

BS 8233:2014



BSI Standards Publication

Guidance on sound insulation and noise reduction for buildings

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Published by BSI Standards Limited 2014

ISBN 978 0 580 74378 8

ICS 91.120.20

The following BSI references relate to the work on this document:

Committee reference B/564

Draft for comment 12/30241578 DC

Publication history

First published 1948

Second edition 1960

Third edition 1987

Fourth edition 1999

Fifth (present) edition, February 2014

Amendments issued since publication

Date	Text affected
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Contents

Foreword *iii*

0	Introduction	1
1	Scope	1
2	Normative references	1
3	Terms, definitions and symbols	2
4	Measuring equipment and accuracy	8
5	Planning and design	9
5.1	Sequence of stages	9
5.2	Assessing the building or site	9
5.3	Design and noise criteria: noise levels	11
5.4	Noise control measures	11
5.5	Quality control and workmanship	14
6	External noise sources	14
6.1	Introduction	14
6.2	Noise from road traffic	15
6.3	Noise from aircraft	17
6.4	Noise from railways	18
6.5	Noise from industry	18
6.6	Noise from construction and open sites	19
6.7	Noise from wind farms	20
6.8	External noise sources: Meteorological effects	21
6.9	Other sources of noise	21
7	Specific types of building	21
7.1	General	21
7.2	Design considerations	22
7.3	Indoor ambient noise criteria	22
7.4	Noise indices	23
7.5	Internal sound insulation	23
7.6	Limits for reverberation time	23
7.7	Specific types of building	24
8	Sound insulation in a building	35
8.1	Factors affecting sound insulation	35
8.2	Flanking transmission	35
8.3	Sound insulation tests	35
8.4	Sound insulation characteristics of common building elements	36
9	Noise from building services	41
9.1	General	41
9.2	Main components	41
9.3	Frequency characteristics of noise	42
9.4	Rating noise from services	42
9.5	Sound-absorbing treatment	42
9.6	Quality control and workmanship	43
Annexes		
Annex A (informative) Noise calculations		44
Annex B (informative) Noise rating		46
Annex C (informative) Specification of sound insulation		48
Annex D (informative) Special problems requiring expert advice: Guidance for specific applications		51
Annex E (informative) Airborne and impact sound insulation		53
Annex F (informative) Legislative framework and guidance		63
Annex G (informative) Typical design problem		64
Annex H (informative) Examples of design criteria adopted by hotel groups		69

Bibliography 73

List of figures

Figure 1 – Characteristics of sound-absorbing materials 33

Figure A.1 – Sound insulation of non-uniform facades comprising windows and cladding 45

Figure E.1 – Transmission paths (via the structure) of noise originating in Room 1 (diagrammatic) 54

Figure E.2 – Indirect sound leakage paths 55

Figure E.3 – Mass law curve 55

List of tables

Table 1 – Typical traffic noise levels measured approximately 1 m from the facade 15

Table 2 – Indoor ambient noise levels in spaces when they are unoccupied and privacy is also important 22

Table 3 – Example on-site sound insulation matrix (dB $D_{nT,w}$) 23

Table 4 – Indoor ambient noise levels for dwellings 24

Table 5 – Noise levels from lifts in living accommodation 26

Table 6 – Typical noise levels in non-domestic buildings 28

Table 7 – Maximum steady noise levels for reliable speech communication 30

Table 8 – The sound insulation of roofs 41

Table A.1 – Standard A-weighting values (dB) 46

Table B.1 – Noise rating values 47

Table B.2 – Values of a and b 48

Table C.1 – Common indices used to describe laboratory airborne and impact sound insulation 51

Table C.2 – Common indices used to describe field airborne and impact sound insulation 51

Table E.1A – Laboratory airborne sound insulation of walls and partitions 58

Table E.1B – Field airborne sound insulation of walls and partitions 60

Table E.1C – Typical performance measured in the field of walls built to Robust Details generic systems 61

Table E.2A – Laboratory airborne sound insulation of floor constructions 62

Table E.2B – Typical performance measured in the field of floors built to Robust Details generic systems 63

Table G.1 – Data used in the calculation of the noise level inside a room 67

Table G.2 – The calculation of the noise level inside a room 68

Table H.1 – Airborne sound insulation 69

Table H.2 – Impact sound insulation for hotels 70

Table H.3 – Indoor ambient noise level ranges for hotel bedrooms 70

Table H.4 – Building services noise in hotels 71

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 78, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 28 February 2014. It was prepared by Technical Committee B/564, *Noise control on building sites*, and Subcommittee EH/1/6, *Building acoustics*. A list of organizations represented on these committees can be obtained on request to their secretaries.

Supersession

This British Standard supersedes BS 8233:1999, which is withdrawn.

Information about this document

This British Standard draws on the results of research and experience to provide information on the design of buildings that have internal acoustic environments appropriate to their functions. It deals with control of noise from outside the building, noise from plant and services within it, and room acoustics for non-critical situations. This document is intended for use by non-specialist designers and constructors of buildings and those concerned with building control, planning and environmental health.

This is a full revision of the standard. The principal changes have been made to reflect:

- changes to the legislative framework since publication of the 1999 edition;
- revisions to Building Regulations Approved Document E [1];
- the publication of specialist documents for specific sectors, such as healthcare and education;
- the publication in England of the National Planning Policy Framework [2] in March 2012, with the concurrent withdrawal of numerous individual planning guidance and policy statement documents, including those specifically relating to noise;
- a reappraisal of the tabular content with respect to setting targets for various classes of living space in the light of research findings; and
- the need to transfer some of the more detailed information from the main text to annexes.

BS 8233:1999 was, like its predecessor CP3 Chapter III:1972, published as a code of practice. However, it was decided to publish this edition as a guide because the text largely comprises guidance that does not support claims of compliance.

