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ROAD TRAFFIC: MEASUREMENT OF NOISE IMMISSION – ENGINEERING METHOD

Key words: Acoustics, traffic noise, noise immission, test method

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1 SCOPE

This NORDTEST method states procedures for measuring road traffic noise inside and outside buildings and in open terrain, under specified traffic and environmental conditions. The accuracy is that of an ISO engineering method (Grade 2). The method aims at obtaining noise levels as they occur during slightly downward atmospheric refraction.

Measurements carried out in accordance with this Nordtest method yield as the main result the total A-weighted energy-equivalent sound pressure level. The method also enables measurement of the maximum A-weighted sound pressure level and sound pressure levels in octave bands.

The method specifies how to measure the noise level at a given position in a well defined way, and how, by measuring road traffic noise simultaneously in several microphone positions, the noise levels in these positions can be determined in an efficient way.

2 FIELD OF APPLICATION

Road traffic noise levels are often calculated in accordance with “Road Traffic Noise, Nordic Prediction Method”. When calculation is considered insufficient, the traffic noise level can be measured in accordance with this Nordtest method. This can for example be the case in particularly complicated topographical situations, with sound reflecting obstacles or several noise barriers or buildings screening the traffic noise.

The method is useful – within its constraints due to measurement uncertainty etc. – to test compliance with noise limits, for example when residents complain about their exposure to traffic noise. The method is also applicable for assessing the effect of noise mitigation measures.

This Nordtest method and the Nordic prediction method for road traffic noise have been designed so that measured and calculated traffic noise levels should be the same. At positions far away from roads, however, there is a trend for measured noise levels to be higher than the calculated noise levels when measurements are carried out during the conditions of downward atmospheric refraction as specified in this Nordtest method.

The method does not give specifications for determining yearly average noise levels from road traffic.

At roads with low traffic intensity, the traffic noise will have to be measured for long time intervals in order to comply with the requirements of this Nordtest method.

Note 1: The bibliography in Annex F gives reference to standards for measuring road surface influence on traffic noise, sound insulation, and sound absorption of building or barrier components, and insertion loss of noise barriers.

Note 2: It is recommended to apply the meteo-window of this Nordtest method when measuring the insertion loss of noise barriers rather than the less restrictive meteo-window of ISO 10847.

3 REFERENCES

The following normative documents contain provisions which, through reference in this text, constitute provisions of this Nordtest method. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this Nordtest method are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Nordtest, as well as members of ISO and IEC, maintain registers of currently valid International Standards.

Nordtest Method ACOU 056, *Road Traffic: Measurement of noise immission. Survey method.*

IEC Publication 60942, *Sound calibrators.*

IEC Publication 61260, *Octave-band and fractional octave-band filters.*

IEC Publication 61672, *Electroacoustics – Sound level meters¹*).

ISO 3207 – *Statistical interpretation of data – Determination of a statistical tolerance interval.*

prEN ISO 10052, *Acoustics – Field measurement of airborne and impact sound insulation and of equipment sound – Survey method.*

TemaNord 1996:525, *Road Traffic Noise, Nordic Prediction Method*, Nordic Council of Ministers 1996.

4 DEFINITIONS

The definitions 4.1–4.4 have been given for unweighted (linear) sound pressure levels. They apply to A-weighted, octave band or third octave band sound pressure levels as well.

4.1 Sound pressure level, in decibels, L_p

The sound pressure level L_p is given by

$$L_p = 10 \log \left(\frac{p}{p_0} \right)^2 \quad (1)$$

p = root mean square sound pressure [Pa]

p_0 = reference sound pressure (20 μ Pa).

4.2 Energy-equivalent sound pressure level, in decibels, $L_{eq,T}$

The value of the sound pressure level of a continuous, steady sound that, within a specified time period, has the same mean square sound pressure as a sound whose level varies with time.²⁾ It is defined as

$$L_{eq,T} = 10 \log \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_0^2} dt \quad [\text{dB}] \quad (2)$$

1) To be published, replaces IEC 60651 and IEC 60804.

2) The expression equivalent noise level has generally been used in this Nordtest method in order to simplify the text.

$L_{\text{eq},T}$ = energy-equivalent sound pressure level for the time interval T , starting at the time t_1 and ending at the time t_2 [dB]

$p(t)$ = instantaneous value of the sound pressure of the noise signal [Pa]

p_0 = reference sound pressure (20 μPa).

4.3 Sound exposure level, in decibels, L_E

The energy-equivalent sound pressure level during a vehicle pass-by, normalised to a reference duration of 1 second, as given by

$$L_E = 10 \log \frac{1}{t_0} \int_{t_1}^{t_2} \frac{p^2(t)}{p_0^2} dt \quad [\text{dB}] \quad (3)$$

$p(t)$ and p_0 are as in Equation (2)

$t_2 - t_1$ = time interval sufficiently long to contain all essential sound energy from the pass-by [s]

t_0 = reference duration (1 s).

4.4 Maximum sound pressure level, in decibels, $L_{F\text{max}}$

The maximum sound pressure level during the pass-by of an individual vehicle or a group of vehicles, determined with time weighting F, IEC 61672. Reference sound pressure 20 μPa .

4.5 Measurement time interval

The time interval within which the squared sound pressure is integrated and averaged.

4.6 Observation time interval

The overall time interval within which traffic noise is recorded, either continuously or by sampling.

4.7 Reference time interval

The time interval over which the squared sound pressure is averaged in order to determine the equivalent noise level for comparison with noise limits.

Note 1: The reference time interval may be longer than the total duration of noise events occurring during the time interval.

Note 2: Different noise limits may be specified for different reference time intervals. For example, the noise limit may be specified in terms of the equivalent noise level during daytime while the noise limits during the evening or night may be expressed as maximum noise level or the highest one-hour or half-hour equivalent noise level.

4.8 Meteo-window

Set of weather conditions within which measurements can be performed with limited and known variation in measurement results due to weather variation.

4.9 Sound path radius of curvature, in metres, R

Radius approximating the curvature of the sound paths due to atmospheric refraction.

4.10 Normalised sound path curvature, in [1/km], k

The inverse of the sound path radius of curvature multiplied by 1000, with R expressed in metres, Equation (4).

$$k = \frac{1}{R} \cdot 10^3 \quad \left[\frac{1}{\text{km}} \right] \quad (4)$$

4.11 Uncertainty

An interval around the measurement result, with 90% probability that the "true" value of the noise level lies in this interval.

Note: In one-sided testing, 95% confidence is obtained.

5 MEASUREMENT PROCEDURE

The traffic noise shall be recorded during time intervals in accordance with Clauses 5.1–5.4. Unless Equation (14) is fulfilled the measurement time interval should be at least 10 minutes to average short-term variation in sound propagation conditions. Signal processing may take place in situ or the recorded signal may be analysed later in the laboratory.

The air temperature shall be measured regularly at a position representative of the vehicle noise emission. The wind speed and direction as well as the air temperature and humidity shall be monitored at a position representative of the sound propagation from the road to the measurement position, see Section 8.3.

The microphone shall be equipped with a windshield during noise recording. It is recommended to listen to the noise signal through high quality headphones to ensure that the signal transmission through the instruments is stable, undistorted and free of disturbing background noise such as electrically generated noise.

During indoor noise measurements, doors and windows shall be closed, while air intakes shall be open.

Frequency band noise measurements shall cover the octave-bands 63 Hz–4 kHz or one-third-octave bands 50 Hz – 5000 Hz.

Measurements may be performed continuously for a certain period of time to characterise the traffic noise within that specific time interval or they may be considered as samples representing the traffic noise during longer periods of time.

5.1 Equivalent noise level measurement

5.1.1 Continuous measurement

By measuring the traffic noise continuously for a specific time interval the equivalent noise level for that time interval

can be determined directly. For example, the 24-hour equivalent noise level $L_{Aeq,24h}$ can be determined based on a full 24-hour measurement.

If the noise levels during day, evening and night are determined separately, $L_{Aeq,24h}$ can be determined using Equation (5).

$$L_{Aeq,24h} = 10 \log \frac{1}{T} \left(\Delta t_d 10^{\frac{L_d}{10}} + \Delta t_e 10^{\frac{L_e}{10}} + \Delta t_n 10^{\frac{L_n}{10}} \right) \quad (5)$$

T = the reference time interval = $\Delta t_d + \Delta t_e + \Delta t_n = 24$ hours

L_d , L_e og L_n are the equivalent noise levels measured for the day (time interval Δt_d hours), evening (Δt_e), and night (Δt_n), respectively.

Note 1: The definition of time intervals day, evening and night may differ from country to country and between categories of source.

Note 2: By adjusting the noise levels in Equation (5) to account for differences in people's sensitivity to noise during different periods of the day, L_{den} chosen as a common European noise indicator can be determined by Equation (6)

$$L_{den} = 10 \log \frac{1}{T} \left(\Delta t_d 10^{\frac{L_d}{10}} + \Delta t_e 10^{\frac{L_e+5}{10}} + \Delta t_n 10^{\frac{L_n+10}{10}} \right) \quad (6)$$

5.1.2 Sampling

As an alternative to continuous measurement, the following procedure can be applied.

