BRITISH STANDARD

BS EN 12354-4:2000

Building acoustics — Estimation of acoustic performance of buildings from the performance of elements —

Part 4: Transmission of indoor sound to the outside

The European Standard EN 12354-4:2000 has the status of a British Standard

ICS 91.120.20

National foreword

This British Standard is the official English language version of EN 12354-4:2000.

The UK participation in its preparation was entrusted by Technical Committee B/209, General building codes, to Subcommittee B/209/18, Sound insulation, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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Building acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 4: Transmission of indoor sound to the outside

Acoustique du bâtiment - Calcul de la performance acoustique des bâtiments à partir de la performance des éléments - Partie 4: Transmission du bruit intérieur à l'extérieur

Bauakustik - Berechnung der akustischen Eigenschaften von Gebäuden aus den Bauteileigenschaften - Teil 4: Schallübertragung von Räumen ins Freie

This European Standard was approved by CEN on 9 September 2000.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 126, Acoustic properties of building products and of buildings, the Secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2001, and conflicting national standards shall be withdrawn at the latest by March 2001.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This document is the first version of a standard which forms a part of a series of standards specifying calculation models in building acoustics:

Part 1: *Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms.*

Part 2: *Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 2: Impact sound insulation between rooms.*

Part 3: *Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 3: Airborne sound insulation against outdoor sound.*

Part 4: *Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 4: Transmission of indoor sound to the outside.*

Part 5: *Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 5: Noise from technical installations and equipment.*

Part 6: *Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 6: Sound absorption in enclosed spaces.*

The accuracy of this standard alone is difficult to specify since it forms just one link in the chain of inside sound level, sound radiation and sound propagation outdoors, the first and last items of which are not covered by this standard. The accuracy can only be specified after widespread comparisons with field data in combination with other prediction standards, i.e. those for outdoor sound propagation. It is the responsibility of the user (i.e. a person, an organization, the authorities) to address the consequences of the accuracy, inherent for all measurement and prediction methods, by specifying requirements for the input data and/or applying a safety margin to the results or applying some other correction.

Annex A forms an integral part of this part of EN 12354, Annexes B, C, D, E, F, G and H are for information only.

1 Scope

This European Standard describes a calculation model for the sound power level radiated by the envelope of a building due to airborne sound inside that building, primarily by means of measured sound pressure levels inside the building and measured data which characterize the sound transmission by the relevant elements and openings in the building envelope. These sound power levels, together with those of other sound sources in or in front of the building envelope, form the basis for the calculation of the sound pressure level at a chosen distance from a building as a measure for the acoustic performance of buildings.

The prediction of the inside sound pressure level from knowledge of the indoor sound sources is outside the scope of this European Standard.

The prediction of the outdoor sound propagation is outside the scope of this European Standard.

NOTE For simple propagation conditions an approach is given for the estimation of the sound pressure level in informative Annex E.

This European Standard describes the principles of the calculation model, lists the relevant quantities and defines its applications and restrictions. It is intended for acoustical experts and provides the framework for the development of application documents and tools for other users in the field of building construction, taking into account local circumstances.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN ISO 140-3, *Acoustics – Measurement of sound insulation in buildings and of building elements – Part 3: Laboratory measurements of airborne sound insulation of building elements (ISO 140-3:1995).*

EN ISO 140-5, *Acoustics – Measurement of sound insulation in buildings and of building elements – Part 5: Field measurements of airborne sound insulation of façade elements and façades (ISO 140-5:1998).*

EN 20140-10, *Acoustics – Measurement of sound insulation in buildings and of building elements – Part 10: Laboratory measurement of airborne sound insulation of small building elements (ISO 140-10:1991).*

EN ISO 7235, *Acoustics – Measurement procedures for ducted silencers - Insertion loss, flow noise and total pressure loss (ISO 7235:1991).*

3 Relevant quantities

The symbols used for the purposes of this European Standard are given in Annex A.

3.1 Quantities to express building performance

3.1.1 Sound power level L_W

The sound power level of a substitute point sound source.

3.1.2 Directivity correction D_c

The deviation in decibels of the sound pressure level of a point sound source in a specified direction from the level of an omni-directional point source producing the same sound power level.

3.2 Quantities to express element performance

3.2.1 Sound reduction index R

The sound reduction index of an element for direct sound transmission as defined and determined according to EN ISO 140-3 or EN ISO 140-5.

3.2.2 Element normalized level difference $D_{n,e}$

The normalized level difference of a small building element as defined and determined according to EN 20140-10.

3.2.3 Insertion loss D (of an element)

The reduction in sound power level at a given location behind the element due to the insertion of the element into the duct in place of a hard-walled duct section as defined and determined according to EN ISO 7235.

NOTE For elements where this standard does not apply equivalent methods should be used.

3.2.4 Other relevant data

For the calculations additional information on constructions could be necessary, e.g.:

- the shape of the building envelope;
- areas.

3.3 Other terms and quantities

3.3.1 Sound pressure level L_p

The sound pressure level at a specified reception point outside a building, due to the sound produced inside the building and by sources associated with the building as normally determined by measurements according to local requirements (specifying relevant positions, integration period and source conditions).

The sound pressure level is normally A-weighted.

3.3.2 Total attenuation due to propagation A_{tot}

The level difference between the radiated sound power and the sound pressure at a position at distance d from the building envelope, due to the total of all propagation effects, such as geometrical divergence, air absorption, ground effect, screening, etc.

3.3.3 Diffusivity term C_d

The level difference between the sound pressure level at 1 m to 2 m from the inside face of the relevant building element and the intensity level of the incident sound perpendicular to that element.

