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Acoustics — Description, measurement and assessment of environmental noise —

Part 2: Determination of sound pressure levels

Acoustique — Description, évaluation et mesurage du bruit de l'environnement —

Partie 2: Détermination des niveaux de pression acoustique

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This third edition cancels and replaces the second edition (ISO 1996-2:2007), which has been technically revised.

A list of all the parts in the ISO 1996 series can be found on the ISO website.

Introduction

Measurements of environmental noise are complicated because there is a great number of variables to consider when planning and performing the measurements. As each measurement occasion is subject to current source and meteorological conditions which cannot be controlled by the operator, it is often not possible to control the resulting uncertainty of the measurements. Instead, the uncertainty is determined after the measurements based on an analysis of the acoustic measurements and collected data on source operating conditions and on meteorological parameters important for the sound propagation.

Because this document has the ambition both to comply with new and stricter requirements on measurement uncertainty calculations and to cover all kinds of sources and meteorological conditions, it has become more complicated than what a standard covering a single, specific source and application could have been. The best use of the standard is to use it as a basis for developing more dedicated standards serving specific sources and aims.

Acoustics — Description, measurement and assessment of environmental noise —

Part 2:
Determination of sound pressure levels

1 Scope

This document describes how sound pressure levels intended as a basis for assessing environmental noise limits or comparison of scenarios in spatial studies can be determined. Determination can be done by direct measurement and by extrapolation of measurement results by means of calculation. This document is primarily intended to be used outdoors but some guidance is given for indoor measurements as well. It is flexible and to a large extent, the user determines the measurement effort and, accordingly, the measurement uncertainty, which is determined and reported in each case. Thus, no limits for allowable maximum uncertainty are set up. Often, the measurement results are combined with calculations to correct for reference operating or propagation conditions different from those during the actual measurement. This document can be applied on all kinds of environmental noise sources, such as road and rail traffic noise, aircraft noise and industrial noise.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1996-1:2016, *Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures*

ISO 20906:2009/Amd 1:2013, *Acoustics — Unattended monitoring of aircraft sound in the vicinity of airports — Amendment 1*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1996-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
measurement time interval
time interval during which measurements are conducted

Note 1 to entry: For measurements of sound exposure level or equivalent-continuous sound pressure level, the measurement time interval is the time period of integration.

Note 2 to entry: For measurements of maximum sound pressure level or percent exceedance level, etc., the measurement time interval is the *observation time interval* (3.2).

3.2
observation time interval
time interval during which a series of measurements is conducted

3.3
prediction time interval
time interval over which levels are predicted

Note 1 to entry: It is now perhaps more common to predict sound levels using computers than to measure them for some sources such as transportation noise sources. The prediction time interval corresponds to the *measurement time interval* (3.1) except, for the former, the levels are predicted, and for the latter, the levels are measured.

3.4
long-term measurement
measurement sufficiently long to encompass all emission situations and meteorological conditions which are needed to obtain a representative average

3.5
short-term measurement
measurement during *measurement time intervals* (3.1) with well-defined emission and meteorological conditions

3.6
receiver location
location at which the noise is assessed

3.7
calculation method
set of algorithms to calculate the sound pressure level at a specified *receiver location* (3.6) from measured or predicted sound power levels and sound attenuation data

3.8
prediction method
subset of a *calculation method* (3.7), intended for the calculation of future noise levels

3.9
meteorological window
set of weather conditions during which measurements can be performed with limited and known variation in measurement results due to weather variation

3.10
emission window
set of emission conditions during which measurements can be performed with limited variation in measurement results due to variations in operating conditions

3.11
sound path radius of curvature
R_{cur}
radius approximating the curvature of the sound paths due to atmospheric refraction

Note 1 to entry: R_{cur} is given in metres.

Note 2 to entry: Often, the parameter used is $1/R_{cur}$ to avoid infinitely large values during straight ray propagation.

3.12
monitor
instrumentation used for a single automated continuous sound monitoring terminal which monitors the A-weighted sound pressure levels, their spectra and all relevant meteorological quantities such as wind speed, wind direction, rain, humidity, atmospheric stability, etc.

Note 1 to entry: Meteorological measurements need not be taken at each monitor provided such measurements are taken within an appropriate distance from the monitors and such distance is given in the report.

3.13
automated sound monitoring system
entire automated continuous sound monitoring system including all *monitors* (3.12), the base or central data collection position (host station) and all software and hardware involved in its operation

3.14
reference condition
condition to which the measurement results are to be referred (corrected)

Note 1 to entry: Examples of reference conditions are atmospheric sound absorption at yearly average temperature and humidity and yearly average traffic flows for day, evening and night, respectively.

3.15
independent measurement
consecutive measurements carried out with a time space long enough to make both source operating conditions and sound propagation conditions statistically independent of the same conditions of other measurements in the series

Note 1 to entry: In order to achieve independent conditions for meteorological conditions, a time space of several days is normally required.

3.16
low-frequency sound
sound containing frequency components of interest within the range covering the one-third octave bands 16 Hz to 200 Hz

Note 1 to entry: This definition is specific for this document. Other definitions can apply in different national regulations.

4 Measurement uncertainty

The uncertainty of sound pressure levels determined as described in this document depends on the sound source and the measurement time interval, the meteorological conditions, the distance from the source and the measurement method and instrumentation. The measurement uncertainty shall be determined in compliance with ISO/IEC Guide 98-3 (GUM). Choose one of the following approaches that are all GUM-compatible:

a) The modelling approach that consists in identifying and quantifying all major sources of uncertainty (the so-called uncertainty budget). This is the preferred method.

b) The inter-laboratory approach that consists in carrying out a round-robin test in order to determine the standard deviation of reproducibility of the measurement method.

NOTE 1 If more than one measurement method exists for a certain measurand, any systematic deviations are taken into account, for example, by implementing ISO 21748[1].

c) The hybrid approach that consists in using jointly the modelling approach and the inter-laboratory approach. In this case, the inter-laboratory approach is used for components of the uncertainty budget for which the contributions cannot be quantified using the mathematical model of the modelling approach because of lack of technical knowledge.

NOTE 2 Note 1 equally applies.

According to the modelling approach, each significant source of uncertainty shall be identified. Systematic effects shall be eliminated or reduced by the application of corrections wherever possible. If the quantity to be measured is L, which is a function of the quantities x_j, the formula becomes:

$$L = f\left(x_1, x_2, x_3, \ldots, x_j\right) \tag{1}$$

If each quantity has the standard uncertainty u_j, the combined standard uncertainty is given by Formula (2):

$$u(L) = \sqrt{\sum_1^n \left(c_j u_j\right)^2} \tag{2}$$

assuming that the input quantities x_j are independent. Under the same assumptions, the sensitivity coefficient c_j is given by Formula (3):

$$c_j = \frac{\partial f}{\partial x_j} \tag{3}$$

The measurement uncertainty to be reported is the uncertainty associated with a chosen coverage probability, the so-called expanded uncertainty. By convention, a coverage probability of 95 % is usually chosen, with an associated coverage factor of 2. This means that the result becomes $L \pm 2\,u$.

NOTE 3 Cognizant authorities can set other coverage probabilities. A coverage factor of 1,3 will, for example, provide a coverage probability of 80 %.

For environmental noise measurements $f(x_j)$, it is extremely complicated and it is hardly feasible to put up exact formulae for the function f. Following the principles given in ISO 3745,[2] some important sources of uncertainty can be identified. For an individual measurement, Formula (4) applies:

$$L = L' + 10\lg\left(1 - 10^{-0,1(L' - L_{\text{res}})}\right)\ \text{dB} + \delta_{\text{sou}} + \delta_{\text{met}} + \delta_{\text{loc}} \tag{4}$$

where

L is the estimated value during the specified conditions for which a measured value is wanted, expressed in decibels (dB);

L' is the measured value including residual sound, L_{res}, expressed in decibels (dB);

L_{res} is the residual sound, expressed in decibels (dB);

δ_{sou} is an input quantity to allow for any uncertainty due to deviations from the expected operating conditions of the source, expressed in decibels (dB);

δ_{met} is an input quantity to allow for any uncertainty due to meteorological conditions deviating from the assumed meteorological conditions, expressed in decibels (dB);

δ_{loc} is an input quantity to allow for any uncertainty due to the selection of receiver location, expressed in decibels (dB).

Often, $\delta_{\text{sou}} + \delta_{\text{met}}$ is determined directly from measurements; see 10.5.

L' and L_{res} are both dependent on δ_{slm} which is an input quantity to allow for any uncertainty of the measurement chain (sound level meter in the simplest case). In addition, L_{res} depends on δ_{res} which is an input quantity to allow for any uncertainty due to residual sound. Table 1 explains further the relationship between the quantities in Formula (4) and their estimate and uncertainty.

Formula (4) is very simplified and each source of uncertainty is a function of several other sources of uncertainty. In principle, Formula (4) could be applied on any measurement lasting from seconds to years. In 9.1, the measurements are divided into long- and short-term measurements, respectively. A short-term measurement may typically range between 10 min and a few hours whereas a typical long-term measurement may range between a month and a year.

In Table 1, guidance is given on how to determine c_j and u_j for insertion into Formula (2).

Table 1 — Example of an uncertainty budget for a measured value

Quantity	Estimate dB	Standard uncertainty, u_j dB	Magnitude of sensitivity coefficient, c_j	Clause for guidance
$L' + \delta_{slm}$	L'	$u(L')$ 0,5[a]	$\frac{1}{1-10^{-0,1(L'-L_{res})}}$	Annex F
δ_{sou}	0	u_{sou}	1	7.2 to 7.5, Annex D
δ_{met}	0	u_{met}	1	Clause 8, Annex A
δ_{loc}	0,0 – 6,0	u_{loc}	1	Annex B
$L_{res} + \delta_{res}$	L_{res}	u_{res}	$\frac{10^{-0,1(L'-L_{res})}}{1-10^{-0,1(L'-L_{res})}}$	Annex F

[a] 0,5 dB refers to a class 1 sound level meter. A class 2 sound level meter would have the standard uncertainty 1,5 dB.

The numbers given in Table 1 refer to A-weighted equivalent-continuous sound pressure levels only. Higher uncertainties are to be expected on maximum levels, frequency band levels and levels of tonal components in noise. In many cases, the measured values shall be corrected to other source operating conditions not representing the measured cases but the yearly average. Similarly, other measurements may be corrected to other meteorological conditions in order to make L_{den} calculations possible. Uncertainty calculations for such cases are given in Annex F.

NOTE 4 Some examples, including a spreadsheet, of complete uncertainty calculations are given in Annex G.

5 Instrumentation for acoustical measurements

5.1 General

The instruments for measuring sound pressure levels, including microphone(s), as well as cable(s), windscreen(s), recording devices and other accessories, if used, shall meet the requirements for a class 1 instrument according to IEC 61672-1 for free-field or random incidence application, as appropriate. Filters shall meet the requirements for a class 1 instrument according to IEC 61260. A windscreen shall always be used during outdoor measurements.

NOTE 1 Class 1 tolerance limits of IEC 61672–1 apply over a temperature range of −10 °C to +50 °C. If the instrument is to be used in temperatures outside the range −10 °C to +50 °C, then there can be an increase in measurement uncertainty.

NOTE 2 Even with windscreens, measured sound pressure levels can be affected by wind noise. As an example, the A-weighted sound pressure level L_{pA} for a 13 mm microphone with a 90 mm diameter windscreen exposed to a wind speed of v m/s is approximately −18+70 lg (v/1 m/s) dB with the wind blowing perpendicular to the microphone membrane and −32+83 lg (v/1 m/s) dB with the wind blowing parallel to the membrane[3].

5.2 Calibration

At the beginning and at the end of every measurement the entire sound pressure level measuring system shall be checked at one or more frequencies by means of a sound calibrator meeting the requirements for a class 1 instrument according to IEC 60942. Without any further adjustment, the difference between the readings of two consecutive checks shall be less than or equal to 0,5 dB. If this value is exceeded, the results of measurements obtained after the previous satisfactory check shall be discarded. For long-term monitoring of several days or more, the requirements of ISO 20906:2009/Amd 1:2013 apply.

5.3 Verification

Compliance of the sound pressure level measuring instrument, the filters and the sound calibrator shall be verified by the existence of a valid certificate of compliance with the measurement parameters specified in the relevant test methods in IEC 61672-3[4], IEC 61260 and IEC 60942.

All compliance testing shall be conducted by a laboratory meeting the requirements of ISO/IEC 17025 to perform the relevant tests and calibrations and ensuring metrological traceability to the appropriate measurement standards. The recommended time interval for testing of system performance is once a year. The maximum allowable interval is 2 years.

5.4 Long-term monitoring

The maximum permissible error for instruments used for meteorological measurements shall be

— ±0,5 K for temperature measuring devices,

— ±5,0 % for relative humidity measuring devices,

— ±0,5 hPa for barometric pressure measuring devices,

— ±0,5 m/s for wind speed measuring devices, and

— ±5° for wind direction measuring devices.