- Measure $L_{eq,T}$ from the flow of traffic long enough for a sufficient number of vehicles to pass the microphone position in order to average individual vehicle noise level variation. The measurement time interval needed depends on the traffic and on the required accuracy, cf. Clause 9.3. Count separately the numbers of each category of vehicle passing during the measurement time interval(s), and measure the average vehicle speed of each category by measuring the speed of vehicles chosen at random.
- Convert the measured equivalent noise level using the Nordic prediction method for road traffic noise to determine the noise level for the time period of interest, e.g. a day with yearly average traffic.

Note 1: The conversion can be made by applying Equations (B.1)–(B.4) given in Annex B.

Note 2: If noise emission data for more categories of vehicles are available, more accurate conversion can be made based on the numbers of each category of vehicle. For example, distinction may be made between light vehicles (or passenger cars and vans), medium vehicles (busses and two-axle trucks) and heavy vehicles (trucks with more than two axles).

Note 3: The equations in Annex B presume that during the measurement time interval the traffic and driving conditions are representative of the average vehicle noise emission. Normally measurements should not be performed during rush hours in case rush hour traffic is significantly slower than the traffic outside rush hours.

At microphone positions close to roads with low traffic intensity it is recommended to measure individual vehicle pass-by sound exposure levels L_{AE} and to calculate $L_{Aeq,T}$ using Equation (7). The minimum number of vehicles per category shall be 30.

$$L_{Aeq,T} = 10 \log \frac{t_0}{T} \left[\sum_i n_i \cdot 10^{\frac{L_{AE,i}}{10}} \right] \quad (7)$$

where

T = reference time interval [s]

t_0 = reference duration (= 1 s)

$L_{AE,i}$ = energy-average pass-by sound exposure level for vehicle category i [dB]

n_i = number of category i vehicles passing during the reference time interval T [–].

5.2 Maximum noise level measurement

The maximum noise levels from road traffic during the day are often the same as during the night. If the maximum noise levels during the night differ from those during the day, the maximum noise levels shall be measured during the night, when they are measured in order to characterise potential sleep interference during the night.

The average maximum noise levels differ between vehicle categories. Within each vehicle category a certain spread of maximum noise levels around the average is encountered due to individual differences between vehicles and due to variation in speed or driving pattern. The maximum noise level should be determined based on the noise level measured during at least 30 pass-bys of vehicles of the category considered.

Note 1: If it is not possible to record maximum noise levels from at least 30 pass-bys, it is recommended in Equation (8) to use the standard deviation given in the Nordic prediction method for road traffic noise. cf. Equation (D.1) and (D.2) in Annex D of this Nordtest method.

Higher maximum noise levels occur when groups of vehicles pass than during an individual vehicle pass-by. The maximum noise level from such vehicle groups should be determined based on the noise level measured during at least 30 vehicle group pass-bys.

Note 2: The number of vehicles contributing to the maximum noise level during a group pass-by is decisive for the overall maximum noise level and it may be relevant to distinguish between groups of different size and composition.

The 5th percentile of normally distributed maximum sound pressure levels can be determined by Equation (8) based on the (arithmetic) average $L_{AFmax,avg}$ and the sample standard deviation s of the recorded maximum noise levels.

$$L_{AFmax,5\%} = L_{AFmax,avg} + 1.65 s \quad (8)$$

Note 3: The standard deviation σ_m due to weather influence, cf. Section 8.3, should be included if it is not insignificant. In that case s in Equation (8) should be replaced by

$$s_r = \sqrt{s^2 + \sigma_m^2}$$

Other percentiles of the normal distribution can be determined using Figure 1. The vertical axis is the wanted percentile of a normal distribution and the horizontal axis gives the number y of standard deviations by which the percentile exceeds the mean value. This value y should replace 1.65 in Equation (8).

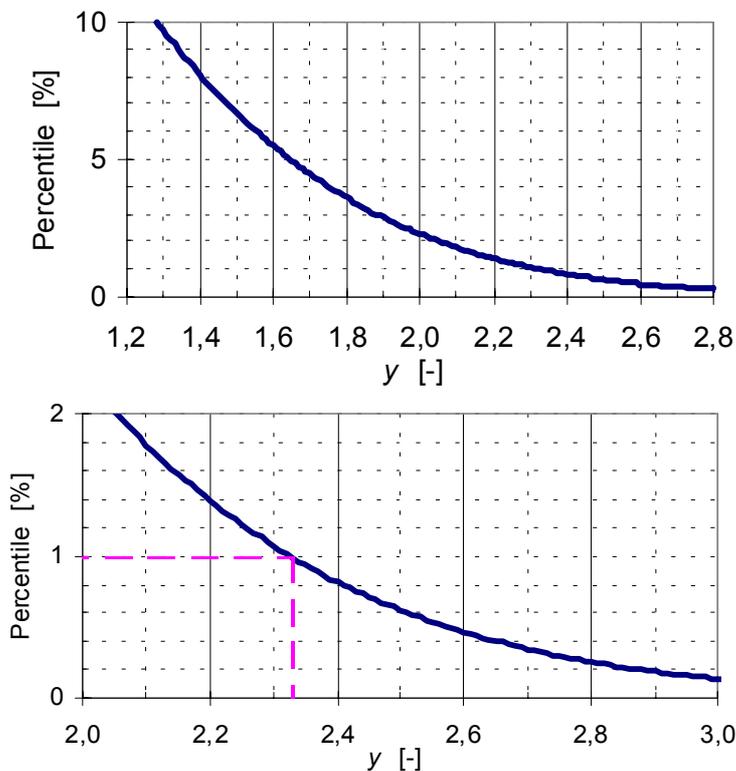


Figure 1. Percentage of single events with a maximum noise level exceeding – by a certain number y of standard deviations – the (arithmetic) mean of a normal distribution of maximum noise levels.

Example: If the fifth highest maximum noise level is wanted out of 500 vehicles passing, then the percentile is $(5/500) * 100 = 1$ and as shown in the bottom part of Figure 1 the factor to replace the factor 1.65 in Equation (8) is $y = 2.33 \approx 2.3$.

5.3 Relative noise level measurement

The traffic noise level at a number of microphone positions can be determined efficiently based on an extended measurement in one reference position and subsequent shorter measurements performed simultaneously in the reference position and in other microphone positions. Any such other microphone position shall be less than 30 m from the reference microphone position.

Based on the difference between these simultaneously measured noise levels the absolute noise level L_i at position No. i can be calculated by Equation (9)

$$L_i = L_{ref} - \Delta L_i \tag{9}$$

L_{ref} = noise level at reference position determined by extended measurement [dB]

ΔL_i = difference between noise levels measured simultaneously in reference position and position No. i [dB].

When measuring indoor noise levels one microphone can be located outdoors in a reference position where the noise level L_{ref} is already known. The second microphone shall be located successively at each of the indoor microphone positions specified in Clause 7.2. The average difference $\overline{\Delta L}$ between the noise levels measured outdoors and indoors shall be subtracted from the outdoor noise level L_{ref} to determine the indoor noise level L_{in}

$$L_{in} = L_{ref} - \overline{\Delta L} \tag{10}$$

For each combination of microphone positions the noise from at least 10 vehicle pass-bys shall be recorded when measuring total noise levels for the whole frequency range, and at least 20 vehicle pass-bys when measuring octave band levels.

When measuring equivalent noise levels indoors with a moving microphone, at least 30 vehicles shall pass during a measurement of total noise levels and at least 60 vehicles during octave-band or one-third-octave-band noise measurements.

Percentile indoor maximum noise levels can be determined based on the statistics described in Clause 5.2, recorded by the outdoor reference microphone, and the average difference between outdoor and indoor noise levels measured during the simultaneous recordings.

The effect of actions to reduce noise, such as building a noise barrier, can be determined by measuring – both before and after the barrier is built – the difference between the noise level at a reference position not affected by the noise reduction and the noise level at the position where the noise reduction shall be evaluated. The change of this level difference is the effect of the barrier in that point.

Note: Such measurements are described in ISO 10847 for determining the insertion loss of a noise barrier. See also Note 2 in Clause 2.

5.4 Background noise

In the microphone position(s), the background noise level – measured as an overall noise level or in each frequency band – shall be at least 10 dB below the road traffic noise level to be measured. This includes noise in measurement instruments. No correction shall be made for the influence of background noise.

If the measurement time interval can not be chosen to ensure such high signal to noise ratio the report shall state that the measurement result is a high estimate of the traffic noise level and the result shall be presented in brackets.

Note: Normally, accurate measurement can not be made of the background noise level prevailing during a road traffic noise measurement and therefore a correction of the measurement result is not allowed in this Nordtest method.

The noise level between vehicle pass-bys may serve as an estimate of the background noise level in situations with not too high traffic intensity, where measurements are most sensitive to background noise influence.

Data recording should be interrupted during periods of no vehicle pass-bys and during periods with noise from

irrelevant sources such as aircraft, trains and warning signals on police cars or ambulances. The number of vehicle pass-bys during the measurement time interval shall be counted, while vehicle pass-bys during periods when recording is interrupted shall be disregarded.

Care shall be taken that noise due to wind acting on the microphone does not influence the result of measurement. A microphone wind shield shall always be used. Listening to the recorded noise signal by means of high quality headphones is useful for ensuring that the wind induced noise levels are not too high.

