclination of window/surfaces

The **degrees from south clockwise** parameter indicates the orientation of the surface, or into which direction it is pointing at. Alternatively, the **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 may contribute to the flickering impact. The check box **Synchronize Shadow and Glare angles** is only relevant if the object is used both for a Shadow and a Glare calculation. Then the change in the angle from the Shadow or the Glare tab will be updated accordingly on the other tab. For Glare calculations, see 6.6.

The default parameters of 1m height and 1m width window, 1m above the ground level can be considered as a standard description of typical windows.

In the case of a receptor defined with a direction (not greenhouse), The orientation can also be defined from the map. This is done by clicking on the icon on the map. Unlike other windPRO objects where the selected object is shown by a square in its center, the shadow receptor also has a diamond just below.

Once selected, the orientation of the window can be varied by putting the cursor on the diamond 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", flat side of the shadow receptor icon is the outward-facing side.

Shadow/Flicker receptor **defined from one or more corners** applies to rectangular surfaces for which the coordinates of one or two corners are known, typically after measurements on site.

Having the coordinates for only one corner, all parameters of direction, height, width and slope will be required and must be ticked and defined. By default, corner C (the bottom left corner as shown on the image above) is defined from the coordinates of the object. To input the coordinates of another corner than C, deselect C and select A, B or D corner.

To be able to define the receptor with two corners, one of the parameters of orientation (degrees from south direction), height or width must be deselected.
The input of two corners will allow windPRO to deduct one or more parameters among the orientation (degrees from south direction), height, width and/or slope. This (or these) parameters will turn grey and will not be editable any longer.

Clicking on **Fill** will have windPRO to fill in the information of coordinates and parameters that can be calculated.

The message **Missing selection**s appears when an information of coordinates or parameters is missing.

The height of the window above the ground can be defined from the bottom or from the top of the window. The input can be made in two different ways:
as **Top/Bottom elevation a.g.l. (above the ground level)** or as **Top/bottom elevation a.s.l. (above the sea level)**. Top or bottom elevation a.s.l. is the equivalent to the z coordinate of the corner.

Tip: the option **Defined from one or more corner** can be used together with control point and excel to measure and input the width of a façade for example in a Shadow receptor. To do so, mark the corners of the façade with two control points. Copy and paste these to excel.

	C	D	E	F	G	H	I
	ystem lab	Object ID	Easting	Northing	Z	Object des	User labe
	126	CtrlPoint	541995	6307242	47.9		
	127	CtrlPoint	542020	6307259	49		

Copy both eastings and Northing for one control point and use **Paste (both eastern and Northern if available on the clipboard)**. Repeat for the second control point:

Shadow/Flicker receptor **defined from the map (flat area only)** applies to rectangles or polygons but only as flat areas. This option is typically used for gardens that can be digitized manually from a map such as an aerial photo.

To defined from the map, the **Edit** button must be selected. In the case of a Rectangle, the area is defined on the map by moving the red squares. To rotate the rectangle, drag one of the corners. The parameters of the rectangle can also be defined by the input of height, width and angle (degrees from south clockwise). If **Fixed size** is selected, only the angle can be changed on the map. In the case of Irregular shape, points can be moved individually. To add a point, right click on the outline of the polygon. To remove a point, right click on the point.
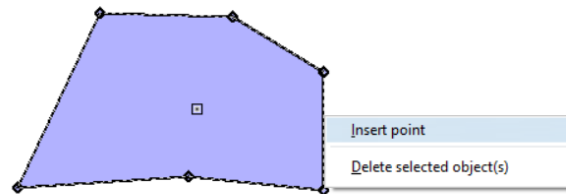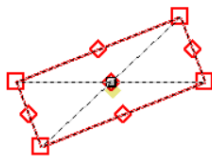
Once the OK button of the small selection window is clicked, the coordinates of the points defining the area are listed in the table. For irregular shapes, points can be added, deleted and copied/pasted to/from clipboard. The

Update button is used to update the coordinates of the points of a rectangular shape, when the width or the height is modified in the form.

Elevation above ground level refers to the elevation of the flat area used in the calculation. It is added to the z coordinates of each points constituting the surface as long as a digital elevation model is loaded.

Note that for a shadow receptor defined from the map (flat area only), the ZVI calculation is more detailed. Only the points (in 1m grid) of the area from which a turbine is visible are considered.

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.

6.2.3   **SHADOW Calculation**

A SHADOW calculation is started from the Environment & Visual tab of the ribbon.
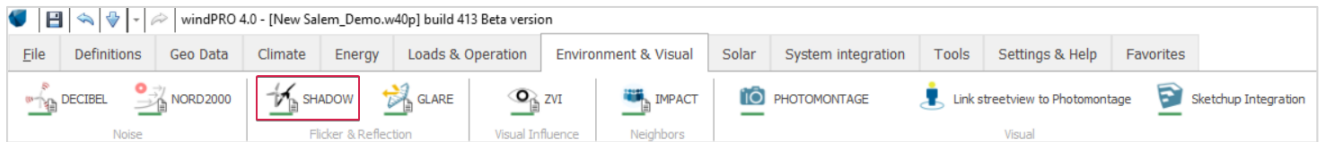
If the bar below the icon is green, it is possible to perform a calculation. If it is yellow, license for the module is needed.

Once selected, you can setup the calculation, as described below.

6.2.3.1   Calculation Setup

Main tab

This is the tab where the type of calculation(s) is/are selected.

It is possible to choose two main types of calculation:
- Shadow flicker at the shadow receptors, including flicker curtailment or not
- A shadow flicker map

The two calculations are not mutually exclusive. It is possible to calculate one or the other or both. However, when including flicker curtailment, it is not possible to calculate the corresponding flicker map.

Flicker curtailment can be defined in two different ways:
- According to a specified plan, where the start and stop time of each turbine can be defined specifically
- By stopping specific turbines, where a given turbine is totally stopped to avoid any shadow flicker at a given receptor.

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.

SHADOW (Flicker)   —   □   ✕

Main | WTGs | Receptors | ZVI | Description

Name Shadow flickering calculation

Calculate:

☑ Flicker at receptors   ☐ Flicker map
    ☑ Worst case   ○ Worst case
    ☐ Real case based on statistics   ○ Real case based on statistics
    ☐ Real case based on time series (Experimental)

☐ Flicker curtailment
    ○ According to specified plan

    ○ By stopping specific turbines. (Only after a calculation)

Info about difference between worst case and real case:
Worst case assumes sun always shining (from sun rise to sun set), turbine always running and rotor oriented perpendicular to neighbour.
Real case uses statistical/calculated values.

☑ Advanced settings (by default the "normal accepted settings" will be used)
    ☑ Limit distance according to blade width   Limit the distance in which flicker is still considered relevant by
                                                       using blade width data from WTG catalogue to calculate
        ● Fixed distance: 2,500 m from WTG   shaded area (more than 20% of the sun covered by blade). If
        ○ First distance circle of WTG (If ellipse: Major axis is used)   no blade data is available, the option selected below the check
        ○ Second distance circle of WTG (If ellipse: Major axis is used) box is used.
        ○ No limit

    Flicker is ignored if sun is less than   3.0 ° above horizon (due to atmospheric diffusion/low irradiance/sheltering)
    ☐ Set reference year

    Ok   Cancel

According to the German guidelines described in Sections 6.2.0 and 6.2.1.1., shadow flickering is only an issue up to distances where at least 20% of the Sun's disk is covered by the blade. So, the maximum distance considered in the calculation is based on the blade width, with the option **Limit distance according to blade width** selected by default. Beyond this maximum distance, the turbine will not contribute to the flickering impact. The calculation uses the average value of the blade width at 90% radius (from the root of the blade) and the maximum blade width (entered in the WTG catalogue for the particular turbine type, as shown on the next figure). The calculated maximum distance is shown on the Result main page of the Shadow report (see 6.2.4).

As an alternative, or if there is no blade width data for the specific WTG, the maximum distance can either be given by typing a fixed maximum distance (by default 2500 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 6.2.0.

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 6.2.0.

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 or elevation grid object with height contours or gridded height data. Area objects defining blocking elements like forests or villages and obstacles (with a porosity between 0 and 0.3) may also be included if such effects are permitted under local regulations.

For receptors, the visibility is calculated from the top of the window or, for flat areas, from the height above the ground level. For shadow maps, the height above ground for the observer is the Eye height, set on the ZVI tab. The grid resolution for the ZVI calculation is 1m (from windPRO 3.2 version).

For more information on the ZVI calculation see Chapter 6.3.

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 exists, the result of the shadow flicker from the turbine will be zero. Calculation time is increased with this option. See explanation in graphics below.

If you are certain that there are no barriers between the wind turbines and the receptors, you can **Deactivate line-of-sight calculation**. This will abort the ZVI calculation and significantly speed up the calculation time.
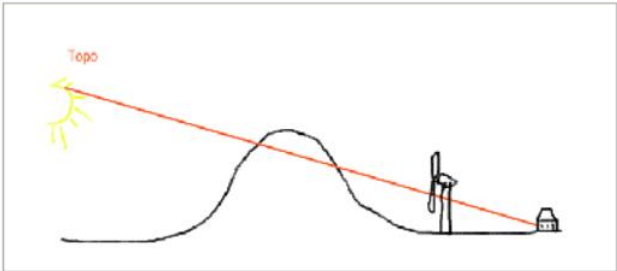
Real case based on statistics
It is also possible to add a real case calculation to the shadow flicker calculation. This gives access to the additional tab: Real case statistics. This takes the standard worst case calculation and applies reduction factors of probability to account for the effects of sunshine and operational hours by sector.

SHADOW (Flicker)   —   □   ✕

Main | WTGs | Receptors | Real case statistics | ZVI | Description

Name [   ]

Calculate:

☑ Flicker at receptors   ☐ Flicker map
  ☑ Worst case   ○ Worst case
  ☑ Real case based on statistics   ○ Real case based on statistics
  ☐ Real case based on time series (Experimental)
☐ Flicker curtailment
  ○ According to specified plan

  ○ By stopping specific turbines. (Only after a calculation)

Info about difference between worst case and real case:
Worst case assumes sun always shining (from sun rise to sun set), turbine always running and rotor oriented perpendicular to neighbour.
Real case uses statistical/calculated values.|

☐ Advanced settings (by default the "normal accepted settings" will be used)

[Ok]   [Cancel]

Three reduction factors are used for the real case:

- Operation time reduction, calculated as the ratio between the total operational hours and the total number of hours in a year. This factor is constant within the year and for all turbines.

- Wind direction reduction, calculated for each pair of receptor-turbine. It is using the ratio between the area of the projected rotor disc onto a plan at a given direction (=center of sector) and the full rotor disc. The ratio is then weighted by the frequency of operation at the given direction (available through the directional operational hours input). Since the factor is turbine dependent, in the case where several turbines give simultaneously shadow flicker at a given receptor, a weighted average is calculated between the reduction factor of each turbines.

- Sun reduction, calculated for each month as the ratio between the average daily sun hours and the average total daily hours. This factor monthly dependent but constant for all turbines.

The number of flicker hours for real case based on statistics is finally calculated from the worst-case result multiplied by the product of the three reduction factors. The three factors for real case calculation can be seen for each month on the calendar page.

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

Operational hours statistics: The number of hours that the WTG will be in operation in the different wind direction sectors during the year. It is used to calculate the operation time reduction and the wind direction reduction. For a given number of sectors, windPRO divides 360° by the number of sectors and centers the first sector to the north. Furthermore, it assumes for every sector that the wind comes from the center of the sector.

When an energy calculation based on wind statistics has been prepared in the same project, it can be linked to the calculation (through the site data object set for WAsP calculation). A Meteo object can also be linked to the calculation. In this case, the operational hours are calculated applying the Weibull distribution and a shear factor to each turbine. The operational hours are calculated starting at a wind speed equal to the cut-in wind speed minus 1 m/s until the "stop wind speed" as entered in the catalogue. 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.

The operational hours statistics can also be typed manually or loaded from a template. Demonstration templates are available from Denmark and Germany.

If other wind farms are included like an existing wind farm, be aware that the calculation will return the average operational hours of all turbines. This might lead to a lower impact from "old/existing" turbines when calculated together with new turbines rather than without the new turbines. The operational hours are indeed dependent on the cut-in wind speed which is lower for new/modern turbines than for old/smaller turbines. By changing the idle start wind speed, the operational hours can be calculated assuming the same "start" wind speed for both "old" and new turbines.

It is possible to run the real case calculation without Operation hours by selecting **No operation reduction**. Consequently, no operational nor wind direction reduction factor will be applied, only sun reduction.

To simulate that the wind is distributed evenly over all directions and thus avoiding the impact of directional reduction, the total number of operational times shall be divided by the number of sectors and used for each sector.

To simulate that the wind comes from a specific direction all the time, then set the sector from which all wind comes to 8760 (=full year), and all other sectors to 0.

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 sunshine data. The sunshine statistics are displayed graphically in the lower diagram. Not every station has sunshine statistics, so check your chosen station before confirming.

Flicker curtailment
When Flicker at receptors is selected (either for worst case and/or real case based on statistics), it is possible to combine it with a flicker curtailment strategy. This way, the final flicker time calculated will take into account the stops defined at given turbines.
Two types of flicker curtailment can be selected:
- According to a specified plan, where the start and stop time of each turbine can be defined specifically
- Or by stopping specific turbines, where a given turbine is totally stopped to avoid any shadow flicker at a given receptor.

Depending on the type of curtailment chosen, a new tab is available for input.

Curtailment according to specified plan
The curtailment plan is defined by turbine, day by day with a start and end time. It can be input manually by clicking on **Add a line** or it can be imported from the clipboard with **Import**.

WTG		Date [dd/mm]		Start	End
WTG1	▾	07/12	▾	08.20	08.35
WTG2	▾	08/12		07.47	07.55
WTG1	▾	08/12		08.22	08.30

Add line   Remove   Paste

Ok   Cancel

The import of data for flicker curtailment is done via the clipboard. The source of the data has to be defined so the data can be loaded correctly from the clipboard.

The first option of source is the windPRO result to file – Periods per WTGs, from an existing Shadow calculation. This result to file contains each time step (in a resolution of 1 min) for which shadow flicker is generated (worst case) together with the information of the responsible turbine. The result to file should be copied to the clipboard before starting the new shadow calculation with flicker curtailment. In order to copy the result to file to the clipboard, right-click on the existing shadow calculation select **Result to file** and **Copy to clipboard** the result for **Periods per WTG**. The data is then available on the clipboard to be used in the Import function of the flicker curtailment according to a specified plan.

The second option for the source of curtailment consists of a general list that would typically be defined in Microsoft Excel or a similar spreadsheet package. This list should contain three columns: WTG ID to identify which turbine is concerned and Start and End of flicker curtailment (date and time). It is then necessary to define how the WTG ID from the list should be recognized by windPRO or, in other words how to link the WTG defined in the list with the selected WTG of the current shadow calculation with flicker stop. The three columns should be copied from Excel and the content of the clipboard can be checked in the bottom part of the window. Once it is imported, it is possible to edit the lines manually or to remove some lines.

Curtailment by stopping specific turbines

With this option, the curtailment of the turbine(s) is defined by stopping turbine(s) for all the shadow flicker events calculated at a given receptor. In this way the contribution from the selected turbine(s) to the total shadow flicker at a given receptor will be reduced to 0. If a shadow calculation without curtailment is calculated at first, it is possible to reuse it (or clone it) in order to include the information about the amount of flicker time each turbine gives at each receptor. This allows an examination of the impact of stopping a turbine in the total amount of flicker remaining at the given receptor (if any) and thereby to select which turbine(s) to stop in order to comply with the maximum allowed flicker time.

The tab for curtailment by stopping specific turbines consists of a table from which the combinations of wind turbine and receptors are selected. The receptors and turbines displayed in the table are the ones selected in the calculation setup. A check mark in a given cell implies that the calculation of shadow flicker will consider a total stop of the given turbine whenever it is supposed to give shadow flicker at the given receptor.

The curtailment can be made according to the results from the worst or the real case calculation. The result shown are Shadow hours/year [hh:mm], Shadow days/year [days] and/or max shadow days/year [hh:mm]. The information shown in the cell refers to the calculated time in the original SHADOW calculation (available only for recalculation or clone of calculation). If several types of result (Shadow hours/year, Shadow days/year and/or max shadow days/year) are selected, they will all be shown in the same cell but separated by /.
It is possible to show the Description or user label or the WTG(s) and receptor(s) by selecting the ID type.
Update total can be checked to have the net flicker time calculated at a receptor resulting from the stop of the selected turbine(s) in the table. This option requires that the current shadow calculation is a recalculation of a Shadow calculation or a clone of it. The concurrent periods of shadow flicker from several turbines are excluded, so that the total refers to the net time and does not count overlapping periods twice. This has the curious effect that stopping a wind turbine in relation to one receptor sometimes has an effect on other receptors.

Real case based on time series
It is possible to use actual observed sunshine and wind condition observations to get to a closer estimate of 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.

The input is made on the tab **Real case time series.**

Wind speed, wind direction and sunshine data must be provided in one WTI file (see Section 3.3.3.4) or one height from a METEO object (see Section 12). The **View** button will show the content and some statistics on the file including an evaluation of the suitability of the data. A WTI file with Sun data is available as an example in the folder WindPRO data/Standards.

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

Signal used for sunshine relates to the signal the selected WTI file or Meteo height holding the parameter indicating if the sun is shining and shadow can occur.

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.

Mean wind speed in hub height for all WTGs is used to scale the wind speed data from the WTI file or Meteo height. The WTI file or Meteo height gives indeed the relative variation in wind speed throughout the period analyzed. In order to get the correct absolute values, the relative values must be scaled with the mean wind speed of the wind turbines.

Idling time can also be defined, so that flicker impact can be considered for lower wind speeds that the cut in wind speed from the power curve.

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 default shadow receptor here is a horizontal 1 x 1m 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.
The flicker map cannot be calculated if flicker curtailment is defined.
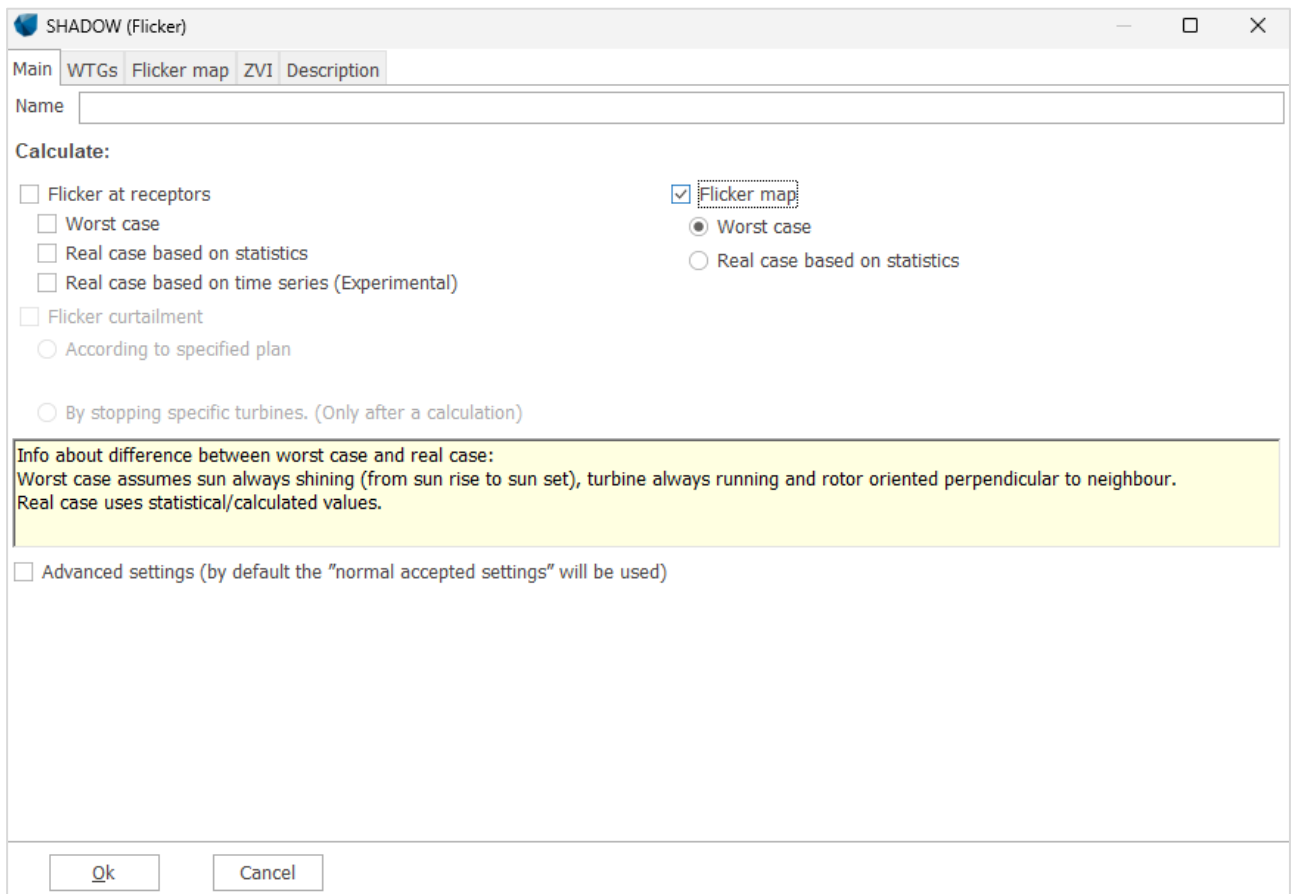
Selecting the Flicker map option enables the flicker map tab.

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/elevation grid object (plus eye height from ZVI tab). The latter is more correct, and should always be used if the heights vary by 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 seconds. 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 included 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 shadow minutes per day.

Three kinds of map reporting are possible:
- Show lines in report, creating a page with shadow 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 shadow 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 required and then define the shadow 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 previously-saved 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.

If the last column is checked windPRO will produce a Result layer object (this is checked by default).

6.2.3.2   SHADOW - Calculation

The calculation starts automatically when you press OK in the calculation setup. Please note that the calculation may take some time depending on the setup parameters (especially the map extend and resolution).

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.

6.2.4   SHADOW – Results/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/viewed. By default, the maps are also shown as result layers on the map.

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).

Click on the checkbox to the left of each page to select/deselect that page. By clicking on the report page 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 as raster

The different result pages produced with a SHADOW calculation are described below:

1. Main result

This shows the results for astronomical maximum shadow (Worst case) or statistical real shadow impact at each shadow receptor The results are also 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.
If flicker curtailment is defined, specific columns will be added to the results showing the avoided shadow flicker time.
In the table presenting the WTG input, the calculated distance refers to the maximum distance between the turbine and each receptor after which the flicker is not considered. By default, this distance is calculated from the blade width such as at least 20% of the sun disc is covered by the blade.
In the table presenting the receptor input, the eye height refers to the height at which the visibility of the turbines is calculated. The eye height corresponds to the top of the window or, for flat areas, the height above the ground level.

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 identifying 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. Calendar graphical

Showing when (hours, days and months) and from which WTGs flickering problems may 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. Flicker curtailment calendar (when selected)

Showing when (hours, days and months) the WTG is planned to be curtailed.