Meteorological classes shall be given according to Clause 8.

NOTE Some modern sonic anemometers are suitable for direct measurement of parameters to be used to determine meteorological classes.

6 Principles

6.1 General

There are two main strategies for environmental noise measurements:

a) make a single measurement under very well-defined meteorological conditions while monitoring the source operating conditions carefully;

b) make a long-term measurement, or many sampled measurements, spread out over time while monitoring the meteorological conditions.

Both types of measurements require post processing of measured data.

Each result and each type of measurement will have a certain uncertainty, which shall be determined. It is up to the user of the results to determine which accuracy to aim for. No upper limits of the measurement uncertainty are given.

The long-term L_{eq}, L_{long}, is given by Formula (5):

$$L_{\text{long}} = 10 \lg \left(\sum_{k=1}^{N_\text{w}} p_k \, 10^{0,1 L_k} \right) \text{dB} \tag{5}$$

where

p_k is the frequency of occurrence of the emission and meteorological conditions of window k yielding the L_{eq}-level L_k, expressed in decibels (dB);

N_w is the number of windows used.

Normally, L_k is determined by several measurements; see Formula (6):

$$L_k = 10 \lg \left(\frac{1}{N_\text{m}} \sum_{i=1}^{N_\text{m}} 10^{0,1 L_i} \right) \text{dB} \tag{6}$$

where

L_i is an independent measurement within window k, expressed in decibels (dB);

N_m is the number of measurements within this window.

In order to be able to calculate L_{den}, day, evening and night periods shall be separated.

A window is a combination of emission (e.g. day, evening, night) and meteorological conditions (e.g. four different classes, as shown in Table 2). Preferably, a window should include constant emission and propagation conditions. In many cases, the emission conditions are independent of the meteorological conditions and in other cases, such as for aircraft noise, there is a strong interrelationship.

Table 2 — Stratification of emission conditions and meteorological conditions during measurements

Meteorological window	1	2	3	4
Emission window				
1				
2				
N				

The uncertainty shall be determined for p_k and L_k. Ideally, the uncertainty of L_k is determined directly from a large number of independent measurements; see 10.5. If only one or few measurements are carried out, the uncertainty shall be determined using other available information. If values of L_k are missing, they shall be estimated using a prediction method. These estimates shall also include estimates of the uncertainty.

For meaningful single measurements, the minimum requirement is that L_k is determined during favourable propagation conditions as defined in Annex A and that the source operating conditions are monitored during these measurements.

6.2 Independent measurements

For two measurements to be independent, disregarding seasonal, diurnal, weekly or other systematic variations, the requirements of Table 3 can be used as a guidance (see Reference [5]).

Table 3 — Minimum time (in hours) between two measurements to be independent

Distance	<100 m		100 m to 300 m		>300 m	
	day	night	day	night	day	night
Road	24 h	24 h	48 h	48 h	72 h	72 h
Rail	24 h	24 h/ source[a]	48 h	72 h	72 h	72 h
Industry	source	source	48 h	48 h	72 h	72 h
Aircraft[b]	source	source	source	source	source	source

[a] If freight trains are dominant.

[b] Depend mostly on flight operation.

NOTE 1 "Source" in Table 3 indicates that the minimum time is influenced by the operating conditions of the source.

NOTE 2 "Day" in Table 3 refers to the time between sunrise and sunset whereas night refers to the time between sunset and sunrise.

7 Operation of the source

7.1 General

The source operating conditions shall be representative of the noise environment under consideration. To obtain a reliable estimate of the equivalent-continuous sound pressure level, as well as the maximum sound pressure level, the measurement time interval shall encompass a minimum number of noise events. For the most common types of noise sources, guidance is given in 7.2 to 7.5. The number of vehicle pass-bys (road vehicles, trains, aircraft) needed to average the variation in individual vehicle noise emission depends on the required accuracy. Less common noise sources, such as shipping traffic, helicopters and trams are not dealt with specifically.

The equivalent-continuous sound pressure level of noise from rail and air traffic can often be determined by measuring a number of single-event sound exposure levels for vehicle/train pass-bys and calculating the equivalent-continuous sound pressure level based on these.

If the measured values are to be corrected to other operating conditions using specified prediction models, the operating conditions shall be monitored using all relevant parameters used as input in the prediction method. The resulting uncertainty will depend on how accurately the different parameters are determined.

NOTE Guidance on how to correct to other conditions are given in Annex D.

The guidance given does not consider potential additional problems with low-frequency sound sources such as helicopters, bridge vibrations, subway trains, freight trains, mine sites, stamping plants, pneumatic construction equipment, etc. ISO 1996-1:2016, Annex C contains a further discussion on low-frequency sound. Procedures to measure low-frequency sound are given in 9.2.2 and 9.3.2.7.

7.2 Road traffic

7.2.1 L_{eq} measurement

When measuring L_{eq}, the number of vehicle pass-bys during the measurement time interval shall be determined by direct counting or by other means. If the measurement result shall be converted to other traffic conditions, distinction shall be made between at least the three categories of vehicles "passenger cars" and "'medium heavy (2 axles)" and "heavy (≥3 axles)". To determine if the measurement conditions are representative, the average traffic speed shall be determined by measurements or by other means and the condition and type of road surface shall be noted.

The number of vehicle pass-bys needed to average the variation in individual vehicle noise emission depends on the required accuracy. If no better information is available, the standard uncertainty denoted u_{sou} in Table 1 can be calculated by means of Formula (7):

$$u_{sou} \cong \frac{C}{\sqrt{n}} \text{ dB} \tag{7}$$

where n is the number of pass-bys.

For mixed traffic $C = 10$, for heavy vehicles only $C = 5$ and for passenger cars only $C = 2{,}5$. In each case, a more accurate standard uncertainty can be determined from the statistics of direct L_E measurements of individual pass-bys either category by category or for a representative traffic mix.

7.2.2 L_{max} measurement

The maximum sound pressure levels differ among vehicle categories. In addition, within each vehicle category, a certain spread of maximum sound pressure levels is encountered due to individual differences among vehicles and variation in speed or driving patterns. Depending on definition the maximum sound pressure level can either be measured directly from a specified number of pass-bys or calculated from the arithmetic mean value and the standard deviation using statistical theory; see Annex H.

7.3 Rail traffic

7.3.1 L_{eq} measurement

When determining L_{eq}, either by direct measurement or by measurement of L_E of individual pass-bys, the number of train pass-bys, the speeds and the train lengths, or, alternatively, the number of cars shall be determined during the measurement time interval. If the measurement result shall be converted to other traffic conditions, distinction shall be made between at least the following categories: high-speed trains, inter-city trains, regional trains, freight trains and diesel trains. For increased accuracy for freight trains, train length and brake type (disc-brakes, tread-brakes using cast iron or sinter) should be recorded.

The number of vehicle pass-bys needed to average the variation in individual vehicle noise emission depends on the required accuracy. If no better information is available, the standard uncertainty denoted u_{sou} in Table 1 can be calculated by means of Formula (8):

$$u_{sou} \cong \frac{C}{\sqrt{n}} \text{ dB} \tag{8}$$

where n is the number of pass-bys.

If the sampling was made regardless of the operating conditions, assume $C = 10$, while if the sampling takes into account the relative occurrence of the different train classes (freight, passenger, etc.), this value can be lowered to 5. In each case, a more accurate standard uncertainty can be determined from the statistics of direct L_E measurements of individual pass-bys either category by category or for a representative traffic mix.

7.3.2 L_{max} measurement

The maximum sound pressure levels differ among train categories. In addition, within each train category, a certain spread of maximum sound pressure levels is encountered due to individual differences among vehicles and variation in speed operating conditions. Depending on definition, the maximum sound pressure level can either be measured directly from a specified number of pass-bys or calculated from the arithmetic mean value and the standard deviation using statistical theory; see Annex H.

7.4 Air traffic

7.4.1 L_{eq} measurement

The L_{eq} value shall be determined from L_E measurements of a representative operation of the airport. This includes the traffic pattern (runway use, take-off and landing procedures, air fleet mix, time-of-day distribution of the traffic) as well as the noise propagation conditions. The main quantity to measure is the A-weighted sound exposure level, L_{AE}, but other measures may be relevant to determine that an event belongs to an aircraft. Such measures may include:

— the continuous A-weighted sound pressure level at a rate of at least 10 Hz;

— the maximum sound pressure level L_{ASmax};

— time stamp for the L_{ASmax};

— duration of the event.

NOTE 1 Additional useful information on measurements can be found in ISO 20906.

Each measured aircraft event shall be identified and, if relevant, grouped according to size (mass) and technology. Number of classes and assignment of aircraft to classes is subject to discussions with airport authorities and/or by national authorities.

NOTE 2 Codes for identification of different types of aircraft are given in ICAO Annex 16[6].

Data needed from the airport authorities are:

a) number of operations for each aircraft group during each measurement window;

b) reference traffic (average traffic data per aircraft type/per operating condition).

A runway can be used in both directions for take-off and landing depending on meteorological conditions. For larger airports with two or more runways, the situation is even more complex. The specific use of the runways is known as the "airport configuration". For the determination of a long-term composite rating like L_{den} or L_{dn}, it is important that each configuration be measured in a separate "window" and that the results be weighted according to the use of each configuration during a "typical" year.

When determining a time-period-average whole-day composite rating level from L_E measurements during a time period like a week or month for a specific airport configuration, airport operation conditions (traffic pattern and noise propagation conditions) during the period shall be checked if those are representative for the configuration.

The number of sound events needed to average the variation in individual aircraft noise emission for a specific airport configuration depends on the required accuracy. If no better information is available, the standard uncertainty denoted u_{sou} in Table 1 can be calculated by means of Formula (9):

$$u_{sou} \cong \frac{C}{\sqrt{n}}\,\mathrm{dB} \qquad (9)$$

where n is the number of sound events.

If the sampling was made regardless of aircraft operating conditions, assume $C = 4$, while if the sampling takes into account the relative occurrence of aircraft types and flight modes, assume $C = 3$ for take-off jet aircraft, $C = 4$ for other take-off aircraft, $C = 2$ for all landing jet aircraft and $C = 3$ for other landing aircraft.

When determining a composite rating level for a specific airport configuration by L_E measurement of all observable aircraft sound events during a period without information of airport operation conditions, the standard uncertainty, u_{sou}, due to the variation in aircraft noise emission can be assumed u_{sou} = 3 dB for an individual day, u_{sou} = 2 dB for a week average and u_{sou} = 1 dB for period longer than a month.

7.4.2 L_{max} measurement

If the purpose is to measure the maximum sound pressure level from air traffic in a specific residential area, ensure that the measurement period contains the aircraft types with the highest noise emission using the flight tracks of nearest proximity. Depending on definition, the maximum sound pressure level can either be measured directly from a specified number of pass-bys or calculated from the arithmetic mean value and the standard deviation using statistical theory; see Annex H.

7.5 Industrial plants

7.5.1 L_{eq} measurement

The source operating conditions shall be divided into classes: for each class, the time variation of the sound emission from the plant shall be reasonably stationary in a stochastical sense. The variation shall be less than the variation in transmission path attenuation due to varying weather conditions; see Clause 8. The operating condition shall be defined by the activity as well as its location; for example, 1) measure L_{eq} values over 5 min to 10 min at a distance; 2) the distance shall be long enough to include noise contributions from all major sources and short enough to minimize meteorological effects (see Clause 8) during a certain operating condition; 3) if the L_{eq} values turn out to vary considerably, a new categorization of the operating conditions shall be made. Measure L_{eq} during each class of operating condition and calculate the resulting L_{eq} taking the frequency and duration of each class of operating condition into account.

In order to be able to carry out uncertainty calculations according to Clause 4, it is necessary to estimate the standard uncertainty of the operating conditions. One way of doing this is to repeat the measurements at a distance sufficiently close to the source to make the sound pressure level variations independent of the meteorological conditions; see Formula (10):

$$u_{sou} = \sqrt{\sum_{i=1}^{n} \frac{\left(L_{mi} - \overline{L_m}\right)^2}{n-1}} \text{ dB} \tag{10}$$

where

L_{mi} is the measured value representing a typical cycle of operation, expressed in decibels (dB);

$\overline{L_m}$ is the arithmetic average of all L_{mi}, expressed in decibels (dB);

n is the total number of all independent measurements.

7.5.2 L_{max} measurement

If the purpose is to measure the maximum sound pressure level of noise from industrial plants, ensure that the measurement period contains the plant operating condition with the highest noise emission occurring at the nearest proximity to the receiver location. Depending on definition, the maximum sound pressure level can either be measured directly from a specified number of operating cycles or calculated from the arithmetic mean value and the standard deviation using statistical theory; see Annex H.

8 Meteorological conditions

8.1 General

Sound pressure levels vary with the weather conditions. For soft ground, such variations are modest when Formula (11) applies:

$$\frac{h_s + h_r}{D} \geq 0{,}1 \tag{11}$$

where

h_s is the source height;

h_r is the receiver height;

D is the horizontal distance between the source and receiver.

