NoizCalc
Technical white paper 1.4 en

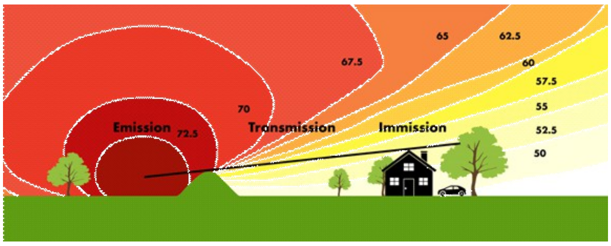
d&b audiotechnik

Contents

1. Introduction

This Technical white paper describes NoizCalc, a simulation software to calculate the noise in the environment from sound systems defined in the ArrayCalc simulation software including a 3D terrain model and meteorological influences.

1.1 Transmission, emission to immission



The prediction and control of unwanted noise from live events has become a more and more serious topic, particularly as the events increase in size and promoters wish to place a number of these within densely populated urban areas. Gaining permissions and licenses to stage an out-door event frequently requires a statement with a prediction of how noise could impact the surrounding area. It is not a new topic for people on both sides of the situation: those in measurement and enforcement (noise experts), and the performers, promoters, technicians, loudspeaker suppliers (emission experts).

Since both, the placement of a stage and the sound system design, can influence where sound is spilled outside the audience area, the potential noise impact is a significant consideration, both during the planning stages and throughout an event. The d&b objective is to put tools in place to simulate and visualize not only the performance of complex high directivity sound systems in an audience area (emission, ArrayCalc) but also the possible noise in surrounding areas of an event (noise impact, NoizCalc).

From experience it is clear that careful planning of the combined directivity achieved by a sound system, the direction in which it points and the electronic controls (ArrayProcessing) influence the result.

1.2 The problem

Sound system design software specifically targets the audience with the objective of achieving a uniform frequency response and a tailored level distribution. Complex summation and cancellation of sound waves from a complete system are taken into account. d&b ArrayCalc considers the direct sound and air absorption (ISO 9613-1).
→ The effects of reflection, diffraction, absorption and weather are necessary to calculate the noise impact of a sound system in the surrounding areas.

Conversely, the environmental noise simulation software available assumes non-coherent sources for road, rail, industry and aircraft noise without any cancellations.
→ In order to achieve an accurate noise prediction with coherently radiating high directivity multi element sound systems, detailed source data is required and the relative phase needs to be taken into account as well.

1.3 The solution

Define the sources in a system design software and import the complex data as one stage object into a powerful environmental noise modeling software and extend the algorithms for complex summation.

The d&b ArrayCalc simulation software is widely recognized as a very accurate tool for its purpose. The software allows complex loudspeaker systems to be modeled, consisting of many types of d&b loudspeaker, including line arrays, point sources, subwoofer arrays, fill and delay systems. It allows a system designer to make adjustments to the way the elements of systems are placed and powered to achieve the desired result.

The acknowledged German specialist SoundPLAN is one of the leading software developers in the field of environmental noise prediction. The complete integration of indoor factory noise, transmission through walls and the noise propagation into the environment make this software the ideal tool for engineers working in the fields of noise planning, noise in the workplace, 3D terrain noise mapping and as part of general environmental assessment studies. The unsurpassed numerical and graphical presentations make it easy to explain the findings to the public and to agencies requesting studies. The SoundPLANnoise software implements a wide range of common worldwide noise prediction standards (around 55 different standards).

1.4 The products

Products of both cooperating companies are available. d&b **NoizCalc**, a software program to predict the noise of d&b sound systems outdoors, while SoundPLAN offers two different packages, both capable of importing system data from ArrayCalc files: **SoundPLANnoise**, a modular environmental noise modelling software with advanced features and **SoundPLANessential** with a simplified user interface and reduced feature set.

The import of an ArrayCalc file includes all complex data defining the sources of a d&b sound system. The sources are imported as one stage object in NoizCalc and SoundPLAN software. Stages can be placed and oriented within the 3D terrain model to enable the prediction of noise. During the planning of an event, the noise impact of sound systems can be evaluated, allowing careful consideration of the components, their aimings and electronic filter settings, especially ArrayProcessing. Searching for a best case scenario, tests with changes to the system setup can be made in ArrayCalc, which are directly updated in NoizCalc or SoundPLAN.

