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

**Part 1:
Airborne sound insulation between
rooms**

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

Partie 1: Isolement acoustique aux bruits aériens entre des locaux



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 15712-1:2005, 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 has been presented in [Annex K](#). 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 predictions 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.

The document also provides details for application to lightweight constructions (typically steel or wood framed lightweight elements as opposed to heavier masonry or concrete elements).

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

Part 1: Airborne sound insulation between rooms

1 Scope

This document specifies calculation models designed to estimate the airborne sound insulation between adjacent 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 3 150 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 I](#)); the single number rating 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; a method to determine uncertainty is proposed for the simplified model (see [Annex K](#)).

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 10140 (all parts), *Acoustics — Laboratory measurement of sound insulation of building elements*

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

ISO 10848-2, *Acoustics — Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms — Part 2: Application to light elements when the junction has a small influence*

ISO 10848-3, *Acoustics — Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms — Part 3: Application to light elements when the junction has a substantial influence*

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 15186-3, *Acoustics — Measurement of sound insulation in buildings and of building elements using sound intensity — Part 3: Laboratory measurements at low frequencies*

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 sound insulation between rooms in accordance with ISO 16283-1 can be expressed in terms of several 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 717-1, for instance R'_w , $D_{nT,w}$ or $(D_{nT,w} + C)$.

3.1.1

apparent sound reduction index

R'

minus 10 times the common logarithm of the ratio of the total sound power W_{tot} transmitted into the receiving room to the sound power W_1 which is incident on a separating element, evaluated from

$$R' = -10 \lg \tau' \text{ dB}$$

Note 1 to entry: This ratio is denoted by τ' , where

$$\tau' = W_{\text{tot}} / W_1$$

Note 2 to entry: In general, the total sound power transmitted into the receiving room consists of the power radiated by the separating element, the flanking elements and other components.

The index R' is normally determined from measurements according to

$$R' = L_1 - L_2 + \left(10 \lg \frac{S_s}{A} \right) \text{ dB}$$

where

L_1 is the average sound pressure level in the source room, in decibels;

L_2 is the average sound pressure level in the receiving room, in decibels;

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

S_s is the area of the separating element, in square metres.

3.1.2

standardized level difference

D_{nT}

difference in the space and time average sound pressure levels produced in two rooms by one or more sound sources in one of them, corresponding to a reference value of the reverberation time in the receiving room, which is evaluated from

$$D_{nT} = L_1 - L_2 + \left(10 \lg \frac{T}{T_o} \right) \text{ dB}$$

where

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

T_0 is the reference reverberation time; for dwellings given as 0,5 s.

3.1.3

normalized level difference

D_n

difference in the space and time average sound pressure levels produced in two rooms by one or more sound sources in one of them, corresponding to the reference equivalent sound absorption area in the receiving room, which is evaluated from

$$D_n = L_1 - L_2 - \left(10 \lg \frac{A}{A_0} \right) \text{dB}$$

where A_0 is the reference absorption area given as 10 m².

3.2 Quantities to express element performance

NOTE 1 The quantities expressing the performance of the elements 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, in accordance with ISO 717-1, for instance $R_w(C; C_{tr})$.

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

3.2.1

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 (all parts) or ISO 15186-3 (use of acoustical intensity).

3.2.2

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: This quantity shall be determined in accordance with ISO 10140-1:2016, Annex G.

3.2.3

element normalized level difference

$D_{n,e}$

difference in the space and time average sound pressure level produced in two rooms by a source in one room, where sound transmission is only due to a small technical element (e.g. transfer air devices, electrical cable ducts, transit sealing systems), which is evaluated from

$$D_{n,e} = L_1 - L_2 - \left(10 \lg \frac{A}{A_0} \right) \text{dB}$$

where A is the equivalent sound absorption area in the receiving room, in square metres.

Note 1 to entry: $D_{n,e}$ is normalized to the reference equivalent sound absorption area (A_0) in the receiving room; $A_0 = 10 \text{ m}^2$

Note 2 to entry: This quantity shall be determined in accordance with ISO 10140-1:2016, Annex E.

3.2.4

normalized level difference for indirect airborne transmission

$D_{n,s}$

difference in the space and time average sound pressure level produced in two rooms by a source in one of them, which is evaluated from

$$D_{n,s} = L_1 - L_2 - \left(10 \lg \frac{A}{A_0} \right) \text{dB}$$

Note 1 to entry: Transmission is only considered to occur through a specified path between the rooms (e.g. ventilation systems, corridors). $D_{n,s}$ is normalized to the reference equivalent sound absorption area (A_0) in the receiving room; $A_0 = 10 \text{ m}^2$.

Note 2 to entry: The subscript s indicates the type of transmission system considered.

Note 3 to entry: This quantity shall be determined with a measurement method which is comparable to ISO 10140-1:2016, Annex G.

3.2.5

flanking normalized level difference

$D_{n,f}$

difference in the space and time average sound pressure level produced in two rooms by a source in one of them, which is evaluated from

$$D_{n,f} = L_1 - L_2 - \left(10 \lg \frac{A}{A_0} \right) \text{dB}$$

Note 1 to entry: Transmission is only considered to occur through a specified flanking path between the rooms (e.g. suspended ceiling, access floor, façade). $D_{n,f}$ is normalized to the reference equivalent sound absorption area (A_0) in the receiving room; $A_0 = 10 \text{ m}^2$.

Note 2 to entry: This quantity shall be determined in accordance with ISO 10848-1, ISO 10848-2 and ISO 10848-3.

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

3.2.6

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 sound 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 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;
 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

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

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; $f_{\text{ref}} = 1\,000$ Hz;
 c_o 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.

3.2.7

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 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 lightweight, often highly-damped junction elements, the use of K_{ij} (3.2.6) is no longer valid (non-uniform vibration field); however, the notion of vibration level difference is still appropriate^[30] and this quantity can be normalized as defined in 3.2.7.

3.2.8

direction-averaged junction velocity level difference

$D_{v,ij}$

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

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

3.2.9

flanking sound reduction index

R_{ij}

minus 10 times the common logarithm of the flanking transmission factor τ_{ij} , which is evaluated from

$$R_{ij} = -\left(10 \lg \tau_{ij}\right) \text{ dB}$$

where

$$\tau_{ij} = W_{ij} / W_1$$

and where

τ_{ij} is the ratio of the sound power W_{ij} radiated from a flanking element j in the receiving room due to incident sound on element i in the source room to the sound power W_1 ;

W_1 is the incident sound power on a reference area in the source room.

Note 1 to entry: The area of the separating element is chosen as the reference area.

Note 2 to entry: The area of the separating element is chosen as the reference since then the contribution of each transmission path to the total transmission is directly indicated, which is not the case with other choices.

3.3 Other terms and quantities

3.3.1

airborne direct transmission

transmission due only to sound incident on a separating element that is then directly radiated by the element or transmitted through parts of it (airborne) such as slits, air moving devices or louvres

3.3.2

indirect transmission

transmission of sound from a source room to a receiving room, through transmission paths other than the direct transmission path

Note 1 to entry: It can be divided into airborne transmission and flanking transmission.

3.3.3

indirect airborne transmission

indirect transmission of sound energy via an airborne transmission path, e.g. ventilation systems, corridors, double facades

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

Note 1 to entry: In cases of cavity walls and suspended ceilings airborne transmission can contribute to or even dominate the transmission.

3.3.5

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 6 dB across the element in the direction perpendicular to the junction line (up to at least the 1000 Hz one-third-octave band)

Note 1 to entry: Examples include cast in situ concrete, solid wood (including cross laminated timber panels), glass, plastic, metal, bricks/blocks/slabs with a finish/topping (e.g. plaster, parge coat, screed, concrete) that mechanically connects them together.

Note 2 to entry: An element may only be defined as Type A over part, or parts of the frequency range. For example, some masonry walls can be Type A elements in the low- and mid-frequency ranges and a Type B element in the high-frequency range.

3.3.6

Type B element

any element that is not a Type A element

Note 1 to entry: Examples typically include plasterboard/timber cladding on timber or metal frames.

Note 2 to entry: An element may only be defined as Type B over part or parts of the frequency range. For example, some masonry walls can be Type A elements in the low- and mid-frequency ranges and a Type B element in the high-frequency range.

4 Calculation models

4.1 General principles

The sound power in the receiving room is due to sound radiated by the separating structural elements and the flanking structural elements in that room and by the relevant direct and indirect airborne sound transmission. The total transmission factor can be divided into transmission factors, related to each element in the receiving room and the elements and systems involved in the direct and indirect airborne transmission, as shown by [Formula \(1\)](#):

$$R' = -10 \lg \tau' \text{ dB} \quad (1)$$

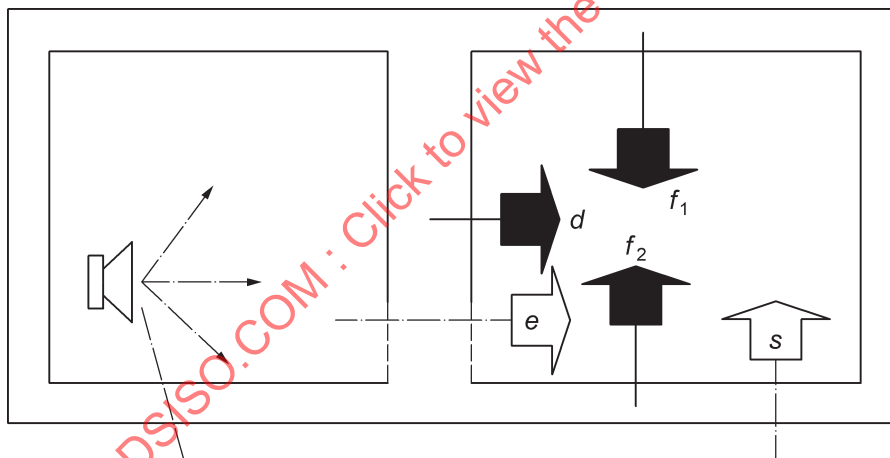
where

$$\tau' = \tau_d + \sum_{f=1}^n \tau_f + \sum_{e=1}^m \tau_e + \sum_{s=1}^k \tau_s$$

and where the indices d, f, e and s refer to the different contributions to the sound transmission illustrated in [Figure 1](#),

and where

- τ' is the sound power ratio of total radiated sound power in the receiving room relative to incident sound power on the common part of the separating element;
- τ_d is the sound power ratio of radiated sound power by the common part of the separating element relative to incident sound power on the common part of the separating element. It includes the paths Dd and Fd shown in [Figure 2](#);
- τ_f is the sound power ratio of radiated sound power by a flanking element f in the receiving room relative to incident sound power on the common part of the separating element. It includes paths Ff and Df shown in [Figure 2](#);
- τ_e is the sound power ratio of radiated sound power in the receiving room by an element in the separating element due to direct airborne transmission of incident sound on this element, relative to incident sound power on the common part of the separating element;
- τ_s is the sound power ratio of radiated sound power in the receiving room by a system s due to indirect airborne transmission of incident sound on this transmission system, relative to incident sound power on the common part of the separating element;
- n is the number of flanking elements; normally $n = 4$, but it can be smaller or larger;
- m is the number of elements with direct airborne transmission;
- k is the number of systems with indirect airborne transmission.

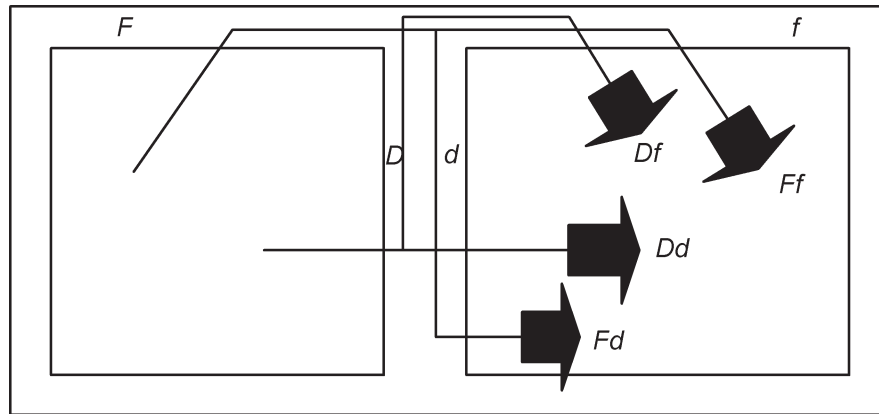


Key

- d radiated directly from the separating element
- f_1 and f_2 radiated from flanking elements
- e radiated from components mounted in the separating element
- s indirect transmission

Figure 1 — Illustration of the different contributions to the total sound transmission to a room

The sound radiated by a structural element can be considered to be the sum of structure-borne sound transmission through several paths. Each path can be identified by the element i on which the sound is incident in the source room and the radiating element j in the receiving room. The paths for a flanking element and the separating element are shown in [Figure 2](#), where in the source room the elements i are designated by F for the flanking element and D for the separating element and in the receiving room the elements j are designated by f for a flanking element and d for the separating element.

**Key***Dd* direct direct path*Df* direct flanking path*Fd* flanking direct path*Ff* flanking flanking path**Figure 2 — Definition of sound transmission paths *ij* between two rooms**

The main assumptions with this approach are that the transmission paths described can be considered to be independent and that the sound and vibrational fields behave statistically. Within these restrictions this approach is quite general, in principle allowing for various types of structural elements, i.e. monolithic elements, cavity walls, lightweight double leaf walls, and different positioning of the two rooms. However, the available possibilities to describe the transmission by each path impose restrictions in this respect. The model presented is therefore restricted to adjacent rooms, while the type of elements is mainly restricted by the available information on the vibration reduction index, the normalized direction-averaged vibration level difference or the normalized flanking level difference. Some indications are given in [Annex J](#) for the application to other double elements such as cavity walls.

The transmission factor for the separating element consists of contributions from the airborne direct transmission and *n* flanking transmission paths, as shown by [Formula \(2\)](#):

$$\tau_d = \tau_{Dd} + \sum_{F=1}^n \tau_{Fd} \quad (2)$$

The transmission factor for each of the flanking elements *f* in the receiving room consists of contributions from two flanking transmission paths, as shown by [Formula \(3\)](#):

$$\tau_f = \tau_{Df} + \tau_{Ff} \quad (3)$$

The transmission factors for these structure-borne transmission paths are related to the sound reduction index for direct transmission R_{Dd} and the flanking sound reduction index R_{ij} as shown by [Formula \(4\)](#):

$$\begin{aligned} \tau_{Dd} &= 10^{-R_{Dd}/10} \\ \tau_{ij} &= 10^{-R_{ij}/10} \end{aligned} \quad (4)$$

The transmission factors for the direct and indirect airborne transmission are related to the element normalized level difference $D_{n,e}$ and the normalized level difference for indirect airborne transmission $D_{n,s}$ as shown by [Formula \(5\)](#):

$$\tau_e = \frac{A_o}{S_s} 10^{-D_{n,e}/10}$$

$$\tau_s = \frac{A_o}{S_s} 10^{-D_{n,s}/10}$$
(5)

where

S_s is the area of the separating element, in square metres;

A_o is the reference equivalent sound absorption area, in square metres.

In order to calculate a single number rating for the building performance in accordance with ISO 717-1, the calculation shall be carried out for octave bands from 125 Hz to 2 000 Hz or for one-third-octave bands from 100 Hz to 3 150 Hz.

NOTE The calculations can be extended to higher or lower frequencies if element data and junction data are available for these frequencies. However, especially for the lower frequencies, no information is available at this time on the accuracy of calculations for these extended frequency regions; see [Annex I](#).

The detailed model deals with both direct and flanking transmission as well as direct and indirect airborne transmission. Since these transmission paths can be considered as independent they are treated separately. The calculation of the direct and flanking transmission is described in [4.2](#). The direct and indirect airborne transmission is described in [4.3](#).

The simplified model calculates the building performance as a single number rating, based on the single number ratings of the performance of the elements involved. The simplified model is described in [4.4](#).

In this document the apparent sound reduction index R' is chosen as the prime quantity to be estimated.

The level differences are related to the apparent sound reduction index as shown by [Formulae \(6\)](#) and [\(7\)](#):

$$D_n = R' + \left(10 \lg \frac{A_o}{S_s} \right) = R' + \left(10 \lg \frac{10}{S_s} \right) \text{dB}$$
(6)

$$D_{nT} = R' + \left(10 \lg \frac{C_{sab} V}{T_o S_s} \right) = R' + \left(10 \lg \frac{0,32 V}{S_s} \right) \text{dB}$$
(7)

where

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

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

A calculation example is given in [Annex L](#).

4.2 Detailed model for structure-borne transmission

4.2.1 Input data

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

- sound reduction index of separating element: R_s ;
- sound reduction index for element i in source room: R_i ;

- sound reduction index for element j in receiving room: R_j ;
- sound reduction index improvement by additional layers added to the separating element in the source room and/or in the receiving room: $\Delta R_D, \Delta R_d$;
- sound reduction index improvement by additional layers added to the element i in the source room and/or element j in the receiving room: $\Delta R_i, \Delta R_j$;
- structural reverberation time for an element in the laboratory: $T_{s,lab}$;
- vibration reduction index for each transmission path from element i to element j : K_{ij} ;
- normalized direction-averaged velocity level difference between element i to element j : $\overline{D_{v,ij,n}}$;
- flanking normalized level difference $D_{n,f}$;

NOTE 1 Normally this concerns only transmission path Ff for a given flanking element, but the quantity could also be applied to other transmission paths like Fd or Df.

- area of separating element: S_s ;
- area of element i in source room: S_i ;
- area of element j in receiving room: S_j ;
- common coupling length between element i and element j as measured from surface to surface: l_{ij} .

NOTE 2 If D_{nT} or D_n is calculated, the area of the separating element serves as an arbitrary reference and could be taken as 10 m² throughout the calculations.

Information on sound reduction index is given in [Annex B](#).

Information on structural reverberation time for homogeneous elements is given in [Annex C](#).

Information on sound reduction index improvement and flanking sound reduction index improvement is given in [Annex D](#).

Information on vibration reduction index and on flanking normalized level difference for common junctions is given in [Annex E](#).

The 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 field measurements. Further information is given in [Annexes B](#) to [E](#). The sources of data used shall be clearly stated.

For each flanking transmission path, the sound reduction index R of the involved elements (including the separating element) should relate to the resonant transmission only. If laboratory measurement results are used as input data, this is therefore correct above the critical frequency; a correction shall be applied below that frequency, see [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 whole frequency range of interest.

For airborne direct transmission, R shall include forced transmission as included in laboratory measurements. However, transferring these laboratory data to the *in situ* situation requires the use of the structural reverberation which applies to resonant transmission only (see [4.2.2](#)).

4.2.2 Transfer of input data to *in situ* values

4.2.2.1 General

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

For the additional layers, the laboratory value can be used as an approximation for the *in situ* value of the improvement ΔR_{situ} , as shown by [Formula \(8\)](#):

$$\Delta R_{\text{situ}} = \Delta R \text{ dB} \quad (8)$$

For each flanking transmission path, the sound reduction index improvement ΔR of the involved elements (including the separating element) should relate to the resonant transmission only. However, measurement methods to determine this are not readily available. There is some evidence to indicate that the improvement for airborne direct transmission is also a reasonable estimate for the improvement for flanking transmission. An exception is lightweight basic elements, for which there are indications that using the same value for flanking transmission as for airborne direct transmission can no longer be assumed. See [Annex D](#).

NOTE With lightweight elements, the additional reduction of sound transmission for flanking transmission (for each frequency band) can then be approximated as $\Delta R_f = \Delta R_d / 2$.

For structural 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* value of the sound reduction index R_{situ} for the separating element and each of the flanking elements follows from [Formula \(9\)](#):

$$R_{\text{situ}} = R - \left(10 \lg \frac{T_{\text{s},\text{situ}}}{T_{\text{s},\text{lab}}} \right) \text{ dB} \quad (9)$$

where

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

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

The structural reverberation time, both for the laboratory and *in situ*, is therefore to be taken into account; see [Annex C](#).

NOTE As a first approximation it can be assumed that $R_{\text{situ}} = R$.

For the junctions, the *in situ* transmission is characterized by the direction-averaged junction velocity level difference $\overline{D_{\text{v},\text{ij},\text{situ}}}$. This follows from the vibration reduction index, as shown by [Formula \(10\)](#):

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

with [Formula \(11\)](#):

$$a_{\text{i},\text{situ}} = \frac{2,2 \pi^2 S_{\text{i}}}{c_o T_{\text{s},\text{i},\text{situ}}} \sqrt{\frac{f_{\text{ref}}}{f}} \quad (11)$$

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

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.

In this case, the *in situ* structural reverberation time shall be taken into account; see [Annex C](#).

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 ($R_{situ} = R$).

For the Type B elements, the *in situ* direction-averaged junction velocity level difference follows from the normalized direction-averaged junction velocity level difference (with l_0 a reference length of 1 m), as shown by [Formula \(12\)](#):

$$\overline{D}_{v,ij,situ} = \overline{D}_{v,ij,n} - \left(10 \lg \frac{l_o l_{ij}}{\sqrt{S_{i,situ} S_{j,situ}}} \right) \text{ dB} \quad (12)$$

In the case of a junction composed of elements of both categories (for example Type B wall on Type A floor), [Formula \(10\)](#) can still be used as an approximation, the equivalent absorption length of the Type B element being taken equal to the element area [[Formula \(13\)](#)] and K_{ij} being estimated as per [3.2.6](#).

$$a_{i,situ} = S_{i,situ} / l_0 \quad (13)$$

4.2.3 Determination of direct and flanking transmission *in situ*

4.2.3.1 General

The sound reduction index for airborne direct transmission is determined from the adjusted input value for the separating element according to [Formula \(14\)](#):

$$R_{Dd} = R_{s,situ} + \Delta R_{D,situ} + \Delta R_{d,situ} \text{ dB} \quad (14)$$

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 flanking sound reduction index is determined from the adjusted input values according to [Formula \(15\)](#), with $ij = Ff, Fd$ and Df :

$$R_{ij} = \frac{R_{i,situ}}{2} + \Delta R_{i,situ} + \frac{R_{j,situ}}{2} + \Delta R_{j,situ} + \overline{D_{v,ij,situ}} + \left(10 \lg \frac{S_s}{\sqrt{S_i S_j}} \right) \text{dB} \quad (15)$$

In the case of diagonal transmission, a separating element of area $S_s = 10 \text{ m}^2$ shall be used.