If the ground is hard, larger distances may be acceptable.

For both long-term and short-term measurements, meteorological parameters shall be measured. As a minimum requirement, wind speed, wind direction, relative humidity and temperature shall be measured. Furthermore, information about atmospheric stability, either from direct measurements or indirectly from cloud coverage and time of day, shall be provided. Information about precipitation, if any, shall be given. For the purpose of defining propagation conditions in the direction of the shortest distance from the receiver to the source, the windows shown in Table 4 can be used to fill in the measurement matrix shown in 6.1. The radius of curvature, R_{cur}, can either be determined indirectly from Table 4 or be calculated from measured meteorological parameters according to Annex A. D is the horizontal distance between the source and the receiver in metres. The radius of curvature is negative when sound paths are curved upwards and a minus sign on the wind speeds indicates that the wind direction is from receiver to source.

NOTE Table 4 is a simplified table and other alternative descriptions are permitted as long as they ensure that the desired curvatures are achieved.

The general description given may not be appropriate for very high sources, for example, wind turbines, where different atmospheric layers and turbulence may become important.

Table 4 — Meteorological windows

Meteorological windows	D/R_{cur} Range	D/R_{cur} Representative value	Verbal description
M1[a]	<−0,04	−0,08	unfavourable
M2[b]	−0,04 ... 0,04	0,00	neutral
M3[c]	0,04 ... 0,12	0,08	favourable
M4[d]	>0,12	0,16	very favourable

[a] Typical value of vector wind speed component at 10 m, <1 m/s and <−1 m/s at day and night, respectively.

[b] Typical value of vector wind speed component at 10 m, 1 m/s to 3 m/s.

[c] Typical value of vector wind speed component at 10 m, 3 m/s to 6 m/s.

[d] Typical value of vector wind speed component at 10 m, >6m/s and ≥−1 m/s at day and night, respectively.

8.2 Favourable propagation

If only one or a few short-term measurements are carried out, they should be taken during favourable or very favourable propagation conditions (Meteorological window M3 or M4) or when Formula (11) applies. In that case, unless better information is available, the standard uncertainty is:

$$u_{\mathrm{met,fav}} = 2\ \mathrm{dB} \tag{12}$$

for distances $D \leq 400$ m. For distances $D > 400$ m, it is given by Formula (13):

$$u_{\mathrm{met,fav}} = \left(1 + \frac{D}{400\,\mathrm{m}}\right)\mathrm{dB} \tag{13}$$

This clause may not be entirely appropriate for aircraft noise as the direction of take-off and landing depends on the vector wind component along the runway. In some microphone locations, there may never be any favourable propagation.

8.3 Effects of precipitation on measurements

Precipitation on the windscreen may generate spurious noise. The measurement results obtained under such conditions shall be discarded unless it can be shown that the effect has been negligible. After the rain has stopped, the acoustic properties of the windscreen may be modified. For standard windscreens (9 cm diameter), this effect can be significant for frequencies higher than 1 kHz if the amount of precipitation is greater than 1 mm. In this case, it remains significant for a duration, T, necessary for the windscreen to dry out.

T can be estimated using Formula (14):

$$T = 16{,}3\lg\left(7{,}4\lg(h) + 1{,}5\right) - 2{,}8; \quad h \geq 1 \tag{14}$$

where

T is the numerical value of the time, expressed in hours;

h is the numerical value of the precipitation, expressed in millimetres.

NOTE Formula (14) can only be regarded as an example as parameters like wind speed, direct sun radiation and relative humidity in practice can have significant influence[17].

When the effect of rain is significant, the measured data remain usable provided that the associated uncertainty is taken into account.

9 Measurement procedures

9.1 Selection of measurement time interval

9.1.1 Long-term measurements

Include as many important emission and propagation conditions as possible. Stratify the measurements to avoid any bias in the source operating conditions. Source operating conditions, e.g. traffic composition and vehicle flow conditions, shall be as representative as possible to minimize later corrections. It is particularly important to include those windows contributing most to the long-term L_{eq}. If propagation conditions or emission conditions vary strongly between the different seasons of the year, for example because of winter tyres and snow cover, it might be necessary to measure during several different seasons to achieve a low measurement uncertainty.

L_{den} for constant industrial noise shall be determined by night-time values.

9.1.2 Short-term measurements

Select the measurement time interval to cover all significant variations in noise emission. If the noise displays periodicity, the measurement time interval should preferably cover an integer number of several periods. If continuous measurements over such a period cannot be made, measurement time intervals shall be chosen so that each represents a part of the cycle and so that, together, they represent the complete cycle. Representative measurement results can be extended in time to cover the period for which they are representative and combined to provide new results.

If the noise is from single events (e.g. aircraft fly-over in which the noise varies during the fly-over and is absent during a considerable portion of the reference time interval), measurement time intervals shall be chosen so that the sound exposure level, $L_{E,T}$, of the single event can be determined.

For short-term measurements requiring favourable conditions involving propagation over distances not covered by Formula (11), the minimum averaging time to average the actual meteorological conditions is 10 min. To achieve a sufficient averaging of source conditions may, however, require a longer time.

9.2 Microphone location

9.2.1 Outdoors

9.2.1.1 Selection of measurement site

Sites for measuring microphones shall be chosen to minimize the effect of residual sound from non-relevant sound sources.

NOTE Some guidance in the selection of measurement site is given in Annex C.

9.2.1.2 Selection of microphone location

Select one of the following kinds of location:

a) To assess the situation at a specific location, use a microphone at that specific location.

b) For other purposes, use one of the following locations:

1) incident sound field (reference condition).

NOTE 1 This is either an actual free-field case or a theoretical case for which the hypothetical free field over ground sound pressure level outside a building is calculated from measurements close to the building; see 2) and 3). The incident field notation refers to the fact that all reflections, if any, from any building behind the microphone are eliminated. A location behind a house which acts as a barrier is also considered to be an incident field location but in this case locations 2) and 3) are not relevant and reflections from the back side of the building are included.

2) Location with the microphone flush-mounted on the reflecting surface.

In this case, the correction to use to get free field is up to 6 dB. It is 5,7 dB if the conditions in Annex B are met. For other conditions, other corrections have to be used.

NOTE 2 +6 dB is the difference between a façade mounted microphone and a free-field microphone in an ideal case. In practice, minor deviations from this value will occur. For further guidance, see Annex B.

3) Location with the microphone 0,5 m to 2 m in front of the reflecting surface.

In this case, the correction to use to get free field is up to 3 dB. It is 3 dB if the conditions in Annex B are met. For other conditions, other corrections have to be used.

NOTE 3 The difference between a microphone 2 m in front of façade and a free-field microphone is close to 3 dB in an ideal case where no other vertical reflecting obstacle influences sound propagation to the studied receiver. In more complex situations (e.g. high building density on the site, canyon street, etc.), this difference can be much higher. Even in the ideal case there can be some restrictions. For near grazing incidence, this location is not recommended as the deviations then can become greater. For further guidance, see Annex B.

In principle, any of the above locations can be used provided that the location used is reported together with a statement whether or not any correction to the reference condition has been made. In some specific cases, the above locations are subject to further restrictions.

For general mapping, unless otherwise specified, use a microphone height of (4,0 ± 0,2) m in multi-storey residential areas.

9.2.2 Indoors

Use at least three discrete locations evenly distributed in areas of the room where affected persons preferably stay, or, as an alternative, for continuous noise, use a moving microphone.

If dominant low-frequency sound is suspected, one of the three locations shall be in a corner and no rotating microphone is allowed. The corner location shall be 0,5 m from all boundary surfaces in a corner with the heaviest walls and without any wall openings nearer than 0,5 m.

The other microphones shall be located 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 distance between neighbouring microphone locations shall be at least 0,7 m. If a continuously moving microphone is used, 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. The above requirements concerning the distance from discrete microphone locations to walls, ceiling, floor and transmission elements also apply to moving microphone locations. The duration of a traverse period shall be not less than 15 s.

NOTE 1 In case of A-weighted measurements only and small contributions to the A-weighted level from low frequencies it can, in some cases, be sufficient with one microphone location.

NOTE 2 The above procedures are primarily intended for rooms with volumes <300 m^3. For larger rooms, more microphone locations might be appropriate.

NOTE 3 National regulations can prescribe different rules to determine measurement positions.

9.3 Measurements

9.3.1 Long-term unattended measurements

9.3.1.1 Quantities to measure

The monitor shall measure continuously and shall store the A-weighted sound pressure levels of the total sound in the form of time-series of one second or less time-averaged sound pressure levels. Relevant meteorological data shall be recorded. Other quantities are optional.

9.3.1.2 Time stamp

A system for monitoring sound of discrete events shall contain an accurate clock for identification of the date and time of day for each measurement of sound events and related phenomena.

9.3.1.3 Event detection

Automatic long-term monitoring of single events is possible only when relevant events are reliably and precisely detected and identified in order to be included in or excluded from the result. Different identification techniques can be used depending on the situation. The uncertainty caused by the identification technique shall be estimated and reported.

9.3.2 Short-term attended measurements

9.3.2.1 General

One or several of the following quantities shall be measured.

9.3.2.2 Equivalent-continuous sound pressure level during the time interval T, $L_{eq,T}$

For short-term averaging, measure in frequency bands during at least 30 min to average meteorological variations in the propagation path unless Formula (11) is complied with or the propagation is favourable; see 8.2. In that case, 10 min is usually sufficient. These minimum times shall be increased in order to get a representative sample of source operating conditions; see Clause 7.

NOTE One-third-octave-band data can be required in order to allow for corrections using prediction methods.

9.3.2.3 Sound exposure level during the time interval T, $L_{E,T}$

Measure a minimum number of events of the source operation as specified in Clause 7. Measure each event during a time period which is long enough to include all important noise contributions. For a pass-by, measure until the sound pressure level has dropped at least 10 dB below the maximum sound pressure level recorded during the actual pass-by. Separate between different categories of vehicles as defined by the relevant prediction method.

NOTE One-third-octave or octave band data are required in order to allow for corrections using prediction methods.

9.3.2.4 N percent exceedance level during the time interval T, $L_{N,T}$

During the measurement interval, carry out short-term logging of $L_{eq,t}$ (where $t \leq 1s$) at least once a second, or of the sound pressure level with a sampling time less than the time constant of the time-weighting used. The class interval into which logged results are placed shall be 1,0 dB or less. The parameter basis and, where applicable, time weighting, the period of logging and the class interval used to determine the $L_{N,T}$ shall be reported (e.g. "Based on 10 ms sampling of L_F with class interval 0,2 dB" or "Based on $L_{eq,1s}$, with class width 1,0 dB").

9.3.2.5 Maximum time-weighted sound pressure level, $L_{F,max}$, $L_{S,max}$

Using time weighting F or S, as specified, $L_{F,max}$ or $L_{S,max}$ are to be measured for a specified number of events of the source operating as specified in Clause 6. Each result shall be recorded.

9.3.2.6 Tonal sound

If the noise characteristics at the receiver location include audible tone(s), an objective measurement of the prominence of the tones should be carried out. Select the microphone locations with the most audible tone(s) and proceed with the analysis as described in Annex J for an engineering method and Annex K for a survey method.

NOTE 1 In general, tonal analysis of indoor noise is not recommended due to the modal behaviour of tones in rooms. For some frequency bands, it will also be problematic at microphones in front of a façade.

NOTE 2 Some national regulations allow for a subjective assessment to characterize the tonal sound.

9.3.2.7 Impulsive sound

There is no International Standard to detect impulsive sound using objective measurements. If impulsive sound occurs, identify the source and compare it to the list of impulsive sound sources in ISO 1996-1. In addition, make sure that the impulsive sound is representative and present in the measurement interval.

NOTE There are examples of regional methods for objective measurements on impulsive sound, for example NT ACOU 112[7] and BS 4142[8].

9.3.2.8 Low-frequency sound

Indoors, measure in three microphone locations as specified in 9.2.2. Outdoors, measure in the free field or directly on a façade; see Annex B.

The methods in this document are generally valid down to the 16 Hz octave band. However, for these low-frequency measurements, the microphone shall be at least 16 m from the nearest significant reflecting surface other than the ground in order to be a free-field (incident sound field) measurement.

NOTE 1 The microphone location in front of the reflecting surface mentioned in 9.2.1.2 b) has not been defined for low-frequency sound measurements.

NOTE 2 For spectral analysis of low frequencies, the BT >> 1 rule (where B = bandwidth in Hz and T = measurement time in s) is important to take note of to avoid too much spread in the measurements. In particular, care is to be taken when extracting data based on automated routines where short continuous sections of recordings can be used. Lower frequencies require longer averaging time.

Thus, at 10 Hz where the bandwidth of one-third-octave analysis is 2,3 Hz, continuous measurement samples of at least 5 s duration are recommended. At 50 Hz, the bandwidth is 11,6 Hz and it is acceptable to extract data based on 1 s samples. These examples are based on a BT product of approximately 10 corresponding to a theoretical standard deviation of 1,4 dB on the measurement results for white noise.