7. Flicker curtailment protection (only for curtailment by stopping specific turbines)

Showing which receptor is protected from the shadow flicker created by a given turbine.

8. 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.

Finally, with the Result to file option, data from the calculation can be exported: the calendar results as .txt files for other presentation or further calculations (imported into a spreadsheet), shadow map iso-lines as .shp (shape) files for use in GIS systems, the properties of the wind turbines used in the calculation…This option of Result to file is accessible from a right-click on the header line of a completed calculation or from the setup window of the results (right-click, Print).
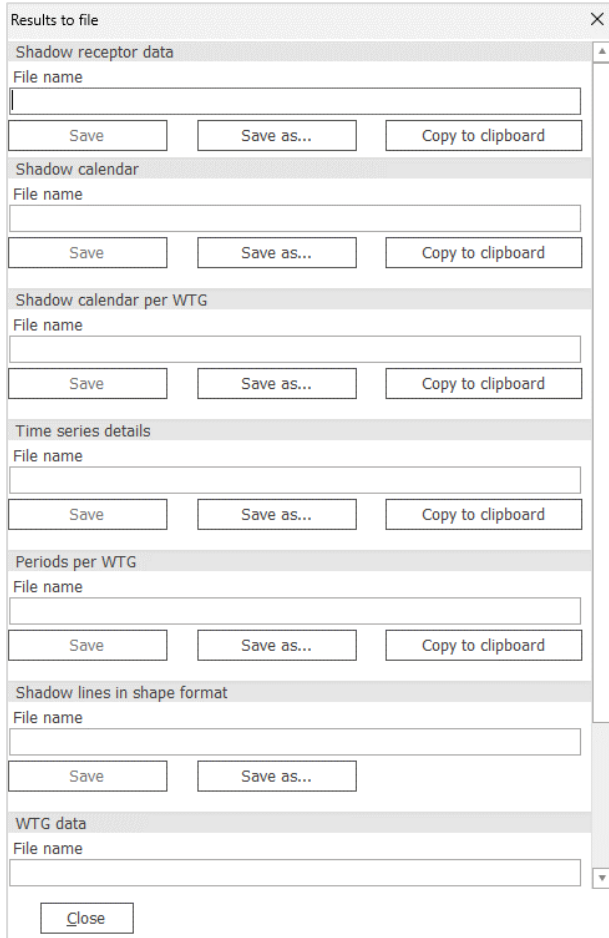
Note that calendar dumps use the time zone details of the calculation. Many flicker stop programs installed in wind turbines do not use daylight saving time. If the calendar includes daylight saving time, the wind turbines will stop at the wrong times. The daylight-saving time can be unselected in the Main tab of the Project Properties.

6.3   ZVI – Zones of Visual Influence

6.3.0   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 locations from where you will be able to see one or more WTGs. and how large they will appear in the field of view. A ZVI calculation can handle the cumulative impact of several wind farms (see Section 6.3.4).

For more detailed analysis, the calculation of vertical and/or horizontal subtended angle can document how important the visual impact of a wind farm can be perceived.

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. It allows for comparison of the visual impact of different layouts of turbines for the same project.

The ZVI analysis is particularly useful when assessing alternative projects or WTG planning proposals. It can also be used to identify possible locations for photomontages.

The ZVI module can also be used to calculate the visibility of wind turbines from radar locations. In some countries the impact of wind turbines on the radar signals can be problematic. With a radar 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 6.3.5).

6.3.1   ZVI - Calculation method

The calculations are based on a digital 3D model of the landscape established from digital height contours or an elevation grid. 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 hub or tip and whether the ray is interrupted by the landscape, a surface (with a defined height) or a local obstacle is checked. 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 6.3.5).

For the vertical subtended angle, in addition to the ray sent to the tip of the turbine, a ray is projected at a tangent to the terrain until it reaches the turbine. The vertical subtended angle is then the angle between these two lines, as shown below. When a wind farm is assessed from a given point, the vertical subtended angle varies from one turbine to the other. The resulting value is the largest calculated value.
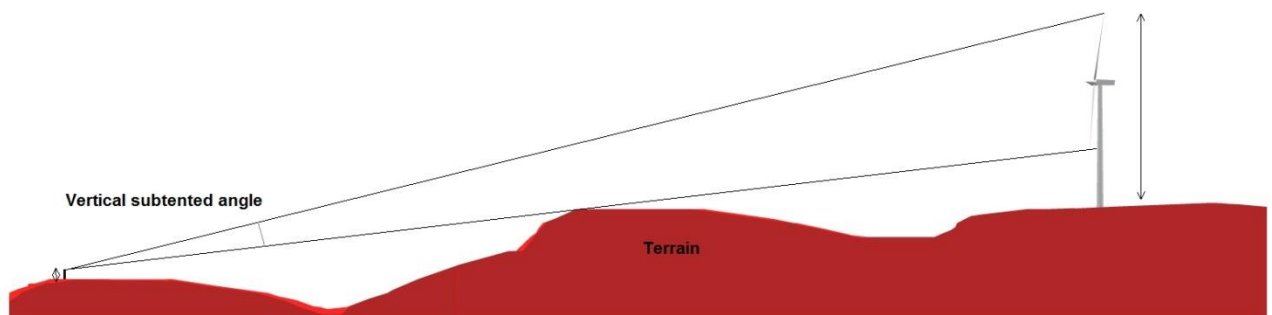
The horizontal subtended angle is the angle between the two lines of sight encompassing the outermost visible point of the rotor disc of the wind turbines of a wind farm as shown below.

All the calculations available in the ZVI module require the following information:

- 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/elevation grid object – see Chapter 2.8)
- Local obstacles if relevant (WAsP format - only obstacles with a porosity lower than 0.3 are included)
- Surface objects if relevant (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.
-

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

6.3.2.1   Input of WTGs

(See Chapter 2. BASIS, Section 2.5.2)

6.3.2.2   Input of Elevation Data

Elevation data are entered in a line object/elevation grid object by loading a data file containing the contour lines/gridded elevation data in an appropriate format or by digitizing the curves directly on-screen with the mouse (line object only).

See Section 2.8 in windPRO BASIS for detailed guidance.

6.3.2.3   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 must be entered as closed polygons.
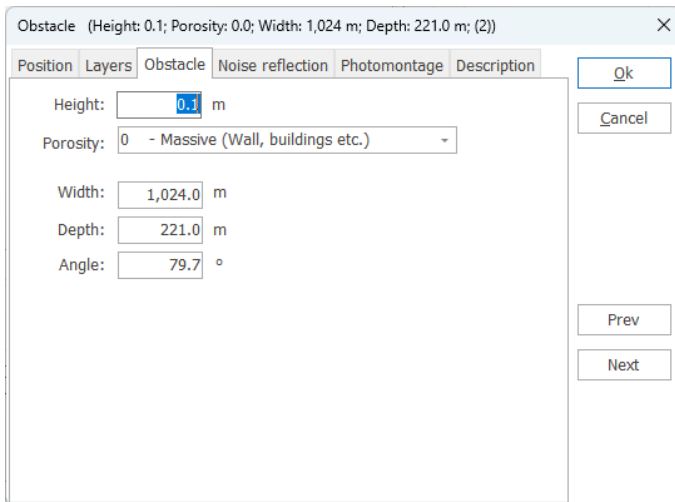
See Section 2.9 in windPRO BASIS for detailed guidance. Notice that the area object must be given a purpose ZVI to have an effect here.

6.3.2.4   Input of Local Obstacles

Local rectangular 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).
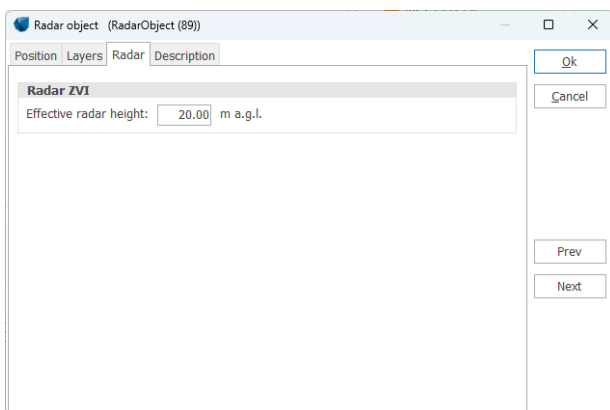
Once the object has been positioned, the following window pops up for setting the height and porosity:

Note: We have chosen a maximum 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.

6.3.2.5   Input of Radars

When required, Radars are entered with this icon 📡. The effective (antenna) height of the radar above the ground needs to be defined. It is the radar radiation centre above ground level. The coordinates of the radar can be entered on the Position Tab, along with an appropriate name.

6.3.3   ZVI - Calculation and Printout

A ZVI calculation is started from the Environment & Visual tab of the ribbon.
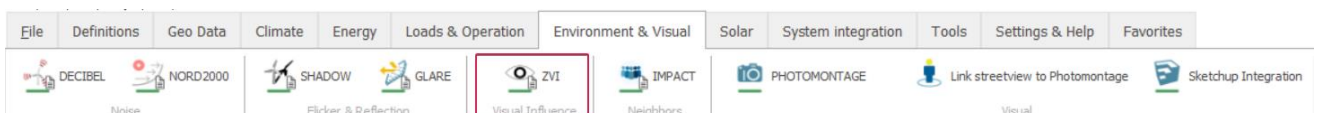
If the bar below the icon is green, it is possible to perform a calculation. If it is yellow, license for the module is needed.

Once selected, you can set up the calculation, as described below.

6.3.3.1 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 multiple ZVI calculations in the same project.

The type of ZVI calculation is then selected from:
- **Wind turbines visibility/Turbines visibility**: calculates and shows on a map the number of wind turbines which are visible within an area;
- **Wind turbines visibility/vertical subtended angle**: calculates and shows on a map the value of the largest vertical angle of the visible turbines;
- **Wind turbines visibility/horizontal subtended angle**: calculates and shows on a map the horizontal angle "occupied" by a wind farm in the field of view.
- **Wind Farms visibility (Cumulative)**: calculates the cumulative visibility of several wind farms (see Section 6.3.4);
- **Radars/Turbines visibility**: calculates whether the WTGs are visible from one or more radars (see Section 6.3.5);
- **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 6.3.5).

For the Wind Turbines visibility/subtended angle calculations, the WTGs tab is used to 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:
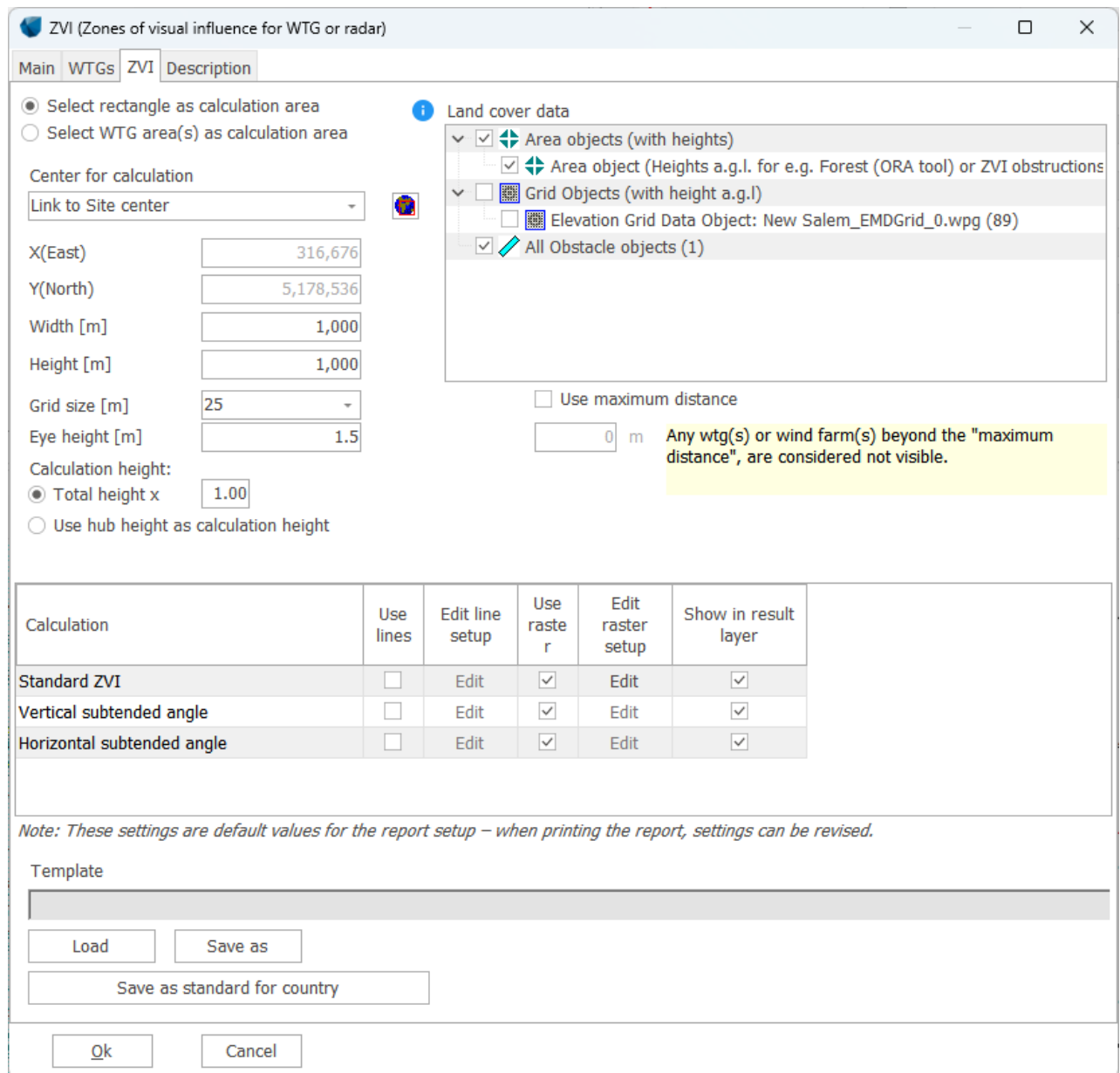
You have the following setup possibilities for a ZVI calculation:

Select rectangle as calculation area for:
- 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. The default area is 1 x 1km centered on the Site Center.
- Graphical definition of the calculation area: Clicking on the globe icon sends you temporarily back to the map window, where you are given a rectangle, with which you can define the extents of the calculation.

Select WTG area(s) as calculation area: this option is relevant for non-rectangle areas or areas defined from a shape file (see section 2.9 from BASIS about WTG area object). This can also be used to calculate circular ZVIs if the WTG area (either by digitization or import of a SHP file) is defined as circular.

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 region 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 region would probably call for a resolution of around 100 m. Grid step will affect calculation time.

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, however local regulations may stipulate a specific value.

Calculation height: It is possible to specify the height of the WTG to account for as the visible height. The first option is relative to the total height of the WTG, which can be decreased by a user defined factor. **Total height x 1.0** means that the WTG is considered visible as soon as the very tip of the blade (in vertical position) is reached by the line-of-sight calculated from a given ZVI grid point. Total height x 0.75 means that the WTG is considered visible as soon as at least 25 % of the WTG (from the top) can be seen. The second option, **Hub height** can be chosen if you should be able to see the hub at least. 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. Some local regulations may require one or the other or both.

Land cover data: obstacles to visibility such as forest or buildings can be selected. Local regulations may define if such obstacles may be used in the calculation. For each cell in the calculation grid, the height of the land cover at the center of the cell is added to the terrain height for the line-of-sight calculations. If the land cover height at a given calculation cell is more than the Eye height input, no WTG can be seen from that cell. The land cover data can be input as:

1. Area(s) with the area object. Only area objects defined for **Heights**, under the Purpose tab are considered in the ZVI calculation.

The height value used in the calculation is the one input as **Type height a.g.l**.
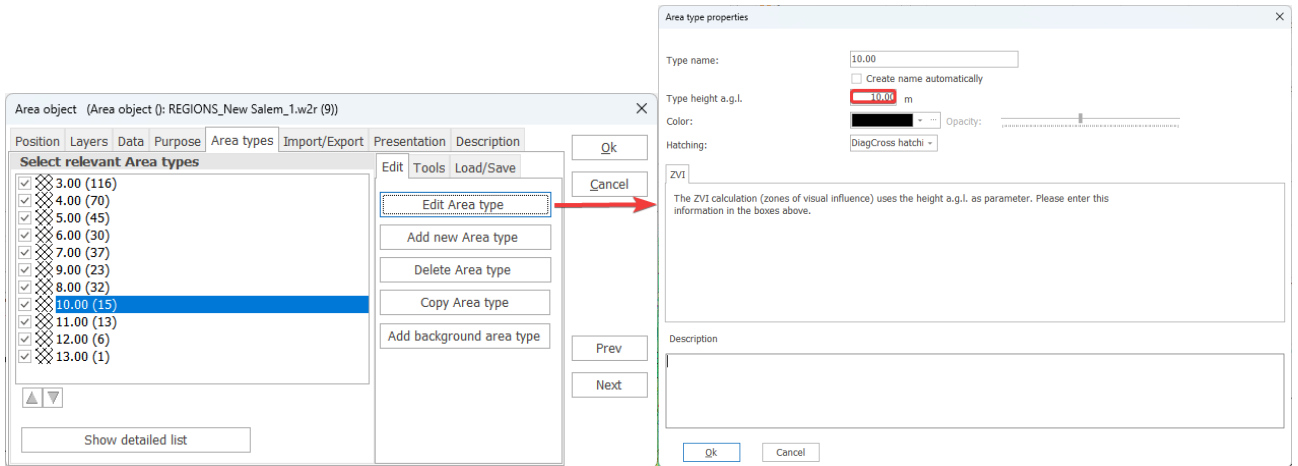
2. grid data with the elevation grid object. Only elevation grid objects with data type **Digital Object Model** are considered in the ZVI calculation.
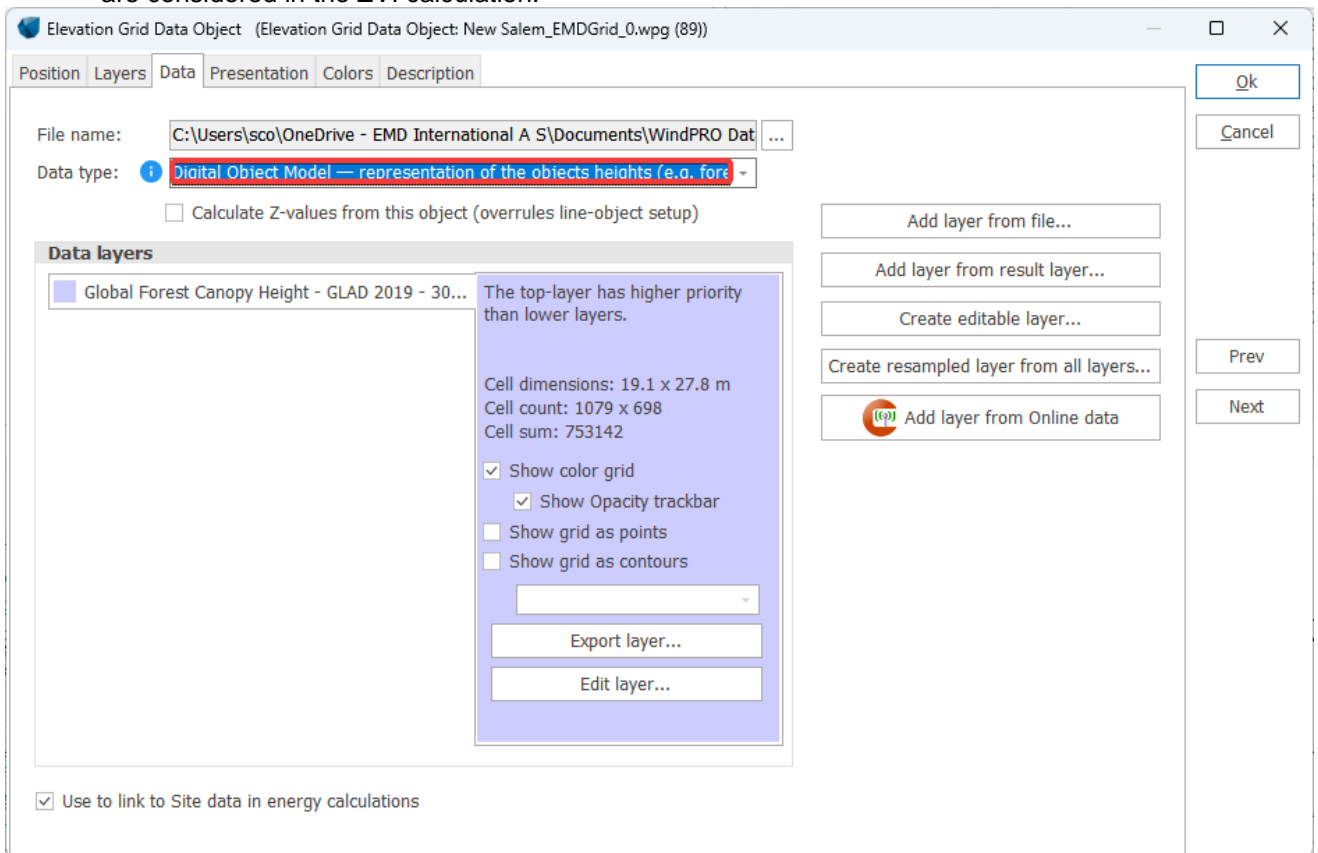
3. single object(s) with the obstacle object. Only obstacles with a maximum porosity of 0.3 Obstacles created solely for energy production calculations should not necessarily be included in the ZVI calculations since the obstacle could, for example, be a row of deciduous trees through which WTGs might be visible during the wintertime.

Use maximum distance: Used for excluding WTGs in projects 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 Section 2.11) and/or in the report setup). Select Show in result layer in order to see the maps in maps and objects (checked by default).

Template: this where pre-defined legends can be loaded or saved.

6.3.3.2 ZVI - Calculation

When you press OK to accept the calculation definition you can choose to start the calculation or save it for later. Calculation speed is dependent on the area specified and the resolution.