NOTE For certain suspended ceilings and light uninterrupted façade, the flanking transmission is dominated by path Ff (the junction having a small influence, the contribution of path Df 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 G](#)).

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 sound level difference $D_{n,f}$, or by using the normalized direction-averaged junction velocity level.

The flanking sound reduction index can be deduced from the flanking sound level difference as shown by [Formula \(16\)](#) (see also [Annex G](#)):

$$R_{ij} = D_{n,f,ij,situ} + \left(10 \lg \frac{S_s I_{lab}}{A_o I_{ij}} \right) \text{dB} \quad (16)$$

In case of dominant structure-borne sound transmission, $D_{n,f,ij,situ}$ can be taken as identical to the laboratory situation. In case of important indirect airborne transmission path, the measured or estimated $D_{n,f,lab}$ for the laboratory situation shall be transferred to *in situ*, as indicated in [G.2.2](#). See [Annex G](#) for further guidance.

The flanking sound reduction index can also be deduced from the performance of the elements by combining [Formulae \(15\)](#) and [\(12\)](#), as shown by [Formula \(17\)](#):

$$R_{ij} = \frac{R_{i,situ}}{2} + \Delta R_{i,situ} + \frac{R_{j,situ}}{2} + \Delta R_{j,situ} + \overline{D_{v,ij,n}} + \left(10 \lg \frac{S_s}{I_o I_{ij}} \right) \text{dB} \quad (17)$$

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

$D_{v,ij,n}$ (see [Annex E](#)) and should relate to resonant transmission only.

The sound transmission by the separating element and by the flanking elements can be calculated in accordance with [Formulae \(2\)](#) and [\(3\)](#), applying [Formulae \(4\)](#), [\(8\)](#) to [\(17\)](#) inclusive. The total sound transmission (apparent sound reduction index) can be calculated with [Formula \(1\)](#), using the results of [4.3](#) if applicable.

4.2.4 Limitations

The limitations are as follows.

- The model can be used only for combinations of elements for which the vibration reduction index or the normalized vibration level difference is known or can be estimated from known values.
- The model is only applicable for bare structural elements which have approximately the same radiation characteristics for both sides.

- c) With very large floors, floors with columns and lightweight internal walls, the floor of a room can no longer be considered as an independent element; see proposed solution in [Annex J](#).
- d) The contribution of secondary transmission paths involving more than one junction is neglected. This is partly compensated by the values for the vibration reduction index or the normalized vibration level difference as far as these are based on field measurements, but could cause an underestimation of flanking transmission with homogeneous elements in other cases. These secondary transmission paths may become important when additional layers are applied to several elements.
- e) The model only describes the transmission between adjacent rooms.

4.3 Detailed model for airborne transmission

4.3.1 Determination from measured airborne direct transmission for small technical elements

The contribution can be directly determined from the element normalized level difference of the elements considered, $D_{n,e}$, through [Formulae \(5\)](#) and [\(1\)](#). In principle the element as applied should be identical to the element for which data are available, so $D_{n,e,situ} = D_{n,e}$.

NOTE However, for some types of elements, like slits or transfer air devices, it is feasible to extrapolate the acoustic behaviour of an element as applied *in situ* from the element data on an equivalent element with for instance a different length. In that case, $D_{n,e,situ}$ could be deduced from $D_{n,e}$ by taking into account the different dimensions in an appropriate way.

4.3.2 Determination from measured total indirect transmission

No standardized methods of measurement are currently available to characterize the indirect airborne transmission $D_{n,s}$ for transmission systems as a whole. While it is desirable to develop such methods for certain transmission systems such as domestic ventilation systems, for many other indirect transmission systems it may be preferable to base predictions on data for the separate elements of such systems (see [4.3.3](#)).

4.3.3 Determination from the performance of the separate elements of a system

No calculation scheme is currently available to determine the normalized level difference $D_{n,s}$ from knowledge and acoustical data on the elements involved in the transmission, i.e. ventilation ducts, silencers, suspended ceilings, corridor/hall, doors and door-gaps. Some proposals do, however, exist, which could form the basis for further development of such schemes. Information is given for some situations in [Annex H](#).

4.4 Simplified model

4.4.1 General

The application of the simplified model is restricted over a frequency range 100 Hz to 3150 Hz; its application to lightweight constructions is restricted to the use of $D_{n,f}$ [see [Formula \(21\)](#)].

4.4.2 Calculation procedure

The simplified version of the calculation model predicts the weighted apparent sound reduction index on the bases of the weighted sound reduction indices of the elements involved. It concerns the weighting in accordance with ISO 717-1. The model is given for the weighted sound reduction index, R_w , but can also be applied to the single number rating with the spectrum adaptation term, i.e. $R_w + C$. The resulting

estimate of the building performance is given in the same type of single number rating as is used for the building elements, i.e. R'_w or $(R'_w + C)$.

NOTE 1 For convenience, the sums with the spectrum adaptation term can be denoted by one symbol, for instance $R'_w + C = R'_A$ and $D_{nT,w} + C = D_{nT,A}$.

NOTE 2 The energetic summation involved in the model is exact for R'_A and a reasonable approximation for R'_w .

The influence of the structural damping of elements is taken into account in an average way, neglecting the specifics of the situation. Each flanking element should be essentially the same on the source and receiving side. Additionally, the airborne transmission through technical elements and other transmission systems can be incorporated.

For the simplified model, the prediction [Formulae \(1\), \(2\), \(3\), \(4\), and \(5\)](#) are re-written and the weighted apparent sound reduction index between two rooms is determined from Formula (18):

$$R'_w = - \left(10 \lg \left(10^{-R_{Dd,w}/10} + \sum_{F=f=1}^n 10^{-R_{Ff,w}/10} + \sum_{f=1}^n 10^{-R_{Df,w}/10} + \sum_{F=1}^n 10^{-R_{Fd,w}/10} + \frac{A_0}{S_s} \sum_{j=1}^m 10^{-D_{n,j,w}/10} \right) \right) \text{ dB} \quad (18)$$

where

$R_{Dd,w}$ is the weighted sound reduction index for airborne direct transmission, in decibels;

$R_{Ff,w}$ is the weighted flanking sound reduction index for the transmission path Ff, in decibels;

$R_{Df,w}$ is the weighted flanking sound reduction index for the transmission path Df, in decibels;

$R_{Fd,w}$ is the weighted flanking sound reduction index for the transmission path Fd, in decibels;

$D_{n,j,w}$ is the weighted normalized sound level difference for the transmission through a small technical element j ($D_{n,e}$) or an airborne transmission system j ($D_{n,s}$), in decibels;

n is the number of flanking elements in a room; normally $n = 4$, but it can be smaller or larger depending on the design and construction of the considered situation (see [Annex J](#));

m is the number of airborne transmission elements or systems j;

S_s is the area of the separating element, in square metres;

A_0 is the reference equivalent absorption area, in square metres; $A_0 = 10 \text{ m}^2$.

NOTE 3 If D_{nT} or D_n is calculated, the area of the separating element serves as an arbitrary reference and could be taken as 10 m^2 throughout the calculations.

NOTE 4 For certain building situations with combination of lightweight elements and massive elements, e.g. with suspended ceilings or lightweight facades, the flanking transmission is dominated by path Ff and the third and fourth terms in Formula (18) can be neglected for that flanking element.

NOTE 5 The contribution by one flanking element to the total flanking transmission can be evaluated by adding the corresponding transmission via the paths Ff and Df; the contribution of flanking transmission to the radiation by the separating element can be evaluated by adding the transmission via the paths Fd for all flanking elements.

For each transmission path the weighted sound reduction index is predicted from the input data on the elements and junctions (see [4.4.2](#)).

The weighted sound reduction index for airborne direct transmission is determined from the input value for the separating element according to [Formula \(19\)](#):

$$R_{Dd,w} = R_{s,w} + \Delta R_{Dd,w} \text{ dB} \quad (19)$$

where

$R_{s,w}$ is the weighted sound reduction index of the separating element, in decibels;

$\Delta R_{Dd,w}$ is the total weighted sound reduction index improvement by additional lining on the source and/or receiving side of the separating element, in decibels.

The weighted flanking sound reduction indices are determined from the input values according to [Formula \(20\)](#):

$$\begin{aligned} R_{Ff,w} &= \frac{R_{F,w} + R_{f,w}}{2} + \Delta R_{Ff,w} + K_{Ff} + \left(10 \lg \frac{S_s}{l_o l_f} \right) \text{ dB} \\ R_{Fd,w} &= \frac{R_{F,w} + R_{s,w}}{2} + \Delta R_{Fd,w} + K_{Fd} + \left(10 \lg \frac{S_s}{l_o l_f} \right) \text{ dB} \\ R_{Df,w} &= \frac{R_{s,w} + R_{f,w}}{2} + \Delta R_{Df,w} + K_{Df} + \left(10 \lg \frac{S_s}{l_o l_f} \right) \text{ dB} \end{aligned} \quad (20)$$

where

$R_{F,w}$ is the weighted sound reduction index of the flanking element F in the source room, in decibels;

$R_{f,w}$ is the weighted sound reduction index of the flanking element f in the receiving room, in decibels;

$\Delta R_{Ff,w}$ is the total weighted sound reduction index improvement by additional lining on the source and/or receiving side of the flanking element, in decibels;

$\Delta R_{Fd,w}$ is the total weighted sound reduction index improvement by additional lining on the flanking element at the source side and/or separating element at the receiving side, in decibels;

$\Delta R_{Df,w}$ is the total weighted sound reduction index improvement by additional lining on the separating element at the source side and/or flanking element at the receiving side, in decibels;

K_{Ff} is the vibration reduction index for transmission path Ff, in decibels;

K_{Fd} is the vibration reduction index for transmission path Fd, in decibels;

K_{Df} is the vibration reduction index for transmission path Df, in decibels;

S_s is the area of the separating element, in square metres;

l_f is the common coupling length of the junction between separating element and the flanking elements F and f, in metres;

l_o is the reference coupling length; $l_o = 1 \text{ m}$.

NOTE 5 In [Formula \(20\)](#), it is assumed that the element absorption length a is equal to the element area S .

For lightweight constructions, the weighted flanking sound reduction index $R_{ij,w}$ for any path Ff, Df or Fd shall be determined from the corresponding weighted flanking normalized level difference $D_{n,f,ij,w}$ using [Formula \(21\)](#):

$$R_{ij,w} = D_{n,f,ij,w} + \left(10 \lg \frac{l_{lab}}{l_{ij}} \frac{S_s}{A_o} \right) \text{ dB} \quad (21)$$

For certain flanking constructions, like suspended ceilings and lightweight facades, the transmission is normally dominated by path Ff, as characterized by the weighted flanking normalized level difference $D_{n,f,w}$, so the contributions of path Df and Fd can be neglected. $D_{n,f,w}$ can be either measured or determined from the performance of elements (see [Annex G](#)). For horizontal flanking elements like ceilings l_{lab} is usually of 4,5 m and for vertical flanking elements like facades l_{lab} is usually 2,5 m.

4.4.3 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 field measurements. Information on this is given in [Annexes B, D, E and J](#). The sources of data used shall be clearly stated.

The input data consist of the following.

- a) The weighted sound reduction index of the elements: $R_{s,w}$, $R_{F,w}$, $R_{f,w}$.

Information for homogeneous elements is given in [Annex B](#).

- b) The vibration reduction index for each junction and path: K_{FF} , K_{Fd} , K_{Df} .

Information for common junctions is given in [Annex E](#). If the values for the vibration reduction index depend on frequency, the mean value averaged over the frequency range 1/3 octave 250 Hz to 1 000 Hz should be taken as an approximation in accordance with ISO 10848 (all parts), but then the result can be less accurate.

If a flanking element has insignificant or no structural contact with the separating element, only K_{FF} is relevant (see [Annex J](#)), while the transmission paths Fd and Df are neglected (i.e. by setting the K_{ij} values very high).

- c) The weighted normalized flanking sound level difference for transmission path Ff: $D_{n,f,Ff,w}$.

- d) The total weighted sound reduction index improvement for the separating element: $\Delta R_{Dd,w}$.

This value follows either directly from available results for the appropriate combination or is deduced from results for each of the layers involved separately, as shown by [Formula \(22\)](#):

$$\begin{aligned} \text{one layer : } \Delta R_{Dd,w} &= \Delta R_{D,w} \quad \text{or} \quad \Delta R_{d,w} \quad \text{dB} \\ \text{two layers : } \Delta R_{Dd,w} &= \Delta R_{D,w} + \frac{\Delta R_{d,w}}{2} \quad \text{or} \quad = \Delta R_{d,w} + \frac{\Delta R_{D,w}}{2} \quad \text{dB} \end{aligned} \quad (22)$$

In the case of two linings, half the value is taken for the lining with the lower value; however, if both linings have a negative value, then half the value is taken for the lining with the higher value.

- e) The total weighted sound reduction index improvement for each flanking path: $\Delta R_{Ff,w}$, $\Delta R_{Fd,w}$, $\Delta R_{Df,w}$.

These values follow either directly from available results for the appropriate combination or are deduced from results for each of the layers involved separately ($ij = Ff, Fd$ or Df), as shown by [Formula \(23\)](#):

one layer : $\Delta R_{ij,w} = \Delta R_{i,w}$ or $\Delta R_{j,w}$ dB

two layers: $\Delta R_{ij,w} = \Delta R_{i,w} + \frac{\Delta R_{j,w}}{2}$ or $= \Delta R_{j,w} + \frac{\Delta R_{i,w}}{2}$ dB (23)

In the case of two linings, half the value is taken for the lining with the lower value; however, if both linings have a negative value, then half the value is taken for the lining with the higher value.

Information on the weighted sound reduction index improvement is given in [Annex D](#).

- f) The weighted normalized sound level difference for technical elements: $D_{n,e,w}$.
- g) The weighted normalized sound level difference for indirect airborne sound transmission through a system: $D_{n,s,w}$.

4.4.4 Limitations

The following comments apply concerning the limitation of the prediction by the models presented.

- a) The limitations for the detailed model also apply for the simplified model.
- b) The simplified model applies mainly to dwellings where the dimensions of the elements are similar to those in the test facility. Deviations from this may result in less accurate results.
- c) The simplified model assumes elements for which the sound reduction index has a similar frequency dependence; with elements which have a clearly deviating frequency behaviour, as for instance double, lightweight elements, the accuracy may be less.

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 have to be gathered in the future by comparing the results of the model with field measurements from a variety of different buildings. However, some indications can be given.

The main experience in the application of similar models has been so far with buildings where the basic structural elements are homogeneous, i.e. brick walls, concrete, gypsum blocks, etc. In those situations, the prediction of the single number rating by the detailed model is on average correct (no bias error) with a standard deviation of 1,5 dB to 2,5 dB (the lower value if all aspects are taken into account, the larger to complex situations and when neglecting the structural reverberation time).

Predictions with the simplified model show a standard deviation of about 2 dB. Uncertainty for the simplified model can be estimated using the method proposed in [Annex K](#).

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. A possibility to do this in a more systematic way by estimating overall accuracy from the accuracy of all acoustic input data is described in [Annex K](#).

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 <i>in situ</i>	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
A_h	equivalent sound absorption area of a hall	m ²
B_i	bending stiffness per unit width of element i	Nm
c_B	bending wave speed	m/s
c_L	quasi-longitudinal wave speed	m/s
C_α	correction term for absorption above suspended ceiling	dB
$C_{\text{doorpos.}}$	correction term to take into account the relative position of the doors in a hall	dB
C_c	coefficient used in presence of elastic interlayers in junction	-
C	spectrum adaptation term 1 in accordance with ISO 717-1	dB
C_{tr}	spectrum adaptation term 2 in accordance with ISO 717-1	dB
c_0	speed of sound in air (= 340 m/s)	m/s
C_{sab}	Sabine constant (= 0,16 s/m)	s/m
C_w	Waterhouse correction	dB
D_{nT}	standardized sound level difference	dB
$D_{\text{nT,w}}$	weighted standardized sound level difference	dB
$D_{\text{n,e}}$	element normalized level difference of small building elements	dB
$D_{\text{n,e,situ}}$	element normalized level difference of small building elements <i>in situ</i>	dB
$D_{\text{n,s}}$	normalized sound level difference for indirect transmission through a system s	dB
$D_{\text{n,f}}$	flanking normalized level difference	dB
$D_{\text{n,f,lab}}$	flanking normalized level difference in laboratory	dB
$D_{\text{n,f,situ}}$	flanking normalized level difference <i>in situ</i>	dB
$D_{\text{n,f,ij}}$	flanking normalized level difference between excited element i and receiving element j	dB
$D_{\text{n,f,ij,situ}}$	flanking normalized level difference between excited element i and receiving element j <i>in situ</i>	dB
$D_{\text{n,f,ij,w}}$	weighted flanking normalized level difference between excited element i and receiving element j	dB
$D_{\text{n,f,Ff,w}}$	weighted flanking normalized level difference for the transmission path Ff	dB
$D_{\text{n,j,w}}$	weighted normalized sound level difference for transmission through an small technical element or system	dB
$D_{\text{n,f,w}}$	weighted flanking normalized level difference	dB
$D_{\text{v,ij}}$	junction velocity level difference between excited element i and receiving element j	dB
$D_{\text{v,ij,situ}}$	direction-averaged junction velocity level difference between elements i and j <i>in situ</i>	dB

Table A.1 (continued)

Symbol	Physical quantity	Unit
$D_{v,ij,n}$	normalized direction-averaged velocity level difference between elements i and j	dB
d	depth of cavity of additional linings	m
E_l	Young's modulus of a flexible interlayer	N/m ²
f	frequency	Hz
f_c	critical frequency	Hz
$f_{c,eff}$	effective critical frequency, taking into account longitudinal and shear waves	Hz
f_{ref}	reference frequency (= 1 000 Hz)	Hz
f_l	characteristic frequency for the effect of flexible inter layers at junctions	Hz
f_p	plateau frequency for the sound reduction index	Hz
f_K	frequency to express the frequency dependence of the vibration reduction index (= 500 Hz)	Hz
f_o	mass-spring resonance frequency	Hz
h_{pl}	free height of the plenum above the ceiling	m
h_{lab}	laboratory value, as reference, for h_{pl} (= 0,7 m)	m
i, j	indices for an element; for a transmission path ij, i indicates an element in the source room (= F, D) and j an element in the receiving room (= f, d)	-
k	index for a border of an element	-
k_o	wave number in air ($k_o = 2 \pi f / c_o$)	rad/m
K_{ij}	vibration reduction index for each transmission path ij over a junction	dB
K_{Ff}	vibration reduction index for each transmission path Ff	dB
K_{Fd}	vibration reduction index for each transmission path Fd	dB
K_{Df}	vibration reduction index for each transmission path Df	dB
$K_{ij,min}$	minimum value for K_{ij} <i>in situ</i>	dB
L_1	average sound pressure level in the source room	dB re 20 µPa
L_2	average sound pressure level in the receiving room	dB re 20 µPa
L_k	length of border k of a total floor plate between load-bearing walls	m
l_{ij}	common coupling length between element i and element j	m
l_f	common coupling length between flanking element f and separating element	m
l_{lab}	laboratory value, as reference, for l_{ij}	m
l_k	length of border k of an element	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
M	$\lg \left(m'_{\perp i} / m'_i \right)$	-
n	number of flanking elements in a room	-
R	sound reduction index of an element	dB
R^*	sound reduction index of an element for the resonant transmission only	dB
R_{meas}	measured sound reduction index of an element	dB
R_{situ}	sound reduction index of an element in the actual field situation	dB
R'	apparent sound reduction index	dB

Table A.1 (continued)

Symbol	Physical quantity	Unit
R'_w	weighted apparent sound reduction index	dB
R_{ij}	flanking sound reduction index	dB
R_s	sound reduction index of separating element	dB
R_f	sound reduction index of flanking element	dB
$R_{s,situ}$	sound reduction index of separating element <i>in situ</i>	dB
R_{Dd}	sound reduction index for airborne direct transmission	dB
R_{Ff}	sound reduction index for the transmission path Ff	dB
R_{Df}	sound reduction index for the transmission path Df	dB
R_{Fd}	sound reduction index for the transmission path Fd	dB
R_i	sound reduction index for element i in source room	dB
$R_{i,situ}$	sound reduction index of element i <i>in situ</i>	dB
R_j	sound reduction index for element j in receiving room	dB
$R_{j,situ}$	sound reduction index of element j <i>in situ</i>	dB
ΔR	sound reduction index improvement by additional layers	dB
ΔR_{situ}	sound reduction index improvement by additional layers <i>in situ</i>	dB
ΔR_{lab}	measured sound reduction index improvement by additional layers	dB
ΔR_f	sound reduction index improvement by additional layers for flanking transmission	dB
ΔR_s	sound reduction index improvement by additional layers for separating element	dB
ΔR_D	sound reduction index improvement by additional layers for separating element in the source room	dB
ΔR_d	sound reduction index improvement by additional layers for separating element in the receiving room	dB
ΔR_i	sound reduction index improvement by additional layers for element i	dB
ΔR_j	sound reduction index improvement by additional layers for element j	dB
$\Delta R_{D,situ}$	sound reduction index improvement by additional layers for separating element in the source room <i>in situ</i>	dB
$\Delta R_{d,situ}$	sound reduction index improvement by additional layers for separating element in the receiving room <i>in situ</i>	dB
$\Delta R_{i,situ}$	sound reduction index improvement by additional layers for element i <i>in situ</i>	dB
$\Delta R_{j,situ}$	sound reduction index improvement by additional layers for element j <i>in situ</i>	dB
R_{hs}	sound reduction index of the wall between a hall and the source room	dB
R_{hr}	sound reduction index of the wall between the hall and the receiving room	dB
R_w	weighted sound reduction index in accordance with ISO 717-1	dB
$R_{s,w}$	weighted sound reduction index of the separating element	dB
$R_{F,w}$	weighted sound reduction index of the flanking element F in the source room	dB
$R_{f,w}$	weighted sound reduction index of the flanking element f in the receiving room	dB
$R_{Dd,w}$	weighted sound reduction index for airborne direct transmission	dB
$R_{Ff,w}$	weighted sound reduction index for the transmission path Ff	dB
$R_{Df,w}$	weighted sound reduction index for the transmission path Df	dB
$R_{Fd,w}$	weighted sound reduction index for the transmission path Fd	dB
ΔR_w	weighted sound reduction index improvement by additional layers	dB
$\Delta R_{w,situ}$	weighted sound reduction index improvement by additional layers <i>in situ</i>	dB
$\Delta R_{Dd,w}$	total weighted sound reduction index improvement by additional lining on the source and/or receiving side of the separating element	dB