9.3.3 Residual sound

When measuring environmental noise, residual sound is often a problem. One reason is that regulations often require that the noise from different types of sources be dealt with separately. This separation, e.g. of traffic noise from industrial noise, is often difficult to accomplish in practice. Another reason is that the measurements are normally carried out outdoors. Wind-induced noise, directly on the microphone and indirectly on trees, buildings, etc., may also affect the result. The character of these noise sources may make it difficult, or even impossible, to carry out any corrections. However, to carry out corrections (see 10.4) and to determine the measurement uncertainty (see Clause 4) it is necessary to measure the residual sound and to determine its standard uncertainty.

NOTE Some guidance on how to determine residual sound is given in Annex I.

9.3.4 Frequency range of measurements

If the frequency content of the noise is required, then, unless otherwise specified, measure the sound pressure level using octave-band filters having the following mid-frequencies: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 000 Hz, 2 000 Hz, 4 000 Hz, 8 000 Hz.

For low-frequency applications, extend the range downwards to 16 Hz. Optionally, the measurements can be made in one-third-octave bands with mid-band frequencies covering the above octave bands.

9.3.5 Measurements of meteorological parameters

The following meteorological parameters should be measured:

a) wind speed;

b) wind direction, air temperature, relative humidity;

c) occurrence of precipitation;

d) atmospheric stability (optional, it may also be determined indirectly from cloud cover and time of day).

Wind speed and wind direction should be measured at a height of 10 m.

The practicalities of on-site surveys may necessitate lower measurement heights but the use of lower heights than 10 m for measurements of wind speed and wind direction will increase the measurement uncertainty as data and experience used in this document are based on measurements at 10 m.

10 Evaluation of the measurement results

10.1 General

Remove all data including unwanted events (see Annex E) or with too high residual sound (see Annex I). Correct all measured outdoor values to the reference microphone location (see Annex D) that is the free-field level excluding all reflections from the façade immediately behind the microphone but including all reflections from the ground and other vertical objects but the façade immediately behind. After that, if relevant,

a) assign each sample to a specific window (based on meteorological and/or operating conditions),

b) correct for residual sound according to Formula (16) or reject the sample if too much noise,

c) correct each sample to reference conditions that include reference traffic and reference atmospheric conditions (see Annex D for guidance),

NOTE 1 The reference conditions normally differ between day, evening and night.

d) calculate $L_{\mathrm{eq},T}$ over each window using Formula (15):

$$L_{\mathrm{eq},T} = 10 \lg \frac{\sum_i^N \Delta T_i \, 10^{0,1 L_{\mathrm{eq},i}}}{\sum_i \Delta T_i} \, \mathrm{dB} \tag{15}$$

where ΔT_i is the duration of each measurement period.

NOTE 2 If L_E has been measured the relevant L_{eq} is calculated as described in 10.6.2.

e) Based on frequency of occurrence during the relevant time period, windows are now combined together according to Formula (6),

f) determine the measurement uncertainty using the principles outlined in Clause 4 and the annexes.

10.2 Determination of $L_{E,T}$, $L_{\mathrm{eq},T}$ and $L_{N,T}$

10.2.1 $L_{E,T}$ and $L_{\mathrm{eq},T}$

For each microphone location and each category of source operating conditions, determine the energy average of each $L_{E,T}$ or $L_{\mathrm{eq},T}$.

NOTE Guidance on how to correct $L_{\mathrm{eq},T}$ to obtain rating levels is given in ISO 1996-1.

10.2.2 $L_{N,T}$

Analyse the sampled values statistically to obtain the statistical level, $L_{N,T}$ for N%.

10.3 Treatment of incomplete or corrupted data

10.3.1 General

A monitoring system or one of its stations may cease acquiring or processing valid sound data as a result of power failure, excessive wind sound, equipment malfunction, etc. Provision shall be made to alert the operator of such a condition, to promote ready resumption of operation and to minimize loss of data. Where data are irretrievably lost or invalidated, sound level calculations shall be modified appropriately. For example, if several hours of downtime are incurred on a certain day, the averaging process to determine the cumulative daily A-weighted sound pressure level shall be carried out over only those hours for which data are available, rather than over the entire day. Another approach could be that only these daytime or night-time hours are taken into account for which the measurement conditions were acceptable. All such data shall be flagged to indicate the circumstances.

10.3.2 Wind sound

Data taken in windy conditions will increase the measurement uncertainty and may adversely affect the accuracy of the data. If the local wind speed at the microphone site is known at the time of each sound event, this should be included in the report. For wind speeds creating noise closer than 5 dB to the level to be measured, the measured data shall be flagged.

NOTE In some cases, wind effects can be identified by the specific spectrum of wind sound (usually a low frequency dominated broad band sound).

10.4 Level correction for residual sound

If the residual sound pressure level is 3 dB or less below the measured sound pressure level, no corrections are allowed. The measurement uncertainty will then be large. The results may, however, still be reported and may be useful for determining an upper boundary to the sound pressure level of the source under test. If such data are reported, it shall clearly be stated in the text of the report, as well as in graphs and tables of results, that the requirements of this test method have not been fulfilled.

For cases when the residual sound pressure level is more than 3 dB below the measured sound pressure level, the level shall be corrected according to Formula (16):

$$L = 10\lg\left(10^{L'/10} - 10^{L_{\text{res}}/10}\right) \text{ dB} \tag{16}$$

where

L is the corrected sound pressure level, expressed in decibels (dB);

L' is the measured sound pressure level, expressed in decibels (dB);

L_{res} is the residual sound pressure level, expressed in decibels (dB).

10.5 Determination of standard uncertainty

The uncertainty to be determined directly from the measurements is the combined uncertainty of the emission by the source and the meteorological conditions. It shall be determined separately for each relevant period, such as day, evening, night and, if required, also for different seasons.

The standard uncertainty of the measurements within window k, u_k is determined using Formula (17):

$$u_k = 10\lg\left(10^{0,1L_k} + S_k\right)\text{dB} - L_k \quad (17)$$

where

L_k is the energy averaged measured sound pressure level for the N_m independent measurements within the meteorological and emission window k, expressed in decibels (dB), that is given in Formula (18):

$$L_k = 10\lg\left(\frac{1}{N_\text{m}}\sum_{i=1}^{N_\text{m}} 10^{0,1L_i}\right)\text{dB} \quad (18)$$

S_k is given by Formula (19):

$$S_k^2 = \left(\frac{1}{N_\text{m}-1}\sum_{i=1}^{N_\text{m}}\left(10^{0,1L_i} - 10^{0,1L_k}\right)^2\right) \quad (19)$$

where L_i is the measured value representing one independent measurement within window k, expressed in decibels (dB).

NOTE 1 Repeated measurements carried out using the same equipment are not independent as far as the uncertainty due to instrumentation is concerned.

NOTE 2 If the difference between different L_i is small, Formulae (17) to (19) can be replaced by Formula (20):

$$u_k = \sqrt{\sum_{i=1}^{n_k}\frac{\left(L_i - L_k\right)^2}{n_k - 1}}\ \text{dB} \quad (20)$$

NOTE 3 The standard deviation of a mean value is given by the standard deviation of the observations divided by the square root of the number of observations.

10.6 Determination of L_den

10.6.1 Determination from long-term L_eq measurements

Carry out calculations using the following steps.

a) Remove unwanted data. Some guidance on how to do that is given in Annex E.

b) Stratify the data into the different windows and correct for residual sound and to reference conditions.

c) Use Formula (6) together with frequency of occurrence according to meteorological statistics to determine L_day, L_evening and L_night.

d) Calculate L_den.

10.6.2 Determination from long-term L_E measurements of individual events

The principle is to determine the average L_E for each type of event, convert it to energy and then add up all events predicted to occur during the time period under study and finally to convert it to L_eq for the time period in question. The determination is carried out according to the following steps.

a) Remove unwanted events.

b) Stratify the measured events into relevant source categories and meteorological windows.

c) For each meteorological window, k, and each source category, i, determine the average sound exposure level $L_{E,i,k}$.

For each meteorological window, k, calculate $L_{\text{day},k}$ using Formula (21):

$$L_{\text{day},k} = 10\lg\left(\sum_i N_{\text{ref},i} \times 10^{0,1L_{E,i,k}}\right)\text{dB} - 10\lg\left(t_{\text{day}} \times 3\,600\right)\text{dB} \tag{21}$$

where

$N_{\text{ref},i}$ is the statistical yearly day average of number of single events of source category i;

t_{day} is the numerical value of the duration of the day, in hours.

The corresponding formulae are valid for L_{evening} and L_{night}.

d) Use Formula (6) together with frequency of occurrence according to meteorological statistics to determine L_{day}, L_{evening} and L_{night}.

e) Calculate L_{den}.

10.6.3 Determination from short-term measurements

In this case, the measurements have either taken place:

a) at a short distance, see Formula (11) minimizing the influence of weather conditions, or

b) under favourable propagation conditions as described in 8.2, or

c) under mixed propagation conditions.

In case a) use the prediction method to normalize the measured sound pressure levels to the traffic flow conditions of the reference time intervals, that is day, evening and night. The values thus obtained are taken as L_{day}, L_{evening} and L_{night}, respectively. For industrial noise sources, each source shall be time-weighted to take into account the actual times of operation.

In case b) and c) proceed as follows:

a) Normalize the measured sound pressure levels to the traffic flow conditions of the reference time intervals, that is day, evening and night.

b) Use meteorological statistics to determine the ratio of time p_i for each meteorological window Mi (see 8.1) distinguishing between day, evening and night.

c) Let the favourable conditions during the measurements be represented either by meteorological window M3 (most common during day-time) or M4 (most common during night-time).

   1) Case b): Use the prediction method to calculate the sound pressure levels for each of the four meteorological classes as described in Table 4. Calculate the difference Δ_i between each meteorological class i and M3 or M4 (Δ_4 = 0 dB), whichever was measured.

   The prediction method is used to calculate L_{eq} using the same operating conditions for each of the four meteorological windows M1 to M4. For each of these, the difference is determined to the window measured (M3 or M4). These differences are applied to the measured value to get the simulated measured values for the other meteorological conditions.

   2) Case c): Use the measured noise levels in selected propagation condition in order to estimate the differences Δ_i between each meteorological window i and M3, respectively M4 (Δ_4 = 0 dB).

d) Calculate L_{day} using Formula (22):

$$L_{\text{day}} = 10\,\text{lg}\left(\sum_{i=1}^{4} p_i\, 10^{0,1(L_i+\Delta_i)}\right)\,\text{dB} \tag{22}$$

where

L_i is the measured value during meteorological window Mi corrected to be valid for the traffic flow of the yearly average day and averaged over the number of measurements carried out under the condition Mi, expressed in decibels (dB);

p_i and Δ_i are defined in b) and c) above.

e) Calculate L_{evening} accordingly.

f) Calculate L_{night} accordingly.

g) Calculate L_{den}.

10.7 Maximum level, L_{max}

For each microphone location and each category of source operating conditions, determine the following values from the measured values of L_{max}, whenever relevant:

— the highest maximum;

— the arithmetic average;

— the energy average;

— the standard deviation;

— the statistical distribution.

Use the values above to determine the desired quantity of L_{max}.

NOTE Annex H provides guidance on how to calculate different quantities of L_{max}.

11 Extrapolation to other locations

11.1 General

Extrapolation of results of measurements is often used to estimate the sound pressure level at another location. Such extrapolation is useful, for example, when residual sound prevents direct measurement at the receiver location.

11.2 Extrapolation by means of calculations

The noise measurements shall be carried out at a well-defined location neither too close (not in the near field of some part of the source) nor too far away (accurate prediction of attenuation is desirable) from the source in relation to the extension of the source. By calculating the attenuation that has taken place during propagation from source to measuring location, an estimate of the source noise emission is established. This estimate is subsequently used to calculate the sound pressure level at a receiver other than the intermediate measurement location.

To perform the calculation of sound transmission attenuation, a calculation method is needed; see Clause 12. The intermediate measurement location shall be chosen so that reliable measurement and calculation is facilitated. For example, there should be no screening obstacles between the source and the microphone and a high microphone location is preferred as this implies minimum influence of the meteorological conditions during the measurement.

11.3 Extrapolation by means of measured attenuation functions

The noise measurements shall be carried out at the location of the desired estimation and, simultaneously, at a reference location relatively close to source (but still out of the near field of some part of the source), preferably between the first location and the source itself. The reference location shall be chosen in order to reduce the level of the residual sound. Simultaneous measurements shall be taken during a limited time period but at least for a period two times to three times longer than the propagation delay expected between the two microphones.

EXAMPLE Assuming the reference and the assessment microphones are placed 400 m far away, the propagation delay is about 1,2 s. Therefore, setting and integration time of 5 s would be an adequate choice.

