Contents

Calculation method for industrial noise

Description of the calculation method ISO 9613-2

General comment on the similarities and differences of ISO9613-2 with the END and on the possible use as Interim Method for END

prepared by Wölfel Meßsysteme · Software GmbH & Co

ISO 9613-2 "Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation" describes a detailed procedure to calculate sound levels from point sources. Area and line sound sources are divided into component point sound sources. Table 5 of clause 9 specifies the maximum distance of calculation depending on the mean height of the source and the receiver. ISO 9613-2 has been prepared by an international group of experts an the current first edition was published in 1996.

In Annex II of the END, ISO 9613-2 is listed as the recommended interim computation method for industrial noise calculations.

The following text describes ISO 9613-2's calculation procedures. A discussion of similarities and differences with the END is added.

1 Noise indicator

ISO 9613-2 predicts both "equivalent continuous A-weighted sound pressure level (as described in parts 1 to 3 of ISO 1996)" and "long-term average A-weighted sound pressure levels as specified in ISO 1996-1 and ISO 1996-2". The method does not specify any assessment period.

"Long-term average sound levels" are calculated on the basis of average sound power levels determine over a sufficiently long period and "a wide variety of meteorological conditions" prevailing over the year. A specific meteorological correction term Cmet is described in clause 8. Cmet is calculated from source height, receiver height, distance between source and receiver and a factor C0 in decibels. The latter directly depends on "local meteorological statistics for wind speed and direction". ISO 9613-2 leaves the actual determination of C0 to the user giving rather rough guidance in NOTES 20 to 21. With corrections ranging from 0 to +5dB and only exceptionally a correction exceeding 2 dB, ISO 9613 states that "only very elementary statistics of the meteorology are needed for a +/- 1 dB accuracy in C0.".

In **END** according to Article 5 the noise indicators

L_{den} (day-evening-night noise indicator)

L_{day} (day-noise indicator)

$L_{evening}$ (evening-noise indicator)

L_{night} (night-time noise indicator)

as defined in Article 3 and further defined in Annex I shall be applied for the preparation and revision of strategic noise mapping.

L_{den} is calculated from L_{day}, $L_{evening}$ and L_{night} by

$$L_{den} = 10.\lg\frac{1}{24}\left(12.10^{L_{day}/10} + 4.10^{(L_{evening}+5)/10} + 8.10^{(L_{night}+10)/10}\right)$$

where

L_{day}, $L_{evening}$ and L_{night} are the long term average sound level as defined in ISO1996-2:1987, determined over all the day periods or evening periods or night periods of a year.

In this ISO standard the long term average sound level is based on the equivalent continuous A-weighted sound pressure level.

According to ISO 1996-2 the averaging is with regard to both variations in source emissions and variations in meteorological conditions influencing the sound propagation.

Variations in the source emission are taken into account by determining an equivalent sound power level over a sufficiently long period of time. This period must be chosen long enough to encompass any significant variations influencing the average level. The length of the period depends on source emission characteristics. Variations in meteorological conditions with their subsequent impact on sound propagation are more difficult to take into account.

ISO 1996-2 and ISO 1996-1, quoted in ISO 1996-2 with respect to a meteorological adjustment, don't give detailed advice. These ISO standards, more than 10 years old, refer primarily to measurements and not to calculations. Basically, while addressing the inclusion of the range of meteorological variations these guidelines say that measurement time intervals are chosen in such a way, that the long term average sound level is determined over the range of meteorological conditions representative for the measurement position. Alternatively, measurements may be made under carefully specified meteorological conditions, normally those ensuring the most stable sound propagation which, in turn, are downwind conditions with a significant positive wind component from source to measurement position. A correction is then applied to the measured value. There is no advice neither on the quantity of this correction nor on the procedure to determine it.

A sentence of Annex II of the END emphasizes that the establishment of the average over the year requires special attention as variations in emission and propagation can contribute to fluctuations over a year.

In summary, the END thus requires calculation of equivalent continuous A-weighted sound pressure levels. They are averaged over the year with respect to variations in source emission and meteorological conditions influencing the sound propagation.

This in turn means that if the right choice is made in ISO 9613-2 basic quantities of ISO 9613-2 and END are the same. With respect to the indicator there are no difficulties to use ISO 9613-2 for calculations according to END.

There is however a need to introduce the notion of assessment periods day, evening and night in ISO 9613-2. Nevertheless, this will not impact on the calculation method in general.

2 Receiver point

In **END** the height of the receiver point is prescribed with 4 m ± 0,2 m.

ISO 9613-2 does not make any provisions to define receivers or receiver locations. No provisions are made to limit the height of the assessment point. There is no counter-indication to fixing assessment point heights to 4 m above the ground as required by the END for the purpose of strategic noise maps and noise indicators.