Table A.1 (continued)

Symbol	Physical quantity	Unit
$\Delta R_{Ff,w}$	total weighted sound reduction index improvement by additional lining on the source and/or receiving side of the flanking element	dB
$\Delta R_{Fd,w}$	total weighted sound reduction index improvement by additional lining on the flanking element at the source side and/or separating element at the receiving side	dB
$\Delta R_{Df,w}$	total weighted sound reduction index improvement by additional lining on the separating element at the source side and/or flanking element at the receiving side	dB
Δ_l	correction of the K_{ij} in presence of elastic interlayers in junction	dB
S_{rec}	area of the part of a floor, seen from the receiving room	m ²
S_{tot}	total area of a floor field between load bearing structural elements	m ²
S_{hs}, S_{hr}	area of the wall between the hall and the source room, and receiving room, respectively	m ²
S_{cs}, S_{cr}	the area of the ceiling in the source room and receiving room, respectively	m ²
S_{lab}	laboratory value, as reference, for S_{cs} and S_{cr} (= 20 m ²)	m ²
S_s	area of separating element	m ²
S_i, S_j	area of an element in the source room (i) and receiving room (j), respectively	m ²
$S_{i,situ}, S_{j,situ}$	area of an element in the source room (i) and receiving room (j), respectively <i>in situ</i>	m ²
S_{mi}	area of an element i over which the velocity is averaged	m ²
s'	dynamic stiffness of a layer	MN/m ³
s'_t	apparent dynamic stiffness of a flexible interlayer	MN/m ³
t	thickness of a structural element	m
t_a	thickness of an absorbing lining	m
t_l	thickness of a flexible interlayer	m
T	reverberation time in the receiving room	s
T_0	reference reverberation time; for dwellings given as 0,5 s	s
T_s	structural reverberation time of a (homogeneous) element	s
$T_{s,tot}$	laboratory structural reverberation time for total (homogeneous) element	s
T_{sf}	structural reverberation time of a (homogeneous) flanking element	s
$T_{s,lab}$	laboratory structural reverberation time for each (homogeneous) element	s
$T_{s,situ}$	structural reverberation time <i>in situ</i>	s
V	the volume of the receiving room	m ³
v_i^2	average square velocity over element i (free waves)	(m/s) ²
v_j^2	average square velocity over element j (free waves)	(m/s) ²
W_{tot}	total radiated sound power into receiving room	W
W_{ij}	radiated sound power by element j due to incident sound on element i	W
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	-
α_k	absorption coefficient for bending wave field at border k of an element	-
γ_{ij}	power transmission factor for bending wave field at a junction between element i and j	-
Δ_l	reduction of vibration reduction index by a flexible layer	dB
η_{ij}	coupling loss factor between element i and j	-
η_{tot}	total loss factor	-
$\eta_{tot,lab}$	total loss factor in the laboratory situation	-

Table A.1 (continued)

Symbol	Physical quantity	Unit
$\eta_{\text{tot,situ}}$	total loss factor <i>in situ</i>	-
η_{int}	internal loss factor	-
ρ	density	kg/m ³
ρ_0	density of air	kg/m ³
σ, σ_s	radiation factor for free bending waves (case of structural excitation)	-
σ_f	radiation factor for forced waves	-
σ_a	radiation factor for airborne excitation	-
τ	transmission factor (sound power ratio)	-
τ_{ij}	flanking transmission factor	-
τ'	sound power ratio of total radiated sound power in the receiving room relative to incident sound power on the common part of the separating element	-
τ_d	sound power ratio of radiated sound power by the common part of the separating element relative to incident sound power on the common part of the separating element; it includes the paths Dd and Fd	-
τ_f	sound power ratio of radiated sound power by a flanking construction f in the receiving room relative to incident sound power on the common part of the separating element; it includes paths Ff and Df	-
τ_{Dd}	sound power ratio of radiated sound power for airborne direct transmission	dB
τ_{Ff}	sound power ratio of radiated sound power for the transmission path Ff	dB
τ_{Df}	sound power ratio of radiated sound power for the transmission path Df	dB
τ_{Fd}	sound power ratio of radiated sound power for the transmission path Fd	dB
τ_s	sound power ratio of radiated sound power in receiving room by indirect airborne transmission system s due to incident sound power on this transmission system, relative to incident sound power on the common part of the separating element	-
τ_e	sound power ratio of radiated sound power in the receiving room by an element in the separating element due to direct airborne sound transmission of incident sound on this element, relative to incident sound power on the common part of the separating element	-
$\%S_0$	percentage of the area over which the additional layer is glued to the basic element	%

Annex B (informative)

Sound reduction index

B.1 General

For each flanking transmission path, the sound reduction index R of the involved elements (including the separating element) should relate to the resonant transmission only. If laboratory measurement results are used as input data, this is therefore correct above the critical frequency; while a correction shall be applied below that frequency, particularly for elements with high critical frequency (lightweight elements). A correction is proposed in [B.2](#). If the values of the sound reduction index are based on calculations from material properties (case of homogeneous elements), it is best to consider only resonant transmission over the whole frequency range of interest, as explained in [B.3](#).

This annex also proposes empirical relations to estimate weighted sound reduction indices (see [B.4](#)).

B.2 Sound reduction index for resonant transmission only

In order to deduce the sound reduction index for resonant transmission R^* from laboratory measurement results R , data on the radiation factor for airborne excitation σ_a and for (indirect) structural excitation σ_s are required. The corrected value then follows as a good estimation from [Formula \(B.1\)](#):^[30]

$$R^* = R + 10 \lg \frac{\sigma_a}{\sigma_s} \quad (\text{B.1})$$

NOTE In the case of double elements with cavity, [Formula \(B.1\)](#) overestimates the correction at frequencies close to the cavity resonance.

There is no standardized method available to determine these radiation factors yet. However, recent measurements, using the method proposed in Reference [\[30\]](#), have indicated that in case of double elements with cavity the correction is small or negligible, while for elements without cavity (i.e. single leaf wall often framed elements), the correction seems to be reasonably independent of the type of element and around 8 dB below the critical frequency.

Thus, an estimate of the correction is given by the following:

- no correction for elements separated by one or two cavities;
- a correction of 8 dB for single, homogeneous or layered, wood or steel frame elements (i.e. without a cavity) below the critical frequency only.

For lightweight and usually stiffened elements, the radiation factors cannot be easily calculated. For homogeneous elements, these factors could be calculated, for instance as indicated in [B.3](#); however, it is then simpler to directly calculate the contribution of resonant transmission as also shown in [B.3](#).

B.3 Frequency dependent calculated sound reduction index

For common homogeneous structural elements, the laboratory sound reduction R can be calculated accurately (see the bibliography). In cases below the critical frequency, the contribution of forced transmission can be neglected for flanking paths in [Formula \(B.2\)](#). 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 10140-5 (see [Annex C](#)).

Formula (B.2) can be used^[10]:

$$R = -10 \lg \tau$$

$$\tau = \left(\frac{2\rho_o c_o}{2\pi f m'} \right)^2 \frac{\pi f_c \sigma^2}{2 f \eta_{\text{tot}}} \quad f > f_c$$

$$\tau = \left(\frac{2\rho_o c_o}{2\pi f m'} \right)^2 \frac{\pi \sigma^2}{2 \eta_{\text{tot}}} \quad f \approx f_c \quad (\text{B.2})$$

$$\tau = \left(\frac{2\rho_o c_o}{2\pi f m'} \right)^2 \left(2\sigma_f \left[\frac{1-f^2}{f_c^2} \right]^{-2} + 2 \frac{\pi f_c}{4 f} \frac{\sigma^2}{\eta_{\text{tot}}} \right) \quad f < f_c$$

where

τ is the transmission factor;

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

f is the frequency in Hertz;

f_c is the critical frequency ($= c_o^2 / (1,8 c_{Lt})$), in Hertz;

η_{tot} is the total loss factor (for the laboratory situation see [Annex C](#));

σ is the radiation factor for free bending waves;

σ_f is the radiation factor for forced transmission;

l_1, l_2 are the lengths of the borders of the (rectangular) element, in metres.

The radiation factor for forced waves is based on Reference [\[16\]](#), and with l_1 greater than l_2 calculated from [Formula \(B.3\)](#):

$$\sigma_f = 0,5 \left(\ln(k_o \sqrt{l_1 l_2}) - \Lambda \right); \sigma_f \leq 2 \quad (\text{B.3})$$

$$\Lambda = -0,964 - \left(0,5 + \frac{l_2}{\pi l_1} \right) \ln \frac{l_2}{l_1} + \frac{5l_2}{2\pi l_1} - \frac{1}{4\pi l_1 l_2 k_o^2}$$

where k_o is the wave number, in radian per metre; $k_o = 2 \pi f / c_o$.

[Table B.1](#) gives the results for two common openings for laboratory measurements of 10 m² and 2 m².

Table B.1 — Calculated radiation efficiency ($=10 \lg \sigma$) in one-third-octave bands for forced transmission for two typical laboratory dimensions

Centre frequency Hz	Opening	
	2 m ² (1,25 m × 1,5 m)	10 m ² (2,65 m × 3,75 m)
50	-6,5	-2,1
63	-4,8	-1,4
80	-3,5	-0,7
100	-2,6	-0,2
125	-1,8	0,3
160	-1,1	0,8
200	-0,5	1,1
250	0,0	1,5
315	0,5	1,8
400	0,9	2,2
500	1,3	2,5
630	1,7	2,7
800	2,0	3,0
1 000	2,3	3,0
1 250	2,6	3,0
1 600	2,9	3,0
2 000	3,0	3,0
2 500	3,0	3,0
3 150	3,0	3,0
4 000	3,0	3,0
5 000	3,0	3,0

The radiation factor for free waves is based on Reference [13] and calculated from Formulae (B.4), (B.5) and (B.6):

$$\sigma_1 = \frac{1}{\sqrt{1 - f_c / f}} \quad \sigma_2 = 4l_1 l_2 \left(\frac{f}{c_0} \right)^2 \quad \sigma_3 = \sqrt{\frac{2\pi f (l_1 + l_2)}{16c_0}} \quad (B.4)$$

$$f_{11} = \frac{c_0^2}{4f_c} \left(\frac{1}{l_1^2} + \frac{1}{l_2^2} \right)$$

if $f_{11} \leq f_c / 2$ then :

$$f \geq f_c : \sigma = \sigma_1$$

$$f < f_c : \sigma = \frac{2(l_1 + l_2)}{l_1 l_2} \frac{c_0}{f_c} \delta_1 + \delta_2$$

$$\delta_1 = \left(\frac{\left((1 - \lambda^2) \ln \frac{1 + \lambda}{1 - \lambda} + 2\lambda \right)}{4\pi^2 (1 - \lambda^2)^{1,5}} \right) \text{ with } \lambda = \sqrt{\frac{f}{f_c}} \quad (B.5)$$

$$\begin{cases} \delta_2 = 0 \text{ for } f > f_c / 2 \\ \delta_2 = \frac{8c_0^2 (1 - 2\lambda^2)}{f_c^2 \pi^4 l_1 l_2 \lambda \sqrt{1 - \lambda^2}} \text{ for } f \leq f_c / 2 \end{cases}$$

$$f < f_{11} < f_c / 2 \text{ and } \sigma > \sigma_2 : \sigma = \sigma_2$$

if $f_{11} > f_c / 2$ then :

$$f < f_c \text{ and } \sigma_2 < \sigma_3 : \sigma = \sigma_2$$

$$f > f_c \text{ and } \sigma_1 < \sigma_3 : \sigma = \sigma_1 \quad (B.6)$$

$$\text{else: } \sigma = \sigma_3$$

In all cases $\sigma \leq 2,0$

These equations are valid for a plate surrounded by an infinite baffle in the same plane. However, in buildings walls and floors are usually surrounded by orthogonal elements which will increase the radiation efficiency well below the critical frequency by a factor of 2 (edge modes) to 4 (corner modes). For the radiation efficiencies alternative equations are available from more recent literature (see References [18], [19] and [27]).

NOTE 1 For homogeneous elements, the efficiencies used in Formula (B.1) could be calculated using Formula (B.7):

$$\sigma_s = \sigma$$

$$\sigma_a = \frac{\sigma_f + r\sigma}{1 + r}; r = \frac{\pi f_c \sigma}{4 f \eta} \quad (\text{B.7})$$

NOTE 2 The method of subtracting the contribution of forced transmission can also be applied with a limit of 8 dB of correction, as proposed in [B.2](#). The only values needed for this correction are the mass m' of the element and the radiation efficiency σ_f which is readily available for the fixed laboratory situations (10 m² and 2 m²; see [Table B.1](#)).

For $f \leq 2f_c \approx 88\,000 / m'$ it follows as shown by [Formula \(B.8\)](#):

$$R^* = R_{\text{meas}} + 10 \lg \left(1 - 10^{R_{\text{meas}}/10} \left(\frac{2\rho c}{2\pi f m'} \right)^2 2\sigma_f \right)^{-1} \quad (\text{B.8})$$

If the term between [] becomes smaller than 0,16 or even negative the correction shall be limited to 8 dB.

Due to the normally small contribution of the resonant transmission, this method provides a smooth calculation method with continuous results over the frequency range without the need to know the critical frequency exactly.

Above the critical frequency, the critical frequency is replaced in the calculation by an effective critical frequency, to take into account other wave types relevant for thick walls and/or higher frequencies (see References [5] and [12]), according to [Formula \(B.9\)](#):

$$f_{c,\text{eff}} = f_c \left(4,05 \frac{tf}{c_L} + \sqrt{1 + \left(4,05 \frac{tf}{c_L} \right)^2} \right) \quad (\text{B.9})$$

where

t is the thickness of the element, in metres;

c_L is the longitudinal velocity of the material, in metres per second.

At even higher frequencies there are indications that the sound reduction index is limited. It is safe to assume a plateau level given by the transmission factor shown by [Formula \(B.10\)](#):

$$\tau_{\text{plateau}} = \left(\frac{4\rho_0 c_0}{1,1\rho c_L} \right)^2 \frac{0,02}{\eta_{\text{tot}}} \quad (\text{B.10})$$

where ρ is the density of the material, in kilograms per cubic metres.

At the high frequencies where this applies the loss factor can be taken as the internal loss factor.

Based on calculations according to this model, some examples of the sound reduction index in 1/3 octave bands for homogeneous elements are given in [Table B.2](#) for a laboratory situation in accordance with [Annex C](#). The calculations are performed at single frequencies at one-third-octave distance and the results averaged over a band-width of one octave in order to ensure a smooth transmission between the three frequency ranges of Formula (B.2). The frequency range around the critical frequency is taken as $f_c/1,12 < f < 1,4 f_c$ using $f = f_c$ in this whole range with $\sigma^2 = 1/0,71$ and $c_0 = 340$ m/s. The material properties are given in [Table B.3](#), together with the generic material names for which they are indicative.

Table B.2 — Calculated sound reduction index in one-third-octave bands for some homogeneous structures: examples

Construction								
Centre frequency Hz	Concrete 120 mm 264 kg/m ²	Concrete 260 mm 572 kg/m ²	Ca-Si blocks 110 mm 198 kg/m ²	Ca-Si blocks 240 mm 432 kg/m ²	Light. blocks 120 mm 168 kg/m ²	Light. blocks 300 mm 420 kg/m ²	Auto. Conc. blocks 100 mm 60 kg/m ²	Auto. Conc. blocks 200 mm 120 kg/m ²
50	31,0	36,1	32,1	33,9	30,6	33,8	21,9	24,1
63	31,5	34,5	33,4	35,0	31,9	34,7	23,4	25,0
80	30,8	34,5	34,4	35,4	33,0	33,9	24,9	25,4
100	28,1	44,8	35,0	34,8	33,6	33,8	26,1	24,5
125	25,5	46,2	34,8	34,8	33,6	33,8	27,0	21,3
160	30,1	47,8	32,8	37,6	32,0	42,2	27,5	23,8
200	30,3	49,3	26,1	41,7	26,8	43,7	26,9	23,8
250	36,6	51,9	31,2	45,1	29,7	45,2	24,2	24,6
315	40,2	54,7	31,2	48,2	29,7	48,2	22,4	29,5
400	43,6	57,5	36,2	51,2	33,6	51,1	22,4	33,3
500	46,5	60,0	39,9	53,9	37,5	53,7	23,2	36,4
630	49,3	62,5	43,3	56,6	40,9	56,2	27,7	39,5
800	52,2	65,1	46,5	59,2	44,2	58,7	31,6	42,4
1 000	54,8	67,4	49,4	61,5	47,0	60,9	34,9	45,0
1 250	57,3	69,7	52,1	63,8	49,7	63,1	37,9	47,5
1 600	60,1	72,1	55,0	66,2	52,6	65,3	41,0	50,1
2 000	62,5	74,2	57,5	68,3	55,1	67,3	43,8	52,4
2 500	64,9	76,2	59,9	70,3	57,5	67,6	46,3	54,5
3 150	67,3	76,1	62,4	70,7	59,9	67,3	48,9	56,7
4 000	69,6	75,7	64,8	70,4	62,2	67,0	51,4	56,8
5 000	71,8	75,3	66,9	70,1	64,3	66,7	53,6	56,7
$R_w(C;C_{tr})$	47(-2 ; -7)	63(-1 ; -5)	43(-1 ; -5)	56(-2 ; -7)	41(-1 ; -4)	56(-2 ; -7)	32(-1 ; -3)	39(-2 ; -6)
$R_w(C_{50};C_{tr,50})$	47(-2 ; -8)	63(-3 ; -12)	43(-1 ; -5)	56(-3 ; -9)	41(-1 ; -4)	56(-2 ; -9)	32(-1 ; -4)	39(-2 ; -6)

NOTE Structure area taken as 10 m² (2,65 m × 3,75 m) and total loss factor estimated in laboratory using [Formula \(C.3\)](#).

Table B.3 — Typical material properties

Material	Density ρ (kg/m ³)	Quasi-longitudinal phase velocity c_L (m/s)	Internal loss factor $\eta_{\text{int}}(-)$
Concrete	2 200	3 800	0,005
Calcium-silicate blocks	1 800	2 500	0,01
Autoclaved aerated concrete blocks	400 to 800	1 900	0,012 5
Lightweight aggregate blocks	1 400	2 200	0,01
Dense aggregate blocks	2 000	3 200	0,01
Bricks	1 500 to 2 000	2 700	0,01
Plasterboard (natural gypsum)	860	1 490	0,014 1
Plasterboard (flue gas and natural gypsum)	680	1 810	0,012 5
Chipboard	760	2 200	0,01

B.4 Weighted sound reduction

Based on calculations according to the model given in [Figure B.1](#) information is given on the weighted sound reduction index R_w for homogeneous structural elements in [Figure B.1](#), as function of the mass per unit area for some common materials (see [Table B.3](#)). The single number ratings are calculated from the one-third-octave band values in accordance with ISO 717-1.

These data can be used to provide a reasonably safe estimate, in cases where no measured data are available. It is applicable to homogeneous single-leaf elements constructed from clay bricks, concrete, calcium-silicate blocks, gypsum blocks, autoclaved aerated concrete and various types of lightweight concrete. Mortar and firmly attached plaster can be included in the determination of the surface mass. Structural elements with holes cannot be considered as homogeneous, unless the dimensions of the holes are small and the volume of holes is less than 15 % of the gross volume.

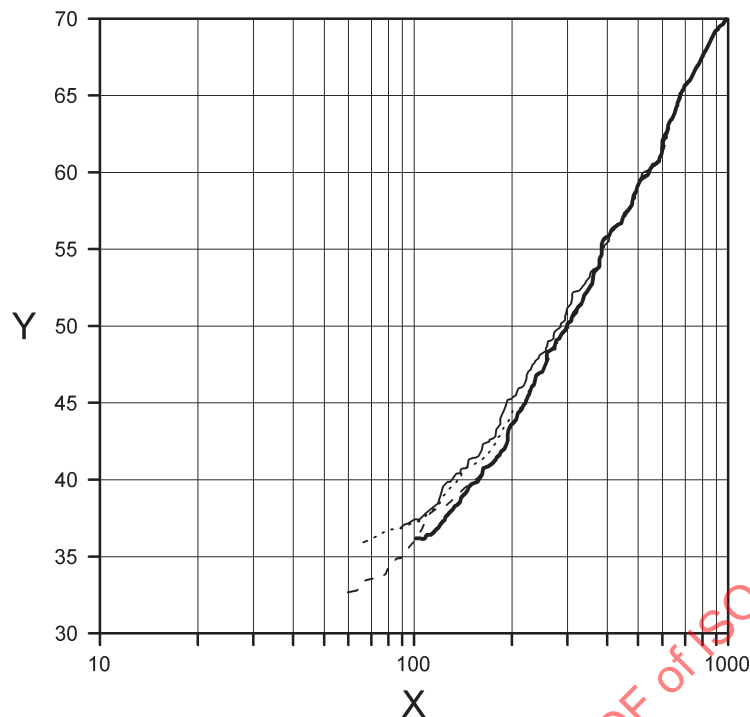
For $m' > 150 \text{ kg/m}^2$ the data in [Figure B.1](#) can, as a safe average, be represented by [Formula \(B.11\)](#):

$$R_w = (37,5 \lg(m' / m'_o) - 42) \text{ dB} \quad (\text{B.11})$$

For the corresponding spectrum adaptation terms [Formula \(B.12\)](#) holds:

C is about constant: -1 till -2 dB for the higher masses,

$$C_{\text{tr}} = (16 - 9 \lg(m'/m'_o)) \text{ dB, limited by } -7 \leq C_{\text{tr}} \leq -1 \text{ dB.} \quad (\text{B.12})$$



Key

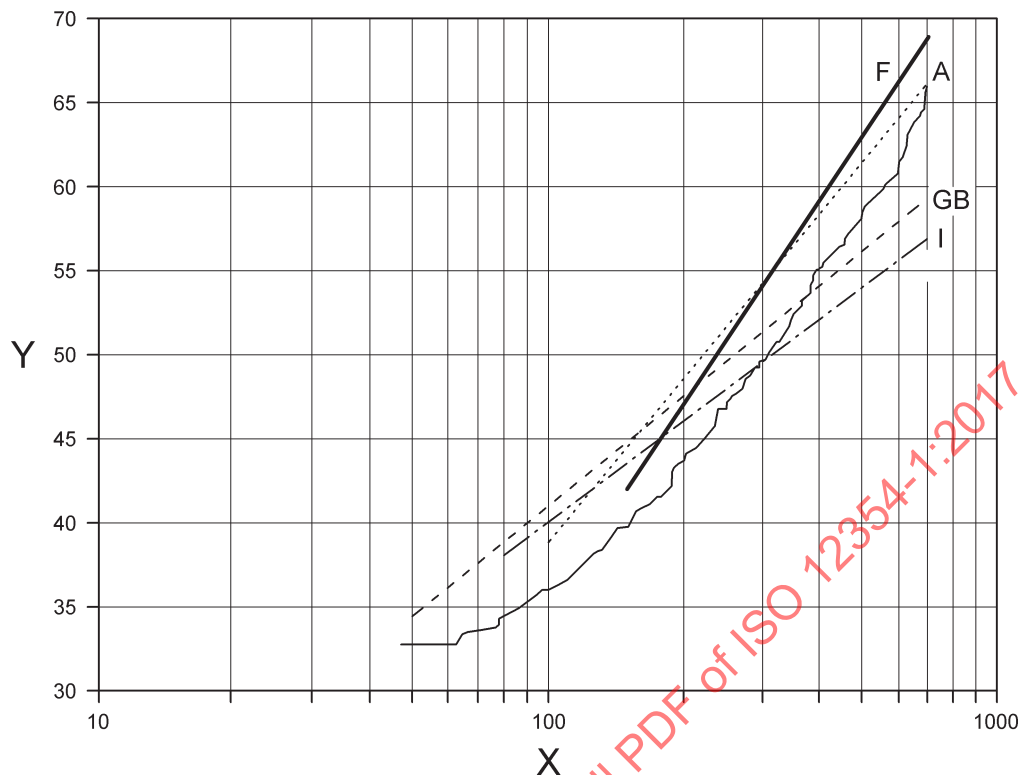
Y	weighted sound reduction index R_w (dB)
X	surface mass m' (kg/m ²)
1	— concrete
2	- - - calcium – silicate
3	 lightweight concrete
4	- - - autoclaved aerated concrete

Figure B.1 — Weighted sound reduction index calculated for some common homogeneous structural elements according to Table B.2

A comparison with measurement results gathered in different laboratories over the past 30 years show that the measured results lie in a range around the given lines from - 4 dB till + 8 dB. This relatively large spread is due to several factors, some related to specific product properties but some to the laboratory facilities and measurement methods applied. It is to be expected that measurement results in accordance with the new version of ISO 10140 (all parts) will show about half this spread. These facts are reflected in the different empirical “mass-law” relations, which have been and are being used within Europe, as shown in the following examples (see Figure B.2).