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Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

Presentational conventions

The guidance in this standard is presented in roman (i.e. upright) type. Any recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

0 Introduction

Noise control in and around buildings is discussed in this British Standard guide on an objective and quantifiable basis as far as is currently possible. For many common situations, this guide suggests criteria, such as suitable sleeping/resting conditions, and proposes noise levels that normally satisfy these criteria for most people. However, it is necessary to remember that people vary widely in their sensitivity to noise, and the levels suggested might need to be adjusted to suit local circumstances. Moreover, noise levels refer only to the physical characteristics of sound and cannot differentiate between pleasant and unpleasant sounds. Important though psychological factors are, it is not practicable to consider them in this guide.

NOTE The standard is intended to be used routinely where noise sources are brought to existing noise-sensitive buildings.

Attention is drawn to the fact that measures taken to control sound might also impinge on fire precautions and other health and safety requirements. All such requirements need to be considered together at an early stage of the design.

1 Scope

This British Standard provides guidance for the control of noise in and around buildings. It is applicable to the design of new buildings, or refurbished buildings undergoing a change of use, but does not provide guidance on assessing the effects of changes in the external noise levels to occupants of an existing building.

This British Standard does not cover:

- a) specialist applications, such as auditoria and cinemas (for cinemas, see BS ISO 9568);
- b) vibration control, except where it is evident in the form of radiated sound; or
- c) noise that breaks out from the building that might affect external receptors.

NOTE Annex A describes some of the simpler types of noise calculation. A method of rating noise is described in Annex B. Methods of measurement of sound insulation are described in Annex C. Annex D outlines some special problems requiring expert advice. Annex E describes airborne and impact sound insulation. Annex F sets out the legislative framework applicable to noise producing developments. Annex G provides example calculations for resolving a typical design problem. Examples of design criteria adopted by various hotel groups are included for reference in Annex H.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 4142, *Methods for rating and assessing industrial and commercial sound* ¹⁾

BS 5502-32, *Buildings and structures for agriculture – Part 32: Guide to noise attenuation*

BS EN 20354, *Acoustics – Measurement of sound absorption in a reverberation room*

¹⁾ Revision in preparation.

BS EN 60942, *Electroacoustics – Sound calibrators*

BS EN 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*

BS EN 61672-2, *Electroacoustics – Sound level meters – Part 2: Pattern evaluation tests*

BS EN ISO 140, *Acoustics – Measurement of sound insulation in buildings and of building elements*

BS EN ISO 140-4, *Acoustics – Measurement of sound insulation in buildings and of building elements – Part 4: Field measurements of airborne sound insulation between rooms*

BS EN ISO 140-7, *Acoustics – Measurement of sound insulation in buildings and of building elements – Part 7: Field measurements of impact sound insulation of floors*

BS EN ISO 10140-1, *Acoustics – Laboratory measurement of sound insulation of building elements – Part 1: Application rules for specific products*

BS EN ISO 10140-2, *Acoustics – Laboratory measurement of sound insulation of building elements – Part 2: Measurement of airborne sound insulation*

BS EN ISO 10140-3, *Acoustics – Laboratory measurement of sound insulation of building elements – Part 3: Measurement of impact sound insulation*

BS EN ISO 10140-4, *Acoustics – Laboratory measurement of sound insulation of building elements – Part 4: Measurement procedures and requirements*

BS EN ISO 10140-5, *Acoustics – Laboratory measurement of sound insulation of building elements – Part 5: Requirements for test facilities and equipment*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1.1 A-weighted sound pressure

p_A

value of overall sound pressure, measured in pascals (Pa), after the electrical signal derived from a microphone has been passed through an A-weighting network

NOTE The A-weighting network modifies the electrical response of a sound level meter with frequency in approximately the same way as the sensitivity of the human hearing system.

3.1.2 A-weighted sound pressure level

L_{pA}

quantity of A-weighted sound pressure given by the following formula in decibels (dBA)

$$L_{pA} = 10 \log_{10} (p_A/p_0)^2$$

where:

p_A is the A-weighted sound pressure in pascals (Pa);

p_0 is the reference sound pressure (20 μ Pa)

NOTE Measurements of A-weighted sound pressure level can be made with a meter and correlate roughly with subjective assessments of loudness. They are usually made to assist in judging the effects of noise on people. The size of A-weighting, in 1/3 octave bands, is shown in Annex A (see A.5). An increase or decrease in level of 10 dBA corresponds roughly to a doubling or halving of loudness.

3.1.3 background sound

underlying level of sound over a period, T , which might in part be an indication of relative quietness at a given location

3.1.4 break-in

noise transmission into a structure from outside

3.1.5 break-out

noise transmission from inside a structure to the outside

3.1.6 cross-talk

noise transmission between one room and another room or space via a duct or other path

3.1.7 C_{tr}

correction term applied against the sound insulation single-number values (R_w , D_w , and $D_{nT,w}$) to provide a weighting against low frequency performance

NOTE The reference values used within the C_{tr} calculation are based on urban traffic noise.

3.1.8 equivalent continuous A-weighted sound pressure level

$L_{Aeq,T}$

value of the A-weighted sound pressure level in decibels (dB) of a continuous, steady sound that, within a specified time interval, T , has the same mean-squared sound pressure as the sound under consideration that varies with time

NOTE 1 This is given by the following formula.

$$L_{Aeq,T} = 10 \log_{10} \left[\frac{1}{T} \int_0^T \frac{p_A^2(t)}{p_0^2} dt \right]$$

where:

$p_A(t)$ is the instantaneous A-weighted sound pressure in pascals (Pa);

p_0 is the reference sound pressure (20 μ Pa).

NOTE 2 Equivalent continuous A-weighted sound pressure level is mainly used for the assessment of environmental noise and occupational noise exposure.

3.1.9 equivalent sound absorption area of a room

A

hypothetical area of a totally absorbing surface without diffraction effects, expressed in square metres (m²), which, if it were the only absorbing element in the room, would give the same reverberation time as the room under consideration

3.1.10 facade level

sound pressure level 1 m in front of the facade

NOTE Facade level measurements of L_{pA} are typically 1 dB to 2 dB higher than corresponding free-field measurements because of the reflection from the facade.