NOTE For a diffuse field and reflecting walls the diffusivity term is $C_d = -6$ dB; for other situations it can have a value between 0 dB and –6 dB.

3.3.4 Inside sound pressure level $L_{p,in}$

The sound pressure level inside the building, 1 m to 2 m from the considered element or segment of the building envelope.

NOTE In the case of a diffuse sound field this corresponds to the average sound pressure level in the diffuse sound field.

3.3.5 Substitute point source

A point source for which the radiated sound is the same as that of a segment of the building envelope.

NOTE The segment may be composed of one or more building elements or of one or more openings.

4 Calculation model

4.1 General principles

The total sound pressure level at a reception point that is a chosen distance from a building is determined by the following contributions:

- the sound radiated by the elements of the building envelope due to the sound pressure level inside;
- the sound radiated by individual sound sources, fixed in or onto the outside of the building;
- the outdoor sound propagation (effects of distance, air absorption, ground effect, screening, reflections etc.).

The sound radiation by the building envelope may be represented by the radiation of one or more substitute point sources. Each point source can represent the contribution of a segment of the building envelope or a group of individual sound sources. The number of point sources required to adequately represent a building depends upon the distance of each reception point from the building and the variation in propagation effects. Normally, the building envelope is represented by at least one point source for each side, i.e. walls and the roof, but often several point sources are required for each side.

The sound pressure level at a reception point outside the building is determined from the contributions of each substitute point source according to:

$$L_{\mathrm{p}} = L_{\mathrm{W}} + D_{\mathrm{c}} - A_{\mathrm{tot}} \qquad (1)$$

where

L_{p} is the sound pressure level at a reception point outside the building due to the sound radiation of a substitute point source, in decibels;

L_{W} is the sound power level of the substitute point source, in decibels;

D_{c} is the directivity correction for the substitute point sources in the direction of the reception point, in decibels;

A_{tot} is the total attenuation that occurs during sound propagation from the substitute point source to the reception point, in decibels.

The calculation model described in this standard is restricted to the calculation of the sound power level of the substitute point sources for the building elements and openings in the building envelope from data on:

- the inside sound pressure level;
- the elements which form the building envelope.

The model will also give indications of the directivity correction that can be expected for various types of elements. The inside sound pressure level will normally be the equivalent sound pressure level over a specified period according to the relevant requirements. However, other types of levels can also be used, for instance the maximum level. The calculation of the inside sound pressure level is outside the scope of this European Standard.

The calculation of the contribution of individual sound sources is outside the scope of this European Standard.

The total attenuation A_{tot} due to propagation effects, necessary for the prediction of the sound pressure level at the reception point, can be estimated according to available methods for outdoor propagation, based on a point source approach. The calculation of these propagation effects is outside the scope of this European Standard.

NOTE One such method is given in ISO 9613-2, where the total attenuation is indicated as A. The total attenuation follows from the addition of the attenuation due to various propagation effects, such as geometrical divergence, air absorption, ground effect, screening etc.

However, for simple propagation conditions an approach is given for the estimation of the sound pressure level in Annex E.

4.2 Determination of substitute point sound sources

The elements contributing to the sound radiation are divided into two groups:

- plane radiators, such as structural elements of the building envelope, i.e. walls, roof, windows, doors, including small building elements with an area of typically less than 1 m^2, such as grids and openings;
- larger openings, area typically 1 m^2 or more, i.e. large ventilation openings, open doors, open windows.

To calculate the sound propagation outside the building each element can be represented by a substitute point sound source. However, the building may also be divided into larger segments which are each represented by a substitute point sound source. For the segmentation the following rules apply:

- the sound propagation to the nearest reception points of interest (A_{tot}) is the same for all elements of a segment;
- the distance to the nearest reception point of interest is larger than twice the largest dimension of the segment;
- for the elements in a segment the same inside sound pressure level is applicable;
- for the elements in a segment the same directivity is applicable.

If one or more of these conditions is not fulfilled, choose different segments for instance smaller segments, until these conditions are met.

Unless otherwise specified in the propagation model, the point source representing a vertical segment is positioned at half the width of the segment and 2/3 the height of the segment; for all other segments the position is at the centroid of the segment.

4.3 Determination of the sound power level for a substitute point source

For each segment the sound power level is determined from the following input data:

- sound pressure level inside: $L_{\mathrm{p,in}}$;
- sound reduction index of large building element i of the building envelope: R_{i};
- element normalized level difference of small element i: $D_{\mathrm{n,e,i}}$;
- insertion loss of silencing element for opening i: D_{i};
- area of building element or opening i: S_{i}.

For a **segment of structural elements of the building envelope** the sound power level for the substitute point source is determined by:

$$L_{\mathrm{w}} = L_{\mathrm{p,in}} + C_{\mathrm{d}} - R' + 10\ \lg \frac{S}{S_{\mathrm{o}}} \qquad (2)$$

where

$L_{\mathrm{p,in}}$ is the sound pressure level at 1 m to 2 m from the inside of the segment, in decibels;

C_{d} is the diffusivity term for the inside sound field at the segment, in decibels;

R' is the apparent sound reduction index for the segment, in decibels;

S is the area of the segment, in square metres;

S_{o} is the reference area, in square metres; $S_{\mathrm{o}} = 1\ \mathrm{m}^2$.