3 Source

ISO 9613-2 makes no provisions as to how to determine the sound power level. There are no objections in using sound power levels determined by means of one or several of the norms listed in the END for that purpose.

Instructions and comments on the use of the listed measurement methods is given in another document.

ISO 9613-2 provides propagation and attenuation algorithms for point sound sources only. Extended sources of the like of line or area sources have to be divided into component point sound sources. The division of the original sound sources into component parts is ruled by a distance criterion given in clause 4: $d \leq 2H_{\max}$ leading to a division with a variable step size depending on the distance ***d*** from the source centre to the assessment point and the largest dimension of the source $\boldsymbol{H_{max}}$. In addition, a stricter division of extended sources is enforced by ISO 9613-2 to ensure that the final source model takes into account all variations in propagation conditions.

It must be noted here that this procedure of dividing extended sources into component noise sources is common to all national methods used in EU M.S.

4 Sound propagation

ISO 9613-2 computes long-term average sound levels in octave bands with nominal midband frequencies from 63 to 8000 Hz.

ISO 9613-2 makes a difference between calculation of short-term and long-term levels. If the first are calculated in downwind conditions (favourable propagation of sound with significant positive wind from source to receiver), the latter are calculated using the same formulas but corrected by means of the meteorological correction term $\boldsymbol{C_{met}}$.

It was mentioned above that the guidance given by ISO 9613-2 on how to determine the meteorological correction term C0 is rather unsatisfactory. In addition, taking into account the lack of assessment periods in ISO 9613-2 and the requirements of END for such periods, meteorological correction for three periods day, evening and night must be defined.

4.1 The influence of the meteorological conditions on sound propagation

In the lower atmosphere temperature and wind speed gradients both vary with height above the ground; the temperature gradient can be negative (normal situation) or positive (temperature inversion) and the wind speed gradient generally increases with height above ground. The combination of both aforementioned gradients causes positive or negative sound velocity gradients. From the plethora of possible combinations of determining meteorological parameters, three conditions are identified for the sake of simplification: conditions of propagation are homogeneous (sound rays are straight), conditions of propagation are favourable to sound propagation (positive vertical sound speed gradient i.e. downwind sound propagation, sound rays bent downwards), conditions of propagation are unfavourable to sound propagation (negative vertical sound speed gradient, sound rays bent upwards).

In reality a plethora of combinations between thermal and aerodynamic effects are possible and vary in time and space. This in turn leads to considerable sound level variations at greater distances from the source. Additionally the ground effect is influenced by the shape of the sound rays.

By introducing meteorological correction ***Cmet***, ISO 9613-2 presents an opportunity to take into account conditions other than favourable downwind. ISO 9613-2 does, however, not provide a scheme to explore local meteorological statistics to determine C0. It can be observed that even within EU M.S. the lack of a clearly outlined method leads to the development of regional methods that yield different results as is the case in Germany where at least three different regional methods are currently in use.

It becomes thus clear that a method has to be provided and that this method must comply with the assessment periods as defined in the END. Furthermore, the following criteria are to be observed:

- ISO 9613-2 shall only be used as INTERIM method. Therefore an eye should be kept on both immediate practicability and limited cost.
- The meteorological correction may not be linked to availability of special data sets or any national or regional data formats.

- The meteorological correction must remain useful in a wide variety of relief from flat planes to mountainous regions (like Austria or northern Italy, where all major transit routes lead through the Alps).

For these reasons and in order to harmonise the use of meteorological corrections across the EU it is suggested to chose a method using overall estimates of propagation conditions for all computations of strategic noise maps in the realm of the **END**. Based on the original overall estimates provided in NMPB/XP S 31-133, a method using ISO 9613-2 propagation algorithms in all favourable conditions, the following “overall estimated fixed values” are suggested:

- 100 % of favourable occurrence for the night period,
- 50 % of favourable occurrence for the daytime period, and
- 75 % of favourable occurrence for the evening period.

NMPB/XP S 31-133 does not make any provisions for an evening period. The suggested overall estimate has been deducted from the two existing overall estimates for day and night based on the observation that from a meteorological point of view the evening period is “night” in winter and “day” in summer. If an EU Member States defines a shorter evening period than the default 4 hours, the above overall estimates have to be adapted accordingly. For instance, if the evening period is chosen to start at 21h and end at 23h, it then would be meteorological night for the greater part of the year resulting in 100 % favourable sound propagation. Consequently, part of the day would be “meteorological night” with respect to sound propagation especially in winter. The percentage of favourable sound propagation during the day period has then to be increased. To ensure consistency the sum of the percentage of favourable sound propagation should be kept constant i.e. $12\times0,5+4\times0,75+8\times1=17$.As ISO 9613-2 does not provide any method to numerically determine the value of C_0 in decibels, the following discussion will be based on the sparse comments that are given in Note 20. Here an average situation with 50% favourable conditions and 50% homogeneous conditions is said to lead to a C_0 = 3 dB. Taking into account the definition of conditions favourable to sound propagation in clause 5, three wind sectors can be defined[1]:

- downwind and thus favourable conditions: “wind direction within an angle of ±45° of the direction connecting the centre of the dominant sound source and the centre of the specified receiver region, with the wind blowing from source to receiver”, and calm wind, or alternatively, “a well-developed moderate ground –based temperature inversion, such as commonly occurs on clear, calm nights”.
- crosswind and thus less favourable conditions: wind blowing either from a sector between 45° to 135° or from a second sector between 225° to 315° measured from the direction connecting the centre of the dominant source and the centre of the specified receiver.
- upwind and thus unfavourable conditions: ±45° of the direction connecting the centre of the dominant sound source and the centre of the specified receiver region, with the wind blowing from receiver to source.

In an attempt to harmonise meteorological correction across INTERIM calculation methods, the example of XPS 31-133 is followed and cross- and upwind are grouped together as “homogeneous” conditions. Each term is, however, represented separately in the following formula in order to ensure that Note 22 is respected. The following equation is then suggested to calculate C_0:

$$C_0 = -10\lg\left(\frac{p_f}{100}\bullet 10^{-\frac{C_f}{10}} + \frac{p_{hc}}{100}\bullet 10^{-\frac{C_{hc}}{10}} + \frac{p_{hu}}{100}\bullet 10^{-\frac{C_{hu}}{10}}\right)$$

where

[1] Meteorologische Korrektur (Cmet), Bayerisches Landesamt für Umweltschutz, München im Januar 1999

- p_f, and p_{hc} and p_{hu} are the respective percentage of occurrences of ***f***avourable and ***h***omogeneous (50% ***c***ross- and 50% ***u***pwind) meteorological conditions,
- and, following Note 20, C_f = 0 dB and C_{hu} = 10 dB,
- and, to ensure that Note 22 is respected, C_{hc} = 1,5 dB

C0 then takes on the following values for day, evening and night respectively:

$$C_{0day} = -10\lg\left(\frac{50}{100} + \frac{25}{100} \bullet 10^{-\frac{1,5}{10}} + \frac{25}{1000}\right) dB = 1,4 dB$$

$$C_{0evening} = -10\lg\left(\frac{75}{100} + \frac{12,5}{100} \bullet 10^{-\frac{1,5}{10}} + \frac{12,5}{1000}\right) dB = 0,7 dB$$

$$C_{0night} = 0 dB$$

Please note that C_0 is only one term of the equation determining C_{met}. Other elements that come into play are source to receiver distance and their respective height above the ground.

4.2 Geometrical divergence

The sound attenuation due to geometrical divergence A_{div} (decrease of sound level due to propagation distance) is calculated in the generally accepted way based on spherical propagation.

4.3 Atmospheric absorption

The sound attenuation due to atmospheric absorption A_{atm} is calculated in the generally accepted way. Even though ISO 9613-2 provides a series of coefficients for selected temperatures and relative humidity, it is recommended to use the full table according to ISO 9613-1. The selection of the proper coefficients depends on national or even better regional climatic conditions.

4.4 Ground effect

Attenuation of sound attenuation due to ground effect A_{grd} is caused by the interference between the sound reflected on the ground and the sound propagating directly from source to receiver. The method defined in ISO 9613-2 to calculate ground effect can be found in this or very similar forms in the national calculation methods of several EU M.S. (Nordic countries, The Netherlands, Austria, France, ...).

For calculations with A-weighted sound power levels, the use of the alternative equation (10) of 7.3.2 (taken from German VDI 2714) should be mandatory. For sources that are placed close to hard ground the correction term D_Ω given in equation (11) has then to be used to account for the “apparent increase in sound power of the source”.

It is considered that the equations used in ISO 9613-2 to calculate the attenuation due to ground effect can be used for calculations according to END throughout Europe.

4.5 Diffraction

ISO 9613-2 defines two distinct equations to take into account attenuation due to screening. The first one is for diffraction over the top edge and the second one for diffraction around a vertical edge. Both equations use D_z, the barrier attenuation in each octave band. There is nothing special about the equation used to determine D_z. It should be noted however that the “correction factor for meteorological effects” K_{met} is not to be confused with the meteorological correction factor C_{met} of clause 9.

Mean height is determined if ground is not flat. The calculation procedure enables to treat the diffraction due to thin and thick barriers, buildings, natural or artificial mounds as well as edges of an embankment, cutting or viaduct.

In a first step it has to be considered, if a diffraction occurs. The path difference between the connection source – receiver and via the top of the obstacle has to be compared with the quantity - λ/20 (λ is the wave length for 500 Hz i.e. - λ/20 = - 0,034 m); if the path difference is less, then there is no need to carry out a diffraction calculation.