The two acquisition instruments shall be synchronized accurately in order to make their relative time difference fall within the measurement time interval. Carry out measurements for each selected propagation condition. The measurement time interval shall be long enough to include relevant source variations.

For almost continuous noise sources (e.g. industries, road with heavy traffic), acquisition can be made for a fixed time chosen in order to ensure enough statistics but still remaining in the same propagation condition. Usually a period of 15 min to 30 min should be appropriate. For variable noise sources (e.g. minor roads and railways), the number of passages should exceed the number of 10; if possible measurement should be extended to last at least 15 min or, if the required number of events has not been reached, even further.

The attenuation function L_{af} is then given by Formula (23):

$$L_{af} = L_{ref} - L_{loc} \quad (23)$$

where

L_{ref} is the measured level at the reference location, expressed in decibels (dB);

L_{loc} is the level at the assessment location, expressed in decibels (dB).

Low levels at the assessment location can then be determined by reversing Formula (23), that is by using Formula (24):

$$L_{loc} = L_{ref} - L_{af} \quad (24)$$

where L_{af} has been determined using a time interval with small influence from residual noise, expressed in decibels (dB).

12 Calculation

12.1 General

In many cases, measurements can be replaced or supplemented by calculations. Calculations are often more reliable than single short-term measurements when long time averages are to be determined and in other cases where it is impossible to carry out measurements because of excessive residual sound pressure levels. In case of the latter, it is sometimes convenient to carry out the measurements at a short distance from the source and then use a prediction method to calculate the result at a longer distance.

When calculating rather than measuring sound pressure levels, data on source noise emission must be available, preferably as a source sound power level (including source directivity), and the location of point source(s) creating the same sound pressure levels in the environment as the real source. For traffic noise, sound power levels are often replaced by sound pressure levels determined under well-defined conditions. Often, such data are given in established prediction models but in other cases they have to be determined in each individual case.

Using a suitable model for the sound propagation from source to receiver the sound pressure level at the assessment point can be calculated. The sound propagation shall be related to well-defined meteorological and ground conditions. Most calculation models refer to neutral or favourable conditions as sound transmission under upward refraction conditions is extremely difficult to predict. The acoustic impedance of the ground is also important, in particular at short distances and low source and receiver heights. Most models only distinguish between hard and soft ground. It is in general easier to carry out accurate calculations with high source and receiver locations.

Various degrees of accuracy are required depending on the purpose of the calculation. The necessary density of grid points to be used as a basis for mapping the noise levels in an area depends on the purpose of the mapping. Noise level variation is strongest in the vicinity of sources and large obstacles. The density of grid points should, therefore, be higher in such places. In general, for overall noise exposure mapping, the difference in sound pressure levels between adjacent grid points should not be larger than 5 dB. When deciding on the selection of noise mitigation measures, grid point density should be chosen so that variation between the adjacent points does not exceed 2 dB.

12.2 Calculation methods

12.2.1 General

There are no internationally recognized complete prediction methods although there are some International Standards on sound propagation which can be applied for sources with known sound power output; see ISO 9613-1, ISO 9613-2[9] and ISO 13474[10]. A list of national and European prediction methods is given in Annex L.

12.2.2 Specific procedures

Separate prediction methods have been developed for the assessment of road, rail and air traffic noise. Most countries have their own national methods. Many methods are limited to calculations of A-weighted sound pressure levels and are applicable for a specific frequency spectrum. Most countries calculate a L_{Aeq}-based metric and sometimes this measure is supplemented by L_{max}. There are, however, exceptions.

13 Information to be recorded and reported

For measurements, the following information shall, if relevant, be recorded and reported:

a) time, day and place for measurements;

b) list of instrumentation used and ways of calibration;

c) measured and, if relevant, corrected sound pressure levels (L_{eq}, L_E, L_{max}), A-weighted (optionally C-weighted as well) and, optionally, in frequency bands;

d) measured N percentage exceedance level ($L_{N,T}$) including the base on which it is calculated (sampling rate and other parameters);

NOTE $L_{N,T}$ is, for example, used to estimate the residual sound using a typical value of N = 95 %.

e) an estimate of the expanded measurement uncertainty together with the chosen coverage probability;

f) information on residual sound levels during the measurements;

g) time intervals for the measurements;

h) a thorough description of the measurement site, including ground cover and condition, and locations, including height above ground, of microphone and source;

i) a description of the operating conditions, including number of events or passing vehicles/trains/aircraft divided into suitable categories;

j) a description of the meteorological conditions, including wind speed, wind direction, atmospheric stability (e.g. cloud cover and time of day), temperature, barometric pressure, humidity and presence of precipitation and location of wind and temperature sensors;

k) method(s) used to extrapolate the measured values to other conditions.

For calculations, relevant information of a) to k), including calculation uncertainty, shall be given.

Annex A
(informative)

Determination of radius of curvature

In the following, it is assumed that the sound speed profile above ground can be described by Formula (A.1):

$$c(z) = c_0 + Az + B \times \lg\left(\frac{z}{z_0}\right) \tag{A.1}$$

where

c is the sound speed;

z is the height above the ground;

z_0 is the roughness length of the ground surface;

A is the linear sound speed coefficient, in 1/s, given by Formula (A.5) and Formula (A.6);

B is the logarithmic sound speed coefficient, in m/s, given by Formula (A.7);

c_0 is the reference sound speed = 331,4 m/s.

NOTE 1 This Monin-Obukhov's similarity theory can be used to derive sound speed profiles. However, this theory is not valid over hilly terrain, urban areas or heterogeneous ground (see e.g. Reference [11]).

For flat terrain, the radius R_{cur} approximating the curvature of the sound paths caused by atmospheric refraction can be determined by Formula (A.2):

$$\frac{1}{R_{\text{cur}}} = \frac{1}{R_A} + \frac{1}{R_B} \tag{A.2}$$

$$R_A = \frac{A}{|A|}\sqrt{\left(\frac{c_0}{|A|}\right)^2 + \left(\frac{D}{2}\right)^2} \tag{A.3}$$

$$R_B = \frac{B}{|B|}\frac{1}{8}\sqrt{\frac{2\pi c_0}{|B|}D} \tag{A.4}$$

where D is the horizontal distance between the source and the receiver, in m.

During day (stability classes S_1, S_2 and S_3), A is given by Formula (A.5):

$$A = \frac{u_*}{C_{vk} L} \cos(wd) + \left(\frac{1}{2} \frac{c_0}{T_{\text{ref}}} \right) \left(0{,}74 \frac{T_*}{C_{vk} L} - \frac{g}{c_p} \right) \tag{A.5}$$

During night (stability classes S_4 and S_5), A is given by Formula (A.6):

$$A = 4{,}7 \frac{u_*}{C_{vk} L} \cos(wd) + \left(\frac{1}{2} \frac{c_0}{T_{\text{ref}}} \right) \left(4{,}7 \frac{T_*}{C_{vk} L} - \frac{g}{c_p} \right) \tag{A.6}$$

For both day and night, B is given by Formula (A.7):

$$B = \frac{u_*}{C_{vk}} \cos(wd) + \left(\frac{1}{2} \frac{c_0}{T_{\text{ref}}} \right) \left(0{,}74 \frac{T_*}{C_{vk}} \right) \tag{A.7}$$

where

u_* is the friction velocity, in m/s;

T_* is the temperature scale, in K;

L is the Monin-Obukhov length, in m;

C_{vk} is the von Karman constant, 0,4;

g is Newton's gravity acceleration, 9,81 m/s^2;

c_p is the specific heat capacity of air at constant pressure, 1 005 J/kg;

T_{ref} is the reference temperature, 273 K;

wd is the wind direction from source to receiver.

The meteorological parameters u_*, T_* and the inverse of the Monin-Obukhov length, $1/L$, can be measured directly or taken from Tables A.1 to A.3.

NOTE 2 Positive values of R_{cur} correspond to downward sound ray curvature (e.g. downwind or temperature inversion); $1/R_{\text{cur}} = 0$ corresponds to straight-line sound propagation ("no-wind", homogeneous atmosphere); negative values of R_{cur} correspond to upward sound propagation (e.g. upwind or on a calm summer day). Temperature inversions occur, for example at night time when the cloud cover is less than 70 %.

Table A.1 — Friction velocity for different wind speed classes

	u_* m/s
W1: 0 m/s to 1 m/s	0
W2: 1 m/s to 3 m/s	0,13
W3: 3 m/s to 6 m/s	0,3
W4: 6 m/s to 10 m/s	0,53
W5: >10 m/s	0,87

Table A.2 — Inverse Monin-Obukhov length, $1/L$, as a function of wind speed (W) and stability class (S)

$1/L$, m^{-1}	S1	S2	S3	S4	S5
	Day 0/8–2/8	**Day 3/8–5/8**	**Day 6/8–8/8**	**Night 5/8–8/8**	**Night 0/8–4/8**
W1: 0 m/s to 1 m/s	−0,08	−0,05	0	0,04	0,06
W2: 1 m/s to 3 m/s	−0,05	−0,02	0	0,02	0,04
W3: 3 m/s to 6 m/s	−0,02	−0,01	0	0,01	0,02
W4: 6 m/s to 10 m/s	−0,01	0	0	0	0,01
W5: >10 m/s	0	0	0	0	0
X/8 indicates ratio of cloud cover of the sky.					

Table A.3 — Temperature scale T_* as a function of wind speed (W) and stability class (S)

T_*, K	S1	S2	S3	S4	S5
	Day 0/8–2/8	**Day 3/8–5/8**	**Day 6/8–8/8**	**Night 5/8–8/8**	**Night 0/8–4/8**
W1: 0 m/s to 1 m/s	−0,4	−0,2	0	0,2	0,4
W2: 1 m/s to 3 m/s	−0,2	−0,1	0	0,1	0,2
W3: 3 m/s to 6 m/s	−0,1	−0,05	0	0,05	0,1
W4: 6 m/s to 10 m/s	−0,05	0	0	0	0,05
W5: >10 m/s	0	0	0	0	0
X/8 indicates ratio of cloud cover of the sky.					

Annex B
(informative)

Microphone locations relative to reflecting surfaces

B.1 General

Normally, the sound pressure level used in regulations is the free-field sound pressure level as described in B.3. In order to make sure that this sound pressure level is not influenced arbitrarily due to uncontrolled reflections from nearby reflecting surfaces other than the ground, it is necessary to select the location of the microphone carefully. An attempt has been made below to identify locations where it is comparatively easy to correct for extra reflections and to estimate the uncertainty due to these corrections. The values given are based on experience and calculations from road traffic noise and may not be fully appropriate for other types of sources like, for example, air traffic noise where the tradition has been to mount the microphone 6 m above the ground and where the angle of incidence of the sound is often quite different from that of road traffic.

B.2 Standard uncertainty of corrections for different locations

For the most common cases, default values for the standard uncertainties using different microphone locations are given in Table B.1 for traffic noise. These values are to be used unless better information is available. For industrial noise and other locations, the uncertainties should be determined for each individual case. For stationary sources and low frequencies, it is not suitable to use the default correction of 3 dB in front of a façade. Instead, it is recommended to use a flush-mounted microphone location with a 5,7 dB correction.

Table B.1 — Standard uncertainty of corrections for reflections of different microphone locations relative to vertical reflecting surfaces

Microphone location	Standard uncertainty, u_{loc} dB
Traffic noise incident from all angles	
Reference location in a free field	0
Location meeting the requirements of B.2	0,5
Location using the correction 5,7 dB and meeting the requirements of B.4	0,4
Location using the correction 3 dB and meeting the requirements of B.5	0,4
Traffic noise with predominantly grazing incidence	
Reference location in a free field	0
Location using the correction 5,7 dB and meeting the requirements of B.4	2,0
Location using the correction 3 dB and meeting the requirements of B.5	1,0

NOTE Table B.1 is valid for A-weighted traffic noise only (moving sources).

B.3 Free-field location

This is a location where there are no reflecting surfaces other than the ground close enough to influence the sound pressure level. The distance from the microphone to any sound reflecting surface apart from the ground shall be at least twice the distance from the microphone to the dominating part of the sound source.

NOTE Exceptions can be made for small sound reflecting surfaces and when it can be shown that the reflection has insignificant effect. This can be based on calculations taking the major dimensions of the reflecting surface and the wavelength into account.

B.4 Microphone directly on the surface — Conditions for nominally +6 dB correction

The default correction for this location is 5,7 dB.

This location is flush-mounted on a reflecting surface and the direct and reflected sound will be in phase below a certain frequency, f. For broad band traffic noise with sound incident from many angles, f is about 4 kHz for a 13 mm microphone mounted on the reflecting surface. This location should be avoided if the sound arrives predominantly at grazing incidence.

The façade shall 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 of the façade wall shall be larger than 1 m. The microphone can be mounted as shown in Figure B.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 dimensions not less than 0,5 m × 0,7 m. The distance from the microphone to the edges and symmetry axes of the mounting plate shall be greater than 0,1 m to reduce the influence of diffraction at the plate edges.

