DELTA Acoustics & Vibration

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REPORT

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Nordic Basis of Calculation of Sound Insulation in Buildings

Client: Nordtest (Project Number 1346-97)

29. December 1998

Title
Nordic Basis of Calculation of Sound Insulation in Buildings

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Client
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Foreword

This project has been financially supported by Nordtest (project NT 1346-97).

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The project group had two meetings. The members of the project group submitted national guidelines and other information on acoustical data for building elements to the project leader. Further, the members performed initial calculations of sound insulation in buildings.

1. Introduction

The coming European standard EN 12354 describes calculation models designed to estimate the acoustic performance of buildings from the performance of building elements. The first two parts concern airborne and impact sound insulation between rooms. Input data for the calculation models are results of laboratory measurements of quantities defined in existing or coming standards of the ISO 140 series (the sound reduction index, the normalized impact sound pressure level, etc.). Alternatively, input data can be calculated by theoretical or empirical methods. Input data for several constructions are proposed in informative annexes of EN 12354. However, input data should be established according to local building practises, for example on national levels or on a Nordic level, more or less based on the informative annexes of the standard.

The aim of the work described in this report is to propose common Nordic input data for the new standard. The proposal is primarily based on existing guidelines from the Nordic countries and a considerable number of comparisons between results of field measurements and calculated values for the sound insulation. The accuracy of the standard with the proposed input data has been documented by the mentioned comparisons between measured and calculated values.

The standard describes both detailed and simplified calculation models. The detailed models were used for the calculations of the project. The investigated calculation models are described in chapter 2.

The calculations of sound insulation were carried out several times with different sets of input data.

The first calculations and comparisons between calculated and measured values were made by each member of the project group for typical buildings in his country (except that the first calculations for Norwegian buildings were made by the project leader). In order to facilitate exchange of data and the subsequent development of a proposal for common Nordic input data, a modified version of the Danish computer programme CADBA was used for the initial calculations. The applied version of CADBA did not fulfil the new standard, but the acoustical models used by the programme were closely related to the standard, and the required input data were the same as for the standard. Fles with data for the actual buildings and results of measurements to be compared with the calculation results were submitted to the project leader.

The remaining calculations were all performed by the project leader with software fulfilling the standard and with varying input data. The present report only presents calculation results with the input data that have been optimised to obtain the best agreement between measured and calculated results. All these input data are given in chapter 3 as calculation methods or tables of values to be used. Most of the data described in chapter 3 are recommended in chapter 5 as a Nordic basis for calculation of sound insulation.

The principles of the proposed input data are:

- Data for monolithic basic constructions are based on theoretical equations taken from informative annexes of EN 12354 with some modifications (see chapter 3.1 and 3.4);
- Data for lightweight double constructions, linings, floating floors, and floorings are primarily taken from measurements in Nordic laboratories;
- Data for junctions and determination of the structural reverberation time for monolithic elements follow informative annexes of EN 12354.

SI units are assumed for all equations in this report.

2. Calculation Models

For the theoretical development of the models it was assumed that the radiation factor is identical for both sides of a vibrating basic element. This is valid for monolithic elements but not for lightweight double constructions. However, the methods have shown to be useful also for lightweight double constructions although the precision is expected to be lower than for monolithic elements.

2.1 Airborne sound insulation

This chapter describes the detailed model of EN 12354-1 for direct and structure-borne transmission (flanking transmission) between two rooms.

The apparent sound reduction index R' is calculated for one-third octave bands.

The total transmission factor can be divided into transmission factors, related to the transmission paths shown in figure 2.1.

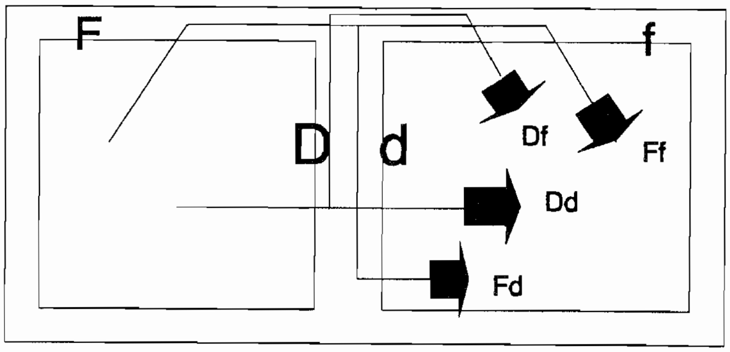

Figure 2.1. Definition of sound transmission paths ij between two rooms

(2.1)
$$R' = -10 \log \tau'$$
$$\tau' = \tau_{Dd} + \Sigma\tau_{ij} = \tau_{Dd} + \sum_{F=1}^{n} \tau_{Fd} + \sum_{F=1}^{n} \tau_{Df} + \sum_{F=1}^{n} \tau_{Ff}$$

τ_{ij} is the sound power ratio of radiated power into the receiving room along transmission path ij, relative to the sound power on the common part of the separating element. n is the number of flanking elements (normally 4). The transmission factors are related to the sound reduction index for direct transmission (R_{Dd}) and the flanking sound reduction index (R_{ij}) as follows:

(2.2) $$\tau_{Dd} = 10^{-R_{Dd}/10} \qquad \tau_{ij} = 10^{-R_{ij}/10}$$

R_{Dd} and R_{ij} are determined according to the following:

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

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

where

$R_{s,situ}$, $R_{i,situ}$, and $R_{j,situ}$ are sound reduction indices in the actual field situation;

$\Delta R_{D,situ}$, $\Delta R_{d,situ}$, $\Delta R_{i,situ}$, and $\Delta R_{j,situ}$ are sound reduction index improvements by additional layers in the actual field situation;

$\overline{D_{v,ij,situ}}$ is the direction-averaged junction velocity level difference between elements i and j in the actual field situation;

S_s, S_i, and S_j are areas of the separating element and flanking elements respectively.

The in-situ values of (2.3) and (2.4) are transformed from invariant input values (e.g. results of laboratory measurements) by

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

where

$T_{s,situ}$ is the structural reverberation time of the element in the actual field situation;
$T_{s,lab}$ is the structural reverberation time of the element in the laboratory;

The correction term in (2.5) shall be taken as 0 dB for lightweight double leaf elements, for elements with high internal loss factor, elements that are much lighter than the surrounding elements, and elements not firmly connected to the surrounding structures.

For additional layers the laboratory value can be used as an approximation for the in-situ value of the improvement ΔR_{situ}:

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

The direction-averaged velocity level difference $\overline{D_{v,ij,situ}}$ is determined from the vibration reduction index K_{ij} by:

$$\overline{D_{v,ij,situ}} = K_{ij} - 10\lg \frac{l_{ij}}{\sqrt{a_{i,situ}\, a_{j,situ}}} \ \text{dB}; \quad \overline{D_{v,ij,situ}} \geq 0 \quad \text{dB} \tag{2.7}$$

with

$$\begin{aligned} a_{i,situ} &= \frac{2{,}2\pi^2 S_i}{c_o T_{s,i,situ}} \sqrt{\frac{f_{ref}}{f}} \\ a_{j,situ} &= \frac{2{,}2\pi^2 S_j}{c_o T_{s,j,situ}} \sqrt{\frac{f_{ref}}{f}} \end{aligned} \tag{2.8}$$

where

$a_{i,situ}$	is the equivalent absorption length of element i in the actual field situation;
$a_{j,situ}$	is the equivalent absorption length of element j in the actual field situation;
f	is the centre band frequency;
f_{ref}	is the reference frequency; $f_{ref} = 1000$ Hz;
c_o	is the speed of sound in air;
l_{ij}	is the coupling length of the common junction between elements i and j;
S_i	is the area of element i;
S_j	is the area of element j;
$T_{s,i,situ}$	is the structural reverberation time of element i in the actual field situation;
$T_{s,j,situ}$	is the structural reverberation time of element j in the actual field situation;

The equivalent absorption length shall be taken as numerically equal to the area of the element for lightweight double leaf elements, for elements with high internal loss factor, elements which are much lighter than the surrounding elements, and elements not firmly connected to the surrounding structures.

The structural reverberation time can be determined according to an informative annex of EN12354-1. Theoretical and empirical methods for determination of input values for the sound reduction index R and the vibration reduction index K_{ij} are also given in informative annexes. The mentioned annexes are included in enclosure 1 of this report.

2.2 Impact sound insulation

The detailed model of EN 12354-2 for direct and structure-borne impact sound pressure level is described in this chapter.

The normalized impact sound pressure level L'_n is calculated for one-third octave bands.

It is assumed that the impact sound pressure level can be obtained by addition of the energy transmitted via each path shown in figure 2.2.

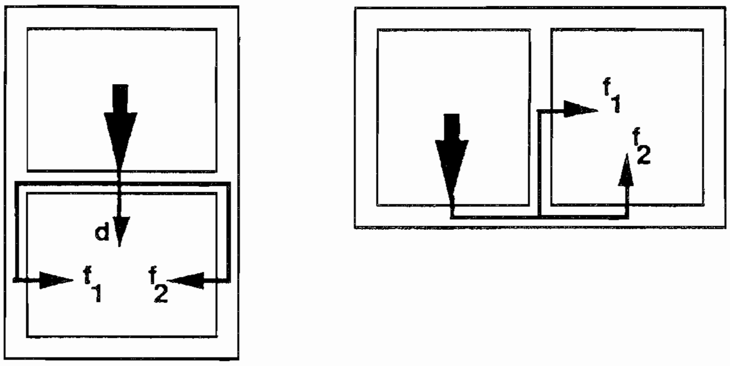

Figure 2.2. Definition of sound transmission paths between two rooms. above each other and next to each other respectively

For rooms above each other the total normalized impact sound pressure level L'_n is determined by:

$$(2.9)\quad L'_n = 10\lg\left(10^{L_{n,d}/10} + \sum_{j=1}^{n} 10^{L_{n,ij}/10}\right)\ \text{dB}$$

where

$L_{n,d}$ is the normalized impact sound pressure level due to direct transmission;
$L_{n,ij}$ is the normalized impact sound pressure level due to flanking transmission;
n is the number of flanking elements (normally 4)

For rooms next to each other the total normalized impact sound pressure level L'_n is determined by:

$$(2.10)\quad L'_n = 10\lg\sum_{j=1}^{n} 10^{L_{n,ij}/10}\ \text{dB}$$

For rooms next to each other the number of transmission paths n is normally 2. As for rooms above each other $L_{n,ij}$ is the normalized impact sound pressure level due to flanking transmission.

