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

Part 2: Impact sound insulation between rooms

Acoustique du bâtiment — Calcul de la performance acoustique des bâtiments à partir de la performance des éléments —

Partie 2: Isolement acoustique au bruit de choc entre des locaux

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Contents

Page

Foreword

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

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

This document was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 126, *Acoustic properties of building elements and of buildings*, in collaboration with ISO Technical Committee TC 43, *Acoustics*, SC 2, *Building acoustics*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition cancels and replaces ISO 15712-2:2005, which has been technically revised.

A list of all the parts in the ISO 12354 series can be found on the ISO website.

Introduction

This document is part of a series specifying calculation models in building acoustics.

Although this document covers the main types of building construction it cannot as yet cover all variations in the construction of buildings. It sets out an approach for gaining experience for future improvements and developments.

The accuracy of this document can only be specified in detail after widespread comparisons with field data, which can only be gathered over a period of time after establishing the prediction model. To help the user in the meantime, indications of the accuracy have been given, based on earlier comparisons with comparable prediction models and an estimation procedure, similar to the one proposed in ISO 12354-1 for airborne sound insulation, can be used for impact sound insulation. 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.

This document 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.

The calculation models described use the most general approach for engineering purposes, with a clear link to measurable quantities that specify the performance of building elements. The known limitations of these calculation models are described in this document. Other calculation models also exist, each with their own applicability and restrictions.

The models are based on experience with prediction for dwellings; they could also be used for other types of buildings provided the construction systems and dimensions of elements are not too different from those in dwellings.

This document also provides details for application to lightweight constructions (typically steel or wood framed lightweight elements as opposed to heavier masonry or concrete elements) and with the possibility of characterizing the impact sound performance of stairs (see Annex F).

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

Part 2: Impact sound insulation between rooms

1 Scope

This document specifies calculation models designed to estimate the impact sound insulation between rooms in buildings, primarily using measured data which characterize direct or indirect flanking transmission by the participating building elements and theoretically-derived methods of sound propagation in structural elements.

A detailed model is described for calculation in frequency bands, in the frequency range 1/3 octave 100 Hz to 3150 Hz in accordance with ISO 717-1, possibly extended down to 1/3 octave 50 Hz if element data and junction data are available (see Annex E); the single number rating of buildings can be determined from the calculation results. A simplified model with a restricted field of application is deduced from this, calculating directly the single number rating, using the single number ratings of the elements; the uncertainty on the apparent impact sound pressure level calculated using the simplified model can be determined according to the method described in ISO 12354-1:2017, Annex K (see Clause 5).

This document describes the principles of the calculation scheme, lists the relevant quantities and defines its applications and restrictions.

2 Normative references

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

ISO 717-1, *Acoustics — Rating of sound insulation in buildings and of building elements — Part 1: Airborne sound insulation*

ISO 717-2:2013, *Acoustics — Rating of sound insulation in buildings and of building elements — Part 2: Impact sound insulation*

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

ISO 10140-3, *Acoustics — Laboratory measurement of sound insulation of building elements — Part 3: Measurements of impact sound insulation*

ISO 10848-1, *Acoustics —Laboratory measurement of flanking transmission of airborne and impact sound between adjoining rooms — Part 1: Frame document*

ISO 10848-4, *Acoustics — Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms — Part 4: Application to junctions with at least one heavy element*

ISO 12354-1:2017, *Building Acoustics — Estimation of acoustic performance of buildings from the performance of elements — Part 1: Airborne sound insulation between rooms*

ISO 16283-2, *Acoustics — Field measurement of sound insulation in buildings and of building elements — Part 2: Impact sound insulation*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, and the symbols and units listed in Annex A, apply.

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

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

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

3.1 Quantities to express building performance

NOTE The impact sound insulation between rooms in accordance with ISO 16283-2 can be expressed in two related quantities. These quantities are determined in frequency bands (one-third-octave bands or octave bands) from which the single number rating for the building performance can be obtained in accordance with ISO 717-2, for instance $L'_{n,w}$, $L'_{nT,w}$ or ($L'_{nT,w} + C_I$).

3.1.1
normalized impact sound pressure level
L'_n
impact sound pressure level corresponding to the reference equivalent absorption area in the receiving room, which is evaluated from

$$L'_n = L_i + \left(10 \lg \frac{A}{A_o}\right) \text{dB}$$

where

L_i is the impact sound pressure level measured in the receiving room, in decibels;

A is the measured equivalent absorption area of the receiving room, in square metres;

A_o is the reference equivalent absorption area; for dwellings $A_o = 10\ m^2$.

Note 1 to entry: This quantity shall be determined in accordance with ISO 16283-2.

3.1.2
standardized impact sound pressure level
L'_{nT}
impact sound pressure level corresponding to a reference value of the reverberation time in the receiving room, which is evaluated from

$$L'_{nT} = L_i - \left(10 \lg \frac{T}{T_o}\right) \text{dB}$$

where

T is the reverberation time in the receiving room, in seconds;

T_o is the reference reverberation time (for dwellings: $T_o = 0{,}5$ s).

Note 1 to entry: This quantity shall be determined in accordance with ISO 16283-2.

3.2 Quantities to express element performance

NOTE 1 The quantities expressing the element performance are used as part of the input data to estimate building performance. These quantities are determined in one-third-octave bands and can also be expressed in octave bands. In relevant cases a single number rating for the element performance can be obtained from this, in accordance with ISO 717-2, for instance $L_{nw}(C_I)$, ΔL_w ($C_{I\Delta}$) or ΔL_{lin} and $R_w(C; C_{tr})$.

NOTE 2 For the calculation, additional information on the elements can be necessary; for example, mass per unit area m' in k/m2, type of element, material, type of junction, etc.

3.2.1
normalized impact sound pressure level
L_n
impact sound pressure level corresponding to the reference equivalent sound absorption area in the receiving room, which is evaluated from

$$L_n = L_i + \left(10 \lg \frac{A}{A_o}\right) \text{dB}$$

where

L_i is the impact sound pressure level measured in the receiving room by using the standard tapping machine in accordance with ISO 16283-2, in decibels;

A is the measured equivalent absorption area of the receiving room, in square metres;

A_o is the reference equivalent absorption area with $A_o = 10\ m^2$.

Note 1 to entry: This quantity shall be determined in accordance with ISO 10140-3.

3.2.2
reduction of impact sound pressure level
ΔL
improvement of impact sound insulation
reduction in normalized impact sound pressure level resulting from installation of the test floor covering, which is evaluated from

$$\Delta L = L_{no} - L_n \text{ dB}$$

where

L_{no} is the normalized impact sound pressure level in the absence of floor covering, in decibels;

L_n is the normalized impact sound pressure level when the floor covering is in place, in decibels.

Note 1 to entry: This quantity shall be determined in accordance with ISO 10140-3.

3.2.3
reduction of impact sound pressure level
ΔL_d
reduction of impact sound pressure level by an additional layer on the receiving side of the separating element (floor)

Note 1 to entry: This quantity shall be determined in accordance with ISO 10140 (all parts).

3.2.4
normalized flanking impact sound pressure level
$L_{n,f}$
space and time average sound pressure level in the receiving room produced by a standardized tapping machine operating at different positions on the element in the source room, normalized to the reference equivalent sound absorption area (A_o) in the receiving room, which is evaluated from

$$L_{n,f} = L_i + \left(10 \lg \frac{A}{A_o}\right) \text{dB}$$

Note 1 to entry: A_0 = 10 m^2. Transmission is only considered to occur through a specified flanking element, e.g. access floor.

Note 2 to entry: This quantity shall be determined in accordance with ISO 10848-1.

Note 3 to entry: For clarity, the term $L_{n,f}$ is used when only one flanking path determines the sound transmission (such as with access floors) and the term $L_{n,f,ij}$ is used when only one specified transmission path *ij* out of several paths is considered (such as with structure-borne sound transmission on junctions of three or four connected elements).

Note 4 to entry: For access floors see ISO 10848–2.

3.2.5
sound reduction index
R
ten times the common logarithm of the ratio of the sound power W_1 incident on a test specimen to the sound power W_2 transmitted through the specimen, which is evaluated from

$$R = \left(10 \lg \frac{W_1}{W_2} \right) \text{dB}$$

Note 1 to entry: This quantity shall be determined in accordance with ISO 10140-2.

3.2.6
sound reduction improvement index
ΔR
difference in sound reduction index between a basic structural element with an additional layer (e.g. a resilient wall skin, a suspended ceiling, a floating floor) and the basic structural element without this layer

Note 1 to entry: For impact direct transmission, this quantity shall be determined in accordance with ISO 10140-1:2016, Annex G.

Note 2 to entry: ISO 12354-1:2017, Annex D gives information on the determination and the use of this quantity.

3.2.7
vibration reduction index
K_{ij}
quantity related to the vibrational power transmission over a junction between structural elements, normalized in order to make it an invariant quantity, which is determined by normalizing the direction-averaged velocity level difference over the junction, to the junction length and the equivalent absorption length, if relevant, of both elements in accordance with

$$K_{ij} = \frac{D_{v,ij} + D_{v,ji}}{2} + \left(10 \lg \frac{l_{ij}}{\sqrt{a_i a_j}} \right) \text{dB}$$

where

$D_{v,ij}$ is the velocity level difference between elements i and j, when element i is excited, in decibels;

$D_{v,ji}$ is the velocity level difference between elements j and i, when element j is excited, in decibels;

l_{ij} is the common length of the junction between element i and j, in metres;

a_i is the equivalent absorption length of element i, in metres;

a_j is the equivalent absorption length of element j, in metres.

Note 1 to entry: The equivalent absorption length is given by

$$a = \frac{2,2\,\pi^2 S}{c_0 T_s}\sqrt{\frac{f_{ref}}{f}}$$

where

T_s is the structural reverberation time of the element i or j, in seconds;

S is the area of element i or j, in square metres;

f is the centre band frequency, in Hertz;

f_{ref} is the reference frequency; f_{ref} = 1000 Hz;

c_0 is the speed of sound in air, in metres per second.

Note 2 to entry: The equivalent absorption length is the length of a fictional totally-absorbing edge of an element if its critical frequency is assumed to be 1 000 Hz, giving the same loss as the total losses of the element in a given situation.

Note 3 to entry: The quantity K_{ij} shall be determined in accordance with ISO 10848-1 and ISO 10848-4.

Note 4 to entry: Values for this quantity can be taken from ISO 12354-1:2017, Annex E of or be deduced from available data on the junction velocity level difference according to that annex.

3.2.8
normalized direction-averaged vibration level difference

$\overline{D_{v,ij,n}}$

difference in velocity level between elements i and j, averaged over the excitation from i and excitation from j, and normalized to the junction length and the measurement areas on both elements in accordance with

$$\overline{D_{v,ij,n}} = \frac{D_{v,ij} + D_{v,ji}}{2} + \left(10\ \lg \frac{l_{ij} l_0}{\sqrt{S_{m,i} S_{m,j}}}\right)\ \text{dB}$$

where

$D_{v,ij}$ is the velocity level difference between element i and j, when element i is excited, in decibels;

$D_{v,ji}$ is the velocity level difference between element j and i, when element j is excited, in decibels;

l_{ij} is the common length of the junction between element i and j, in metres;

$S_{m,i}$ is area of element i over which the velocity is averaged, in square metres;

$S_{m,j}$ is area of element j over which the velocity is averaged, in square metres;

l_0 is the reference junction length, in metres; l_0 = 1 m.