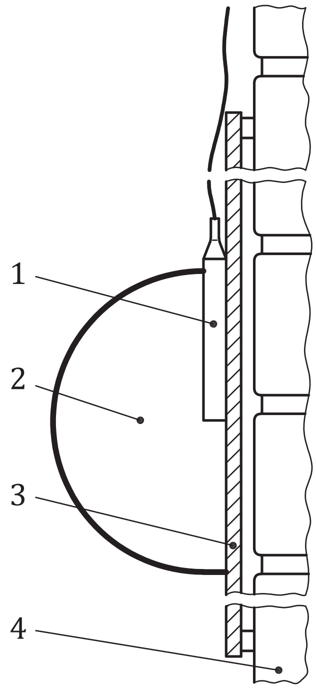
The plate shall be of an acoustically hard and stiff material in order to avoid sound absorption and resonance in the frequency range of interest.

EXAMPLE A painted chipboard thicker than approximately 19 mm or a 5 mm aluminium plate with minimum 3 mm vibration damping material on the side facing the wall.

Care shall be taken that no disturbing aerodynamic noise is created between the plate and a rough façade.

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 should be flat within ±0,01 m within a radius of 1 m from the microphone.

For octave-band measurements, a 13 mm microphone or smaller should be used. If the frequency range is expanded above 4 kHz, a 6 mm microphone should be used.



Key

1 microphone

2 windscreen

3 mounting plate

4 wall or reflecting surface

Figure B.1 — Microphone mounting on reflecting surface

B.5 Microphone near reflecting surface — Conditions for nominally +3 dB correction

When the microphone is at a distance from a reflecting surface, provided that certain conditions are met, 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 sound pressure level.

The façade shall be plane within ±0,3 m and the microphone shall not be placed at locations 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.

Criteria B.1 to B.3 ensure that the overall equivalent sound pressure level measured deviates less than 1 dB from the level of the incoming sound plus 3 dB. Two cases are distinguished between, compare Figure B.2 a) extended source (i.e. the source angle of view α is 60° or more) and b) point source (i.e. α is less than 60°).

For narrow-band sources or frequency band measurement, free-field or +6 dB locations are recommended.

The distance from the microphone, M, perpendicular to the point 0 on the reflecting surface is d; see Figure B.2. Point 0 is considered representative of the microphone location when determining the angle of view, α. The distances a' and d' are measured along the dividing line of the angle α.

The distances from point 0 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 to 4 kHz, Criterion B.1 shall be fulfilled.

Criterion B.1: $b \geq 4d$ and $c \geq 2d$

Criterion B.2 ensures that the incident and reflected sounds are equally strong.

Criterion B.2:

Extended source: $d' \leq 0{,}1a'$

Point source: $d' \leq 0{,}05a'$

Criterion B.3 ensures that the microphone is sufficiently far away from the +6 dB region near the façade.

Criterion B.3:

Extended source:

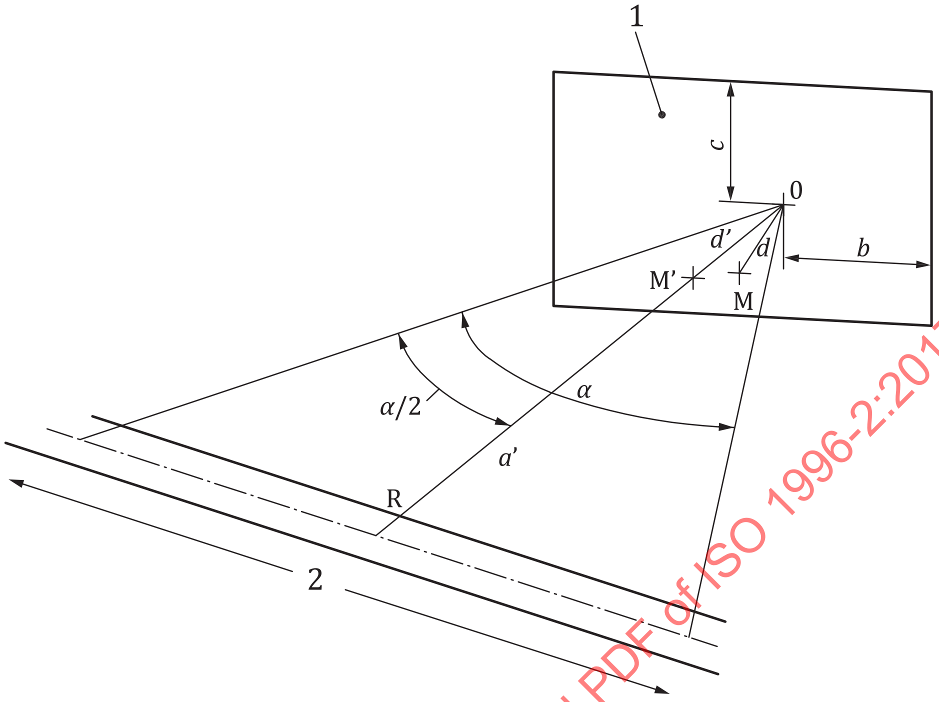
Overall A-weighted sound pressure levels: $d' \geq 0{,}5$ m

Octave band sound pressure levels: $d' \geq 1{,}6$ m

Point source:

Overall A-weighted sound pressure levels: $d' \geq 1{,}0$ m

Octave band sound pressure levels: $d' \geq 5{,}4$ m



Key

0 point on the reflecting surface in front of which the microphone is mounted

1 building façade or other reflecting surface

2 extended source

M microphone position

R point where the ray from 0 meets the centre line of the road

R0 dividing line of the angle α in two halves

α angle of view of road/rail on one side of the normal seen from 0

M' equivalent microphone position on the line R0

d perpendicular distance from the microphone position to the reflecting surface, 0

d' distance 0M'

a' distance 0R

b, c distances to the edges of the reflecting surfaces

Figure B.2 — Geometry of microphone location near reflecting surface

In Figure B.2, the extended source shown is a road with the centre line dashed. In Nordic 1996 Road model (see L.1), a calculation distance for excess sound attenuation corresponding to the half angle of the segment from the perpendicular point, R, to the ends of the road in each direction is used. If the road is symmetric, then α is split symmetrically. Thus, if the view of the road is 180° and symmetric, then use 45° from the perpendicular. If the view of the road is asymmetric with respect to the normal, then analyse $\alpha/2$ on each side of the perpendicular separately. Thus, for example, if the view of the road covers 90° in one direction and 50° in the other (i.e. 140° in total), use 45° for $\alpha/2$ in the one direction and 25° for $\alpha/2$ in the other direction.

If the view of the road is greater than 180°, then subdivide the road into smaller segments for this calculation.

Annex C
(informative)

Selection of measurement/monitoring site

C.1 General

The location of sound measuring stations is critical in obtaining accurate and useful sound data. Because the requirements for sound data at particular locations may vary considerably, the engineering guidelines for placing sound measuring stations may also differ considerably. The selection of measurement sites should be considered early in the development of a measurement plan once the objectives for the measuring system have been clearly identified. In order to analyse to what extent a proposed site influences the uncertainty of the results at that site, it is necessary to examine the relation between the residual sound and the sound pressure levels to be measured. If the level difference is greater than 15 dB, the influence of residual sound is negligible.

C.2 Process of site selection

The selection of sound measurement sites is usually a two-stage process. The first stage involves the general location of the measuring stations. This is based upon measuring objectives, which might include the following:

— to obtain accurate sound information in specific sound-sensitive community areas;

— to obtain accurate information on the sound pressure levels produced by different types of noise sources at the particular location, etc.;

— to obtain sound information to monitor noise events;

— to meet monitoring system technical considerations, particularly the need to obtain sound information from more than one station under important noise events;

— to monitor compliance with periodical sound exposure level requirements.

The second stage of the site selection process is the selection of specific monitor sites within the general area. This is based upon practical and other considerations such as:

— interference from other sound sources (other traffic or industry, wildlife, leisure activities etc.);

— ease of access to utilities (telephone and electrical power);

— terrain and building obstructions;

— ease and costs of obtaining site access and approvals (location on private property may require payments of rent or easements; location on publicly owned land such as parkways may be less costly for public agencies, but obtaining formal approvals may be difficult and/or time consuming);

— monitor station security considerations (vandalism and theft);

— the likely uncertainty of the measurements.

C.3 Method to determine acoustically suitable sound measurement sites

For an acoustically reliable measurement, the event to be measured shall be clearly distinguishable from environmental (residual) sound, i.e. the gap between the average residual sound and the onset of a measurement shall be at least 3 dB and preferably more than 5 dB. Thus, the instrumentation should only be installed at sites where the maximum sound pressure levels, $L_{p,\mathrm{AS,max}}$, of events of interest are at least 15 dB greater than the level of the average residual sound. The only reliable method to determine acceptable levels of residual sound is to estimate its effect on measurement uncertainty (see Clause 4, F.2 and Annex I for guidance).

For more guidance on site selection, in particular for aircraft noise, see ISO 20906.

Annex D
(informative)

Correction to reference condition

D.1 Atmospheric sound attenuation

D.1.1 Calculation of correction to reference condition

Measured data are stratified into different windows. Each window will include data with an average temperature, t (°C), and an average relative humidity, h (%). The measurements will also represent a certain measurement distance d (m). Using ISO 9613-1 and using the spectrum of the source, the atmospheric sound attenuation $\Delta L_a(t, h, d)$ can be calculated. However, to determine L_{den} this atmospheric sound attenuation shall represent the representative yearly average temperature t_{ref} and the representative yearly average humidity h_{ref}. Thus the measured data shall be corrected by the value ΔL_a given by Formula (D.1):

$$\Delta L_a = \Delta L_a \left(t_{ref}, h_{ref}, d\right) - \Delta L_a \left(t, h, d\right) \quad \text{(D.1)}$$

NOTE Formula (D.1) can either be applied on each data sample or on the average of all samples within a window.

For a point source, the distance d is the distance between the source and the microphone. However, for a straight road or railway where there is an integration over many distances, the distance d is the average distance to the moving sound source which can be approximated by Formula (D.2):

$$d = \frac{d_0}{\cos(\alpha / 2)} \quad \text{(D.2)}$$

where d_0 is the distance along the normal and α, the angle of sight of the largest visible segment on either side of the normal.

EXAMPLE If a segment has an angle of sight of 90° with 60° on one side and 30° on the other side of the normal, the angle α becomes 60°.

The measured value, L'_{eq}, corrected to reference atmospheric sound attenuation is given by Formula (D.3):

$$L_{eq,ref} = L'_{eq} + \Delta L_a \quad \text{(D.3)}$$

D.1.2 Calculation of uncertainty

Starting from Formula (D.3) both sensitivity coefficients are 1 and the standard uncertainty can be estimated from Formula (D.4):

$$u_{L_{eq,ref}} = \sqrt{u_{L'_{eq}}^2 + u_{\Delta L_a}^2} \quad \text{(D.4)}$$

$u_{L'_{eq}}^2$ is evaluated from the measurement(s) according to the guidance given in this document. As to the uncertainty of the atmospheric attenuation, it is rather sensitive to errors in the humidity, in particular when the humidity is low (<30 %) and also to the spectrum of the sound source. It is also proportional to the distance. It is recommended to determine it in each case but as a first approximation, $u_{\Delta L_a} = 1$ dB/km may be used.

D.2 Road traffic

D.2.1 Calculation of correction to reference condition

Modern prediction models[12] are based on sound power levels of different vehicle categories. Propulsion noise and rolling noise are separated. The sound power level is a function of speed and temperature for rolling noise and of speed and acceleration for propulsion noise. Because of the complexity due to the number of variables and formulae involved, it is recommended to use a complete prediction method to determine the correction to reference condition as shown in the following example where relevant notations are shown in Table D.1.

Table D.1 — Overview of notations and parameters used for the computations

		Number	Speed	Temperature	Measured	Calculated
Measured	Category 1	N_1	v_1	t	L'_{eq}	L'_{eq} (calc)
	Category 2	N_2	v_2			
	Category 3	N_3	v_3			
Calculated	Category 1	$N_{1,ref}$	$v_{1,ref}$	t_{ref}	—	$L_{eq,ref}$ (calc)
	Category 2	$N_{2,ref}$	$v_{2,ref}$			
	Category 3	$N_{3,ref}$	$v_{3,ref}$			

As an alternative to working with several different vehicle categories, each vehicle in a category can be converted into an equivalent number of another category, e.g. one medium heavy vehicle equals *y* light vehicles and one heavy vehicle equals to *x* light vehicles. The numbers *x* and *y* shall be taken from a database and they will vary with speed and other operating conditions.

The measured value corrected to reference conditions is given by Formula (D.5):

$$L_{eq,ref} = L'_{eq} + L_{eq,ref}(\text{calc}) - L'_{eq}(\text{calc}) \quad (D.5)$$

NOTE Depending on the program used for the calculations, the correction for atmospheric attenuation according to D.1 can be included in the result given by Formula (D.5).