5.5 Reverberation in rooms

When regulation is based on the indoor traffic noise level with a specific room reverberation time T_{ref} the measurement result shall be corrected for the influence of reverberation. The correction may be estimated by means of ISO 10052 when $T_{ref} = 0,5$ s. Alternatively the reverberation time can be measured according to EN ISO 140-5 and the correction can be made in each frequency band as shown in Equation (11)

$$L_{ref} = L_{meas} - 10 \cdot \lg \frac{T_{meas}}{T_{ref}} \quad (11)$$

L_{ref} is the traffic noise level corrected to the reference reverberation time T_{ref} , and L_{meas} is the measured traffic noise level in the room with the reverberation time T_{meas} .

Note: In dwellings a simple procedure may be used. When traffic noise levels have been measured in an empty room then a good estimate of the traffic noise level to be expected in the room with furniture can be obtained by subtracting 3 dB from the measurement result, when $T_{ref} = 0.5$ s.

6 INSTRUMENTATION

6.1 General requirements

Measurement equipment applied for measuring road traffic noise, as a basis for official decision making, shall be Class 1 as specified by IEC. The complete measurement system shall comply with the IEC requirements, whether it is a sound level meter or a larger system including DAT-recorders or PC-based analysers. The equipment shall be calibrated at least every two years at a laboratory accredited for traceable calibration.

The instrumentation system shall have a sufficient dynamic range. This is normally the case when the measurement result is 15 dB or more above the inherent instrumentation system noise, provided the system is not overloaded during measurement.

Equipment used for automated noise measurement shall have facilities to record periods of overload. This enables the exclusion of erratic data. The equipment shall record the analogue signal ("the noise") on magnetic tape, disc or otherwise, during periods with unexpectedly high noise levels. During subsequent analysis the operator shall check whether such unexpectedly high noise levels were due to the traffic or whether they were due to other sources to be

excluded from the measurement. For such monitoring 5–10 seconds' recording of the noise from each event is sufficient, and only limited frequency and dynamic range is required (band width 50 Hz – 4 kHz, and 40 dB dynamic range should be sufficient).

The equipment applied for the measurement shall be specified in the report. Special equipment shall be described.

6.2 Calibration

Prior to and after each measurement the measurement system shall be checked at one or more frequencies using an acoustical calibrator according to IEC 60942. It is recommended to calibrate the equipment regularly during extended periods of measurement.

The acoustic calibrator shall be calibrated at least once a year. Record for all equipment the date of the last check and confirmation of compliance with the IEC standard.

6.3 Integrated-averaged sound level measurement

The measurement equipment shall fulfil the requirements in IEC 61672.

6.4 Maximum sound level measurement

The measurement equipment shall fulfil the requirements in IEC 61672. Unless specified otherwise, time weighting F shall be applied and the measurement result shall be updated at least every 50 ms.

Note: Time weighting F denotes exponential averaging with time constant $\tau = 0,125$ s. In case the instrument does not provide this, linear averaging with an averaging time of 0,250 s shall be applied.

6.5 Frequency spectrum measurement

The measurement equipment shall fulfil the requirements in IEC 61672 and IEC 61260.

6.6 Wind measurement

The average wind direction and average wind speed shall be recorded every 10 minutes of the measurement time interval, preferably at a height of 10 m above the ground. The uncertainty of the average wind speed in the range from 2 m/s to 10 m/s shall be smaller than 1 m/s and the uncertainty of the average wind direction shall be smaller than 10°.

Equipment directly measuring the wind speed component from road to microphone position shall measure the average wind speed component with an uncertainty smaller than 1 m/s.

Note: If the wind speed is measured at another height than 10 m, see Annex C.

6.7 Temperature measurement

The air temperature (as well as the road surface temperature, when recorded) shall be measured with an uncertainty of less than 1 °C.

Note: Temperature sensors based on infrared radiation are useful for measuring road surface temperatures while they are not applicable for air temperature measurement.

Thermometers for measuring air temperature differences for determining sound path curvatures shall be screened against radiation, they shall be ventilated, and they shall have an uncertainty of 0.1 °C or less in measured temperature difference.

6.8 Vehicle speed measurement

The uncertainty of measured vehicle speed shall be smaller than 3%.

6.9 Humidity measurement

Humidity shall be measured with an uncertainty of less than 20%.

7 MICROPHONE LOCATION

7.1 Outdoor noise measurement

Three categories of outdoor microphone locations are defined below: “free-field”, “pressure-doubling reflection (+6 dB)”, and “in-coherent reflection (+3 dB)”. The requirements in Clauses 7.1.2–7.1.4 are normally sufficient when measuring overall A-weighted noise levels for the whole frequency range. For more complex situations, including frequency spectrum measurement, see Annex A.

7.1.1 Microphone height

Outdoor noise levels to be used for calculating indoor noise levels (using sound reduction data for building components etc.) shall be measured at a height above the bottom of the window frame corresponding to two-thirds of the height of the windows.

Note 1: This often corresponds to 2 m above the ground in one-storey houses built since 1960.

Outdoor noise levels in gardens, parks and recreational areas shall be measured at a height of 1.5–2 m.

Note 2: The difference in road traffic noise levels at a height of 1.5 m and 2 m, respectively, is normally in the order of 0.5 dB and the noise level may be higher or lower at 2 m than at 1.5 m depending on terrain surface and geometry.

7.1.2 “Free-field”

The distance from the microphone to any sound reflecting surface apart from the terrain shall be at least twice the distance from the microphone to the dominating part of the sound source.

Exceptions can be made for small sound reflecting surfaces and when it can be shown that the reflection has insignificant effect (<0.5 dB).

Note: To assist in evaluating the effect of sound reflection, the contribution from reflection can be calculated according to the Nordic prediction method for road traffic noise.

7.1.3 “+6 dB”

The microphone shall be located directly on a plane and hard facade (of concrete, tile, glass, wood or similar material). The measurement yields a noise level equal to the level of the incoming sound plus 6 dB.

The facade must be plane within ±0.05 m within a distance of 1 m from the microphone, and the distance from the microphone to the surface edges shall be larger than 1 m. Annex A specifies how to deal with non-plane facades.

7.1.4 “+3 dB”

The microphone shall be positioned at a distance *d* given in Table 1 in front of the facing wall. The equivalent or maximum noise level measured deviates less than 1 dB from the level of the incoming sound plus 3 dB.

The distance *a* from the microphone to the road and the distances *b* and *c* from the microphone projection on the facing wall to the nearest horizontal edge and vertical building edge, respectively, shall be as specified in Table 1.

Note: The distances *a*, *b* and *c* are illustrated in Figure A.2 in Annex A.

Table 1. Distances from the microphone to the road, a, to the facing wall, d, and to its horizontal edge, b, and vertical edge, c, required for +3 dB measurement.

	L_{Aeq} from source seen under more than 60°	L_{AFmax} or L_{Aeq} from source seen under 60° or less
<i>d</i> [m]	0.5	1.0
<i>a</i> [m]	≥ 5	≥ 20
<i>b</i> [m]	≥ 2	≥ 4
<i>c</i> [m]	≥ 1	≥ 2

The facade shall be plane within ±0.3 m, and the microphone shall not be placed at positions where the sound field is influenced by multiple reflection of sound between protruding building surfaces.

Windows shall be considered as any other part of the façade. They shall be closed during measurement, but a small opening for the microphone cable is allowed.

The specifications in Annex A shall be adhered to when the above conditions can not be fulfilled.

7.2 Indoor noise measurements

The microphones shall be positioned at least 0.5 m from walls, ceiling or floor, and at least 1 m from significant sound

transmission elements such as windows or air intake openings.

The microphones shall be distributed uniformly within the permitted space throughout the room. The distance between neighbouring microphone positions shall be at least 0.7 m.

At least three microphone positions shall be selected when measuring overall A-weighted sound pressure levels. When measuring octave-band or one-third-octave-band sound pressure levels, at least five microphone positions shall be selected.

The average equivalent noise level for the room shall be calculated according to Equation (12).

$$L_{Aeq} = 10 \log \frac{1}{n} \left(10^{\frac{L_{Aeq1}}{10}} + 10^{\frac{L_{Aeq2}}{10}} + \dots + 10^{\frac{L_{Aeqn}}{10}} \right) \quad (12)$$

n = the number of microphone positions [–]

$L_{Aeq1}, L_{Aeq2}, \dots, L_{Aeqn}$ = equivalent noise level in positions 1, 2, ..., n [dB].

Note: If measurements are carried out during different measurement time intervals with different traffic conditions, each of the noise levels $L_{Aeq1}, L_{Aeq2}, \dots, L_{Aeqn}$ shall be converted to reference traffic conditions, cf. Clause 5.1.

A continuously moving microphone can be used for measuring equivalent noise levels. Its sweep radius shall be at least 0.7 m. The plane of traverse shall be inclined in order to cover a large portion of the permitted room space and shall not lie within 10° of the plane of any room surface. Measurements should be made along at least two different microphone paths for approximately equal amounts of time. The above requirements concerning the distance from discrete microphone positions to walls, ceiling, floor, and transmission elements also apply to moving microphone positions. The duration of a traverse period shall be not less than 15 s.

When measuring indoor percentile maximum noise levels it is recommended to determine the maximum noise level distribution outdoors in a reference position. The difference between indoor and outdoor noise levels is then measured according to Clause 5.3 and this difference is subtracted from the outdoor noise level.