1.5 Why multiple products?

NoizCalc is intended for use by sound system designers to investigate how possible noise of d&b sound systems will impact the surrounding area of events.
SoundPLAN offers license based software for acoustic consultants with a wide range of different source and noise types (road, rail, industry, aircraft), comprehensive calculation and reporting tools in order to satisfy the need for official noise prediction reports when licensing authorities request this.

2. NoizCalc

NoizCalc enables noise predictions with d&b sound systems at out-door events. A noise grid map is calculated in dB(A) or dB(C) with a chosen emission spectrum and SPL level at the reference point (usually Front of House). Three calculation standards are available:
ISO 9613-2, CNOSSOS-EU and Nord2000.

2.1 What NoizCalc does

NoizCalc calculates the propagation of sound from the source (one or multiple stages) to the grid points in the calculation area. The calculation is done according to the chosen standard and takes the system data and complex summation along with several propagation effects into account.

2.2 What NoizCalc does not do

NoizCalc does not give any indication whether the noise limits in the neighborhood are exceeded or does not provide any evaluation of the calculation results in terms of a time histogram. In order to obtain this kind of prediction, an acoustic consultant should be involved.

2.3 The workflow

After designing a sound system in ArrayCalc, the NoizCalc project is set up by selecting a calculation standard and entering project information (housekeeping).

Import geo-data
The basis of the model is the import of geo-data from Google Maps (GM) and OpenStreetMap (OSM). The location and type of map (satellite, OSM map, terrain) are selected in the integrated map data interface. The viewport is adjusted to show an overview of the venue and its possibly affected surrounding areas. The import includes:

- Bitmap of selected viewport
- Elevation data from GM
- Objects from OSM
  (buildings, ground effects and forests)

NoizCalc automatically calculates a digital ground model (DGM) from the elevation data and places the bitmap on the topography. It uses the OSM data to create so called noise relevant objects: Buildings, Ground effects (acoustical ground properties) and Forests. Where building heights are not available the user definable default building height is used.

Sources
A sound or noise source is represented by a stage object, which is placed on the terrain and assigned an ArrayCalc file. A separate file can be assigned to each stage or used for multiple stages.
All relevant data is read from the ArrayCalc file: position, orientation, complex transfer function, directivity, level, delay and filter settings of each loudspeaker, as well as ArrayProcessing data (if used), relative levels and mute status of each loudspeaker and source group. Therefore, relevant source groups should not be muted for the prediction.
For each stage, a reference level has to be defined and a spectrum has to be selected from the emission library. The spectra can be edited and even measured spectra can be entered.

Noise relevant objects
A **ground effect area** defines the acoustic property of the ground within the entered area. The standards use different parameters and default values: ISO 9613-2 and CNOSSOS-EU use a Ground factor while Nord2000 uses classes of the effective flow resistivity and roughness.

The **default ground** can be set to "rural" for predominantly vegetated land or "urban" for mostly paved land.

Forests attenuate sound depending on the acoustical path length, height and tree density. The latter can only be defined when using the Nord2000 standard.

Buildings and **walls** block and reflect sound. The level loss of reflections from the facade of a building and a wall is defined for each object.

Calculation
A calculation area can be defined, otherwise the calculation is performed for the entire DGM. The result is shown as a grid noise map in the Graphic plot tab.

3. How does it work?

ArrayCalc and NoizCalc use a complex point source directivity model (CPSD) to calculate the complex sum of the propagated sound from each source point (loudspeaker) to each grid point ("receiver"). Of course, both account for source strength, directivity, geometrical divergence and atmospheric absorption. The difference is that ArrayCalc only considers direct sound while NoizCalc calculates reflections from the ground, buildings and walls, diffraction from obstacles as well as further attenuation effects according to international standards.

Terrain, surrounding objects and the local atmosphere need to be modeled because they affect sound propagation. The geometrical data needs to be obtained and acoustical properties defined. The ground may be dense and mostly reflecting as in urban areas, or partially absorbing like in park areas or fields. The atmosphere may have layers with different air temperatures and/or different wind speeds. Obtaining actual building heights requires some effort.