The apparent sound reduction index for the segment follows from the data on the composing elements i by:

$$R' = -10\ \lg \left[\sum_{\mathrm{i}=1}^{\mathrm{m}} \frac{S_{\mathrm{i}}}{S} 10^{-R_{\mathrm{i}}/10} + \sum_{\mathrm{i}=\mathrm{m}+1}^{\mathrm{m}+\mathrm{n}} \frac{A_{\mathrm{o}}}{S} 10^{-D_{\mathrm{n,e,i}}/10} \right] \qquad (3)$$

where

R_{i} is the sound reduction index of element i, in decibels;

S_{i} is the area of element i, in square metres;

$D_{\mathrm{n,e,i}}$ is the element normalized sound level difference for a small element i, in decibels;

A_{o} is the reference absorption area, in square metres; $A_{\mathrm{o}} = 10\ \mathrm{m}^2$;

m is the number of large elements of the segment;

n is the number of small elements of the segment.

Information on the inside sound pressure level and diffusivity of the sound field is given in Annex B, based on the type of enclosed space and internal conditions for the elements of the building envelope.

NOTE 1 In the case of an ideal diffuse sound field and non-absorbing elements $C_{\mathrm{d}} = -6$ dB; for industrial spaces and segments which are non-absorbing at the inside a value of $C_{\mathrm{d}} = -5$ dB is generally more appropriate.

NOTE 2 The contribution of structure-borne sound to the sound radiation is not incorporated into the model. It could roughly be incorporated through an adjusted sound reduction index; some indications are given in Annex C.

Information on the sound reduction index to be used is given in Annex C.

For a **segment of openings** the sound power level for the substitute point source is determined by:

$$L_{\mathrm{W}} = L_{\mathrm{p,in}} + C_{\mathrm{d}} + 10\lg \sum_{\mathrm{i}=1}^{\mathrm{o}} \frac{S_{\mathrm{i}}}{S} 10^{-D_{\mathrm{i}}/10} \qquad (4)$$

where

S_i is the area of opening i, in square metres;

S is the area of the segment being the total area of the openings in that segment, in square metres;

D_{i} is the insertion loss for a silencing element for opening i, in decibels;

o is the number of openings of the segment.

The calculation of the sound power level is performed in frequency bands, based on acoustic data for the elements in frequency bands (one-third octave bands or octave bands). The calculation is performed at least for the octave bands from 125 Hz to 2 000 Hz or for the one-third octave bands from 100 Hz to 3 150 Hz.

NOTE 3 The calculations can be extended to higher or lower frequencies if acoustic data are available for such larger frequency range. However, especially for the lower frequencies no information is currently available on the accuracy of the calculations.

NOTE 4 For rough indications it could be sufficient to apply the model directly to A-weighted levels and single number ratings of the performance of building elements according to EN ISO 717-1. Guidelines for this are given in Annex F.

4.4 Determination of the directivity correction for a substitute point source

The directivity correction D_{c} contains the inherent directivity of the radiating elements and openings as given by the directivity index D_{I}. It can also contain the effect of the vicinity of hard surfaces (reflection and screening) as given by the solid angle index D_{Ω}.

For a specific direction the directivity correction is determined from:

$$D_{\mathrm{c}} = D_{\mathrm{I}} + D_{\Omega} = D_{\mathrm{I}} + 10\ \lg \frac{4\pi}{\Omega} \qquad (5)$$

where

Ω is the solid angle into which radiation occurs, in steradians.

Whether or not the solid angle index is included in the directivity correction depends on the propagation model used. When reflections on the ground and other surfaces are taken into account by image sources, the solid angle index D_{Ω} = 0 dB. However, when the reflecting surfaces are the building envelope itself, it is recommended to include the effect of these surfaces in the solid angle index. In giving the directivity correction the value of the included solid angle index is therefore to be stated clearly.

Information on the directivity correction is given in Annex D.

4.5 Limitations

Although large, homogeneous building elements, for instance a complete side wall, can have specific radiation patterns, favouring certain directions; these effects are not taken into account in the model.

The possible contribution of structure-borne sound by machinery in the building is not included in the model, although an approximate approach is indicated in Annex C.

5 Accuracy

The accuracy of prediction of the model depends on many factors: the accuracy of the input data, the fitting of the situation into the model, the type of elements involved, the geometry of the situation, the type of quantity to be predicted and the workmanship. It is therefore not possible to specify the accuracy in general for all types of situations and applications. Data on the accuracy will have to be gathered in the future by comparing the results of the model with a variety of field situations.

In applying the predictions it is advisable to vary the input data, especially in complicated situations and with rare elements with questionable input data. The resulting variation in the results gives an impression of the expected accuracy for situations where good workmanship can be assumed.

Annex A
(normative)

List of symbols

Table A.1 — List of symbols

Symbol	Physical quantity	Unit
A_o	reference absorption area; A_o = 10 m^2	m^2
$A_{tot,}$	total attenuation due to the outside sound propagation from a point source	dB
$A'_{tot,j}$	estimated total attenuation due to the outside propagation in a simple propagation situation for a side of the building	dB
C_d	diffusivity term for the inside sound field at a segment or side	dB
c_o	speed of sound in air (≈ 340 m/s)	m/s
D_c	directivity correction for a substitute point source	dB
D_I	directivity index of a substitute point source	dB
D_Ω	solid angle index of a substitute point source	dB
$D_{n,e,i}$	element normalized sound level difference for a small element i	dB
D_i	insertion loss for a silencing element for opening i	dB
d	distance from the centre of a side of the building to the reception point	m
$d_\perp$	perpendicular distance from the reception point to a side	m
d_o	reference distance; d_o = 1 m	m
f	frequency	Hz
h_1, h_2	vertical distances to the two borders of a side from the projection of the reception point on the side	m
i	index for element or opening for a segment of the building	-
j	index for a segment or side of the building	-
l_1,l_2	horizontal distances to the two borders of a side from the projection of the reception point on the side	m
$L_{p,d}$	sound pressure level at a reception point at distance d at the outside the building	dB re 20 µPa
$L_{p,in}$	sound pressure level at 1 m to 2 m from the inside of a segment or side	dB re 20 µPa
L_w	sound power level of a substitute point sound source	dB re 1 pW
m	number of large elements of segment or side j	-
n	number of small elements of segment or side j	-
o	number of openings of segment or side j	-
R_i	sound reduction index of element i	dB
R'	apparent sound reduction index for a segment or side	dB
S_i	area of element or opening i	m^2
S	area of a segment or side	m^2
S_o	reference area; S_o = 1 m^2	m^2
ϕ	angle between the orientation of a substitute point sound source and the direction from this source to the reception	°
Ω	solid angle into which radiation occurs	sr