$L_{n,d}$ and $L_{n,ij}$ are determined according to the following:

$$(2.11)\quad L_{n,d} = L_{n,situ} - \Delta L_{situ} - \Delta L_{d,situ} \quad \text{dB}$$

$$(2.12)\quad L_{n,ij} = L_{n,situ} - \Delta L_{situ} + \frac{R_{i,situ} - R_{j,situ}}{2} - \Delta R_{j,situ} - \overline{D_{v,ij,situ}} - 10\lg\sqrt{\frac{S_i}{S_j}} \quad \text{dB}$$

where

$L_{n,situ}$ is the normalized impact sound pressure level of the floor in the actual field situation;

ΔL_{situ} is the reduction of impact sound pressure level of a floor covering in the actual field situation;

$\Delta L_{d,situ}$ is the reduction of impact sound pressure level by an additional layer on the receiving side of the separating element in the actual field situation;

$R_{i,situ}$ and $R_{j,situ}$ are sound reduction indices in the actual field situation;

$\Delta R_{j,situ}$ is the sound reduction index improvement by an additional layer in the actual field situation;

$\overline{D_{v,ij,situ}}$ is the direction-averaged junction velocity level difference between elements i and j in the actual field situation;

S_i, and S_j are areas of the floor element and flanking elements respectively.

The in-situ values of (2.11) and (2.12) are transformed from invariant input values (e.g. results of laboratory measurements) by eqns (2.5)-(2.7) and by:

$$(2.13)\quad L_{n,situ} = L_n + 10\lg\frac{T_{s,situ}}{T_{s,lab}} \quad \text{dB}$$

where

$T_{s,situ}$ is the structural reverberation time of the element in the actual field situation;

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

The correction term in (2.13) shall be taken as 0 dB for lightweight double leaf elements, for elements with high internal loss factor, elements which are much lighter than the surrounding elements, and elements not firmly connected to the surrounding structures.

For additional layers and coverings the laboratory value can be used as an approximation for the in-situ value:

$$\Delta R_{situ} = \Delta R \text{ dB}$$
$$\Delta L_{situ} = \Delta L \text{ dB} \qquad (2.14)$$
$$\Delta L_{d,situ} = \Delta L_d \text{ dB}$$

ΔL_d can be estimated by ΔR.

Theoretical equations for determination of input values for the normalized impact sound pressure level L_n of homogeneous floor constructions and for the reduction of impact sound pressure level ΔL of floating floors are given in informative annexes of EN12354-2.

3. Input Data for the Calculations

3.1. Sound reduction index for monolithic elements

The sound reduction index R for monolithic elements is calculated according to Annex B1 of EN 12354 (see enclosure 1). However, some important modifications are taken into account in this report:

- The radiation factor is limited by a maximum value of 1;
- The value of the sound reduction index around the critical frequency is taken to be at least the same as the highest value calculated for lower frequencies, i.e. the curve showing the sound reduction index as a function of the frequency is flat around the critical frequency;
- The calculated sound reduction index is corrected by 5 lg(m'/200), where m' is the mass per unit area of the element [kg/m^2];
- The thick-plate correction according to eqn (B4) of Annex B1 for frequencies below a plateau frequency f_p is used for the whole frequency range, including frequencies above f_p;

The laboratory value of the sound reduction index is calculated for the dimensions 4 m x 3 m.

The calculated sound reduction index includes forced transmission as included in laboratory measurements. This value is used in the model for both direct and flanking transmission.

The material data used for the calculations are given in table 3.1.

	Density [kg/m^3]	Long. velocity [m/s]	Internal loss factor
Concrete	2300	3500	0.006
Hollow concrete slab	Actual	3500	0.006
Bricks	1600	2200	0.015
Sandlime bricks	1900	2200	0.015
Lightweight concrete	Actual	1700	0.015
Aerated concrete	700	1400	0.01

Table 3.1. Material data

The critical frequency depends on the longitudinal wavelength and the thickness of the element. In case of a top layer or render, e.g. a thin layer of concrete on the top of lightweight concrete elements, the thickness of the elements is used for determination of the critical frequency.

For a flanking double wall with ties the sound reduction index is calculated for the inner leaf, i.e. the leaf towards the rooms. Half the surface mass of the outer leaf is added to the surface mass of the inner leaf.

3.2. Sound reduction index for heavy double leaf walls

For heavy double leaf walls with connections between two identical leaves the sound reduction index is calculated as for one leaf but with the total surface mass. Hence, the sound reduction index of the double wall is approximated by the sound reduction index for one leaf +6 dB.

For heavy double leaf walls without connections the sound reduction index is estimated by adding ΔR_{double} to the sound reduction index of one leaf. ΔR_{double} is calculated as in the Danish programme CADBA as follows:

$$\begin{array}{lll}
 & \Delta R_{\text{double}} = 6 + \Delta R_1 + \Delta R_2 \quad \text{dB} & \\
 & \Delta R_1 = 0 \quad \text{dB}, & f < f_0 \\
 & \Delta R_1 = 20 \lg \dfrac{f}{f_0} \quad \text{dB}, & f_0 < f < f_1 \\
 & \Delta R_1 = 20 \lg \dfrac{f_1}{f_0} \quad \text{dB}, & f > f_1 \\
(3.1) & \Delta R_2 = 0 \quad \text{dB}, & f < f_0 \cdot 10^{-1/5} \\
 & \Delta R_2 = 30 \left| \lg \sqrt{\dfrac{f}{f_0}} \right| - 6 \quad \text{dB}, & f_0 \cdot 10^{-1/5} < f < f_0 \cdot 10^{1/5} \\
 & \Delta R_2 = 0 \quad \text{dB}, & f > f_0 \cdot 10^{1/5} \\
 & f_0 = 80 \sqrt{\dfrac{2}{d\, m'}} \quad \text{Hz} & \\
 & f_1 = \dfrac{55}{d} \quad \text{Hz} &
\end{array}$$

where

f is the centre band frequency;

d is the cavity depth;

m' is the mass per unit area for one leaf of the double wall

3.3. Sound reduction index for lightweight double leaf constructions

Laboratory values for the sound reduction index of double plaster board walls and wooden floor constructions are taken from the national guidelines SBI 172 and NBI 28 and from [Novak]. The data shown in figures 3.1 and 3.2 have been selected for the calculations. In case the actual constructions of a building are not identical to any construction listed in figure 3.1 or 3.2, data are taken for a relevant construction with lower sound insulation, for example with stiffer connections between the leaves, with smaller cavity, or with less mineral wool in the cavity.