3.1.11 free-field level

sound pressure level away from reflecting surfaces

NOTE Measurements made 1.2 m to 1.5 m above the ground and at least 3.5 m away from other reflecting surfaces are usually regarded as free-field. To minimize the effect of reflections the measuring position has to be at least 3.5 m to the side of the reflecting surface (i.e. not 3.5 m from the reflecting surface in the direction of the source). Estimates of noise from aircraft overhead usually include a correction of 2 dB to allow for reflections from the ground.

3.1.12 impact sound pressure level

L_i

average sound pressure level in a specific frequency band in a room below a floor when it is excited by a standard tapping machine or equivalent

NOTE For additional information on impact sound pressure level and the standard tapping machine see Annex C and BS EN ISO 140-7.

3.1.13 indoor ambient noise

noise in a given situation at a given time, usually composed of noise from many sources, inside and outside the building, but excluding noise from activities of the occupants

NOTE The location(s) within the room at which the ambient indoor noise is to be measured or calculated ought to be considered.

3.1.14 noise criteria

numerical indices used to define design goals in a given space

3.1.15 noise rating

NR

graphical method for rating a noise by comparing the noise spectrum with a family of noise rating curves

NOTE Noise rating is described in Annex B.

3.1.16 normalized impact sound pressure level

L_n

impact sound pressure level normalized for a standard absorption area in the receiving room

NOTE Normalized impact sound pressure level is usually used to characterize the insulation of a floor in a laboratory against impact sound in a stated frequency band (see Annex C and BS EN ISO 140-7).

3.1.17 octave band

band of frequencies in which the upper limit of the band is twice the frequency of the lower limit

3.1.18 percentile level

$L_{AN,T}$

A-weighted sound pressure level obtained using time-weighting "F", which is exceeded for $N\%$ of a specified time interval

EXAMPLE

$L_{A90,1h}$ is the A-weighted level exceeded for 90% of 1 h.

NOTE Percentile levels determined over a certain time interval cannot accurately be extrapolated to other time intervals. Time-weighting “F” or “S” can be selected on most modern measuring instruments and used to determine the speed at which the instrument responds to changes in the amplitude of the signal. Time-weighting “F” is shorter than “S” and so its use can lead to different values when rapidly changing signals are measured.

3.1.19 rating level

$L_{A,r,Tr}$

equivalent continuous A-weighted sound pressure level of the noise, plus any adjustment for the characteristic features of the noise

NOTE This is used in BS 7445 and BS 4142 for rating industrial noise, where the noise is the specific noise from the source under investigation.

3.1.20 reverberation time

T

time that would be required for the sound pressure level to decrease by 60 dB after the sound source has stopped

NOTE Reverberation time is usually measured in octave or third octave bands. It is not necessary to measure the decay over the full 60 dB range. The decay measured over the range 5 dB to 35 dB below the initial level is denoted by T_{30} , and over the range 5 dB to 25 dB below the initial level by T_{20} .

3.1.21 sound exposure level

L_{AE}

level of a sound, of 1 s duration, that has the same sound energy as the actual noise event considered

NOTE 1 The L_{AE} of a discrete noise event is given by the formula:

$$L_{AE} = 10 \log_{10} \left[\frac{1}{t_0} \int_{t_1}^{t_2} \frac{p_A^2(t)}{p_0^2} dt \right]$$

where:

$p_A(t)$ is the instantaneous A-weighted sound pressure in pascals (Pa);

$t_2 - t_1$ is a stated time interval in seconds (s) long enough to encompass all significant sound energy of the event;

p_0 is the reference sound pressure (20 μ Pa);

t_0 is the reference time interval (1 s).

NOTE 2 L_{AE} is also known as L_{AX} (single-event noise exposure level).

3.1.22 sound level difference

D

difference between the sound pressure level in the source room and the sound pressure level in the receiving room

NOTE D is given by the following formula.

$$D = L1 - L2$$

where:

$L1$ is the average sound pressure level in the source room;

$L2$ is the average sound pressure level in the receiving room.

3.1.23 sound pressure **p**

root-mean-square value of the variation in air pressure, measured in pascals (Pa) above and below atmospheric pressure, caused by the sound

3.1.24 sound pressure level **L_p**

quantity of sound pressure, in decibels (dB), given by the formula:

$$L_p = 10 \log_{10} (p / p_0)^2$$

where:

p is the root-mean-square sound pressure in pascals (Pa);

p_0 is the reference sound pressure (20 μ Pa)

NOTE The range of sound pressures for ordinary sounds is very wide. The use of decibels gives a smaller, more convenient range of numbers. For example, sound pressure levels ranging from 40 dB to 94 dB correspond to sound pressures ranging from 0.002 Pa to 1 Pa. A doubling of sound energy corresponds to an increase in level of 3 dB.

3.1.25 sound reduction index **R**

laboratory measure of the sound insulating properties of a material or building element in a stated frequency band

NOTE For further information, see Annex C and BS EN ISO 10140-2.

3.1.26 standardized impact sound pressure level **L'_{nT}**

impact sound pressure level normalized to a reverberation time in the receiving room of 0.5 s

NOTE Standardized impact sound pressure level is used to characterize the insulation of floors in buildings against impact sounds in a stated frequency band (see Annex C and BS EN ISO 140-7).

3.1.27 standardized level difference **D_{nT}**

difference in sound level between a pair of rooms, in a stated frequency band, normalized to a reference reverberation time of 0.5 s for dwellings

NOTE Standardized level difference takes account of all sound transmission paths between the rooms (see Annex C and BS EN ISO 140-4).

3.1.28 Groundborne and structure-borne noise

NOTE When elements of a structure vibrate they radiate noise and, if the vibration is high enough, this noise can be audible. Groundborne and structure-borne noise are rarely an issue outside buildings or structures.