Annex B
(informative)

Interior sound field

The inside sound pressure level, relevant for the predictions of sound radiation, is the sound pressure level at a distance of 1 m to 2 m from the interior of the building envelope. It is considered as input data for the model described in this European Standard. This level could be based on measurements in the actual situation, measurements in similar situations or calculations, for instance by empirical models, image source models or ray-tracing models.

The **diffusivity term** C_d is influenced by the amount of diffusivity of the interior sound field and the inside absorption of the considered segment of the building envelope. Indications of its value for different rooms are given in Table B.1.

Table B.1 — Indication of the diffusivity term for different rooms, based on a general description of the spaces and local surface properties of the inside of the building envelope

Situation	C_d dB
Relatively small, uniformly shaped rooms (diffuse field); in front of reflecting surface	–6
Relatively small, uniformly shaped rooms (diffuse field); in front of absorbing surface	–3
Large flat or long halls, many sources (average industrial building); in front of reflecting surface	–5
Industrial building, few dominating directional sources; in front of reflecting surface	–3
Industrial building, few dominating directional sources; in front of absorbing surface	0

Annex C
(informative)

Sound reduction index

The sound reduction index of elements can be obtained from laboratory measurements according to EN ISO 140-3 or EN 20140-10 and field measurements according to EN ISO 140-5. Some information on the sound reduction index according to these standards is also given in EN 12354-1 and EN 12354-3.

However, the dimensions of the elements and the mounting methods are generally quite different from those used for laboratory measurements. This can give rise to large deviations between the acoustic data for elements from the laboratory and the apparent values in the actual situation. Moreover, the sound reduction index of composed parts is normally limited by the sound transmission through connections between elements, sealing of slits and small openings. This transmission is difficult to predict and normally not well represented by laboratory measurements. For these reasons it is strongly recommended to apply data based on representative field measurements. If laboratory data are used it is recommended to limit the resulting sound reduction index for a segment in each frequency band to a practical maximum, relevant for the type of constructions and the situation considered.

Direct excitation of the building structures by internal sources causes structure-borne sound transmission through the building which could contribute to the sound radiation. Estimations of this contribution can be performed in accordance with the relevant clauses of EN 12354-5 1).

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1) In course of preparation.

Annex D
(informative)

Directivity of sound radiation

D.1 Plane radiator

Large homogeneous constructions show a directionality for frequencies above the critical frequency, resulting overall in a higher sound radiation parallel to the plane than perpendicular. However, due to inhomogenities in practical constructions and leakages this is normally not very important. Large plane constructions radiate sound essentially only into a half sphere, so the solid angle into which radiation occurs is $\Omega = 2\,\pi$ leading to D_c = +3 dB. In practice the directivity correction in front of a plane varies between D_c = +5 dB and D_c = –5 dB. It may be taken on average as D_c = 0 dB for radiation angles between 0° and 90° relative to the normal on the plane.

D.2 Openings

Openings show in general a radiation pattern with predominance towards the front. The directivity index roughly varies between D_I = +2 dB and D_I = –10 dB. If the opening is silenced (absorbing muffler, lined ducts) the radiation towards the front can be even more pronounced.

If an opening is positioned in a plane or at short distance (less than one wavelength) from one or more reflecting surfaces, the effect of these planes can be incorporated in the directivity correction by considering the solid angle to which radiation is restricted. If the opening is at large distance from a plane, i.e. at the end of a duct protruding through the plane, the radiation will be in all directions and the directivity correction should contain just the directivity index of the opening, the plane being treated as a reflecting object in the propagation model.

Annex E
(informative)

Simplified model to predict exterior sound pressure levels

The simplified model avoids the need to construct an array of equivalent point sources by presenting the result of the array calculation under certain restriction, leading directly to the outside sound pressure level as radiated by a side of the building. This applies to situations where:

- the same inside sound pressure level applies for the whole relevant part of the side of the building;
- the distance to the reception point is relatively short;
- the distance to the reception point from large openings is large compared to their dimensions;
- no contribution from individual sound sources is considered;
- no screening exists between the building envelope and the reception point;
- the ground surface is mainly hard.

The distance to the side of the building may be small compared to the dimensions of the building but shall not be large enough for substantial meteorological effects (approximately less than 100 m) or for substantial contributions from radiation by other building sides. This last assumption normally holds true as long as the sound power level of the other side of the building is not substantially larger than that of the considered side.

It is assumed that the considered side of the building envelope radiates uniformly over the area, giving a total sound power level. By representing the side by several identical point sources, the attenuation due to geometrical divergence of the envelope as a whole can then be obtained from the attenuation by geometrical divergence for a point source, by summation over all these point sources taking a density of point sources which is sufficient for the considered distance. Together with the radiation of the side of the building into a quarter sphere formed by the side of the building itself and the hard ground, this gives one expression for the total attenuation, indicated for this simplified model as the estimated total attenuation A'_{tot}.