The data in Figure B.2 can be represented by Formula (B.13) with adaptation terms similar to Figure B1:

$$\begin{aligned}
 \text{A,} \quad m' \geq 100 \text{ kg/m}^2 : R_w &= 32,4 \lg(m' / m'_0) - 26,0 \text{ dB} \\
 \text{F,} \quad m' \geq 150 \text{ kg/m}^2 : R_w &= 40,0 \lg(m' / m'_0) - 45,0 ; C = -1 \text{ dB} \\
 \text{GB,} \quad m' \geq 50 \text{ kg/m}^2 : R_w &= 21,65 \lg(m' / m'_0) - 2,3 \pm 1 \text{ dB} \\
 \text{I} \quad m' \geq 80 \text{ kg/m}^2 : R_w &= 20,0 \lg(m' / m'_0) \text{ dB}
 \end{aligned}
 \tag{B.13}$$

**Key**X surface mass m' in kg/m^2 Y weighted sound reduction index R_w in dBNOTE The minimum values from [Figure B.1](#) are given for comparison.**Figure B.2 — Existing empirical relations for the weighted sound reduction index (laboratory situation) of homogeneous structural elements (A, F, GB, I)**

The following formula is used in Germany, derived from laboratory measurements of various kinds of homogeneous constructions and including a correction to a representative loss factor as it can be expected in typical solid buildings:

Concrete floors, concrete, CaSi and brick walls:

$$65 \text{ kg/m}^2 \leq m' \leq 720 \text{ kg/m}^2: \quad R_w = (30,9 \lg (m'/m'_0) - 22,2) \text{ dB}$$

The spectrum adaptation terms are constant: $C = -1,6 \text{ dB}$ and $C_{tr} = -4,6 \text{ dB}$

Annex C (informative)

Structural reverberation time: Type A elements

C.1 General

The reverberation time of a structural element T_s can be evaluated from the total loss factor, which follows from the internal losses, the losses due to radiation and the losses at the perimeter of the element, as shown by [Formula \(C.1\)](#):

$$T_s = \frac{2,2}{f \eta_{\text{tot}}}$$

$$\eta_{\text{tot}} = \eta_{\text{int}} + \frac{2\rho_o c_o \sigma}{2\pi f m'} + \frac{c_o}{\pi^2 S \sqrt{f f_c}} \sum_{k=1}^4 l_k \alpha_k \quad (\text{C.1})$$

where

η_{tot} is the total loss factor;

F is the band centre frequency, in Hertz;

η_{int} is the internal loss factor of the material;

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

σ is the radiation factor for free bending waves;

f_c is the critical frequency [$= c_o^2 / (1,8 c_L t)$], in Hertz;

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

α_k is the absorption coefficient for bending waves at the perimeter k ;

l_k is the length of the junction at the perimeter k , in metres;

c_o is the speed of sound in air, in metres per second; $c_o = 340$ m/s;

ρ_o is the density of air, in kilogram per cubic metres.

For calculations in one-third-octave bands the frequency can be taken as the centre frequency of the band considered. For calculations in octave bands the best estimate is obtained by using the centre frequency of the lower one-third-octave band within the octave band considered.

The internal loss factor for common homogeneous building materials is roughly 0,01. The radiation losses can normally be neglected. The absorption coefficients depend on the situation and the structural elements connected at the perimeter.

C.2 Laboratory situation

For measurements in the laboratory in accordance with ISO 10140 (all parts), the average absorption coefficient, is about 0,15 for heavy constructions (around 400 kg/m²). This can be represented by

a heavy frame of 600 mm concrete around the test opening. For that situation α_k can be calculated according to [Formula \(C.2\)](#):

$$\alpha_k = \alpha (1 - 0,9999 \alpha)$$

$$\alpha = \frac{1}{3} \left[\frac{2\sqrt{\chi\psi} (1 + \chi)(1 + \psi)}{\chi(1 + \psi)^2 + 2\psi(1 + \chi^2)} \right]^2$$

$$\chi = \sqrt{\frac{31,1}{f_c}} \quad \psi = 44,3 \frac{f_c}{m'}$$
(C.2)

This is based on a one dimensional theory (see Reference [2]), empirically adjusted for diffuse fields. Based on this the total loss factor for the laboratory situation can be estimated as shown by [Formula \(C.3\)](#):

$$\eta_{\text{tot,lab}} \approx \eta_{\text{int}} + \frac{m'}{485\sqrt{f}} \approx 0,01 + \frac{m'}{485\sqrt{f}}$$
(C.3)

This formula holds for structural elements with a surface mass below $m' = 800 \text{ kg/m}^2$; η_{int} can normally be taken as 0,01.

NOTE 1 The loss factor of a given building element type mounted in a given laboratory can differ from the above averaged estimation.

NOTE 2 For a specific laboratory the values can be calculated as *in situ*, making use of the appropriate values for the vibration reduction index at the borders of the test opening.

C.3 In situ

The *in situ* absorption coefficient at a perimeter will vary between 0,05 and 0,5.

This absorption coefficient α_k for a structure i can be deduced from the vibration reduction index (K_{ij}) at the junction between the considered element i and the element j connected to it, as shown by [Formula \(C.4\)](#).

$$\alpha_k = \sum_{j=1}^3 \sqrt{\frac{f_{c,j}}{f_{\text{ref}}}} 10^{K_{ij}/10}$$
(C.4)

where

f_c is the critical frequency, in Hertz;

f_{ref} is the reference frequency, in Hertz; $f_{\text{ref}} = 1\,000 \text{ Hz}$;

J indicates the elements which are connected to the considered element i at border k.

If the area considered is part of a larger structural element and the junctions are formed by light elements, the actual structural reverberation time can be influenced or dominated by the behaviour of the larger structural element as a whole due to the back flow of vibrational energy.

This effect can be incorporated by maximizing the sum-term in [Formula \(C.1\)](#) for a sub-area S of a large structural element to [Formula \(C.5\)](#):

$$\sum_{k=1}^4 l_k \alpha_k \leq \sum_{k=1}^4 L_k \alpha_k \quad (\text{C.5})$$

where

L_k is the length of junction k of large structural element, in metres;

α_k is the absorption coefficient of junction k of the total floor slab.

By this approach an effective structural reverberation time is calculated which is not the actual structural reverberation time, but yields the correct results for the *in situ* sound reduction index. The actual structural reverberation time is larger by a factor S_{tot}/S .

The *in situ* total loss factor can in general be estimated by [Formula \(C.6\)](#):

$$\eta_{\text{tot,situ}} \approx \eta_{\text{int}} + \frac{c}{\sqrt{f}} \approx 0,01 + \frac{c}{\sqrt{f}} \quad (\text{C.6})$$

with c being a constant depending on the typical building system.

Based on References [21] and [31] the following can be applied:

- $c = 1$ for masonry or concrete elements connected to at least two walls on each of its four sides;
- $c = 0,5$ for elements with $m > 150 \text{ kg/m}^2$ in typical masonry or concrete buildings in Germany and France, since it has been recognized that in these countries

$$10 \lg \eta_{\text{tot,situ}} \approx -12,4 - 3,3 \lg (f/100)$$

- $c = 0,05$ for heavy elements in a further rather light weight surrounding.
- c could be taken as $m/300$ with $\eta_{\text{int}} = 0,005$ based on the German research for lighter elements than 150 kg/m^2 , since it has been recognized that in general

$$10 \lg \eta_{\text{tot,situ}} \approx -12,4 - 3,3 \lg (f/100) + 10 \lg (m/150)$$

NOTE 1 An expression as in [Formula \(C.6\)](#) is preferred since it is based on theory with empirical adjustment of constants, if such an expression covers measured results as well as other empirical expressions.

NOTE 2 The loss factor of a given building element type mounted *in situ* can differ from the above averaged estimation.

Annex D (informative)

Sound reduction index improvement of additional layers

D.1 Sound reduction index improvement of layers

D.1.1 General

The improvement in sound reduction by a layer, such as a resiliently mounted wall lining, thermal insulation system, floating floor or suspended ceiling, is in principle different for flanking transmission and airborne direct transmission and depends additionally on the type of basic structural elements it is applied to. It should therefore be determined by measurements in a laboratory, both for direct and flanking transmission, with the same basic structural element as is applied in the field situation considered.

For the time being there is a standardized measurement method available for airborne direct transmission, but none for flanking transmission, nor any accurate possibilities to derive the effect for flanking transmission from the one for airborne direct transmission or to correct results for changes in the basic structural element. Information is given in this annex for a realistic and practical approach.

D.1.2 Airborne direct transmission, ΔR

- The improvement by a layer is measured in accordance with ISO 10140-1:2016, Annex G. Results can be given for a heavy basic wall or floor, a light weight one or an arbitrary basic wall or floor. At least the results for the heavy basic structural element (approximately 350 kg/m²) will be presented.
- Apply the laboratory results for the heavy basic wall or floor in the calculations for airborne direct transmission; this will be relevant for all kind of walls or floors with a mass of at least 200 kg/m². In other cases use results for a more appropriate basic element, if available.

NOTE The improvement decreases generally with an increase in the surface mass of the basic structural element, mainly due to direct or indirect (at the perimeter) coupling between the layer and the basic structural element. The result for the standardized basic structural element will therefore be correct or on the safe side for structural elements with a surface mass not much larger than that of the standardized basic structural element.

D.1.3 Flanking transmission

Concerning the flanking transmissions, the following comments apply.

- a) The improvement can be determined by measurements in the field or special laboratory facilities as in ISO 10848 (all parts), where it can be ensured that transmission occurs only by a flanking path (i.e. path Ff). This can be realized by special constructions and/or by applying very efficient wall linings and floor coverings to prevent all other transmission paths. The sound reduction index improvement is obtained from the measurement of the sound transmission with and without the lining to be tested, applied to one of the structural elements involved in the flanking transmission path considered. To get results at least comparable as with airborne direct transmission, it is recommended to use as the basic structural element a homogeneous, plastered element with an equivalent mass to the heavy basic element from ISO 10140-1:2016, Annex G. Care should be taken that the sound reduction index for the basic structural element alone is not affected by any indirect airborne transmission through leaks in the element and around the perimeter. Other basic structural elements can be used in addition.
- b) Apply the results for the standardized basic structural element in the calculations for flanking transmission, unless results for a more appropriate basic element are available.

- c) As an estimate, the sound reduction index improvement for flanking transmission can be taken as equal to the improvement for airborne direct transmission, with an exception for lightweight supporting element as mentioned in 4.2.2.

NOTE The improvement for flanking transmission can deviate from that for airborne direct transmission. At low frequencies, that is below the critical frequency of the lining and below the frequency where coupling effects occur, this is due to the different excitation involved, while at higher frequencies this is mainly caused by the effect of leakages in the basic structural element for the measurements without linings.

D.2 Weighted sound reduction index improvement of layer

D.2.1 General

If additional layers (wall linings, floating floors or suspended ceilings) are fixed to a homogeneous basic structural element (separating element or flanking element) the airborne sound insulation can be improved or reduced depending on the resonance frequency f_0 of the system.

For elements where the insulation layer is fixed directly to the basic construction (without studs or battens) the resonance frequency f_0 is calculated by [Formula \(D.1\)](#):

$$f_0 = \frac{1}{2\pi} \sqrt{s' \left(\frac{1}{m'_1} + \frac{1}{m'_2} \right)} \quad (\text{D.1})$$

where

s' is the dynamic stiffness of the insulation layer in accordance with EN 29052-1, in meganewtons per cubic metres;

m'_1 is the mass per unit area of the basic structural element, in kilograms per square metres;

m'_2 is the mass per unit area of the additional layer, in kilograms per square metres.

For additional layers built with metal or wooden studs or battens not directly connected to the basic structural element, where the cavity is filled with a porous insulation layer with an air resistivity $r \geq 5 \text{ kPa s/m}^2$ in accordance with EN 29053, the resonance frequency f_0 is calculated by [Formula \(D.2\)](#):

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{0,111}{d} \left(\frac{1}{m'_1} + \frac{1}{m'_2} \right)} \quad (\text{D.2})$$

where d is the depth of the cavity, in metres.

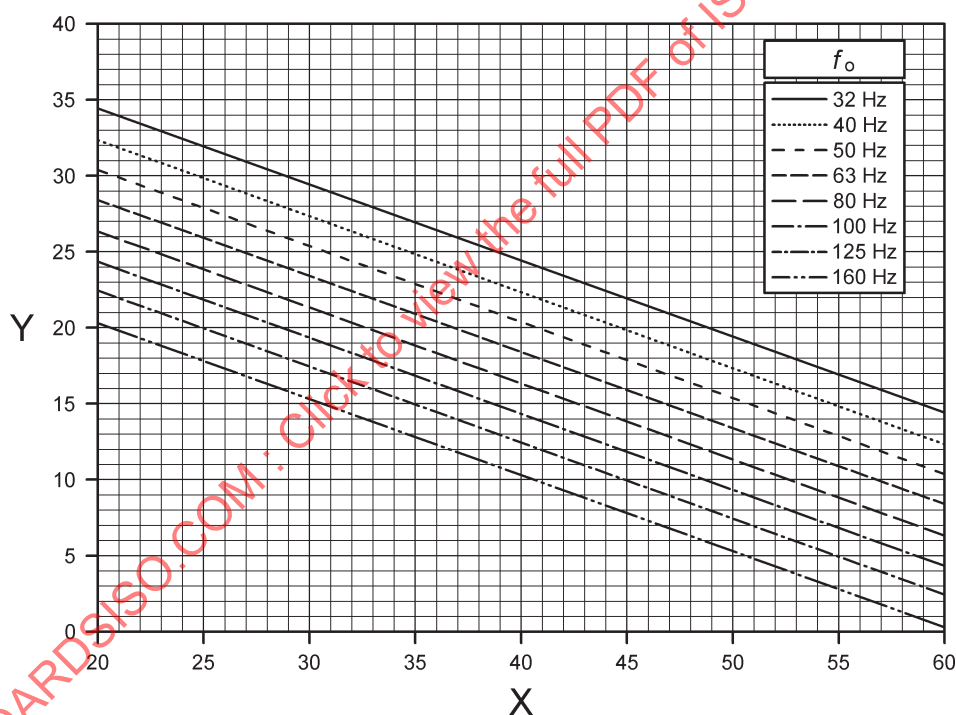
D.2.2 Prediction of performance for interior linings

For basic structural elements with a weighted sound reduction index in the range of $20 \text{ dB} \leq R_w \leq 60 \text{ dB}$, the resulting weighted sound reduction index improvement as a result of an additional layer can be estimated from the resonance frequency f_0 (rounded to the centre frequency of the one-third-octave band in which f_0 falls), according to [Table D.1](#). For resonance frequencies lower than 200 Hz the value also depends upon the weighted sound reduction index of the basic structural element; this is illustrated in [Figure D.1](#).

Table D.1 — Weighted sound reduction index improvement by a lining, depending on the resonance frequency

Resonance frequency f_0 of the lining Hz	ΔR_w dB
$30 \leq f_0 \leq 160$	$74,4 - 20 \lg(f_0) - R_w/2$
200	- 1
250	- 3
315	- 5
400	- 7
500	- 9
630 to 1 600	- 10
$1\,600 \leq f_0 \leq 5\,000$	- 5

NOTE 1 For resonance frequencies below 200 Hz, the minimum value of ΔR_w is 0 dB.
NOTE 2 R_w denotes the weighted sound reduction index of the bare wall or floor in dB.

**Key**

- X weighted sound reduction index of the bare wall/floor R_w in dB
Y weighted sound reduction index improvement ΔR_w in dB

Figure D.1 — Weighted sound reduction index improvement by an additional layer with resonance frequency below 200 Hz, as function of R_w for the bare structural element**D.2.3 Prediction of performance for exterior linings**

For the reference situation with the system applied to the heavy basic wall of about 350 kg/m² with 40 % glued area and no anchors or battens the improvement is estimated with the [Formula \(D.3\)](#) for mineral wool and [Formula \(D.4\)](#) for foams like polystyrene (PS), extruded polystyrene (EPS) or elastified extruded polystyrene (EPPS). The presence of anchors or a different glued area is then taken into account though [Formulae \(D.5\)](#) and [\(D.6\)](#).

Mineral wool:

$$\begin{aligned}\Delta R_w &= -36 \lg f_o + 82,5 \geq -4 \\ \Delta R_A &= -42 \lg f_o + 92,0 \geq -4 \\ \Delta R_{Atr} &= -39 \lg f_o + 87,7 \geq -4\end{aligned}\quad (D.3)$$

Foams:

$$\begin{aligned}\Delta R_w &= -33 \lg f_o + 76,0 \geq -3 \\ \Delta R_A &= -33 \lg f_o + 74,0 \geq -3 \\ \Delta R_{Atr} &= -36 \lg f_o + 77,0 \geq -3\end{aligned}\quad (D.4)$$

Results following [Formulae \(D.3\)](#) and [\(D.4\)](#) are the results for the reference situation and are illustrated in [Figure D.2](#)

If anchors or battens are applied, in the order of 4 per m² to 10 per m², different from the reference situation, the correction shown in [Formulae \(D.5\)](#) is applied:

$$\begin{aligned}\Delta R_w &= 0,66 \Delta R_{w,ref} - 1,2 \\ \Delta R_A &= 0,62 \Delta R_{A,ref} - 1,3 \\ \Delta R_{Atr} &= 0,54 \Delta R_{Atr,ref} - 1,6\end{aligned}\quad (D.5)$$

If the glued area differs from 40 % as in the reference situation, the following corrections can be applied to all single number ratings, resulting from [Formulae \(D.3\)](#), [\(D.4\)](#) and [\(D.5\)](#):

$$\Delta R_{w,A,Atr} = \Delta R_{w,A,Atr;eq.D2,3,4} - 0,05 \% S_o + 2,0 \quad (D.6)$$

where %S₀ is the percentage of the area over which the layer is glued to the basic element.

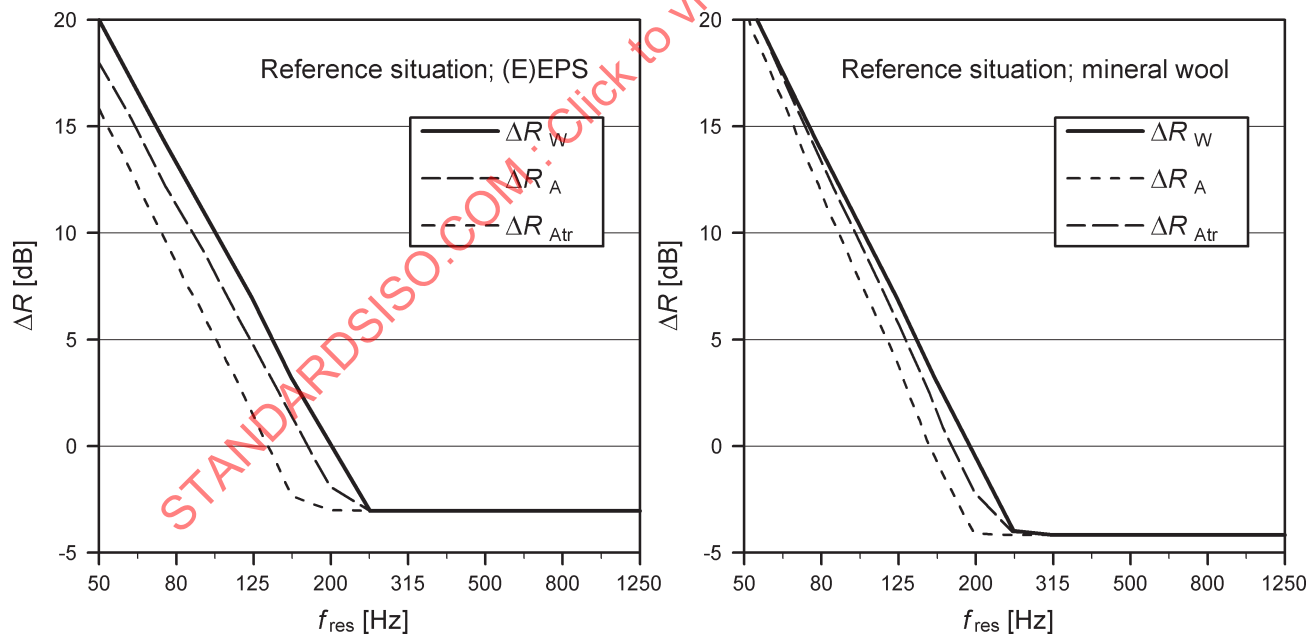


Figure D.2 — Single number ratings of the sound reduction index improvement by an additional layer as function of the resonance frequency and type of interlayer; layer fixed to the basic wall

For additional layers built with metal or wooden studs or battens not directly connected to the basic structural element, the resonance frequency is calculated by [Formula \(D.2\)](#).