3.1.28.1 groundborne noise

audible noise caused by the vibration of elements of a structure, for which the vibration propagation path from the source is partially or wholly through the ground

NOTE Common sources of groundborne noise include railways and heavy construction work on adjacent construction sites.

3.1.28.2 structure-borne noise

audible noise caused by the vibration of elements of a structure, the source of which is within a building or structure with common elements

NOTE Common sources of structure-borne noise include building services plant, manufacturing machinery and construction or demolition of the structure.

3.1.29 third octave band

band of frequencies in which the upper limit of the band is $2^{1/3}$ times the frequency of the lower limit

3.1.30 weighted level difference

D_w

single-number quantity that characterizes airborne sound insulation between rooms, but which is not adjusted to reference conditions

NOTE Weighted level difference is used to characterize the insulation between rooms in a building as they are. Values cannot normally be compared with measurements made under other conditions (see BS EN ISO 717-1).

3.1.31 weighted normalized impact sound pressure level

$L'_{n,w}$

single-number quantity used to characterize the impact sound insulation of floors over a range of frequencies

NOTE Weighted normalized impact sound pressure level is usually used to characterize the insulation of floors tested in a laboratory (see Annex C and BS EN ISO 717-2).

3.1.32 weighted sound reduction index

R_w

single-number quantity which characterizes the airborne sound insulating properties of a material or building element over a range of frequencies

NOTE The weighted sound reduction index is used to characterize the insulation of a material or product that has been measured in a laboratory (see Annex C and BS EN ISO 717-1).

3.1.33 weighted standardized impact sound pressure level

$L'_{nT,w}$

single-number quantity used to characterize the impact sound insulation of floors over a range of frequencies

NOTE Weighted standardized impact sound pressure level is used to characterize the insulation of floors in buildings (see Annex C and BS EN ISO 717-2).

3.1.34 weighted standardized level difference

$D_{nT,w}$

single-number quantity that characterizes the airborne sound insulation between rooms

NOTE Weighted standardized level difference is used to characterize the insulation between rooms in a building (see Annex C and BS EN ISO 717-1).

3.2 Symbols

For the purposes of this British Standard the following symbols apply.

A Equivalent sound absorption area (m^2)

D Sound level difference (dB)

D_w Weighted level difference (dB)

D_{nT}	Standardized level difference (dB)
$D_{nT,w}$	Weighted standardized level difference (dB)
L_{Amax}	Maximum noise level (dB)
$L_{Ar,Tr}$	Rating level (dB)
L_i	Impact sound pressure level (dB)
L_n	Normalized impact sound pressure level (dB)
L'_{nT}	Standardized impact sound pressure level (dB)
$L'_{nT,w}$	Weighted standardized impact sound pressure level (dB)
$L'_{n,w}$	Weighted normalized impact sound pressure level (dB)
L_p	Sound pressure level (dB)
L_{pA}	A-weighted sound pressure level (dB)
$L_{AN,T}$	Percentile level (dB)
L_{AE}	Sound exposure level (dB)
$L_{Aeq,T}$	Equivalent continuous A-weighted sound pressure level (dB)
p	Sound pressure (Pa)
p_A	A-weighted sound pressure (dB)
$p_A(t)$	Instantaneous A-weighted sound pressure (Pa)
p_0	Reference sound pressure (Pa)
R	Sound reduction index (dB)
R_w	Weighted sound reduction index (dB)
T	Time interval (also used for reverberation time) (s)
t_0	Reference time interval (s)

4 Measuring equipment and accuracy

The equipment to be used for measuring noise levels should:

- conform to the accuracy requirements specified in BS EN ISO 140, BS EN ISO 10140 or BS 4142, as applicable; or
- if not stated, meet Class 2 or better (see BS EN 61672-1, BS EN 61672-2 and BS EN 60942).

In critical situations, for example, where the measurements are to confirm that a specification has been met or for the resolution of a dispute, the appropriate guidelines for the building use should also be followed.

NOTE 1 Quantification of measurement uncertainty is generally described in the relevant British or International standard and specific guidance, such as that supporting the Building Regulations (see, for example, 7.7.3.1), healthcare design technical manuals and schools building bulletins (see, for example, 7.7.8).

NOTE 2 Where there are no specific measurement requirements for a building use, the guidelines published by the Association of Noise Consultants [3] or other professional bodies may be followed.

5 Planning and design

5.1 Sequence of stages

The recommended sequence of stages in the planning and early design stages of a development is as follows.

- a) Assess the site, identify significant existing and potential noise sources, measure or estimate noise levels (see Clause 6), and evaluate layout options (see 5.2).
- b) Determine design noise levels for spaces in and around the building(s) (see 5.3 and Clause 7).
- c) Determine sound insulation of the building envelope, including the ventilation strategy (see 5.4.5 and Clause 6).
- d) Identify internal sound insulation requirements (see 5.3 and Clause 8).
- e) Identify and design appropriate noise control measures (see 5.4).
- f) Establish quality control and ensure good quality workmanship (see 5.5).

Although this British Standard does not cover the impacts on external receptors of noise that breaks out from the building, it might be necessary to address this within the overall design and planning process.

The same sequence [a) to f)] can be applied where a new noise-making development is to be introduced near an existing noise-sensitive development, such as housing.

5.2 Assessing the building or site

5.2.1 Need for noise assessment

When planning permission is sought for a new building or for a change of use to an existing building, the local planning authority may:

- a) refuse permission if the site is too noisy for the proposed use and local or national noise policies will not be met; or
- b) refuse permission if the proposed use is likely to cause noise disturbance to the occupants of existing buildings such that local or national noise policies will not be met; or
- c) grant permission, with or without conditions regarding noise levels, so that local or national noise policies are met.