6.3.3.3 ZVI – Results/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/viewed.
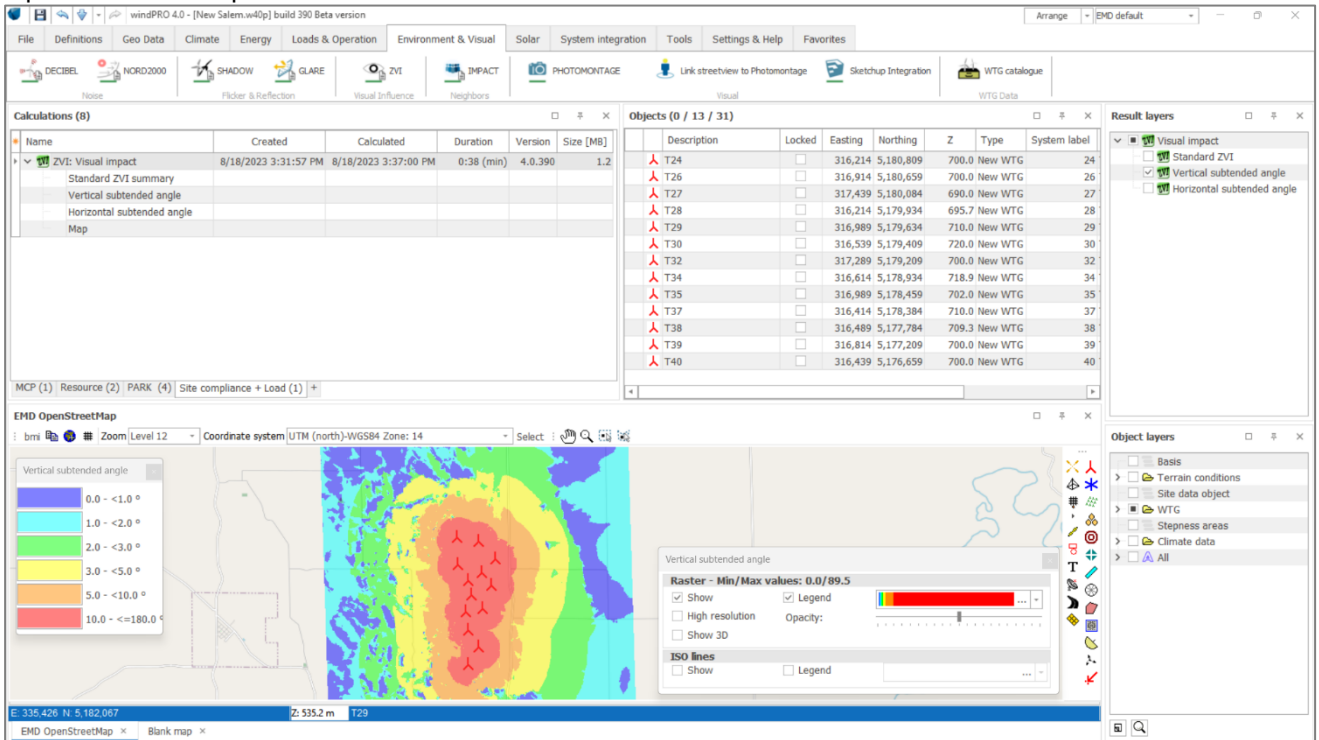
In the ZVI calculation module there are two types of different reports available:

1. A summary report that gives the assumptions for the calculation together with the resulting areas of visual impact (one page for the number of turbines visible and if selected, one page for the vertical subtended angle and one page for the horizontal subtended angle). 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 relevant result on the map (one map for visibility and if selected, one for vertical subtended angle and one for horizontal subtended angle)
Note: A double-click on a report name automatically shows a preview of the report on the screen.

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: Properties - edit the assumptions, Calculation - recalculate, Print - print and preview, Clone - make a copy, Delete, Rename - change the calculation name and Result to File.

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.

6.3.3.4 ZVI presentation in the result layer

It is possible to display the resulting ZVI map in Maps and Objects using the result layer. By default the result layer is selected in the calculation setup. It is possible to calculate the difference or the ratio between two different layers of the same type of calculation in order to compare different layouts for example. In this way, it is also, for example, possible to display both tip- and hub-height ZVIs on the same map. See Chapter 2 Section 2.10.

6.3.4   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 <u>any</u> turbine from a project can be seen at the given grid node rather <u>how many</u> turbines are visible).

6.3.4.1   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 (for example by location - north, west, etc., or by status - operating, consented, etc.).

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

6.3.4.2   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 combinations is then 2^n, i.e. for three wind farms, there would be eight categories in the legend.
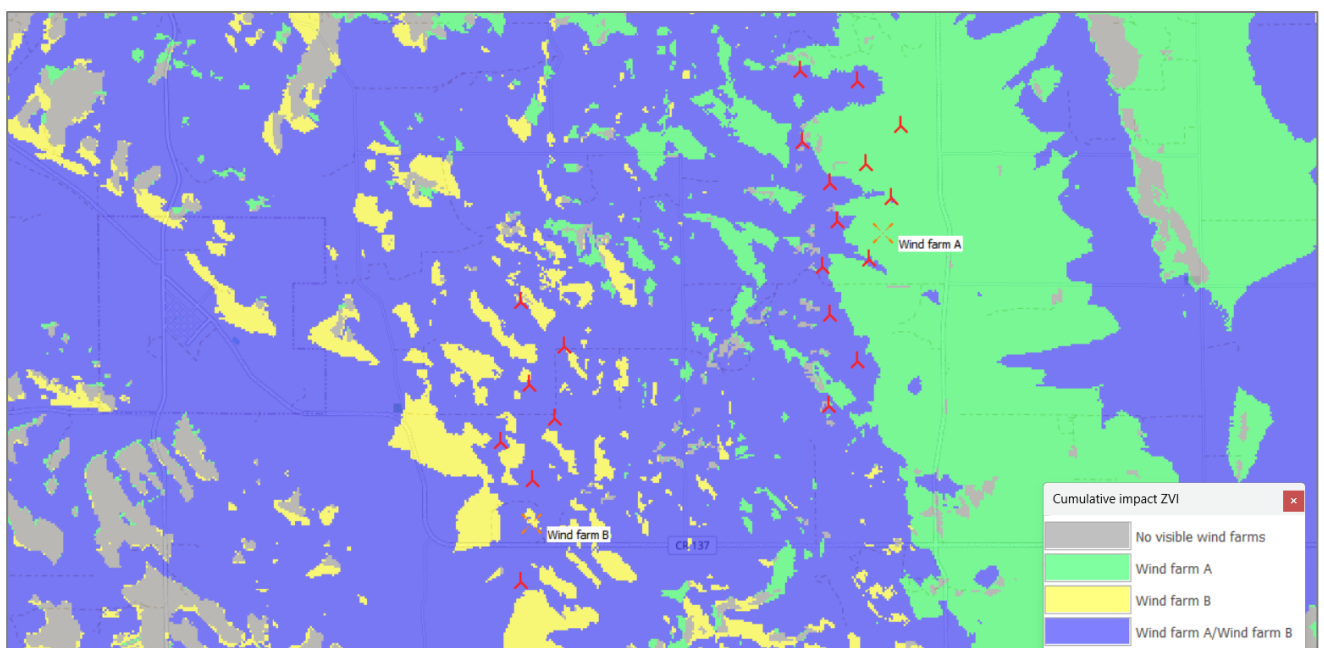
In addition, the display can be manipulated to add or remove colours from any of the legend entries. If you want to see only those areas where wind farm A adds to the visibility of wind farms in the area, then you can set all other colours to white (i.e. not shown on the map) and you will be left with 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.

6.3.5   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 (see 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.
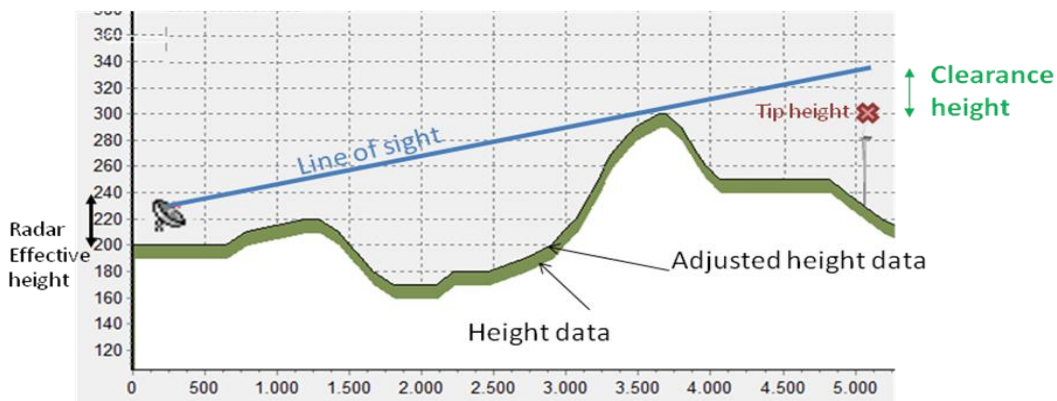
Definition of the clearance height in a Radar ZVI calculation

6.3.5.1   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 6.3.2.
The option **Grid step** sets the grid size/resolution for the calculation.
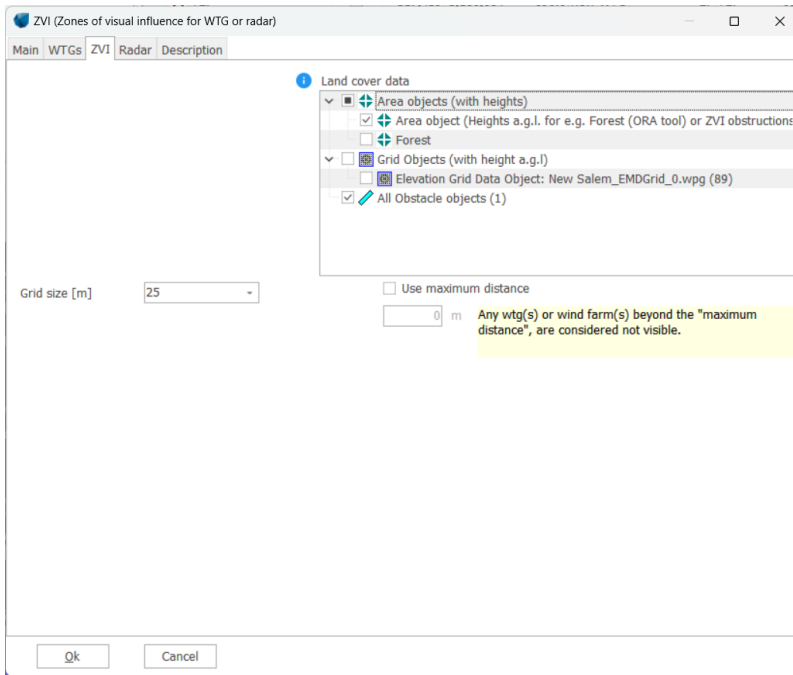
On the Radar tab, the radar(s) to be considered can be selected.

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 in Europe is 1.33 ($4/3$). In the USA, k is between 1.25 and 1.90. You may need to consult local experts to determine an appropriate value.
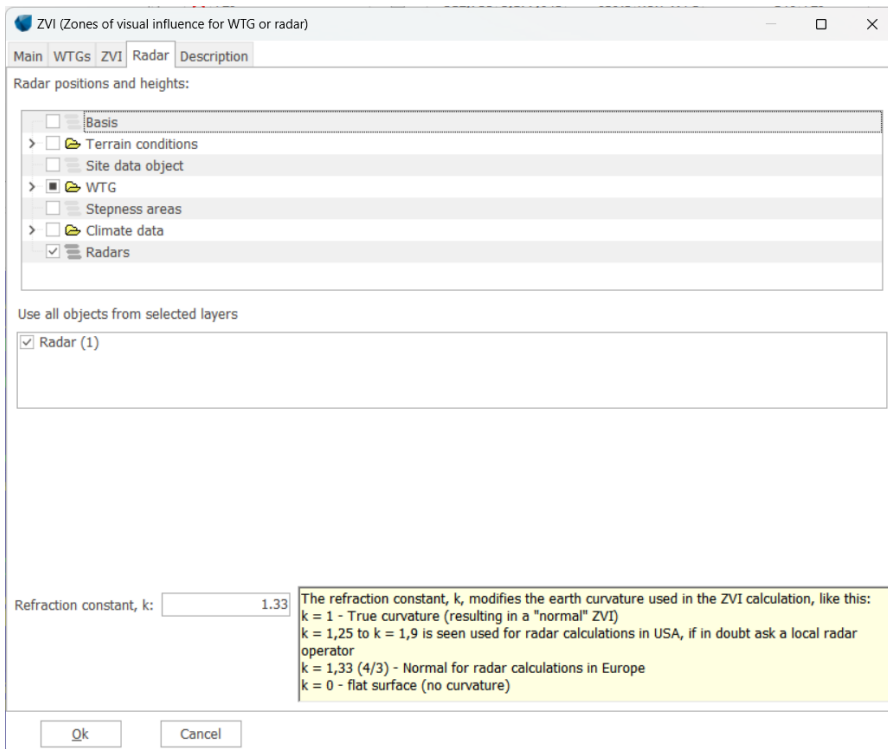
Planning map calculation

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

For the input of wind turbines and radar(s) see Chapter 6.3.2.

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. The default is a 1 x 1 km area centered on the Site Center. For a graphical definition of the calculation area: clicking on the globe icon sends you temporarily back to the map window, where you are given a rectangle, with which you can define the extents of the calculation.
It is also possible to define the calculation area from a WTG area object in which area(s) have been loaded from shape files or digitized manually (see Section 2.9 of the BASIS chapter).

The option **Grid step** sets the grid size/resolution for the calculation. The finer the resolution, the longer the calculation will take.
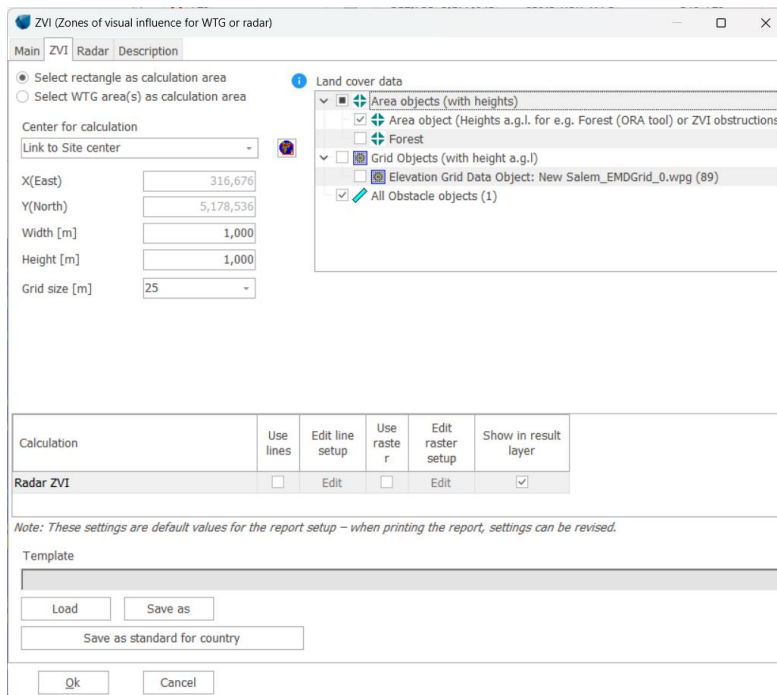
The WTG type is selected on the Radar tab.

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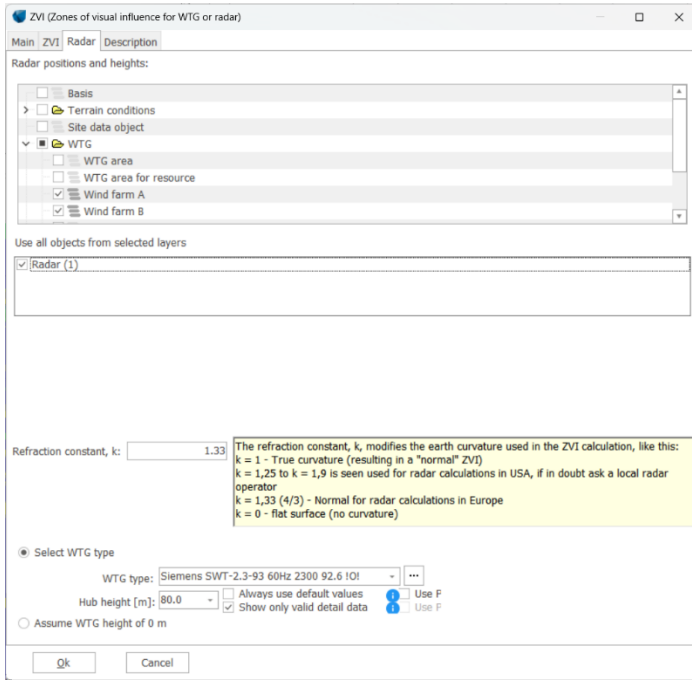
6.3.5.2   Radar ZVI - Printout

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 (i.e. it can be detected by the radar).

		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.
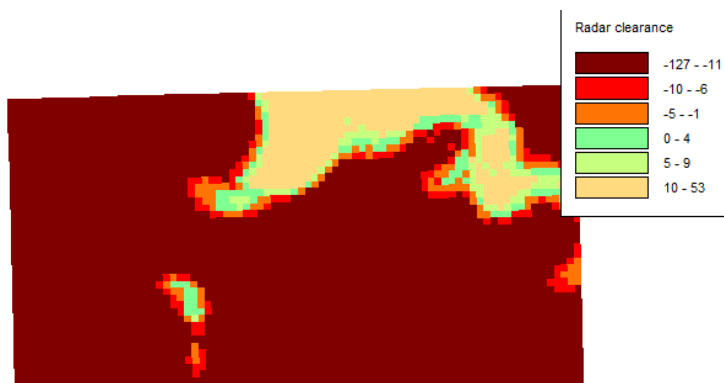
Map of clearance height for a 125m high turbine (total height)

6.4   IMPACT - Calculation of Neighbor Nuisance

6.4.0   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 freely defined, and could, for example, hold a photo of the house seen from wind farm area (or the opposite)

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.

6.4.1   IMPACT - Calculation Method and Setup

The calculation follows the descriptions found in Sections 6.1 (Decibel), 6.2 (Shadow) and 6.3 (ZVI) of this chapter.

What is unique about this calculation module is that all environmental impact calculation results are included in 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.

6.5   NORD2000 – Advanced Noise Calculations

6.5.1   6.5.1 NORD2000 – Introduction and step-by-step guide

6.5.1.1   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, thermal 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 for 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 for example, 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 today's large projects mean millions of Euros gained.

6.5.1.2   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 Environment & Visual tab of the ribbon, run NORD2000, set up calculation parameters.
- ❑ Print/View reports.

6.5.2 NORD2000 Calculations

6.5.2.0 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 implementing 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 (Sørensen, et.al. 2009).

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

A note on solver version:
With WindPRO 3.2, a new NORD2000 solver is released (version 5.022). This solver is significantly faster than previous solvers. It has also fixed a few bugs related to complex terrain descriptions and in the implementation problems with large wind farms has been solved. Please be aware that changes in the solver including any future changes can lead to slightly different calculation results.
With WindPRO 3.3 the solver was updated again to version 6.005. This have solved problems with spikes in the calculations.

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 conditions.

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 (impedance). Hard terrain like water or a parking lot may attenuate very little noise, while soft ground like natural or agricultural land may attenuate the noise well.

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

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

- Wind direction

- Wind speed
- Humidity
- Temperature
- Wind speed shear
- Turbulence strength (wind)
- Turbulence strength (temperature)
- Standard deviation of wind fluctuations
- Inverse Monin-Obukhov 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 returns 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 (except for low frequency calculations) or behind noise-reducing structures.

6.5.2.1   Shared information with Decibel

NORD2000 is a separate module in WindPRO because it requires an external solver provided by Force Technology. However the user interface is very similar and from WindPRO 4.0 an effort has been made to synchronize concepts and conventions as well as work flow.

A lot of the elements required for a NORD2000 calculation is shared with DECIBEL and for an explanation of these element the user is referred to section 6.1.

This includes:

Establishing and use of Noise Sensitive Areas is entirely identical to DECIBEL. NORD2000 reads and use the NSAs exactly the same way. Please refer to section 6.1.2.2.

Entering, data selection and entering source noise levels for WTGs. All facilities available in the WTGs is accessible to Nord2000. Please refer to section 6.1.2.1.

Use of noise curtailment matrix. Nord2000 uses noise curtailment matrix exactly the same way as DECIBEL. In the calculation setup there may be some variation, but that is explained below.

Calculation setup. The calculation setup for NORD2000 follows the same format and conventions as DECIBEL. This means that the structure and options are identical where possible. The description below will refer to sections in the DECIBEL manual where they are identical.

6.5.3   Calculation Parameters in NORD2000

6.5.3.1   The Main tab

NORD2000 can be started from the **Environment & Visual** tab.
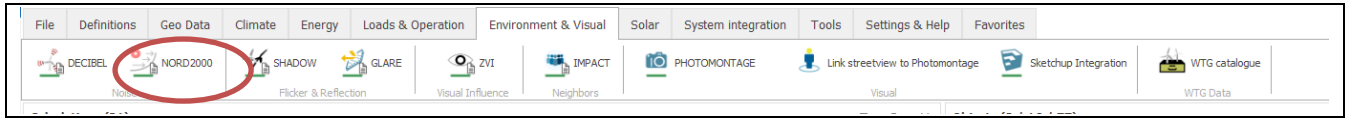
If the bar below the icon is green, it is possible to perform a calculation. If it is yellow, license for the module is needed.

When a NORD2000 calculation is started, the selections are blank.
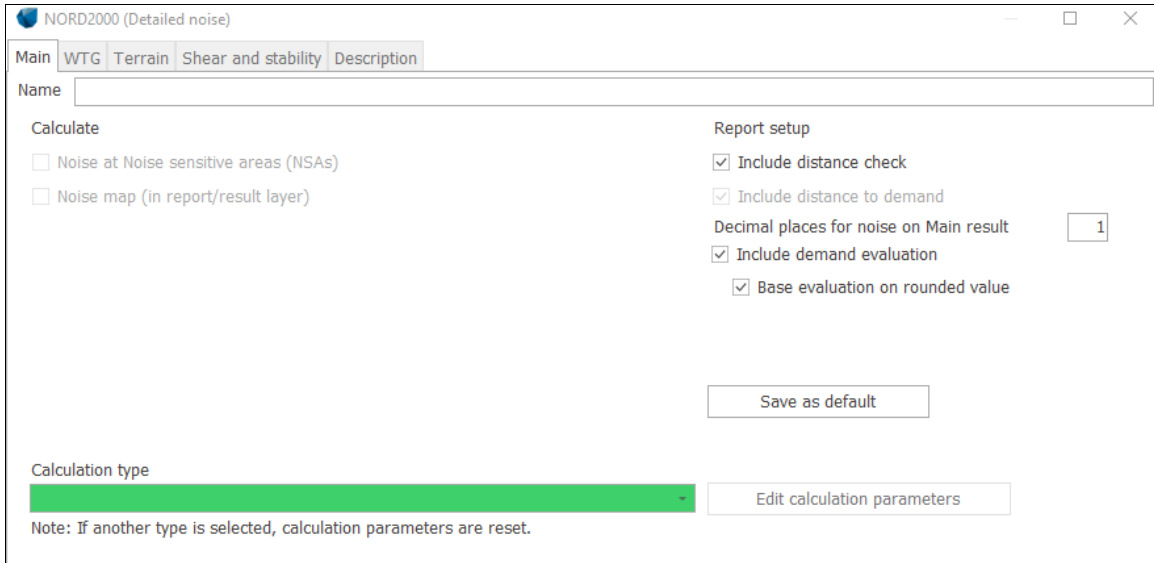
The green field indicates that a calculation type must be selected. The General option allows access to all parameters except Statistical noise, while the other options are hardcoded to lock particular settings. These are described in section 6.5.4. The parameters for the General option is described below.
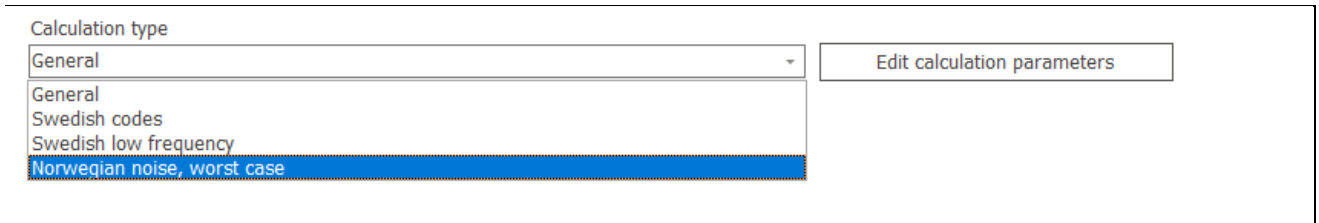
There are two checkboxes to select what should be calculated: Noise at Noise sensitive areas and Noise map. The former gives access to the tab for selection of NSA and the latter gives access to the Noise map tab.