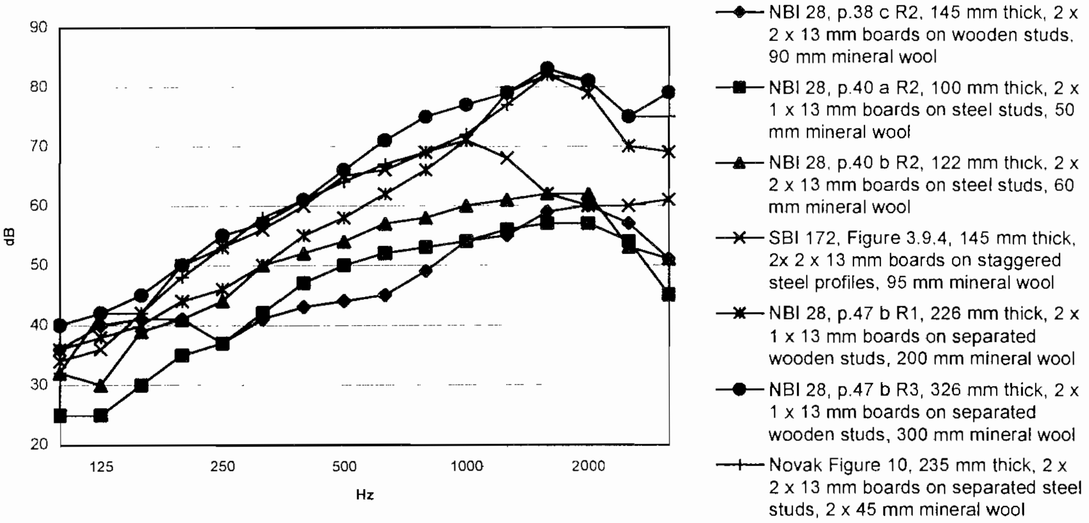

Figure 3.1. Sound reduction index R for double plaster board walls

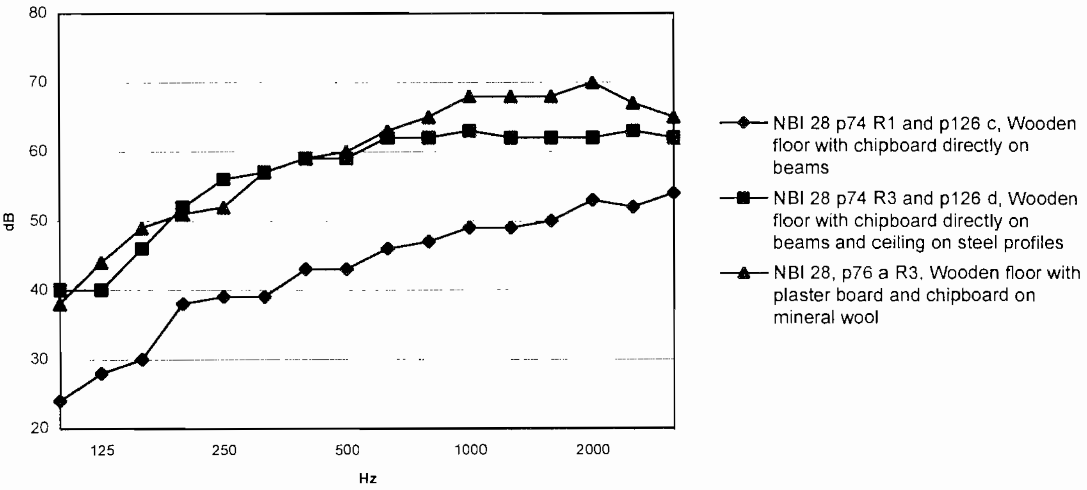

Figure 3.2. Sound reduction index R for wooden floors

3.4. Normalized impact sound pressure level for monolithic floor constructions

Calculations of the normalized impact sound pressure level L_n for monolithic floors are based on eqn (B2) that is given in an informative annex of EN12354-2 and mentioned below:

$$L_n \approx 155 - 30 \lg m' + 10 \lg T_s + 10 \lg \sigma + 10 \lg (f/f_{ref}) \quad \text{dB} \qquad (3.2)$$

where

m' is the mass per unit area;

σ is the radiation factor for free bending waves (calculated according to annex B1 of EN 12354-1 and chapter 3.1 of this report);

T_s is the structural reverberation time (calculated for the laboratory situation described in chapter 3.9 with the dimensions 4 m x 3 m of the element);

f is the centre band frequency;

f_{ref} is the reference frequency 1000 Hz.

Eqn (3.2) is applicable for homogeneous constructions. In order to obtain an approximation for lightweight concrete and hollow concrete slabs the value of L_n calculated by eqn (3.2) has been corrected by 7.5 lg (f / 250 Hz). This correction is applied for all monolithic floor constructions. Therefore, the calculated normalized impact sound pressure level is expected to be too high at high frequencies for massive concrete floors.

3.5. Normalized impact sound pressure level for lightweight floor constructions

Laboratory values for the normalized impact sound pressure level of wooden floor constructions are taken from the Norwegian guideline NBI 28. The data shown in figure 3.3 have been selected for the calculations. In some cases the impact sound insulation of the actual construction in a building is expected to be better than the selected data in figure 3.3.

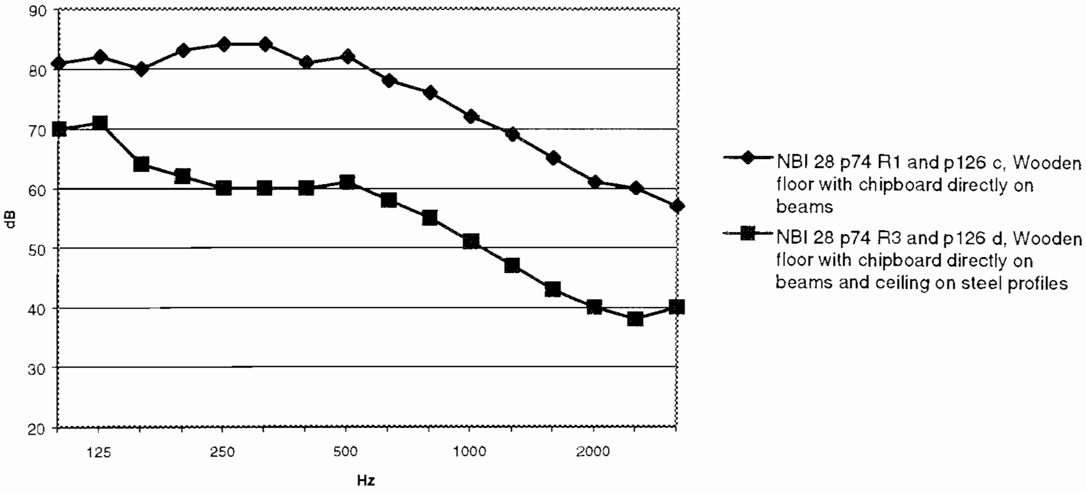

Figure 3.3. Normalized impact sound pressure level L_n for wooden floors

3.6. Sound reduction index improvement by linings

The sound reduction index improvement ΔR for linings of plaster boards with mineral wool is calculated as in the Danish programme CADBA as follows:

$$
\begin{array}{lll}
 & \Delta R = \Delta R_1 + \Delta R_2\,, \quad \Delta R \le 20 \quad \text{dB} & \\
 & \Delta R_1 = 0 \quad \text{dB}, & f < f_0 \\
 & \Delta R_1 = 20\lg\left(f^2\, m'_1\, d\right) - 77 \quad \text{dB}, & f_0 < f < f_1 \\
 & \Delta R_1 = 20\lg\left(f\, m'_1\right) - 42 \quad \text{dB}, & f > f_1 \\
(3.3) & \Delta R_2 = 0 \quad \text{dB}, & f < f_0 \cdot 10^{-1/5} \\
 & \Delta R_2 = -2 + 10\left|\lg\dfrac{f}{f_0}\right| \quad \text{dB}, & f_0 \cdot 10^{-1/5} < f < f_0 \cdot 10^{1/5} \\
 & \Delta R_2 = 0 \quad \text{dB}, & f > f_0 \cdot 10^{1/5} \\
 & f_0 = 80\sqrt{\dfrac{1}{d\, m'_1}} \quad \text{Hz} & \\
 & f_1 = \dfrac{55}{d} \quad \text{Hz} &
\end{array}
$$

where

f is the centre band frequency;
d is the cavity depth;

m'$_l$ is the mass per unit area for the lining.

The linings are assumed to cover a heavy monolithic constructions. If the linings are connected to the basic structure by rigid metal profiles or wooden studs, ΔR is limited by a maximum value of 9 dB.

Additional data have been estimated for linings that are primarily used in Iceland (see figure 3.4).

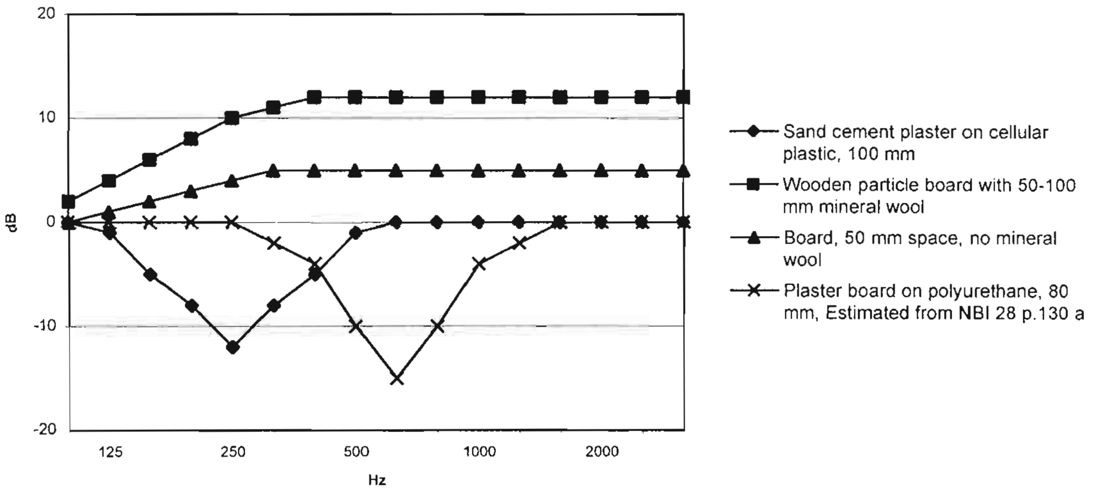

Figure 3.4. Sound reduction index improvement ΔR by linings

3.7. Sound reduction index improvement and reduction of impact sound pressure level by floating floors and floorings

Data used for floating floors and floorings are taken from the national guidelines SBI 172 and NBI 28 and from Swedish laboratory measurements. A few additional data have been estimated. All data are shown in figures 3.5-3.9. Except for one floating floor (boards on mineral wool, see figures 3.5-3.6) the measured data in the laboratory are for the floating floor or flooring on a concrete slab. Nevertheless, the values have been used on both heavy floors and wooden floors in the field situation.

Data for the Swedish EW-floors mentioned in enclosure 2 are taken to be the same as for 22 mm parquet on steel studs on Sylomer S100R with loose linoleum (figures 3.7 and 3.8).

The sound reduction index improvement is taken as 0 dB for all floorings.