Note 1 to entry: The quantity $\overline{D_{v,ij,n}}$ shall be determined in accordance with ISO 10848-1 and ISO 10848-4.

Note 2 to entry: In case of Type B elements, as defined in 3.3, the use of K_{ij} (3.2.7) is no longer valid (non-uniform vibration field); however, the notion of vibration level difference is still appropriate[20] and this quantity can be normalized as defined in 3.2.8.

3.2.9
direction-averaged junction velocity level difference

$\overline{D_{v,ij}}$

average of the junction level difference from element i to j and from element j to i, evaluated from

$$\overline{D_{v,ij}} = \frac{D_{v,ij} + D_{v,ji}}{2}$$

3.3 Other terms and quantities

3.3.1
Type A element
element with a structural reverberation time that is primarily determined by the connected elements (up to at least the 1 000 Hz one-third-octave band), and a decrease in vibration level of less than 6dB across the element in the direction perpendicular to the junction line (up to at least the 1 000 Hz one-third-octave band)

3.3.2
Type B element
any element that is not a Type A element

3.3.3
impact direct transmission
transmission due to impact excitation and sound radiation from a separating element

3.3.4
flanking transmission
indirect structure-borne transmission
transmission of sound energy from an excited element in the source room to a receiving room via structural (vibrational) paths in the building construction, e.g. walls, floors, ceilings

4 Calculation models

4.1 General principles

The sound power radiated into the receiving room is due to sound radiated by each structural element in that room. The sound radiated by each of the structural elements is caused by sound transmitted to that element due to impact on a structural element in the source room. It is assumed that the transmission via each of these paths can be considered to be independent and that the sound and vibrational fields behave statistically, so that the impact sound pressure level L'_n can be obtained by addition of the energy transmitted via each path. The transmission paths considered are defined in Figures 1 and 2, where d indicates the direct impact sound transmission and f the flanking impact sound transmission.

For rooms above each other the total impact sound pressure level L'_n in the receiving room is determined by Formula (1):

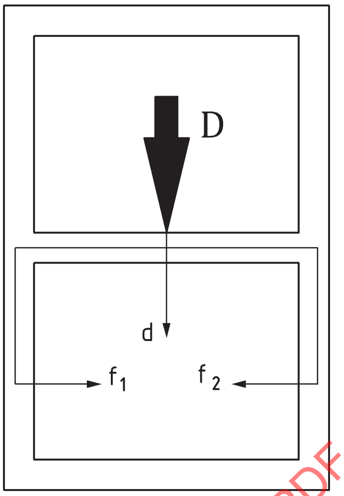
$$L'_n = \left(10 \lg \left(10^{L_{n,d}/10} + \sum_{j=1}^{n} 10^{L_{n,ij}/10} \right) \right) \text{dB} \qquad (1)$$

where

$L_{n,d}$ is the normalized impact sound pressure level due to impact direct transmission, in decibels;

$L_{n,ij}$ is the normalized impact sound pressure level due to flanking transmission, in decibels;

n is the number of elements.



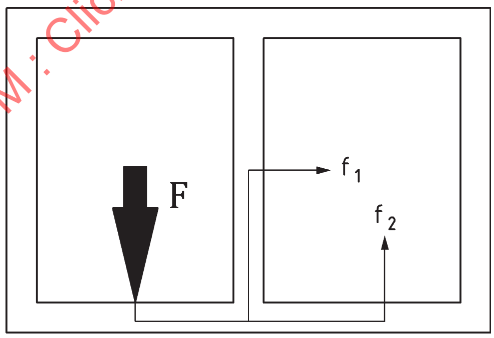
Key

d direct impact sound transmission

Dd direct path

Df_1 or Df_2 flanking path

Figure 1 — Definition of sound transmission paths between two rooms —above each other



Key

f flanking impact sound transmission

Ff_1 or Ff_2 flanking path

Figure 2 — Definition of sound transmission paths between two rooms —next to each other

For rooms next to each other the total impact sound pressure level L'_n in the receiving room is determined by Formula (2):

$$L'_n = \left(10 \lg \sum_{j=1}^{n} 10^{L_{n,ij}/10} \right) \text{dB} \tag{2}$$

NOTE 1 For common situations the number of flanking elements to consider is $n = 4$ for rooms above each other and $n = 2$ for rooms next to each other.

The detailed model calculates the building performance in frequency bands, based on acoustic data for the building elements in frequency bands (one-third-octave bands or octave bands). As a minimum the calculation shall be performed for octave bands from 125 Hz to 2 000 Hz or for one-third-octave bands from 100 Hz to 3150 Hz. From this the single number rating for the building performance can be obtained in accordance with ISO 717-2.

NOTE 2 The calculations can be extended to higher or lower frequencies if element data are available for these frequencies. However, no information is available at this time on the accuracy of calculations for the extended lower frequency regions.

The detailed model is described in 4.2.

The simplified model calculates the building performance directly as a single number rating, based on the single number ratings of the performance of the elements involved.

The simplified model is described in 4.3.

The relation between the quantities L'_{nT} and L'_{n} is given by Formula (3):

$$L'_{nT} = L'_{n} - \left(10 \lg \left(\frac{C_{sab} V}{A_o T_o} \right) \right) \text{dB} \tag{3}$$

where

C_{sab} is the Sabine constant, in seconds per metre with C_{sab}=0,16 s/m;

V is the volume of the receiving room, in cubic metres.

It is sufficient to estimate one of these quantities to deduce the other one. In this document the normalized impact sound pressure level L'_{n} is chosen as the prime quantity to be estimated.

A calculation example is given in Annex G.

4.2 Detailed model

4.2.1 Input data

The transmission for each of the paths can be determined from the following:

— normalized impact sound pressure level of the floor: L_{n};

— reduction of the impact sound pressure level of the floor covering: ΔL;

— reduction of the impact sound pressure level of additional layers on the receiving room side of the separating element i (floor): ΔL_{d};

— sound reduction index of the excited element (floor): R_{i};

— sound reduction index for impact direct transmission of flanking element j in the receiving room: R_{j};

— sound reduction index improvement by internal layers of flanking element j in the receiving room: ΔR_{j};

— structural reverberation time for an element in the laboratory: $T_{s,lab}$;

— vibration reduction index for each transmission path between element i (floor) and element j: K_{ij};

— normalized direction-averaged velocity level difference between element i to element j: $\overline{D_{v,ij,n}}$;

— flanking normalized impact sound pressure level $L_{n,f}$;

NOTE Normally this concerns only transmission path Ff_2 if dominant for a given flanking element, but the quantity can also be applied to any isolated transmission paths ij.

— area of the separating element (floor): S_i;

— area of the flanking element j in the receiving room: S_j;

— common coupling length between element i (floor) and flanking element j: l_{ij}.

Information on normalized impact sound pressure level for common homogeneous floors is given in B.1.

Information on impact sound improvement index for common floor coverings is given in C.1.

Information on sound reduction index of common homogeneous elements is given in ISO 12354-1:2017, Annex B.

Information on sound reduction index improvement is given in ISO 12354-1:2017, Annex D.

Information on vibration reduction index and on flanking normalized level difference for common junctions is given in ISO 12354-1:2017, Annex E.

For each flanking transmission path the sound reduction index, R, of the elements involved (including the separating element) should relate to the resonant transmission only. It is correct to apply the laboratory sound reduction index above the critical frequency. Below the critical frequency, a correction shall be applied, particularly for elements with high critical frequency such as lightweight elements, as explained in ISO 12354-1:2017, Annex B. If the values of the sound reduction index are based on calculations from material properties, it is best to consider only resonant transmission over the frequency range of interest.

4.2.2 Transfer of input data to *in situ* values

4.2.2.1 General

Acoustic data for elements (separating and flanking structural elements, additional layers and coverings, junctions) shall be converted into *in situ* values before the actual determination of the sound transmission.

For additional layers and coverings, the *in situ* values can be taken as the laboratory value as an approximation, as shown by Formula (4):

$$\begin{aligned} \Delta R_{situ} &= \Delta R \quad \text{dB} \\ \Delta L_{situ} &= \Delta L \quad \text{dB} \\ \Delta L_{d,situ} &= \Delta L_d \quad \text{dB} \end{aligned} \qquad (4)$$

If appropriate data for the impact sound improvement index ΔL_d by suspended ceilings on the receiving side of the separating floor is not available, the airborne sound improvement index ΔR shall be used with care; this approximation may lead to significant errors.

For elements and junctions, two cases shall be considered: Type A elements (4.2.2.2) and Type B elements (4.2.2.3).

4.2.2.2 Type A elements

For Type A elements, the *in situ* values for the normalized impact sound pressure level $L_{n,situ}$ and the sound reduction index R_{situ} follow from Formula (5) for impact sound pressure level:

$$L_{n,situ} = L_n + \left(10 \lg \frac{T_{s,situ}}{T_{s,lab}} \right) dB \tag{5}$$

and Formula (6) for sound reduction index:

$$R_{situ} = R - \left(10 \lg \frac{T_{s,situ}}{T_{s,lab}} \right) dB \tag{6}$$

where

$T_{s,\,situ}$ is the *in situ* structural reverberation time for the element, in seconds;

$T_{s,\,lab}$ is the structural reverberation time for the element in the laboratory, in seconds.

The structural reverberation time, both for the laboratory and *in situ*, shall be taken into account in accordance with ISO 12354-1:2017, Annex C.

NOTE As a first approximation, it can be assumed that $L_{n,situ} = L_n$ *and* $R_{situ} = R$.

For junctions between Type A elements, the *in situ* transmission is characterized by the direction-averaged junction velocity level difference $\overline{D_{v,ij,situ}}$. This follows from the vibration reduction index, as shown by Formula (7):

$$\overline{D_{v,ij,situ}} = K_{ij} - \left(10 \lg \frac{l_{ij}}{\sqrt{a_{i,situ}\ a_{j,situ}}} \right) dB\ ;\ \overline{D_{v,ij,situ}} \geq 0\ dB \tag{7}$$

with as shown by Formula (8):

$$a_{i,situ} = \frac{2{,}2\ \pi^2 S_i}{c_o T_{s,i,situ}} \sqrt{\frac{f_{ref}}{f}}$$

$$a_{j,situ} = \frac{2{,}2\pi^2 S_j}{c_o T_{s,j,situ}} \sqrt{\frac{f_{ref}}{f}} \tag{8}$$

where

$a_{i,situ}$ is the *in situ* equivalent absorption length of element i, in metres;

$a_{j,situ}$ is the *in situ* equivalent absorption length of element j, in metres;

f is the band centre frequency, in Hertz;

f_{ref} is the reference frequency; f_{ref} = 1 000 Hz;

c_o is the speed of sound in air, in metres per second;

l_{ij} is the coupling length of the common junction between elements i and j, in metres;

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

S_j is the area of element j, in square metres;

$T_{s,i,situ}$ is the *in situ* structural reverberation time of element i, in seconds;

$T_{s,j,situ}$ is the *in situ* structural reverberation time of element j, in seconds.