NOTE 1 The local planning authority needs to take account of the following government publications:

- in England: the National Planning Policy Framework published by the Department for Communities and Local Government (March 2012) [2], relevant National Policy Statements and the Noise Policy Statement for England [4];
- in Wales: the Welsh Government publications "Planning Policy Wales" [5] and Technical Advice Note (TAN) 11: Noise [6];
- in Scotland: the Scottish Government's Planning Advice Note 1/2011: Planning and Noise [7] and the accompanying Technical Advice Note [8];
- in Northern Ireland: where appropriate, the relevant Planning Policy Statement [9] or relevant Development Control Advice Note [10]; and
- any noise action plans published under the relevant Environmental Noise Regulations [11, 12, 13, 14].

It is therefore important that, even when a full environmental assessment is not mandatory, proposals for developments on noisy sites, or sites which generate noise, should take account of noise, and an assessment should be made of the possible effects of:

- 1) noise generated outside the site that might enter any building on site;
- 2) noise generated inside the site or a building on site that could affect people outside the site/building;

NOTE 2 The noise in item 2) is outside the scope of this British Standard.

- 3) the effect of the proposed development on the existing ambient noise outside the site.

Some noise sources (e.g. airports) might not always be active, or might change their mode of operation under different weather conditions and/or at certain times of day or night. Furthermore, buildings might not necessarily be occupied when the outside environment is noisy. It is therefore essential to make a full assessment of the site before considering the need for, and extent of, noise control.

5.2.2 Noise generated inside or outside the building

5.2.2.1 Noise generated inside the building

For noise generated and heard within the building, the design guidance in Clause 8 for sound insulation within the building should be followed.

The existing and expected noise source(s) should first be identified and the designer should apply the following procedures.

- a) Select metrics to use for measuring or predicting noise levels (e.g. $L_{Aeq,T}$ or L_p in octave or third octave bands).
- b) Assess effects of topography and other features, such as noise screens or reflecting surfaces.
- c) Measure or predict noise levels at strategic points. In some complex situations it might be worth drawing a contour map of external noise levels.
- d) If appropriate, assess noise levels due to user activities around the buildings and site.

The levels of existing noise and noise expected in the foreseeable future should be based on measurement where practicable, or may be predicted if there is reliable information.

5.2.2.2 Noise generated outside the building

For noise sources outside the building, the initial appraisal should take account of the options for:

- a) location of the site in relation to the noise source(s);
- b) reduction of noise at source;
- c) positioning of buildings on site;
- d) orientation of buildings on site;
- e) provision of barriers;
- f) increasing the sound insulation of the building envelope; and
- g) re-planning the interior layout of the building.

These options might also be applicable to protecting neighbouring buildings that are likely to be disturbed by noise generated within the building.

5.3 Design and noise criteria: noise levels

The designer should establish the intended use, including noise activity, noise sensitivity and privacy, of the proposed rooms and other spaces.

To achieve satisfactory sound insulation inside the building, it is necessary to know how each space is to be used so that appropriate noise criteria can be chosen. The designer can then decide which noise criteria are appropriate for the relevant parts of the proposed building, and select appropriate noise levels (see 7.2 and 7.3).

NOTE Advice on indoor ambient noise criteria for various building types is given in 7.3.

The designer should also:

- a) compare external noise levels with internal design criteria;
- b) calculate the noise reduction required between the exterior and interior;
- c) if appropriate, assess internal noise sources;
- d) calculate the noise reduction required between internal user areas and, if necessary, the noise reduction required to reduce noise from internal sources to the level required outside the building; and
- e) identify which noise control measures would be appropriate to deliver this noise reduction (see 5.4).

5.4 Noise control measures

5.4.1 General approach

All reasonable noise control measures should be designed and implemented to ensure that the noise levels are met, along with local or national noise management policies, as appropriate.

NOTE Effective design for noise control requires a good understanding of the behaviour of sound. While the general approach is explained in this subclause, practical information on the transmission of sound within buildings and propagation across the ground is given in the Building Research Establishment document BR 238/CIRIA report 127 [15]. Specialist advice is required for more complex situations, such as those listed in Annex D.

In determining the appropriate noise control measures, the designer should take the following steps, which may be iterative.

- a) Check the feasibility of reducing noise levels and/or relocating noise sources.
- b) Consider options for planning the site or building layout.
- c) Consider the orientation of proposed building(s).
- d) Select construction types and methods for meeting building performance requirements (see 5.4.4).
- e) Examine the effects of noise control measures on the requirements for ventilation, fire regulation, health and safety, cost, CDM (construction, design and management), etc.
- f) Assess the viability of alternative solutions.

The designer should then decide which of the following options can be applied to reduce noise levels.

- 1) Quietening or removing the source of noise (5.4.2).
- 2) Attenuating the sound on its path to the receiver (5.4.3).
- 3) Obstructing the sound path between source and receiver (5.4.4).

- 4) Improving the sound insulation of the building envelope (5.4.5).
- 5) Using agreements to manage noise (5.4.6).

5.4.2 Quietening the source

Reducing the noise at source should always be considered because the number of people benefiting might be large and it can be the most cost-effective method.

5.4.3 Attenuating the noise

Noise is attenuated as it travels through the air because it:

- a) spreads out;
- b) is affected by nearby surfaces, such as grass-covered ground; and
- c) is partly absorbed by the air itself.

These mechanisms for attenuating noise become more effective as the distance between the source and the receiver increases. Spreading is usually the most important effect. For small sources, the reduction is up to approximately 6 dB for each doubling of distance between source and receiver. For extended sources, there is a smaller reduction with distance. For example, the noise level from dense road traffic diminishes at approximately 3 dB for each doubling of distance.

In some circumstances, the noise might not attenuate at expected rates, with poor attenuation occurring with traffic in city streets with high buildings on both sides. In this situation, the noise level diminishes vertically very slowly as the storey height increases because of multiple reflections between the facades (canyon effect).

Ground attenuation is negligible for hard ground and water surfaces. For grassland and other types of ground considered "soft", the attenuation varies with frequency.