For the reference situation with the system applied to the heavy basic wall of about 350 kg/m² the improvement is estimated with [Formula \(D.7\)](#) and is illustrated in [Figure D.3](#).

$$\begin{aligned}\Delta R_w &= -20 \lg f_o + 48 \geq -4 \\ \Delta R_A &= -22 \lg f_o + 51 \geq -4 \\ \Delta R_{Atr} &= -24 \lg f_o + 54 \geq -4\end{aligned}\tag{D.7}$$

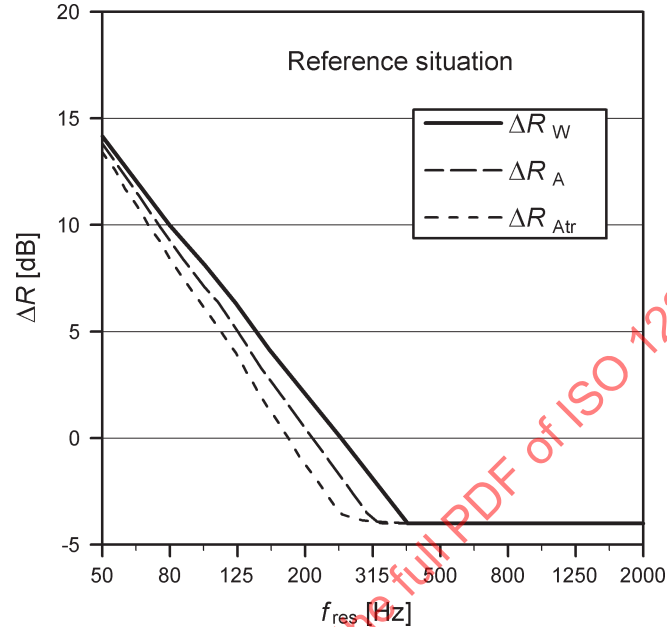


Figure D.3 — Single number ratings of the sound reduction index improvement by an additional layer as function of the resonance frequency; system with studs, not directly fixed to the basic wall

D.2.4 Data transfer to field situation

Even if the sound reduction index improvement for a layer is invariant to the properties of the basic element, the single number rating of the improvement still depends on the acoustic properties of the basic element. So for predictions of performance using single numbers ratings following this document and/or ISO 12354-3, the measured or estimated laboratory single number rating shall be transferred into a field single number rating, taking into account the acoustic performance of the basic element as expressed in R_w . For all types of weighted values this can be done by applying [Formula \(D.8\)](#):

$$\begin{aligned}\Delta R_{w,A,Atr;situ} &= \Delta R_{w,A,Atr;lab} + aX \\ a &= (1,35 \lg f_o - 3,5) \leq 0 \\ X &= (R_{w,situ} - 53) \text{ with } -10 \leq X \leq +7\end{aligned}\tag{D.8}$$

where

- ΔR_{lab} is the measured or estimated single number rating of the sound reduction index improvement in accordance with ISO 10140-1:2016, Annex G for the heavy basic element;
- $R_{w,situ}$ is the weighted sound reduction index for the basic element in the considered field situation, which could be deduced from [Annex B](#).

D.2.5 Accuracy

The performance estimation following [D.2](#) gives the average result with a standard deviation of about 2 dB for all three types of single number rating. If data on the safe side are required, the estimated value could best be reduced by this value.

Annex E (informative)

Vibration transmission over junctions: case of heavy buildings

E.1 General

In this annex, buildings with heavy structures such as masonry or concrete wall and floors are considered, for which junctions are characterized by K_{ij} . The presence of lightweight elements such as partitions, separating walls or façades is still possible, thus leading to junctions mixing heavy and lightweight elements and also treated using K_{ij} as explained in 4.2.2.2. Two types of K_{ij} data are introduced: (i) empirical data deduced from standardized measurements or theory or both (see E.3); and (ii) data from simulations, more difficult to use (with additional input parameters) but more traceable (see E.4). First comparisons have shown that both K_{ij} data types lead to very close calculated building performances.

E.2 Determination methods

The vibration reduction index K_{ij} at junctions can be measured in accordance with ISO 10848-3 or ISO 10848-4.

NOTE It is probably feasible and better (see 4.2.4) to deduce these quantities from *in situ* standardized measurements.

For homogeneous elements the vibration reduction index can also be calculated from the structure-borne power transmission factor γ_{ij} for the transmission over the junction of elements i and j or from the coupling loss factor η_{ij} as used in SEA models.[20,21] γ_{ij} or η_{ij} can be calculated or measured. See Formulae (E.1) and (E.2):

$$K_{ij} = \left(-10 \lg \gamma_{ij} \right) + \left(5 \lg \frac{f_{c,j}}{f_{\text{ref}}} \right) = \left(-10 \lg \gamma_{ji} \right) + \left(5 \lg \frac{f_{c,i}}{f_{\text{ref}}} \right) \text{ dB} \quad (\text{E.1})$$

$$K_{ij} = -10 \lg \eta_{ij} \frac{\pi^2 S_i}{c_o l_{ij}} \sqrt{\frac{f_{c,i}}{f_{c,j}}} \sqrt{f_{\text{ref}} f} \quad (\text{E.2})$$

where

f_c is the critical frequency, in Hertz;

f_{ref} is reference frequency, in Hertz; $f_{\text{ref}} = 1\,000$ Hz;

η_{ij} is the coupling loss factor between element i and j ;

γ_{ij} is the structure-borne power transmission factor between element i and j .

E.3 Empirical data from measurements or theory or both

E.3.1 General

In this section, data on K_{ij} are given with dependency on the mass per unit area of the elements connected at the junction, denoted as m_1 and m_2 . Data are only available for junctions where the elements at either side of the junction in the same plane have the same mass. The relations for K_{ij} are given as function of the quantity M defined as shown by [Formula \(E.3\)](#):

$$M = \lg \frac{m'_{\perp i}}{m'_i} \quad (\text{E.3})$$

where

m'_i is the mass per unit area of the element i in the transmission path ij , in kilograms per square metres;

$m'_{\perp i}$ is the mass per unit area of the other, perpendicular, element making up the junction, in kilograms per square metres.

NOTE 1 The choice of the mass ratio for M is actually arbitrary for transmission around the corner, since the reciprocal of the result for transmission around the corner is the same for $M = \lg m_1/m_2$ or $M = \lg m_2/m_1$.

The background and choice made for the K_{ij} data presented are indicated for each type of junction. Data on K_{ij} are generally deduced from data on the junction velocity level differences. The other terms in the formula for K_{ij} ([3.2.6](#)) are estimated on the basis that the vibration reduction index should be such that for all structural elements and different buildings, the estimated junction velocity level difference should on average be correct. This resulted generally in values for K_{ij} which are 5 dB lower than the corresponding direction-averaged junction velocity level difference. If other relevant data are available on the junction velocity level difference, the same approach could be used to deduce values for the vibration reduction index K_{ij} for application of the model.

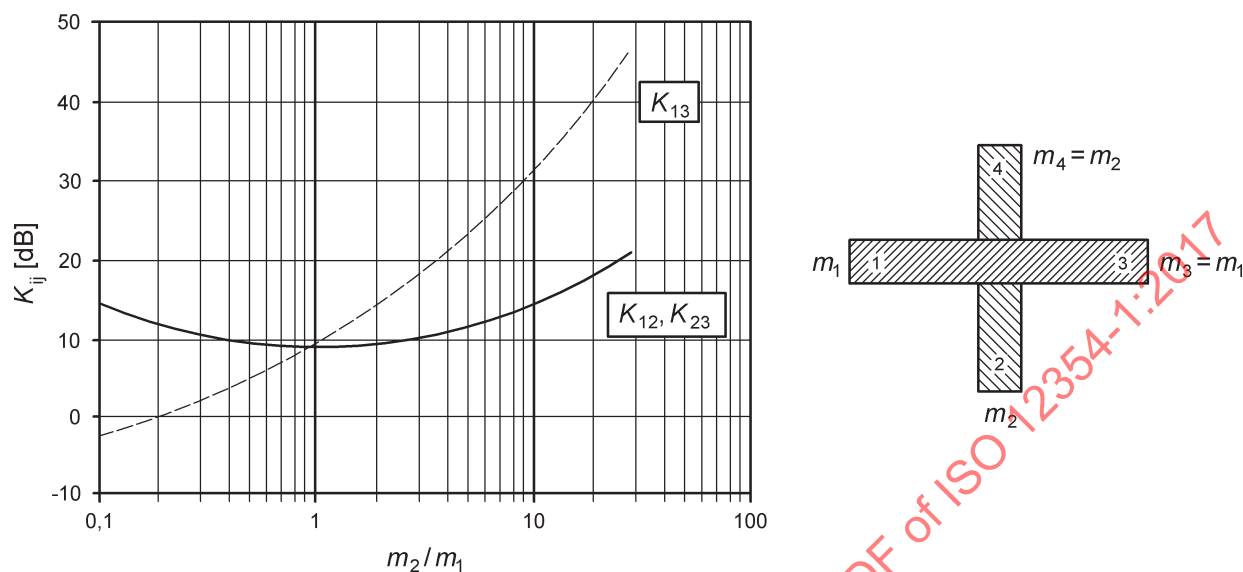
The measured data show a typical spread around the given lines of ± 3 dB; in some cases the deviation can be much larger due to variations in junction details and in workmanship. It is therefore recommended to gather data at national level in accordance with ISO 10848-4 in order to deduce averaged K_{ij} values more adapted to the types of constructions used.

The transmission is in general only slightly dependent on frequency, at least in the frequency range from 125 Hz to 2 000 Hz. Where possible an indication is given of the frequency dependency in this range; the frequency to be applied is the centre frequency of the one-third-octave band or octave band considered. Outside this range the frequency effect can be larger.

For the sake of clarity, graphs of K_{ij} as a function of M are only given in the case where K_{ij} is not dependent on frequency.

E.3.2 Rigid cross-junction

The vibration reduction index K_{ij} for a rigid cross-junction is given in [Figure E.1](#). Examples of such junction are given in [Figure E.2](#).



$$K_{13} = 8,7 + 17,1 M + 5,7 M^2 \text{ dB ; } 0 \text{ dB / oct}$$

$$K_{12} = 8,7 + 5,7 M^2 (= K_{23}) \text{ dB ; } 0 \text{ dB / oct}$$

Figure E.1 — Rigid cross-junction

NOTE The above data are purely based on *in situ* measurements and confirmed by theory, at least for $m_2/m_1 = 1$. For values of m_2/m_1 either much lower or much greater than 1, the data presented take into account better the realistic coupling between elements than the theoretically assumed rigid coupling.

Examples

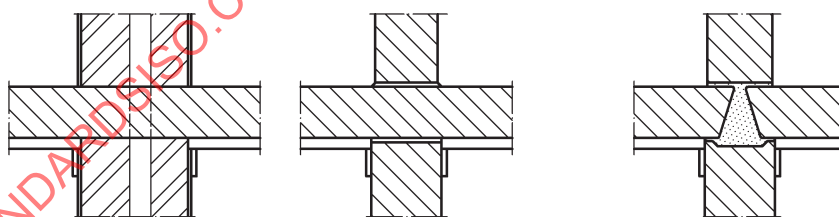
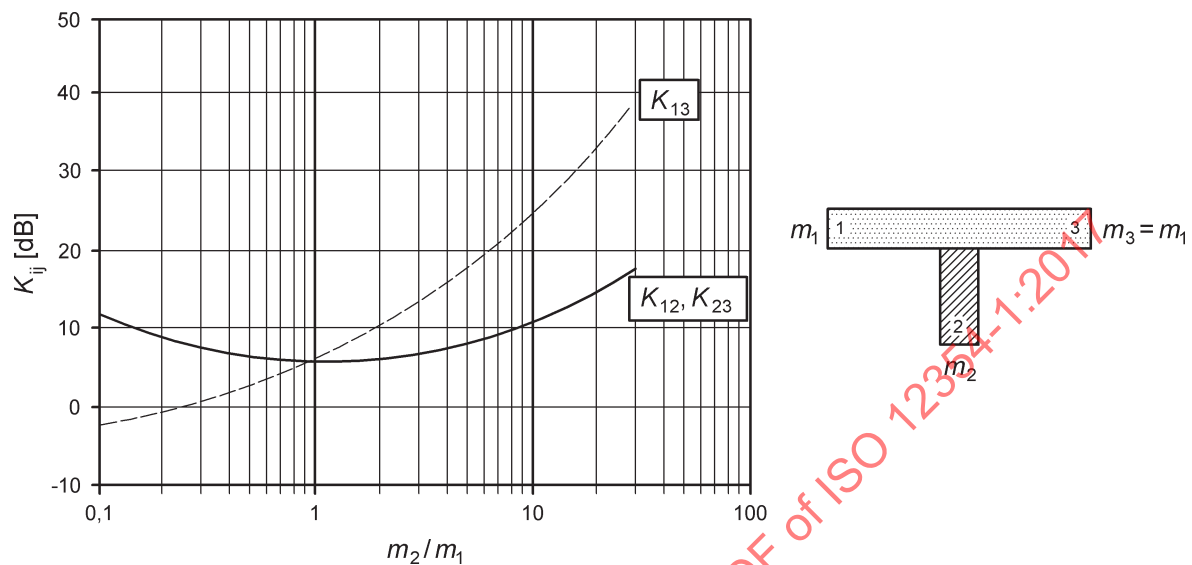


Figure E.2 — Examples of rigid cross-junction

E.3.3 Rigid T-junction

The vibration reduction index K_{ij} for a rigid T-junction is given in [Figure E.3](#). Examples of such junction are given in [Figure E.4](#).



$$K_{13} = 5,7 + 14,1 M + 5,7 M^2 \text{ dB ; } 0 \text{ dB / oct}$$

$$K_{12} = 5,7 + 5,7 M^2 (= K_{23}) \text{ dB ; } 0 \text{ dB / oct}$$

Figure E.3 — Rigid T-junction

NOTE The above data are obtained from the data for cross junctions, by applying the theoretical difference between T and X junctions according to Reference [2].

Examples

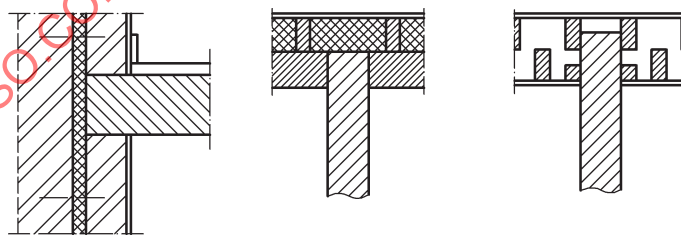


Figure E.4 — Examples of rigid T-junction

E.3.4 Wall junction with flexible interlayers

The vibration reduction index K_{ij} for a wall junction with flexible interlayers is given in Figure E.5. Examples of such junction are given in Figure E.6. The presence of flexible interlayers in junction can modify the junction type; for example, a cross-junction can be changed into a T-junction or a T-junction into an L-junction (corner junction).

For masonry wall junction and for common resilient joints (resilient layer with an apparent dynamic stiffness s'_t between 50 MN/m³ and 100 MN/m³ in accordance with EN 29052-1):

- a) if the transmission path crosses one joint:

$$K_{ij} = K_{ij,rigid} + \Delta_l \text{ (dB)}$$

- b) if the transmission path crosses two joints:

$$K_{ij} = K_{ij,rigid} + 2 \Delta_l \text{ (dB)}$$

where

$$\Delta_l = C_c \lg \frac{f}{f_1} \text{ (dB)}$$

$C_c = 20$ for a load lower than 80 kN/m² on the resilient layer;

$C_c = 15$ for a load between 80 kN/m² and 750 kN/m² on the resilient layer;

$C_c = 10$ for a load higher than 750 kN/m² on the resilient layer.

and, $\Delta_l \geq 5$ dB

$f_1 = 110$ Hz for typical resilient joint where s'_t is between 50 MN/m³ and 100 MN/m³ in accordance with EN 29052-1.

NOTE 1 $f_1 = 50$ Hz for more flexible resilient joint where s'_t is between 30 MN/m³ and 49 MN/m³ in accordance with EN 29052-1.

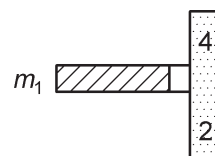
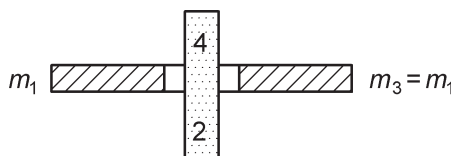
NOTE 2 The frequency f_1 varies as $\left(E_1 / t_1 \sqrt{\rho_1 \rho_2}\right)^{1,5}$ with E_1 and t_1 being respectively the Young's modulus and the thickness of the interlayer, and ρ_1, ρ_2 the densities of the connected elements.

NOTE 3 For more accuracy, the coefficient C_c of Δ_l can be estimated with the following empirical formula ("load" is the right load applied on the resilient joint in kN/m²):

$$C_c = -\frac{\text{load}}{\text{load}_{ref}} + 20$$

$$\text{Load}_{ref} = 100 \text{ kN/m}^2$$

NOTE 4 $K_{24} = 3,7 + 14,1 M + 5,7 M^2$ dB ; $0 \leq K_{24} \leq -4$ dB ; (slope: 0 dB/oct.)



NOTE 5 $K_{23} = 5,7 + 14,1 M + 5,7 M^2$ dB ; (slope: 0 dB/oct.)

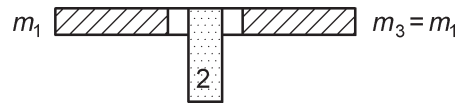
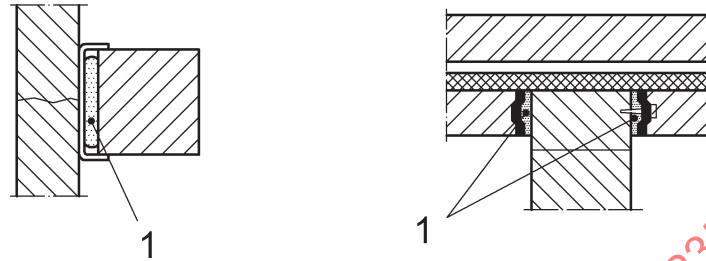


Figure E.5 — Wall junction with flexible interlayers

Examples



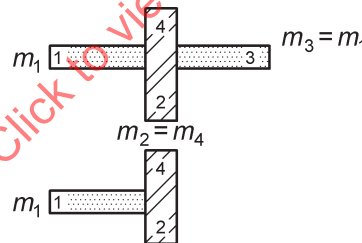
Key

1 elastic

Figure E.6 — Examples of wall junction with flexible interlayers

E.3.5 Junction of lightweight double leaf wall and homogeneous elements

The vibration reduction index K_{ij} for a junction of lightweight double leaf wall and homogeneous elements is given in Figure E.7. Examples of such junction are given in Figure E.8.



$$K_{13} = 10 + 20 M - 3,3 \lg \frac{f}{f_k} \text{ dB and minimum 10 dB}$$

$$K_{24} = 3,0 + 14,1 M + 5,7 M^2 \text{ dB ; } \frac{m_2}{m_1} > 3 ; 0 \text{ dB / oct}$$

$$K_{12} = 10 + 10 |M| + 3,3 \lg \frac{f}{f_k} \left(= K_{23} \right)$$

$$f_k = 500 \text{ Hz}$$

The lightweight elements are considered as single element of absorption length $a_{\text{situ}} = S / l_0$.

NOTE The above data are purely based on *in situ* measurements.

Figure E.7 — Junction of lightweight double leaf wall and homogeneous elements

Examples

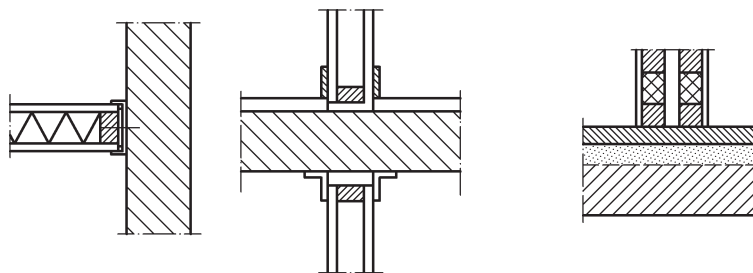
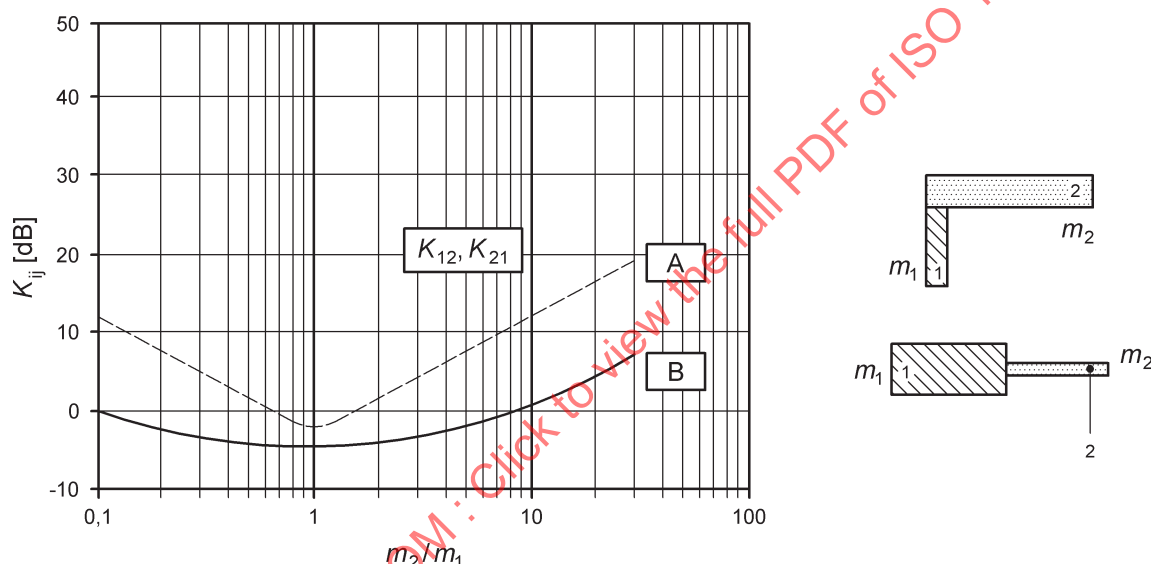


Figure E.8 — Examples of junction of lightweight double leaf wall and homogeneous elements

E.3.6 Corner or thickness change

The vibration reduction index K_{ij} for corner or thickness change is given in Figure E.9.



where

A Corner:

$$K_{12} = 15 |M| - 3 \text{ dB and minimum } -2 \text{ dB } (= K_{21}); 0 \text{ dB / oct.}$$

B Change:

$$K_{12} = 5 M^2 - 5 \text{ dB } (= K_{21}); 0 \text{ dB / oct.}$$

Figure E.9 — Corner or thickness change

NOTE The above data are purely based on theory according to Reference [2] and globally adjusted for random incidence.