3.1 Following the standards

In order to compare noise predictions calculation rules are implemented according to standards, which also define test scenarios that need to be passed successfully .
There is a variety of standards. They define sound propagation in different types of atmospheres and can be source dependent, e. g. road or industrial noise.

3.2 The choice of the propagation model

The choice of the noise calculation standard depends either on the requirements of local authorities, or on the purpose of the calculation. Three standards are implemented in NoizCalc:

- ISO 9613-2: 1996
- CNOSSOS-EU: 2015
- Nord2000

ISO 9613-2 is widely accepted and assumes favorable conditions for sound propagation thus providing a solid base for a worst-case noise scenario regarding meteorological conditions. The calculation is comparably fast, due to its simplified heuristic formulas.

CNOSSOS-EU stands for Common noise assessment methods in Europe and is the common methodological framework for strategic noise mapping under the Environmental Noise Directive (2002/49/EC). It provides higher accuracy than ISO 9613-2 and the probability of favorable weather conditions for sound propagation is user definable, which corresponds to the worst-case noise scenario regarding meteorology.

Nord2000 provides the highest accuracy of the three standards, because it uses physical models rather than heuristic formulas. Specific weather and wind scenarios can be calculated. The sophisticated calculations requires more CPU time.

4. Propagation standards

A few things can happen to sound on its journey from source to receiver. It is radiated, directed, diverged, absorbed into the atmosphere, reflected and absorbed by ground, and has to travel over barriers along with a number of other effects. All these effects are treated separately and independently, and also differently for each standard.

Note: ISO 9613-2 originally intended calculations with a representative frequency or in octave frequency bands. CNOSSOS-EU and Nord2000 prescribe calculations in third octave bands. In NoizCalc, the calculation is performed with a third octave spectrum. The results are shown as the sum level with either A- or C-weighting.

The standards use a similar approach to the calculation: the sound pressure level at the receiver is calculated as the sum of the sound power of sources including the directivity factor and minus the sum of all attenuation factors in dB.

Please refer to the table for a comparison of how the standards treat the different attenuation effects. Detailed information can be found in [1], [2] and [3]

5. Simulation limits

The calculations are only as good as the models and the standards.
ISO 9613-2 is considered to be accurate in the distance range of up to 1 km. Nord2000 provides high accuracy up to 1 km and good accuracy up to 3 km. However, the model was validated at a distance of 200 m.
Precise input data increases the quality of the simulation, which means the user has a great influence on the quality of the results. However, the model is based on the specific parameters used during the calculation. That means if there are changes in the meteorological conditions such as wind speed or direction, the results may not be reliable.

6. References

1. ISO 9613-2
2. CNOSSOS-EU: 2015
3. Delta, Nordic environmental noise prediction method, Nord2000, Summary Report
4. Delta, Nord2000. Comprehensive outdoor sound propagation model. Part 1: Propagation in an atmosphere without significant refraction
5. K. Attenborough, K.M. Li, K. Khoroshenkov, Predicting outdoor sound

<table>
<tr><th>ISO 9613-2</th><th>CNOSSOS-EU</th><th>Nord2000</th></tr>
<tr><td colspan="3">Formulas</td></tr>
<tr><td colspan="3">NoizCalc utilizes SoundPLAN's dynamic ray tracing core with optimized search algorithms for relevant rays from all sources to each point of the grid noise map:
Direct rays, reflections, diffractions and their combinations. Each ray is subject to various attenuation effects, which are calculated according to the selected standard.
Rays that are more the 20 dB below the loudest ray are considered non-relevant.