As noise maps in NORD2000 are very slow to calculate, it is recommended to only check this box when the map is needed and exclude it from all preparatory calculations.

On the left side a number of calculation settings are available. These are described in section 6.1.3.1.

When a Calculation type is selected, a form for selection of parameters will open. This form can also be accessed using the Edit calculation parameters button.

6.5.3.2   **Wind speed**

The **Wind Speed** selection is identical to DECIBEL. This includes the selection of **Wind speed inside wind farm** (Wiw). Please refer to section 6.1.1.1.

The only difference is that the following wind speed settings are not available:

95% rated power
95% rated power else fixed wind speed
Loudest up to 95% rated power

As these models do not refer to a specific wind speed, NORD2000 cannot use these.
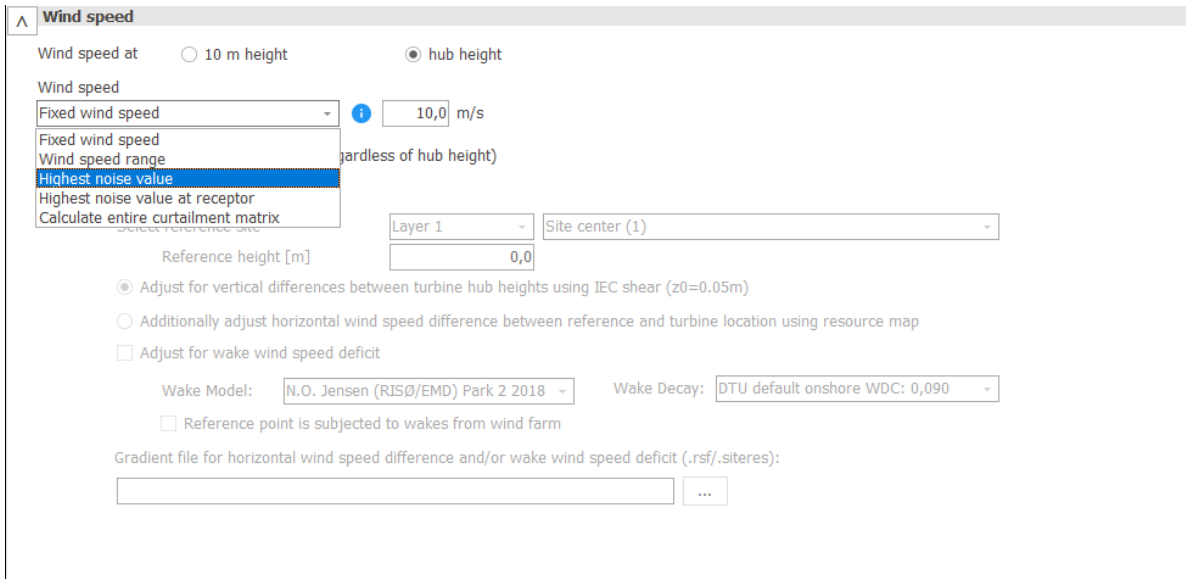
6.5.3.3   **Frequency**

NORD2000 can select between a **Standard frequency** and a **Low frequency** calculation.

A **Standard Frequency** calculation is a broadband calculation in the range of 63 Hz to 8000 Hz or 50 Hz to 10000 Hz if 1/3 octave data are available.

NORD2000 requires octave bad distributions. If no distribution is available for the WTGs, generic octave bands will be assumed. The selection of not using octave band data is therefore not available.
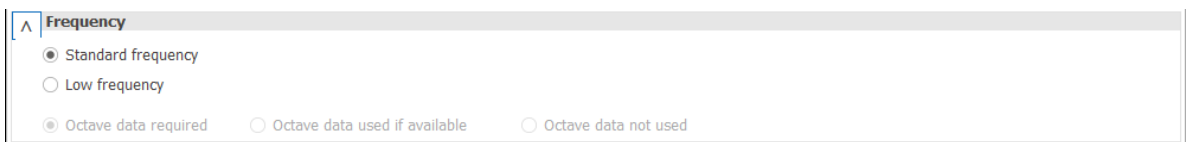
A **Low frequency** calculation is a calculation across the lower range of frequencies and is always done on 1/3 octave data.

If the calculation is an indoor calculation, it will need noise insulation values. Press the **Edit** button to select among the different noise insulation tables available in WindPRO.

The options are described in the DECIBEL manual section 6.1.1.7 and 6.1.1.11. The difference here is that in NORD2000 the full range of frequencies from 1 Hz to 200 Hz is available if the reference has a value for the frequency. It is also possible to enter a custom noise insulation table.

If **No attenuation** is selected, the calculation is considered an outdoor calculation.

Edit ΔLσ

Noise insulation of dwellings

Select:

No attenuation (outdoor noise)

Frequency [Hz]	ΔLσ 60% fractile noise insulation (Danish EPA) [dB]	ΔLσ 90% fractile noise insulation (Danish EPA) [dB]	ΔLσ Summer houses (Danish EPA 2018) [dB]	Finnish DL90 Keränen et.al., 2017	Finnish DL84 Keränen et.al., 2018	Finnish DL84 Keränen et.al., 2019	Custom values [dB]
10,0	4,9	1,2	6,8	4,0	7,0	6,2	0,0
12,5	5,9	3,2	3,9	5,0	7,0	6,6	0,0
16,0	4,6	2,1	0,4	5,0	7,0	7,1	0,0
20,0	6,6	3,6	-0,2	6,0	8,0	7,6	0,0
25,0	8,4	4,6	4,8	6,0	9,0	8,3	0,0
31,5	10,8	6,7	6,2	7,0	10,0	9,2	0,0
40,0	11,4	7,6	8,4	7,0	11,0	10,3	0,0
50,0	13,0	10,3	10,5	8,0	12,0	11,5	0,0
63,0	16,6	14,2	11,9	9,0	14,0	13,0	0,0
80,0	19,7	17,5	11,9	10,0	15,0	14,8	0,0
100,0	21,2	18,4	16,0	11,0	17,0	16,8	0,0
125,0	20,2	17,5	17,5	12,0	19,0	18,8	0,0
160,0	21,2	18,6	17,9	13,0	21,0	21,1	0,0
200,0	25,0	22,4	16,6	14,0	21,0	22,8	0,0
250,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Lσ(60%) at 200Hz is an estimated value based on the literature (Hoffmeyer and Jakobsen, 2010 and Danish Statutory order 1284, 2011)"

Ok   Cancel

The Low frequency calculation can either be done against a frequency sum threshold (**Threshold is a sum across frequency range**) or a spectrum threshold (**Threshold is a 1/3 octave spectrum**). In the former case, the NSA's need to have a low frequency threshold as a aggregated dBA value, while in the later the NSA must be equipped with a threshold for each frequency. If the calculation finds NSAs without the expected threshold the calculation cannot be completed. Whether or not the thresholds are A-weighted is set on the NSA.

The low frequency calculation can be accompanied by an A-C weighting test. The A-C weighting test is described in section 6.5.4.3. If an A-C weighting test is made, a threshold can be set at this point for compliance.

The frequency interval for the test can be set from 10 Hz to 250 Hz.

A low frequency calculation can be used in an optimization, but will only rarely be as restrictive as a broadband optimization.

6.5.3.4 Wind direction

NORD2000 can calculate the effect of sound propagation at an angle to the wind direction. This should not be confused with directivity, which is the sound emission from the wind turbine as a function of with direction. NORD2000 will always assume downwind sound emission even when accounting for wind direction.

If Directional correction is selected, three options become available:

Fixed wind direction: In which case a single wind direction is assumed for all WTG – receptor pairings. For most WTG – receptor pairings this will not be the down wind direction and the option is mostly used to test particular meteorological situations.

Number of sectors: The calculation will run through a range of wind directions, starting in sector 0 with the center of the direction defined in the input field. 360˚ is divided by the number of sectors to give the sector width. In the calculation result, the wind direction that results in the highest total impact from all turbines is reported and compared to the threshold. In this way, this option tests for the worst wind direction.

Calculate entire curtailment matrix: In this case, windPRO will look into the binning definition of the curtailment matrix of the wind turbines to identify the sector definition.

As an alternative NORD2000 can calculate **All receptors downwind of all wind turbines**. In this case, wind direction is ignored and all WTG – receptor pairings are calculated as downwind. This is a worst-case scenario often requested in noise guidelines even if it a scenario that is only realistic in a single turbine case. With two or more wind turbines, the wind direction in reality will not be downwind in all WTG – receptor pairings at the same time.

The **All receptors downwind of all wind turbines** can actually be used in a curtailment optimization with wind direction as an active dimension. Compliance in each wind direction is then tested using down wind direction to each receptor, meaning that sectors with longer distance or higher threshold at receptors require less noise reduction.

6.5.3.5 Type of threshold in calculation

The **Type of threshold in calculation** selection is identical to DECIBEL. Please refer to section 6.1.1.1.

6.5.3.6 Noise values in calculation

The **Noise values in calculation** selection is identical to DECIBEL. Please refer to section 6.1.1.1.

6.5.3.7   Tonality

The **Tonality** selection is identical to DECIBEL. Please refer to section 6.1.1.1.

6.5.3.8   Height of immission point

The **Height of immission point** selection is identical to DECIBEL. Please refer to section 6.1.1.1.

6.5.3.9   Uncertainty

The **Uncertainty** selection is identical to DECIBEL. Please refer to section 6.1.1.1.

6.5.3.10   Uncertainty

The NORD2000 solver calculates air absorption attenuation according to ISO 9613-1. This requires input of temperature, relative humidity and atmospheric pressure.

The user interface for the selection of these parameters is identical to that of DECIBEL. Please refer to section 6.1.1.1 for details on this selection. This also includes its use as dimensions for noise curtailment optimization.

A difference to the ISO 9613-2 model is that NORD2000 is not restricted to 1/1 octaves, but can calculate air absorption attenuation at 1/3 octave level.

6.5.3.11   Time domain

The **Time domain** selection is identical to DECIBEL. Please refer to section 6.1.1.1.

6.5.3.12   Terrain

The **Terrain** tab concerns all input data concerning terrain for the NORD2000 calculation.
These are Elevation data, Roughness data, Impedance (Terrain type) and Forest data.

Elevation data

The elevation data is the height model used.

There are three 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 may cause an incorrect calculation result.
2. **Link to a line object**. In this case you link to a line object holding the elevation model (contours) 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).
3. **Link to elevation grid object**. As for line object, but referring to a grid data object.

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.

Roughness data

The roughness is the surface texture properties that identify the drag the terrain exerts on the wind. The higher the roughness, the faster wind speed increases 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 propagates. It is not used to calculate the hub height wind speed of the turbines. NORD2000 receives the roughness length directly from this input, while the shear input can be derived from this input. See section 6.5.3.13 for a description of shear input.

Impedance

The impedance is the acoustic hardness of the terrain as identified from terrain type, 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 impedance is an important property of the ground. In windPRO we use 8 categories of terrain each corresponding to a hardness value (Plovsing, 2010). These types are shown below.

Terrain hardness (impedance) for NORD2000	Value
A Very soft (snow or moss-like)	12.5
B Soft forest floor (short, dense heather-like or thick moss)	31.5
C Uncompacted, loose ground (turf, grass, loose soil)	80
D Normal uncompacted ground (forest floors, pasture field)	200
E Compacted field and gravel (compacted lawns, park area)	500
F Compacted dense ground (gravel road, car park)	2000
G Hard surfaces (most normal asphalt, concrete)	20000
H Very hard and dense surfaces (dense asphalt, concrete, water)	200000

Throughout a site the acoustic hardness can vary considerably. 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.

In the Area object select the purpose **NORD2000 Terrain hardness (impedance)**.
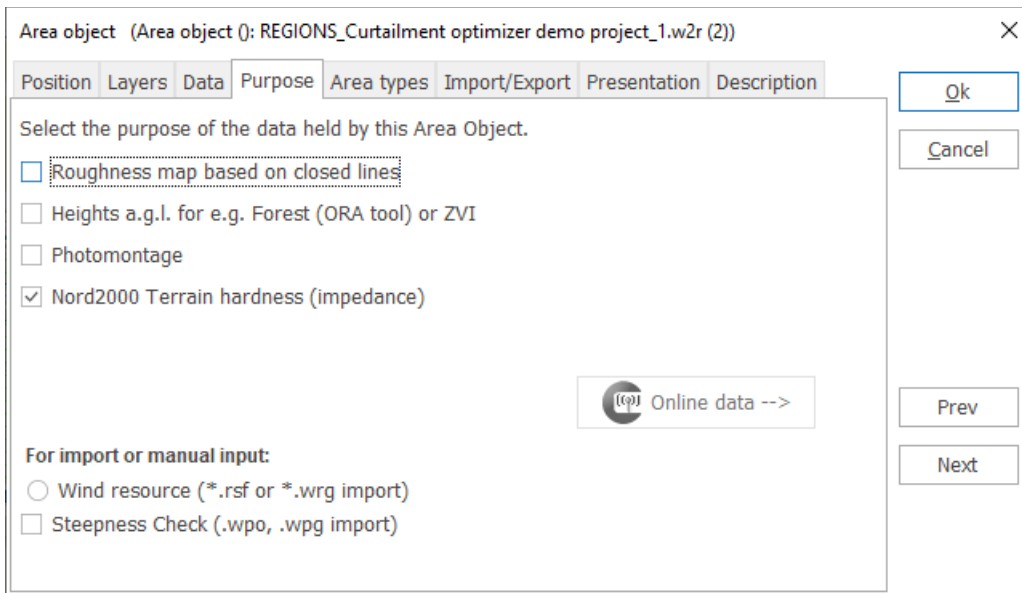
It is possible to recycle area objects, for example use the same area object for roughness and impedance, but please beware that while a roughness description is supposed to give large scale changes in roughness, the impedance map has to map exactly the change in impedance. The result for receptors is highly sensitive to the distance to an impedance change, so for example lake shores must be digitized very precisely, something rarely necessary for a roughness map.
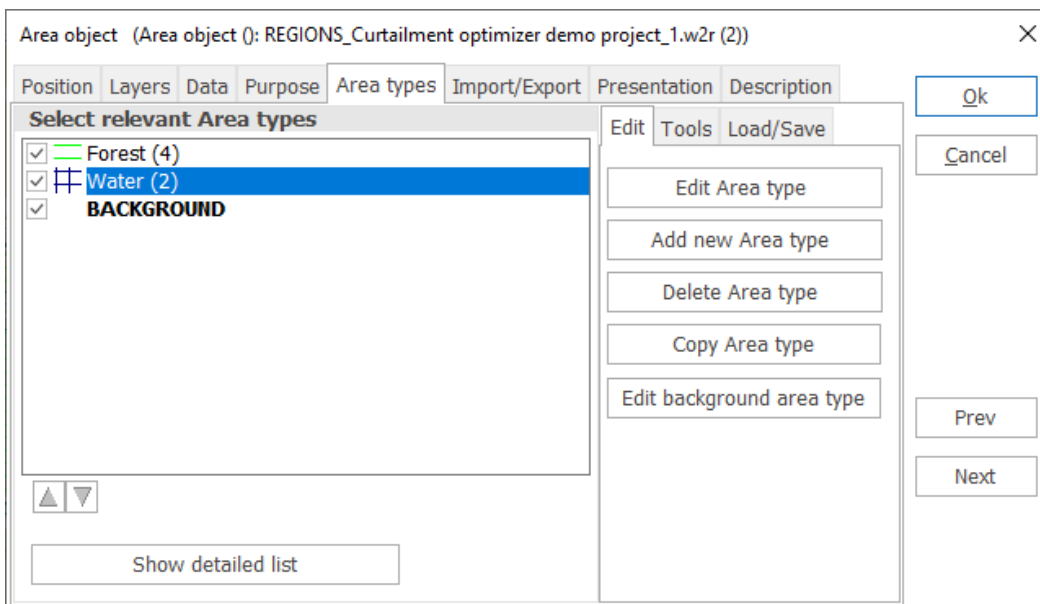
A set of area types needs to be defined including a background. This follows the standard procedure for area objects as described in Section 2.9.

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 checking the relevant months. In the calculation it is possible to select a month and thus pick the correct hardness values for the terrain.

It is possible to load land use maps into the area object and assign an acoustic hardness to each type. However, the speed of the calculation is proportional to the detail level of the hardness map, so very detailed maps will slow down the calculation. If that is happening a reduction of the level of detail can usually be made with only minor loss in precision of the calculation as long as distance to impedance change from receptors is not compromised.

Forest

NORD2000 can include the scattering effect of forests. To do this it needs to understand start and end position of forests along the line-of-site between WTG and receptor. The properties of the forest (tree density, height of trees etc.) are not relevant for the calculation. This means that forest information can be drawn for the standard forest form in windPRO.

There are two options:
1. No forest model. Forests are ignored.
2. Link to forest model. Forest start and end locations in each WTG – receptor pairing is drawn from the forest model in WindPRO. The forest model is described in section 3.3.6

6.5.3.13 Shear

Shear conditions are set on the **Shear and stability** tab.

Shear has two functions. It is used to transform wind speed in order to look up the source noise level on the noise curve and it is used by the propagation model to describe the wind profile through which the sound is passing. windPRO makes a hard distinction between these two purposes for shear.

To translate the wind speed from one height above ground to another, windPRO is hardcoded to use the IEC profile shear (IEC 61400-11:2012, roughness length 0.05m). This means that if the calculation is set to calculate

at 10 m wind speed, NORD2000 will automatically use the IEC shear to translate this to hub height wind speed in order to look up into the noise curve.

For any other transformation of wind speed in the wind farm, please use the Wind speed inside wind farm function, section 6.1.1.1

In versions prior to WindPRO 4.0 there were several options to get this shear translation. These have been removed. A recalculation of an earlier calculation will be changed to use the IEC shear.
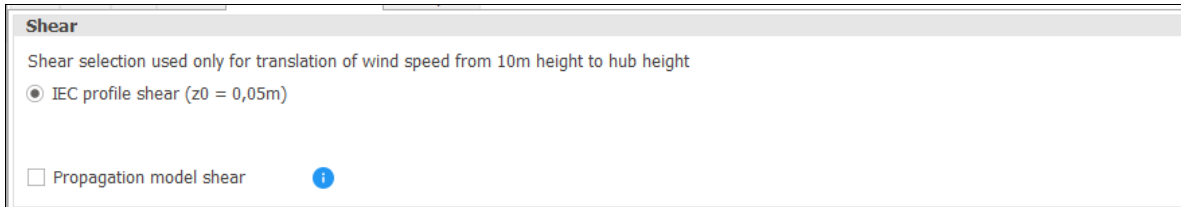
If no selection is made for propagation shear, the value 0.15 is used as the shear coefficient in the NORD2000 calculation. Versions prior to windPRO 4.0 were hardcoded with this value, so this corresponds to legacy mode.

Checking the Propagation model shear offers four choices.
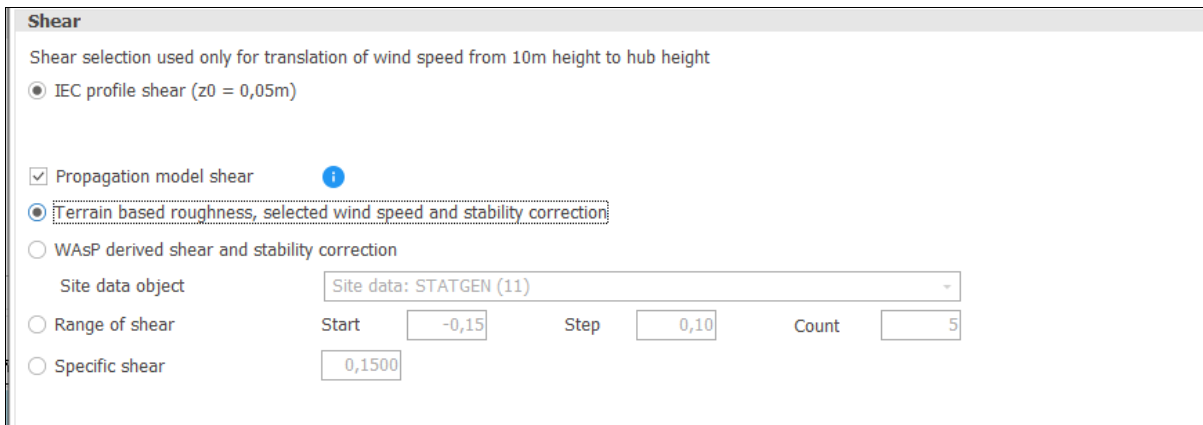
Terrain based roughness, selected wind speed and stability correction.
The terrain 10 km upwind from the wind turbine is read from the roughness description entered on the **Terrain** tab, the wind speed is picked up from the **wind speed** selection, including the Wiw selection if used and stability is picked up from the **stability** selection. These combine into a logarithmic wind profile including stability correction. The shear coefficient is read from this wind profile using wind speed 20 m below and 20 m above the hub height of the wind turbine. The shear coefficient is considered uniform the entire distance from the wind turbine to the receptor regardless of wake.

WAsP derived shear and stability correction
This is similar to the above selection except that the interpretation of the terrain is done by WASP. It uses a neutral stability WAsP setting to create a wind profile at the turbine in the wind direction of the calculation. The wind profile is corrected for stability as above and the shear coefficient is read based on wind speed 20 m below and 20 m above the hub height of the wind turbine. WAsP reads the terrain from a **Site data object** which must be linked to. This option also requires license access to WAsP.

Range of shear

Calculations are done for a range of shear values, each resulting in a noise impact result in the report. Only the result with the highest impact is reported in the Main result of the report. **Start, Step** and **Count** values must be entered. This selection overrides any stability correction so that the NORD2000 calculation will be done with these specific shear coefficient values.

Specific shear
A specific shear coefficient is entered and used for the calculation. The default value is 0.15, the legacy value of NORD2000 prior to windPRO 4.0.

6.5.3.14   Stability

Stability conditions are set on the Shear and stability tab.

The parameters of the Stability setup are sent directly to NORD2000, but can also be used to adjust the shear coefficient being sent to NORD2000.