8 MEASUREMENT CONDITIONS

8.1 Traffic

The number of vehicles passing shall be counted, cf. Clause 5, and sufficient, cf. Clause 9.

The speed limit shall be registered, and it is recommended to measure the average vehicle speed. This can be done using a radar device to measure the speed of vehicles selected at random, or by measuring the time it takes randomly selected vehicles to pass a given section of the road.

When studded tyres are in use during the measurement this shall be registered.

8.2 Road and ground cover

The road shall be dry, the adjacent terrain shall be free of snow and ice, and the soil shall not be frozen or soaked with water unless such conditions are the topic for investigation.

The type and age of the road surface shall be registered, and it is recommended to measure the surface temperature at a location representative of the surface temperature in the wheel tracks.

Note 1: The road surface temperature can be measured based on infrared light radiation. If instead a contact sensor is applied, the sensor shall have radiation screening and heat conductive paste shall be applied on rough textured road surfaces to ensure thermal contact.

Note 2: When it is impractical to monitor the road surface temperature continuously, the temperature should be registered regularly, preferably every 15 minutes. During long measurement time intervals (e.g. 24 hours) the road surface temperature shall be recorded sufficiently frequently to register major temperature variations.

Note 3: The road surface texture is decisive for the noise generated by the tyre/road contact. The information given in Annex E can be applied for assessment and comparison of measurement results.

8.3 Weather

8.3.1 Road surface

For road surface conditions during traffic noise measurements, see Clause 8.2.

8.3.2 Air temperature and humidity

The air temperature influences vehicle power train noise as well as tyre/road emission. The air temperature shall be recorded during the measurement time interval in a position as close to the road as practical and safe, at a height of 1.5 m above the ground. A temperature of 15°C should be aimed at during measurements, and data recording should not normally be carried out at less than 5°C or more than 30°C air temperature.

Note 1: If – according to future standards – corrections can be made for the influence of air temperature on vehicle noise emission, the results should be corrected to a reference temperature of 15°C.

The air temperature and humidity influence sound propagation and the air temperature should be measured at a location representative of the sound propagation from the road to the measurement position.

Note 2: In many cases one thermometer is sufficient for measuring the air temperature representative for vehicle noise emission and sound propagation, respectively. Before and after the measurement time interval, measure the “propagation temperature”. During the measurement time interval, monitor the “emission temperature”.

Note 3: When it is impractical to monitor the air temperature continuously, the temperature should be registered regularly, preferably every 15 minutes. During long measurement time intervals (e.g. 24 hours) the air temperature shall be recorded sufficiently frequently to register major temperature variations.

Variation in humidity is only in extreme cases significant for overall A-weighted road traffic noise levels, but in cases when frequency band sound pressure levels above 2 kHz are of interest, the humidity shall be registered and reported.

8.3.3 Sound propagation

8.3.3.1 Sound path curvature

For the purpose of this Nordtest method the weather influence on sound propagation is characterised by the normalised curvature k of the sound path caused by wind speed and temperature gradients in the lowest part of the atmosphere.

k can be approximated by Equation (13). When $k > 0$, the sound paths have a downward curvature (as is the case, for example, in downwind). A curvature $k = 0$ corresponds to straight-line sound propagation, while $k < 0$ means upward curvature (as is the case during upwind propagation or on a calm, clear day in summer). For further information, see Annex C.

$$k = \frac{0.6 \Delta T + \Delta u}{3.2} \left[\frac{1}{\text{km}} \right] \quad (13)$$

ΔT is the difference between the air temperatures, and Δu is the difference between the wind speed components at 10 m and 0.5 m above the ground, respectively.

8.3.3.2 Requirements and weather-induced measurement uncertainty

The weather conditions required during traffic noise measurements depend on the source height h_S and receiver height h_R above the ground and on the source-receiver separation d . For the purpose of this Nordtest method the source is considered situated on the road surface. When

$$h_S + h_R \geq 0.1 d \quad (14)$$

traffic noise measurements can be carried out under any weather condition.

Note 1: There should not be too much noise generated by wind, and temperature and other requirements shall be fulfilled.

Note 2: h_S and h_R are the "local" heights, i.e. the height above the point of the terrain nearest to the source and receiver, respectively. When the terrain, including any noise barrier or building, is higher than a line connecting the terrain points nearest to the source and receiver, respectively, then h_S and h_R are the local heights minus the largest height of the terrain above this connecting line.

Equation (14) requires microphone heights in excess of 5 or 10 m at distances of 50–100 m or more from the road. For measurements at more typically used microphone heights Figure 2 specifies the curvature requirement and states the associated standard deviation σ_m of measurement results to be expected as a consequence of weather variation.

Distinction is made in Figure 2 between "High" and "Low" situations, depending on the source height h_S and receiver height h_R . Situations are "High" when both the road and the microphone are 1,5 m or more above the ground. When the road is less than 1,5 m above the ground the microphone must be at 4 m height or more for the situation to be "High". In "Low" situations the requirements on weather conditions during measurement are stricter than in "High" situations.

High: $h_S \geq 1.5 \text{ m}$ and $h_R \geq 1.5 \text{ m}$

$$h_S < 1.5 \text{ m} \text{ and } h_R \geq 4 \text{ m} \quad (15)$$

Low: $h_S < 1.5 \text{ m}$ and $h_R = 1.5\text{--}2 \text{ m}$

When the whole terrain surface between the road and the measurement position is hard, the weather induced standard deviation can be neglected as long as no sound shadow is formed, i.e. $\sigma_m \cong 0$ up to 25 m in "Low" and up to 50 m in "High" situations.

Note 3: Figure 2 is valid for unscreened terrain. No quantitative information is available for screened receiver positions, and until such information becomes available it is recommended to use Figure 2 for screened situations as well and to define screened positions to be "Low" situations.

Note 4: ISO 10847 defines less restrictive weather conditions for the measurement of screen insertion loss. It is recommended instead to use the meteo-window in Figure 2 for such measurements.

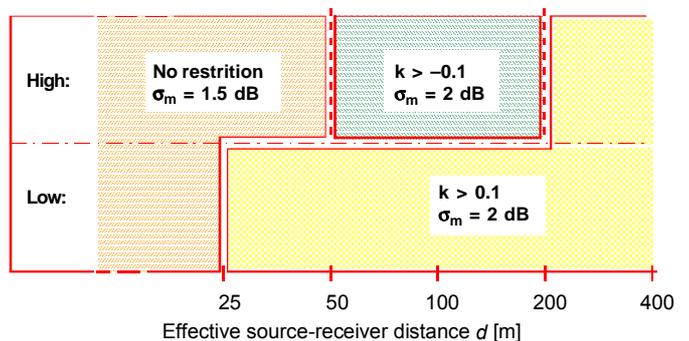


Figure 2. Requirements on sound path curvature k , and the associated measurement uncertainty – expressed as standard deviation σ_m – due to weather influence, for various combinations of effective source-receiver distances, cf. Figure 3, and source/receiver heights, cf. text.

Note: At distances d of more than 400 m: $k > 0.1$; $\sigma_m = 1 + d/400$ [dB].

The curvature shall be determined in a vertical plane through the microphone position, perpendicularly to the road centre line. The average wind direction shall be in the interval ± 60 degrees around the normal from the road through the microphone position. The effective source-receiver distance d shall be determined along the bisector of the angle between the average wind speed vector and the normal from the road to the microphone position, cf. Figure 3. This distance shall be used to determine the standard deviation σ_m in Figure 2 in order to determine the measurement uncertainty.

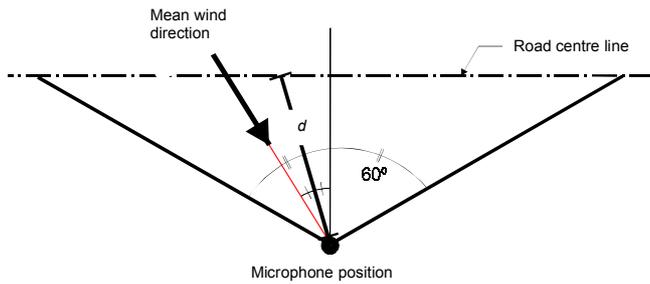


Figure 3. Illustration of the allowed wind direction interval and the effective source-receiver distance d , measured along the bisector of the angle between the average wind speed vector and the normal from the road to the microphone position.

9 UNCERTAINTY

The measurement uncertainty depends on the measurement time interval, the traffic intensity etc. and can be estimated according to Clauses 9.1–9.2.

9.1 Equivalent noise levels

9.1.1 One measurement

After having carried out one measurement, the uncertainty δ of the measured equivalent noise level can be determined by Equation (16) where σ is the standard deviation of the distribution of measurement results. Since only one measurement has been carried out, the standard deviation σ must be taken from experience obtained in similar measurements. The numbers given for contributions to σ in Clause 9.3 and Clause 8.3.3.2 are based on such experience.

$$\delta = 1.65 \sigma \tag{16}$$

9.1.2 More than one measurement

When more than one measurement has been carried out, the measurement result shall be the (arithmetic) mean of all independent results, and then the uncertainty can be estimated by Equation (17) with n = the number of independent measurements. To be independent, measurements should in general be separated by at least 24 hours.

$$\delta = \frac{1.65}{\sqrt{n}} \sigma \tag{17}$$

In case three or more independent measurements have been carried out, the value of σ can be estimated directly from the N measurement results by Equation (18).

$$\delta = \frac{t_{N-1}}{\sqrt{N}} s \tag{18}$$

t_{N-1} (Student's t) for 95% confidence in one-sided tests has been listed in Annex D.

s is the sample standard deviation of the N measurement results.