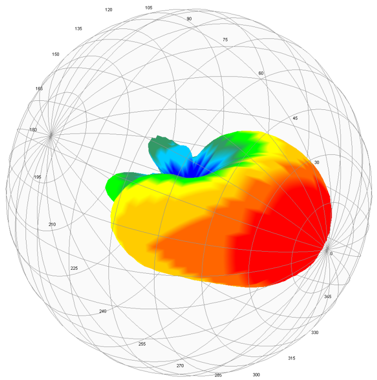
The underlying principle is the same: the sound pressure level at the receiver equals the difference of the sound power level of the source and the summed attenuation factors.</td></tr>
<tr>
<td>$$L = L_W + D_c - A$$
$$A = A_{\mathrm{div}} + A_{\mathrm{atm}} + A_{\mathrm{gr}} + A_{\mathrm{bar}} + A_{\mathrm{misc}}$$
L sound pressure level at a receiver location calculated for each point source with downwind
L_W sound power of source
D_c directivity of source
A summed attenuation factors that occur during propagation from the source to the receiver
Attenuation due to:
A_{div} geometrical divergence
A_{atm} atmospheric absorption
A_{gr} ground effect
A_{bar} barriers
A_{misc} miscellaneous (forest etc.)</td>
<td>$$L_{F/H} = L_{W,0,dir} - A_{F/H}$$
$$A_{F/H} = A_{\mathrm{div}} + A_{\mathrm{atm}} + A_{boundary,F/H}$$
$L_{F/H}$ sound pressure level at a receiver location for a path with favorable conditions (F) or in homogeneous atmosphere (H)
$L_{W,0,dir}$ sound power of source including directivity
$A_{F/H}$ summed attenuation factors in F/H
Attenuation due to:
A_{div} geometrical divergence
A_{atm} atmospheric absorption
$A_{boundary,F/H}$ boundaries in F/H, may contain:
$A_{ground,F/H}$ ground effect in F/H
$A_{dif,F/H}$ diffraction in F/H
The levels $L_{F/H}$ are weighted by p_{Fav} the probability of favorable conditions:
$$L = 10 \times \lg\left(p_{Fav} \cdot 10^{\frac{L_F}{10}} + (1 - p_{Fav}) \cdot 10^{\frac{L_H}{10}}\right)$$</td>
<td>$$L_R = L_w + \Delta L_d + \Delta L_a + \Delta L_t + \Delta L_s + \Delta L_r$$
L_R sound pressure level at the receiver for each frequency band
L_W sound power level of source including directivity for each frequency band
Attenuation due to:
ΔL_d spherical divergence
ΔL_a air absorption
ΔL_t terrain (ground and barriers)
ΔL_s scattering zones
ΔL_r reflections from obstacle (dimensions and surface properties)</td>
</tr>
<tr><td colspan="3">The sound pressures of all contributing rays are summed up:
$$L = 20 \times \lg\left(\sum_n 10^{\frac{L_n}{20}}\right)$$
This is performed for all third octave bands.
Then the frequency weighting is applied for the sum level.
This procedure is repeated for each receiver point.

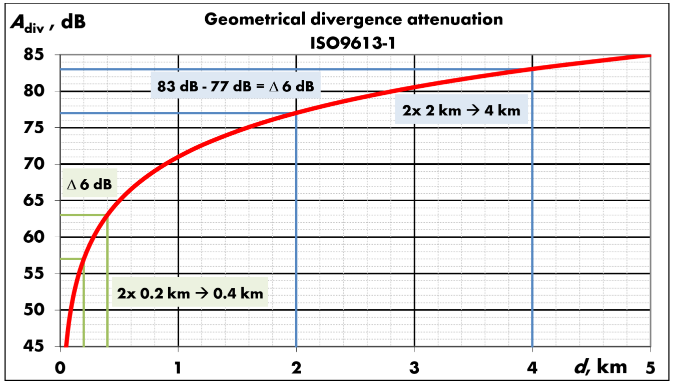
Complex summation is applied for rays from:
- line arrays and sub arrays for all frequencies.
- different source groups up to 163 Hz (e. g. left and right main array).
(Corresponds to a spacial resolution of approximately 1 m.)</td></tr>
</table>

ISO 9613-2	CNOSSOS-EU	Nord2000

Directed sound sources and propagation

The source model and the geometrical divergence are independent of the applied standard.