4.2.2.3 Type B elements

For Type B elements, the structural reverberation time $T_{s,situ}$ shall be taken as being equal to $T_{s,lab}$ which leads to a correction term of 0 dB ($L_{n,situ} = L_n$ *and* $R_{situ} = R$).

For junctions between Type B elements, the *in situ* direction-averaged junction velocity level difference follows from the normalized direction-averaged junction velocity level difference as (with l_0 a reference length of 1 m), as shown by Formula (9):

$$\overline{D_{v,ij,situ}} = \overline{D_{v,ij,n}} - \left(10 \lg \frac{l_0 l_{ij}}{\sqrt{S_{i,situ} S_{j,situ}}} \right) \text{dB} \tag{9}$$

In the case of junctions composed of elements of both categories (for example Type B wall on a Type A floor), Formula (7) can still be used as an approximation, the equivalent absorption length of the Type B element being taken equal to the element area [Formula (10)] and K_{ij} being estimated as per 3.2.7.

$$a_{i,situ} = S_{i,situ} / l_0 \tag{10}$$

4.2.3 Determination of direct and flanking transmission

4.2.3.1 General

The normalized impact sound pressure level for impact direct transmission is determined from adjusted input values as shown by Formula (11):

$$L_{n,d} = L_{n,situ} - \Delta L_{situ} - \Delta L_{d,situ} \ \text{dB} \tag{11}$$

For flanking transmission, two cases shall be considered: Type A elements (4.2.3.2) and Type B elements (4.2.3.3).

4.2.3.2 Type A elements

For Type A elements, the normalized impact sound pressure level for flanking transmission from the separating element i (floor) to the flanking element j is determined from adjusted input values as shown by Formula (12):

$$L_{n,ij} = L_{n,situ} - \Delta L_{situ} + \frac{R_{i,situ} - R_{j,situ}}{2} - \Delta R_{j,situ} - \overline{D_{v,ij,situ}} - \left(10 \lg \sqrt{\frac{S_i}{S_j}} \right) \text{dB} \tag{12}$$

NOTE For certain floors such as access floors, the flanking transmission is dominated by path Ff_2 (the junction having a small influence, the contribution of path Ff_1 can be neglected). In that case it is possible to characterize the flanking transmission for this construction as a whole by laboratory measurements (see Annex D).

4.2.3.3 Type B elements

For buildings made of Type B elements, the flanking transmission can be characterized adequately either by the normalized flanking impact sound pressure level $L_{n,f,ij}$, or by using the normalized direction-averaged junction velocity level.

The normalized impact sound pressure level for flanking transmission can be deduced from the normalized flanking impact sound level as shown by Formula (13):

$$L_{\text{n,ij}} = L_{\text{n,f,ij,situ}} - \left(10\lg \frac{S_{\text{i}} l_{\text{lab}}}{S_{\text{i,lab}}\ l_{\text{ij}}} \right) \text{dB} \tag{13}$$

The normalized flanking impact sound level in laboratory situation shall be transferred to the field situation, as indicated in Annex D.

The normalized impact sound pressure level for flanking transmission can also be deduced from the performance of the elements by combining Formulae (11) and (8), as shown by Formula (14):

$$L_{\text{n,ij}} = L_{\text{n,ii}} - \Delta L_{\text{i}} + \frac{R_{\text{i}} - R_{\text{j}}}{2} - \Delta R_{\text{j}} - \overline{D_{\text{v,ij,n}}} - \left(10\ \lg \frac{S_{\text{i}}}{l_0 l_{\text{ij}}} \right) \text{dB} \tag{14}$$

The sound reduction indices, R_{i} and R_{j}, refer to either the double element as a whole or the inner leaf element, that are also distinguished in the normalized direction-averaged vibration level difference $\overline{D_{\text{v,ij,n}}}$ (see ISO 12354-1:2017, Annex F), and should relate to resonant transmission only (see ISO 12354-1:2017, Annex B).

With suspended ceilings or wall linings, the additional reduction of sound transmission can be taken into account separately through ΔR_{j}. However, there are indications that with timber or metal frame lightweight elements it is no longer a fair assumption to use the same value for flanking transmission as for impact direct transmission.

NOTE With timber or metal frame lightweight elements, the additional reduction of sound transmission for flanking transmission (for each frequency band) can then be approximated as: $\Delta R_{\text{j}} \approx \Delta R_{\text{d}} / 2$.

The sound transmission by the separating element and by the flanking elements can then be calculated in accordance with Formulae (1) and (2), applying the formulae defined in 4.2.2 and 4.2.3.

4.2.4 Interpretation for several types of elements

Information on the interpretation for several types of elements is given in ISO 12354-1:2017.

4.2.5 Limitations

The limitations are as follows.

a) The model is only applicable to combinations of elements for which the vibration reduction index or the normalized vibration level difference is known or can be estimated from known values.

b) The bare elements should have approximately the same radiation characteristics for both sides.

c) The contribution of secondary transmission paths, involving more than one junction, is neglected.

d) The reduction of impact sound pressure level ΔL measured on a massive floor in accordance with ISO 10140-3 cannot be applied to timber floors or other lightweight composite floor constructions.

4.3 Simplified model

4.3.1 General

The application of the simplified model is restricted over a frequency range 100 Hz to 3 150 Hz; its application to lightweight constructions is restricted to the use of $L_{\text{nf,ij}}$ [see Formula (17)].

4.3.2 Calculation procedure

The simplified version of the calculation model predicts the weighted normalized impact sound pressure level on the basis of weighted values of the elements involved, determined in accordance with the weighting procedure of ISO 717-2:2013. The influence of structural damping is taken into account in an average way, neglecting the specifics of the situation. The flanking transmission is calculated for the same paths as the detailed model but with single number quantities.

NOTE The simplified model is equally applicable to other weighting systems.

The weighted normalized impact sound pressure level for the direct path is given by Formula (15):

$$L_{n,d,w} = L_{n,eq,0,w} - \Delta L_w - \Delta L_{d,w} \text{ dB} \tag{15}$$

where

$L_{n,d,w}$ is the weighted normalized impact sound pressure level for the direct path;

$L_{n,eq,0,w}$ is the equivalent weighted normalized impact sound pressure level of the bare floor;

ΔL_w is the weighted reduction of impact sound pressure level by a floor covering;

$\Delta L_{d,w}$ is the weighted reduction of impact sound pressure level of an additional layer on the receiving side of the separating element; this quantity is rarely available and often approximated by the sound reduction improvement index $\Delta R_{d,w}$.

The weighted normalized flanking impact sound pressure level for the flanking path ij is given by Formula (16)

$$L_{n,ij,w} = L_{n,eq,0,w} - \Delta L_w + \frac{R_{i,w} - R_{j,w}}{2} - \Delta R_{j,w} - K_{ij} - \left(10 \lg \frac{S_i}{l_0 l_{ij}} \right) \text{dB} \tag{16}$$

where

$L_{n,ij,w}$ is the weighted normalized flanking impact sound pressure level generated on floor (i) and radiated by element (j);

$L_{n,eq,0,w}$ is the equivalent weighted normalized impact sound pressure level of the bare floor;

ΔL_w is the weighted reduction of impact sound pressure level by a floor covering;

$R_{i,w}$ is the weighted sound reduction index of the floor (i);

$R_{j,w}$ is the weighted sound reduction index of element (j);

K_{ij} is the vibration reduction index for path ij;

$\Delta R_{j,w}$ is the weighted sound reduction index improvement of an additional layer on the receiving side of the flanking element (j) (see 4.3.2).

NOTE In Formula (16), it is assumed that the element absorption length a is equal to the element area S.

If the values for the vibration reduction index K_{ij} depend on frequency, the mean value averaged over the frequency range 1/3 octave 250 Hz to 1 000 Hz (as defined in ISO 10848-1) may be taken as an approximation, but the result can then be less accurate.

For Type B elements, the weighted flanking impact sound level $L_{ij,w}$ for any isolated path ij shall be determined from the corresponding weighted flanking impact sound level $L_{nf,ij,lab,w}$ measured in laboratory using Formula (17).

$$L_{n,ij,w} = L_{nf,ij,lab,w} + \left(10\ \lg \frac{S_{i,lab}\ l_{ij}}{S_i\ l_{ij,lab}}\right) \text{dB} \quad (17)$$

For certain flanking constructions, like access floors, the transmission is normally dominated by path Ff_2, as characterized by the weighted flanking normalized level $L_{nf,w}$, so the contribution of path Ff_1 can be neglected. $L_{n,f,w}$ can be either measured or determined from the performance of elements (see Annex D). For horizontal flanking elements like access floors $l_{ij,lab}$ = 4,5 m.

For rooms above each other the total impact sound pressure level $L'_{n,w}$ in the receiving room is determined by Formula (18):

$$L'_{n,w} = \left(10\ \lg\left(10^{L_{n,d,w}/10} + \sum_{j=1}^{n} 10^{L_{n,ij,w}/10}\right)\right) \text{dB} \quad (18)$$

where

$L_{n,d,w}$ is the weighted normalized impact sound pressure level due to impact direct transmission, in decibels;

$L_{n,ij,w}$ is the weighted normalized impact sound pressure level due to flanking transmission, in decibels;

n is the number of elements.

And for rooms next to each other, the total impact sound pressure level $L'_{n,w}$ in the receiving room is determined by Formula (19):

$$L'_n = \left(10\lg \sum_{j=1}^{n} 10^{L_{n,ij,w}/10}\right) \text{dB} \quad (19)$$

4.3.3 Input data

Acoustic data on the elements involved should be taken primarily from standardized laboratory measurements. However, they may also be deduced in other ways, using theoretical calculations, empirical estimations or measurement results from field situations. Information on this is given in some annexes. The sources of data used shall be clearly stated.

The input data consist of the following.

a) Equivalent weighted normalized impact sound pressure level of the floor base: $L_{n,eq,0,w}$.

The single number rating to express element performance of heavy floor bases is obtained by rating the frequency depending normalized impact sound pressure level following the procedure described in ISO 717-2:2013, Annex B; information on $L_{n,eq,0,w}$ for common homogeneous floors is given in B.2 and B.3.

b) Weighted reduction of impact sound pressure level by a floor covering: ΔL_w.

The single number rating to express element performance of floor coverings (floating floors or soft floor coverings) is obtained by applying the procedure described in ISO 717-2:2013, Clause 5; information on ΔL_w for common floating floors is given in C.2.

c) Weighted reduction of impact sound pressure level $\Delta L_{d,w}$; in the presence of both floor covering and lining on the receiving side of the separating element, half of the value of $\Delta L_{d,w}$ shall be used.

d) Weighted sound reduction index of elements R_w: information on R_w for common homogeneous elements is given in ISO 12354-1:2017, Annex B.

e) Weighted sound reduction index improvement ΔR_w: information on ΔR_w for common linings is given in ISO 12354-1:2017, Annex D (as well as general information in 4.2.2); in the presence of both floor covering and lining on the receiving side of a flanking element, half of the value of ΔR_w shall be used.

f) Vibration reduction index K_{ij}: information on K_{ij} for common homogeneous constructions is given in ISO 12354-1:2017, Annex E.

g) Weighted flanking normalized impact sound level $L_{nf,ij,w}$ (see Annex D).