9.2 Maximum noise levels

The uncertainty of the 5th percentile $L_{AFmax,5\%}$ of the distribution of maximum noise levels can be determined in a way similar to the way described in Section 9.1. ISO 3207 defines a "statistical tolerance interval" as an interval such that there is a fixed probability (confidence level) that the interval will contain at least a proportion p of the population from which the sample is taken. The limits of the interval are called "statistical tolerance limits".

The statistical tolerance limit L_i in Equation (19) represents the upper limit of the 90% confidence interval of the 5th percentile of the maximum sound pressure level during pass-bys of the vehicle³⁾ category considered. If this noise level L_i does not exceed a given noise limit there is 95% probability that the 5th percentile is below the noise limit.

$$L_i = \bar{x} + k_u \cdot s \tag{19}$$

\bar{x} = (arithmetic) average of n observations

k_u = coefficient tabulated in ISO 3207, cf. in Annex D⁴⁾

s = sample standard deviation (estimate of the population standard deviation σ).

Note: The standard deviation σ_m due to weather influence, cf. Section 8.3, should be included if it is not insignificant. In that case s in Equation (19) and (20) should be replaced by

$$s_r = \sqrt{s^2 + \sigma_m^2}$$

The lower limit of the confidence interval of the 5th percentile can be determined by Equation (20)

$$L_i = \bar{x} + k_l \cdot s \tag{20}$$

k_l = coefficient tabulated in Annex D⁵⁾

s = sample standard deviation (estimate of the population standard deviation σ).

There is no simple way of specifying the uncertainty of the " n^{th} -highest" noise level occurring during a specified period.

Note: The percentile depends on a) the number " n^{th} -highest" and b) the total number of vehicle pass-bys during the time period considered.

The percentile of the maximum noise level distribution corresponding to the " n^{th} -highest" vehicle noise level can be calculated, cf. Figure 1 in Clause 5.2, and subsequently coefficients k_u and k_l can be calculated for that percentile, similar to the constants for the 5th percentile, cf. Annex D.

9.3 Standard deviation σ

In this Nordtest method the total standard deviation is considered to consist of a contribution σ_i from instruments, a contribution σ_k from variation in vehicle noise emission, a contribution σ_r from the effect of reflections, and a contribution σ_m from weather induced variation in sound

3) Or group of vehicles.

4) With an accuracy better than 10% the coefficient can be determined by $k_u = 2.7 \cdot (\log n)^{-0.5}$

5) With an accuracy better than 10% the coefficient can be determined by $k_l = 1.0 \cdot (\log n)^{-0.45}$

transmission path attenuation. The total standard deviation σ is calculated by Equation (21)

$$\sigma = \sqrt{\sigma_i^2 + \sigma_k^2 + \sigma_m^2 + \sigma_r^2} \quad (21)$$

The measurement instrument contribution σ_i depends on the equipment. For a precision sound level meter handled as specified by its manufacturer $\sigma_i = 0.7$ dB, and in combination with a precision tape recorder or similar, in general the contribution $\sigma_i < 1$ dB, provided the instruments have been properly maintained, controlled and calibrated.

The contribution σ_k from variation in individual vehicle noise emission due to variation in vehicle, speed and driving pattern depends on the number n of vehicle pass-bys during the measurement time interval. σ_k can be taken from Figure 4 or calculated by means of Equation (22).

$$\sigma_k \cong \frac{10}{\sqrt{n}} \text{ [dB]} \quad (22)$$

The specified microphone location, cf. Clause 7, ensures that the variation in reflection contributions is $\sigma_r < 1$ dB. For indoor measurements, the uncertainty caused by the limited number of microphone positions depends strongly on the volume, shape and damping of the room. The contribution σ_r to the standard deviation of the total A-weighted noise level is typically in the range 1–2 dB.

The contribution σ_m from weather induced variation has been described in Clause 8.3.3.2.

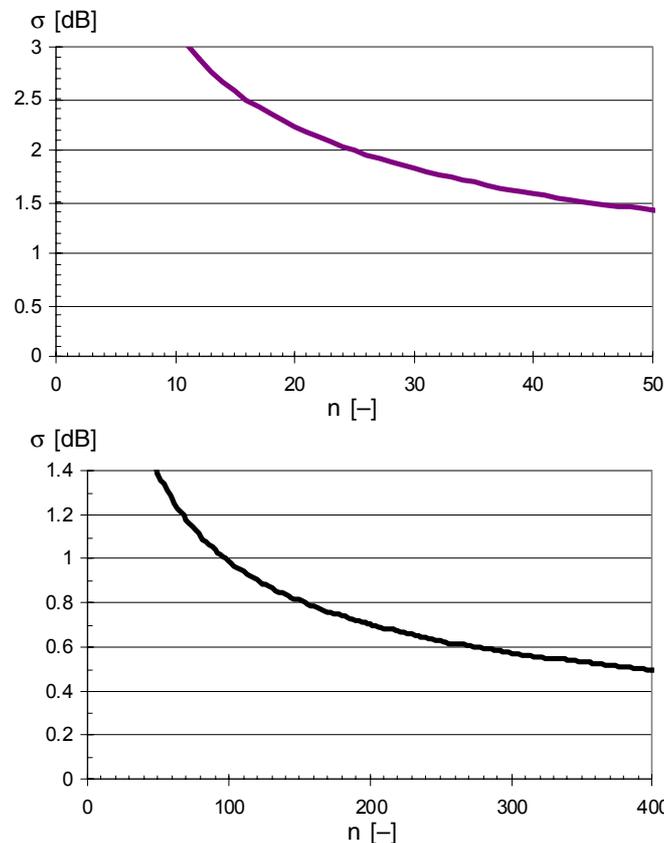


Figure 4. Standard deviation σ_k [dB] as a function of the total number n [-] of vehicle pass-bys during the measurement time interval.

10 INFORMATION TO BE REPORTED

The purpose of the report is to document the measurement result, its uncertainty, and the measurement conditions in sufficient detail for another laboratory to be able to repeat the measurement.

The report shall include all information that might be needed in subsequent official decision making.

State that the measurement has been performed in accordance with the specifications in this Nordtest method and state the measurement result and its associated uncertainty.

The report shall contain the following information, when relevant:

- Plan of measurement site showing road and microphone positions with surrounding buildings, terrain and vegetation, including scale and the direction of North
- Vertical sections with microphone positions relative to road, buildings, terrain, and other reflecting surfaces etc, and calculation results assessing the influence of reflections
- Description or drawing showing indoor microphone positions, room dimensions, materials and furniture, windows, air intakes, facing walls and other facts of importance for the indoor noise level.

Note: Some of the above information may be given in clear photographs.

- Recording and analysis equipment, type, make and model, and time of latest control
- Procedure used when calibrating the equipment
- Measurement time and observation time interval, weekday and date
- Weather conditions: wind speed and direction, wind speed component; cloud cover; sound path curvature in a vertical plane perpendicularly to the road; humidity (when required, cf. Section 8.3.2) and temperature, equipment used for weather measurement, measurement position, incl. height
- Traffic: intensity for each vehicle category (or percentage of heavy vehicles during the measurement time interval(s)); speed limit and preferably average vehicle speed for each vehicle category; driving pattern: freely flowing or stop and go; use of studded tyres
- Yearly average traffic intensity and average vehicle speed
- Conversion of equivalent noise levels; standard deviation of maximum noise levels
- Road: road surface type, age and condition; road gradient; road width and number of lanes; position of traffic light or other traffic regulation; road surface temperature (optional)
- Background noise: sources; L_{Aeq} ; frequency spectrum (when measuring octave band noise levels); time variation
- Measured noise levels L_d , L_e , L_n , $L_{Aeq,24h}$ etc. and their uncertainties (results shall be reported in brackets as

estimated highest values when background noise levels could not be kept sufficiently low)

- Name, address, telephone, fax, and E-mail for the person or laboratory having carried out the measurement with identification of accreditation or certification
- Name, address, telephone, fax, and E-mail for the person/organisation having ordered the measurement

ANNEX A (NORMATIVE): MICROPHONE POSITIONS

A.1 MICROPHONE DIRECTLY ON THE SURFACE (+6 dB MEASUREMENT)

When the microphone is mounted directly on a reflecting surface, the total sound pressure level of the direct sound and the reflected sound is 6 dB higher than the sound pressure level of the direct sound. Before comparison with noise limits expressed as free-field noise levels, 6 dB shall be subtracted from the measurement result.

The surface shall be sound reflecting and flat within ±0.05 metres within a distance of 1 metre from the microphone. The distance from the surface edges shall be

$$b \geq 1.0\text{m} \quad \text{and} \quad c \geq 1.0\text{m} \quad (\text{A.1})$$

The microphone can be mounted as shown in Figure A.1 or with the microphone membrane flush with the surface of the mounting plate. The plate should not be thicker than 25 mm and its size not less than 0.5 × 0.7 metres. The distance from the microphone to the edges and symmetry axes of the mounting plate shall be greater than 0.1 metres to reduce the influence of diffraction at the plate edges.