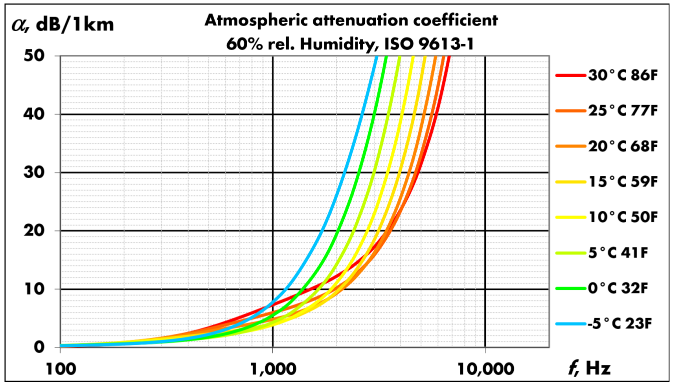


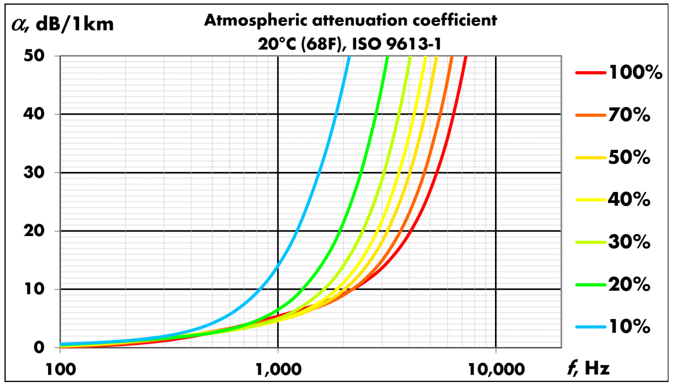


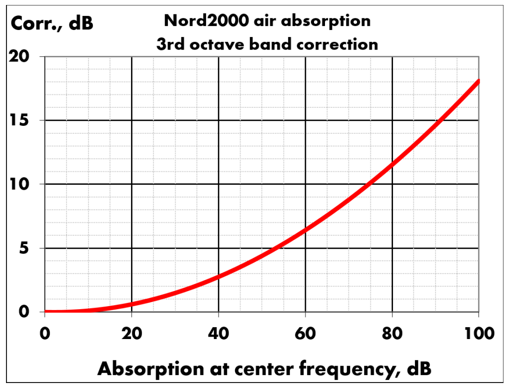
In a Complex Directivity Point Source model (CDPS) each loudspeaker is represented by a point source with a frequency dependent, far field (6 m), complex directivity balloon.

The spherical divergence decreases the SPL by slightly more than 6 dB per double distance.

Atmospheric absorption





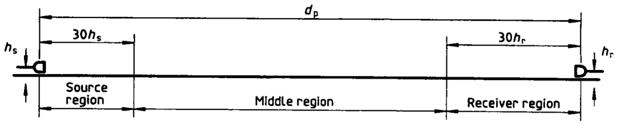


ISO 9613-2 and CNOSSOS-EU apply temperature and humidity dependent pure-tone attenuation coefficients according to ISO 9613-1.
Nord2000 applies a correction to these pure-tone coefficients in order to obtain one-third octave band attenuation coefficients.

Terrain & Ground effect

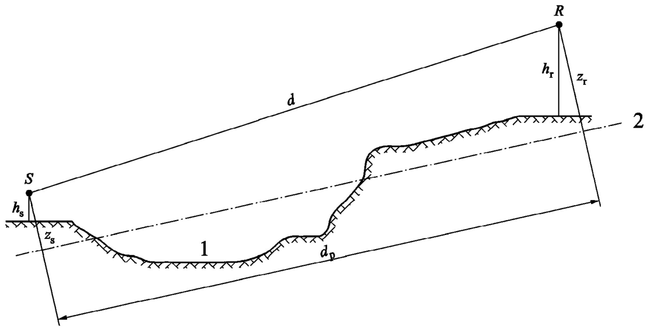
ISO 9613-2	CNOSSOS-EU	Nord2000
The distance between source and receiver and their heights are used for the attenuation, not the shape of the terrain. The acoustical ground property is defined by a factor G.	Equivalent heights are used for sources and receivers. They are orthogonal to the mean profile plane along a path. The acoustical ground property is defined by a factor G.	Terrain is segmented and the model is divided into 3 cases: virtually flat, valley-shaped and hill-shaped.