Two figures show the calculation of path length difference for single and double diffraction. It is this path length difference that determines D_z.

Equation (12) contains a term to compensate for the ground effect calculated by means of the ground effect equations. However, Dz incorporates ground effect in the presence of a barrier. Therefore ground effect Agrd is subtracted for diffractions on the horizontal edge of an obstacle. It must be noted that equation (12) of ISO 9613-2 contains an error. The equations should read:

$$A_{bar}=D_z - A_{gr}$$

ISO 9613-2 imposes a condition “> 0” that should be omitted, to allow for continuous compensation of ground effect in all situations. The ground effect in presence of a barrier is included in the barrier attenuation term D_z.

The calculation procedure for the attenuation by diffraction can be used in all European countries and with the exception of the correction suggested for equation (12) no further change or addition is needed.

4.6 Reflection

Image sources are used to take into account reflections. The same approach is used in NMPB/XP S 31-133 and several national industrial noise calculation methods. Obstacles with dimensions that are small with respect to the wavelength have to be neglected. The sound power level of the image source has to take into account the absorption coefficient of the reflecting surface.

The method to calculate the effect of reflections can be used in the **END INTERIM method** without any change or addition.

4.7 Additional types of attenuation

ISO 9613-2 defines in Annex A (informative) three additional types of attenuation for foliage, industrial sites and housing. Each of them applies a simplified overall attenuation proportional to some extent to both height of the virtual obstacles and size of the attenuating area. There are no particular technical reasons to prohibit the use of these additional attenuations. However, it should be noted here that the EU INTERIM calculation method for road traffic noise based on ISO 9613-2 does not use these additional and informative corrections. In an attempt to harmonise the way to handle noise from different sources, it may thus be indicated to prohibit the use of these additional attenuations.

5 Calculation: overall A-weighted or frequency-dependent

Point 1 of ISO 9613-2 states that “this part of ISO 9613 consists specifically of octave-band algorithms (with nominal midband frequencies from 63 Hz to 8 kHz)”. Note 1 indicates how the frequency-dependent attenuation terms should be applied to overall A-weighted sound power levels emitted from the source: “If only A-weighted sound power levels of the sources are known, the attenuation terms for 500 Hz may be used to estimate the resulting attenuation.”

Note 1 should be replaced by: “If only A-weighted sound power levels of the sources are known, the attenuation terms for 500 Hz should be used to estimate the resulting attenuation, except for ground effect where the alternative method outlined in 7.3.2 . should be used.”

6 Summary

Differences and similarities between ISO 9613-2 and END and, where needed, amendments or modifications as proposed in the above are summarized in the following table.

subject	result of comparison - action
noise indicator	the definition of the base indicators are found to be identical A-weighted long-term average sound level determined over a long period of time of several months or a year taking into account variations in both emission and propagation assessment periods day, evening, night have to be introduced
Assessment point	no objections to using 4 ± 0,2 m above the ground as required by the END
source	no objections to using norms as required by the END to determine sound power levels no objections as to using the extended source division into component point sources
propagation	caution: long-term average levels are calculated only if meteorological correction factor C_{met} is applied!
influence of meteorological conditions	define percentage of occurrence of favourable conditions; proposed EU overall estimates 50 % for day, 75 % for evening, 100 % for night with the possibility to adapt to shorter evening periods if needed
geometrical divergence atmospheric absorption	no objections and no further adaptation needed
ground effect	table with air attenuation coefficient versus temperature and relative humidity typical for European regions based on ISO 9613-1 has to be inserted and relevant data have to be chosen on a national leveluse alternate method 7.3.2, equation (10) for overall A-weighted sound power levels and equations of table 3 for all frequency-dependent calculations. No other objections.
diffraction	A-weighted: calculate at 500 Hz; frequency-dependent: no objections and no further adaptation needed
reflection	no objections and no further adaptation needed
additional attenuations	in order to harmonise with other INTERIM calculation methods (especially NMPB/XP S 31-133 based on the same propagation algorithm) it may be necessary to prohibit the use of these attenuations for the purpose of strategic noise mapping

Positive mention should be made of the close relationship between NMPB/XP S 31-133 and ISO 9613-2: in favourable conditions NMPB/XP S 31-133 almost exactly follows ISO 9613-2. Although similar, both methods are different. This is an unfortunate decision as from a physical point of view noise propagation is by no means dependent on the source type (caution: the initial sound radiation definitely is dependent on source types with different directivities, source heights and differences in source geometry, etc.). However, following the decisions made in the END, the EU has decided to live with differences in propagation methods until the single final harmonised method replaces the current selection of interim methods[2].

[2] END, Article 6, 2.: Common assessment methods for the determination of L_{den} and L_{night} shall be established by the Commission in accordance with the procedure laid down in Article 13(2) through a revision of ANNEX II.