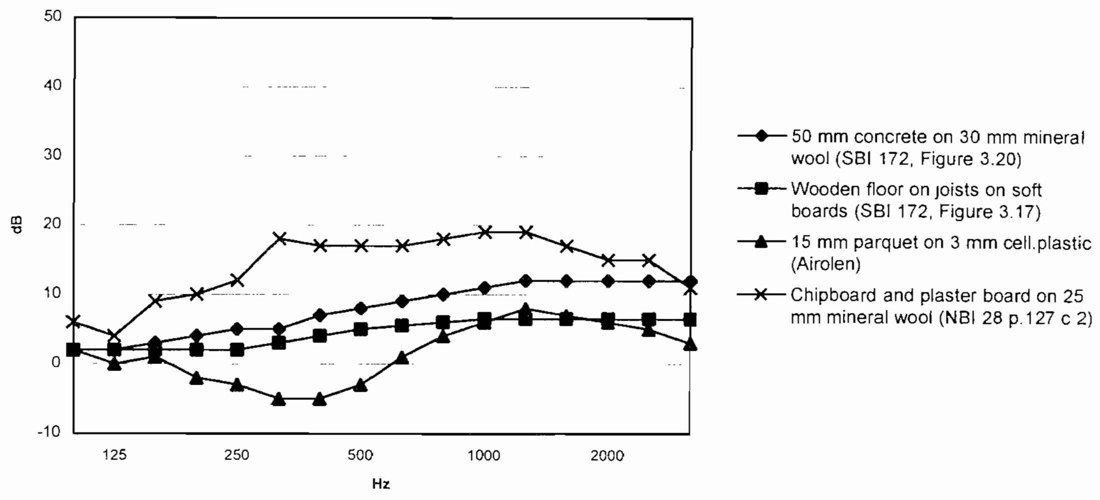

Figure 3.5. Sound reduction index improvement ΔR by floating floors

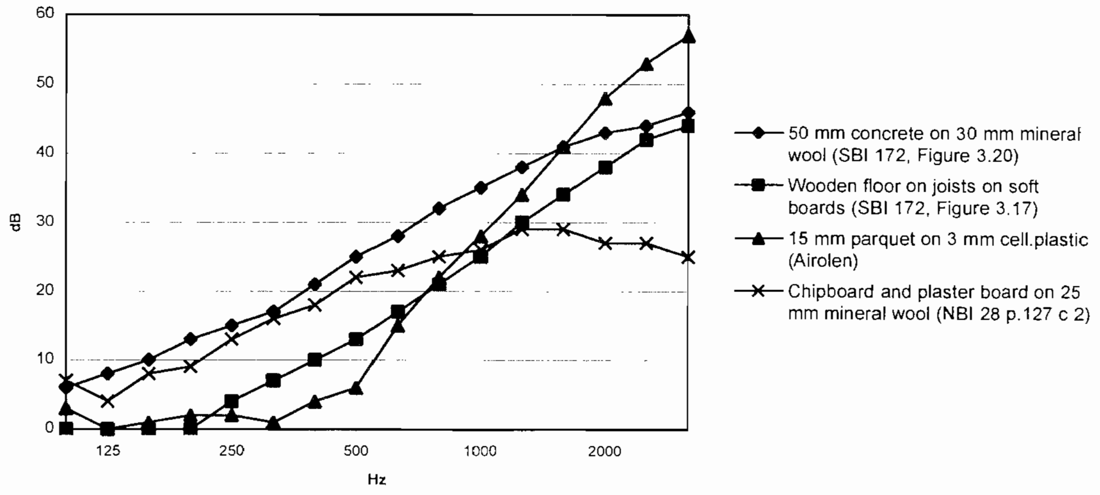

Figure 3.6. Reduction of impact sound pressure level ΔL by floating floors

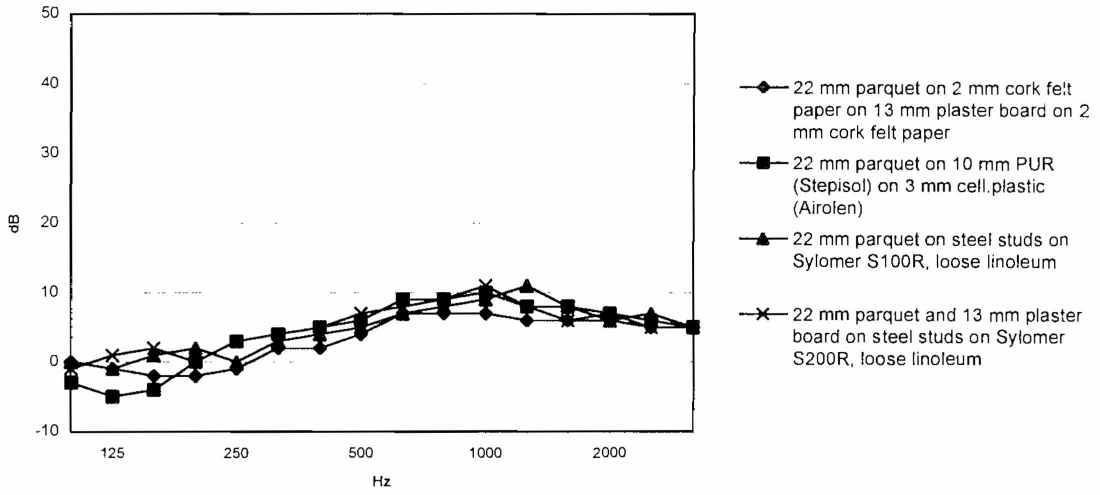

Figure 3.7. Sound reduction index improvement ΔR by floating floors

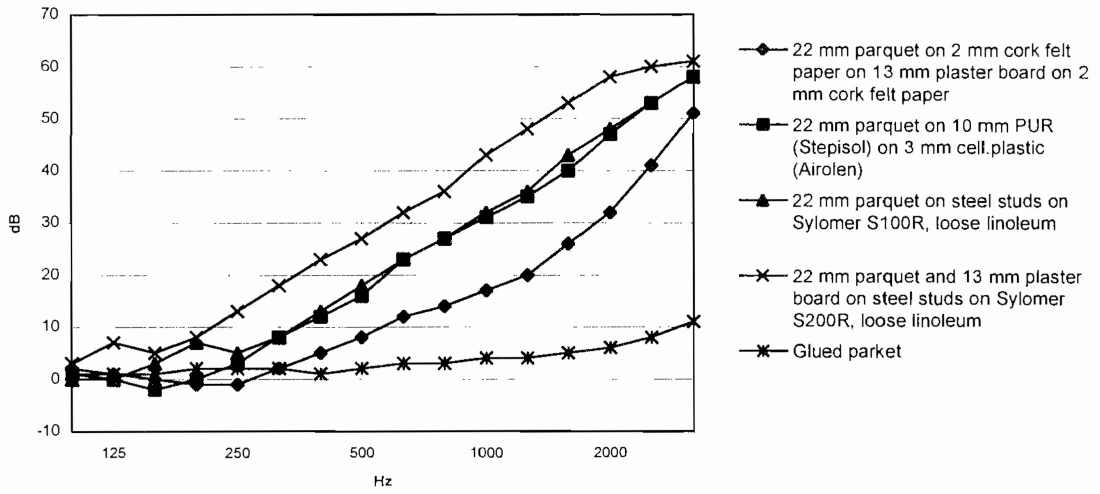

Figure 3.8. Reduction of impact sound pressure level ΔL by floating floors

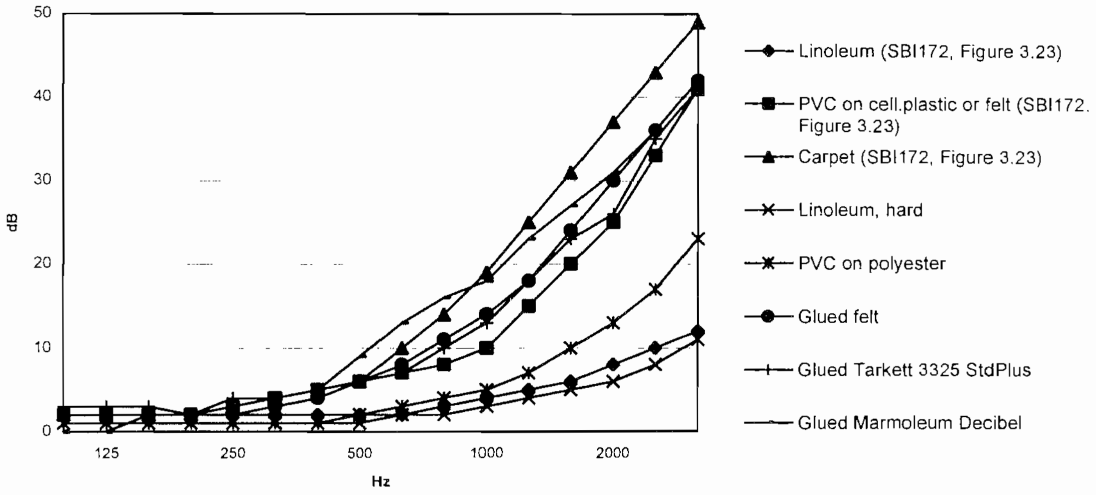

Figure 3.9. Reduction of impact sound pressure level ΔL by floorings

3.8. Vibration reduction index

The vibration reduction index K_{ij} is calculated according to empirical equations in Annex E of EN 12354 (see enclosure 1).

For flanking constructions like heavy double walls with ties between the two leaves, or heavy sandwich walls, transmission can pass through the outer leaf if not interrupted at the separating element. The following estimate is in accordance with the Danish programme CADBA:

$$(3.4) \qquad K_{ij} = 8 + 10 \left| \lg \frac{m'_{in}}{m'_{out}} \right| + 10 \lg \frac{m'_{out}}{285} \text{ dB}$$

where

m'_{in} is the mass per unit area for the inner leaf of the construction (towards the rooms)
m'_{out} is the mass per unit area for the outer leaf of the construction

3.9. Structural reverberation time

The structural reverberation time T_s is calculated for monolithic elements according to Annex C of EN 12354 (see enclosure 1).