By assuming radiation into a quarter sphere, leading to a contribution to the directivity correction of +6 dB in front of a side of the building, the resulting sound pressure levels are normally on the safe side. In the cases where the ground between the building and reception point is essentially absorbing, the sound pressure level will be over-estimated by at most a few decibels.

The resulting sound pressure at a reception point in front of a side of the building follows from:

$$L_{\mathrm{p}} = 10\ \lg\left[10^{L_{\mathrm{W,e}}/10} + 10^{L_{\mathrm{W,o}}}\right] - A'_{\mathrm{tot}} \tag{E.1}$$

where

$L_{\mathrm{W,e}}$ is the sound power level for the whole side of the building envelope, in decibels;

$L_{\mathrm{W},o}$ is the sound power level for the (group of) openings in the side of the building, in decibels;

$A'_{\mathrm{to}t}$ is the estimated total attenuation for the simplified propagation for the side of the building, due to geometrical divergence, directivity and ground effect, in decibels.

The sound power level for the considered side of the building envelope as a whole and for the considered total group of openings is determined according to 4.3.

For reception points in front of the considered side of the building the estimated total attenuation follows from (see Figure E.1):

$$A'_{\text{tot}} = -10 \lg \frac{S_o}{\pi S}\left[\tan^{-1}\frac{l_1}{d_\perp} + \tan^{-1}\frac{l_2}{d_\perp}\right]\left[\tan^{-1}\frac{h_1}{d_\perp} + \tan^{-1}\frac{h_2}{d_\perp}\right] \qquad \text{(E.2)}$$

where

$d_\perp$ is the perpendicular distance from the reception point to the plane of the side in metres;

S is the area of the side of the building, in square metres;

S_o is the reference area, in square metres; S_o = 1 m^2;

l_1, l_2 are the horizontal distances to the two borders of the side from the projection of the reception point on the side, in metres;

h_1, h_2 are the vertical distances to the two borders of the side from the projection of the reception point on the side, in metres.

NOTE 1 In deducing this equation from the radiation of point sources an approximation has been used for large distances compared with the dimensions of the radiating side. However, for shorter distances this leads to values which have been shown to be more realistic than making a correct deduction; this is due to the actual directivity of a radiating side.

NOTE 2 For a reception point in front of the centre of the side ($d = d_\perp$, $l_1 = l_2$, $h_1 = h_2$) the relation simplifies to:

$$A'_{\text{tot}} = -10 \lg \frac{4S_o}{\pi S} \tan^{-1}\frac{L}{2d} \tan^{-1}\frac{H}{2d} \qquad \text{(E.2a)}$$

where

L is the width $(=2\,l_1=2\,l_2)$;

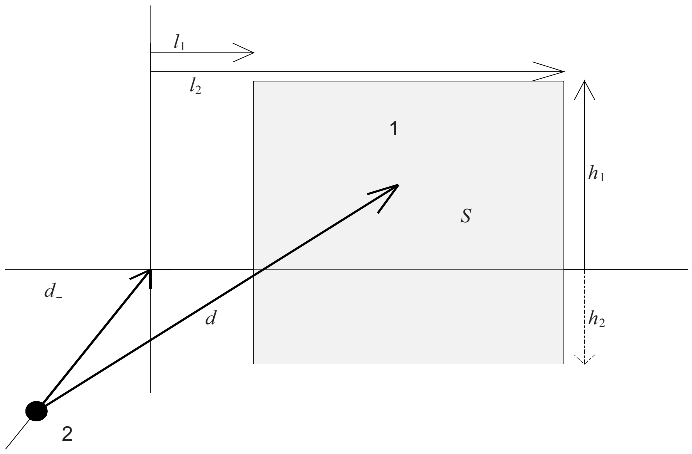
H the height of the radiating area in metres; ($S = L\,H$).

NOTE 3 At a distance that is larger than the largest dimension of the side the attenuation term becomes simply

$$A'_{\text{tot}} = -10 \lg \frac{S_o}{\pi d^2} \qquad \text{(E.2b)}$$

where

d is the distance to the centre of the plane in metres.



Key

1 Building side

2 Reception point

Figure E.1 - Illustration of the geometric situation of a radiating side of a building and a reception point

If the projection of the reception point is outside the radiating area S, the smallest l and/or h is to be taken negative, i.e. the corresponding $\tan^{-1}$-term is to be subtracted from the other, otherwise both distances l and/or h are to be taken positive.

The sound pressure level at a distance significantly less than the dimensions of the side, can differ locally from the calculated average level if the sound reduction indices of the composite parts differ significantly or the distance to openings and sources is too small.

Since the attenuation term is independent of frequency, the calculations can also be performed directly for the A-weighted sound pressure level using the A-weighted sound power levels.

NOTE 4 In the case of a reception point at very short distance, e. g. at 1 m, from a part of the building envelope, assuming that this distance is also small compared to the height above the ground, the relations (2), (E2) and (E3), adjusted so as to neglect the ground reflection, simplify to

$$L_{\mathrm{p,d}\approx 1\mathrm{m}} = L_{\mathrm{p,in}} + C_{\mathrm{d}} - R' + 4 \tag{E.3}$$

This relation can be used to estimate the in-situ apparent sound reduction index of that part of the building envelope from field measurements.