5 Accuracy

The calculation models predict the measured performance of buildings, assuming good workmanship and high measurement accuracy. The accuracy of the prediction by the models presented depends on many factors: the accuracy of the input data, the fitting of the situation to the model, the type of elements and junctions involved, the geometry of the situation and the workmanship. It is therefore not possible to specify the accuracy of the predictions 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. However, some indications can be given.

The main experience in the application of similar models, as far as the detailed model is concerned, is based on buildings with homogeneous building elements, e.g. brick walls, concrete floors and walls, gypsum blocks, etc. For vertical impact sound transmission the prediction of the single number value is correct with a standard deviation of 2 dB. For horizontal transmission the calculated single number values have a varying bias error of 0 dB to 5 dB with a standard deviation of around 3 dB. The bias is expected to be caused largely by neglecting the structural reverberation time.

Uncertainty for the simplified model can be calculated using the method proposed in ISO 12354-1:2017, Annex K; however, the formulae used for the impact noise simplified model (4.3.1) are different from the ones used for airborne sound insulation and the partial derivatives required for the determination of uncertainty should be modified consequently.

In applying the predictions it is advisable to vary the input data, especially in complicated situations and with atypical elements with questionable input data. The resulting variation in the results gives an impression of the expected accuracy for these situations, assuming similar workmanship.

Annex A
(normative)

Symbols

Table A.1 — List of symbols

Symbol	Physical quantity	Unit
a	equivalent absorption length of a structural element	m
a_{situ}	equivalent absorption length of a structural element in the actual field situation	m
A	equivalent sound absorption area in the receiving room	m^2
A_0	reference equivalent sound absorption area; for dwellings given as 10 m^2	m^2
c_0	speed of sound in air (= 340 m/s)	m/s
c_L	longitudinal wave speed	m/s
C_I	spectrum adaptation term for impact sound in accordance with ISO 717-2	dB
$C_{I\Delta}$	spectrum adaptation term for impact sound reduction by floor coverings according to ISO 717-2:2013, Annex A	dB
$D_{v,ij}$	junction velocity level difference between excited element i and receiving element j	dB
$\overline{D_{v,ij,situ}}$	direction-averaged junction velocity level difference between elements i and j in the actual field situation	dB
$\overline{D_{v,ij,n}}$	Normalized direction-averaged junction velocity level difference between elements i and j	dB
f	frequency	Hz
f_{ref}	reference frequency (= 1000 Hz)	Hz
i	indices for an element in the source room (= D,F)	-
j	indices for an element in the receiving room (= d,f)	-
K	correction term for flanking transmission	dB
K_{ij}	vibration reduction index for each transmission path ij over a junction	dB
$K_{ij,min}$	minimum value for K_{ij} in the actual field situation	dB
L_i	average impact sound pressure level in the receiving room	dB re 20 µPa
L_n	normalized impact sound pressure level	dB re 20 µPa
$L_{n,f}$	normalized flanking impact sound pressure level (path Ff dominant)	dB re 20 µPa
$L_{n,f,ij}$	normalized flanking impact sound pressure level (path ij isolated)	dB re 20 µPa
$L_{n,situ}$	normalized impact sound pressure level in the actual field situation	dB re 20 µPa
$L_{n,w,eq}$	equivalent weighted normalized impact sound pressure level	dB re 20 µPa
L'_n	normalized impact sound pressure level in the field	dB re 20 µPa
$L'_{n,w}$	weighted normalized impact sound pressure level in the field (ISO 717-2:2013)	dB re 20 µPa
L'_{nT}	standardized impact sound pressure level in the field	dB re 20 µPa
$L_{n,d}$	normalized impact sound pressure level by impact direct transmission	dB re 20 µPa
$L_{n,ij}$	normalized impact sound pressure level by flanking transmission	dB re 20 µPa
L_2	average impact sound pressure level in the receiving room due only to sound transmission via path Ff (for certain flanking elements)	dB re 20 µPa
ΔL	reduction of impact sound pressure level by a floor covering	dB re 20 µPa

Table A.1 *(continued)*

Symbol	Physical quantity	Unit
ΔL_{situ}	reduction of impact sound pressure level by a floor covering in the actual field situation	dB re 20 µPa
ΔL_d	reduction of impact sound pressure level by an additional layer on the receiving side of the separating element	dB re 20 µPa
$\Delta L_{d,situ}$	reduction of impact sound pressure level by an additional layer on the receiving side of the separating element in the actual field situation	dB re 20 µPa
ΔL_w	weighted reduction of impact sound pressure level by a floor covering (ISO 717-2)	dB re 20 µPa
ΔL_{lin}	unweighted linear reduction of impact sound pressure level by a floor covering (ISO 717-2:2013, Annex A)	dB re 20 µPa
l_{ij}	common coupling length between element i and element j	m
l_{Ff}	common coupling length between flanking elements F, f and the separating element	m
l_{lab}	laboratory value, as reference, for l_{ij}	m
l_o	reference length (= 1 m)	m
m'	mass per unit area of an element	kg/m^2
m'_o	reference mass per unit area (= 1 kg/m^2)	kg/m^2
n	number of flanking elements in a room	-
R	sound reduction index of an element	dB
R_{situ}	sound reduction index of an element in the actual field situation	dB
R_i	sound reduction index of the excited element i in source room	dB
$R_{i,situ}$	sound reduction index of the excited element i in the actual field situation	dB
R_j	sound reduction index for element j in receiving room	dB
$R_{j,situ}$	sound reduction index of element j in the actual field situation	dB
ΔR_j	sound reduction index improvement by an additional layer on the receiving side of element j	dB
$\Delta R_{j,situ}$	sound reduction index improvement by an additional layer on the receiving side of element j in the actual field situation	dB
S_i	surface area of the excited element (floor)	m^2
S_j	surface area of the radiating element	m^2
S_f	surface area of the excited element in the actual field situation	m^2
$S_{f,lab}$	surface area of the excited element in the laboratory situation	m^2
s'	dynamic stiffness per unit area	N/m^3
T	reverberation time in the receiving room	s
T_o	reference reverberation time; for dwellings given as 0,5 s	s
T_s	structural reverberation time of a (homogeneous) element	s
$T_{s,lab}$	structural reverberation time for each (homogeneous) element in the laboratory situation	s
$T_{s,situ}$	structural reverberation time for each (homogeneous) element in the actual field situation	s
$T_{s,i,lab}$	structural reverberation time for element i in the laboratory situation	s
$T_{s,i,situ}$	structural reverberation time for element i in the actual field situation	s
t	thickness	m
V	the volume of the receiving room	m^3
$\overline{v_i^2}$	average square velocity over element i (free waves)	(m/s)^2

Table A.1 *(continued)*

Symbol	Physical quantity	Unit
v_{j}^2	average square velocity over element j (free waves)	$(m/s)^2$
W_1	sound power incident on a test specimen in the source room	W
W_2	sound power radiated from a test specimen into the receiving room due to incident sound on that specimen in the source room	W
w	index to indicate weighted sound reduction indices in accordance with ISO 717-1	-
ρ	density	kg/m^3
σ	radiation factor for free bending waves	-

Annex B
(informative)

Homogeneous floor constructions

B.1 Normalized impact sound pressure level L_n of homogeneous floor constructions

For homogeneous floor constructions the calculation following 4.2 can be based on the following data if measured values of the normalized impact sound pressure level L_n are not available.

For common monolithic floors the normalized impact sound pressure level can be calculated accurately.[5] The total loss factor as influenced by the laboratory is important and shall be taken into account in accordance with the specifications given in ISO 10140-1. This is described in ISO 12354-1:2017, Annex C.

Formulae (B.1) and (B.2) can be used:

$$L_n = L_F + \left(\left(10 \lg \frac{\mathrm{Re}(Y)}{\left(1 \frac{\mathrm{m}}{\mathrm{Ns}}\right)} \right) + \left(10 \lg \sigma\right) - \left(10 \lg \frac{m'}{\left(\frac{1\mathrm{kg}}{\mathrm{m}^2}\right)} \right) + \left(10 \lg \frac{T_s}{(1\mathrm{s})} + 10{,}6 \right) \right) \mathrm{dB} \quad \text{(B.1)}$$

NOTE The force level L_F characterizes the standard tapping machine only in the case of a low mobility floor (such as the homogeneous heavy floors given in this annex); otherwise, the above force level represents the contact force which also depends on the receiving floor properties.

With the force level of the standard tapping machine in accordance with ISO 10140-5 it follows for one-third-octave bands:[1]

$$L_n \approx 155 - \left(\left(30 \lg \frac{m'}{\left(1\ \mathrm{kg/m}^2\right)} \right) + \left(10 \lg \frac{T_s}{(1\ \mathrm{s})} \right) + \left(10 \lg \sigma\right) + \left(10 \lg \frac{f}{\left(f_{\mathrm{ref}}\right)} \right) \right) \mathrm{dB} \quad \text{(B.2)}$$

where

L_F is the force level of the tapping machine, in decibels (reference 10^{-6} N);

m' is the mass per unit area, in kilograms per square metre;

$\mathrm{Re}(Y)$ is the real part of the floor mobility, in Newton second per metre;

σ is the radiation factor for free bending waves;

T_s is the structural reverberation time, in seconds;

ρ is the density of the floor, in kilograms per cubic metre;

f_{ref} is the reference frequency; f_{ref} = 1 000 Hz.

The radiation factor for free waves and the structural reverberation time is calculated in accordance with ISO 12354-1:2017, Annexes B and C.

The forces applied by the tapping machine are reduced at higher frequencies, depending on the dynamic stiffness of the top layer of the floor. This can be taken into account empirically.

Based on calculations according to this model, some examples of the normalized impact sound pressure level in octave bands for monolithic floors are given in Table B.2 for a laboratory situation in accordance with ISO 12354-1:2017, Annex C. The calculations are performed for frequencies at one-third octave distance and results averaged over a band width of an octave. The applied material properties are given in Table B.1, together with the generic material names for which they are indicative.

Table B.1 — Typical material properties

Material	Density ρ kg/m^3	Longitudinal velocity c_L m/s	Internal loss factor η -
Concrete	2 300	3 500	0,006
Lightweight concrete	1 300	1 700	0,015

Table B.2 — Calculated normalized impact sound pressure level in octave bands for some monolithic structural elements (examples)

Construction	m' kg/m^2	Normalized impact sound pressure level (dB) in octave bands (Hz)							$L_{n,w}$ (C_I)
		63	125	250	500	1 k	2 k	4 k	
100 mm concrete + 20 mm finish	268	65	73	78	78	78	78	76	80 (−11)
180 mm concrete + 50 mm finish	509	64	60	65	66	67	68	66	69 (−11)
200 mm lightweight concrete	260	65	72	78	77	77	76	70	77 (−9)
300 mm lightweight concrete	390	64	68	70	70	70	70	64	71 (−9)

For reasons of reciprocity the sum of the airborne sound reduction index R and the normalized impact sound pressure level L_n for homogeneous floor constructions depends only on frequency, if forced transmission is negligible.[7] This is normally valid for frequencies up to 1 kHz due to the influence of the stiffness of the top layer of the floor. Thus the normalized impact sound pressure level of a construction can be estimated from data on the sound reduction index of that construction.

For calculations in octave bands the relation is given by Formula (B.3):

$$R + L_n = 43 + \left(30 \lg \frac{f}{(1\ \text{Hz})} \right) \text{dB} \tag{B.3}$$

where f octave band centre frequency in Hertz.