The structural reverberation time depends on internal losses of the element, losses due to radiation of sound, and losses caused by absorption of vibration energy at the perimeter of the element. Usually the losses at the perimeter are the most important. In Annex C relations are given between the vibration reduction index and the absorption coefficient of a junction between two or more elements.

The laboratory situation is simulated by a concrete frame of 400 mm thickness. The junctions between the element and the surrounding concrete frame are taken to be rigid T-junctions.

In the field situation the absorption coefficient is determined for the actual junctions around the separating element. For the remaining parts of the perimeters of the flanking elements the absorption coefficient is taken as 0.2.

4. Comparisons between Measured and Calculated Results

A large number of comparisons have been made between measured and calculated results. All comparisons are listed in enclosure 2 (most important data for the building constructions as well as measured and calculated R'_w- or $L'_{n,w}$-values). In the tables of enclosure 2 a numbering is given of each set of measurement/calculation. The same numbering is used in the following figures and in enclosures 3 and 4 where all results are shown for one-third octave bands.

The average, standard deviation, and 90% confidence limits of the difference between measured and calculated results have been determined for different types of basic constructions and for different directions of transmission. A few results were not included in this analysis because the data used for the calculations were obviously not correct, or because appropriate input data were not available for the actual building constructions. These "outliers" are marked to the right in the tables of enclosure 2. The exclusion of data was based on studies of the curves in enclosures 3 and 4, for example because $L'_{n,w}$ was determined by the values at high frequencies for a flooring with inaccurate values for the reduction of impact sound pressure level at these frequencies.

4.1. Airborne sound insulation

	Direction of transm.	Average	St. dev.	90% conf. limits
Monolithic basic constructions	Horizontally (walls) Vertically (floors)	0.2 dB 0.4 dB	1.9 dB 2.6 dB	± 3.4 dB ± 4.5 dB
Lightweight double constructions	Horizontally (walls) Vertically (floors)	0.1 dB 0.4 dB	3.1 dB 3.2 dB	± 5.3 dB ± 5.5 dB

Table 4.1. Average, standard deviation, and 90% confidence limits for the difference between calculated and measured R'_w-values.

The average values in table 4.1 show that the calculated sound insulation slightly overestimates the sound insulation. The standard deviation for airborne sound insulation is 2-3 dB. The standard deviation for monolithic walls is comparable with an indicative value of 1.5 dB given in EN 12354-1 for situations that are not too complex. For complex situations and when neglecting the structural reverberation time the standard indicates a standard deviation of 2.5 dB (about the same value as in table 4.1 for monolithic floor constructions).

The relatively high standard deviation for floor constructions is probably due to the application of floating floors in a great number of buildings and a higher amount of flanking transmission compared with the direct transmission. It appears from figure 4.2 that the calculated airborne sound insulation is in average too high for floors in Iceland and too low for Danish floors. For walls this tendency is not seen (figure 4.1). The systematic differences between measured and calculated values for floors in Iceland is associated with relatively irregular measured frequency curves for R' (see enclosures 3.19-3.23). The most important reason for irregular curves from Iceland is the application of linings.

For lightweight double constructions the standard deviation of the difference between calculated and measured R'_w-values is higher than for monolithic constructions (3.1-3.2 dB).

The standard deviation of the difference between calculated and measured R'_w-values for heavy double leaf walls is 3.5 dB (data shown in figure 4.5). Although a limited number of comparisons have been made it seems that calculations for heavy double leaf walls can be relatively accurate.

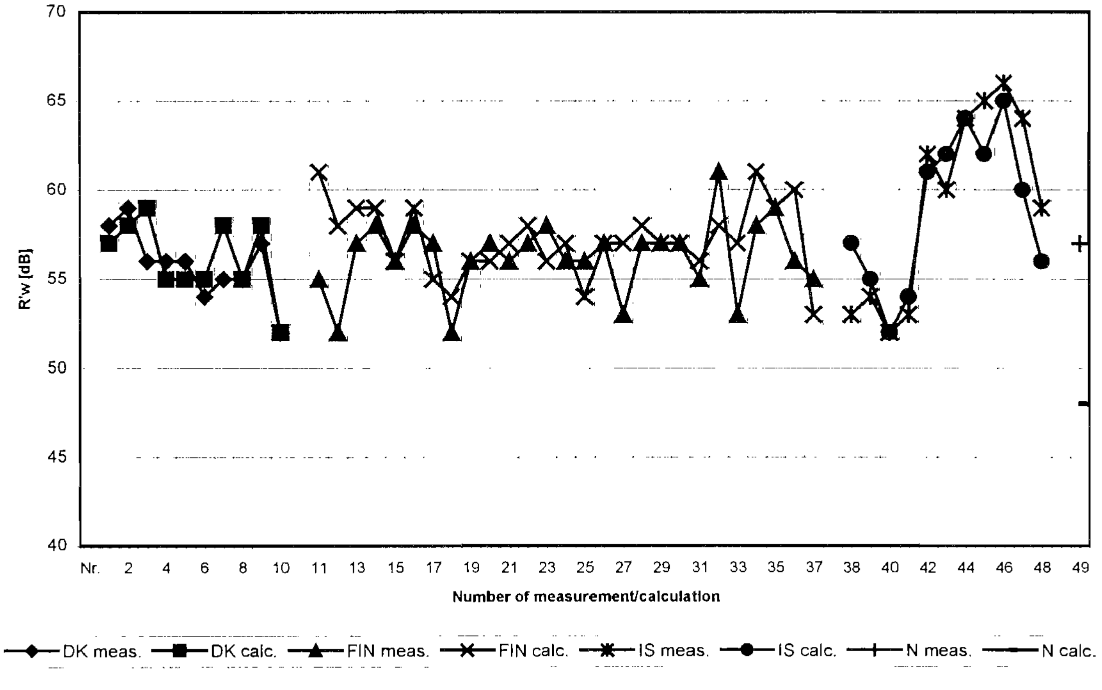

Figure 4.1. Measured and calculated airborne sound insulation horizontally, monolithic walls

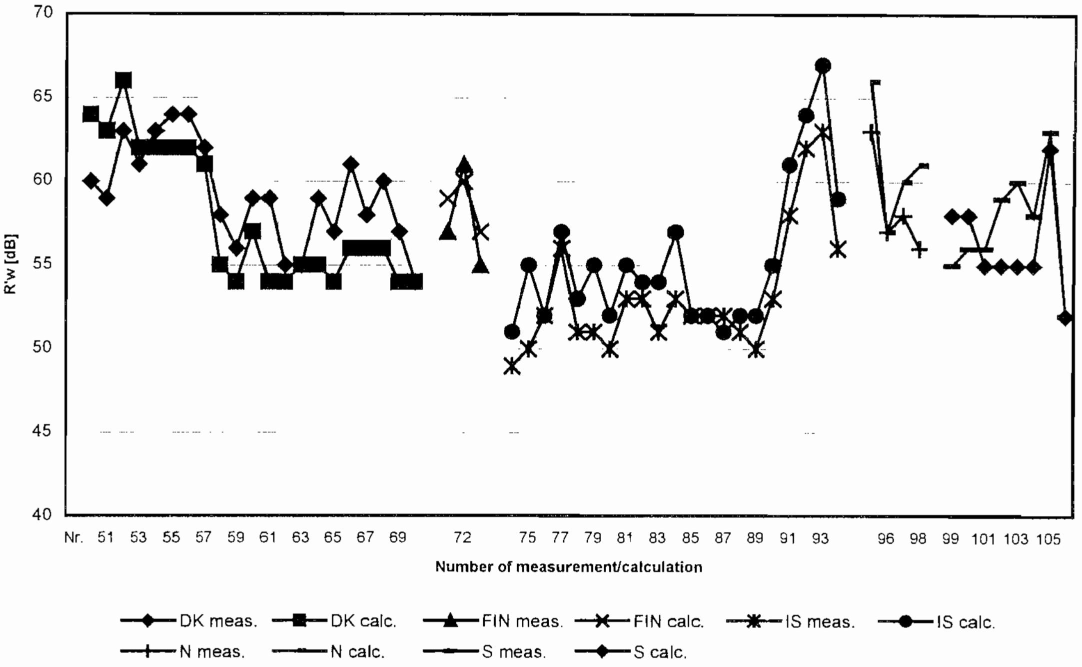

Figure 4.2. Measured and calculated airborne sound insulation vertically, monolithic floors

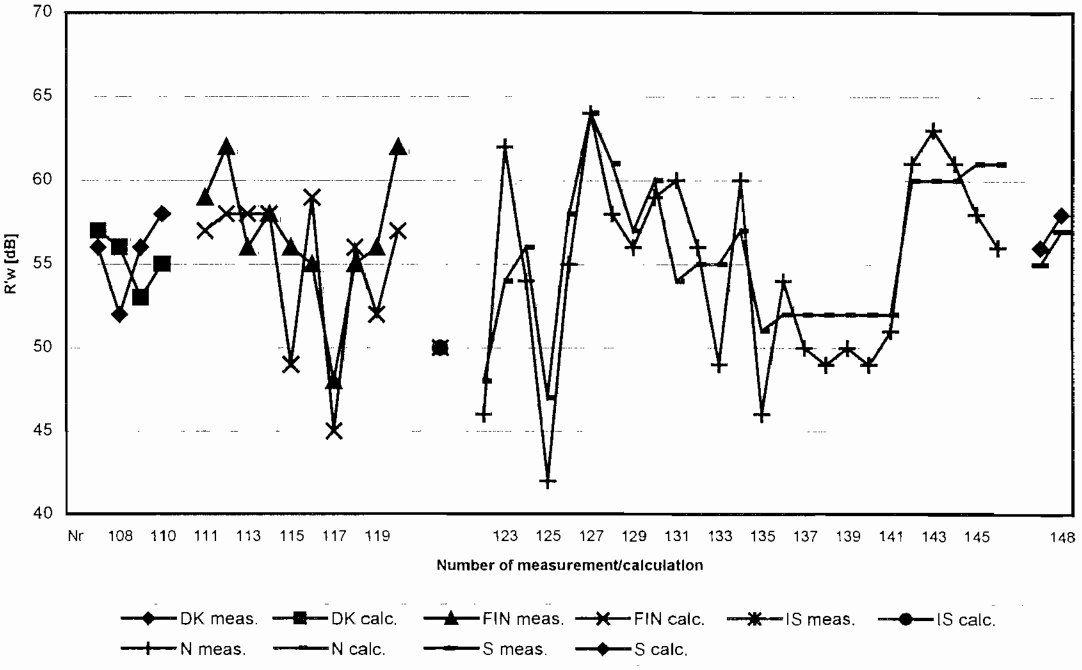

Figure 4.3. Measured and calculated airborne sound insulation horizontally, lightweight double walls