E.4 Data from simulations

In this section, data on K_{ij} have been obtained from numerical simulations of vibration transmission across L-, T- and X- junctions of homogeneous, isotropic plates.[41] As more experience is gained with

using these values, the intention in future revisions is to use numerical simulations to provide data on K_{ij} for more complex types of junctions.

In [E.3](#), K_{ij} is assumed to be frequency-independent to simplify the calculation procedure; however, in practice K_{ij} becomes frequency-dependent in the mid- and high-frequency range where there are in-plane waves as well as bending waves generated when bending waves are incident upon the junction. For this reason the data from numerical simulations in this section is given in three different frequency ranges: a low-frequency range (50 Hz to 200 Hz), a mid-frequency range (250 Hz to 1k Hz) and a high-frequency range (1,25 kHz to 5 kHz). For most junctions of heavyweight walls and floors, the generation of in-plane waves only becomes important in the mid- and high-frequency ranges.

In [E.3](#), K_{ij} is shown as a function of the ratio of mass per unit areas. However, in this section the structure-borne power transmission factor, γ_{ij} , is calculated as a function of the PC ratio from which K_{ij} can then be calculated. (Note that the PC ratio equals the ratio ψ / χ in Reference [1]). The advantage of this approach is that (a) it provides a strong relationship between the variables, where there are only bending waves, and (b) it reduces the scatter in results when there are bending and in-plane waves. See [Formula \(E.4\)](#):

$$\text{PC ratio} = \sqrt[4]{\frac{m'_{\perp i} B_{\perp i}^3}{m'_i B_i^3}} = \frac{m'_{\perp i}}{m'_i} \left(\frac{f_{c,i}}{f_{c,\perp i}} \right)^{3/2} = \frac{m'_{\perp i}}{m'_i} \left(\frac{t_{\perp i} c_{L,\perp i}}{t_i c_{L,i}} \right)^{3/2} \quad (\text{E.4})$$

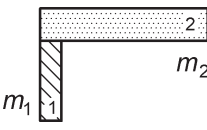
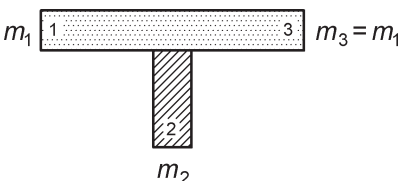
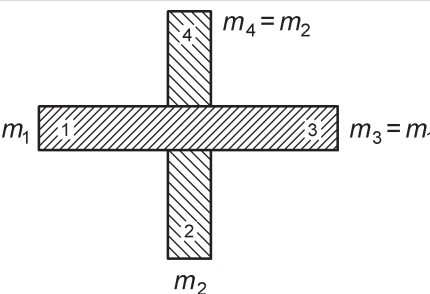
Two different types of models are used to determine transmission loss values: (1) wave theory and (2) finite element methods, both of which assume thin plate bending theory. For the approach using wave theory [\[27,38\]](#) the low-frequency range considers only bending waves by assuming a pinned junction line whereas the mid- and high-frequency ranges consider bending, transverse-shear and quasi-longitudinal waves with an unpinned junction line. Wave theory assumes that there is a diffuse vibration field on the source plate. For the finite element approach [\[39,40,41\]](#) a pinned junction line is also used for the low-frequency range and an unpinned junction line for the mid- and high-frequency ranges with all other plate boundaries pinned. The *in situ* total loss factor that was applied in the finite element models was calculated using [Formula \(C.6\)](#) where $c = 1$. An ensemble of plate junctions was calculated using the material properties from Reference [2], given in [Table B.3](#), and where the plates represented walls or floors with dimensions in the range from 2,5 m to 6 m. Regression lines were determined using the data points from wave theory and the ensemble average value from FEM with $R^2 > 0,87$.

For the junction under consideration, calculate PC according to [Formula \(E.5\)](#):

$$\text{PC} = \lg(\text{PC ratio}) = \lg \left(\sqrt[4]{\frac{m'_{\perp i} B_{\perp i}^3}{m'_i B_i^3}} \right) = \lg \left(\frac{m'_{\perp i}}{m'_i} \left(\frac{f_{c,i}}{f_{c,\perp i}} \right)^{3/2} \right) = \lg \left(\frac{m'_{\perp i}}{m'_i} \left(\frac{t_{\perp i} c_{L,\perp i}}{t_i c_{L,i}} \right)^{3/2} \right) \quad (\text{E.5})$$

The numbering system for the plates in the L, T and X-junctions is the same as in [E.3](#). The structure-borne power transmission loss is calculated according to the formulae given in [Table E.1](#), which are valid for $-1,2 \leq \text{PC} \leq 2,4$ (equivalent to $0,064 \leq \text{PC ratio} \leq 242$).

Table E.1 — Structure-borne power transmission loss expressions for L, T and X-junctions as a function of PC

L-junction		
	Low-frequency range	$-10 \lg \gamma_{12} = -0,8PC^3 + 5PC^2 + 1,5PC + 5,9$
	Mid- and high-frequency ranges	$-10 \lg \gamma_{12} = -0,24PC^3 + 3PC^2 + 1PC + 9,5$
T-junction		
	Low-frequency range	$-10 \lg \gamma_{12} = -0,4PC^3 + 4,8PC^2 - 1,4PC + 9,4$ $-10 \lg \gamma_{13} = -0,3PC^3 + 4,5PC^2 + 7,5PC + 8,9$
	Mid-frequency range	$-10 \lg \gamma_{12} = -0,43PC^3 + 3,8PC^2 - 0,3PC + 11,5$ $-10 \lg \gamma_{13} = -0,2PC^3 + 1,3PC^2 + 6,9PC + 9,1$
	High-frequency range	$-10 \lg \gamma_{12} = -0,43PC^3 + 3,8PC^2 - 0,3PC + 11,5$ $-10 \lg \gamma_{13} = -0,04PC^3 + 1PC^2 + 4,5PC + 5$
X-junction		
	Low-frequency range	$-10 \lg \gamma_{12} = -0,5PC^3 + 4,1PC^2 + 1,4PC + 12,5$ $-10 \lg \gamma_{13} = -0,2PC^3 + 3,7PC^2 + 10,3PC + 11,7$
	Mid-frequency range	$-10 \lg \gamma_{12} = -0,5PC^3 + 4,1PC^2 + 1,4PC + 12,5$ $-10 \lg \gamma_{13} = 0,03PC^3 + 1,8PC^2 + 8,8PC + 11,4$
	High-frequency range	$-10 \lg \gamma_{12} = -0,5PC^3 + 4,1PC^2 + 1,4PC + 12,5$ $-10 \lg \gamma_{13} = 0,2PC^3 + 1,4PC^2 + 5,9PC + 7,3$

Calculate K_{ij} from the transmission loss according to [Formula \(E.1\)](#) for which the critical frequency can be calculated using [Formula \(E.6\)](#)

$$f_c = \frac{c_0^2}{\pi} \sqrt{\frac{3m'(1-\nu^2)}{Et^3}} = \frac{c_0^2 \sqrt{3}}{\pi t c_L} \quad (\text{E.6})$$

where

t is the plate thickness, in m;

E is the Young's modulus, in N/m².

Annex F (informative)

Vibration transmission over junctions: case of lightweight buildings

F.1 General

In this annex, two types of lightweight buildings are considered:

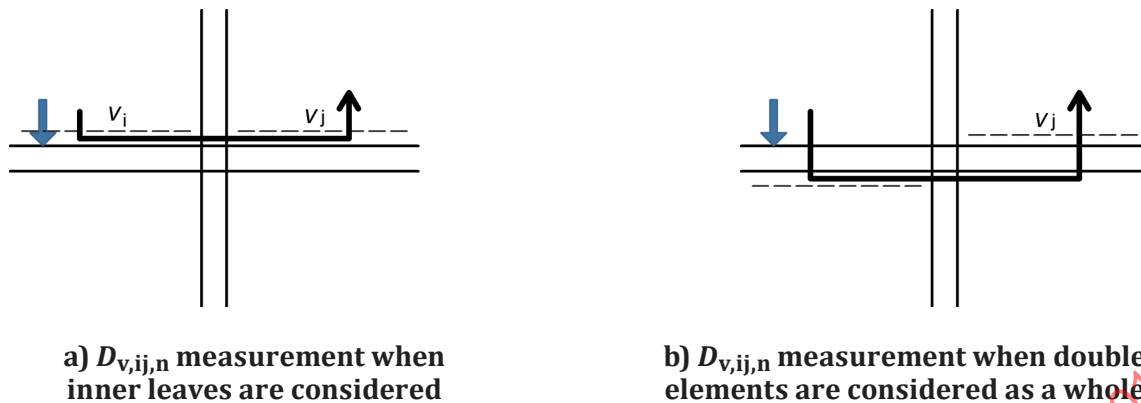
- a) buildings made of massive wood based elements such as cross laminated timber elements, for which the structural reverberation time is in most cases principally determined by the connected elements and the corresponding junctions are characterized by K_{ij} (see [E.3](#));
- b) buildings such as steel or wood frame lightweight buildings for which junctions are characterized by $D_{v,ij,n}$ (see [E.4](#)).

F.2 Determination methods

The vibration reduction index K_{ij} at junctions as well as the normalized direction-averaged velocity level difference $D_{v,ij,n}$ at junctions can be measured in accordance with ISO 10848-3 or ISO 10848-4.

NOTE It is probably feasible and better (see [4.2.4](#)) to deduce these quantities from *in situ* standardized measurements.

For steel or wood frame lightweight elements it is necessary to identify which element is to be considered in the source room and the receiving room. Two kinds of elements are considered, single-frame elements where the layer(s) on both sides of the wall/floor are directly connected to the same frame and double-frame elements where there are two isolated frames that support the layer(s) on each side of the wall/floor. In the prediction model for both single-frame and double-frame walls/floors it is possible to consider either the whole element or only the inner leaf (i.e. layer(s) and frame) that faces into the source and receiving rooms. Note that the appropriate $D_{v,ij,n}$ index will be measured differently as shown in [Figure E.1](#). Empirical data on $D_{v,ij,n}$ are given for both cases in [F.4](#).



Key

blue arrow excitation location
dotted lines measuring surfaces

Figure F.1 — Possible junction measurement configurations

F.3 Empirical data for junctions characterized by K_{ij}

F.3.1 General

Junctions between cross-laminated timber (CLT) building elements is the only case presented in this section.

F.3.2 Junctions between cross-laminated timber (CLT) building elements

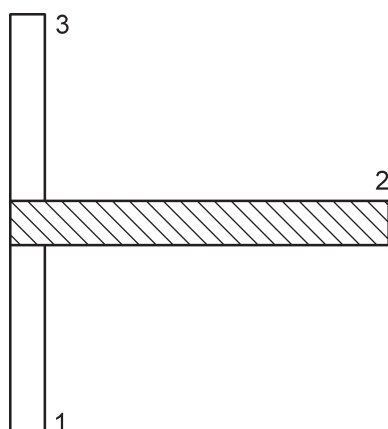
F.3.2.1 General

Cross laminated timber building elements are elements for which the structural reverberation time is in most cases principally determined by the connected elements. The junctions can therefore be characterized by the vibration reduction index K_{ij} . However, these junctions are not rigid and the K_{ij} values are higher than for rigid junctions and show a significant dependency on frequency.

So far, only data for junctions between elements of mass per unit area ratio $0,5 < m_1/m_2 < 2$ are available. The values given are mean values obtained from junction measurements in a few buildings.^[37]

F.3.2.2 T-junction

The vibration reduction index K_{ij} for a T-junction is given in [Figure F.2](#).



$$K_{13} = 22 + 3.3 \lg(f/f_k)$$

$$K_{23} = 15 + 3.3 \lg(f/f_k)$$

$$f_k = 500 \text{ Hz (slope: 1dB/oct.)}$$

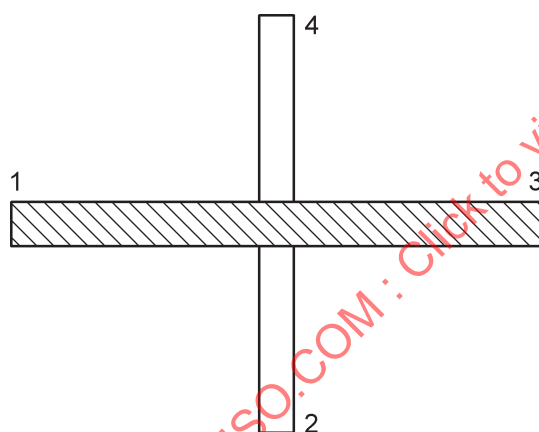
Key

1, 2, 3 junction element numbering used in K_{ij} formulae

Figure F.2 — T junction between CLT elements

F.3.2.3 Cross-junction

The vibration reduction index K_{ij} for a cross-junction is given in [Figure F.3](#).



$$K_{13} = 10 - 3.3 \lg(f/f_k) + 10 M$$

$$K_{24} = 23 + 3.3 \lg(f/f_k)$$

$$K_{14} = 18 + 3.3 \lg(f/f_k)$$

$$f_k = 500 \text{ Hz}$$

Key

1, 2, 3, 4 junction element numbering used in K_{ij} formulae

Figure F.3 — Cross junction between CLT elements

F.4 Empirical data for junctions characterized by $\overline{D}_{v,ij,n}$

F.4.1 General

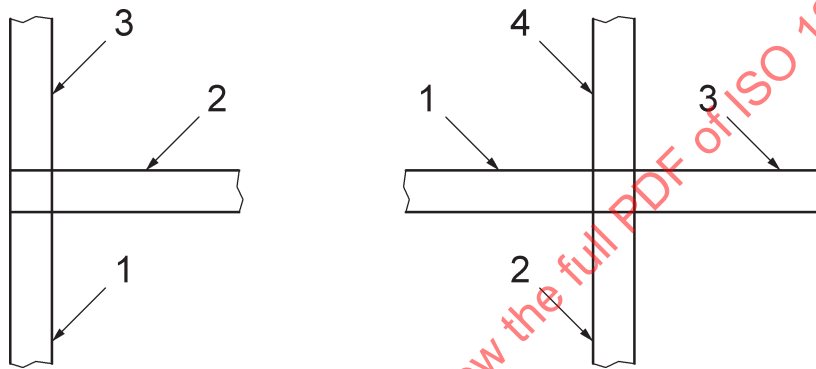
In this section, building such as steel or wood frame lightweight buildings are considered. The junction data obtained usually show a frequency dependency stronger than for heavy homogeneous elements. Attention is required for which element is to be considered in the source room and the receiving room: either the whole element or only the inner leaf, as described in [F.2](#). Both are possible in combination with the appropriate sound reduction indices R_i , R_j of the elements and the appropriate $\overline{D}_{v,ij,n}$ which will be measured differently (see [Figure F.1](#)), and will lead to very different values. Empirical data on

$D_{v,ij,n}$ are given here for both cases, with indications on which element is to be considered. The data given have been obtained from available measurements of timber frame lightweight elements; [37] their use should be restricted to this type of elements.

F.4.2 Timber frame lightweight building elements; inner leaf transmission

F.4.2.1 General

For this type of elements, the mass per unit area is in general not too different between elements, so its influence has been neglected. These elements are highly damped and the junctions can therefore be characterized by the normalized direction-averaged vibration level difference $D_{v,ij,n}$. The values given correspond to double elements taken into account as inner leaf (see E.2) and are mean values obtained from junction measurements in different timber frame lightweight buildings. Figure F.4 indicates the inner leaves considered in the formulae given in this section.



Key

1, 2, 3, 4 junction element numbering used in K_{ij} formulae

Figure F.4 — T and X junction inner leaf numbering

The formulae given in F.4.2.2, F.4.2.3, F.4.2.4 and F.4.2.5 are valid over the frequency range 50 Hz to 5 000 Hz for the following categories of lightweight elements (mass per surface area without frame):

- floors in the range 30 kg/m² to 70 kg/m²;
- façades in the range 25 kg/m² to 45 kg/m²;
- double frame wall in the range 35 kg/m² to 75 kg/m²;
- single frame partition in the range 20 kg/m² to 40 kg/m².

Solid wood and CLT elements are excluded.

The measured data show a typical spread around the given values of ± 6 dB. It is therefore recommended to gather data at national level in order to deduce averaged $D_{v,ij,n}$ values more adapted to the types of constructions used and with smaller uncertainty.

F.4.2.2 T-junction floor: façade

Floor-façade or façade-façade path, as shown by [Formula \(F.1\)](#):

$$\overline{D_{v,12,n}} = \overline{D_{v,13,n}} = 30 + 10 \lg(f / f_k) \quad (\text{F.1})$$

$$f_k = 500 \text{ Hz (slope: 3dB/oct.)}$$

Examples

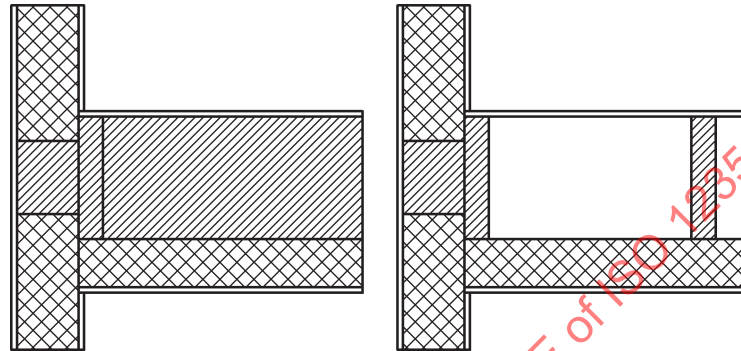


Figure F.5 — Examples of T-junction between a floor and a façade

F.4.2.3 Cross-junction floor: double frame separating wall

Any horizontal path through the cavity (except floor-floor), as shown by [Formula \(F.2\)](#):

	$\overline{D_{v,ij,n}} = 38 + 13,3 \lg(f / f_k)$	(slope: 4 dB/oct.)	
Floor-floor path	$\overline{D_{v,13,n}} = 36 + 3,3 \lg(f / f_k)$	(slope: 1 dB/oct.)	(F.2)
Floor-separating wall	$\overline{D_{v,12,n}} = 18 + 3,3 \lg(f / f_k)$		
Separating wall-separating wall	$\overline{D_{v,24,n}} = 22 + 3,3 \lg(f / f_k)$		

$$f_k = 500 \text{ Hz}$$

Examples

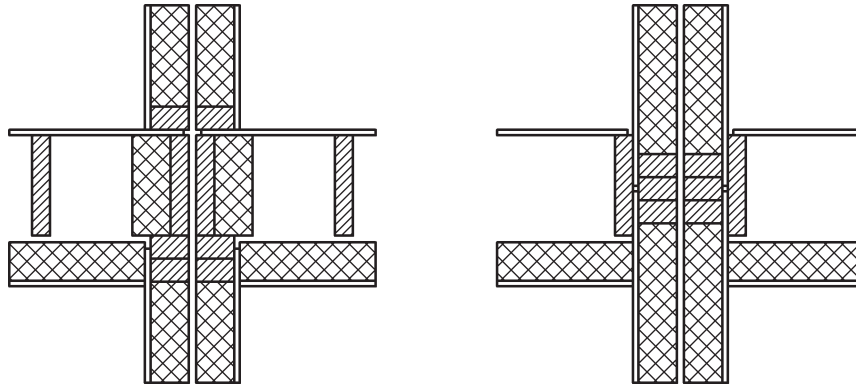


Figure F.6 — Examples of cross-junction between a floor and a double frame separating wall

F.4.2.4 T junction façade: double frame separating wall

Any path through the cavity, as shown by [Formula \(F.3\)](#):

$$\overline{D_{v,12,n}} = \overline{D_{v,13,n}} = 38 + 13,3 \lg(f / f_k) \quad (F.3)$$

$$f_k = 500 \text{ Hz}$$

Examples

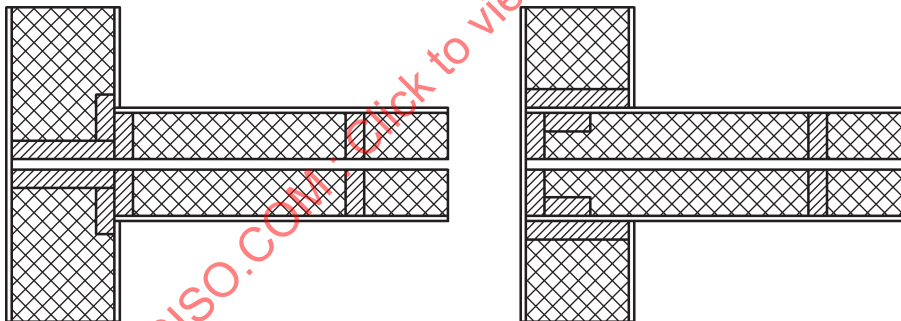


Figure F.7 — Examples of T-junction between a façade and a double frame separating wall