For calculation of data in third-octave band width the expression is shown by Formula (B.4):

$$R + L_n = 38 + \left(30 \lg \frac{f}{(1\text{Hz})} \right) \text{dB} \tag{B.4}$$

where f one-third-octave band centre frequency in Hertz.

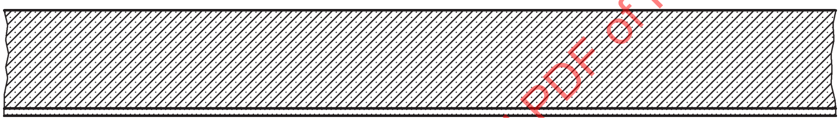
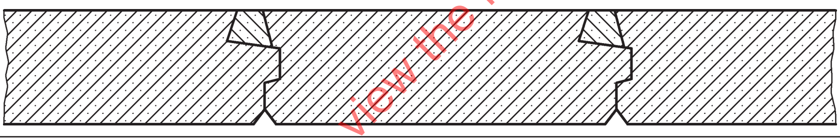
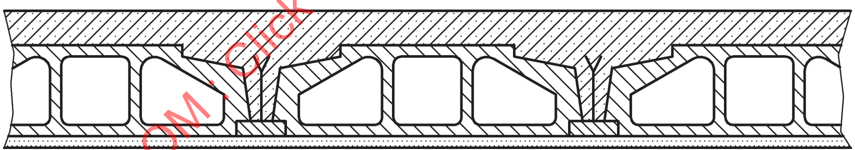
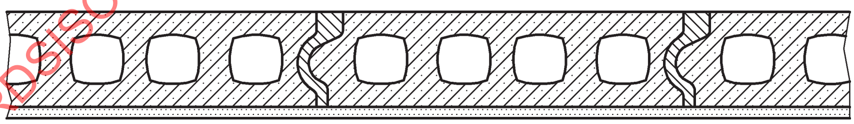
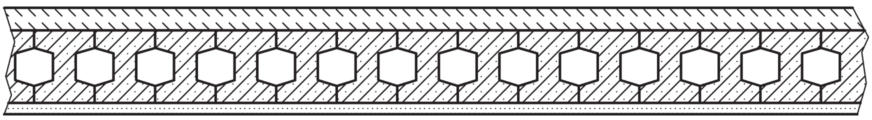
B.2 Equivalent weighted normalized impact sound pressure level $L_{n,eq,0,w}$ of homogeneous floor constructions

For homogeneous floor constructions the equivalent weighted normalized impact sound pressure level $L_{n,eq,0,w}$ used for the calculation following 4.3 can be calculated from the mass per unit area m' (in the range of 100 kg/m² to 600 kg/m²) from Reference [8], as shown by Formula (B.5):

$$L_{n,eq,0,w} = 164 - \left(35 \lg \frac{m'}{\left(1 \text{ kg} / \text{m}^2\right)} \right) \text{dB} \tag{B.5}$$

This formula is for homogeneous concrete floors; for lightweight concrete or porous concrete the actual values will be somewhat lower, so Formula (B.5) is on the safe side in those cases. Table B.3 shows floor constructions which behave like homogeneous constructions.

Table B.3 — Types of basic floor constructions

Floor constructions without voids
in situ concrete solid floor 
autoclaved aerated concrete solid floor 
beam and pot 
wide slab concrete floor 
concrete beam floor 

B.3 Equivalent weighted normalized impact sound pressure level *L*n,eq,0,w of floor constructions with clay hollow-pots and upper light screed layer (partially homogeneous)

For floor constructions made with concrete beams and clay bricks or blocks and an upper light screed layer (partially homogeneous structure), the equivalent weighted normalized impact sound pressure level $L_{n,eq,0,w}$ used for the calculation following 4.3 can be calculated from the mass per unit area m' (in the range of 270 kg/m² to 360 kg/m²) from Reference [13], as shown by Formula (B.6):

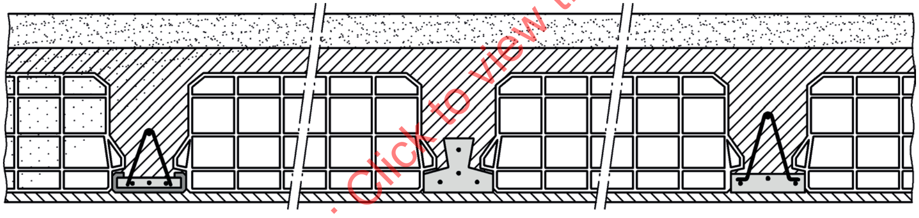
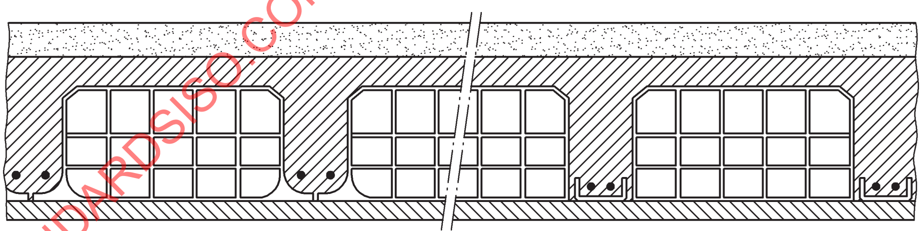
$$L_{n,eq,0,w} = 160 - \left(35 \lg \frac{m'}{\left(1 \text{ kg} / \text{m}^2\right)} \right) \text{dB} \tag{B.6}$$

Formula (B.6) is for rib and clay hollow-pot floors (partially homogeneous) as defined in EN 15037-3:2009 + A1:2011 with an upper light screed layer with thickness between 50 mm and 100 mm and density 650 ± 150 kg/m³.

For floors with clay hollow-pots without light screed layer, formulae from EN 15037–1:2008, L.3 should be used.

Table B.4 shows floor constructions which behave like this kind of rib and hollow-pot constructions.

Table B.4 — Types of beam and clay block floors

Floor constructions with ribs and hollow-pots and an upper light screed layer
prefabricated beams and clay blocks 
cast-in-place beams and clay blocks 

Annex C
(informative)

Floating floors

C.1 Reduction of impact sound pressure level ΔL of floating floors

If no measured values for the reduction of impact sound pressure level ΔL of floating floors are available the following formulae can be applied.

a) The reduction of impact sound pressure level ΔL of floating floor screeds made of sand/cement or calcium-sulfate can be calculated by Formula (C.1):

$$\Delta L = \left(30 \lg \frac{f}{f_o} \right) \text{dB} \quad \text{(C.1)}$$

where

f octave or third-octave band centre frequency, in Hertz;

f_0 the resonance frequency of the system, in Hertz, according to Formula (C.2):

$$f_o = 160 \sqrt{\frac{s'}{m'}} \quad \text{(C.2)}$$

where

s' is the dynamic stiffness per unit area of the resilient layer in accordance with EN 29052-1 measured without any pre-load, in Meganewtons per cubic metre;

m' is the mass per unit area of the floating floor, in kilograms per square metre.

NOTE 1 The theory of impact sound insulation leads to the formula $\Delta L = 40 \lg (f / f_0)$ which relates to infinite plates. However, experimental data show that for practical situations the above formula is on the safe side.

b) The reduction of impact sound pressure level ΔL for asphalt floating floors or dry floating floor constructions can be calculated from Formula (C.3):

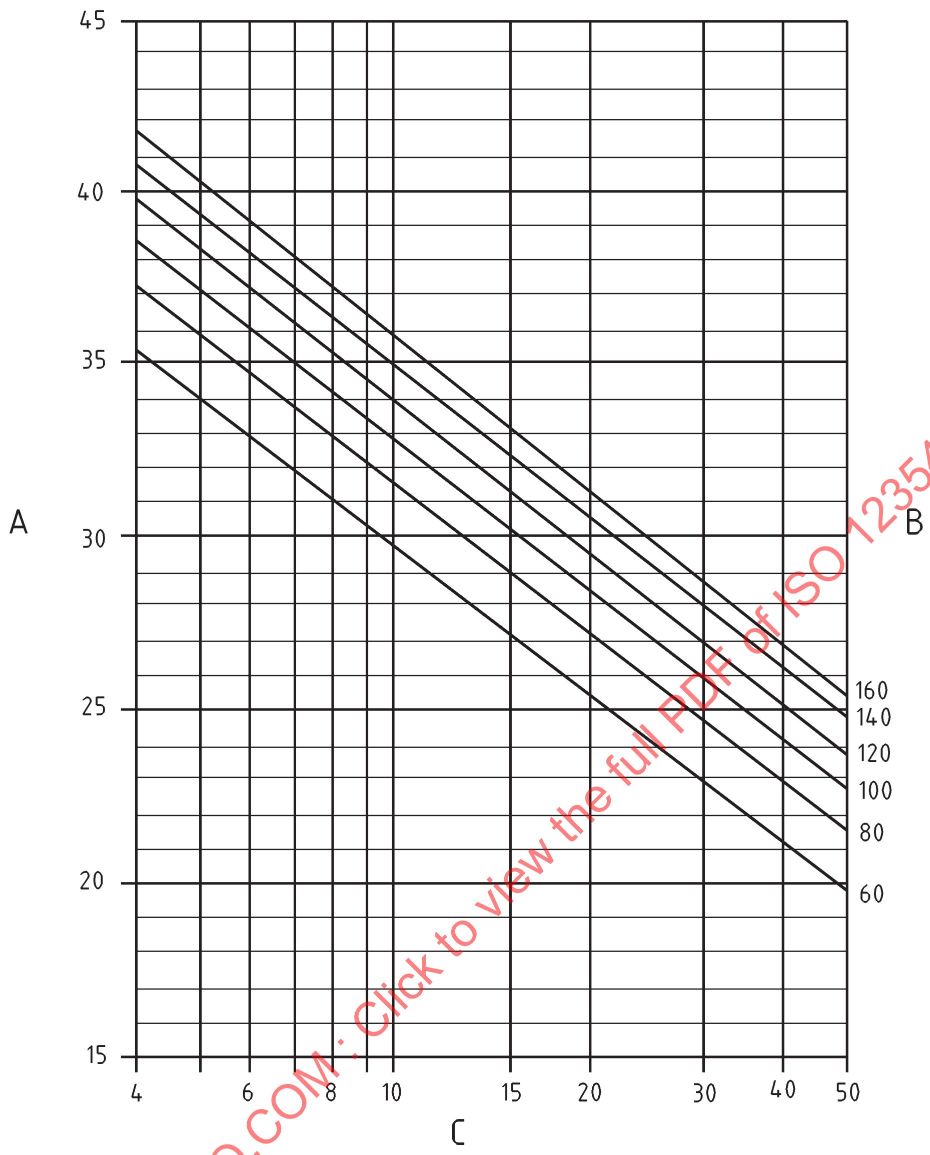
$$\Delta L = \left(40 \lg \frac{f}{f_o} \right) \text{dB} \quad \text{(C.3)}$$

NOTE 2 Due to the relatively high internal loss factor of the constructions mentioned, the reduction of impact sound pressure level ΔL increases with frequency according to the theory for infinite plates in most cases. This is confirmed by experimental data obtained under test conditions.