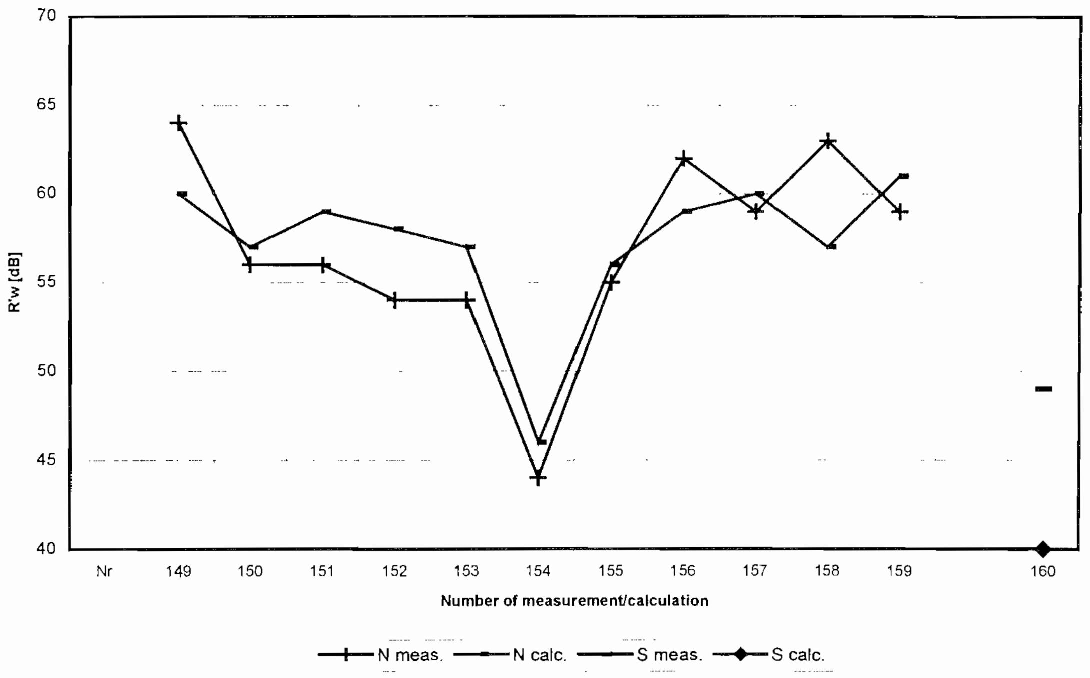

Figure 4.4. Measured and calculated airborne sound insulation vertically, lightweight floors

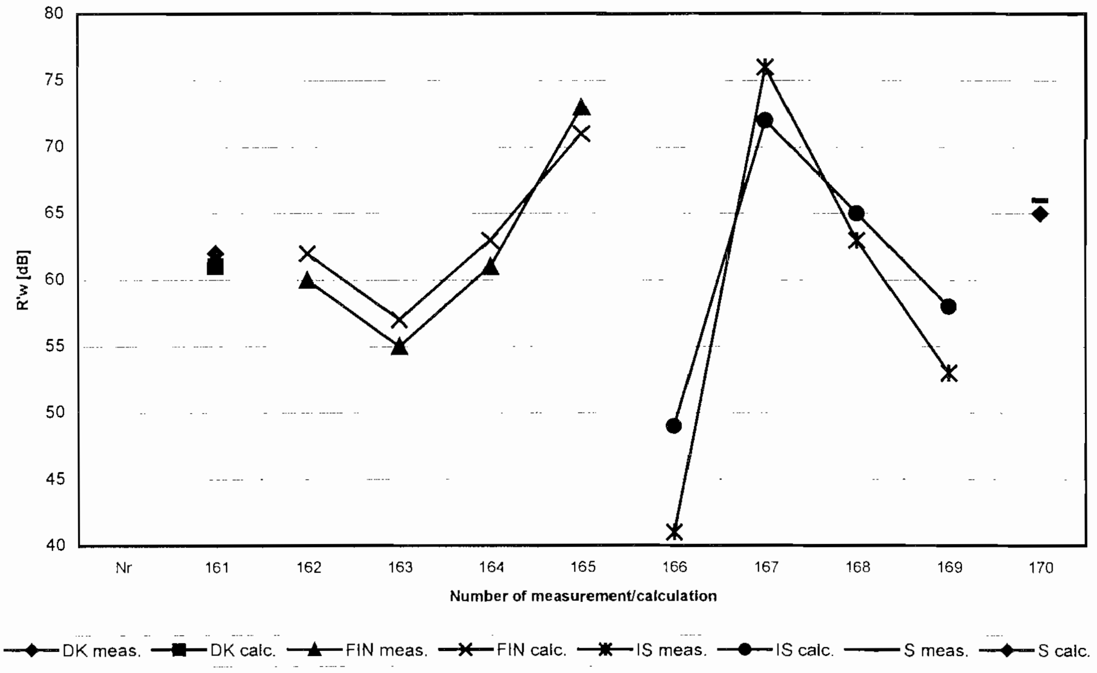

Figure 4.5. Measured and calculated airborne sound insulation horizontally, heavy double leaf walls

4.2. Impact sound insulation

	Average	St. dev.	90% conf. limits
Monolithic basic constructions	-0.5 dB	3.1 dB	± 5.2 dB
Lightweight double constructions	0.0 dB	5.4 dB	± 9.1 dB

Table 4.2. Average, standard deviation, and 90% confidence limits for the difference between calculated and measured $L'_{n,w}$-values vertically.

Table 4.2 shows that for monolithic floors the calculated $L'_{n,w}$–value is in average slightly lower than the measured value. For lightweight double constructions (i.e. wooden floors) there is no systematic difference between calculated and measured values.

The standard deviation of the difference between measured and calculated $L'_{n,w}$-values for vertical transmission is 3.1 dB for monolithic slabs and 5.4 dB for lightweight floor constructions.

Calculations for horizontal transmission of impact sound insulation have shown a much lower accuracy for both monolithic and lightweight double constructions (see enclosures 2.7 and 2.10).

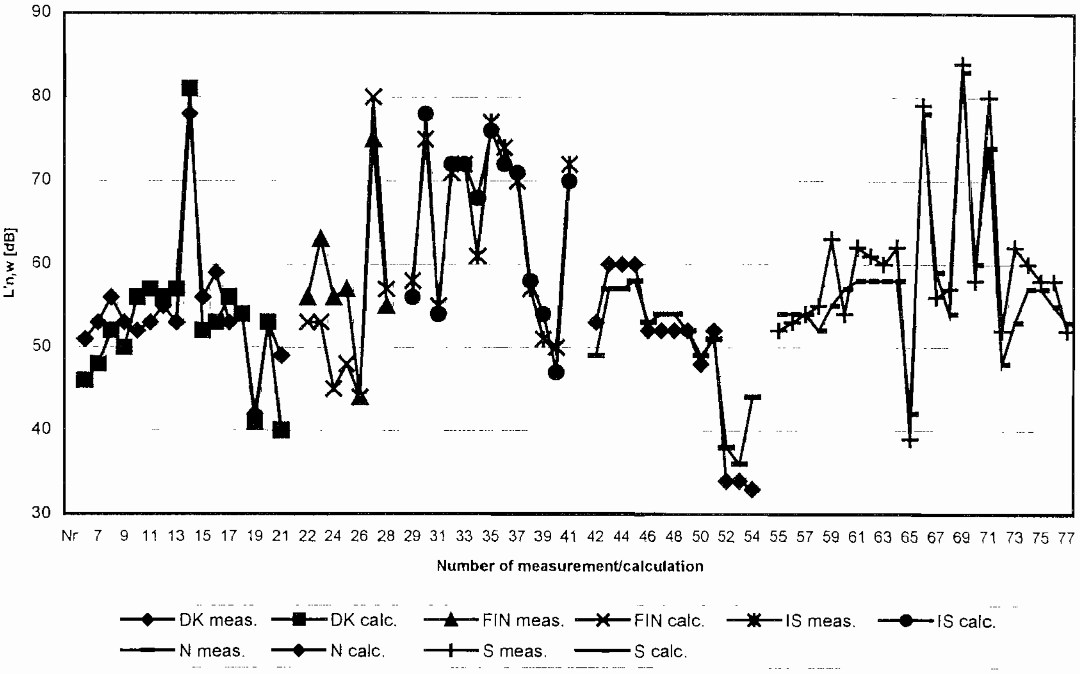

Figure 4.6. Measured and calculated impact sound insulation vertically, monolithic floors