The plate shall be of an acoustically hard and stiff material in order to avoid sound absorption and resonance in the frequency range of interest⁶⁾.

The microphone can be used without a plate when the wall is made of concrete, stone, glass, wood, or similar hard material. In this case the wall surface must be flat within ±0.01 metres within a radius of 1 metre from the microphone⁷⁾.

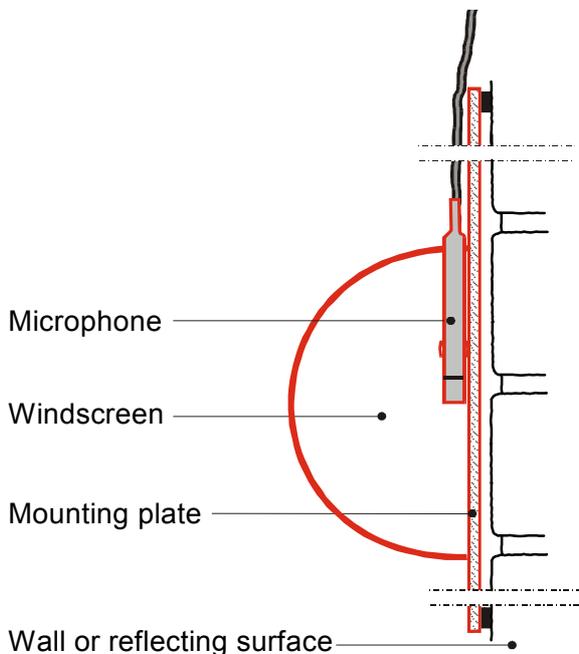


Figure A.1. Microphone mounting on reflecting surface.

A.2 MICROPHONE NEAR REFLECTING SURFACE (+3 dB MEASUREMENT)

When the microphone is placed at a distance from a reflecting surface, the direct and reflected sound is equally strong and when the frequency band considered is wide enough the reflection causes a doubling of the energy of the direct sound field and a 3 dB increase in noise level. Before comparison with noise limits expressed as free-field noise levels 3 dB shall be subtracted from the measurement result.

The distance from the microphone (M) perpendicularly to the point O on the reflecting surface is *d*, see Figure A.2. The distances from point O to the nearest edges of the reflecting surface are *b* (measured horizontally) and *c* (measured vertically). To avoid edge effects in the frequency range including the octave bands 125 Hz – 4 kHz, Criterion (A.2) shall be fulfilled:

$$b \geq 4d \quad \text{and} \quad c \geq 2d \quad (\text{A.2})$$

If these criteria cannot be fulfilled, see Clause A.3.

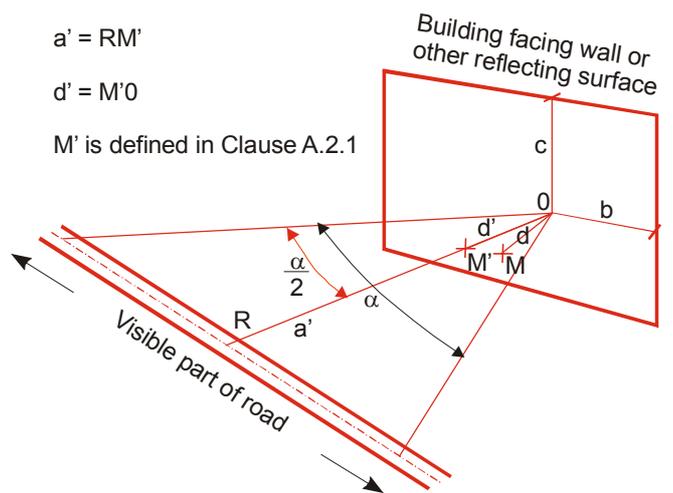


Figure A.2. MO is the perpendicular distance from the microphone position to the reflecting surface. RO is the bisector of the angle, α .

A.2.1 Extended source

When measuring L_{Aeq} at positions with $\alpha > 60^\circ$, Figure A.2, position O can be considered representative of the microphone position when estimating the angle α . *a'* and *d'* are measured along the bisector of the angle. *M'* is the point on the bisector which lies at a perpendicular distance, *d*, from the reflecting surface.

Criterion (A.3) ensures that the reflected and the direct sound have approximately the same sound pressure level (the sum is equal to the direct sound pressure level plus between 2.5 and 3 dB):

$$d' \leq 0.1a' \quad (\text{A.3})$$

Criteria (A.4) and (A.5) ensure that the coherence between the direct and the reflected sound is insignificant (the sum of the direct and reflected sound pressure levels is equal to the

6) E.g. painted chipboard thicker than approx. 19 mm or 5 mm aluminium plate with minimum 3 mm damping material on the side facing the wall.

7) For octave band measurements a ½" microphone or smaller must be used.

direct sound pressure level plus 3 dB, with an error less than approximately ±0.5 dB).

For measurements of L_{Aeq} $d' \geq 0.5m$ (A.4)⁸⁾

or when octave band results are required: $d' \geq 1.6m$ (A.5)⁸⁾

A.2.2 Point source

When measuring L_{Aeq} with less than 60° of the road visible from point 0, and when measuring L_{AFmax} with an accuracy of ±0.5 dB

$d' \leq 0.05a'$ (A.6)⁸⁾

ensures approximately equal direct and reflected sound pressure levels.

To ensure insignificant coherence $d' \geq 1.0m$ (A.7)⁸⁾

when measuring L_{Aeq} and L_{AFmax} , and when measuring in octave bands $d' \geq 5.4m$ (A.8)⁸⁾

A.2.3 Uneven reflecting surfaces

When the reflecting surface is uneven, the distances d and d' should be measured from the geometrical average location of the surface. The microphone should be placed at a position where the surface in question crosses this average (Figure A.3). Δd should not be greater than 0.5 metres when measuring total A-weighted sound pressure levels and not greater than 0.08 metres for octave band measurements.

Care should be taken to avoid microphone positions where

multiple reflections may occur between surfaces perpendicular to the facade, as e.g. cheek walls on balconies. Where this cannot be avoided, it shall be stated in the test report, and it shall be stated that the uncertainty is greater than for measurement in front of an even surface.

A.3 MICROPHONE POSITION IN COMPLEX SURROUNDINGS

The microphone position may be chosen as described in Clauses A.1 and A.2 when the purpose of the measurement is to determine the noise level in one particular position, near or on a reflecting surface (e.g. in front of a window). The criteria given in (A.2)–(A.8) may be disregarded when the noise measurement is not to be considered typical of a whole building.

When measurements to determine a noise level representative of several positions or buildings have to be made in complex surroundings, care must be taken to avoid influences of local reflections, screens and edges. The results may be inaccurate, and normally the easiest way to obtain a more accurate estimate is to repeat the measurement at several positions in the region of interest. The accuracy can be assessed on the basis of the measurement results.

When estimating α , d' and a' it should be taken into consideration that the effective length of the “line source” may be increased by reflection. If there is any doubt as to the effective length of the source, the criteria for a “point source” should be used.

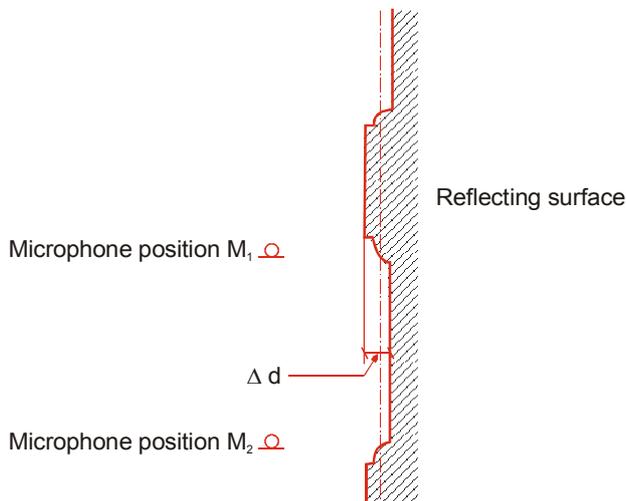


Figure A.3. Illustration of microphone position at an uneven surface.

8) In narrow streets it may be difficult to fulfil the criteria (A.3)–(A.5). By increasing the uncertainty to ±1 dB, these criteria can be rewritten as:

$d' \leq 0.2a'$ (A.3a)

$d' \geq 0.3m$ (A.4a)

$d' \geq 1.1m$ (A.5a)

Similarly for criteria (A.6)–(A.8):

$d' \leq 0.1a'$ (A.6a)

$d' \geq 0.5m$ (A.7a)

$d' \geq 2.7m$ (A.8a)

ANNEX B (NORMATIVE): CONVERSION OF EQUIVALENT NOISE LEVELS

As an alternative to measuring the whole day, evening or night period, measurements can be carried out during shorter time intervals, while counting the number of vehicles in each category separately. Then the measured noise levels from the traffic passing during the measurement time interval can be converted to correspond to average traffic conditions.