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

Turbulence strength (wind) (or turbulence intensity) is the standard deviation of the wind speed divided by mean wind speed in a 10-minute interval and is well described in Section 3. It is expressed as a 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-Obukhov 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 are set at representative values.

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

Checking **Input advanced options manually** aborts the preset settings and allows 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. It may be useful to calculate a range of stability situations. This is done by selecting **Range of stabilities**.

windPRO allows for three stability classes to be calculated (Stable, neutral and unstable). The definition follows the standard windPRO definition for stability as defined when pressing the **Setup** button.

This replaces **Inverse Monin Obukov length** and **Temperature scale T*.** The remaining parameters can still be manually edited.

6.5.4   Preset models

6.5.4.1   Statistical noise

The statistical noise option has been temporarily removed from windPRO 4.0.

To run a statistical calculation, please refer to WindPRO 3.6. The below guide is only valid in version 3.6.

The statistical noise calculation is not concerned with particular wind speeds or directions but rather looks at all speeds and directions. Essentially it calculates the noise impact at each receptor at all integer wind speeds in all of 12 sectors and then uses a wind distribution (the Weibull distribution, not the time series) of a site to calculate the weight of each event. The result can be a mean noise level or a particular percentile (e.g. L10 or L90). Please note that in this definition L90 means that the noise level will be below this level 90% of the time.

Statistical noise can also be combined with Lden, in which case no exceedance value is required or used. That combination will comply with the WHO guideline for Lden calculations.

Wind
Only the Wind tab changes.

The wind distribution is based on a Meteo object (in the above example from meso-scale model data at100 m) and these are scaled to the height at which the calculation is performed using the shear information on the Shear tab. For the final result the height is actually less important since we are not looking at a particular wind speed, so it is sensible to choose a height near the measurement height in order to reduce the scaling of the wind speed.

If the WAsP model is used to calculate the differences in wind speed across the site, then this relative difference is applied to the wind distribution for each of the calculation points.

Please note that this model does not take into account the stability variations over the day or year, so a wind distribution based on low height may not sufficiently catch that effect. It is strongly recommended to use time series based on heights close to hub height.

Also the terrain is considered constant over the period calculated, meaning that no seasonal effects on terrain are included nor in the atmospheric conditions except for wind speed and direction.

As mentioned for the general calculation also directivity of the turbine source noise level is not included.

The source noise level from the wind turbines used is the mean noise level (LWA). The L90 source noise level is not used for an L90 result at the receptors.

6.5.4.2   Swedish codes

The Swedish noise codes are described by Naturvårdsverket in the guideline vagledning-om-buller-fran-vindkraftverk.pdf (naturvardsverket.se) (2020).

The guideline recommends that NORD2000 is used to calculate wind farm noise, but unfortunately, very little advice is provided concerning the parameterization of the model. Only two items are addressed directly: Noise must be calculated for the wind speed with the highest noise and the noise at all receptors must be calculated using downwind conditions from all turbines at the same time. In other parts of the methodology it can be assumed that requirements outlined in the general method Mätning och beräkning av ljud från vindkraft (naturvardsverket.se) are valid.

The Swedish codes option in the NORD2000 calculation in windPRO locks the settings to the values and configurations described in the references above and leaves open a number of options not described in the guideline.

Wind speed
The calculation is set to highest noise value. Wind speed inside windfarm is not allowed.

Wind direction
The Swedish codes require a calculation downwind from the turbines. This option is therefore preselected.

Height of immision point
Receptor height is automatically set to 1,5 m.

Air absorption
The climate settings are not specified in the guideline, so all options are available. Note that 15˚ and 70% humidity will produce the lowest air absorption attenuation and therefore be most conservative.

Time domain
Calculating day and night results may be useful as there may be different thresholds day and night.

Shear and stability
Shear and stability are not specified in the guideline, so all options are available.

6.5.4.3   Swedish low frequency noise

A calculation option has been designed specifically for Swedish low frequency sound.

The methodology for a low frequency sound calculation is described by Naturvårdsverket in the guideline vagledning-om-buller-fran-vindkraftverk.pdf (naturvardsverket.se) (2020).

Additional recommendations can be found in Vägledning om buller inomhus och höga ljudnivåer — Folkhälsomyndigheten (folkhalsomyndigheten.se) (2019).

The recommendation is to conduct a noise impact calculation for indoor noise using Nord2000 or similar in the frequency range of 31.5 Hz to 200 Hz. The threshold is a reference spectrum published by Folkhälsomyndigheten FoHMFS 2014:13 Folkhälsomyndighetens allmänna råd om buller inomhus (folkhalsomyndigheten.se), which cannot be exceeded at any frequency.

Noise sensitive areas
The noise sensitive area must use the country specific form for Sweden and Swedish low frequency. The default setting is to use the threshold spectrum from Folkhälsomyndigheten. These values are:

Frequency, Hz	31,5	40	50	63	80	100	125	160	200
Threshold, dB	56	49	43	41,5	40	38	36	34	32

The threshold values are not A-weighted.

A-C weighting test
Earlier versions of the guideline described an A-C weighing test. The A-C weighing test is a comparison in the frequency range of 31.5 Hz to 200 Hz between A-weighted sum and C-weighted sum using the same calculation setup as for the actual low frequency calculation. The A-C weighting test result is presented in the WindPRO main result and detailed result.

According to the former guideline a difference larger than 20 dB means that a detailed low frequency analysis needs to be conducted for the dwelling, meaning that the calculated noise impact must be compared to the threshold.

The status of this test is at present unclear and it therefore remains a part of the Swedish low frequency calculation in WindPRO.

Low frequency
The frequency range from 31.5 Hz to 200 Hz is automatically selected. It is possible to Edit and View the noise insulation values. See section 6.5.3.3 for selection of noise insulation values.

According to Naturvårdsverket the noise insulation of dwelling is to be considered by the acoustician. If specific values are used these can be inserted as Custom values. Screening for low frequency noise in Sweden is usually done using the Danish 90% fractile values, which is normally a conservative value for Sweden.

Report
The calculation report (see section 6.5.3.3) includes an A-C weighing test (calculated as C – A sum) and a test against the reference spectrum with the most critical frequency highlighted.

6.5.4.4   Norwegian noise, worst case

This is an implementation of the worst-case conditions as described in the Norwegian guideline from NVE 2017-18.

The Norwegian guideline was in 2021 replaced by "Veileder til retningslinje for behandling av støy i arealplanlegging (T-1442/2021)", referring to the document M-128 – 2020 from Miljødirektoratet. The revision primarily provides a guideline for use of Nord2000.

Wind speed
The calculation is set to highest noise value. Wind speed inside windfarm is not allowed.

Wind direction
The Norwegian worst-case codes require a calculation downwind from the turbines. This option is therefore preselected.
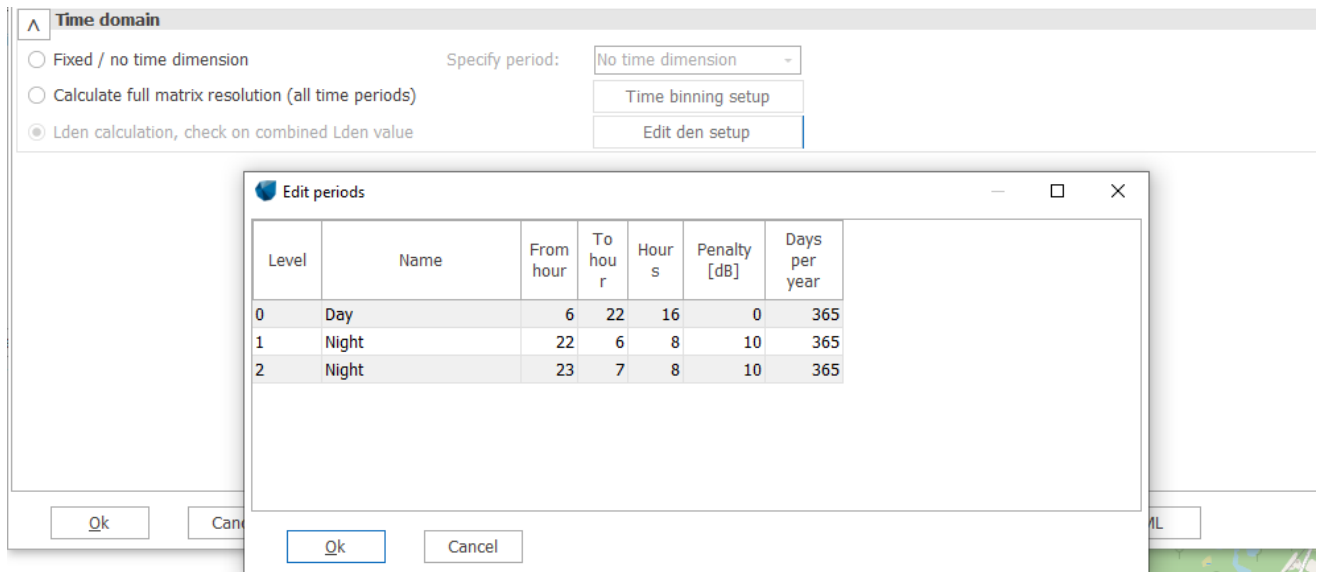
Height of immision point
Receptor height is automatically set to 4 m.

Air absorption
The climate settings are not specified in the guideline, so all options are available. Note that 15˚ and 70% humidity will produce the lowest air absorption attenuation and therefore be most conservative.

Time domain
The Time domain setting is locked to L_{den}

With this setting the Lden option is automatically selected with the Norwegian definition of Lden parameters.

Shear and stability
Shear and stability are not specified in the guideline, so all options are available.

6.5.4.5   Norwegian noise, real case

The Norwegian real case option has been temporarily removed from windPRO 4.0.

**To run a Norwegian real case calculation, please refer to WindPRO 3.6. The below guide is only valid in version 3.6.**

This is an implementation of the real case conditions as described in the Norwegian guideline from NVE 2017-18. In effect it is a combination of the Norwegian worst-case model and the Statistical model.

As above the Lden is selected with Norwegian settings.

The noise level obtained is the average noise, thus the statistical noise level is the L50 noise level.

On the **Wind** tab Range is preselected giving the full range of wind speeds from 1 to 25 m/s as well as all sectors from 0 to 330 degrees.
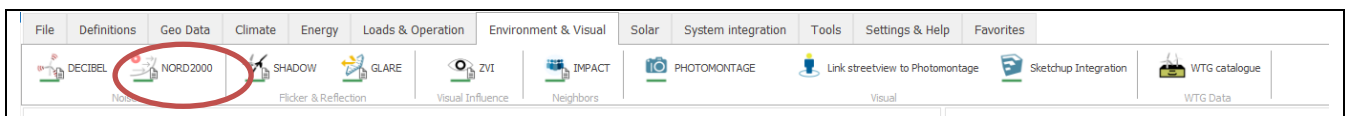
As for the **Statistical** model a wind dataset has to be selected with the same considerations as described under the **Statistical** model.
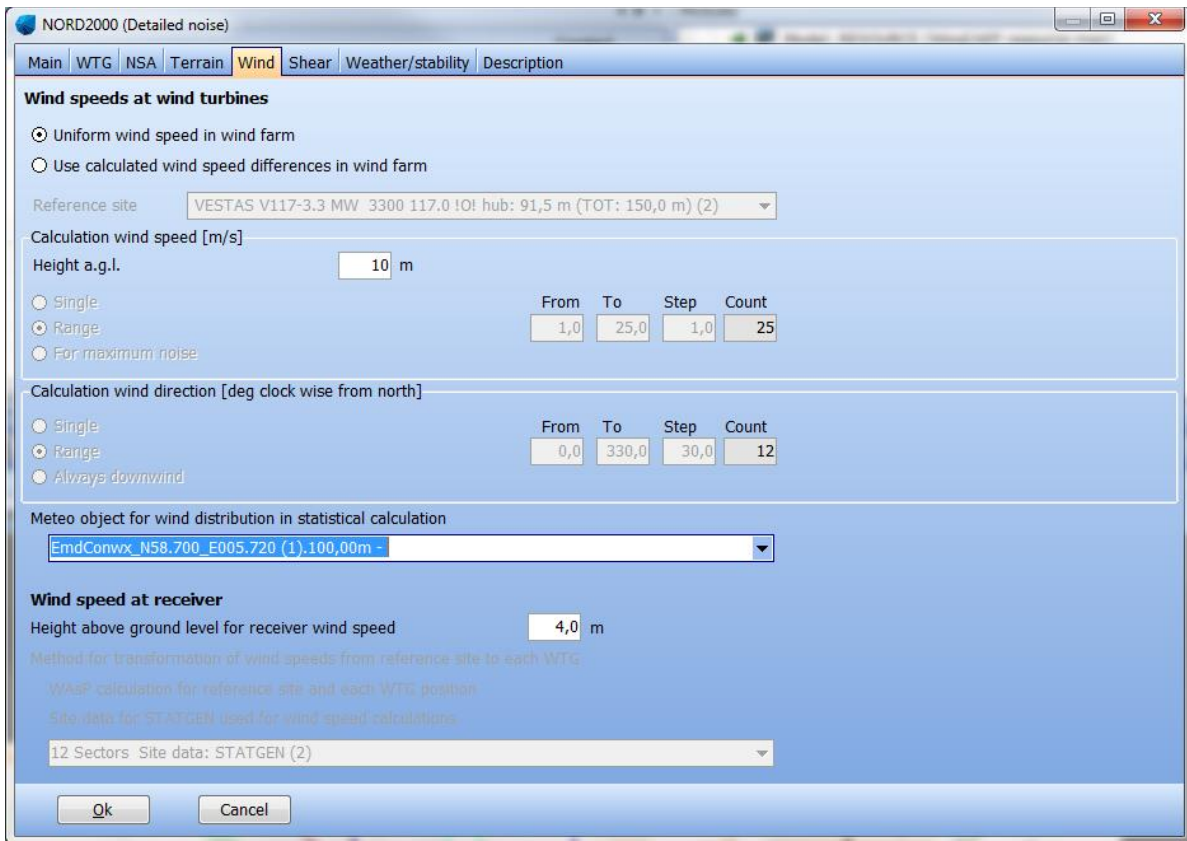
There is full freedom to set **Weather/stability** parameters.

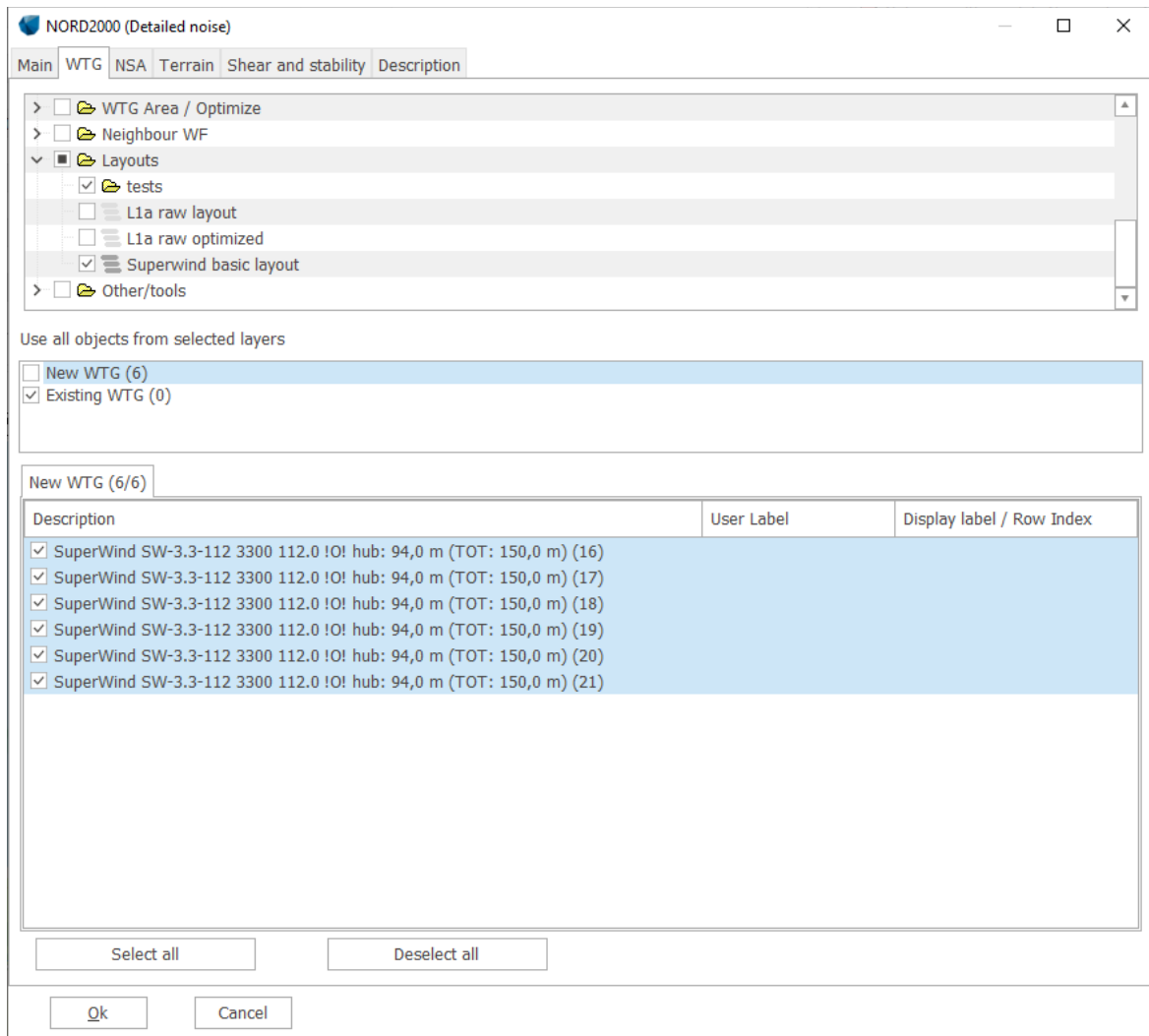## 6.5.5   Starting the NORD2000 calculation

NORD2000 can be started from the **Environment & Visual** tab.

The Main, Terrain and Shear and stability tabs are described in section 6.5.3.

6.5.5.1   The WTG tab

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 6.1.3.1).

The top section is a list of layers in the windPRO project. The layers visible when starting the calculation are automatically selected (checked). Additional layers can be selected or deselected at this point. It is a good idea to organize the project so that each layout iteration gets its own layer.

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

If the boxes are not checked 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.

6.5.5.2   The NSA tab

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

The procedure is described in Section 6.1.3.1 and follows the same principles as for selection of wind turbines.

The noise sensitive areas are fully described in the DECIBEL manual (Section 6.1.2.2). There are no special NORD2000 settings.

6.5.5.3   Noise map

Most calculation options can be combined with a noise iso-line map. The map is identical to the one calculated with Decibel, except that it is calculated with NORD2000.

Selecting the noise map option on the main tab activates the Noise map tab. For details on the noise map see Section 6.1.3.1.

Please note that the noise map calculation can be very slow, especially if multiple wind speeds and directions or very detailed hardness maps are used. However, with the solver used from version 3.2 it is now realistic to perform a noise map even on a larger wind farm.

6.5.6   NORD2000 - Printout

The reports from NORD2000 are in principle 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 following, only differences to the DECIBEL reports are described. Where the reports are identical, please refer to section 6.1.3.3 .

6.5.6.1   General 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.

Weather stability lists the climate parameters selected for the calculation including the two most important stability parameters T* and the inverse Monin-Obukhov length (see Section 6.5.3.14).

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 Wind speed inside wind farm is used to calculate the hub height wind speed at each turbine, then the location used as reference is mentioned.

Uncertainty, type of threshold, noise value and tonality settings are listed.

Finally, the NORD2000 solver version is listed. Inconsistencies in calculation results may be due to use of different solver versions.

Shear in the report

Shear coefficient values can be set or calculated in the calculation setup. The resulting shear for each WTG – receptor pairing can then be found on the Detailed results pages. A range of shear simply results in additional calculation lines.

NORD2000 - Detailed results

Calculation: Standard calculation

Calculation Results

Noise sensitive area: A Noise sensitive point: User defined (3)

WTG No.	Distance	Wind speed	Wind direction	Air temperature	Relative humidity	Wind speed at hub height	Shear	Sound level	63	125	250	500	1000	2000	4000	8000	Source noise LwA,ref
	[m]	[m/s]	[°]	°C	[%]	[m/s]		[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]
1	484	10,0	0,0	15,0	70,0	10,0	0,1497	40,97	23,2	28,8	28,6	36,9	36,9	29,6	15,6	-27,8	106,55
1	484	10,0	30,0	15,0	70,0	10,0	0,1403	40,99	23,2	28,8	28,8	36,8	37,1	29,6	15,6	-27,8	106,55
1	484	10,0	60,0	15,0	70,0	10,0	0,1435	41,00	23,2	28,8	28,9	36,8	37,1	29,6	15,6	-27,8	106,55
1	484	10,0	90,0	15,0	70,0	10,0	0,1365	40,99	23,2	28,8	28,8	36,8	37,0	29,6	15,6	-27,8	106,55
1	484	10,0	120,0	15,0	70,0	10,0	0,1365	40,96	23,2	28,8	28,6	36,9	36,9	29,6	15,6	-27,8	106,55
1	484	10,0	150,0	15,0	70,0	10,0	0,1400	40,90	23,2	28,7	28,2	37,0	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	180,0	15,0	70,0	10,0	0,1539	40,84	23,2	28,7	28,0	36,9	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	210,0	15,0	70,0	10,0	0,1418	40,79	23,2	28,6	27,9	36,8	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	240,0	15,0	70,0	10,0	0,1593	40,76	23,2	28,6	27,9	36,7	36,8	29,5	15,5	-27,9	106,55
1	484	10,0	270,0	15,0	70,0	10,0	0,1622	40,79	23,2	28,6	27,9	36,8	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	300,0	15,0	70,0	10,0	0,1692	40,85	23,2	28,7	28,0	36,9	36,8	29,6	15,6	-27,8	106,55

Stability in the report

If a range of stability conditions are set, a stability column is added to the Detailed results table.