Annex F
(informative)

Application of the model to single number ratings

F.1 General

In some cases only the A-weighted sound pressure level inside the building and the weighted performance of the elements forming the building envelope are known. The following guidelines can be applied in those cases to determine a rough estimate of the A-weighted sound power levels as in 4.3.

F.2 Input data

The input data to consider are the following:

- the A-weighted sound pressure level $L_{\text{pA,in}}$ in dB(A) inside the building;
- the weighted airborne sound insulation index R_w and the spectrum adaptation terms C and C_tr according to
EN ISO 717-1 of the large elements of the building envelope;
- the weighted element normalized level difference $D_{\text{n,e,w}}$ and the spectrum adaptation terms C and C_tr according to EN ISO 717-1 of the small elements of the building envelope.

F.3 Model for single number ratings

The A-weighted sound power level L_WA radiated by a segment of structural elements of the building envelope is estimated in accordance with equation (2) by:

$$L_\text{WA} = L_{\text{pA,in}} - 6 - X'_\text{As} + 10 \lg \frac{S}{S_\text{o}} \qquad \text{(F.1)}$$

where

$L_{\text{pA,in}}$ is the A-weighted sound pressure level at 1 m to 2 m from the inside of segment j, in decibels;

X'_As is the quantity characterizing the A-weighted sound level difference over segment j for source spectrum s, in decibels;

S is the area of segment j, in square metres;

S_o is the reference area, in square metres; S_o = 1 m^2.

NOTE In several countries X'_A1 is indicated as the apparent weighted sound reduction index R'_A and X'_A2 as the apparent weighted sound reduction index R'_Atr.

The characterization of the A-weighted sound level difference for the segment follows from the data on the composing elements i by:

$$X'_{\mathrm{As}} = -10\ \lg\left[\sum_{\mathrm{i}=1}^{\mathrm{m}} \frac{S_{\mathrm{i}}}{S} 10^{-(R_{\mathrm{w,i}}+C_{\mathrm{s,i}})/10} + \sum_{\mathrm{i}=1}^{\mathrm{m}} \frac{A_{\mathrm{o}}}{S} 10^{-(D_{\mathrm{n,e,w,1}}+C_{\mathrm{s,i}})/10}\right] \tag{F.2}$$

where

$R_{\mathrm{w,i}}$	is the weighted sound reduction index of element i, in decibels;
$D_{\mathrm{n,e,w,i}}$	is the weighted element normalized level difference of a small element i, in decibels;
$C_{\mathrm{s,i}}$	is the spectrum adaptation term for spectrum s of element i, in decibels;
S_{i}	is the area of element i, in square metres;
A_{o}	is the reference absorption area, in square metres; A_{o} = 10 m^2;
m	is the number of large elements of the segment;
n	is the number of small elements of the segment.

According to EN ISO 717-1 the spectrum s = 1 refers to A-weighted pink noise, the spectrum adaptation term being denoted as C; this spectrum is also relevant for factory noise with mainly medium and high frequency sound (Annex A of EN ISO 717-1:1996). The spectrum s = 2 refers to A-weighted road traffic noise, the spectrum adaptation term being denoted as $C_{\mathrm{tr;}}$ this spectrum is also relevant for factory noise with mainly low and medium frequency sound and for disco music.

F.4 Limitations

Since the procedure for evaluating the single number rating of sound reduction index assumes an interior spectrum with an emphasis on either the high frequencies or the lower frequencies, the accuracy of estimated A-weighted sound power level depends on the agreement between the shapes of the actual interior sound spectrum and the chosen fixed spectrum according to EN ISO 717-1. The A-weighted sound power level can still be underestimated for sound spectra with main components at frequencies around and below about 250 Hz.

The interior sound field should be diffuse. This condition is fulfilled in enclosed spaces with relatively uniform shape and low sound absorption.

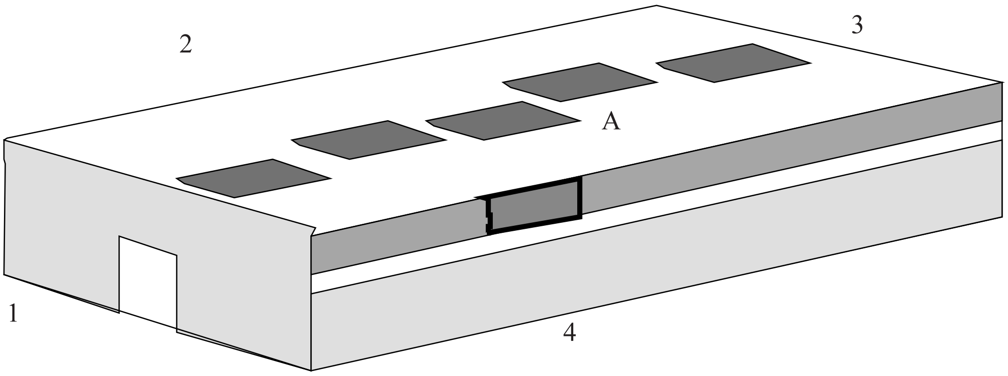
Annex G
(informative)

Calculation example

G.1 Situation

Given is an industrial building, width 60 m, length 100 m, height 10 m (see Figure G.1).

Side 1, 10 m × 60 m:	100 mm light concrete with a large industrial door, 6 m × 4 m.
Side 2, 10 m × 100 m:	100 mm light concrete with glazing over the whole length; height 1 m, 4 mm glass, partly openable.
Side 3, 10 m × 60 m:	100 mm light concrete with a small door, 1 m × 2 m.
Side 4, 10 m × 100 m:	as side 2, with silenced ventilation opening (gross 1 m × 4 m, net 32 %).
Side 5, 60 m × 100 m:	light weight metal roof, with 5 glazed light openings (2 m × 2 m) on the centre line.