The conversion can be made applying Equations (B.1)–(B.4):

Heavy vehicles: L_{AE} (10 m) =

$$\begin{cases} 80.5 + 30 \log \left(\frac{v}{50} \right); & 50 \leq v \leq 90 \text{ km/h} \\ 80.5; & 30 \leq v < 50 \text{ km/h} \end{cases} \quad (B.1)$$

Light vehicles: L_{AE} (10 m) =

$$\begin{cases} 73.5 + 25 \log \left(\frac{v}{50} \right); & v \geq 40 \text{ km/h} \\ 71.1; & 30 \leq v < 40 \text{ km/h} \end{cases} \quad (B.2)$$

Note 1: Equations (B.1)–(B.2) have been taken from the 1996 version of the Nordic prediction method for road traffic noise. The most recent version should be used at any time. The newest proposal, Nord 2000, uses 3 categories of vehicles.

Traffic flow

$$L_{Aeq,1h}(10m) = 10 \log \frac{1}{3600} \left[n_{heavy} \cdot 10^{\frac{L_{AE,heavy}}{10}} + n_{light} \cdot 10^{\frac{L_{AE,light}}{10}} \right] \quad (B.3)$$

n_{heavy} and n_{light} are the average numbers per hour of heavy and light vehicles, respectively, in the traffic flow.

L_{Aeq} shall be calculated for the yearly average traffic flow (YDT) and for the actual traffic flow (MTT) as it was counted

during the measurement time interval. The measurement result shall be converted using Equation (B.4).

$$L_{Aeq,meas,YDT} = L_{Aeq,meas,MTT} + (L_{1,YDT} - L_{1,MTT}) \quad (B.4)$$

$L_{Aeq,meas,YDT}$ = Measured equivalent noise level converted to yearly average traffic conditions

$L_{Aeq,meas,MTT}$ = Equivalent noise level measured during the measurement time interval

$L_{1,YDT}$ = value L_1 of equivalent noise level, calculated by Equation (B.3) for yearly average traffic conditions

$L_{1,MTT}$ = value L_1 of equivalent noise level, calculated by Equation (B.3) for measurement time interval traffic conditions

Example:

MTT *Measured during 30 minutes $L_{Aeq,30 min}$ = 67.3 dB with 600 vehicles, including 22% heavy vehicles, average speed 54 km/h*

Calculation: $L_{1,MTT} = 72.5$ dB

YDT *16,000 vehicles, including 16% heavy vehicles, average speed 52 km/h*

Calculation: $L_{1,YDT} = 68.8$ dB

$L_{Aeq,meas,YDT} = 67.3 + (68.8 - 72.5) = 67.3 - 3.7$ dB = 63.6 dB

Note 2: Equations (B.1)–(B.4) presume that during the measurement time interval the traffic and its driving conditions are representative of the daily average vehicle noise emission. Normally measurements should not be performed during rush hours in case rush hour traffic is significantly slower than the traffic outside rush hours.

ANNEX C (INFORMATIVE): GUIDANCE ON WHEN THE RAY CURVATURE $k > -0.1$ AND $k > 0.1$

Figure C.1 indicates the smallest acceptable downwind component at 10 m above the ground that ensures the curvature of the sound path is larger than -0.1 and 0.1 , respectively, at approx. 56 degrees northern latitude.

The upper part of Figure C.1 shows for each month of the year the time intervals the altitude of the sun – and hence the temperature gradient – is within certain limits. For each area in the figure the necessary downwind is indicated in the table at the bottom of the figure. The demand on downwind component depends on the cloudiness and on the required curvature k .

The area marked “A” corresponds to “in the middle of the day in summer”. With thick and dense clouds a downwind component of 1.3 m/s is required before the criterion $k > 0.1$ is fulfilled. For lightly clouded or bright weather a downwind component of 2.7 m/s or more is necessary.

The area marked “B” represents morning and afternoon in summer and the time around noon in spring and autumn. In the time periods shown, the criterion $k > 0.1$ can be fulfilled e.g. by a downwind component of 2.3 m/s when the cloud cover is less than 6/8.

The area marked “C” in Figure C.1 comprises day hours beyond the time marked either A or B. The criterion $k > 0.1$ can e.g. be fulfilled in lightly clouded weather at a downwind wind speed component of 1.7 m/s.

The hours marked “D” indicate the time from sunrise to 1½ hour after sunrise and from 1½ hour before sunset until sunset. In these hours large local variation of temperature may occur, and it is recommended not to carry out weather-sensitive measurements within these time periods.

During night (shown in black in Figure C.1) only a small downwind component is required when the cloud cover is more than 6/8. If the cloudiness is less than 6/8 during night, large local temperature gradients may occur and a wind speed of 2 m/s or more is required with a component in the propagation direction when the weather is clear during night.

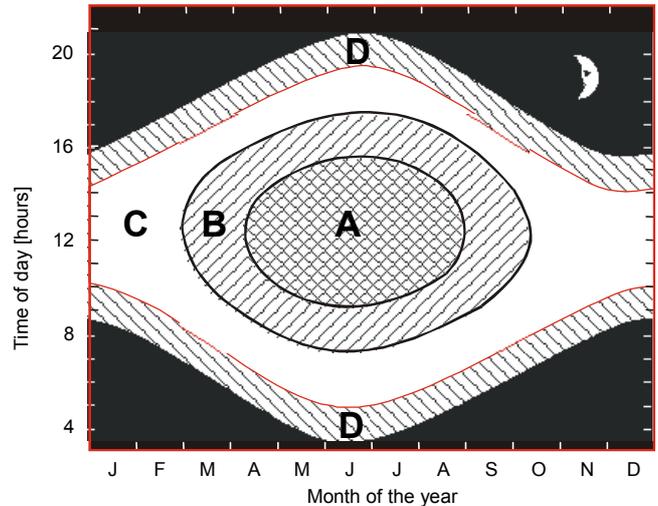
Note 1: The normalised curvature k is the inverse of the sound path radius of curvature multiplied by 1000, with R expressed in metres, Equation (C.1).

$$k = \frac{1}{R} \cdot 10^3 \quad \left[\frac{1}{\text{km}} \right] \tag{C.1}$$

For nearly horizontal propagation, and when the wind speed is much smaller than the speed of sound, R can be determined by Equation (C.2).

$$R = \frac{c}{\frac{\text{const}}{\sqrt{T}} \frac{\partial T}{\partial z} + \frac{\partial u}{\partial z}} \tag{C.2}$$

- c = speed of sound in air = $20,05 \sqrt{T}$, [m/s]
- u = wind speed component in the direction of propagation, [m/s]
- const = constant $\left(= 10 \frac{\text{m}}{\text{s}\sqrt{\text{K}}} \right)$
- T = absolute temperature of the air, [K]
- z = height above the ground, [m].



Time period	Cloud cover	Smallest wind speed component [m/s] where	
		$k > -0.1$	$k > 0.1$
A	8/8 thick and dense	0.4	1.3
	6/8–8/8	1.2	2.0
	< 6/8	2.0	2.7
B	8/8 completely dense	0.2	1.2
	6/8–8/8	0.9	1.7
	< 6/8	1.6	2.3
C	8/8 completely dense	0	0.9
	6/8	0.3	1.3
	< 4/8	0.8	1.7
Night	6/8–8/8	0.1	0.5
	< 6/8	Wind speed >2 m/s, component > 0.1	
D	Only measurements near the road		

Figure C.1. Time of day and demands on downwind component [m/s] at 10 m above the ground to ensure that the curvature k is larger than -0.1 and 0.1 , respectively, for various cloud covers, at 56 degrees northern latitude.

Note 2: If the wind speed component $u(h)$ is only measured at one height h , preferably 10 m above the ground, then the difference Δu between the wind speed components at 10 m and 0.5 m above the ground can be determined by Equation (C.3) assuming a logarithmic wind speed profile.

$$\Delta u = \frac{u(h)}{\ln \frac{h}{z_0}} \cdot \ln 20 \quad (\text{C.3})$$

z_0 is the terrain surface roughness length. Guidance values of z_0 are given in Table C.1.

Table C.1. Guidance values of the roughness length z_0 .

Landscape type	Roughness length [m]
Sea, lake, fjord	0.001
Open, no screening obstacles	0.01
Agricultural, sparsely built-up area	0.05
Residential, forest	0.3

Note 3: The temperature difference ΔT in Equation (13) is difficult to measure, and ΔT is often calculated based on the height of the sun above the horizon. This is described in Report No. 148 from DELTA, Acoustics & Vibration.

ANNEX D (NORMATIVE): STATISTICAL CONSTANTS

D.1 STANDARD DEVIATION OF MAXIMUM NOISE LEVELS

The standard deviation *s* of maximum noise levels as a function of speed *v* is given in Equation (D.1)–(D.2) taken from the Nordic prediction method for road traffic noise.

Heavy vehicles

$$\begin{cases} s = 4.1\text{dB}; 30 \leq v \leq 50 \text{ km/h} \\ s = 10 \cdot e^{-0.9 \cdot \frac{v}{50}} \text{ dB}; v \geq 50 \text{ km/h} \end{cases} \quad (D.1)$$

Light vehicles

$$s = 5.5 \cdot e^{-0.7 \cdot \frac{v}{50}} \text{ dB}; \quad v \geq 30 \text{ km/h} \quad (D.2)$$

D.2 STATISTICAL TOLERANCE INTERVALS

Table D.1 shows values of the coefficients $k_2(n, p, 1 - \alpha)$ for a one-sided statistical tolerance interval depending on the number *n* of observations, with confidence level $1 - \alpha = 0.95$

and proportion of population $p = 95\%$, after ISO 3207 and [1]. Values of *Student's t*, for one-sided confidence level 95%, are also given in Table D.1 for use in Equation (18).