5.4.4 Obstructing the sound

Complete enclosure of the noise source or receiver is the most effective form of barrier, provided it is impervious and sufficiently heavy. The walls and roof of a building usually perform this function (see Clause 8). Their effectiveness as a sound insulator is reduced by weaknesses in the envelope (e.g. ventilation openings, thin glazing and doorways), especially when windows are opened. It is therefore important that the effectiveness of measures for obstructing sound is determined.

Barriers that are not complete enclosures (e.g. screens) are normally most effective when tall, long, sound-absorbent, and close to either the source or the receiver.

Solid fences, walls, earth bunds or buildings should extend to the ground.

Whilst neither of the national methods for calculating noise from road traffic or from railways provides for any reduction in noise due to the presence of vegetation, other available guidance suggests that appreciable attenuation can be expected under certain conditions. ISO 9613-2 includes procedures for estimating the attenuation from foliage (trees and shrubs) in each octave band as a function of the total propagation distance that the sound travels through the foliage.

In the context of promoting sustainable methods for reducing road traffic noise, the HOSANNA (Holistic and Sustainable Abatement of Noise by Optimised Combinations of Natural and Artificial Means) Research Project (see Note), funded by the European Union Seventh Framework Programme, was tasked with investigating the theoretical performance of different forms and configurations of vegetation-based noise mitigation, including trees (rows and belts), shrubs and bushes. The study reports that, through an optimized combination of scattering, dispersion, absorption and diffraction effects, appreciable reductions in traffic noise can be expected from compositions of vegetation elements (such as twigs, leaves, stems and trunks).

NOTE To calculate the attenuation for road and rail traffic noise and construction noise, see the references given in Clause 6. Attenuation values of approximately 10 dB are common, but a barrier can reduce the benefit of any ground absorption.

5.4.5 Sound insulation of the building envelope

5.4.5.1 General

Where the designer proposes a form of construction that is intended to obstruct noise, and which might take into account cost and other constraints, the proposed design should be examined and calculations carried out to determine whether the target noise reduction is likely to be achieved. The results indicate whether a higher standard of noise reduction might be necessary or whether a lower standard is adequate. If the need for a change in the design is indicated, further calculations should be carried out and the process repeated until a satisfactory result is obtained. In a situation where a low standard suffices it might be prudent to consider future uses of the building.

When the sound insulation of the building envelope is not known, this may be calculated using one of the methods given in 5.4.5.2 (see also BS EN 12354).

5.4.5.2 Calculations

5.4.5.2.1 General

The required sound insulation should be determined on the basis of the assessment of:

- a) the level and characteristics of the noise outside the building (see 5.2 and Clause 6);
- b) the design noise levels in the rooms and other spaces of the building (see 5.3 and Clause 7).

The sound insulation required can then be determined.

5.4.5.2.2 Initial estimates

Initial estimates may be obtained using calculations based on single-figure data such as the following.

- a) The level of the noise at a key position, such as the equivalent continuous A-weighted sound pressure level ($L_{Aeq,T}$) at the location of the nearest facade of the proposed building. The time period, T , should be chosen to cover the normal operation of the source, or particular occupational requirements of the building if more appropriate. If the source level varies, the maximum level having an appreciable duration should be chosen.
- b) The sound reduction of appropriate parts of the building envelope, e.g. estimated from values of R_w (see Clause 8 and Annex E).

NOTE Annex A contains a method for estimating the sound insulation of a non-uniform facade comprising windows, ventilation openings and cladding.

- c) The design sound level at the receiver (e.g. $L_{Aeq,T}$). If the source operates at night, it might be appropriate to have separate design noise levels for day and night periods.

It is important to understand that there is no simple relationship connecting these single-figure data and that the results are approximate (see Clause 6).

5.4.5.2.3 Detailed calculations

For detailed calculations, knowledge of the following is required.

- a) Frequency characteristics of the noise source(s).
- b) Frequency characteristics of the sound reducing elements.
- c) Surface area of the common construction separating the two areas.
- d) Reverberation time of the receiving space.

Generally, frequency data should be for contiguous octave bands.

5.4.6 Agreements

For certain types of building, it might be possible to assist the management of noise by express provisions in agreements. For example, a contract specification might set noise limits, a tenancy agreement can restrict the use of musical instruments, providing the restriction is sufficiently specific to be enforceable, or a noise management plan might require monitoring of noise levels and actions if limits are exceeded.

5.5 Quality control and workmanship

Quality control and workmanship should always be considered very carefully. Noise control measures can fail to perform adequately if they are not built as the designer intended. Such variations might appear to be unimportant, but often have serious implications for noise control, e.g. a slight warp in a window frame can reduce the effectiveness of the seals. To establish good quality control and workmanship the following aspects should be considered by the designer and discussed with the builder.

- a) Detailed specifications.
- b) The standards of materials and workmanship.
- c) Performance specification in the contract documentation.
- d) Checking and testing procedures that are to be used to demonstrate the standard of workmanship during construction.
- e) Checking and testing procedures that are to be used to assess the building performance.

6 External noise sources

6.1 Introduction

Noise from common sources in the environment is dealt with in 6.2 to 6.7. In each case, information is given on the characteristics of the noise and guidance is given as to how levels can be determined and controlled for each specific source. Example calculations for resolving a typical design problem are given in Annex G.

6.2 Noise from road traffic

6.2.1 General

Road traffic noise generation depends upon a number of factors, including:

- a) traffic flow, which can vary considerably within and between days of the week;
- b) type of vehicles, i.e. proportion of heavy or light;
- c) mode of operation, i.e. on level or inclined road;
- d) surface texture of the road; and
- e) traffic speed and whether flow is continuous or interrupted.

NOTE Weather conditions, e.g. surface water on road, can also affect noise generation.

As with other types of noise the propagation depends upon meteorological conditions, topographical features and ground cover characteristics.