NORD2000 - Detailed results

Calculation: Standard calculation

Calculation Results

Noise sensitive area: A Noise sensitive point: User defined (3)

WTG No.	Distance	Wind speed	Wind direction	Air temperature	Relative humidity	Wind speed at hub height	Shear	Stability	Sound level	63	125	250	500	1000	2000	4000	8000	Source noise LwA,ref
	[m]	[m/s]	[°]	°C	[%]	[m/s]			[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]
1	484	10,0	0,0	15,0	70,0	10,0	0,1008	0,0050	40,96	23,2	28,8	28,5	37,0	36,9	29,6	15,6	-27,8	106,55
1	484	10,0	30,0	15,0	70,0	10,0	0,0938	-0,0050	40,98	23,2	28,8	28,7	36,9	37,0	29,6	15,6	-27,8	106,55
1	484	10,0	60,0	15,0	70,0	10,0	0,0962	-0,0050	40,98	23,2	28,8	28,7	36,9	37,0	29,6	15,6	-27,8	106,55
1	484	10,0	90,0	15,0	70,0	10,0	0,090	-0,0050	40,97	23,2	28,8	28,6	36,9	37,0	29,6	15,6	-27,8	106,55
1	484	10,0	120,0	15,0	70,0	10,0	0,090	-0,0050	40,95	23,2	28,8	28,5	37,0	36,9	29,6	15,6	-27,8	106,55
1	484	10,0	150,0	15,0	70,0	10,0	0,0975	-0,0050	40,91	23,2	28,7	28,2	37,0	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	180,0	15,0	70,0	10,0	0,1040	-0,0050	40,86	23,2	28,7	28,0	36,9	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	210,0	15,0	70,0	10,0	0,0949	-0,0050	40,83	23,2	28,7	28,0	36,9	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	240,0	15,0	70,0	10,0	0,1081	-0,0050	40,81	23,2	28,6	27,9	36,8	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	270,0	15,0	70,0	10,0	0,1103	-0,0050	40,82	23,2	28,6	27,9	36,9	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	300,0	15,0	70,0	10,0	0,1168	-0,0050	40,86	23,2	28,7	28,1	36,9	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	330,0	15,0	70,0	10,0	0,1171	-0,0050	40,91	23,2	28,7	28,3	37,0	36,8	29,6	15,6	-27,8	106,55
1	484	10,0	0,0	15,0	70,0	10,0	0,1497	0,0000	40,97	23,2	28,8	28,6	36,9	36,9	29,6	15,6	-27,8	106,55
1	484	10,0	30,0	15,0	70,0	10,0	0,1403	0,0000	40,99	23,2	28,8	28,8	36,8	37,1	29,6	15,6	-27,8	106,55
1	484	10,0	60,0	15,0	70,0	10,0	0,1435	0,0000	41,00	23,2	28,8	28,9	36,8	37,1	29,6	15,6	-27,8	106,55
1	484	10,0	90,0	15,0	70,0	10,0	0,1365	0,0000	40,99	23,2	28,8	28,8	36,8	37,0	29,6	15,6	-27,8	106,55
1	484	10,0	120,0	15,0	70,0	10,0	0,1365	0,0000	40,96	23,2	28,8	28,6	36,9	36,9	29,6	15,6	-27,8	106,55

The additional page on the Detailed results, graphic option can be used to include stability. In the above example the two parameters shown on the additional page are wind direction and stability. The stability results are shown for the worst wind direction (here 300˚.

Report Setup — □ ✕

Reports	Pages
☑ Main results	1
☑ Detailed results	1
☑ Detailed results, graphic	1
☑ Assumptions for NORD20…	1
☑ Map:	1

Detailed results, graphic

☑ Include custom graph

Select dimension: Wind direction ▾

For worst dimension in bin: Stability ▾

☐ Watermark DRAFT

Report language

English ▾

Preview	Settings...
PDF file	Print setup
Print	Result to file

Ok	Cancel

NORD2000 - Detailed results, graphic

Calculation: Standard calculation

Noise sensitive point: User defined (11)
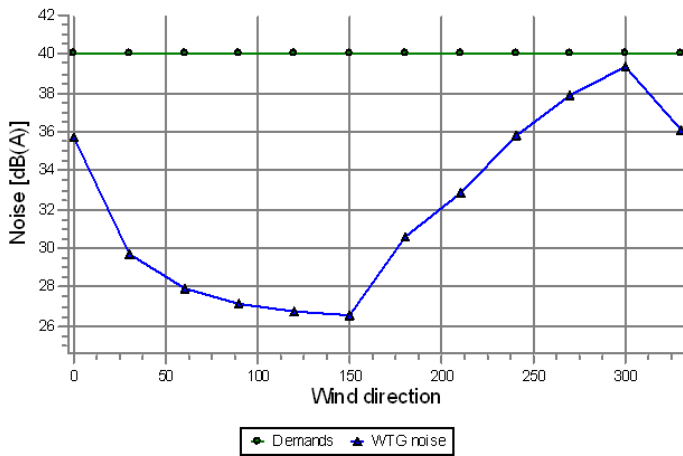
Sound level, Max impact Stability: -0,0050

Wind direction [°]	Demands [dB(A)]	WTG noise [dB(A)]	Demands fulfilled ?
0	40,0	35,7	Yes
30	40,0	29,7	Yes
60	40,0	27,9	Yes
90	40,0	27,2	Yes
120	40,0	26,8	Yes
150	40,0	26,6	Yes
180	40,0	30,6	Yes
210	40,0	32,9	Yes
240	40,0	35,8	Yes
270	40,0	37,9	Yes
300	40,0	39,3	Yes
330	40,0	36,1	Yes
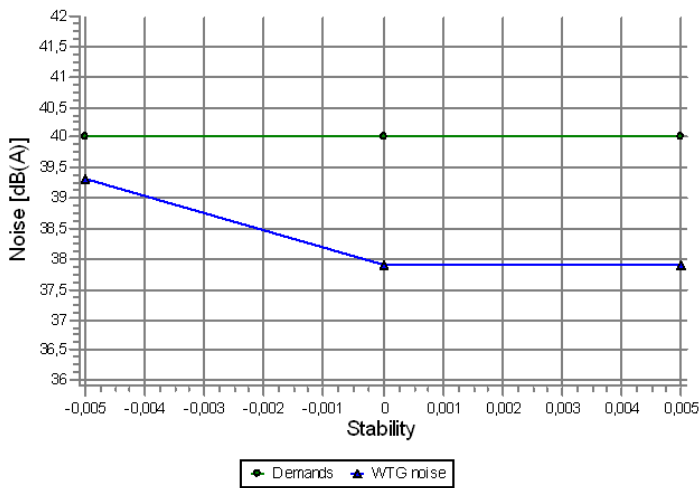
Sound level, Max impact Wind direction: 300 [°]

Stability	Demands [dB(A)]	WTG noise [dB(A)]	Demands fulfilled ?
-0,0050	40,0	39,3	Yes
0,0000	40,0	37,9	Yes
0,0050	40,0	37,9	Yes

Calculated noise [dB(A)]

Wind direction [°]	Stability -0,0050	0,0000	0,0050
0	35,7	35,7	35,7
30	29,7	29,7	29,7
60	27,9	27,9	27,9
90	27,2	27,2	27,2
120	26,8	26,8	26,8

6.5.6.2   Statistical analysis report

The statistical noise option has been temporarily removed from windPRO 4.0.

To run a statistical calculation, please refer to WindPRO 3.6.

6.5.6.3   Swedish low frequency report

Main result

The main result includes an A-C weighting test (calculated as C – A weighting sum difference). It is tested against the threshold value.

Also the most critical frequency is reported in the calculation against the reference spectrum
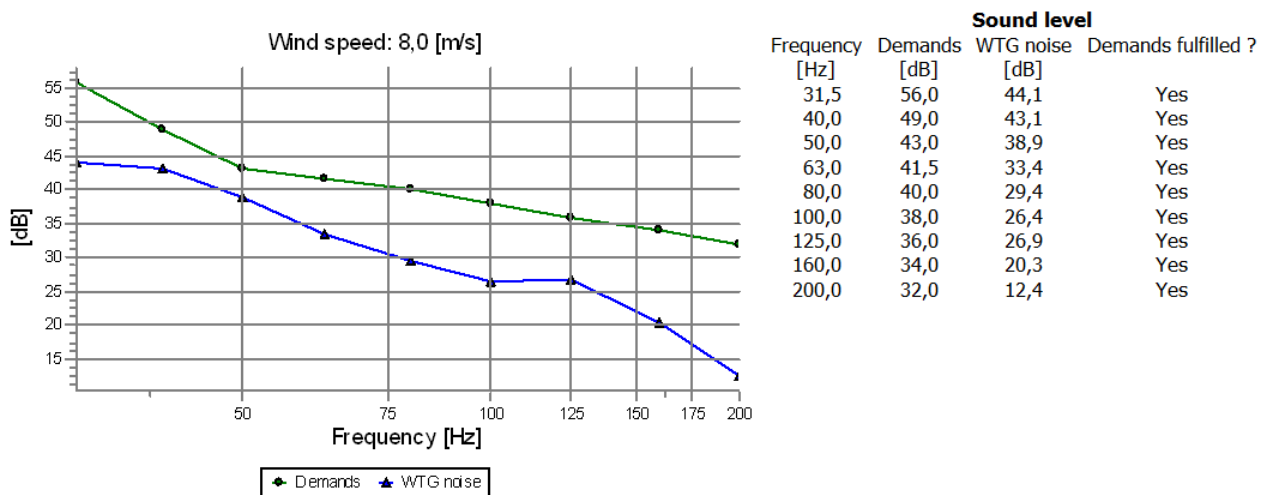

Detailed results, graphics

Graphical presentations are included for each receptor of the calculated spectrum against the reference spectrum. Both are presented un-weighted.

Each frequency is tested against the threshold value. All results must be beneath the threshold for the receptor to pass the test.

6.5.7   References

Plovsing, B. and Søndergaard, B., PSO-07 F&U project no. 7389, Noise and energy optimization of wind farms, DELTA Acoustics, Report AV 1238/09, 2009.

Madsen, K.D., Plovsing, B, Sørensen, T, Madsen, H.A. and Bertagnolio, F, EFP07-II, Project no. A580841, Noise emission from Wind turbines in wake, DELTA Acoustics, Report AV 110/11, 2011.

Sørensen, T., Nielsen, P., Villadsen, J., Plovsing, P., Implementation of the Nord2000 Model for Wind Turbines: New Possibilities for Calculating Noise Impact, 3rd International Conference on Wind Turbine Noise, 17th-19th June 2009, Aalborg, Denmark.

Plovsing, B: Proposal for a Nordtest Method: Nord2000 – Prediction of Outdoor Sound Propagation, DELTA Acoustics Report AV 1106/07, 2007, revised 2010

Plovsing, B. and Søndergaard, B., Prediction of Noise from Wind Farms with Nord2000. Part 1, 3rd International Conference on Wind Turbine Noise, 17th-19th June 2009, Aalborg, Denmark.

Vägledning om buller från vindkraftverk, Naturvårdsverket, 2020

Vägledning om buller inomhus och höga ljudnivåer, Folkhälsomyndigheten, 2019

Folkhälsomyndighetens allmänna råd om buller inomhus, FoHMFS 2014:13, Folkhälsomyndigheten, 2014

Vejleder M-128, Miljødirektoratet, 2021

Eurasto, R. NORD2000 for road traffic noise prediction. Weather classes and statistics, No. VTT-R-02530-06, VTT Technical Research Centre of Finland, 2006.

## 6.6 GLARE – Reflections from PV Panels and 3D Objects

6.6.1 GLARE – Introduction

GLARE is a windPRO module that calculates and documents the impact of glare from PV panels and 3D objects on the surroundings. The GLARE calculation provides information about the time, length and intensity of reflections from PV panels and 3D objects visible at a specified receptor.

Glare and glint are defined as unwanted reflections of the Sun's rays by the face of a reflective surface. Glare is a continuous source of bright light and is experienced by static or slowly moving receptors. Glint is a momentary flash of bright light and is experienced by moving receptors. Calculations in windPRO are done for static receptors, hence the module name – GLARE.

Calculations of Glare are often needed when new solar PV plants are planned. Depending on country regulations or local requirements, limits can be imposed on the maximum duration of glare experienced by neighboring buildings, roads etc.

The GLARE module in windPRO allows users to assess the expected glare duration and analyze how different configurations of solar PV plant or other reflecting objects will influence the nearby locations.
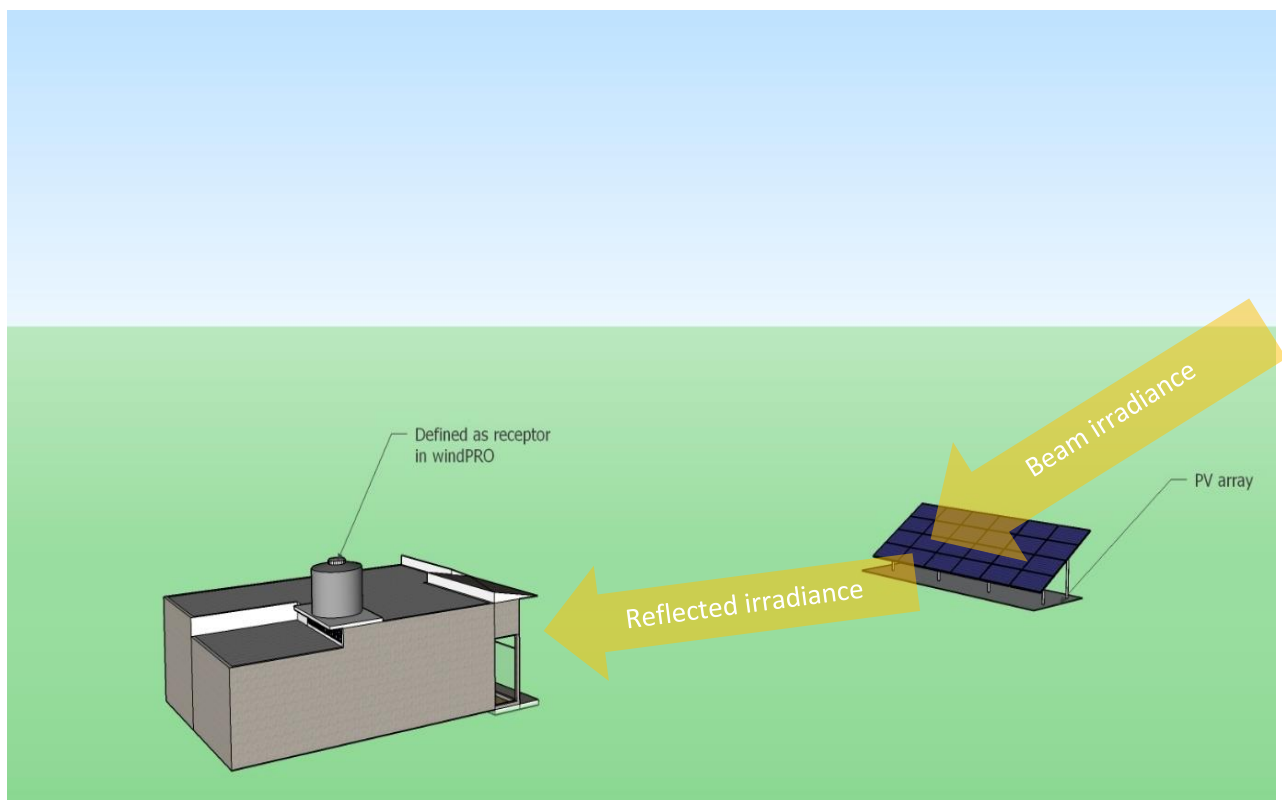

6.6.2 GLARE – Calculation Methods

The GLARE calculation is performed for specified reflectors (solar PV areas, 3D objects) and receptors. It is based on a 3D model of the Sun, reflector and receptor positions. The Sun's positions, for which glare can be observed at a receptor, are found by:
1. Drawing a ray from the receptor to each of the corners of a PV table or corners of 3D object,
2. Reflecting the ray with the same angle from normal to the PV table,
3. Finding the Sun's position for which this reflection will happen (here impossible Sun positions are discarded),

4. Translating the identified Sun position to a time series of glare.

The geometry of the calculation is shown here:
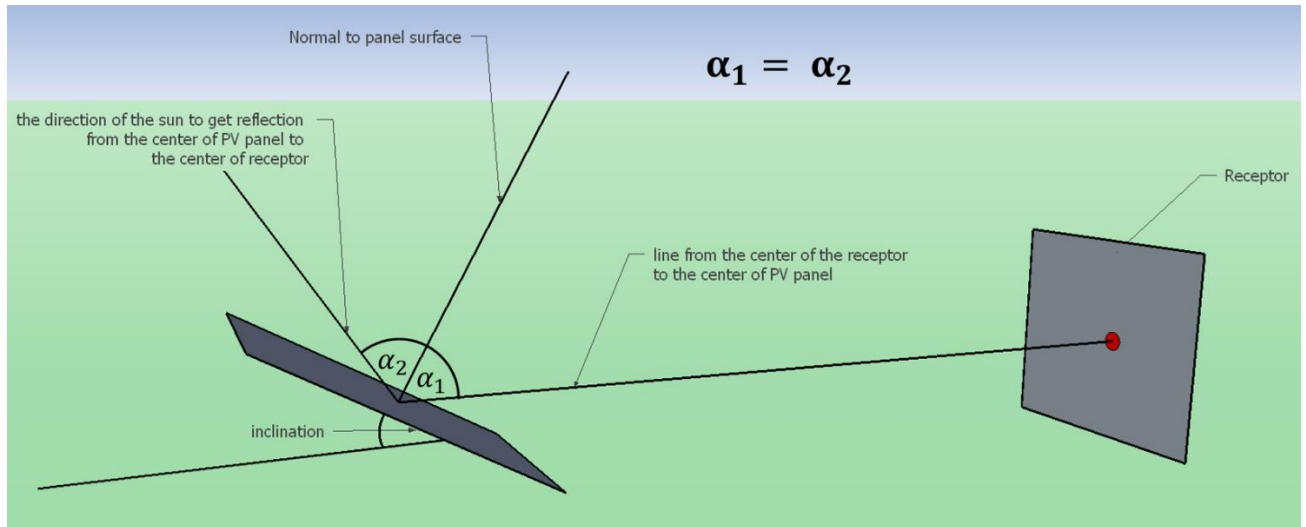
The intensity calculation is based on the identified incidence angles for which glare is observed. Having this information, depending on the specified surface reflectivity, the reflection intensity is calculated.

The intensity calculation is required as part of glare assessments in some countries. In Switzerland, the regulations specify that glare should only be considered a disturbance if the power density of reflection is greater than 30 W/m² and the luminance of the reflection is greater than 50 000 cd/m². In France, for pilots, a luminance above 20,000 cd/m² must be avoided in a field of vision of +/-30°. A luminance above 10,000 cd/m² is prohibited in a field of vision of +/-1°. The intensity of reflection in the GLARE module is calculated as an hourly value expressed in W/m².

6.6.3   GLARE – Input to the Calculation

6.6.3.1   Input of Elevation Data

Elevation data are entered in a line object/elevation grid object by loading a data file containing the contour lines/gridded elevation data in an appropriate format or by digitizing the curves directly on-screen with the mouse (line object only).

See Sections 2.8 and 2.10 in windPRO BASIS for detailed guidance.

Elevation data are used to determine the exact position of PV panels, 3D objects and receptors.
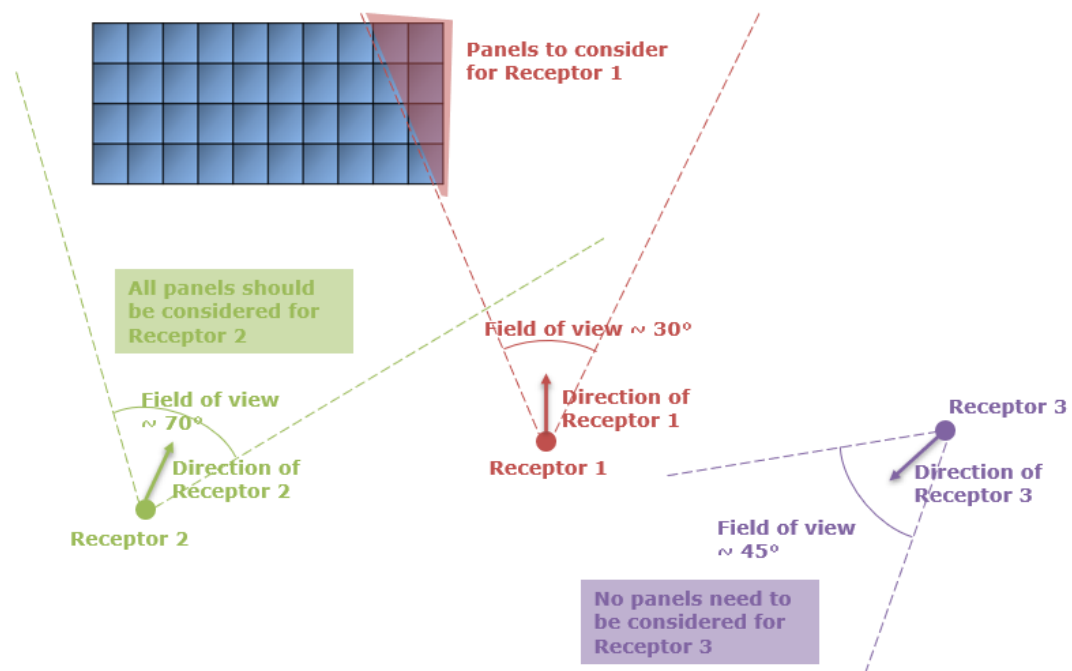
6.6.3.2   Glare Receptor

The Shadow/Glare receptor object has an optional setting called Glare receptor. The Shadow/Glare receptor object can be used for Shadow and Glare calculations, and also for both at the same time if the Shadow receptor is "Defined from center".

New glare receptors can be inserted by using the object icon 🔧 and placing it on the map. The exact location and identifying name can be specified on the Position tab. For the receptor to be considered a Glare receptor the checkbox "Use for Glare Calculation" must be selected in the Glare tab.
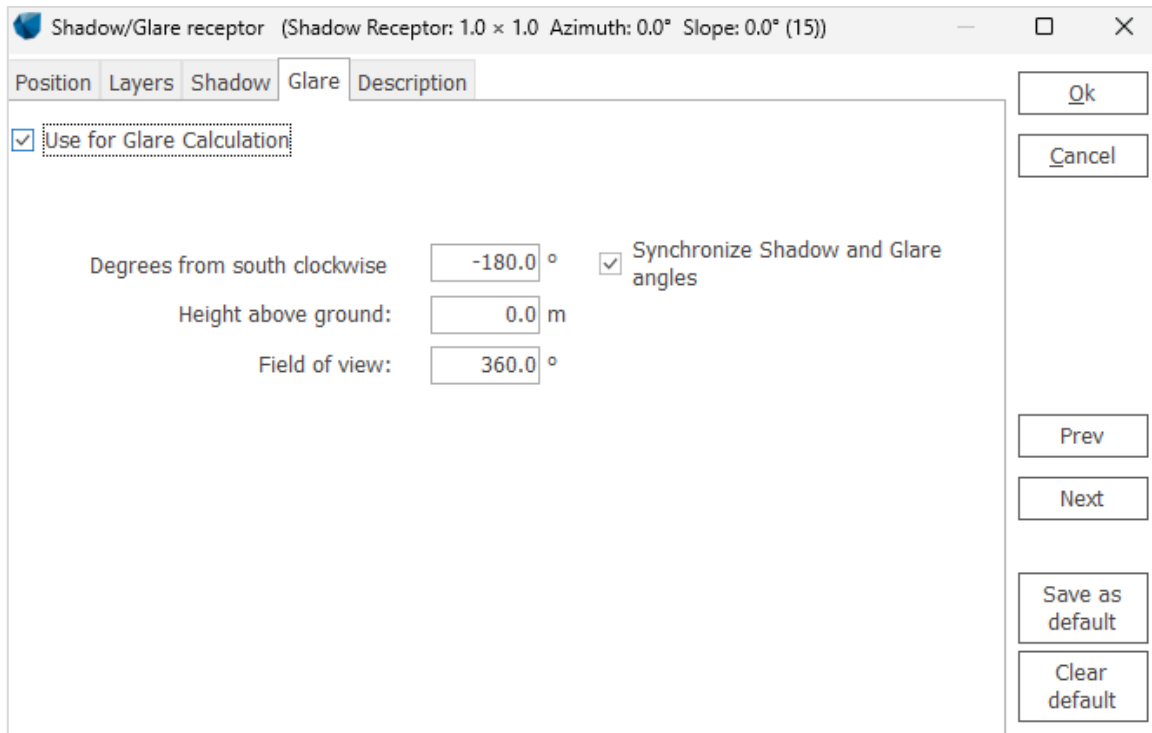
The following parameters need to be specified:
- **Degrees from south clockwise** [°] – defines the direction of Glare receptor. If the checkbox "Synchronize Shadow and Glare angles" is chosen, this parameter will be synchronized for Shadow and Glare receptor.
- **Height above the ground** [m]– height above the ground of the Glare receptor.
- **Field of view** [°] – defines the field of view for which Glare will be considered. It is an angle, which middle is defined by the direction of the receptor (Degrees from south clockwise). This is a common parameter specified in the regulations, where glare should be considered only for a specific field of view, e.g., in France glare should be avoided in +/- 30° - field of view of 60°.

