

Vertical directivity and radiation from smokestacks

SP Net info 32

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General information about DI

Directivity indices (DI's) can be attached to industrial point source, line source, area sources and facades of an industry building. In order to attach a DI to a specific source the relevant check mark under "Directivity" must be set on the index card Values in the Emission Lib. A DI already included in the project Lib can be picked by clicking the down pointing arrow in the window Horizontal/Vertical Directivity. To state a new DI click the double arrow.

The DI can be frequency dependant. When attaching a DI to a specific frequency the cursor must point to that frequency band in the table showing the sound power levels (index card Values in the Emission Lib). Alternatively the attaching can take place on the index card Directivities.

When keying in DI's in the Directivity Lib only a few values need to be stated, since the rest of the DI can be established by interpolation. The interpolation is performed on the index card Diagram. Even if a lot of values spread all over the 360° are keyed in, the values must be interpolated before closing the Directivity Lib. Otherwise SoundPLAN does not know the values in between the keyed in figures.

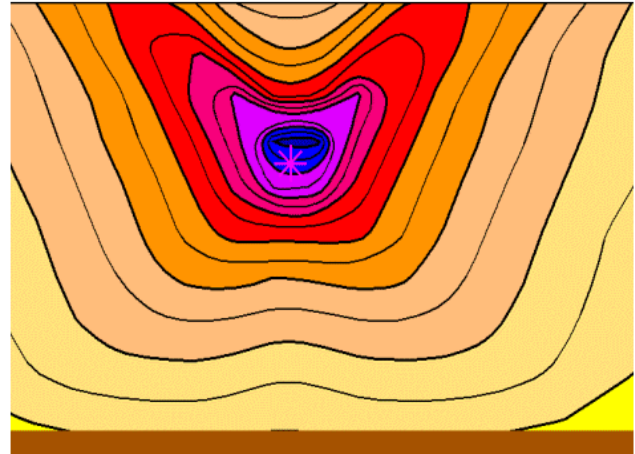
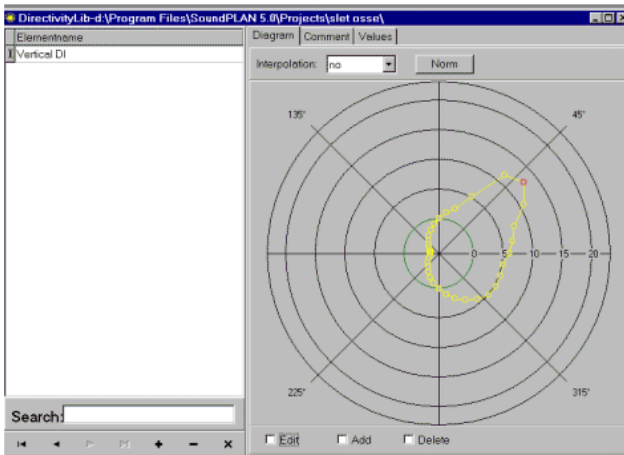
The interpolation can be done either according to a 3. degree polynomium or an exponential function with a user defined tension. Tension = 1 is equal to a 3. degree polynomium. Choose the function you think returns the best-looking DI curve; there is no "right" or "wrong" way to do the interpolation.

Last the values can be normalised so attaching the DI doesn't affect the overall sound power level of the source. To level the values press the button Norm.

When attaching a horizontal DI to a source it is important to know, that the DI is referenced to the global X-axis, i. e. 0 degree is pointing straight to the east. On the index card Additional in the Source properties window the DI can be rotated to point in any relevant direction, e.g. Rotation angle 135° if the 0-axis of the source is pointing to the northwest. When attaching a DI to a façade of an industry building the 0-axis is always perpendicular to the façade.

If you attach a horizontal DI to a line source the stated rotation angle will be used for all sub segments of the source. The consequences of this are important, if you digitise an industrial line source to model a path along which for instance a fork-lifter is working. If you want to attach a DI to the radiation from the fork-lifter you must divide the path into straight lines and state the Rotation angle individually for each segment. This is because the Rotation angle is an angle relative to the global X-axis and not an angle relative to the line itself. In a future version of SoundPLAN it will be user defined if the rotation angle should refer to the global X-axis or to the line source itself.

The 2-D vertical directivity is defined in a special way. Only the values stated from 90° through 0° till 270° (the values to the right of the Y-axis) are taken into account and this part of the directivity graph is mirrored in the Y-axis to complete the DI for all 360°. In this way the DI will be symmetrical relative to the Y-axis. Please take a look at SP32 gif1 below; this will make it clear how it works.