ISO 9613-2



G	Ground	Description
1	Porous "Rural"	Grass, trees, any vegetation, farming land
%	Mixed	Fraction of porous ground
0.2	"Urban"	Mostly hard
0	Hard	Paving, water, ice, concrete, tamped ground and all other surfaces having low porosity.

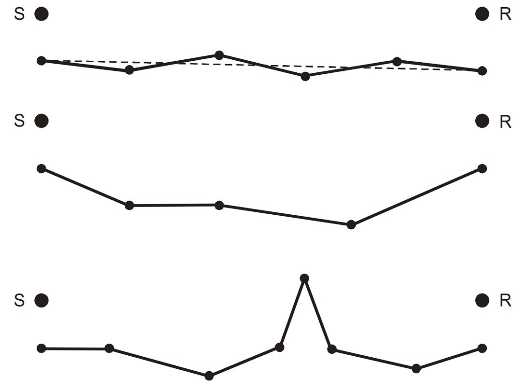
CNOSSOS-EU



G	Ground	Description
1.0	Uncompacted loose "Rural" default	Grass, pasture fields, forest floors
0.7	Compacted field and gravel	Compacted lawns, park area
0.3	Compacted dense	Gravel road, car park
0.2	"Urban" default	Mostly hard
0.0	Hard, dense	Most normal and dense asphalt, concrete, water

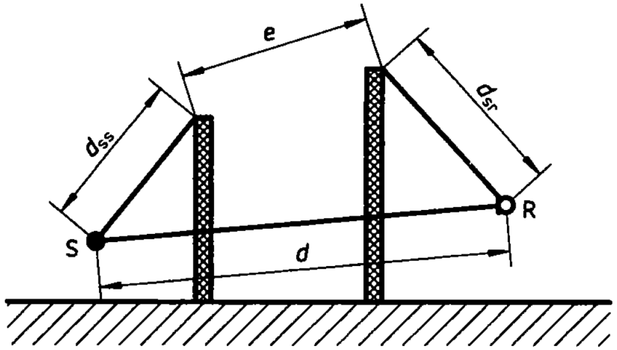
Values for Default ground "Rrual" and "Urban".

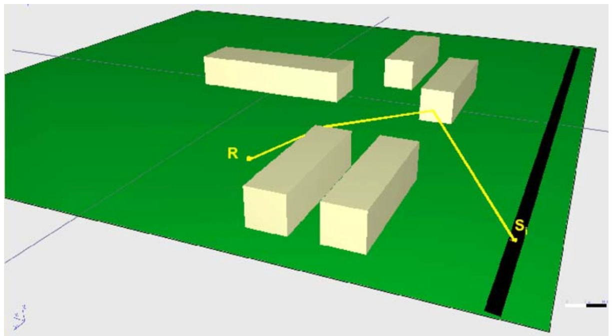
Nord2000

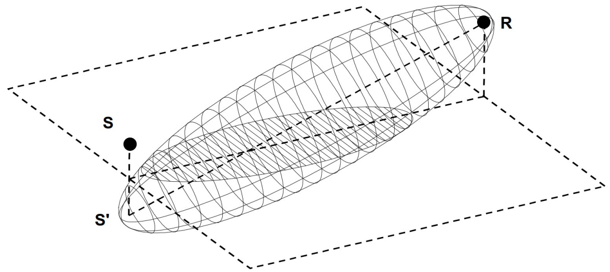


Impedance Class	Flow resistivity ($kNsm^{-4}$)	Description
A	12.5	Very soft (snow or moss-like)
B	31.5	Soft forest floor (short, dense heather-like or thick moss)
C	80	Uncompacted, loose ground (turf, grass, loose soil)
D	200	Normal uncompacted ground, "Rural" (field, forest floors)
E	500	Compacted field and gravel (compacted lawns, park area)
F	2000	Compacted dense ground (gravel road, parking lot, ISO 10844)
G	20000	Hard surfaces, "Urban" (most normal asphalt, concrete)
H	200000	Very hard and dense surfaces (dense asphalt, concrete, water)