Glare receptor icon on the map
The receptor can be used for both shadow and glare calculation or for any of these separately. If it is used for both shadow and glare and the angles are not synchronized, the orientation on the map is controlled by the

settings for the shadow receptor. Nevertheless, it is possible to view the orientation and view angle of the glare receptor when clicking on it. View angle is illustrated by an angle, which middle is determined by the parameter "Degrees from south clockwise", and angle by the value entered in the view angle field.

Example:
Receptor used for shadow and glare.

For shadow calculation:
Degrees from south clockwise: 180°

For glare calculation:
Degrees from south clockwise: 60°, view angle: 60°

The receptor, when selected, will be represented as:

6.6.3.3   3D Objects

3D objects can be inserted by using the 3D Object icon and placing it on the map. The exact position and identifying name can be specified on the Position tab. The color of the object can also be changed in that tab and is used for plotting glare from the 3D object.
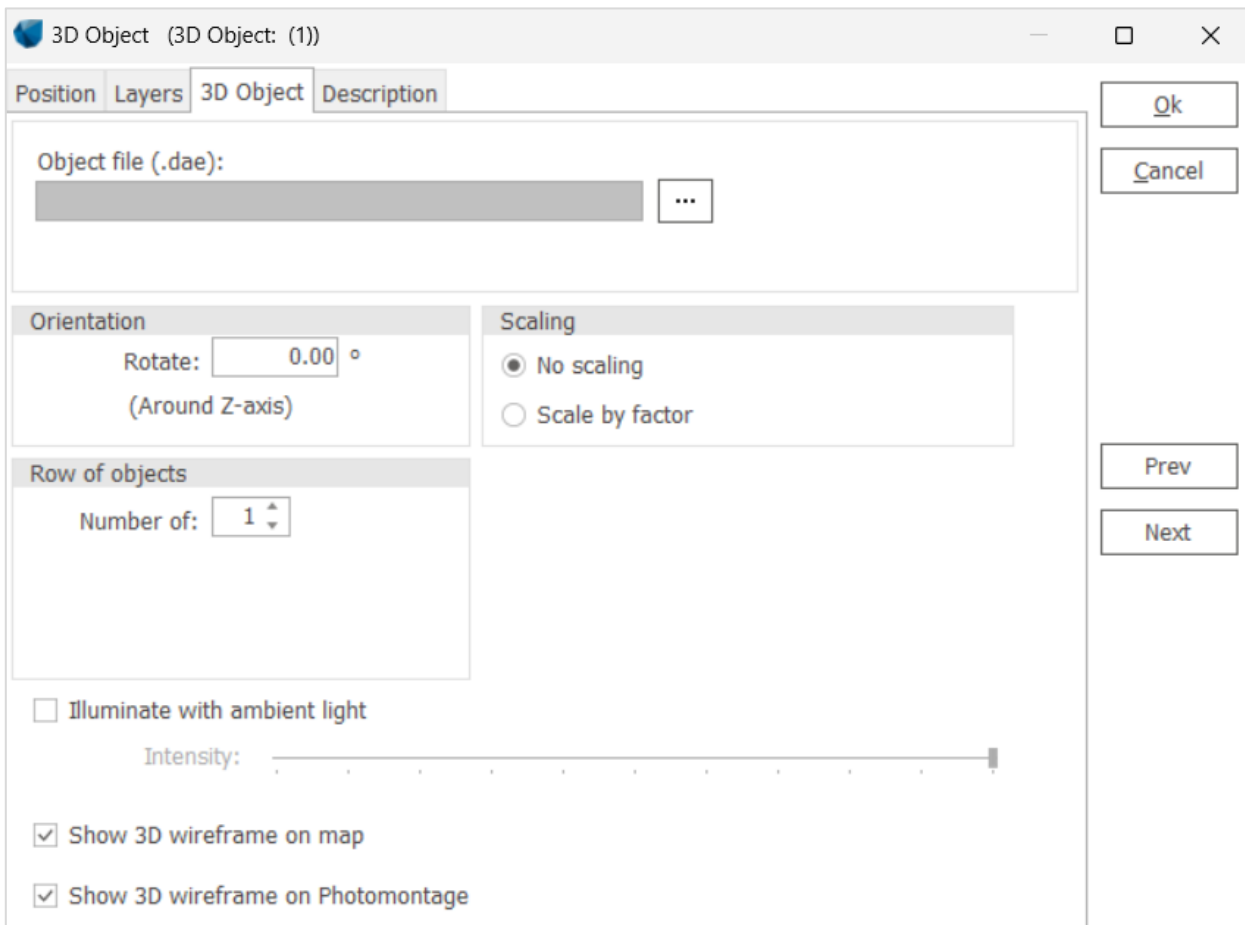
When inserting a 3D object, the following needs to be specified:
- **Object file** (.dae) – the file contains a 3D model of the object. For use in Glare calculations two predefined files are included in windPRO

o   Vertical rectangle – can represent windows of buildings or glass facades
o   Cube – can represent glass buildings
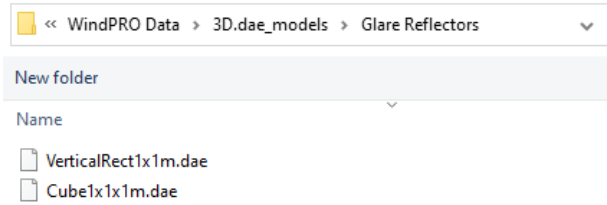
The size of the predefined 3D models is set to be 1m in each dimension. This allows for easy scaling of the object.

- **Orientation** – specifies how the object is oriented on the map. It is easy to modify the orientation of the object interactively on the map.
- **Scaling** – allows to scale each dimension. With the predefined objects for glare, it is easy to scale to correct size by simply entering the correct size as scaling.
- **Row of objects** – this setting allows to place multiple identical objects in a row.
- **Illuminate with ambient light** – this setting is not relevant for GLARE calculation.

6.6.3.4   Solar PV Areas

To calculate glare from PV areas, a Solar PV object must be inserted in windPRO. This is done by placing the Solar PV object icon 🔶 on the map. It is important to specify the solar PV areas accurately, since the parameters of tilt, azimuth and row spacing will have a significant influence on GLARE calculation.

Setting of area color will have influence on glare graphical representation in the reports.

For details about creating solar PV areas please see Chapter 14. SOLAR-PV, Section 14.4.

6.6.4   GLARE – Calculation and Printout

A GLARE calculation is started from the Environment & Visual tab of the ribbon.
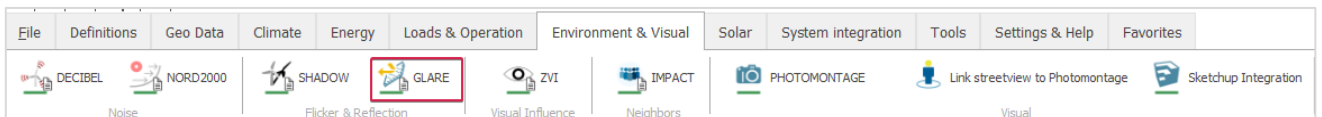
If the bar below the icon is green, it is possible to perform a calculation. If it is yellow, license for the module is needed.

6.6.4.1   Setup and Calculation

In the Main tab, it is possible to select what should be included in the calculation and the settings for the calculation.

The name of the GLARE calculation can be specified in the Name field.

The calculation of glare occurrence will always be done. The calculation will consider all hours in the calculation and calculate worst case scenario - no cloud cover or any reduction is considered in the calculation. Additionally, it is possible to include two more options:

- **Include beam spread** – beam spread will be included in the calculation. This setting will consider that the reflection from the surface is not ideal. See explanation in the following sections.
- **Include intensity of glare** – intensity of the reflection will be calculated together with the glare occurrence calculation. Depending on selected settings, the calculation can be performed for worst case or with a more realistic assumption – more details in the description of Irradiance input tab. Note that in the current windPRO version, the result for reflected irradiance is only available in Result to file.

Advanced settings can be specified for the calculation. If the checkbox is not selected, the default settings will be used. In the advanced settings it is possible to set:

- **Distance limit** – glare coming from PV panels further away from the receptor will not be considered.

- **Grid resolution** – refers to the grid of Sun positions in the sky. This setting is used for calculation of timesteps with glare. If a reflection is found to be in a specific grid cell (Sun position within the specified resolution), the time steps associated with this grid cell will be considered as the ones during which glare is visible. The finer the grid, the more accurate the result. With coarse grid, the results will overestimate glare duration. The default setting of 0.05° provide good accuracy and should not be too demanding for modern computers.

- **Timestep for calculation** – defines the timestep used for glare calculation.

- **Glare is not considered if the angle between reflection and the Sun is less than** – this setting allows to disregard glare coming from similar direction as the Sun. This is often mentioned in regulations, e.g. in Germany: "For the times of immission, only those times shall be considered, during which the line of vision towards the Sun and towards the PV panel differs with a minimum of 10°". Hence, this setting should be changed to 10° to follow the regulation.

- **Reference year** – allows to produce result with timestamp of the selected year. If not set, the results will be shown with a 1990 timestamp.

Receptors to be used in the calculation need to be specified in the Receptors tab. All Shadow/Glare receptors, which are set to be used in glare calculation will be available in this window. The user can select multiple receptors for a calculation.
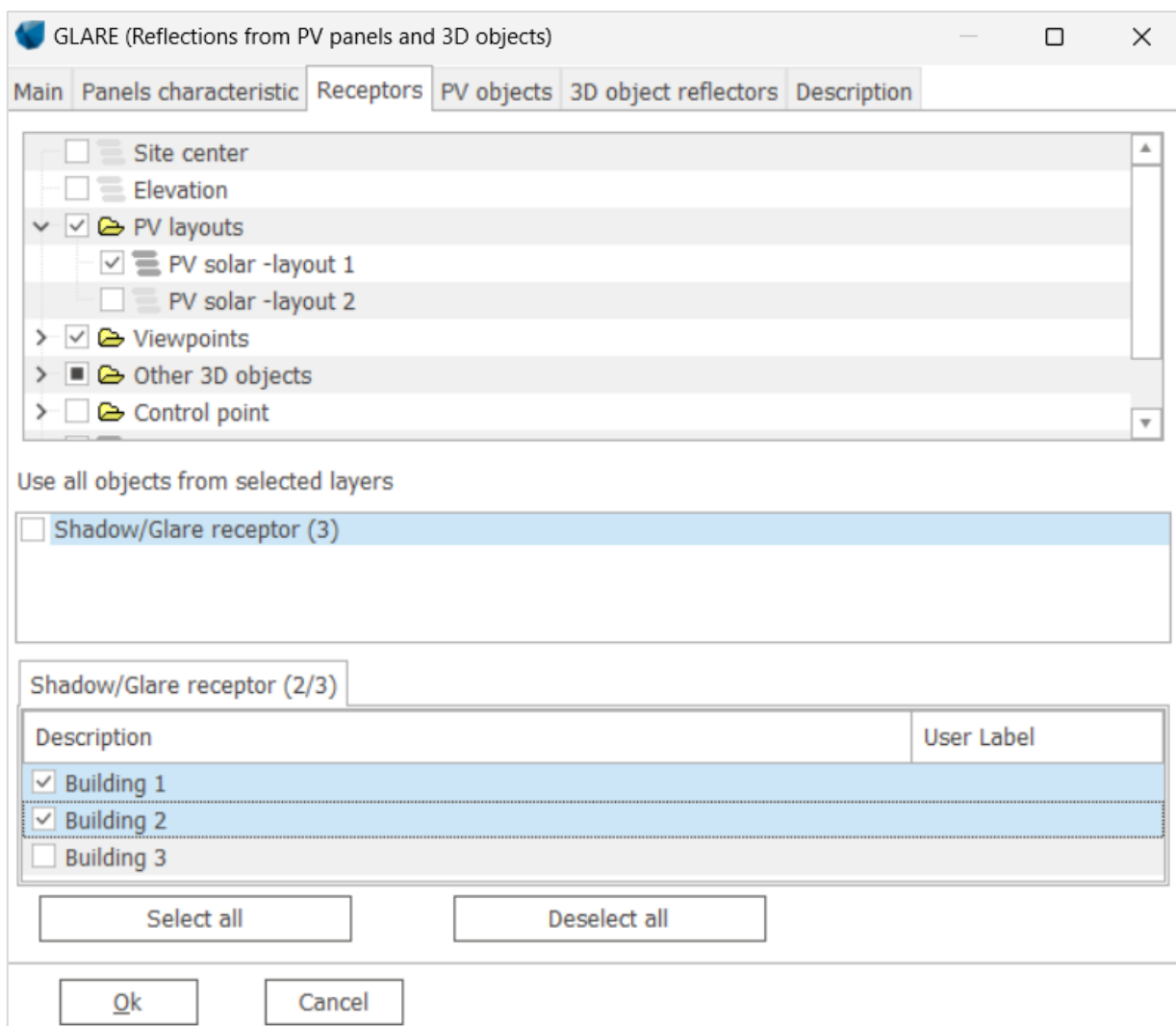
The PV objects to be used as reflectors in glare calculation can be selected in PV objects tab and the 3D objects in 3D object reflectors. Multiple PV objects and 3D objects can be selected for a calculation.

If "Include beam spread" or "Include intensity calculation" are selected, a new tab will be available – **Panel characteristic**:
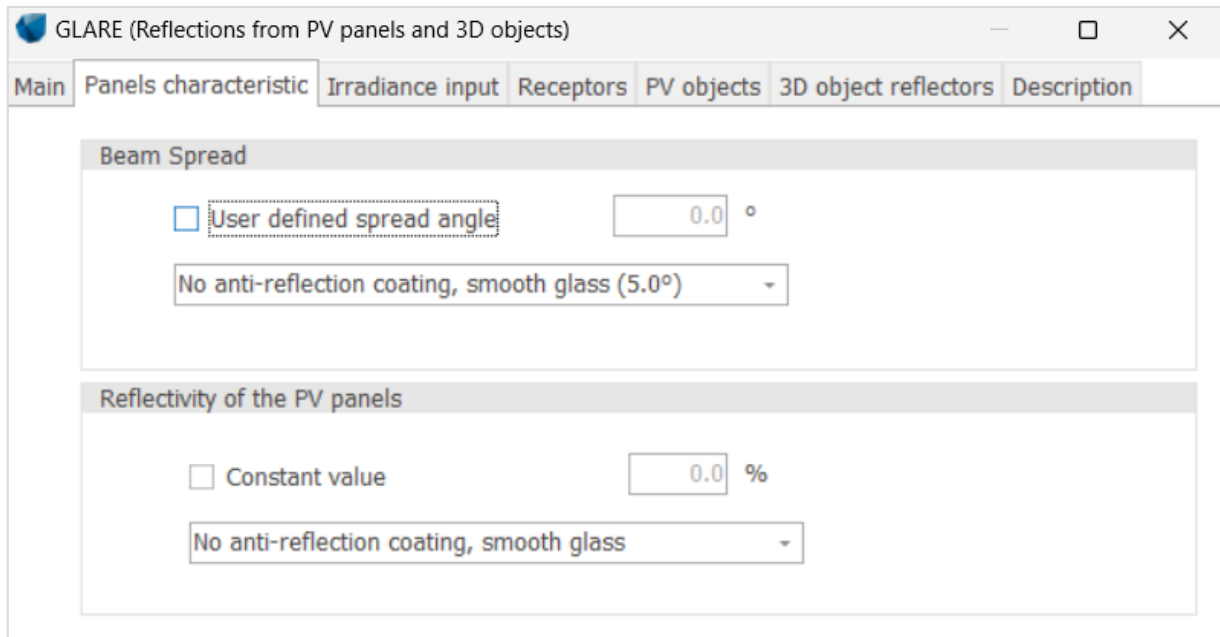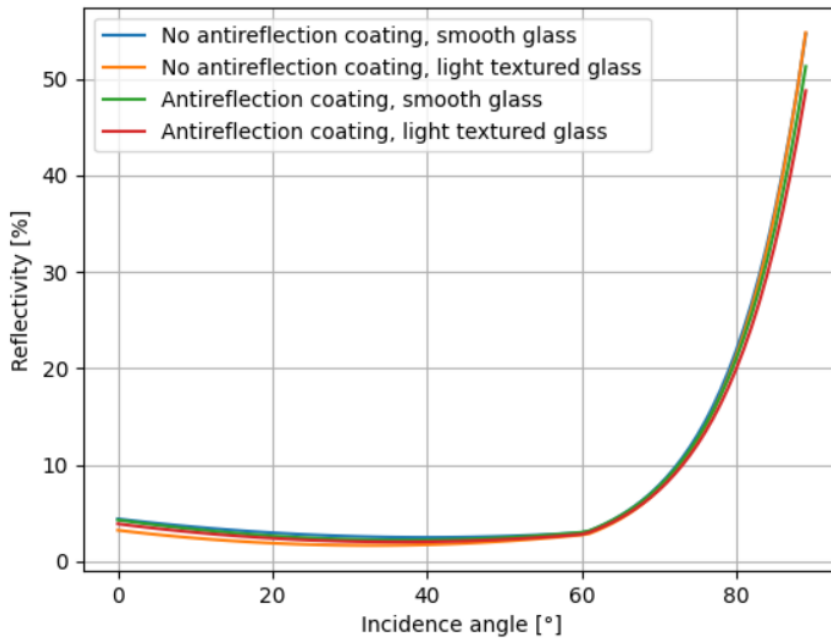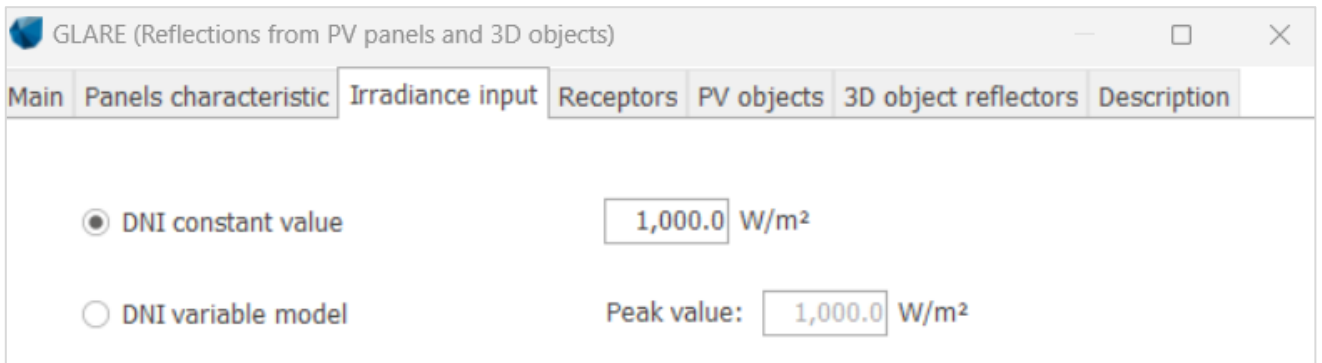
Here it is possible to specify:

- **Beam Spread** - it can be a user defined value, or a value chosen from a dropdown list for different types of glass coating. This parameter describes how big the reflection of the Sun from the surface will be. The less smooth the surface, the bigger the reflection will appear
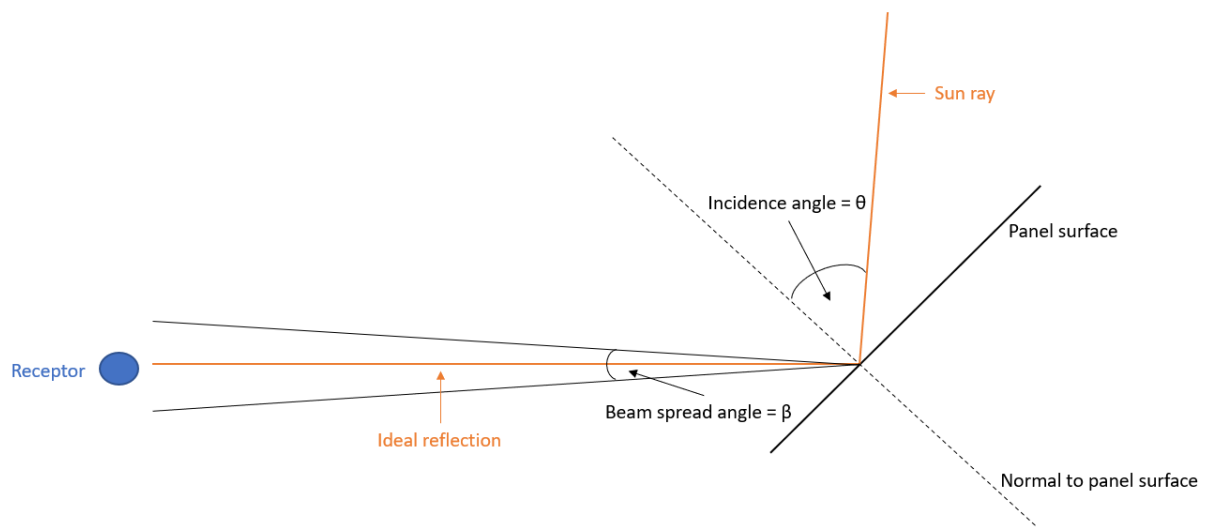
- **Reflectivity of the PV panels** – it can be entered as a constant value, or a reflection characteristic depending on the glass type:

If "Include intensity of glare" is selected a new tab is available – **Irradiance input**:

Here it is possible to select which input should be used for irradiance in the intensity calculation. The following are available:

DNI constant value
The direct normal irradiance (DNI) used in the calculation of reflected irradiance will be constant throughout the day and equal to the specified value. This method will result in overestimation of the intensity if the user enters peak DNI value, because the same will be used in all hours.

DNI variable model
The variable direct normal irradiance (DNI) feature (if selected) scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a Sun-position algorithm and the latitude and longitude
The equation for finding the variable DNI is:

$$I_{DNIvar} = \cos{(1 - t_s)}$$

Where:

t_s represents the normalized time relative to solar noon. Normalization is based on the amount of time between sunrise or sunset and solar noon.