C.2 Weighted reduction of impact sound pressure level ΔL_W of floating floors

The weighted reduction of impact sound pressure level ΔL_W depends on the mass per unit area m' of the floating floor and the dynamic stiffness per unit area s' of the resilient layer in accordance with EN 29052-1 measured without any pre-load.

a) For floating floor screeds made of sand/cement or calcium-sulfate, values can be taken from Figure C.1.



Key

A weighted reduction of impact sound pressure level by a floor covering ΔL_w in dB

B mass per unit area of the floating floor in kgm^{-2}

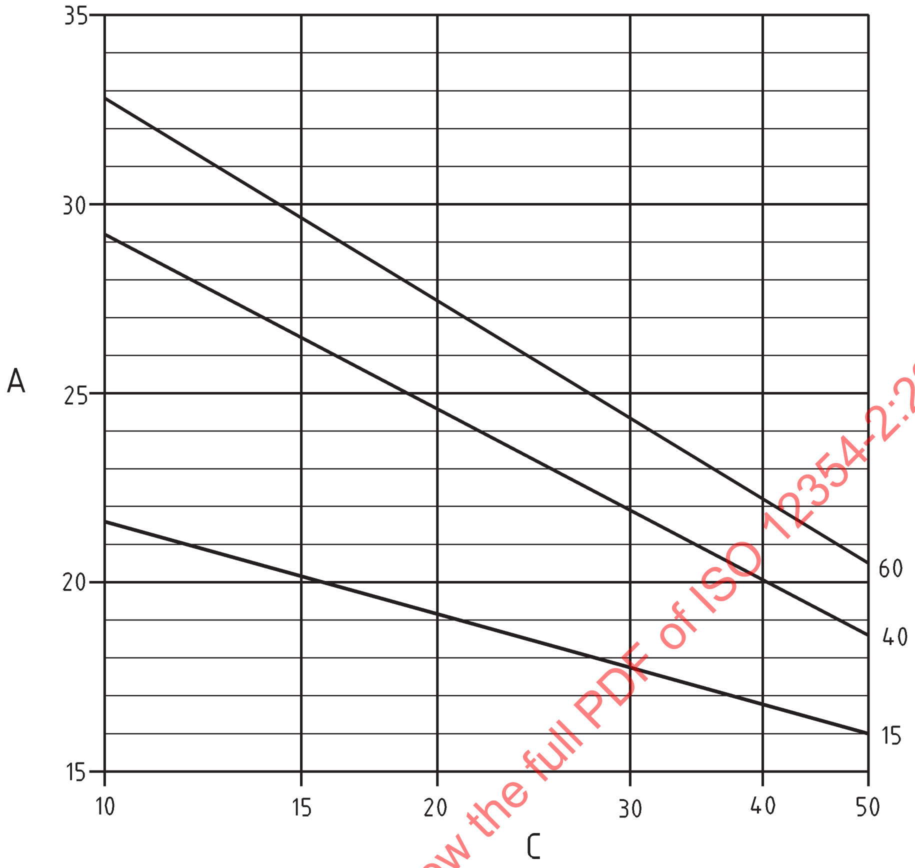
C dynamic stiffness per unit area s' of the resilient layer in MNm^{-3}

Figure C.1 — Weighted reduction of impact sound pressure level for floating floor screeds made of sand/cement or calcium-sulfate

The above values can be calculated using Formula (C.4):

$$\Delta L_w = \left(13 \lg\left(m'\right)\right) - \left(14{,}2 \lg\left(s'\right)\right) + 20{,}8 \text{ dB} \quad \text{(C.4)}$$

b) For asphalt floating floors or dry floating floor constructions values can be taken from Figure C.2.



Key

A weighted reduction of impact sound pressure level by a floor covering ΔL_w in dB

B mass per unit area of the floating floor in kgm^{-2}

C dynamic stiffness per unit area s' of the resilient layer in MNm^{-3}

Figure C.2 — Weighted reduction of impact sound pressure level for asphalt floating floors or dry floating floor constructions

The above values can be calculated using Formula (C.5):

$$\Delta L_w = \left(\left(-0,21\ m' \right) - 5,45 \right) \lg \left(s' \right) + \left(0,46\ m' \right) + 23,8\ \text{dB} \tag{C.5}$$

In case of two or more resilient layers the resulting total dynamic stiffness per unit area should be calculated by Formula (C.6):

$$s'_{tot} = \left(\sum_{i=1}^{n} \frac{1}{s'_i} \right)^{-1} \tag{C.6}$$

where s'_i is the dynamic stiffness per unit area of the resilient layer i in accordance with EN 29052-1 measured without any pre-load.

This holds only if every resilient layer covers the whole area of the floor without any separations or cuttings, e.g. by heating or water supply pipes, electrical devices.

Annex D
(informative)

Laboratory measurement of flanking transmission

D.1 Transfer of laboratory data to *in situ*

With the restriction that the transmission connected with a flanking structural element is dominated by path Ff_2 it is possible to characterize this transmission by laboratory measurements. This will be the case with flanking constructions like access floors. In this case the transmission will often be primarily structure-borne, though airborne transmission may be of influence. To express the results from such measurements it would be desirable to use an invariant quantity that is a quantity which is independent of the measurement situation. From such a quantity the behaviour in the field could be extrapolated. However, such a quantity cannot be given in general, it is at most feasible to deduce such a quantity if the main transmission mechanism is known, i.e. primarily structure-borne or primarily airborne.

For the time being therefore the laboratory measurement of indirect transmission has the primary objective of intercomparison of different products in a standardized measurement situation. The measurement results are for that purpose expressed sufficiently as the flanking normalized impact sound pressure level L_{nf}, related to the specified laboratory situation. As shown by Formula (D.1):

$$L_{nf} = L_2 + \left(10 \lg \frac{A}{A_o} \right) dB \; ; \; A_o = 10 \text{ m}^2 \tag{D.1}$$

where

L_2 is the average impact sound pressure level in the receiving room due only to sound transmitted by the floor construction considered;

A is the equivalent absorption area in the receiving room; reference value $A_o = 10$ m^2.

For access floors this is determined in accordance with ISO 10848-2. Other flanking measurement methods are specified in ISO 10848-1.

In the case of mainly structure-borne transmission, Formula (D.2) can be used to determine the flanking impact sound pressure level $L_{n,ij}$ *in situ* from the product information L_{nf}.

$$L_{n,ij} = L_{nf} + \left(10 \lg \frac{S_{i,lab}}{S_i} \frac{l_{ij}}{l_{ij,lab}} \right) + \left(10 \lg \frac{T_{s,i}}{T_{s,i,lab}} \right) + \left(10 \lg \frac{T_{s,j}}{T_{s,j,lab}} \right) dB \tag{D.2}$$

where

S_i is the *in situ* area of the excited floor, in square metres;

$S_{i,lab}$ is the area of the excited floor in laboratory, in square metres;

l_{ij} is the *in situ* coupling length between elements i and j, in metres;

$l_{ij,lab}$ is the coupling length between elements i and j in laboratory, in metres;

$T_{s,i}$ is the *in situ* structural reverberation time of element i, in seconds;

$T_{s,j}$ is the *in situ* structural reverberation time of element j, in seconds;

$T_{s,i,lab}$ is the structural reverberation time of element i in laboratory, in seconds;

$T_{s,j,lab}$ is the structural reverberation time of element j in laboratory, in seconds.

For Type B elements, the last terms with the structural reverberation time are negligible and the flanking normalized impact sound level can represent any isolated flanking path ij; then Formula (D.2) becomes Formula (D.3):

$$L_{n,ij} = L_{n,f,ij} + \left(10 \lg \frac{S_{i,lab} \, l_{ij}}{S_i \, l_{ij,lab}} \right) \text{dB} \tag{D.3}$$

NOTE 1 If airborne sound transmission is also of importance or even dominant, this relation is not valid. In the latter case a possible approach would be as for suspended ceilings; see ISO 12354–1:2017, Annex G.

NOTE 2 For the use of this, and future improved relations, it would be necessary for some types of construction to perform additional laboratory measurements, to establish that the structure-borne transmission is indeed dominant.

D.2 Determination from performance of the elements

The normalized flanking impact sound level $L_{n,f,ij}$ can be deduced from an appropriate combination of measured, calculated or estimated data on the acoustic performance of the elements as given in Formula (D.4). It is advantageous to apply this approach first to the laboratory situation; in that way a direct comparison between the two approaches is possible. This approach can also be helpful in estimating the effect of changes in a system for which measurement results of $L_{nf,ij}$ are available particularly for Type B elements.

$$L_{n,f,ij} = L_{n,ii} - \Delta L_i + \frac{R_i - R_j}{2} - \Delta R_j - \overline{D_{v,ij,n}} - \left(10 \lg \frac{S_{i,lab}}{l_0 l_{ij,lab}} \right) \text{dB} \tag{D.4}$$

$L_{n,ii}$ is the normalized impact sound pressure level of element i . All the data for elements (index i or j) in Formula (D.4) are supposed to be converted into “in situ” values, where “in situ” means the laboratory situation used to measure the normalized flanking level difference $L_{n,f,ij}$.

NOTE Formula (D.4) is mostly used for Type B elements, for which the conversion into *in situ* values is negligible.

Annex E
(informative)

Impact sound insulation in the low frequency range

NOTE This annex is similar to ISO 12354-1:2017, Annex I and has been adapted to impact noise.

E.1 General

At low frequencies, there are three issues that need to be considered when comparing estimates of the impact sound insulation with field measurements. The first issue concerns the large spatial variation of the sound pressure level in the receiving room.[14,15] The second issue concerns the fact that sampling the sound pressure in the central zone of a room does not account for the higher energy density near the room boundaries.[16,17] The third issue is that the accuracy of estimating the *in situ* performance depends on the laboratory measurement of the impact sound pressure level and sound reduction index of building elements and on the measurement or estimation of the vibration reduction index (or normalized vibration level difference) of junctions between elements. For the 50 Hz, 63 Hz and 80 Hz one-third-octave bands, measurements in accordance with ISO 10140 tend to be highly variable between laboratories and tend to overestimate the actual sound reduction index[18,19] and to underestimate the actual impact sound level. For this reason it is advisable to use laboratory measurements of the sound reduction index in accordance with ISO 15186-3 as input data, although there is currently no equivalent International Standard for laboratory measurement of the impact sound level using sound intensity. The intention is for future editions of the ISO 10848-series for junction measurements to take into account low frequency measurement issues.

Field measurements (engineering grade) of impact sound insulation are carried out in accordance with ISO 16283-2. Survey grade measurements can also be carried out in accordance with ISO 10052 but the lower accuracy means that it is less critical to make any allowances for the low-frequency range.

The first and second issues that were described above become particularly important with room volumes smaller than 25 m^3, but remain important for larger room volumes. These issues are specifically considered in ISO 16283-2 which describes a low-frequency procedure that shall be used for the 50 Hz, 63 Hz and 80 Hz one-third-octave bands when the room volume is smaller than 25 m^3. The low-frequency procedure is carried out in addition to the default procedure and requires additional measurements of the sound pressure level in the corners of the receiving room using either a fixed microphone or a manually-held microphone. However, for comparison of estimates with measurements made in accordance with ISO 16283-2 in receiving room volumes below 25 m^3, it is advisable to account for the higher energy density near the room boundaries using the Waterhouse correction (see E.2).