For a typical urban situation where road speed is below 60 km/h, sound energy is concentrated in the low frequency end of the spectrum because of high levels of exhaust noise, particularly from diesel commercial vehicles. At greater speeds (i.e. 80 km/h or higher), more energy is present at higher frequencies due to the road/tyre surface interaction and aerodynamic noise. This difference in spectral characteristics can affect the nature of the noise heard within a building, and should be considered when different noise control measures are being examined.

For initial design purposes, typical noise levels for three common situations are given in Table 1.

Table 1 **Typical traffic noise levels measured approximately 1 m from the facade**

Situation	dB $L_{Aeq,16h}$
At 20 m from the edge of a busy motorway carrying many heavy vehicles; average traffic speed 100 km/h; intervening ground turfed	78
At 20 m from the edge of a busy main road through a residential area; average traffic speed 50 km/h; intervening ground paved	68
On a residential road parallel to a busy main road and screened by the houses from the main road traffic; free flowing traffic	58

NOTE Values are for dry road.

A typical noise spectrum for assessing sound reduction near roads is given in BS EN 1793-3. For more complex situations, detailed calculations or measurements should be undertaken.

6.2.2 Modelling traffic noise

The noise from road traffic can be calculated for a specified range of situations using the method in *Calculation of Road Traffic Noise* (CRTN) [16]. This method predicts the $L_{A10,18h}$ for the period 06:00 to 24:00 or the $L_{A10,1h}$ for roads carrying more than 1 000 vehicles per 18 h day or 50 vehicles per hour. It is the recognized national method for calculating road traffic noise levels, but has been augmented by additional guidance published by the Highways Agency (*Design Manual for Roads and Bridges*, Volume 11, Section 3, Part 7, HD 213/11 – Revision 1) [17]. This additional guidance includes updated advice on calculating night-time noise levels, determining the extent of the study area, vehicle classification, corrections for contemporary road surfaces, speed data, and other approaches to modelling certain specific situations. It is usual to make flow rate forecasts 15 years ahead.

The method takes the following factors into account.

- a) Hourly or 18-hourly traffic flow rate.
- b) Mean traffic speed.
- c) Percentage of heavy vehicles.

Other information required for the calculation includes:

- 1) road surface and gradient;
- 2) ground type;
- 3) height of receiver;
- 4) shielding by barriers and cuttings;
- 5) reflections at facades and from nearby buildings; and
- 6) angle of view of the road.

The method can be used to draw noise contours on a site plan, and this is now usually implemented through a number of proprietary noise prediction models which implement the calculation procedure in CRTN [16]. However, where traffic conditions are complex or unusual it might be necessary to measure noise levels on site, and procedures for measurements are contained within CRTN [16].

A Defra-commissioned study, prepared by TRL and entitled "*Method for Converting the UK Road Traffic Noise Index $L_{A10,18h}$ to the EU Noise Indices for Road Noise Mapping*" [18], is the source of the method promulgated in Highways Agency document HD 213/11 [17] for estimating night-time noise levels from the calculated or measured $L_{A10,18h}$.

This study, however, also provides methods for the conversion of $L_{A10,18h}$ index to other indices, including various period $L_{Aeq,T}$ values. Whilst these conversions have been developed primarily for compliance with strategic EU noise mapping requirements, they provide one potential approach to estimating the range of noise indicators which are relevant to modelling traffic noise.

Otherwise, conversion of L_{A10} to L_{Aeq} can be achieved by the (approximate) relationship: $L_{Aeq,16h} = L_{A10,18h} - 2$ dB. This is generally correct with a 95% confidence interval of ± 2 dB for moderate and heavy traffic flows.

6.3 Noise from aircraft

6.3.1 General

For most airports, the airport operator is responsible for the noise management, which has to be designed to align with Government policy. The exceptions are Heathrow, Gatwick and Stansted, for which the Department of Transport has noise management responsibility. Airports covered by Directive 2002/49/EC [19] have published Noise Action Plans which describe their noise management, including information about flight paths, hours of operation, the planning conditions under which they operate and other noise mitigation practices.

Aircraft noise can be controlled by voluntary noise abatement procedures, which can include:

- a) the adoption of noise preferential routes; and
- b) restrictions on the number of movements and/or classes of aircraft.

Aerodromes used for commercial air transport of passengers and for training in aircraft above certain total maximum total weights are licensed by the Civil Aviation Authority (CAA). Many aerodromes, including general aviation (private and recreational flying and aviation work), do not require a licence for their operation, but the CAA remains responsible for all matters affecting the safety of aircraft and provides guidance on noise consideration at general aviation aerodromes [20].

Planning conditions and legally binding agreements between local planning authorities and landowners can also impose restrictions on aircraft types and operating times, and number of movements, to control noise.

Military aircraft operate under the control of the Military Aviation Authority (MAA).

6.3.2 Prediction of noise from aircraft

Prediction of noise from aircraft or airports is complex, though aircraft noise modelling software packages are available. Many airports periodically produce contours showing the noise exposure around the airport. Care is needed in interpreting these contours as they tend to show average exposure, taking account of different modes of airport operation. This means that, on a particular day, the noise exposure at a particular location might be higher than implied by the contours, and consideration should be given to designing the building envelope for those operational days.

These contours show the noise of aircraft departing from and arriving at an airport without the presence of any shielding effects from buildings or topographical features. They also do not include the noise from ground operations such as taxiing, auxiliary or ground power units or engine testing. Where appropriate, these sources need to be considered separately.

Where it appears that sound insulation treatment is necessary, noise exposure data should be obtained by on-site noise measurements, taking account of wind direction and runway usage. The survey duration of on-site measurements should be sufficient to take account of the various permutations of runway use that can occur, as certain flight paths might only be used under certain wind direction conditions. Where treatment of the building envelope is required to achieve internal design standards then site-specific measurements should be recorded, including provision for the frequency content of the noise (predominantly low frequency noise). It should be noted that for a jet aircraft the frequency content of noise when landing is generally different from that when departing. Typically, landing jet aircraft produce relatively higher levels of high-frequency noise and departing jet aircraft produce relatively higher levels of low-frequency noise.