F.4.2.5 Cross-junction with continuous floor

Floor-floor or floor-wall path, as shown by [Formula \(F.4\)](#):

$$\overline{D_{v,13,n}} = \overline{D_{v,34,n}} = 20 - 3,3 \lg(f / f_k) \quad (F.4)$$

Wall-wall path

$$\overline{D_{v,24,n}} = 30 + 3,3 \lg(f / f_k)$$

$$f_k = 500 \text{ Hz}$$

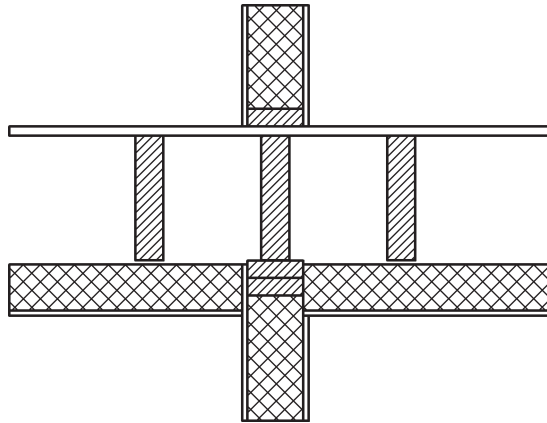
Example

Figure F.8 — Example of cross-junction with a continuous floor

F.4.3 Timber frame lightweight building elements; double elements as a whole**F.4.3.1 Junction of lightweight coupled double leaf walls**

As shown by [Formula \(F.5\)](#):

$$\overline{D_{v,13,n}} = 15 + 20 M - \left(3,3 \lg \frac{f}{f_k} \right) \text{ dB} \quad \text{and minimum 10 dB}$$

$$\overline{D_{v,12,n}} = 15 + 10 |M| - \left(3,3 \lg \frac{f}{f_k} \right) \text{ dB} \quad \left(= \overline{D_{v,23,n}} \right) \quad (\text{F.5})$$

$$f_k = 500 \text{ Hz}$$

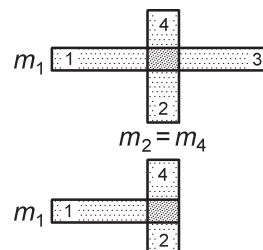


**Figure F.9 — Junction of lightweight couple double leaf walls
(composed elements considered as a whole)**

Examples

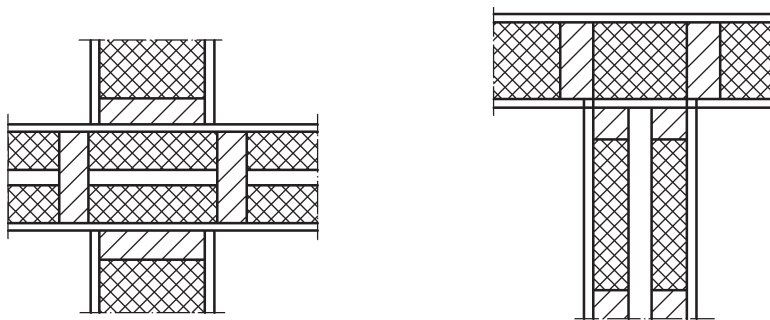


Figure F.10 — Examples of junction of lightweight couple double leaf walls

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Annex G (informative)

Determination of normalized flanking level difference

G.1 Laboratory measurement of total normalized flanking transmission

For many lightweight, composed elements the flanking transmission only marginally depends on the type of surrounding structures and the way it is mounted, due to a large damping in the materials and structures. In these cases, the total flanking transmission can be adequately characterized by the normalized flanking level difference $D_{n,f}$ as measured in accordance with ISO 10848-1, ISO 10848-2 and ISO 10848-3. The transmission is mostly dominated by path Ff, as is the restriction of the standard. However, if necessary, the same approach could be used for other paths like Df or Fd if the appropriate junction is available and precautions are taken to restrict transmission to those paths.

The flanking sound transmission can be described as being either structure-borne, airborne or a combination of structure-borne and airborne. This determines the data transfer from laboratory to *in situ* which is described in [E.3](#).

G.2 Transfer of laboratory data to *in situ*

G.2.1 Dominant structure-borne transmission

In case of mainly structure-borne transmission the normalized flanking level difference will be the same *in situ* as in the laboratory situation. Hence, [Formula \(G.1\)](#) can be assumed:

$$D_{n,f,situ} = D_{n,f,lab} \quad (G.1)$$

NOTE It might become necessary for some types of construction to perform additional laboratory measurements, to establish that the structure-borne transmission is indeed dominant.

G.2.2 Dominant airborne transmission

In the case of mainly airborne transmission the following relation can be used to determine the field value of the normalized flanking level difference $D_{n,f,situ}$ from the product information $D_{n,f,lab}$, see [Figure G.1](#) and [Formulae \(G.2\)](#) and [\(G.3\)](#).

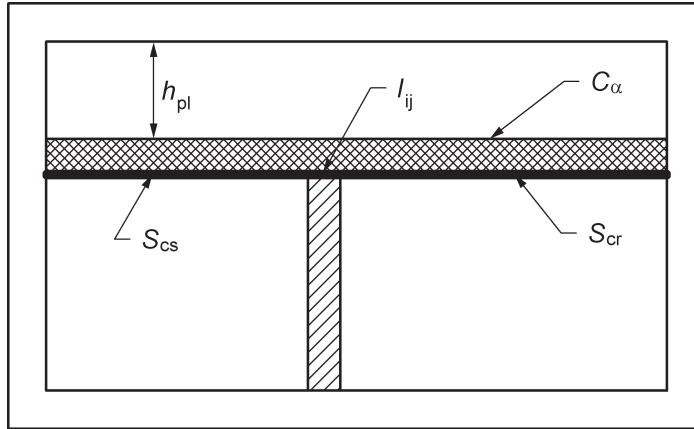


Figure G.1 — Illustration of the relevant quantities for the prediction of indirect airborne transmission

$$D_{n,f,situ} = D_{n,f,lab} + \left(10 \lg \frac{h_{pl} l_{ij}}{h_{lab} l_{lab}} \right) + \left(10 \lg \frac{S_{cs,lab} S_{cr,lab}}{S_{cs} S_{cr}} + C_{\alpha} \right) \text{ dB} \quad (\text{G.2})$$

with

a) no absorbing lining:

$$C_{\alpha} = 0 \text{ dB}$$

b) absorbing lining:

$$C_{\alpha} = 0 \text{ dB} \quad f \leq 0,015 \frac{c_o}{t_a} \quad (\text{G.3})$$

$$C_{\alpha} = 10 \lg \sqrt{\frac{S_{cs} S_{cr}}{S_{cs,lab} S_{cr,lab}} \frac{h_{lab}}{h_{pl}}} \text{ dB} \quad 0,015 \frac{c_o}{t_a} < f < \frac{0,3 c_o}{\min(h_{lab}, h_{pl})}$$

$$C_{\alpha} = 10 \lg \sqrt{\frac{S_{cs} S_{cr}}{S_{cs,lab} S_{cr,lab}} \frac{h_{lab}^2}{h_{pl}^2}} \text{ dB} \quad f \geq \frac{0,3 c_o}{\min(h_{lab}, h_{pl})}$$

where

S_{cs}, S_{cr} is the area of the ceiling in the source room and receiving room, respectively, in square metres; in the laboratory, as reference, with the index “lab”, which for the laboratory fulfilling ISO 10848-series recommendations can be taken as $S_{cs,lab} = S_{cr,lab} = 20 \text{ m}^2$;

h_{pl} is the free height of the plenum above the ceiling, in metres; in the laboratory, as reference, this is h_{lab} , which for the laboratory fulfilling ISO 10848-series recommendations can be taken as $h_{lab} = 0,7 \text{ m}$;

t_a is the thickness of the absorbing lining in the plenum, in metres;

c_o is the sound speed in air, in metres per second; $c_o = 340 \text{ m/s}$.

NOTE 1 It might become necessary for some types of construction to perform additional laboratory measurements, to establish that the indirect air-borne transmission is indeed dominant and to establish a more accurate discriminant for the absorption in the plenum.

NOTE 2 The flanking normalized level difference will normally relate to the complete flanking construction, including the indirect airborne transmission through auxiliaries such as air inlets and light fixtures. However, in this case it could be constructed from separate data on the indirect transmission for the ceiling and the auxiliaries.

G.3 Determination from performance of the elements

The normalized flanking level difference can be deduced from an appropriate combination of measured, calculated or estimated data on the acoustic performance of the elements as given in [Formula \(G.4\)](#). 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 $D_{n,f,ij}$ are available.

$$D_{n,f,ij} = \frac{R_i + R_j}{2} + \Delta R_i + \Delta R_j + \overline{D_{v,ij,n}} + \left(10 \lg \frac{A_o}{l_o l_{ij,lab}} \right) \text{ dB} \quad (\text{G.4})$$

The normalized direction-averaged vibration level difference can be determined in accordance with ISO 10848 (all parts).

Annex H (informative)

Determination of indirect airborne transmission from performance of system elements

H.1 Hall or corridor

The normalized level difference $D_{n,s}$ for transmission via halls and corridors or the cavity within a double facade can be estimated from [Formula \(H.1\)](#) if diffuse sound fields in the rooms and the hall can be assumed, see [Figure H.1](#).

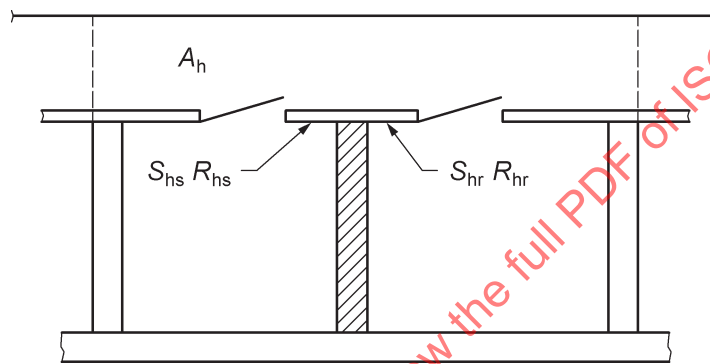


Figure H.1 — Illustration of two rooms along a corridor with relevant quantities

$$D_{n,s} = D_{n,h} = R_{hs} + R_{hr} + \left(10 \lg \frac{A_h A_o}{S_{hs} S_{hr}} + C_{\text{doorposition}} \right) \text{dB} \quad (\text{H.1})$$

where

- R_{hs} is the sound reduction index of the wall between the hall and the source room, in decibels;
- R_{hr} is the sound reduction index of the wall between the hall and the receiving room, in decibels;
- S_{hs} is the area of the wall between the hall and the source room, in square metres;
- S_{hr} is the area of the wall between the hall and the receiving room, in square metres;
- A_h is the equivalent sound absorption area of the hall, in square metres;
- $C_{\text{doorposition}}$ is a correction term to take into account the effect of the orientation of the doors to each other.

NOTE The value for this correction term can be estimated to be between -2 dB for doors at 90° to each other and less than 1 m apart to 0 dB for greater distances and/or parallel positions.

The sound reduction index of the walls, R_h , follows from the sound reduction indices of the different composing elements R_{hi} , such as the wall itself, doors and windows including seals. Normally the sound reduction to the hall is dominated by the doors in those walls and the quality of the seals.

For halls the absorption is normally dominated by the area of the opening to the stairways; for (long) corridors the parts of the corridor beyond the rooms under consideration can be taken into account as absorption by the open cross section of the corridor.

H.2 Ventilation system

The normalized level difference $D_{n,s}$ for transmission via ventilation systems could be estimated from the transmission loss through the elements involved, such as bends, grids, silencers and area changes. This is treated in EN 12354-5, which examines the estimation of the sound levels due to installations, especially in [4.2](#).

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Annex I (informative)

Sound insulation in the low frequency range

I.1 General

At low frequencies, there are three issues that need to be considered when comparing estimates of the airborne sound insulation with field measurements. The first issue concerns the large spatial variation of the sound pressure level in the source and receiving rooms.^[22,23,32] 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.^[24,25] The third issue is that the accuracy of estimating the *in situ* performance depends on the laboratory measurement of the 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.^[32,33] For this reason it is advisable to use laboratory measurements of the sound reduction index in accordance with ISO 15186-3 as input data. 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 airborne sound insulation are carried out in accordance with ISO 16283-1. 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 m³, but remain important for larger room volumes. These issues are specifically considered in ISO 16283-1 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 m³. 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 source and/or receiving room using either a fixed microphone or a manually-held microphone. However, for comparison of estimates with measurements made in accordance with ISO 16283-1 in receiving room volumes below 25 m³, it is advisable to account for the higher energy density near the room boundaries using the Waterhouse correction (see [I.2](#)).

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

I.2 Waterhouse correction

See [Formula \(I.1\)](#):

$$C_w = \left(10 \lg \left(1 + \frac{c_o S_t}{8 f V} \right) \right) \text{ dB} \quad (\text{I.1})$$

where

c_o is the sound speed in air (c_o 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 subtracted from the estimate of the *in situ* airborne 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 I.1](#).

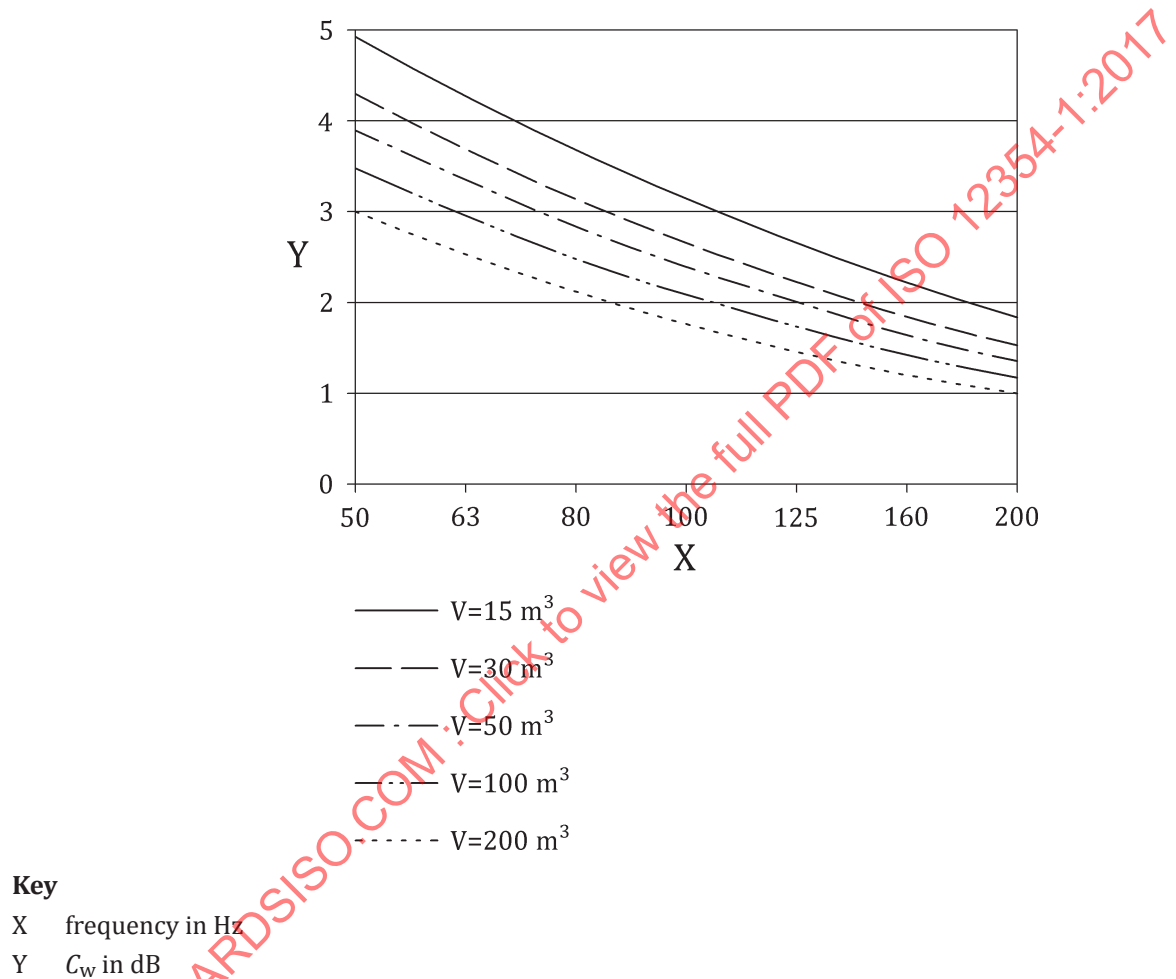


Figure I.1 — Examples of the Waterhouse correction for rectangular rooms

Annex J (informative)

Guidelines for practical use

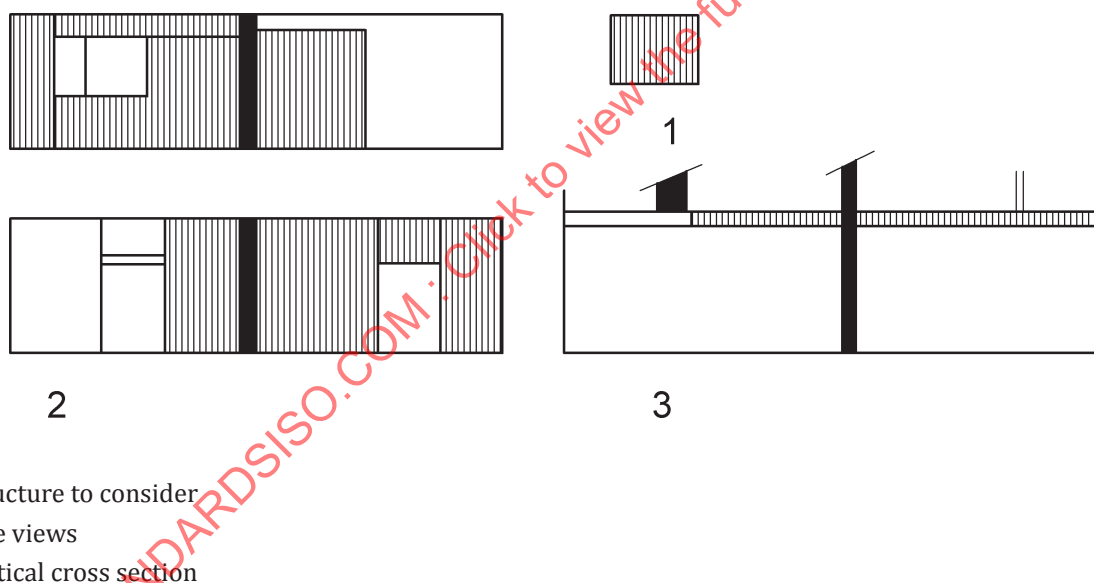
J.1 General

This annex gives guidelines for the interpretation and application of the prediction models and the needed input data.

J.2 Interpretation of the situation

J.2.1 Interpretation of different building situations is proposed in [J.2.2](#) to [J.2.7](#).

J.2.2 Flanking elements constructed of several parts. The sound reduction index of the larger part directly connected to the separating element should be taken into account. If complete discontinuities occur in the element, such as doors or heavy cross elements, the parts behind these discontinuities can be neglected. See [Figure J.1](#)

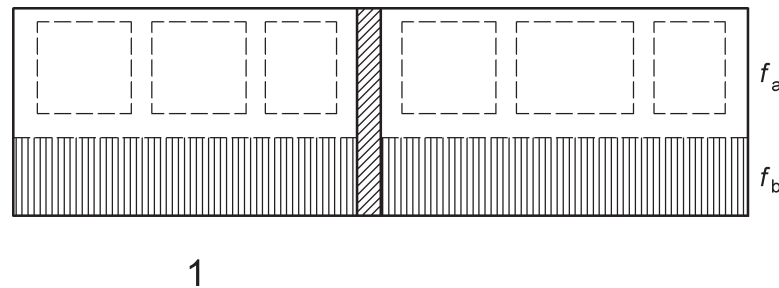


Key

- 1 structure to consider
- 2 side views
- 3 vertical cross section

Figure J.1 — Interpretation example for flanking elements constructed of several parts

J.2.3 Flanking elements. For each directly connected to the separating element, each of these types has to be considered as a separate flanking element (in [Figure J.2](#) the flanking element f consists of the two types a and b).

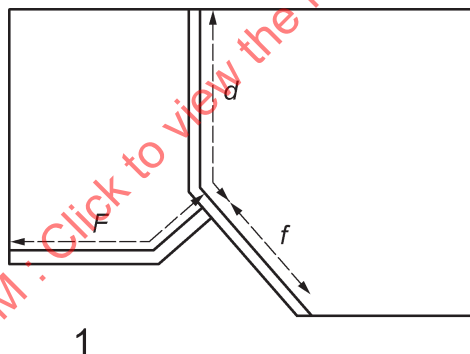


Key

1 side view

Figure J.2 — Interpretation example for flanking elements flanking elements, each directly connected to the separating element

J.2.4 Flanking elements not in a single plane, i.e. with bends or other shapes. The total area can be used, unless the angles at the discontinuities are large such as those with 90-degree corners; in such cases an effective total area can be used, taking into account the vibration level difference at the discontinuity. See [Figure J.3](#).

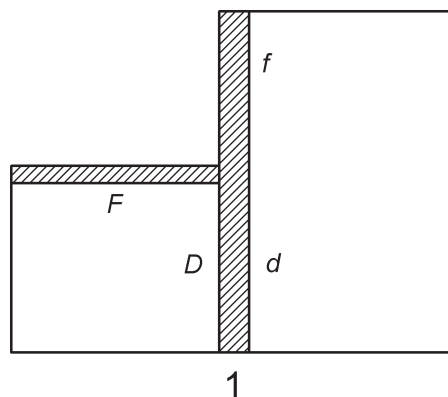


Key

1 horizontal cross section

Figure J.3 — Interpretation example for flanking elements not in a single plane

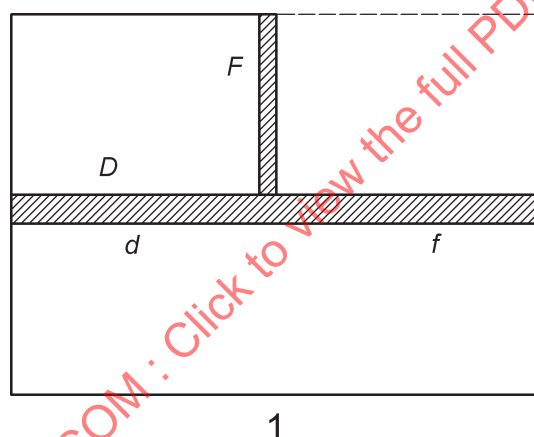
J.2.5 Split-level (i.e. stepped) or **horizontally displaced** (i.e. staggered) **rooms**. The continuation of the separating construction should be treated as a flanking element, often the dominant one (see [Figures J.4](#) and [J.5](#) respectively).