<table>
<tr><th>ISO 9613-2</th><th>CNOSSOS-EU</th><th>Nord2000</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><th>Roughness class</th><th>Representative σ_r</th><th>Range of heights</th></tr>
<tr><td>N: Nil</td><td>0</td><td>±0.25 m</td></tr>
<tr><td>S: Small</td><td>0.25 m</td><td>±0.5 m</td></tr>
<tr><td>M: Medium</td><td>0.5 m</td><td>±1 m</td></tr>
<tr><td>L: Large</td><td>1 m</td><td>±2 m</td></tr>
</table>
</td></tr>
<tr><td colspan="3">Paths, Reflections & Diffractions</td></tr>
<tr><td>There is one type of barrier. The calculation of the attenuation for a single and double diffraction is based on empirical values. In case of more than two barriers in a path, the two most relevant barriers are chosen, neglecting the effects of the others.


</td><td>Paths are categorized into 4 types for different combinations of reflections and diffractions (either at horizontal or lateral edges of obstacles). Reflections on vertical obstacles are also taken into account.


</td><td>Simplified Fresnel zones are used to include the involved areas for reflections and diffractions. In addition, the sound rays have coherence factors in order to take the decreasing ability of cancellation over distance into account.


</td></tr>
</table>

ISO 9613-2	CNOSSOS-EU	Nord2000

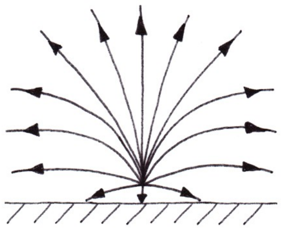
Meteorology

In addition to temperature and humidity dependent air absorption, the sound propagation strongly depends on vertical wind and temperature gradients within the atmosphere:

Sound rays are straight in a homogeneous atmosphere.
Sound rays curve towards the ground with downwind or a positive temperature gradient, which are denoted as favorable conditions for sound propagation
Sound rays curve towards the sky with headwind or a negative temperature gradient (not considered by ISO and CNOSSOS).

ISO 9613-2

An empirical model assumes favorable conditions for sound propagation, which provides a solid base for a worst-case noise scenario regarding meteorological conditions. (Downwind is not explicitly calculated! A temperature inversion is also favorable for propagation.)

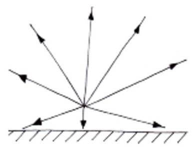


Favorable weather conditions for propagation.

CNOSSOS-EU

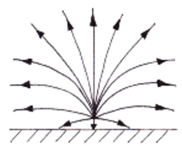
The attenuation factors for each path are calculated for two weather scenarios:

Homogeneous atmosphere



no wind, no vertical temperature gradient
(less noise)

Favorable weather conditions
for sound propagation



downwind and/or temperature inversion
(more noise)

0% .... p_{Fav} 100%

The results are then averaged according to the user defined probability of favorable conditions, p_{Fav} .

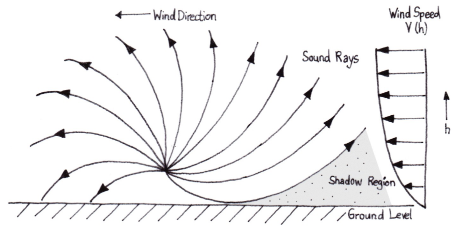
SoundPLAN default values for different day times:

	Day	Evening	Night
Time, h	6 – 18	18 – 22	22 – 6
p_{Fav} , %	50	75	100

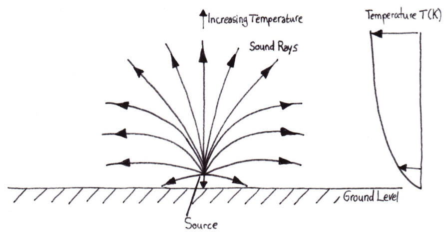
Nord2000

Specific weather scenarios can be calculated, including, wind speed, direction and temperature gradients.

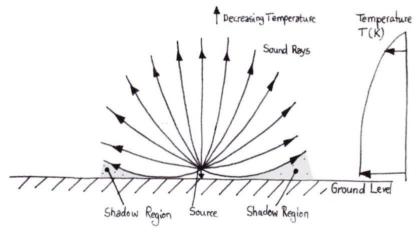
Wind direction and speed



Positive temperature gradient (inversion)
(favorable condition for propagation)



Negative temperature gradient
(unfavorable condition for propagation)



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