For other than the 5th percentile the constants can be calculated according to Equation (D.3)

$$k_{2l}(n, p, 1 - \alpha) = -\frac{t_{p/100}(n-1, -u_p \cdot \sqrt{n})}{\sqrt{n}} \quad (D.3)$$

where

n = sample size

$t_{p/100}(f, \delta)$ = *p*th percentile of a non-central *t*-distribution with *f* degrees of freedom and with the non-central parameter

$$\delta = u_p \cdot \sqrt{n}$$

u_p is the *p*th percentile of the standardised normal distribution, for example $p = 0.05 \Rightarrow u_p = 1.65$.

[1] P. Thyregod, personal communication, July–August 2000.

Table D.1. Selected statistical constants for various sample sizes.

Sample size <i>n</i>	k_2 5 th percentile		Student's <i>t</i> t_{N-1}	Sample size <i>n</i>	k_2 5 th percentile		Student's <i>t</i> t_{N-1}
	Lower	Upper			Lower	Upper	
3	-	-	2.92	26	1.22	2.27	1.71
4	-	-	2.35	28	1.24	2.24	1.70
5	0.82	4.21	2.13	30	1.25	2.22	1.70
6	0.87	3.71	2.02	35	1.28	2.17	1.69
7	0.92	3.40	1.94	40	1.30	2.13	1.68
8	0.96	3.19	1.90	45	1.31	2.09	1.68
9	0.99	3.03	1.86	50	1.33	2.07	1.68
10	1.02	2.91	1.83	60	1.35	2.02	1.67
11	1.04	2.82	1.81	70	1.37	1.99	1.67
12	1.06	2.74	1.80	80	1.39	1.97	1.67
13	1.08	2.67	1.78	90	1.40	1.94	1.67
14	1.10	2.61	1.77	100	1.41	1.93	1.66
15	1.11	2.57	1.76	150	1.45	1.87	1.66
16	1.13	2.52	1.75	200	1.48	1.84	1.65
17	1.14	2.49	1.75	250	1.49	1.81	1.65
18	1.15	2.45	1.74	300	1.51	1.80	1.65
19	1.16	2.42	1.73	400	1.52	1.78	1.65
20	1.17	2.40	1.73	500	1.54	1.76	1.65
22	1.19	2.35	1.72	1000	1.57	1.73	1.65
24	1.21	2.31	1.71	∞	1.65	1.65	1.65

ANNEX E (INFORMATIVE): ROAD SURFACE AND TRAFFIC NOISE LEVELS

The road surface texture is decisive for the noise generated by the tyre/road contact. Rough textured and uneven surfaces cause higher noise levels than smooth surfaces in some cases, but lower noise levels in other cases. In the majority of cases the traffic noise levels are higher at old road

surfaces than at new road surfaces, but not always. After a new asphalt concrete surface has been built, the noise level gradually increases by a few decibels during the first couple of years, due to compression of the wearing course and to wearing off of fine material leading to a rougher texture.

Table E.1. Relative traffic noise levels at various road surfaces, expressed as a correction of a reference value for stone mastic asphalt (SMA) (13–16 mm). Minus means lower noise level. (U. Sandberg; J. Ejsmont, "Tyre/Road Noise Reference Book", ISBN 91–631–2610–9, INFORMEX, Harg 2002.)

Road surface type			Correction [dB] for various speeds and per cent heavy vehicles							
No.	Type and (maximum chipping size)	Age [yrs]	40–60 km/h			61–80 km/h			81–130 km/h	
			0–5%	6–19%	20–100	0–5%	6–19%	20–100	0–5%	6–100%
1a.	Stone mastic asphalt (SMA) (13–16 mm)	1–20	ref	ref	ref	ref	ref	ref	ref	ref
1b.	Same, newly laid	<1	0	0	0	0	0	0	0	0
2a.	Stone mastic asphalt (SMA) (10–12 mm)	1–20	-1	-1	-1	-1	-1	-1	-1	-1
2b.	Same, newly laid	<1	-1	-1	-1	-1	-1	-1	-1	-1
3a.	Stone mastic asphalt (SMA) (max 7–9 mm)*	1–20	-2	-1	-1	-2	-1	-1	-2	-1
3b.	Same, newly laid *	<1	-3	-2	-2	-3	-2	-2	-3	-2
4a.	Stone mastic asphalt (SMA) (max 4–6 mm)	1–20	-3	-2	-1	-3	-2	-1	-3	-1
4b.	Same, newly laid	<1	-4	-3	-2	-4	-3	-2	-4	-2
5a.	Dense asphalt concrete (DAC) (11–16 mm)	1–20	-1	0	0	-1	0	0	-1	0
5b.	Same, newly laid	<1	-2	-1	-1	-3	-2	-1	-3	-2
6a.	Dense asphalt concrete (DAC) (8–10 mm)	1–20	-1	0	0	-2	-1	0	-2	-1
6b.	Same, newly laid	<1	-2	-1	-1	-3	-2	-1	-3	-2
7.	Slurry Seal and other thin surfacings	0–5	-3	-2	-1	-3	-2	-1	-3	-1
8.	Hot rolled asphalt (HRA)	0–20	-0	0	0	+1	+1	0	+1	+1
9a.	Surface dressing, single-layer, 16–20mm	1–20	-0	0	0	+1	+1	0	+1	+1
9b.	Same, newly laid	<1	+2	+1	0	+2	+1	-1	+1	0
10a.	Surface dressing, single-layer, 10–12mm	1–20	-1	0	0	-1	0	0	-1	0
10b.	Same, newly laid	<1	-1	0	0	-1	-1	-1	-1	-1
11a.	Surface dressing, single-layer, 6–9 mm	1–20	-1	0	0	-2	-1	0	-2	0
11b.	Same, newly laid	<1	-2	0	0	-2	-1	-1	-2	-1
12a.	Surface dressing, double-layer, 16–20mm	1–20	-1	0	0	-1	0	-1	-1	0
12b.	Same, newly laid	<1	0	-1	-1	0	-1	-2	0	-1
13a.	Surface dressing, double-layer, 10–12mm	1–20	-1	0	0	-1	-1	-1	-1	-1
13b.	Same, newly laid	<1	-1	-1	-1	-1	-1	-2	-1	-1
14a.	Porous asph concr, <14–16mm ≥20% voids	3–7	-1	0	0	-2	-1	-1	-2	-1
14b.	Same, "average age"	1–2	-2	-1	-1	-2	-2	-2	-2	-2
14c.	Same, newly laid	<1	-3	-2	-2	-3	-3	-3	-3	-3
15a.	Porous asph concr, <8–12 mm (≥20% voids)	3–7	-1	0	0	-2	-1	-1	-3	-2
15b.	Same, "average age"	1–2	-2	-1	-1	-3	-3	-2	-4	-3
15c.	Same, newly laid	<1	-4	-3	-3	-5	-5	-5	-6	-5
16a.	Porous asph concr, Duradrain	3–7	?	?	?	?	?	?	?	?
16b.	Same, "average age"	1–2	-4	-3	-3	-5	-4	-4	-5	-4
16c.	Same, newly laid	<1	-5	-4	-4	-6	-5	-5	-6	-5
17a.	Porous asph concr, Twin-lay >80mm (DK version)	3–7	?	?	?	?	?	?	?	?
17b.	Same, "average age"	1–2	?	?	-?	-?	-?	-?	-?	-?
17c.	Same, newly laid	<1	-7	-7	-6	-8	-7	-6	-9	-7
18.	Cement concr, dense, smooth, <20–80 mm	0–40	+1	+1	+1	+1	+2	+2	+1	+2
19.	Cement concr, dense, smooth, <12–18 mm	0–40	0	+1	+1	+1	+2	+2	+1	+2
20a.	Cement concr, exposed aggr, max 22 mm	2–10	0	+1	+1	+1	+1	+1	+1	+1
20b.	Same, newly laid	<2	-1	-1	0	-1	-1	-1	-1	-1
21a.	Cement concr, exposed aggr, <11–16mm	2–10	0	0	0	0	0	0	0	0
21b.	Same, newly laid	<2	-1	-1	-1	-1	-1	-1	-1	-1
22a.	Cement concr, exposed aggr, max 7–9 mm	2–10	-2	-1	0	-2	-1	0	-2	-1
22b.	Same, newly laid	<2	-3	-2	-2	-3	-2	-2	-3	-2
23.	Cement concr, machine ground (unworn)	0–5	-3	-2	-2	-3	-2	-2	-2	-1
24.	Paving stones, cobblestones & large stones	0–90	+6	+5	+4	+6	+6	+5	+6	+6
25.	Paving stones, stones appr 10x10 cm	0–90	+3	+3	+2	+4	+4	+3	+4	+4
26.	Cement concrete blocks, normal	0–10	+2	+2	+2	+3	+3	+3	+3	+3
27.	Cement concrete blocks, best type	0–10	-1	0	0	-1	0	0	-1	0

*Reference road surface ISO 10844 (for vehicle noise emission testing etc.) corresponds to surface No. 3.

ANNEX F (INFORMATIVE): BIBLIOGRAPHY

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⁹⁾ It is recommended to apply the meteo-window of this Nordtest method when measuring the insertion loss of noise barriers rather than the less restrictive meteo-window of ISO 10847.