Key

1 horizontal cross section

Figure J.4 — Interpretation example for split-level rooms



Key

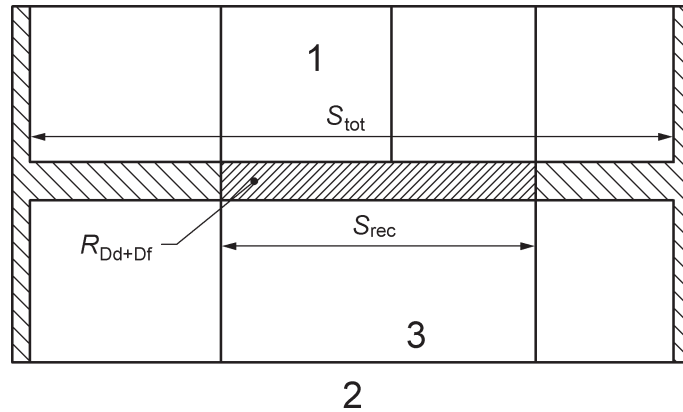
1 vertical cross section

Figure J.5 — Interpretation example for horizontally displaced rooms

J.2.6 Large floor slabs or long heavy walls with lightweight partitions. See [Figure J.6](#). The transmission is determined by the vibrations of the total floor or wall area. In the limiting case of very light walls it is preferred to estimate the direct and flanking transmission by the floor or wall as a whole by [Formula \(J.1\)](#):

$$R_{Dd+Df} = R_s - 10 \lg(T_{s,tot} / T_{s,lab}) - 10 \lg(S_{rec} / S_{tot}) \quad (J.1)$$

where S_{rec} is the total floor or wall area in the receiving room and the subscript “tot” refers to the total floor or wall between the load-bearing walls. This corresponds to applying the model for the relevant flanking path with $D_{v,ij,situ} = 0$ dB.

**Key**

- 1 source room
- 2 vertical cross section
- 3 receiving room

Figure J.6 — Interpretation example for large floor slabs or long heavy walls with lightweight partitions

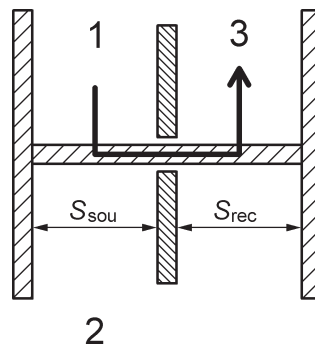
J.2.7 Flanking elements with insignificant or no structural contact with the separating element. See [Figure J.7](#). Only R_{Ff} is relevant, while the transmission paths Fd and Df are neglected. The flanking transmission is then estimated as [Formula \(J.2\)](#):

$$R_{Ff} = R_f - 10 \lg \left(T_{sf,tot} / T_{sf,lab} \right) + 10 \lg \left(S_s \left(\frac{1}{S_{sou}} + \frac{1}{S_{rec}} \right) \right) \quad (J.2)$$

where the subscript f refers to the flanking element considered. This corresponds to applying the model for the relevant flanking path with $D_{v,ij,situ} = 0$ dB. [Formula \(J.2\)](#) leads to the approximation of K_{Ff} shown by [Formula \(J.3\)](#):

$$K_{Ff} \approx 10 \lg \left(l_{ij} l_0 \left(\frac{1}{S_{sou}} + \frac{1}{S_{rec}} \right) \right) \quad (J.3)$$

which can be seen as a minimum value for the vibration reduction index and is close to -5 dB for current room dimensions.

**Key**

- 1 source room
- 2 vertical cross section
- 3 receiving room

Figure J.7 — Interpretation example for flanking elements with insignificant or no structural contact with the separating element

J.3 Interpretation of composed and complicated elements

J.3.1 Interpretation of composed and complicated elements is proposed in [J.3.2](#) to [J.3.5](#).

J.3.2 With additional layers, such as wall linings or floating floors, the sound reduction index and junction transmission index relates to the basic structural element, the effect of the additional layer being taken into account separately by ΔR (see [Figure J.8](#)).

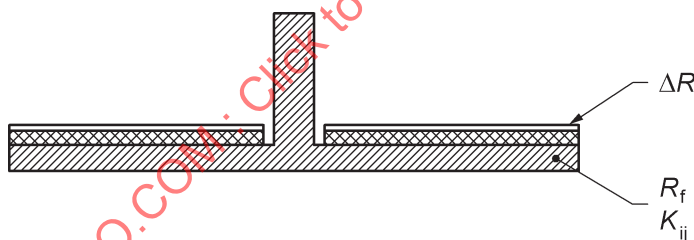


Figure J.8 — Interpretation for additional linings such as wall linings or floating floors

J.3.3 With additional external layers, such as lightweight external lining, which have negligible influence on the behaviour of the basic structural element, the calculation should concern only the basic inner element. The effect of the external lining or construction may be neglected or otherwise be taken into account through the vibration reduction index (see [Figure J.9](#)).

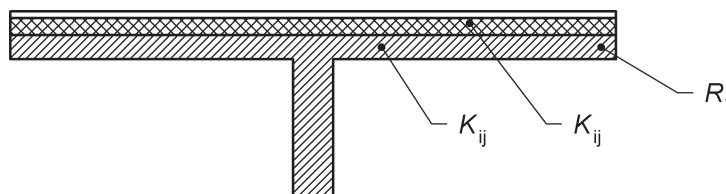


Figure J.9 — Interpretation for additional linings such as lightweight exterior linings

J.3.4 With cavity flanking elements the calculation should concern primarily the inner element with the effect of the external element taken into account through the vibration reduction index. This index can

be based on measurements in similar situations or be estimated by considering the various transmission paths contributing to the vibration reduction index (see [Figure J.10](#)).

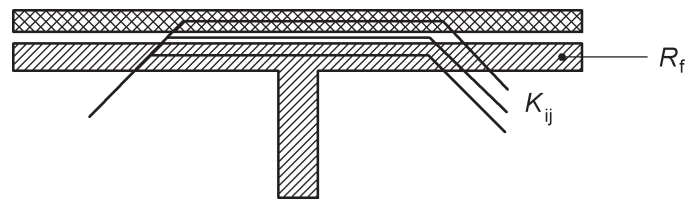


Figure J.10 — Interpretation for cases with cavity flanking elements

J.3.5 With cavity walls as a separating element the sound reduction index should include the effect of the transmission from one leaf to the other via the connections around the perimeter of the element, if any (see [Figure J.11](#)).

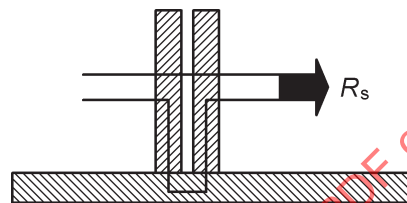


Figure J.11 — Interpretation for cases with cavity walls as separating element

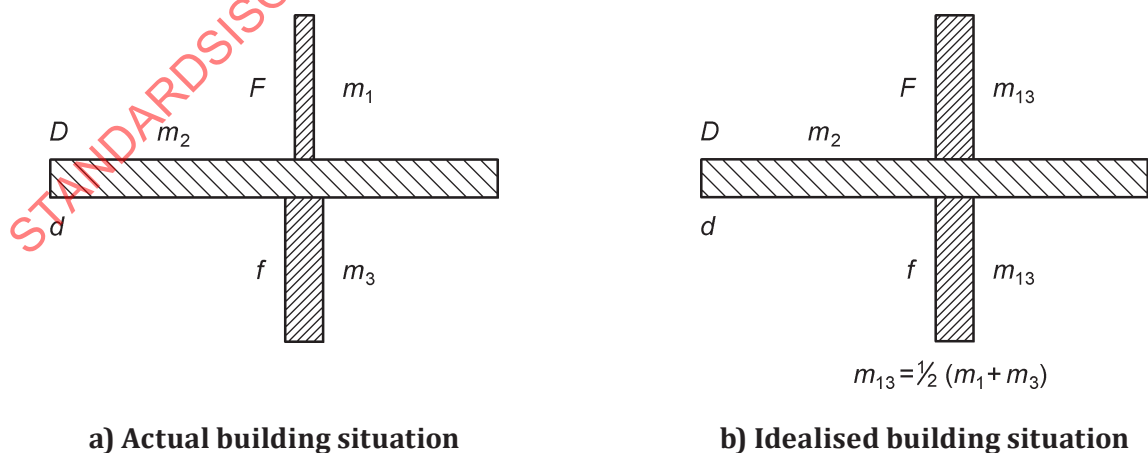
J.4 Interpretation of complicated junctions

J.4.1 General

Interpretation of complicated junctions is proposed in [J.4.2](#) to [J.4.4](#).

J.4.2 Cross-junction with more than 2 element types

[Figure J.12](#) presents the proposed interpretation for a cross-junction with more than 2 element types.



Key

m surface mass of the elements

Figure J.12 — Interpretation for cross-junction with more than 2 element types

J.4.3 T-junction with more than 2 element types

Figure J.13 proposes an interpretation in the case of T junctions with different façade elements: junction between a heavy (concrete) ground floor façade of mass m_2 with a lighter façade (i.e. hollow bricks ...) of mass m_3 on top and a heavy (concrete) floor of mass m_1 .

Condition on surface masses: $m_1, m_2 \geq 2 m_3$.

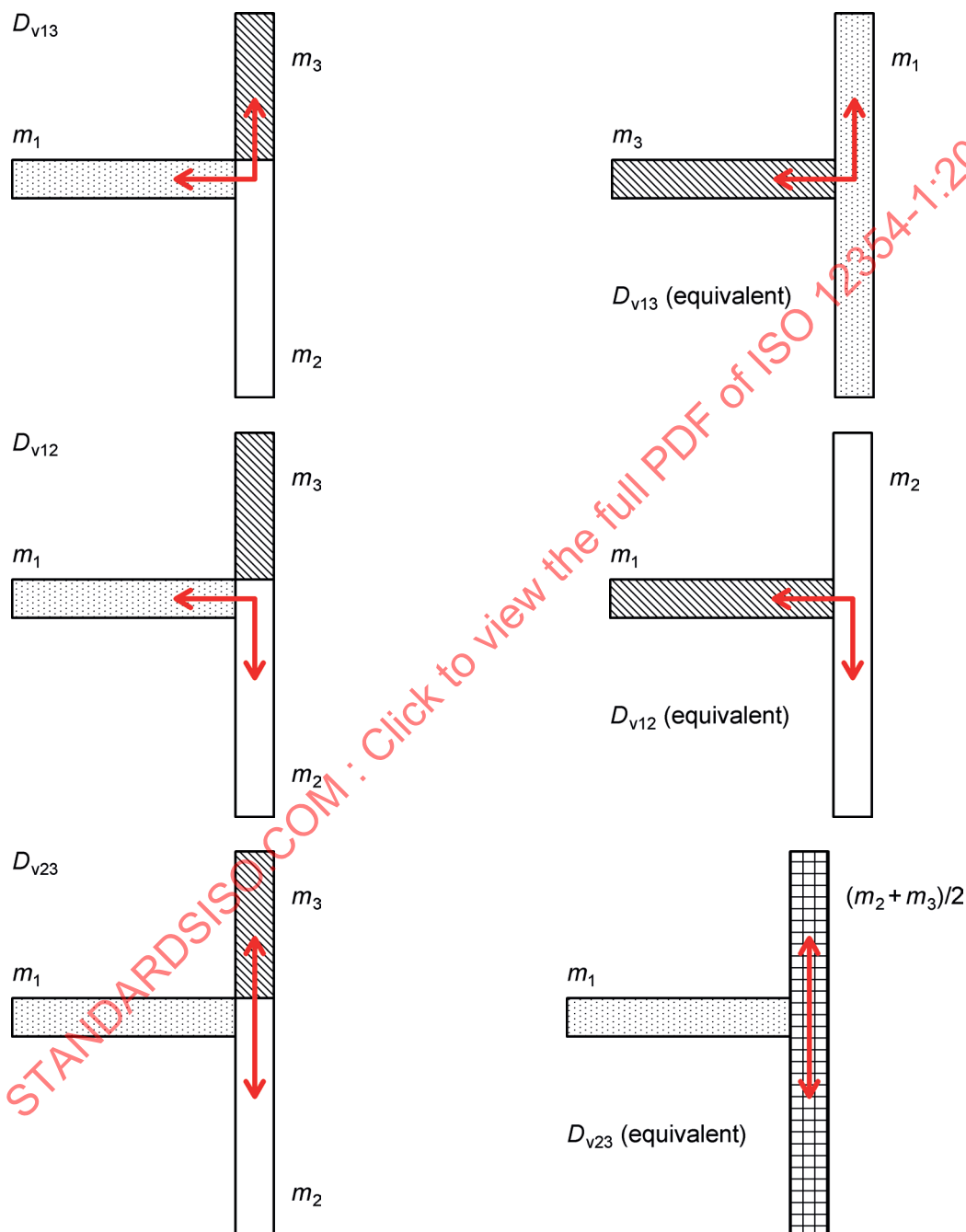


Figure J.13 — Interpretation for T-junction with more than 2 element types

J.4.4 Junctions with small offset

Figure J.14 proposes an interpretation in the case of junctions with a small offset.

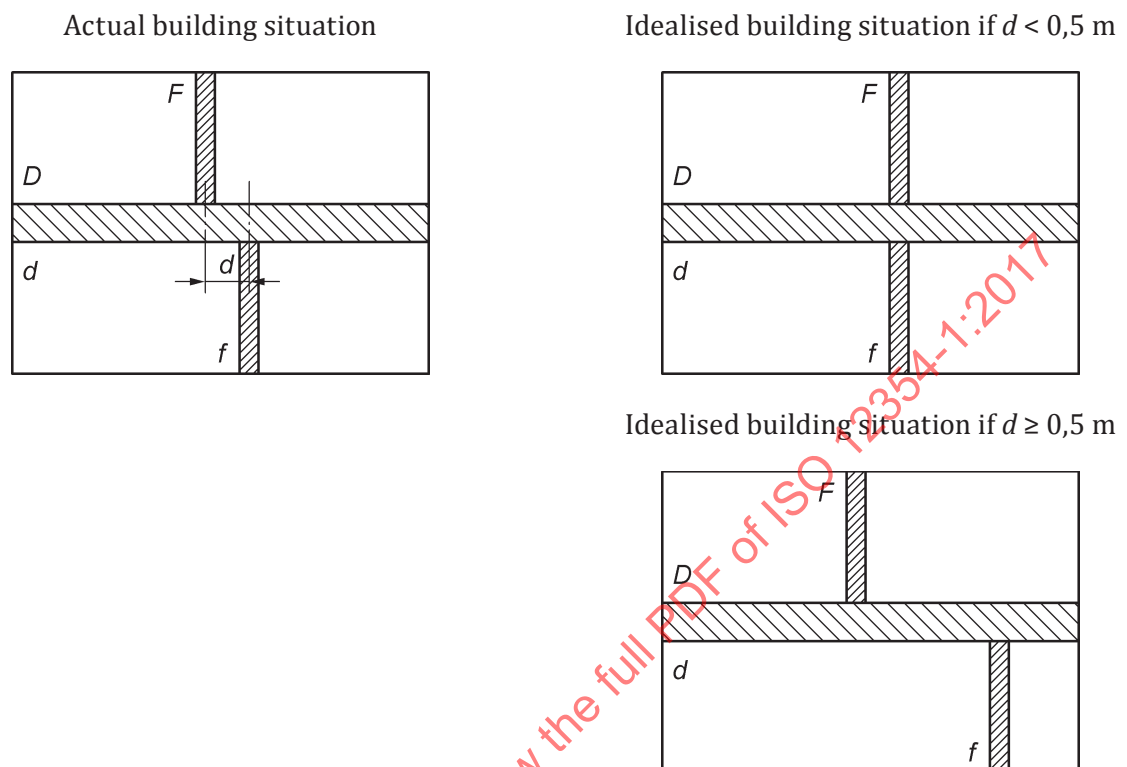


Figure J.14 — Interpretation for junctions with a small offset

J.4.5 Junctions with heavy double wall

Figure J.15 proposes an interpretation in the case of junctions with heavy double wall.

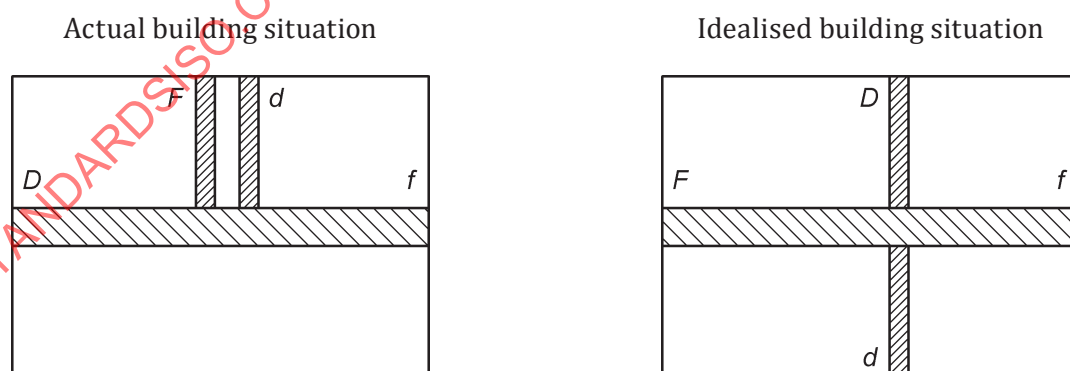


Figure J.15 — Interpretation for junctions with heavy double wall

Annex K (informative)

Estimation of uncertainty

This annex describes a method to determine the uncertainty of the predicted airborne sound reduction index from the uncertainties of the input quantities using the Guide to the expression of uncertainty in measurement.^[34] The procedure is applied to the simplified model of 4.4. It can be extended to the detailed model if input uncertainties are available per frequency bands.

The apparent sound reduction index is calculated according to Formula (18) in 4.4. Formula (K.1) establishes the functional relationship g between R'_w and the input quantities X_i .

$$R'_w = g(X_i) \quad (\text{K.1})$$

The input quantities X_i are geometric or acoustic parameters. Only the acoustic quantities and their uncertainties will be considered, since the uncertainty contribution from all the geometric quantities can be neglected. The input quantities for the transmission between two adjacent rectangular rooms are thus

- the weighted sound reduction index of the separating element $R_{S,w}$;
- the weighted sound reduction indices of the four flanking elements $R_{F,w}$ in the sending room (Room 1);
- the weighted sound reduction indices of the 4 flanking elements $R_{f,w}$ in the receiving room (Room 2);
- the 12 (unweighted and averaged, see 4.4.3) vibration reduction indices K_{ij} of the 4 junctions;
- the weighted improvements of altogether 10 possible linings $\Delta R_{i,w}$.

Depending on the number of linings, this leads to 21 to 31 acoustic input quantities. The combined uncertainty of the apparent weighted sound reduction index is shown by Formula (K.2):

$$u(R'_w) = \sqrt{\sum_{i=1}^{31} [c_i u(X_i)]^2 + u_{\text{pred}}^2} \quad (\text{K.2})$$

Here, an additional uncertainty contribution for the prediction method u_{pred} is included which is estimated to be 0,8 dB.^[35] The sensitivity coefficients, shown by Formula (K.3), are partial derivatives of the function f with respect to the input quantity X_i .

$$c_i = \frac{\partial R'_w}{\partial X_i} \quad (\text{K.3})$$

Using Formula (18) from 4.4, they can be expressed by analytic equations. The separating element is shown by Formula (K.4):

$$\frac{\partial R'_w}{\partial R_{s,w}} = \frac{10^{-R_{Dd,w}/10} + \frac{1}{2} \sum_{i=1}^4 10^{-R_{id,w}/10} + \frac{1}{2} \sum_{i=1}^4 10^{-R_{Di,w}/10}}{\sum_{j=1}^{13} 10^{-R_{j,w}/10}} \quad (K.4)$$

where $R_{Dd,w}$ is the weighted sound reduction index of the direct path, $R_{id,w}$ are the weighted sound reduction indices of the flanking paths Fd, $R_{Di,w}$ are the weighted sound reduction indices of the flanking paths Df and the $R_{j,w}$ are the weighted sound reduction indices of all 13 paths. For the other input quantities, the partial derivatives are shown by Formulae (K.5), (K.7) and (K.8):

$$\frac{\partial R'_w}{\partial K_{ij,w}} = \frac{10^{-R_{ij,w}/10}}{\sum_{j=1}^{13} 10^{-R_{j,w}/10}} \quad (K.5)$$

$$\frac{\partial R'_w}{\partial R_{i,w}} = \frac{\frac{1}{2} \left(10^{-R_{ii,w}/10} + 10^{-R_{id,w}/10} \right)}{\sum_{j=1}^{13} 10^{-R_{j,w}/10}} \quad (K.6)$$

$$\frac{\partial R'_w}{\partial \Delta R_{i,w}} = \frac{10^{-R_{i,w}/10}}{\sum_{j=1}^{13} 10^{-R_{j,w}/10}} \quad (K.7)$$

For two linings in path i, the partial derivative for the lining with the smaller sound reduction improvement is shown by Formula (K.8):

$$\frac{\partial R'_w}{\partial \Delta R_{j,w}} = \frac{\frac{1}{2} \cdot 10^{-R_{i,w}/10}}{\sum_{j=1}^{13} 10^{-R_{j,w}/10}} \quad (K.8)$$

The input uncertainties $u(X_i)$ are determined from the superposition of the standard deviation of reproducibility of 1,2 dB for the weighted sound reduction index from ISO 12999-1, the standard deviation for the product scatter of 1,0 dB and an additional uncertainty for the difference between the laboratory and the *in situ* situation of 0,8 dB^[35], as shown by Formula (K.9):

$$u(R_{ii,w}) = \sqrt{1,2^2 + 1,0^2 + 1,0^2 + 0,8^2} \text{ dB} \approx 2,0 \text{ dB} \quad (K.9)$$

The product scatter has to be included twice, once for the measurement in the laboratory and once for the choice of the individual specimen *in situ*. The value for the product scatter is estimated to be 1,0 dB and may be considerably larger for special specimens. There is no solid knowledge available on the