6.4 Noise from railways

6.4.1 General

Noise from passing trains is characterized in two ways.

- a) The passage of trains over the day and night periods, which is dependent upon timetabling. Passenger trains follow strict daily timetables; freight train passage is less predictable and often occurs at night when passenger services have ceased.
- b) The specific characteristic associated with the passage of each train type, but this is generally characterized by short periods of high noise levels dependent upon speed, locomotive type, power type (electric/diesel), etc.

6.4.2 Prediction of airborne noise from railways

The recognized national calculation method for airborne noise from railways is given in *Calculation of Railway Noise (CRN)* [21], with additional source terms given in *Additional railway noise source terms for "Calculation of Railway Noise 1995"* [22]. The method begins with the calculation of a reference sound exposure level (SEL or L_{AE}) for rolling noise at 25 m, which is speed-based. The calculated value is then corrected for vehicle type/description which takes into account number of axles and brake type. The procedure enables calculation of two $L_{Aeq,T}$ values:

- a) day $L_{Aeq,16h}$ (07.00 to 23.00); and
- b) night $L_{Aeq,8h}$ (23.00 to 07.00).

This method takes into consideration the following factors for each type of train.

- 1) SEL (or L_{AE}) of the train(s).
- 2) Number and times of train movements.
- 3) Distance from track.
- 4) Air absorption.
- 5) Ground type.
- 6) Track bed type.
- 7) Screening.
- 8) Angle of view.
- 9) Reflection and facade effects.

6.5 Noise from industry

6.5.1 General

Industrial noise can originate from specific processes, either internal or external to buildings, or from related transport operations, such as loading/unloading vehicles or activities involving other plant such as fork lift trucks.

NOTE Normal traffic movements on site may be assessed using the measures in 6.2.

6.5.2 Assessment of industrial noise

Where industrial noise affects residential or mixed residential areas, the methods for rating the noise in BS 4142 should be applied. BS 4142 describes methods for determining, at the outside of a building:

- a) noise levels from factories, industrial premises or fixed installations, or sources of an industrial nature in commercial premises; and
- b) background noise level.

6.6 Noise from construction and open sites

6.6.1 General

Noise from construction and open sites can disturb occupants of nearby buildings, whether in residential or other uses. Noise at night can cause sleep disturbance. On this basis, it is commonly accepted that controls are necessary for many construction and open sites, unless they are sufficiently remote from occupied buildings. BS 5228-1 gives recommendations for basic methods of noise control for construction and open sites where work/activities/operations, including demolition, generate significant noise levels. Industry-specific guidance is also included. The legislative background to noise control is described and recommendations are given for establishing effective liaison between developers, site operators and local authorities. Guidance is also given on methods of predicting and measuring noise and assessing its impact on those exposed to it.

6.6.2 Noise effects and community reaction

The main factors that affect the acceptability of noise arising from construction sites are:

- a) site location;
- b) existing ambient noise levels;
- c) duration of site operations;
- d) hours of work;
- e) attitude of the site operator, e.g. if the site operator communicates with affected residents on a regular basis as to when and for how long noisy events are planned to occur, the expected noise is perceived as less annoying than unexpected noise of an unknown duration;
- f) noise characteristics; and
- g) whether additional mitigation has been provided in the form of sound insulation or temporary or permanent rehousing.

BS 5228-1 describes methods for noise control and for determining the significance of noise effects. Several example assessment methods are provided from various significant projects. However, one of the key elements is the provision in BS 5228-1:2009, Annex F, of methods for estimating noise from sites, which is assisted by the inclusion of a large data set of source terms for plant and activities.

6.6.3 Prediction of construction site noise

Noise from construction sites arises from a wide range of plant and activities with many different characteristics. BS 5228-1:2009, Annex F, provides methods for estimating the $L_{Aeq,T}$ levels, taking into account:

- a) sound power outputs of processes and plant;
- b) periods of operation of processes and plant;
- c) distances from sources to receivers;
- d) presence of screening by barriers;
- e) reflection of sound; and
- f) soft ground attenuation.

The levels from the range of equipment used are combined to give an overall $L_{Aeq,T}$ level.

NOTE Slightly different procedures exist for stationary and mobile plant, and these are described in a flowchart in BS 5228-1:2009, Figure F.1.

6.7 Noise from wind farms

6.7.1 General

Wind turbines vary in size and power output, from those just a few metres in diameter to large turbines of around 90 m in diameter. As the turbine blades rotate, aerodynamic noise is generated, which sounds like a swishing noise. Many modern pitch-regulated turbines achieve a maximum level of noise emission at or around the wind speed at which they reach their maximum power generation capacity, which then remains constant, or in some cases declines, as wind speed increases. Mechanical noise from the gearbox (when fitted) and, to a lesser extent, the generator is not usually significant, except in small or older turbine designs. The hub is isolated from the tower and the blade assembly to prevent significant structure-borne noise occurring, which in turn prevents any significant vibrations being transmitted to the ground.

6.7.2 Assessment of wind farm noise

The design, size and rotational speed of a turbine influences the character of the noise generated. The quantification of the noise emissions of medium to large wind turbines is set out in BS EN 61400-11. A particular feature of aerodynamic noise, which is often cited as an adverse feature of medium to large wind turbines, is that of amplitude modulation (AM), which is the modulation or rhythmic swish. Excess AM can sometimes occur. However, it cannot be predicted at the planning stage with the current state of the art. Within the UK, ETSU-R-97 [23] may be used to assess and rate the noise from wind farms. ETSU requires wind farms to achieve defined noise limits in order to preserve day time outdoor amenity and sleep quality at night.

In comparison, small turbines generally have a lower noise emission level, but generate higher frequencies since the blades rotate at greater speeds. Thus the noise impact from these turbines is relatively localized. Offshore turbines might only influence the design and construction of buildings when there is nearby onshore infrastructure, such as electrical substations and converter stations.