NOTE *In situ* measurements of impact sound insulation and predictions of impact sound insulation from element performance measured in the laboratory consider several source positions to ensure that all room and building element modes are excited at low frequencies and the resulting impact sound level is spatially averaged. However, in common usage of the building with a structural source at one position on the floor and a listener at one position in the receiving room, the corresponding apparent impact sound insulation could differ significantly from the average performance that is measured or predicted.

E.2 Waterhouse correction

See Formula (E.1):

$$C_W = \left(10 \lg \left(1 + \frac{c_o S_t}{8 f V} \right) \right) \text{dB} \tag{E.1}$$

where

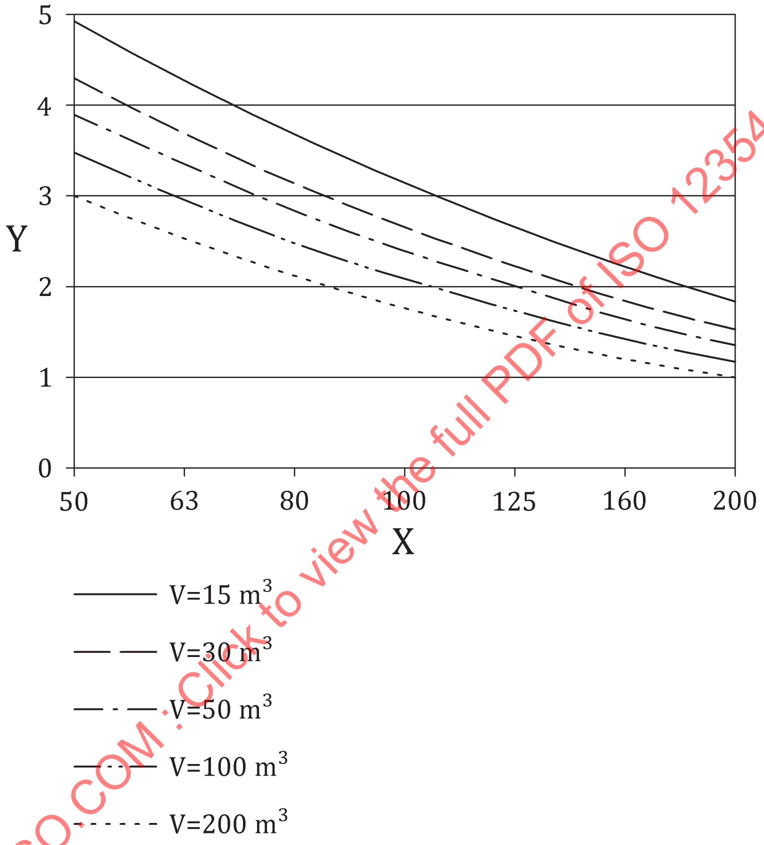
c_0 is the sound speed in air (c_0 approximately 340 m/s), in m/s;

f is the centre frequency of the band, in Hertz;

V is the room volume, in cubic metres;

S_T is the total surface area of the room, in square metres.

C_W should be added to the estimate of the *in situ* impact sound insulation in one-third-octave bands below 250 Hz or octave bands below 250 Hz. This correction is not exact for small rooms but in many cases it will err on the side of caution. Examples of C_W are shown in Figure E.1.



Key

X frequency in Hz

Y C_W in dB

Figure E.1 — Examples of the Waterhouse correction for rectangular rooms

Annex F
(informative)

Impact sound performance of stairs

F.1 General

In this annex, the performance of isolated heavy stairs or lightweight stairs connected to a receiving (vertical or horizontal) heavy building element and excited by the ISO tapping machine is expressed, like any floor covering, as a reduction of impact sound pressure level ΔL (improvement of impact sound insulation). This annex applies to any type of isolated heavy stairs and to timber or metal lightweight stairs connected to heavy receiving building elements, assuming the (low) point mobility of the receiving element is not affected by the connection to the stairs (see EN 15657 for definition and measurement of building element point mobility).

This approach includes the possibility of applying the impact noise prediction method to vertical (heavy) elements.

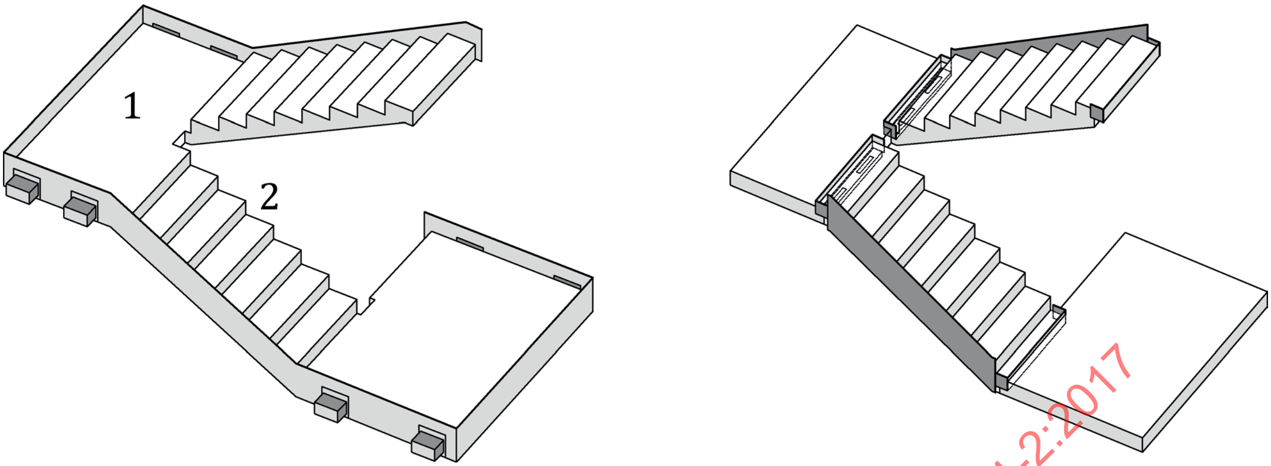
F.2 Isolated heavy stairs

F.2.1 General

Isolated heavy stairs, made of reinforced concrete, are located in stairwells, e.g. in apartment buildings, where the impact sound transmission into adjacent rooms in horizontal direction can be relevant. For the isolation from the building there are two main variants as illustrated in Figure F.1.

a) Isolation of the landing from the walls, Figure F.1 a).

b) Isolation of the flight of stairs from the floor and the landing, Figure F.1 b).



a) Landing isolated from walls **b) Flight of stairs isolated from landing and floor**

Key

1 landing

2 flight of stairs

Figure F.1 — Variants for isolated heavy stairs

Each isolated heavy element can be considered like a floating floor and characterized by a reduction of impact sound pressure level ΔL as explained in F.2.2 for heavy landings isolated from the building walls and F.2.3 for heavy flights of stairs isolated from the building floors and landings, respectively.

F.2.2 Impact sound reduction of isolated landings

The impact sound reduction of an isolated landing $\Delta L_{\text{Landing}}$ is defined as shown by Formula (F.1):

$$\Delta L_{\text{Landing}} = L_{\text{n0,Wall}} - L_{\text{n,Landing}} \quad \text{(F.1)}$$

where

$L_{\text{n0,Wall}}$ is the normalized impact sound pressure level of the wall without landing);

$L_{\text{n,Landing}}$ is the normalized impact sound pressure level of the wall connected to the isolated landing when the landing is excited.

NOTE A proposal for a laboratory measurement procedure in a defined reference situation is given in Reference [10].

The *in situ* values can be taken as the laboratory values: $\Delta L_{\text{Landing,situ}} = \Delta L_{\text{Landing}}$.

Figure F.2 shows the corresponding building configuration. For prediction, only the receiving wall is modelled, the landing being not modelled and characterized by the impact sound reduction defined above. This horizontal impact sound transmission from a wall is similar to the vertical impact sound transmission from a floor with one direct path and four flanking paths.

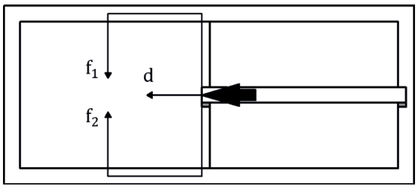


Figure F.2 — Landing isolated from the building walls (vertical section)

F.2.3 Impact sound reduction of isolated flights of stairs

The impact sound reduction of an isolated flight of stairs ΔL_{Flight} is defined as shown by Formula (F.2):

$$\Delta L_{\text{Flight}} = L_{\text{n0,Landing}} - L_{\text{n,Flight}} \tag{F.2}$$

where

$L_{\text{n0,Landing}}$	is the normalized impact sound pressure level of the landing without flight of stairs;
$L_{\text{n,Flight}}$	the normalized impact sound pressure level of the landing connected to the isolated flight of stairs, when the flight of stairs is excited.

NOTE 1 A proposal for a laboratory measurement procedure in a defined reference situation is given in Reference [10].

NOTE 2 Experimental investigations in laboratory and in buildings have shown that the highest impact sound transmission occurs when the tapping machine is located on the step closest to the landing and that for this location the transmission path via the floor can be neglected.

The *in situ* values can be taken as the laboratory values: $\Delta L_{\text{Flight,situ}} = \Delta L_{\text{Flight}}$.

Figure F.3 shows the corresponding building configuration. For prediction, both the receiving wall and the landing rigidly connected to the building walls are modelled, the flights of stairs being not modelled and characterized by the impact sound reduction defined above. This horizontal impact sound transmission from a landing through a T junction is similar to the horizontal impact sound transmission from a floor with only two flanking paths.

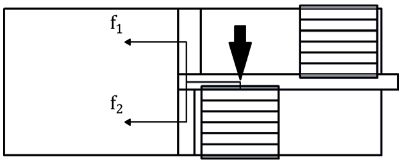


Figure F.3 — Flights of stairs isolated from building landing and floor (vertical section)

F.3 Lightweight stairs

The impact sound reduction of a lightweight flight of stairs connected to a receiver (wall or floor) ΔL_{Flight} is defined as shown by Formula (F.3):

$$\Delta L_{\text{Flight}} = L_{\text{n,0,Receiver}} - L_{\text{n,Flight}} \tag{F.3}$$

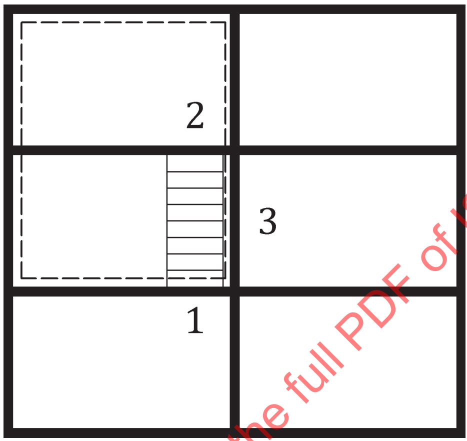
where

$L_{n,0,Receiver}$ is the normalized impact sound pressure level of the receiver without flight of stairs;

$L_{n,Flight}$ is the normalized impact sound pressure level of the receiver with the lightweight flight of stairs, when the flight of stairs is excited.

A laboratory measurement procedure similar to the ones given for isolated heavy stairs can then be used.