Key

A Roof (side 5)

Figure G.1 - Illustration of a building as example

The sound pressure level near the walls and roof is the same and given in Table G.1.

The acoustic performance of the building elements is given in Table G.2.

Table G.1 - Inside sound pressure level in octave bands

	Octave bands (Hz)							
	63	125	250	500	1 k	2 k	4 k	8 k
$L_{p,in}$ dB re 20 μ Pa	70	74	76	72	70	67	62	57

None of the walls or the roof has internal absorbing lining. The minimum distance for reception points of interest is 50 m from the sides of the building.

Acoustic data for elements

Table G.2 - Acoustic data for the building elements, as input to the calculations

Element	Quantity	Octave bands with mid frequency in Hz							
	dB	63	125	250	500	1 k	2 k	4 k	8 k
100 mm light concrete	R 1)	32	36	36	33	39	49	57	63
4 mm glass windows	R 1)	15	19	23	25	25	25	25	25
Industrial door	R 2)	21	23	28	30	30	30	30	30
Normal door	R 2)	13	17	22	25	25	25	25	25
Roof construction	R 2)	16	24	27	30	37	44	47	49
Roof glass elements	R 2)	9	11	15	22	26	30	30	30
Ventilation silencers	D 1)	0	4	11	13	10	8	8	5

1) Data from laboratory measurements.

2) Data from field measurements.

G.2 Results complete model

G.2.1 Substitute point sources

Minimum distance d = 50 m, thus maximum dimension segments are as follows (see Figure G.2):

- wall segment = 1/4 $\sqrt{2}$ d = 17,7 m, thus segments of 10 m × 20 m;
- roof segment = 1/4 $\sqrt{2}$ (d + 30) = 28,3 m, thus segments of 20 m × 20 m;
- Side 1:3 substitute point sources; j = 1 with door, j = 2 and 3 without door;
- Side 2:5 substitute point sources; j = 1 to 5, all identical;
- Side 3:3 substitute point sources; j = 1 with door, j = 2 and 3 without door;
- Side 4:6 substitute point sources; j = 1 to 5 identical envelope segments, j = 6 for openings;
- Side 5:15 substitute point sources; j = 1 to 5 identical roof segments with light glass elements, j = 6 to 15 identical roof segments without glass.

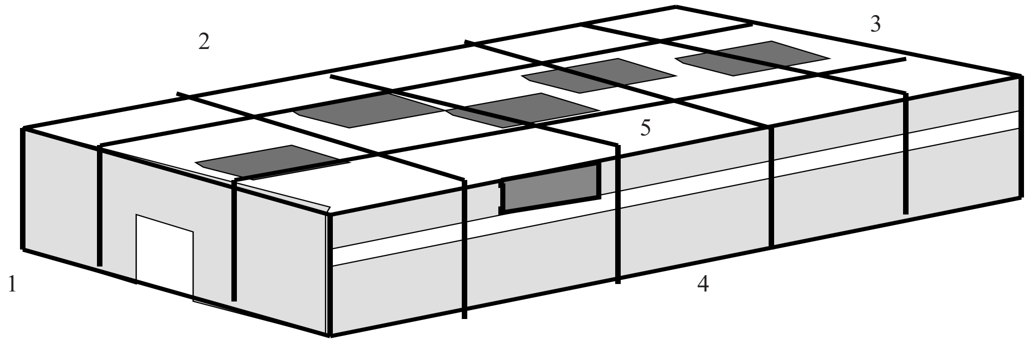


Figure G.2 - Illustration of the division in segments of the building

G.2.2 Sound power level

For each segment the sound power level follows from the input data and the equations (2) to (5). In the Tables G.3 to G.7 this is illustrated for the segments of each side of the building.

Table G.3 - Calculation of sound power level for segments of side 1

Segments	Quantity	Octave bands with mid frequency in Hz							
		63	125	250	500	1 k	2 k	4 k	8 k
All segments	$L_{p,in}$	70	74	76	72	70	67	62	57
All segments	C_d, Annex B	–5	–5	–5	–5	–5	–5	–5	–5
Envelope segment with door (j = 1)	R', equation (3) wall + door 1)	28,2	30,8	33,9	31,8	34,8	36,4	36,5	36,5
	10 lg S/S_o	23	23	23	23	23	23	23	23
	L_W, equation (2)	59,8	61,2	60,1	58,2	53,2	48,6	43,5	38,5
	D_c, Annex D 2)	0	0	0	0	0	0	0	0
Envelope segments without door (j = 2,3)	R', equation (3), wall 1)	32	36	36	33	36	39	40	40
	10 lg S/S_o	23	23	23	23	23	23	23	23
	L_W, equation (2)	56	56	58	57	52	46	40	35
	D_c , Annex D 2)	0	0	0	0	0	0	0	0

1) Apparent sound reduction index limited to 40 dB to take account of field situations.

2) Including a solid angle index of 3 dB for the directions in front of the side.

Table G.4 - Calculation of sound power level for segments of side 2

Segments	Quantity	Octave bands with mid frequency in Hz							
		63	125	250	500	1 k	2 k	4 k	8 k
All segments	$L_{p,in}$	70	74	76	72	70	67	62	57
All segments	C_d, Annex B	–5	–5	–5	–5	–5	–5	–5	–5
Envelope segments (j = 1 to 5)	R', equation (3), wall+glass 1)	24,2	28,0	30,8	30,6	32,8	33,7	33,8	33,8
	10 lg S/S_o	23	23	23	23	23	23	23	23
	L_W, equation (2)	63,8	64,0	63,2	59,4	55,2	51,3	46,2	41,2
	D_c, Annex D 2)	0	0	0	0	0	0	0	0

1) Apparent sound reduction index limited to 40 dB to take account of field situations.