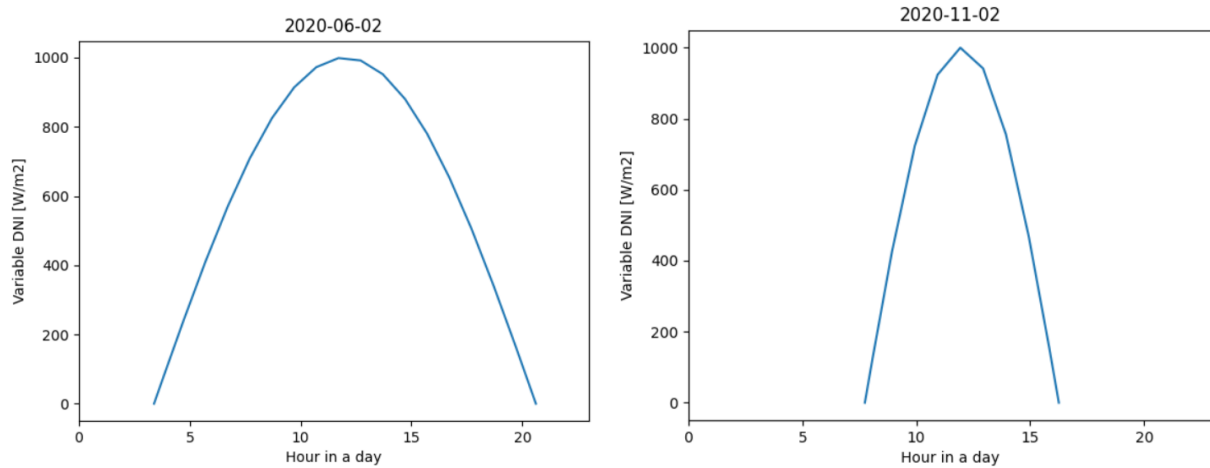t_s is calculates based on the following formula:

$$t_s = \frac{\frac{\pi}{2}}{t_{sunrise} - 12} \cdot t_{TST} + 1 - \frac{6\pi}{t_{sunrise} - 12}$$

Where:

$t_{sunrise}$ is the time of sunrise
t_{TST} is the true solar time

The resulting irradiance profiles for two sample days for a location in Denmark:

The variable DNI method will result in a smaller overestimation of glare intensity compared to the constant DNI method. Glare intensity will be particularly overestimated for winter months if a fixed DNI is used.

Running the calculation
Once all the necessary inputs are specified, the calculation can be started by clicking "OK".

6.6.4.2   **Results/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/viewed.

In a GLARE calculation, four main reports are available:

Main result
This report provides the list of inputs and assumptions used in the calculation together with main results.
The first section summarizes the calculation setup settings together with a map with relevant receptors and reflectors included:

GLARE - Main result

Setup

Distance limit   3000m
Grid Resolution   0.05°
Time Step   1 minutes
Low angle limit   0.0°

All coordinates are in
Geo [deg]-WGS84

Scale 1:10,000
🐾 Shadow receptor   ⟐ 3D Object
🐾 Solar PV

The second part summarizes the inputs about receptors and reflectors:

Solar areas

Solar data:

Area description	Size	Number of PV panels	Tilt angle [°]	Orientation [°]	Table size	Row spacing [m]
Area_1	1.6 ha	4854	39.6	90.0	1.96x2.97m	5.0
Sum	**1.6 ha**	**4854**				

3D reflector objects

3D reflector input

No.	Name	Longitude	Latitude	Z [m]	Rotation [°]
1	3D Object: Cube 1x1x1m.dae (3)	10.008631° E	56.970714° N	27.8	-10.0

Glare Receptors

Glare receptor input

No.	Name	Longitude	Latitude	Z [m]	Degrees from south cw [°]	View angle [°]
1	Glare Receptor: Azimuth: -180.0° Field of view: 360.0° (1)	10.008008° E	56.970585° N	27.3	180.0	360.0

The last part summarizes the main results – maximum glare duration and overall glare duration in a year at each receptor:

Calculation result

Glare receptor

| No.	Name	Total time with glare in a year [h/year]	Maximum daily glare duration [min/day]	Day with max glare duration [Date]
1	Glare Receptor: Azimuth: -180.0° Field of view: 360.0° (1)	98.8	51.0	2 May 07.11-08.02

Occurrence Sun angles

This report illustrates when glare will be visible at a receptor based on the Sun position,(Sun altitude on Y-axis and azimuth on X-axis. The blue, pink, brown, green and red lines show the different possible Sun positions on 21st of December, 21st of February and October, 21st of March and September, 21st of April and August and 21st of June respectively. The red "eights" are analemmas, which show the Sun position in specific hours over the year. One graph is produced for each receptor and glare from different reflectors is plotted with a color assigned to that object.

In the example below, glare comes from two objects, green and blue. Glare from the blue object will be visible for low Sun altitudes around March and September, both in the early mornings and late evening, whereas, glare from the green object will be visible for higher Sun altitudes from April to August.
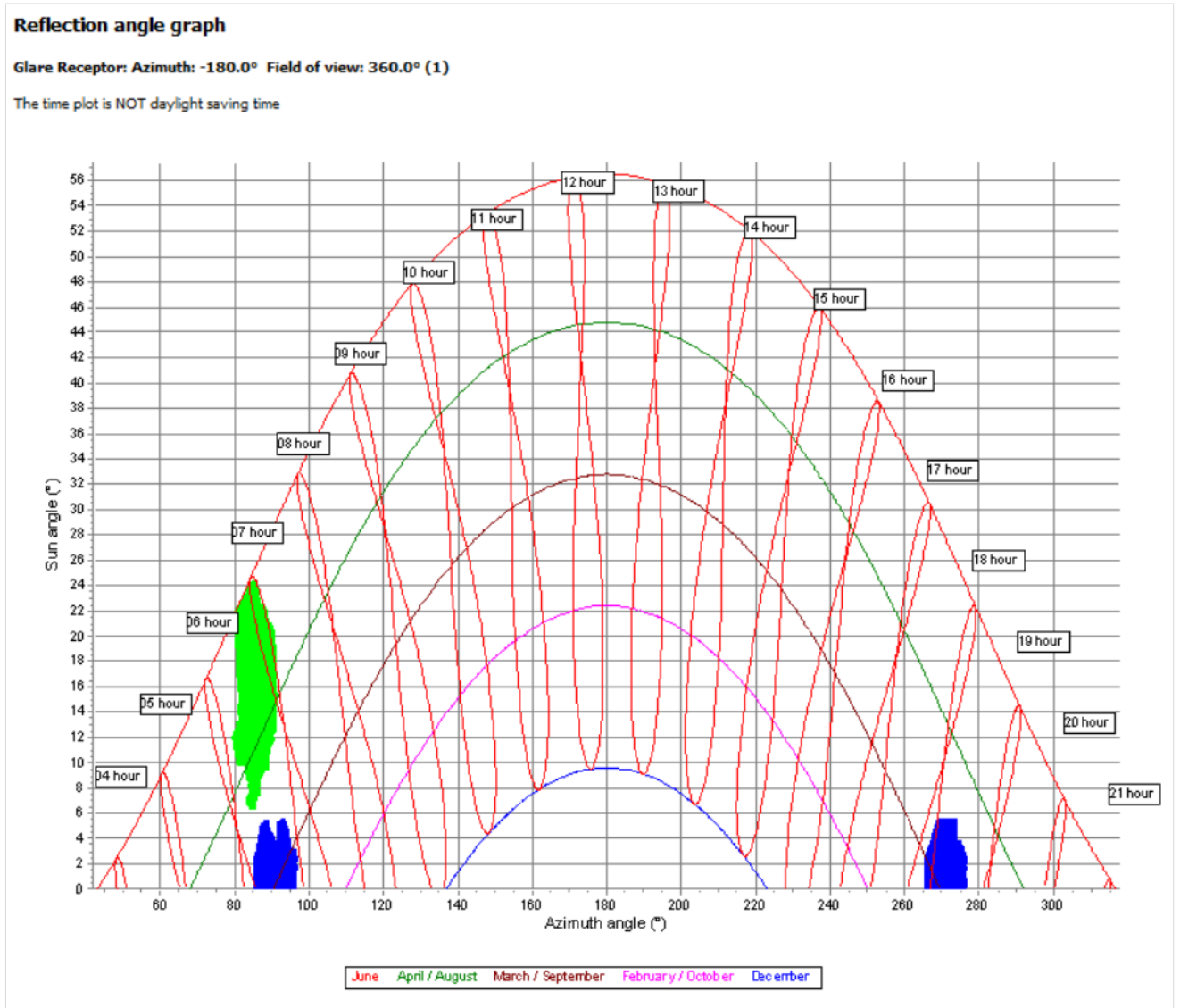

Occurrence time

This report is similar to the Occurrence Sun angles report. It is constructed based on the same data, but the graph is represented in a more understandable form (for the majority of the users). The Sun altitudes and azimuths are translated to specific hours and dates. This way it is possible to get a quick overview of when glare will be visible at the receptor location. One graph is produced for every receptor in the calculation and glare time is colored according to the settings on the reflector object causing the glare. Time when glare can be observed is marked on a graph for each hour, every day of the year:

Glare - Calendar, graphical
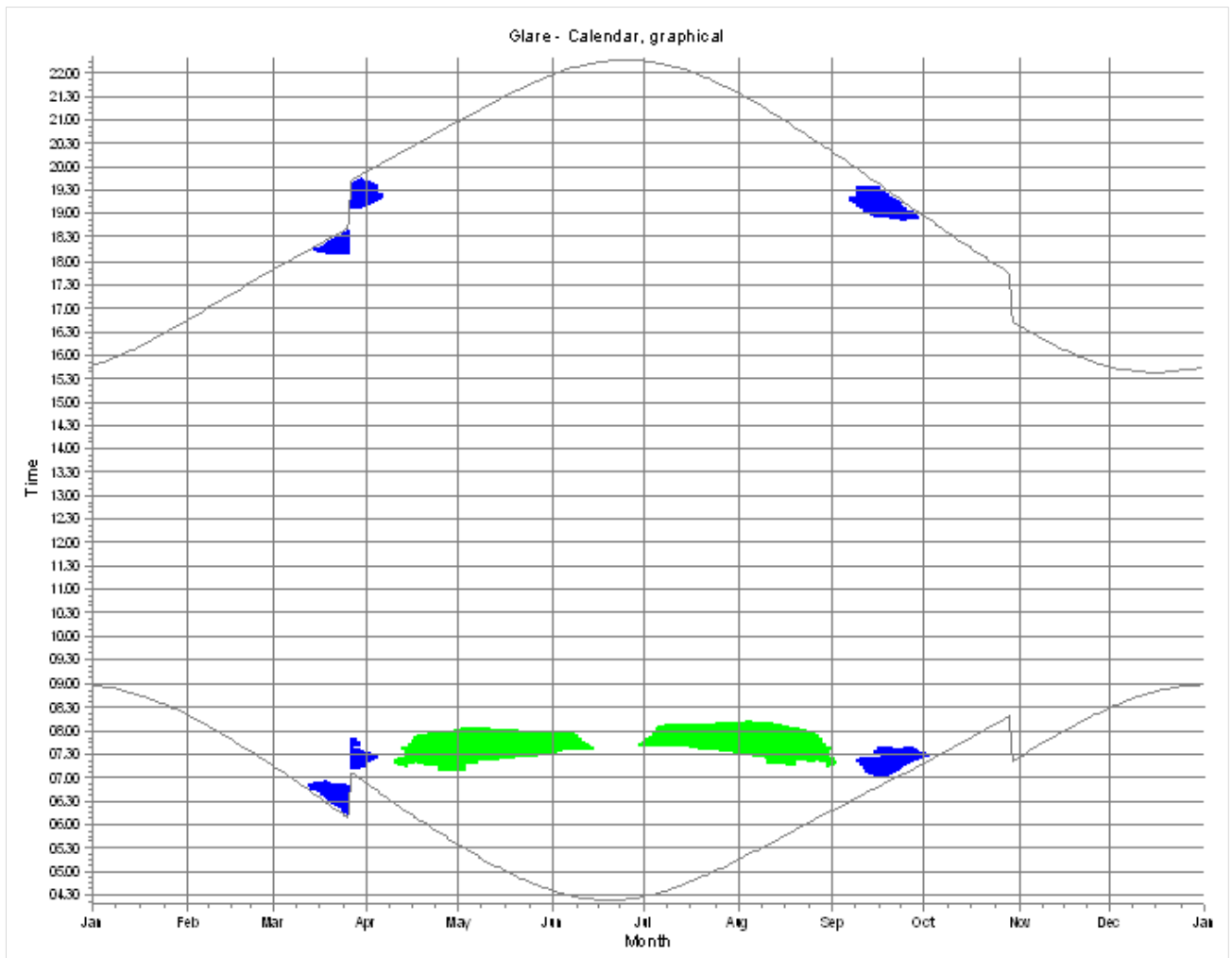
The grey lines represent the sunrise and sunset times, considering daylight saving times.

Map
The final report is a map. The map includes all objects used in the GLARE calculation. Moreover, the panels causing glare are highlighted in yellow on the map.
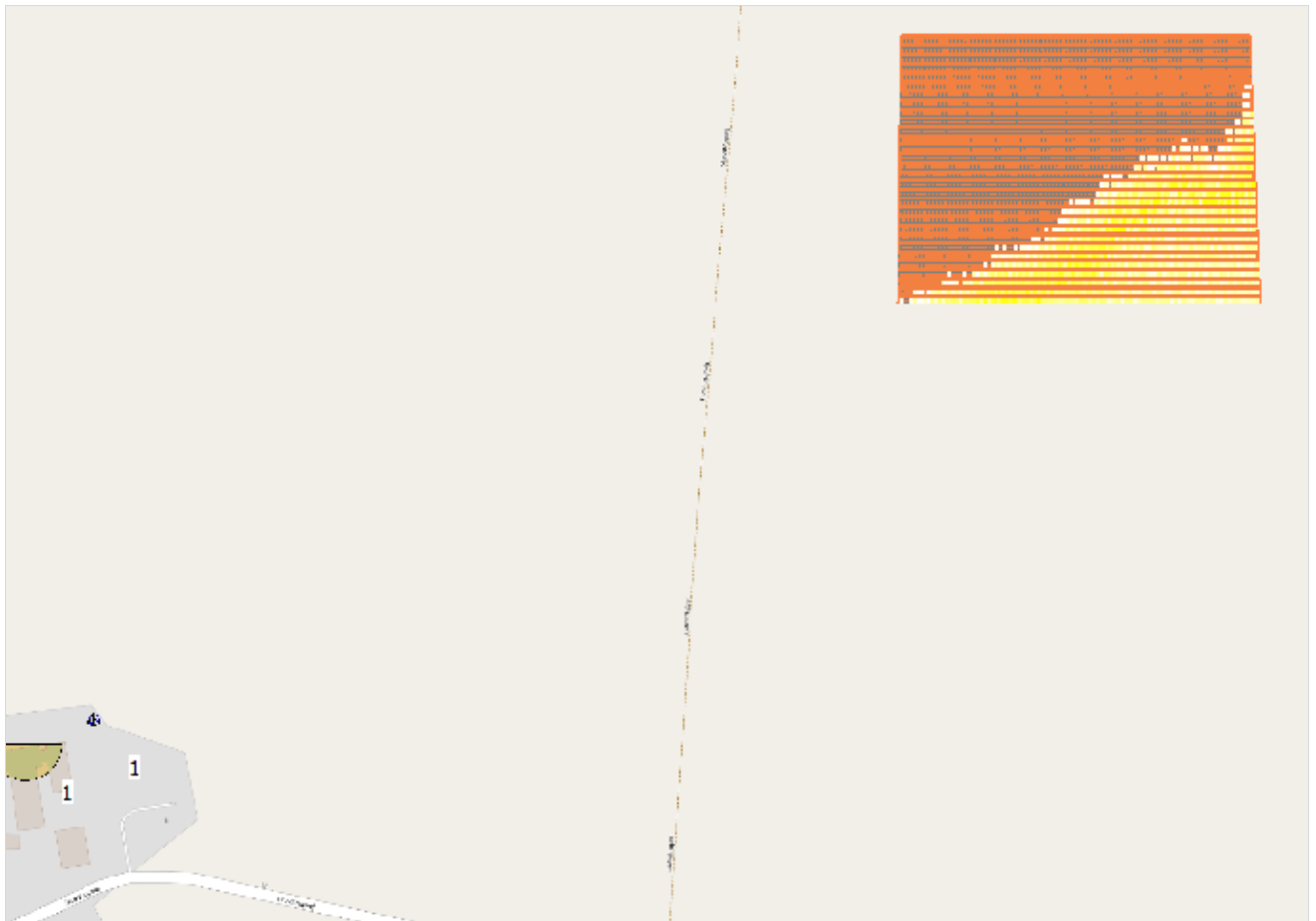
Result to file

Apart from reports, a result to file is also available in the GLARE module. It enables the user to export the glare time-series for each of the receptors separately:
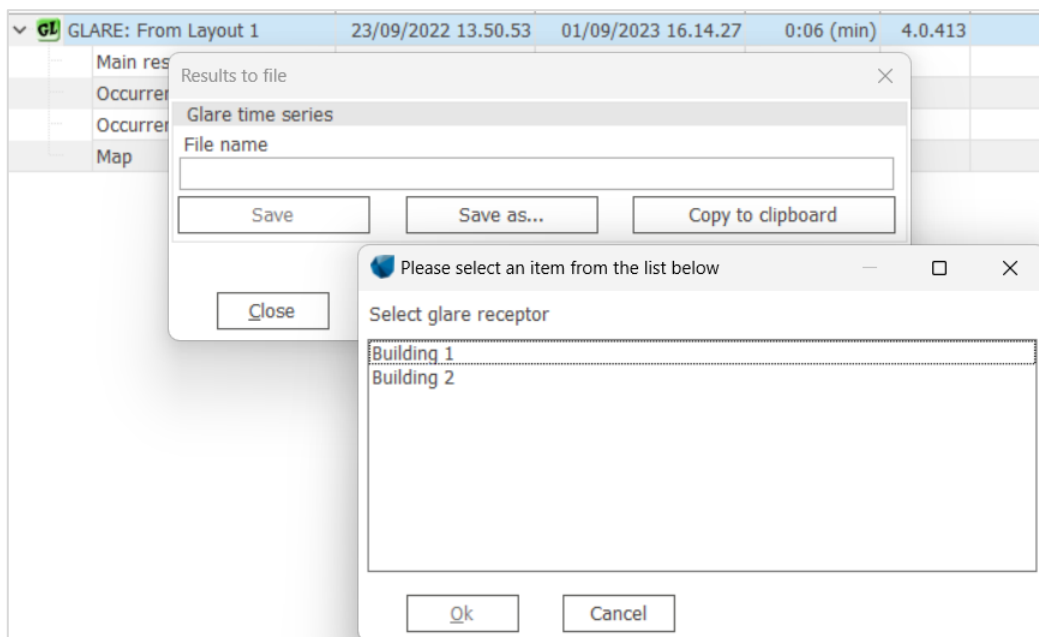
It contains a list of timesteps for which glare can be observed at the receptor, for each timestep the following information are recorded:

- Time – time of glare, resolution depends on the settings, default – 1min
- Glare table count
- Incidence angle
- Sun azimuth
- Sun altitude
- Reflected irradiance

6.6.4.3 Quick preview

Apart from a full calculation with possibility to modify the settings, choose objects and create reports, a feature of quick glare preview is available in windPRO.

When a Glare receptor is added to the map, it is possible to right click on the receptor and select Show glare:
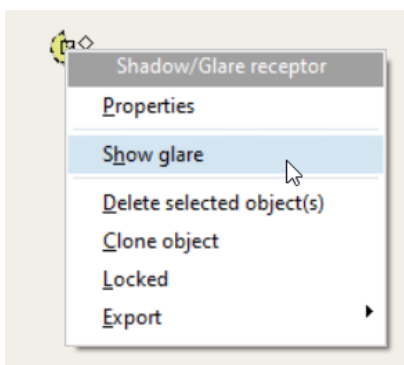
When selected a graph with glare from all active 3D objects and Solar PV object will be shown:
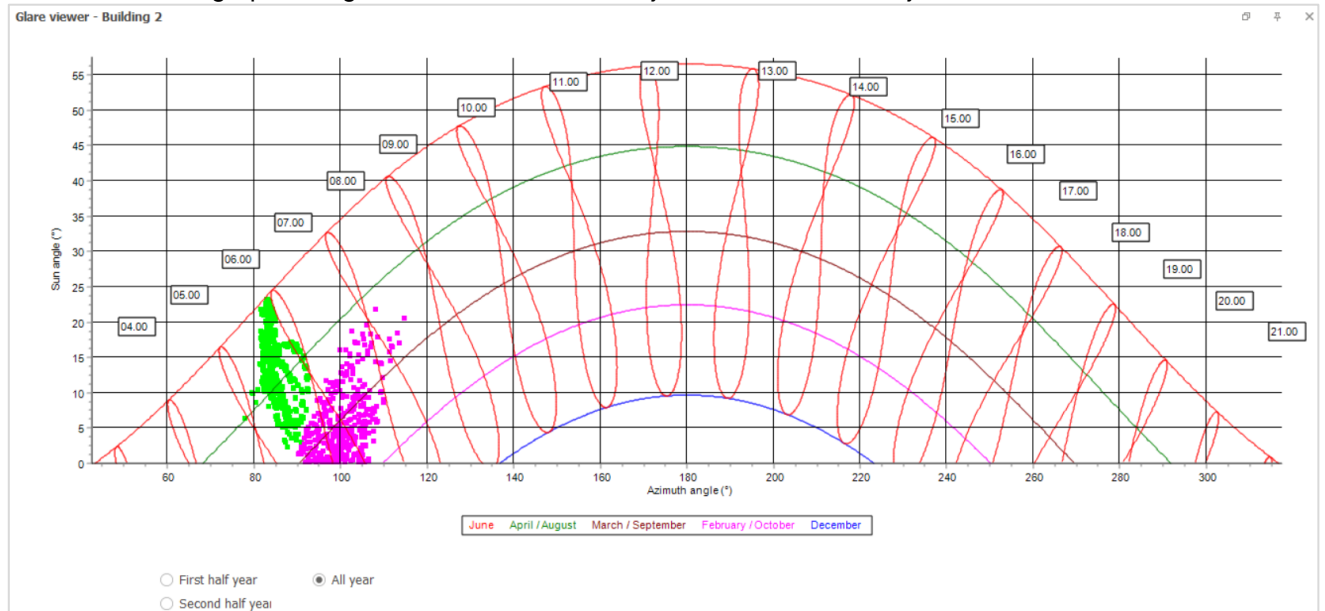
The graph is interactive and changes automatically when the Glare receptor is moved around on the map. This is a functionality especially useful when the user needs to get a quick overview if any glare will reach the receptor in multiple locations.

The graph is created using the default settings for a GLARE calculation, but without beam spread included. This means it assumes perfect reflection.