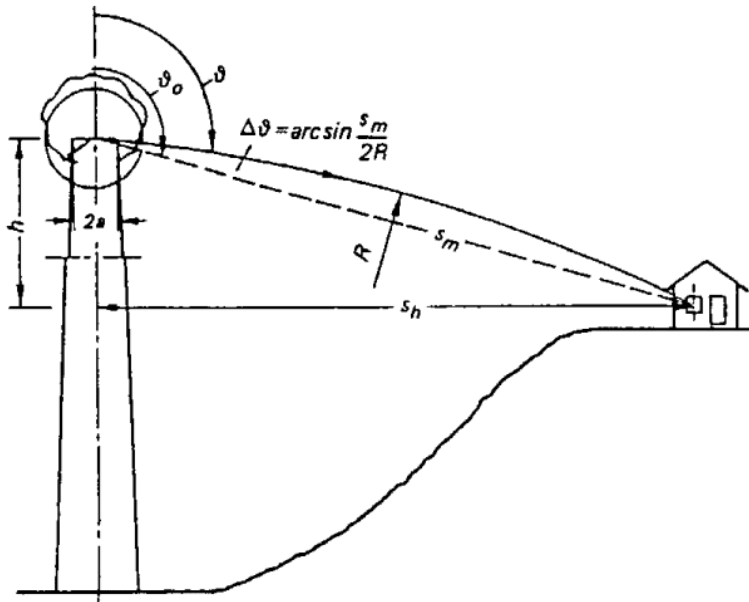


SP32 gif1

The propagation path

Most standards for calculating environmental noise assume weather conditions, which cause the sound to propagate along not the line of sight but along a circular arc. According to General Prediction Method the radius of curvature is 8 times the distance from source to receiver whereas other standards use a fixed radius.

Consequently when a vertical DI is attached to a source SoundPLAN does not pick the DI representing the direct line between source and receiver. According to German traditions SoundPLAN assumes the radius of curvature is 5000 m causing the propagation path at the source to form a small angle with the straight line between source and receiver (take a look at SP32 gif2). With a constant radius of curvature R equal to 5000 m this “additional angle” is equal to $\arcsin(s/2R) = \arcsin(s/10000)$, where s is the distance in metres between source and receiver. At distances up to 100 m this angle is less than 1° , at 500 m the angle is $2,9^\circ$ and at 1000 m the angle is $5,7^\circ$. Even if these angles are small this is a matter that cannot be ignored, especially if the source has a strong directivity, as is the case for hot outlets, e.g. most smokestacks.



SP32 gif2

In the attached Excel spreadsheet on the worksheet “Angle” the additional angle used by SoundPLAN is shown for distances up to 5000 m. Please note that a radius of curvature equal 8 times the distance as used in the Nordic method results in a constant angle equal $3,6^\circ$.

Two sets of Danish guidelines

What follows is mainly addressed to our Danish customers since Denmark has special guidelines for handling radiation from smokestacks. Radiation from smokestacks in general still needs research and there are a lot of unanswered questions related to this topic. Moreover the present Danish guidelines were developed for individual single point calculations and not for multi receivers spread all over a large area. These facts make it difficult to adopt the Danish guidelines in SoundPLAN for reasons that will be explained below.

In this Net info we will not deal with what is scientifically correct when it comes to sound radiation from smokestacks. But until we learn more about this topic we need some recommendations in order for Danish SoundPLAN users to avoid violating the guidelines.

In projects where the noise contribution from the smokestack is crucial (either because the noise from the smokestack is dominating to the total level or the total level is close to the noise limit) it is recommended that the directivity is handled individually for each receiver point and not according to the general hints given below.

In duct method

According to guidelines published by the Danish Reference Laboratory For Measurements Of Environmental Noise (Orientering nr 21: “Ny metode til måling af skorstenes kildestyrke”) the sound power level radiated from the top of a smokestack can be estimated from measurements of sound pressure level inside the pipe e.g. close to the foot of the smokestack. The sound power level can be calculated from the following equation:

$$L(W) = L(p) + dL(\text{probe}) + dL(\text{att}) + dL(DI) + 10\log S - 3$$

where

$L(W)$ is the sound power level radiated from the top of the smokestack

$L(p)$ is the sound pressure level inside the pipe, “in duct level”

$dL(\text{probe})$ is the transfer function of the measurement probe

$dL(\text{att})$ is the sound attenuation from the measurement position to the top of the smokestack

$dL(DI)$ is the directivity of the radiation from the top

S is the area in square metres of the pipe opening at the measurement position.