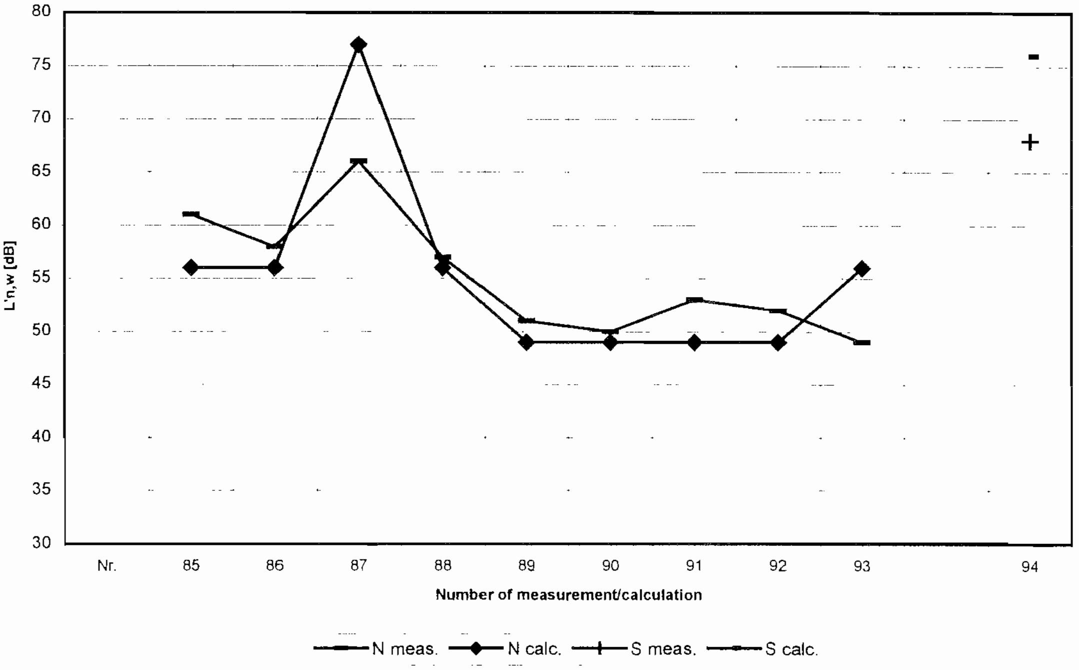

Figure 4.7. Measured and calculated impact sound insulation vertically, lightweight floors

5. Proposal for Nordic Input Data

It is recommended to establish Nordic input data for EN 12354 from:

- the calculation methods for monolithic elements described in chapter 3.1, 3.4, and 3.9;
- results of laboratory measurements (and a few estimated data) for lightweight double leaf constructions, linings, floating floors, and floorings;
- the empirical equations given in the informative Annex E of EN 12354-1 for the vibration reduction index of junctions.

In this chapter examples are given for calculated values of the sound reduction index and normalized impact sound pressure level of monolithic basic constructions, and data are proposed for lightweight double leaf constructions, linings, floating floors, and floorings.

Values for the vibration reduction index of specific junctions are shown in enclosure 1.

The structural reverberation time for building elements in situ can be determined as described in annex C of EN 12354-1 and in chapter 3.9 of this report.

Data and calculation methods for some constructions given in chapter 3 are not included in this proposal for Nordic input data because the number of comparisons between measurement and calculation results carried out as a part of the project is too low. However, these data and calculation methods might still be useful for some applications.

5.1. Sound reduction index for monolithic elements

Examples of calculated laboratory values of the sound reduction index for monolithic basic constructions are given in the following tables. The calculated values can of course be used for estimations of sound insulation in buildings, but such estimations are time consuming without a suitable computer programme. The purpose of the tables is primarily to indicate laboratory values that will lead to field values as estimated in this report.

Frequency, Hz	100 mm	120 mm	150 mm	180 mm	200 mm
100	33.4	33.4	33.4	35.2	37.9
125	33.4	33.4	35.5	38.0	40.6
160	33.4	33.9	38.0	41.2	43.1
200	33.4	36.5	40.5	43.8	45.6
250	35.7	39.0	43.0	46.3	48.1
315	38.3	41.6	45.6	48.8	50.7
400	40.9	44.1	48.1	51.3	53.2
500	43.5	46.7	50.6	53.8	55.7
630	46.1	49.3	53.2	56.3	58.1
800	48.7	51.8	55.7	58.8	60.6
1000	51.2	54.4	58.2	61.3	63.0
1250	53.8	56.9	60.7	63.7	65.4
1600	56.4	59.4	63.1	66.1	67.8
2000	58.9	61.9	65.5	68.4	70.1
2500	61.5	64.4	67.9	70.7	72.3
3150	63.9	66.8	70.2	72.9	74.5
R_w	48	50	54	57	59

Table 5.1. Sound reduction index R [dB] for concrete (2300 kg/m^3)

Frequency, Hz	110 mm	170 mm	230 mm	330 mm
100	35.3	35.4	35.1	41.2
125	35.9	35.4	35.8	43.0
160	35.9	35.4	38.7	45.5
200	35.9	36.4	41.9	48.0
250	35.9	39.4	44.5	50.6
315	35.9	42.0	47.1	53.1
400	37.5	44.6	49.6	55.5
500	40.2	47.2	52.2	57.9
630	42.8	49.8	54.7	60.3
800	45.5	52.4	57.1	62.7
1000	48.2	54.9	59.6	64.9
1250	50.8	57.4	61.9	67.1
1600	53.4	59.9	64.2	69.2
2000	56.0	62.2	66.4	71.3
2500	58.5	64.5	68.6	73.3
3150	60.9	66.7	70.7	75.2
R_w	46	51	55	61

Table 5.2. Sound reduction index R [dB] for brickwork (1600 kg/m^3)

Frequency, Hz	110 mm	170 mm	230 mm	330 mm
100	37.3	37.5	37.1	43.1
125	37.9	37.5	37.8	45.0
160	37.9	37.5	40.7	47.5
200	37.9	38.5	43.9	50.0
250	37.9	41.4	46.5	52.5
315	37.9	44.0	49.1	55.0
400	39.5	46.6	51.6	57.5
500	42.2	49.3	54.2	59.9
630	44.8	51.8	56.7	62.3
800	47.5	54.4	59.1	64.6
1000	50.2	56.9	61.5	66.9
1250	52.8	59.4	63.9	69.1
1600	55.4	61.8	66.2	71.2
2000	57.9	64.2	68.4	73.2
2500	60.4	66.5	70.5	75.2
3150	62.8	68.7	72.6	77.2
R_w	48	53	57	63

Table 5.3. Sound reduction index R [dB] for brickwork of sandlime bricks (1900 kg/m^3)

Frequency, Hz	75 mm	100 mm	150 mm	200 mm
100	28.9	31.1	32.9	32.9
125	30.7	32.5	33.2	32.9
160	32.3	33.6	33.2	32.9
200	33.7	34.0	33.2	32.9
250	34.5	34.0	33.2	35.0
315	34.5	34.0	33.2	37.6
400	34.5	34.0	35.6	40.2
500	34.5	34.0	38.2	42.8
630	34.5	34.6	40.8	45.3
800	34.5	37.3	43.4	47.8
1000	35.7	40.0	46.0	50.2
1250	38.4	42.6	48.5	52.6
1600	41.1	45.2	50.9	54.9
2000	43.7	47.7	53.2	57.1
2500	46.2	50.1	55.5	59.2
3150	48.7	52.5	57.7	61.3
R_w	38	40	43	47

Table 5.4. Sound reduction index R [dB] for lightweight concrete (1000 kg/m^3)

Frequency, Hz	100 mm	150 mm	200 mm	250 mm	300 mm
100	37.8	39.9	39.9	39.7	39.5
125	39.2	40.2	39.9	39.7	40.2
160	40.4	40.2	39.9	40.8	43.2
200	40.8	40.2	39.9	43.1	46.2
250	40.8	40.2	42.0	45.7	48.7
315	40.8	40.2	44.6	48.2	51.2
400	40.8	42.5	47.1	50.7	53.6
500	40.8	45.1	49.7	53.2	56.0
630	41.3	47.7	52.2	55.6	58.4
800	44.0	50.2	54.6	58.0	60.7
1000	46.6	52.7	57.0	60.3	62.9
1250	49.2	55.2	59.4	62.5	65.1
1600	51.8	57.6	61.6	64.7	67.1
2000	54.3	59.9	63.8	66.8	69.2
2500	56.7	62.2	66.0	68.8	71.1
3150	59.1	64.4	68.0	70.8	73.1
R_w	47	50	54	57	59

Table 5.5. Sound reduction index R [dB] for lightweight concrete (1800 kg/m^3)

Frequency, Hz	75 mm	100 mm	150 mm	200 mm	400 mm
100	25.0	27.2	29.3	29.6	30.4
125	26.8	28.7	29.9	29.6	33.6
160	28.4	29.9	29.9	29.6	36.0
200	29.9	30.7	29.9	29.6	38.5
250	31.0	30.7	29.9	29.6	40.8
315	31.3	30.7	29.9	31.8	43.2
400	31.3	30.7	29.9	34.3	45.5
500	31.3	30.7	32.3	36.8	47.7
630	31.3	30.7	34.8	39.2	49.9
800	31.3	31.4	37.3	41.6	52.0
1000	31.3	34.0	39.8	44.0	54.0
1250	32.5	36.5	42.2	46.3	56.0
1600	35.0	39.0	44.6	48.5	57.9
2000	37.5	41.4	46.8	50.7	59.8
2500	40.0	43.8	49.0	52.7	61.7
3150	42.4	46.1	51.2	54.8	63.5
R_w	34	35	38	41	51

Table 5.6. Sound reduction index R [dB] for aerated concrete (700 kg/m³)