D.2.2 Calculation of uncertainty

The basic formula for L_{eq} for one category of vehicle is Formula (D.6):

$$L_{eq} = L_E - 10\lg(T)\text{dB} + 10\lg(N)\text{dB} = L_W(v,t) + \Delta L_{tf} - 10\lg(v)\text{dB} + 10\lg\left(\frac{N}{T}\right)\text{dB} \quad (D.6)$$

where

L_W is the total sound power level, expressed in decibels (dB);

ΔL_{tf} is the total transfer function between L_W and sound exposure level, expressed in decibels (dB);

v is the speed;

T is the time;

N is the number of vehicles during the time, T.

According to the *Harmonoise* prediction method,[12] the speed dependence of L_W, if focused on tyre/road noise and assumed that the noise level is dominated by light vehicles, is approximately 30 lg (v), but here it will be assumed that it is 35 lg (v) (see Reference [13]). The temperature dependence is $-K(t-20)$. Formula (D.6) can now been written as Formula (D.7):

$$L_{\mathrm{eq}} = L_W\left(v = v_0, t = t_0\right) + \Delta L_{\mathrm{tf}} + 25\,\lg\left(\frac{v}{v_0}\right)\mathrm{dB} + 10\,\lg\left(\frac{N}{T}\right)\mathrm{dB} - 10\,\lg\left(v_0\right)\ \mathrm{dB} - K\left(t - t_0\right) \tag{D.7}$$

or, for the reference condition

$$L_{\mathrm{eq,ref}} = L'_{\mathrm{eq}} + 25\lg\left(\frac{v_{\mathrm{ref}}}{v}\right)\mathrm{dB} + K\left(t_{\mathrm{ref}} - t\right) + 10\lg\left(\frac{N_{\mathrm{ref}}}{N}\right)\mathrm{dB} \tag{D.8}$$

Thus, the sensitivity coefficient, c_v, for speed is

$$c_v = \frac{\partial L_{\mathrm{eq}}}{\partial v} = -25\frac{1}{v}\lg(e) = -\frac{10{,}9}{v} \tag{D.9}$$

and

$$c_{v_{\mathrm{ref}}} = \frac{\partial L_{\mathrm{eq}}}{\partial v_{\mathrm{ref}}} = 25\frac{1}{v_{\mathrm{ref}}}\lg(e) = \frac{10{,}9}{v_{\mathrm{ref}}} \tag{D.10}$$

and for traffic flow

$$c_N = \frac{\partial L_{\mathrm{eq}}}{\partial N} = -\frac{10}{N}\lg(e) = -\frac{4{,}3}{N} \tag{D.11}$$

$$c_{N_{\mathrm{ref}}} = \frac{\partial L_{\mathrm{eq}}}{\partial N_{\mathrm{ref}}} = \frac{10}{N_{\mathrm{ref}}}\lg(e) = \frac{4{,}3}{N_{\mathrm{ref}}} \tag{D.12}$$

and for temperature

$$c_t = \frac{\partial L_{\mathrm{eq}}}{\partial t} = -K \tag{D.13}$$

$$c_{t_{\text{ref}}} = \frac{\partial L_{\text{eq}}}{\partial t_{\text{ref}}} = K \tag{D.14}$$

The total combined standard uncertainty of Formula (D.8) is then given by Formula (D.15):

$$u_{L_{\text{eq,ref}}} = \sqrt{\left(c_{L'}u_{L'}\right)^2 + \left(c_{v_{\text{ref}}}u_{v_{\text{ref}}}\right)^2 + \left(c_v u_v\right)^2 + \left(c_N u_N\right)^2 + \left(c_{N_{\text{ref}}}u_{N_{\text{ref}}}\right)^2 + \left(c_t u_t\right)^2 + \left(c_{t_{\text{ref}}}u_{t_{\text{ref}}}\right)^2}\ \text{dB} \tag{D.15}$$

Assuming that the uncertainty of the measurement conditions is equal to the uncertainty of the reference conditions, Formula (D.16) is obtained:

$$u_{L_{\text{eq,ref}}} = \sqrt{u_{L'}^2 + 2\left(\frac{10,9}{v}\right)^2 u_v^2 + 2\left(\frac{4,3}{N}\right)^2 u_N^2 + 2K^2 u_t^2}\ \text{dB} \tag{D.16}$$

If further assumed that the standard uncertainty in average speed and average number corresponds to 5 %, that K = 0,1 (typical number according to *Harmonoise* prediction method[12]), and that $u_t = 1$, Formula (D.17) is obtained:

$$u_{L_{\text{eq,ref}}} = \sqrt{u_{L'}^2 + 0,60 + 0,09 + 0,02}\ \text{dB} \tag{D.17}$$

The numbers in Formula (D.17) are just examples. They shall be estimated in each case.

D.3 Rail traffic

D.3.1 Calculation of correction to reference condition

The most accurate way to deal with rail traffic measurements is to measure the sound exposure level, $L_{E,i}$, for each relevant category of train and for the reference conditions, it is then obtained using Formula (D.18):

$$L_{\text{eq,ref}} = 10\lg\left(\sum_{i=1}^{n} N_{\text{ref},i} 10^{0,1\overline{L_{E,i}}}\right)\text{dB} - 10\lg\left(T_{\text{ref}}\right)\text{dB} \tag{D.18}$$

where

$\overline{L_{E,i}}$	is the measured average sound exposure level of trains of category i, expressed in decibels (dB);
n	is the number of train categories used;
$N_{\text{ref},i}$	is the number of trains of category i passing during the reference time, T_{ref}.

NOTE In some cases, it can be convenient to introduce the train length as an additional parameter. This is, for example, often the case if only few freight trains are measured.

D.3.2 Calculation of uncertainty

Following the principles described in F.1, Formula (D.19) is obtained:

$$u_{L_{\text{eq,ref}}} = \sqrt{\sum_{i=1}^{n}\left[\frac{N_{\text{ref},i}\,10^{0,1\overline{L}_{E,i}}}{\sum_{i=1}^{n} N_{\text{ref},i}\,10^{0,1\overline{L}_{E,i}}}\right]^2 u_{L_{E,i}}^2 + \sum_{i=1}^{n}\left[\frac{10^{0,1L_{E,i}}}{\sum_{i=1}^{n} N_{\text{ref},i}\,10^{0,1\overline{L}_{E,i}}}\right]^2 u_{N_{\text{ref},i}}^2}\ \text{dB} \tag{D.19}$$

where $u_{L_{E,i}}^2$ is evaluated from the measurement(s) according to the guidance given in the main body of this document.

D.4 Air traffic

The principle is here the same as for rail traffic, the main difference being that more aircraft categories are required and that the airport configurations shall be included among the windows.

D.5 Industrial noise

D.5.1 Calculation of correction to reference condition

The most accurate way to deal with industrial noise measurements is to determine $L_{\text{eq},i}$, for each relevant operating condition and then determine

$$L_{\text{eq,ref}} = 10\lg\left(\sum_{i=1}^{n} N_{\text{ref},i}\,10^{0,1\overline{L_{\text{eq},i}}}\right)\text{dB} - 10\lg\left(T_{\text{ref}}\right)\ \text{dB} \tag{D.20}$$

where

T_{ref} is equal to $\Sigma T_{\text{ref},i}$

With

$T_{\text{ref},i}$ is the time of operation of operating condition i during the reference interval T_{ref}.

NOTE In practice, the situation can be so complicated that the above procedure is difficult to follow.

D.5.2 Calculation of uncertainty

Following the principles described in F.1, Formula (D.21) is obtained:

$$u_{L_{\text{eq,ref}}} = \sqrt{\sum_{i=1}^{n}\left[\frac{T_{\text{ref},i}\,10^{0,1\overline{L}_{\text{eq},i}}}{\sum_{i=1}^{n} T_{\text{ref},i}\,10^{0,1\overline{L}_{\text{eq},i}}}\right]^2 u_{L_{\text{eq},i}}^2 + \sum_{i=1}^{n}\left[\frac{10^{0,1L_{E,i}}}{\sum_{i=1}^{n} T_{\text{ref},i}\,10^{0,1\overline{L}_{E,i}}}\right]^2 u_{T_{\text{ref},i}}^2}\ \text{dB} \tag{D.21}$$

where $u_{L_{\text{eq},i}}^2$ is evaluated from the measurement(s) according to the guidance given in the main body of this document.

Annex E
(informative)

Elimination of unwanted sound

E.1 General

There is no single, general method to apply to eliminate unwanted sound when making measurements. Depending on the actual circumstances, examples of possible methods are:

— use directional microphones to suppress sound from unwanted directions;

— screen sound from behind by mounting the microphone on a façade or screen;

— exclude measurement intervals with unwanted sound (see E.2 for discrete events);

— select, if relevant and possible, measurement intervals during quiet (for unwanted sound) times of the day;

— record the time history of the noise to be measured and use statistical or other methods to exclude unwanted sound;

— select more suitable alternative location(s).

E.2 Discrete sound event data (typically aircraft and rail traffic noise)

A discrete event is established when

— the A-weighted sound pressure level exceeds a threshold for a continuous period, and

— discrimination tests or human operator indicate a discrete event source which can be characterized by several parameters, specified by the manufacturer or supplier.

As a minimum, an automatic system shall provide processing to produce the maximum time and frequency-weighted sound pressure level of i-th event, $L_{\mathrm{max},i}$, the local time at which this maximum sound pressure level takes place, the sound exposure level of i-th event, $L_{E,i}$, and the duration of i-th event, ΔT_i. In addition, the system may determine the time interval between initial threshold crossing and attainment of the maximum sound pressure level, the final threshold crossing, the complete time history and other potentially useful data.

Not all events reported from monitors are related to operation of the source. Before any further data processing takes place, the events shall be verified and non-relevant events shall be dismissed. Verification of an unknown event can be made by correlation with a known event, using previous experience or earlier attended measurements.

When automatic event detection is used, the algorithms and associated criterion values used for this process at any given time shall be well described and recorded. Accordingly, the procedures used for human operators, if any, shall be described and recorded.

Annex F
(informative)

Measurement uncertainty

F.1 Determination of standard uncertainty and sensitivity coefficients for a mixture of conditions

L_{eq} for condition i, which lasts for p_i of the total time, is denoted L_i. The total L_{eq} for the whole time interval is denoted L. Then Formula (F.1) is obtained:

$$L = 10\lg\left(p_1 10^{L_1/10} + p_2 10^{L_2/10} + ... + p_n 10^{L_n/10}\right)\text{dB} \tag{F.1}$$

If L_1 to L_n are independent, the sensitivity coefficient c_{L_i} is then given by Formula (F.2):

$$c_{L_i} = \frac{\partial L}{\partial L_i} = 10\lg(e)\frac{p_i \cdot 10^{L_i/10}\ln(10)\cdot 0{,}1}{p_1 10^{L_1/10} + p_2 10^{L_2/10} + ... + p_n 10^{L_n/10}} = \frac{p_i 10^{L_i/10}}{\sum_{j=1}^{n} p_j \cdot 10^{L_j/10}} \tag{F.2}$$

As $\sum p_j = 1$, these coefficients are not independent. To derive c_{p_i}, Formula (F.1) can be written as follows:

$$L = 10\lg\left(p_1 10^{L_1/10} + p_2 10^{L_2/10} + ... + p_{n-1} 10^{L_{n-1}/10} + (1 - \sum_{j=1}^{n-1} p_j)10^{L_n/10}\right)\text{dB} \tag{F.3}$$

c_{p_i} is given by Formula (F.4):

$$c_{p_i} = \frac{\partial L}{\partial p_i} = 10\lg(e)\frac{10^{L_i/10} - 10^{L_n/10}}{\sum_{j=1}^{n} p_j 10^{L_j/10}}\text{dB} \tag{F.4}$$

L_i is determined with the standard uncertainty, u_{L_i}, and p_i with the standard uncertainty, u_{p_i}. To avoid gross underestimate of error, p_n is the period with the highest average sound level (i.e. usually M4). The standard uncertainty of L is then given by Formula (F.5):

$$u = \sqrt{\sum_{j=1}^{n}\left|\frac{\partial L}{\partial L_j}\right|^2 u_{L_j}^2 + \sum_{j=1}^{n-1}\left|\frac{\partial L}{\partial p_j}\right|^2 u_{p_j}^2}\ \text{dB} \tag{F.5}$$

F.2 Determination of sensitivity coefficient and standard uncertainty for residual sound

For residual sound, the sensitivity coefficient is no longer 1. The basic formula is Formula (F.6):

$$L = L' + 10\lg\left(1 - 10^{-0,1(L' - L_{res})}\right) \text{dB} \tag{F.6}$$

where

L is the residual sound corrected sound pressure level, expressed in decibels (dB);

L' is the measured sound pressure level, expressed in decibels (dB);

L_{res} is the residual sound pressure level, expressed in decibels (dB).