Figure F.4 shows the configuration of a two storey apartment with a lightweight flight of stairs connecting the two floors and also connected to the separating wall. For prediction, each impact sound transmission path (bottom floor, top floor and separating wall) should be considered separately and for each path, only the receiver is modelled, the flight of stairs being not modelled and characterized by the impact sound reduction defined above.



Key

Receiving building elements connected to the stairs:

1 bottom floor

2 upper floor

3 separating wall

Figure F.4 — Lightweight flight of stairs connected to floors and separating wall (vertical section)

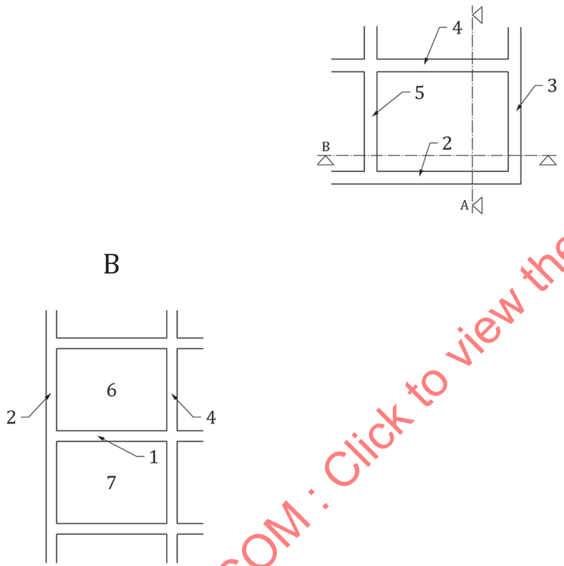
Annex G
(informative)

Calculation examples

G.1 Heavy homogeneous building systems

G.1.1 Situation

The normalized impact sound pressure level between two dwellings is calculated for two rooms, one above the other, separated by a concrete floor with a floating floor (see Figure G.1). The room volumes are 55 m^3, the other construction details are given below.



Key

A ground plan
B section A
C section B
1 separating floor
2 external wall 1
3 external wall 2
4 internal wall 1
5 internal wall 2
6 sending room
7 receiving room

Figure G.1 — Situation for heavy homogeneous building calculation example

Separating element:

Floor	S_i = 5,00 m x 4,00 m = 20,00 m^2;
	220 mm concrete, m' = 0,22 m x 2 200 kg/m^3 = 484 kg/m^2;
	η_{int} = 0,005, c_L = 3 800 m/s, f_c = 76,8 Hz; [1)]
Floating floor	35 mm concrete on mineral wool slab with s' = 8 MN/m^3;
	m' = 0,35 m x 2 100 kg/m^3 = 73,5 kg/m^2; f_0 = 52,8 Hz

Flanking elements:

External wall 1	S_i = 4,00 m x 2,75 m = 11,00 m^2; rigid *T* junction;
($F = f = 1$)	365 mm autoclaved aerated concrete blocks, m' = 0,365 m x 600 kg/m^3 = 219 kg/m^2;
	η_{int} = 0,012 5, c_L = 1 900 m/s, f_c = 92,6 Hz;[1)]
External wall 2	S_i = 5,00 m x 2,75 m = 13,75 m^2; rigid T junction;
($F = f = 2$)	365 mm autoclaved aerated concrete blocks, m' = 0,365 m x 600 kg/m^3 = 219 kg/m^2;
	η_{int} = 0,012 5, c_L = 1 900 m/s, f_c = 92,6 Hz;[1)]
Internal wall 1	S_i = 4,00 m x 2,75 m = 11,00 m^2; rigid cross junction;
($F = f = 3$)	200 mm calcium-silicate blocks, m' = 0,2 m x 1 800 kg/m^3 = 360 kg/m^2;
	η_{int} = 0,01, c_L = 2 500 m/s, f_c = 128,4 Hz;[1)]
Internal wall 2	S_i = 5,00 m x 2,75 m = 13,75 m^2; rigid cross junction;
($F = f = 4$)	200 mm calcium-silicate blocks, m' = 0,2 m x 1 800 kg/m^3 = 360 kg/m^2;
	η_{int} = 0,01, c_L = 2500 m/s, f_c = 128,4 Hz;[1)]

c_0 = 340 m/s; ρ_0 = 1,29 kg/m^3

____

1) Rounded to one decimal point; for the calculations unrounded values were used.

G.1.2 Detailed model

G.1.2.1 Results

The resulting direct and flanking normalized impact sound pressure levels are given in Table G.1 per element, per path and total, in third-octave bands and as a weighted value. Values given in the subsequent tables are rounded to one or more decimal points while all calculations were performed with unrounded values.

Table G.1 — Resulting direct and flanking normalized impact sound pressure levels

Frequency Hz	Sep. floor $L_{n,Dd}$ dB	Ext. wall 1 $L_{n,Df1}$ dB	Ext. wall 2 $L_{n,Df2}$ dB	Int. wall 1 $L_{n,Df3}$ dB	Int. wall 2 $L_{n,Df4}$ dB	Total L'_{n} dB
50	57,3	47,3	49,0	43,9	45,0	**58,6**
63	55,9	44,9	46,6	41,9	43,0	**57,0**
80	53,8	46,2	47,9	43,2	44,3	**55,9**
100	51,8	42,4	44,2	43,8	44,9	**54,0**
125	49,9	40,2	42,0	41,2	42,5	**51,9**
160	47,7	38,0	39,7	38,5	39,8	**49,6**
200	45,2	35,9	37,7	35,3	36,6	**47,1**
250	42,5	33,4	34,9	32,1	33,4	**44,3**
315	39,7	30,6	32,0	29,1	30,3	**41,4**
400	36,9	27,6	29,1	26,0	27,3	**38,6**
500	34,3	24,9	26,3	23,2	24,4	**35,9**
630	31,7	22,1	23,5	20,3	21,5	**33,3**
800	28,9	19,2	20,6	17,3	18,5	**30,4**
1 000	26,3	16,5	17,9	14,5	15,8	**27,8**
1 250	23,8	14,1	15,5	11,7	13,0	**25,3**
1 600	20,9	12,7	14,1	8,6	9,8	**22,7**
2 000	18,4	11,4	12,8	5,8	7,0	**20,4**
2 500	15,8	9,9	11,2	3,2	4,4	**18,2**
3 150	13,1	7,0	8,3	0,3	1,4	**15,4**
4 000	10,3	4,0	5,3	−2,8	−1,7	**12,5**
5 000	7,7	1,1	2,4	−5,7	−4,6	**9,8**
$L_{n,w}$ dB	**39,1**	**29,6**	**31,4**	**29,8**	**31,1**	**41,0**

$L'_{n,w}$ (C_I ; $C_{I,50\text{-}2500}$) = 41,0 (2 ; 7) dB (see definition of C_I and $C_{I,50\text{-}2500}$ in ISO 717-2:2013)

G.1.2.2 Detailed steps for separating floor and flanking walls

The radiation factors of all elements are given in Table G.2 for free waves and forced waves (index f).

Table G.2 — Radiation efficiencies

Frequency	Separating floor		Ext. wall 1		Ext. wall 2		Int. wall 1		Int. wall 2	
	σ_{situ}	$\sigma_{situ,f}$	σ_{situ}	$\sigma_{situ,f}$	σ_{situ}	$\sigma_{situ,f}$	σ_{situ}	$\sigma_{situ,f}$	σ_{situ}	$\sigma_{situ,f}$
Hz	-	-	-	-	-	-	-	-	-	-
50	0,720 9	0,791 2	0,624 3	0,638 0	0,669 0	0,680 5	0,392 9	0,638 0	0,358 1	0,680 5
63	0,809 2	0,905 9	0,700 8	0,752 0	0,751 0	0,794 8	0,519 0	0,752 0	0,476 5	0,794 8
80	0,911 9	1,024 8	0,789 7	0,870 4	0,846 2	0,913 4	0,847 3	0,870 4	0,778 3	0,913 4
100	1,019 6	1,136 1	0,883 0	0,981 4	0,946 1	1,024 5	1,878 3	0,981 4	1,725 2	1,024 5
125	1,139 9	1,247 4	0,987 2	1,092 6	1,057 8	1,135 8	2,000 0	1,092 6	2,000 0	1,135 8
160	1,289 6	1,370 7	1,116 9	1,215 7	1,196 7	1,259 0	2,000 0	1,215 7	2,000 0	1,259 0
200	1,274 2	1,482 2	1,248 7	1,327 1	1,338 0	1,370 5	1,671 8	1,327 1	1,671 8	1,370 5
250	1,201 5	1,593 7	1,260 3	1,438 6	1,260 3	1,482 0	1,434 1	1,438 6	1,434 1	1,482 0
315	1,150 0	1,709 2	1,190 1	1,554 1	1,190 1	1,597 5	1,299 4	1,554 1	1,299 4	1,597 5
400	1,112 5	1,828 7	1,140 7	1,673 5	1,140 7	1,716 9	1,213 7	1,673 5	1,213 7	1,716 9
500	1,087 0	1,940 2	1,107 8	1,785 1	1,107 8	1,828 4	1,160 0	1,785 1	1,160 0	1,828 4
630	1,067 2	2,000 0	1,082 7	1,900 6	1,082 7	1,944 0	1,120 8	1,900 6	1,120 8	1,944 0
800	1,051 8	2,000 0	1,063 4	2,000 0	1,063 4	2,000 0	1,091 5	2,000 0	1,091 5	2,000 0
1 000	1,040 8	2,000 0	1,049 8	2,000 0	1,049 8	2,000 0	1,071 2	2,000 0	1,071 2	2,000 0
1 250	1,032 2	2,000 0	1,039 2	2,000 0	1,039 2	2,000 0	1,055 7	2,000 0	1,055 7	2,000 0
1 600	1,024 9	2,000 0	1,030 3	2,000 0	1,030 3	2,000 0	1,042 7	2,000 0	1,042 7	2,000 0
2 000	1,019 8	2,000 0	1,024 0	2,000 0	1,024 0	2,000 0	1,033 7	2,000 0	1,033 7	2,000 0
2 500	1,015 7	2,000 0	1,019 1	2,000 0	1,019 1	2,000 0	1,026 7	2,000 0	1,026 7	2,000 0
3 150	1,012 4	2,000 0	1,015 0	2,000 0	1,015 0	2,000 0	1,021 0	2,000 0	1,021 0	2,000 0
4 000	1,009 7	2,000 0	1,011 8	2,000 0	1,011 8	2,000 0	1,016 5	2,000 0	1,016 5	2,000 0
5 000	1,007 8	2,000 0	1,009 4	2,000 0	1,009 4	2,000 0	1,013 1	2,000 0	1,0131	2,000 0

Input data

Separating element, L = 4 m, B = 5 m, f_c = 76,8 Hz

External wall, L = 4 m, H = 2,75 m, f_c = 92,6 Hz

Internal wall, L = 5 m, H = 2,75 m, f_c = 128,4 Hz

Formulae

Radiation factor for free waves (σ_{situ}): ISO 12354–1:2017, Formulae (B.4) and (B.5)

Radiation factor for forced waves ($\sigma_{situ,f}$): ISO 12354–1:2017, Formula (B.3)

The *in situ* loss factors, sound reduction indices and normalized impact sound pressure level are given in Table G.3.