2) Including a solid angle index of 3 dB for the directions in front of the side.

Table G.5 - Calculation of sound power level for segments of side 3

Segments	**Quantity**	**Octave bands with mid frequency in Hz**							
		63	125	250	500	1 k	2 k	4 k	8 k
All segments	$L_{p,in}$	70	74	76	72	70	67	62	57
All segments	C_d, Annex B	–5	–5	–5	–5	–5	–5	–5	–5
Envelope segment with door (j = 1)	R', equation (3), wall + door 1)	29,4	32,6	33,8	32,0	35,9	38,4	38,7	38,8
	10 lg S/S_o	23	23	23	23	23	23	23	23
	L_W, equation (2)	58,6	59,4	60,2	58,0	52,1	46,6	41,3	36,2
	D_c, Annex D 2)	0	0	0	0	0	0	0	0
Envelope segments without door (j = 2,3)	L_W and D_c	as side 1, j = 2,3							

1) apparent sound reduction index limited to 40 dB to take account of field situations.

2) including a solid angle index of 3 dB for the directions in front of the side.

Table G.6 - Calculation of sound power level for segments of side 4

Segments	**Quantity**	**Octave bands with mid frequency in Hz**							
		63	125	250	500	1 k	2 k	4 k	8 k
All segments	$L_{p,in}$	70	74	76	72	70	67	62	57
All segments	C_d, Annex B	–5	–5	–5	–5	–5	–5	–5	–5
Envelope segments (j = 1 to 5)	L_W	as side 2, j = 1 to 5							
Openings segment (j = 6)	D	0	4	11	13	10	8	8	5
	10 lg S_i/S_o $S_i = (0{,}32 \times 4)\ m^2$	1	1	1	1	1	1	1	1
	L_W, equation (4)	69	73	75	71	69	66	61	56
	D_c, opening in plane Annex D 1)	3	3	3	3	3	3	3	3

1) Including a solid angle index of 3 dB for the directions in front of the side.

Table G.7 - Calculation of sound power level for segments of side 5 (roof)

Segments	**Quantity**	**Octave bands with mid frequency in Hz**							
		63	125	250	500	1 k	2 k	4 k	8 k
All segments	$L_{\mathrm{p,in}}$	70	74	76	72	70	67	62	57
All segments	C_{d}, Annex B	–5	–5	–5	–5	–5	–5	–5	–5
Segments with glass (j = 1 to 5)	R' equation (3), roof + glass	15,8	23,2	26,3	29,8	36,5	43,1	45,3	46,5
	10 lg S/S_{o}	26	26	26	26	26	26	26	26
	L_{W}, equation (2)	75,2	71,8	70,7	63,2	54,5	44,9	37,7	31,5
Segments without glass (j = 6 to 15)	R' equation (3), roof	16	24	27	30	37	44	47	49
	10 lg S/S_{o}	26	26	26	26	26	26	26	26
	L_{W}, equation (2)	75	71	70	63	54	44	36	29
	D_{c}, Annex D 1)	0	0	0	0	0	0	0	0

1) Including a solid angle index of 3 dB for the directions in front of the side.

G.3 Results from simplified model

The sound power level for a side of the building is calculated in the same way as in G.2, treating the whole side as a segment. The total sound power level for each side can thus also be deduced from the results in the Tables G.3 to G.7, by adding the sound power levels of all the segments of a side. Table G.8 gives the results for all sides, including the A-weighted sound power level.

Table G.8 - Calculation of A-weighted sound power levels for sides of building

L_{W} **(dB re pW)**	**Octave bands with mid frequency in Hz**								**dB (A)**
	63	125	250	500	1 k	2 k	4 k	8 k	
Side 1	62,4	63,3	63,6	62,2	57,2	51,8	46,3	41,3	62,9
Side 2	70,8	71,0	70,2	66,4	62,2	58,3	53,2	48,2	68,3
Side 3	61,8	62,2	60,2	62,1	56,8	51,0	45,2	40,2	62,2
Side 4	72,0	74,0	74,2	70,3	67,5	64,3	59,2	54,2	72,9
Side 5 (roof)	86,8	83,0	82,0	74,8	65,9	56,1	48,4	41,8	76,6

The resulting sound pressure level follows from the total attenuation for a side, which depends on the distance and relative position of the reception point. Since these attenuation terms are independent of frequency for the simplified model, the calculation can directly give the A-weighted sound pressure levels. In Table G.9 this is calculated for some reception points in front of the centre of side 1 and side 4, using equations (E.1) and (E.2).

In this example the sound power level for side 1 is much lower than that for the roof or side 4, thus the estimation of the sound pressure level at the larger distance for this side could be too low since the contribution of the sound radiation by other building sides is not taken into account. For side 4 this will not be the case.

Table G.9 - Calculation of A-weighted sound pressure level for reception points in front of the centre of side 1 and side 4 (see Figure G.1)

Distance d	**Quantity**	L_p **side 1** dB (A)	L_p **side 4** dB (A)
5 m	L_W	62,9	72,9
	A'_{tot}, equation (E.2)	26,3	28,3
	L_p, equation (E.1)	36,6	44,6
25 m	L_W	62,9	72,9
	A'_{tot}, equation (E.2)	34,4	35,6
	L_p, equation (E.1)	28,5	37,3

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