Thus the sensitivity coefficients shown in Formula (F.7) and Formula (F.8) are obtained:

$$c_{L'} = \frac{1}{1 - 10^{-0,1(L' - L_{res})}} \tag{F.7}$$

$$c_{res} = \frac{-10^{-0,1(L' - L_{res})}}{1 - 10^{-0,1(L' - L_{res})}} \tag{F.8}$$

The total uncertainty is given by Formula (F.9):

$$u_L = \sqrt{c_{L'}^2 u_{L'}^2 + c_{res}^2 u_{res}^2} \text{dB} \tag{F.9}$$

NOTE For determination of residual sound, see Annex I.

F.3 Uncertainty of corrections of operating conditions

See Annex D.

Annex G
(informative)

Examples of uncertainty calculations

NOTE An excel spreadsheet from which some of the calculations according to the examples in G.1 and G.2 can be seen and can be freely downloaded from: http://standards.iso.org/iso/1996/-2/. The source is road traffic noise in all examples.

G.1 One long-term measurement stratified into meteorological classes

Table G.1 — Uncertainty calculation for a single long-term measurement

		Formulae used	M1	M2	M3	M4	Result of calculation
Day	Occurrence[a]		0,2	0,4	0,4	0	
	Samples		15	30	30		
	$L_{k'}$	Formula (15)	48,8	55,3	58,1		
	$u_{k'}$	Formulae (16), (17), (18)	0,8	0,5	0,5		
	L_{res}		43	39	43		
	u_{res}		1,0	0,5	0,7		
	L_k	Formula (19), (F.6)	47,4	55,2	57,9		
	u_k	Formula (F.9)	1,1	0,5	0,5		
	L_{day}	Formula (9)					55,92
	u_{weight}	Formula (F.5) with $u_{p_i} = 0,05$					0,60
	L_{dayref}[b]	L_{day} +1					56,92
	u_{dayref}[c]	Formula (6) with u_{air} = 0,2					0,63
Evening	Occurrence[a]		0,1	0,3	0,3	0,3	
	Samples		15	20	20	20	
	$L_{k'}$	Formula (15)	46,5	52,2	55,5	56,7	
	$u_{k'}$	Formulae (16), (17), (18)	0,8	0,6	0,5	0,5	
	L_{res}		42	39	43	43	
	u_{res}		1,0	0,7	0,9	0,9	
	L_k	Formulae (19), (F.6)	44,7	52,0	55,3	56,5	
	u_k	Formula (F.9)	1,2	0,6	0,5	0,5	
	$L_{evening}$	Formula (9)					54,54
	u_{weight}	Formula (F.5) with $u_{p_i} = 0,05$					0,42
	$L_{eveningref}$[b]	$L_{evening}$ +0,8					55,34

[a] Fraction of total time.

[b] See Annex D for definition.

[c] See Annex D.

Table G.1 *(continued)*

		Formulae used	M1	M2	M3	M4	Result of calculation
	$u_{\text{eveningref}}$[c]	Formula (6) with u_{air} = 0,2					0,47
Night	Occurence[a]		0,1	0,2	0,3	0,5	
	Samples		15	20	20	20	
	$L_{k'}$	Formula (15)	44,9	50,4	53,7	54,9	
	$u_{k'}$	Formulae (16), (17), (18)	0,7	0,5	0,5	0,4	
	L_{res}		40	39	43	43	
	u_{res}		1,0	0,7	0,9	0,9	
	L_k	Formulae (19), (F.6)	43,2	50,1	53,4	54,6	
	u_k	Formula (F.9)	1,1	0,6	0,5	0,5	
	L_{night}	Formula (9)					53,21
	u_{weight}	Formula (F.5) with u_{p_i} = 0,05					0,43
	L_{nightref}[b]	L_{night} +0,6					53,81
	u_{nightref}[c]	Formula (6) with u_{air} = 0,2					0,47
DEN	L_{den}	Formula (1)					60,6
	u_{den}	Formula (F.5) with u_{p_i} = 0					0,34

a Fraction of total time.

b See Annex D for definition.

c See Annex D.

In Table G.1 and Formula (G.1), an example of an uncertainty calculation of a long-term measurement is given. 75 efficient 24 h measurements have been taken, each stratified between day, evening and night and between four different meteorological classes. It is assumed that the samples are unbiased in such a way that representative source variations can be considered to be included. In Table G.1, the measured values (indicated) are used to estimate the standard uncertainty for each meteorological class. Corrections are made for residual sound (corrected values without ′), separately for day, evening and night. The frequencies of occurrence have been taken from meteorological statistics and the standard uncertainty of this statistics is estimated to be 0,05. Table G.1 excludes uncertainties due to sound level meter and microphone location. These are assumed to be the same for all measurements and they are dealt with in Formula (G.1).

Including the uncertainty due to the sound level meter and the microphone location, the combined standard uncertainty (multiply by 2 to get expanded uncertainty) is then given by Formula (G.1):

$$u = \sqrt{u_{\text{den}}^2 + u_{\text{slm}}^2 + u_{\text{loc}}^2} = \sqrt{0,3^2 + 0,5^2 + 0,4^2}\,\text{dB} = 0,7\ \text{dB} \qquad \text{(G.1)}$$

G.2 Single measurement under favourable conditions

In Table G.2, a possible uncertainty calculation of a single measurement along a road during 1 h under favourable propagation conditions is given. Background information necessary to understand Table G.2 is given in B.1, F.2, Formula (12) and Formula (14).

Table G.2 — Uncertainty budget for a single measurement under favourable propagation conditions

Quantity	Estimate	Standard uncertainty, u_i dB	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i u_i$ dB
$L_{eq,1h}$	L' = 58 dB	0,5	$c_{L'} = \frac{1}{1-10^{-0,1(L'-L_{res})}}$ Formula (F.7)	0,59
δ_{slm}	0 dB	0,5 (default)		see L'
δ_{sou}	1 000 vehicles	$\frac{10}{\sqrt{1\,000}} = 0,3$ Formula (8)	1	0,3
δ_{met}	favourable	2,0 Formula (12)	1	2,0
δ_{loc} Annex B	+5,7 dB	0,40	1	0,40
δ_{res}	L_{res} = 50 dB	2	$c_{res} = \frac{-10^{-0,1(L'-L_{res})}}{1-10^{-0,1(L'-L_{res})}}$ Formula (F.8)	0,38
$u(L_m) = \sqrt{\sum_{1}^{n}(c_j u_j)^2}$				2,18
Expanded uncertainty (coverage prob. 95 %)				4,36

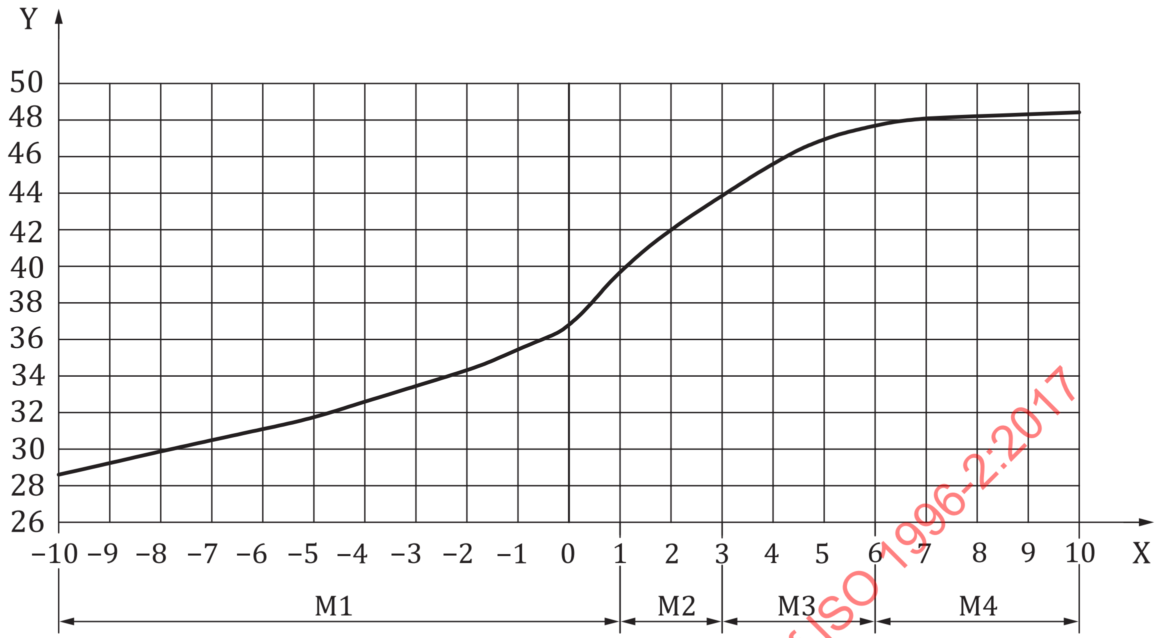
G.3 Long-term values calculated from short-term measurements

NOTE This example neglects the uncertainty of frequency of occurrence (see F.1) and uses other meteorological classes than those of Clause 8.

For each short-term measurement, the uncertainty can be determined as outlined in Table G.2. The measurement value shall be corrected to the reference condition for which the long-term level is to be estimated. The procedure for this is described in Annex D.

The next correction to take into account is the one for the meteorological conditions. It is necessary to have results for a sufficient number of meteorological conditions to make it possible to combine the results to correspond to the actual mixture of conditions. To do that, it is either needed to repeat the measurement under additional meteorological conditions or to adjust the measured levels using a recognized prediction method. It is not unlikely to assume that it is at least as accurate to use a prediction method than to use single measurements as single measurements under all conditions but favourable are very inaccurate.

It is assumed that the yearly average shall be calculated. Access to complete meteorological statistics is available and the propagation conditions are divided into four (example) different windows: unfavourable [ufa] (M1), neutral [neu] (M2), favourable [fav] (M3) and very favourable [vfa] (M4). These classes are illustrated in Figure G.1, which shows the calculated sound pressure level 200 m from a road using Nord 2000 (see Annex L). It can be seen that the sound pressure level varies about 20 dB due to the different meteorological conditions.



Key

X downwind component, in m/s

Y level, in dB

M1 meteorological window for unfavourable conditions

M2 meteorological window for neutral conditions

M3 meteorological window for favourable conditions

M4 meteorological window for very favourable conditions

Figure G.1 — Calculated sound pressure levels using Nord 2000 (see Annex L) 200 m from a road

It is assumed that each meteorological condition exists during the ratio p_i of the time or in the example below 40 %, 30 %, 20 % and 10 % of the time, respectively. One measurement during favourable conditions, L_{fav}, is available. The other conditions are calculated as a difference ΔL_i to L_{fav}. The yearly average is then given by Formula (G.2):

$$L_{year} = L_{fav} + 10 \lg \left[\sum_{i=1}^{4} p_i \, 10^{0,1 \Delta L_i} \right] \text{dB} \tag{G.2}$$

ΔL_i shall be calculated by a prediction method capable of having meteorological conditions as input variables. Examples of such methods are Harmonoise[18] and Nord 2000 (see Annex L). In this case, using the data above and in column 2 of Table G.3 it is obtained

$$L_{year} = L_{fav} - 1{,}3 \text{dB} \tag{G.3}$$

In Table G.3, an example of a possible uncertainty calculation is given. The sensitivity coefficients are given by Formula (F.4) by replacing L_i with ΔL_i. The denominator of Formula (F.4) becomes 0,75. The standard uncertainties of the calculated corrections ΔL_i are just examples which have been taken from Figure G.1. In Figure G.1, the values during upwind conditions are probably not very accurate and experience indicates that the spread in data are greater. Nevertheless, the data of the figure will be used here as an example and as can be seen it is not very critical what data are used for upwind conditions as the sensitivity coefficients become very small. For the frequency of occurrence, it is assumed that the uncertainty in the statistics is 25 % which corresponds to 1 dB. It can be seen that for the values chosen, the influence of the calculated terms on the uncertainty is moderate.

Table G.3 — Uncertainty budget of long-term values calculated from short-term measurements

Quantity	Estimate dB	Standard uncertainty, u_i, dB	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i u_i$ dB
L_{fav} (measured)	L_{fav} (see G.2)	2,18	1	2,18
ΔL_{fav} (M3, measured)	0	0	$\frac{0,2}{0,75}=0,27$	0
ΔL_{vfa} (M4, calculated)	+2	2	$\frac{0,3 \cdot 10^{0,2}}{0,75}=0,64$	1,27
ΔL_{neu} (M2, calculated)	−6	3	$\frac{0,2 \cdot 10^{-0,6}}{0,75}=0,07$	0,20
ΔL_{ufa} (M1, calculated)	−12	5	$\frac{0,3 \cdot 10^{-1,2}}{0,75}=0,03$	0,13
p_1	0,3	0,1	8,9	0,09
p_2	0,2	0,1	7,8	0,08
p_3	0,2	0,1	3,4	0,03
p_4	0,3	0,1	0	0
$u(L_{year})=\sqrt{\sum_1^n (c_j u_j)^2}$				2,8
Expanded uncertainty (coverage prob. 95 %)				5,6