Due to the temperature and maybe aggressive gas as well it takes a special probe to measure the sound pressure level in the gas flow. The guidelines mentioned above recommends a certain design of the probe and states the corresponding transfer function, $dL(\text{probe})$.

$dL(\text{att})$ is a function of the absorbing properties of the inner surface of the smokestack. This parameter has to be guessed within a rather wide range, which adds a considerable uncertainty to the result.

In general the directivity of the radiation from the top is a function of the outlet diameter as well as of the temperature of the gas relative to the temperature of the air around the smokestack. Wind speed at the top is another important parameter that cannot be taken into account at the present state of the art. Consequently a moderate downwind is assumed in most prediction methods.

The directivity to be used is stated in the guidelines from The Reference Laboratory. As a descriptor of the directivity the product ka is used. k is equal to 2π divided by the wavelength at the centre frequency of the octave band in question and a is the radius of the outlet in metres. Since the speed of sound depends on the temperature the directivity does too. With acceptable accuracy it can be assumed that $k = 0,016f_c$ for outlet temperature $100^\circ - 150^\circ \text{ C}$ and $k = 0,018 f_c$ for outlet temperatures below 50° C ; f_c is the centre frequency. In the enclosed Excel spreadsheet on the worksheet “Orient nr 21, hot outlet, General” and “Orient nr 21, hot outlet, Examples” the values for $dL(DI)$ for hot outlet according to the guidelines can be seen. The DI for cold outlet is 3 dB smaller.

It is stated in the guidelines that the relevant DI to attach to the sound power level radiated from the top is the DI at an angle approx. 20° above the line of sight. This conflicts with the way SoundPLAN picks the DI. In the first place SoundPLAN picks an angle, which depends on the distance between source and receiver. Secondly the angle is far from 20° when dealing with “normal” distances as can be seen from the examples above. Strictly speaking SoundPLAN cannot fulfil the “in duct method”.

However, considering the fact that the “in duct method” must be regarded as an approximation (mainly due to the unknown absorbing properties of the inner surfaces of the smokestack) it seems fair to introduce a few assumptions. If we assume the frequency spectrum of the noise radiated from the smokestack to be “normal”, i. e. with the maximum A-weighted octave band not higher than 1000 Hz, and if we restrict receiver points to be within 500 m from the smokestack the DI stated in the guidelines can be transformed in order for SoundPLAN to return a received A-weighted level, which will deviate less than 0,5 – 1 dB from the one calculated strictly in accordance with the guidelines.

The DI to be used in SoundPLAN projects is derived in the following way. On the worksheet “Orient 21, hot outlet, Examples” the DI according to the guidelines is shown for 4 different outlet diameters and outlet temperature 100 – 150° C. In order for SoundPLAN to pick the correct directivity these DI’s should be shifted 20° clockwise (actually they should be shifted 20° minus the “additional angle” used by SoundPLAN, but for short propagation distances the “additional angle” is small and can be ignored). In this way it is obtained that SoundPLAN picks the DI stated in the guidelines. The result of shifting the angle 20° can be seen in the worksheet “SP, hot outlet, in duct method”. For cold outlet 3 dB should be subtracted from all values in the table.

The Sphere method

According to another set of Danish guidelines the sound power level of a smokestack can be estimated from the sound pressure level measured near the outlet (Miljøstyrelsens vejl. 5/1993: “Skorstensmetoden”). The measurement distance shall be at least 1,5 times the outlet diameter. If the sound power level is meant for predicting the immission level at receiver points further away than 3 times the height of the smokestack the microphone position should be 5° to 20° above the horizontal plane of the outlet. So the method says. In this way the directivity of the radiation is included in the pressure measurement.

No DI is recommended in the method, but it seems reasonable to reuse the directivity from Orientering nr 21. However, first the DI must be levelled to 0 dB in a direction 20° below a horizontal plane since this will be the direction towards receiver points in a distance equal 3 times the height of the smokestack. Again we ignore the “additional angle” and furthermore we assume the terrain to be more or less flat. On the worksheet “SP, hot outlet, long distance” the DI is levelled to 0 dB in the direction 340°.

The enclosed 2D directivity lib (for version 6.5 or younger) contains two records, one to be used together with the In duct method (#4) and another if the sound power has been estimated using the Sphere method (#5). Both DI’s are valid for 63 Hz and an outlet diameter in the range 0,75 m to 1,50 m. These are just examples but from the values in the enclosed spreadsheet it should be possible in a straightforward way to produce a relevant DI of your own.