Frequency	185 mm	260 mm	185 + 40 mm	260 + 40 mm
Hz	300 kg/m^2	330 kg/m^2	390 kg/m^2	420 kg/m^2
100	32.1	36.6	35.4	39.5
125	33.9	38.2	37.3	41.1
160	37.3	40.7	40.7	43.6
200	39.8	43.2	43.2	46.1
250	42.3	45.7	45.7	48.6
315	44.9	48.2	48.2	51.1
400	47.4	50.7	50.7	53.5
500	49.9	53.1	53.3	56.0
630	52.4	55.6	55.8	58.4
800	54.9	58.0	58.2	60.8
1000	57.3	60.3	60.7	63.2
1250	59.8	62.7	63.1	65.5
1600	62.2	64.9	65.5	67.8
2000	64.5	67.1	67.8	70.0
2500	66.8	69.3	70.1	72.1
3150	69.0	71.3	72.3	74.1
R_w	53	56	56	59

Table 5.7. Sound reduction index R [dB] for hollow concrete floors with and without a 40 mm thick top layer of concrete

5.2. Sound reduction index for lightweight double leaf constructions

Laboratory values for the sound reduction index of double plaster board walls and wooden floor constructions are taken from the national guidelines SBI 172 and NBI 28 and from [Novak]. All data shown in figures 3.1 and 3.2 are proposed as Nordic input data and listed in tables 5.8 and 5.9. In case the actual constructions of a building are not identical to any construction given in the tables, the sound reduction indices are taken for a relevant construction with lower sound insulation, for example with stiffer connections between the leaves, with smaller cavity, or with less mineral wool in the cavity.

Frequency, Hz	1	2	3	4	5	6	7
100	36	25	32	34	36	40	32
125	40	25	30	36	38	42	42
160	41	30	39	42	40	45	42
200	41	35	41	50	44	50	48
250	37	37	44	53	46	55	53
315	41	42	50	56	50	57	58
400	43	47	52	60	55	61	61
500	44	50	54	65	58	66	64
630	45	52	57	66	62	71	67
800	49	53	58	69	66	75	69
1000	54	54	60	71	71	77	72
1250	55	56	61	68	79	79	77
1600	59	57	62	62	82	83	82
2000	60	57	62	60	79	81	81
2500	57	54	53	60	70	75	75
3150	51	45	51	61	69	79	75
R_w	49	48	54	59	58	64	62

1 *145 mm thick, 2 x 2 x 13 mm boards on wooden studs, 90 mm mineral wool (NBI 28, p.38 c R2)*
2 *100 mm thick, 2 x 1 x 13 mm boards on steel studs, 50 mm mineral wool (NBI 28, p.40 a R2)*
3 *122 mm thick, 2 x 2 x 13 mm boards on steel studs, 60 mm mineral wool (NBI 28, p.40 b R2)*
4 *145 mm thick, 2x 2 x 13 mm boards on staggered 75 mm steel profiles, 95 mm mineral wool (SBI 172, Figure 3.9.4)*
5 *226 mm thick, 2 x 1 x 13 mm boards on separated wooden studs, 200 mm mineral wool (NBI 28, p.47 b R1)*
6 *326 mm thick, 2 x 1 x 13 mm boards on separated wooden studs, 300 mm mineral wool (NBI 28, p.47 b R3)*
7 *235 mm thick, 2 x 2 x 13 mm boards on separated steel studs, 2 x 45 mm mineral wool (Novak, Figure10)*

Table 5.8. Sound reduction index R [dB] for plaster board walls

Frequency, Hz	1	2	3
100	24	40	38
125	28	40	44
160	30	46	49
200	38	52	51
250	39	56	52
315	39	57	57
400	43	59	59
500	43	59	60
630	46	62	63
800	47	62	65
1000	49	63	68
1250	49	62	68
1600	50	62	68
2000	53	62	70
2500	52	63	67
3150	54	62	65
R_w	47	61	63

1 Wooden floor with particle board directly on beams (NBI 28 p74 R1)
2 Wooden floor with particle board directly on beams and ceiling on steel profiles (NBI 28 p74 R3)
3 Wooden floor with plaster board and particle board on mineral wool (NBI 28, p76 a R3)

Table 5.9. Sound reduction index R [dB] for wooden floors

5.3. Normalized impact sound pressure level for monolithic floors

Examples of calculated laboratory values of the normalized impact sound pressure level for hollow concrete slabs are given in the following table. The calculated values can of course be used for estimations of sound insulation in buildings, but such estimations are time consuming without a suitable computer programme. The purpose of the table is primarily to indicate laboratory values that will lead to field values as estimated in this report.

Frequency	185 mm	260 mm	185 + 40 mm	260 + 40 mm
Hz	300 kg/m^2	330 kg/m^2	390 kg/m^2	420 kg/m^2
100	64.4	62.1	60.4	58.7
125	66.0	63.8	62.1	60.4
160	67.2	65.0	63.3	61.6
200	68.4	66.2	64.5	62.8
250	69.6	67.4	65.6	64.0
315	70.8	68.6	66.8	65.2
400	71.9	69.7	68.0	66.4
500	73.1	70.9	69.1	67.5
630	74.2	72.0	70.2	68.7
800	75.3	73.2	71.4	69.8
1000	76.4	74.3	72.5	70.9
1250	77.5	75.4	73.6	72.0
1600	78.6	76.5	74.6	73.1
2000	79.6	77.6	75.7	74.2
2500	80.7	78.6	76.8	75.3
3150	81.7	79.7	77.8	76.3
$L_{n,w}$	86	84	82	81

Table 5.10 Normalized impact sound pressure level L_n [dB] for hollow concrete floors with and without a 40 mm thick top layer of concrete

5.4. Normalized impact sound pressure level for lightweight floor constructions

Laboratory values for the normalized impact sound pressure levels for wooden floor constructions are taken from the Norwegian guideline NBI 28. The data shown in figure 3.3 are proposed as Nordic input data and listed in table 5.11.

Frequency, Hz	1	2
100	81	70
125	82	71
160	80	64
200	83	62
250	84	60
315	84	60
400	81	60
500	82	61
630	78	58
800	76	55
1000	72	51
1250	69	47
1600	65	43
2000	61	40
2500	60	38
3150	57	40
$L_{n,w}$	77	58

1 Wooden floor with particle board directly on beams (NBI 28 p126 c)

2 Wooden floor with particle board directly on beams and ceiling on steel profiles (NBI 28 p126 d)

Table 5.11. Normalized impact sound pressure level L_n [dB] for wooden floors

5.5. Sound reduction index improvement by linings

Estimated values for the sound reduction index improvement of linings used in Iceland are given in table 5.12. The linings are covering heavy walls and slabs.

Frequency, Hz	1	2	3
100	0	2	0
125	-1	4	1
160	-5	6	2
200	-8	8	3
250	-12	10	4
315	-8	11	5
400	-5	12	5
500	-1	12	5
630	0	12	5
800	0	12	5
1000	0	12	5
1250	0	12	5
1600	0	12	5
2000	0	12	5
2500	0	12	5
3150	0	12	5

1 Sand cement plaster on cellular plastic, 100 mm
2 Wooden particle board with 50-100 mm mineral wool
3 Board, 50 mm space, no mineral wool

Table 5.12. Sound reduction index improvement ΔR [dB] by linings

5.6. Sound reduction index improvement and reduction of impact sound pressure level by floating floors and floorings

Proposed Nordic input data for floating floors are listed in tables 5.13 and 5.14. The data are taken from National guidelines and from a measurement carried out at SP, Borås. Except for the construction consisting of chipboard and plaster board on mineral wool, all results are measured in the laboratory with the floating floor on a heavy slab. The mentioned construction of boards on mineral wool was situated on top of a wooden construction when the results in table 5.14 was measured.

Frequency, Hz	1	2	3
100	2	2.0	2.0
125	2	2.0	0.0
160	3	2.0	1.0
200	4	2.0	-2.0
250	5	2.0	-3.0
315	5	3.0	-5.0
400	7	4.0	-5.0
500	8	5.0	-3.0
630	9	5.5	1.0
800	10	6.0	4.0
1000	11	6.5	6.0
1250	12	6.5	8.0
1600	12	6.5	7.0
2000	12	6.5	6.0
2500	12	6.5	5.0
3150	12	6.5	3.0

1 50 mm concrete on 30 mm mineral wool (SBI 172, Figure 3.20)
2 Wooden floor on joists on soft boards (SBI 172, Figure 3.17)
3 15 mm parquet on 3 mm cell.plastic (Airolen), data from SP

Table 5.13. Sound reduction index improvement ΔR [dB] by floating floors

Frequency, Hz	1	2	3	4
100	6	0	3	7
125	8	0	0	4
160	10	0	1	8
200	13	0	2	9
250	15	4	2	13
315	17	7	1	16
400	21	10	4	18
500	25	13	6	22
630	28	17	15	23
800	32	21	22	25
1000	35	25	28	26
1250	38	30	34	29
1600	41	34	41	29
2000	43	38	48	27
2500	44	42	53	27
3150	46	44	57	25
ΔL_w	28	18	17	26

1 50 mm concrete on 30 mm mineral wool (SBI 172, Figure 3.20)
2 Wooden floor on joists on soft boards (SBI 172, Figure 3.17)
4 15 mm parquet on 3 mm cell.plastic (Airolen), data from SP
4 Chipboard and plaster board on 25 mm mineral wool (NBI 28 p. 127 c 2)

Table 5.14. Reduction of impact sound pressure level ΔL [dB] by floating floors

Data for three floorings are proposed as Nordic indata. The three floorings are a relatively hard surface (linoleum), a layer of PVC on a softer layer, and a thin carpet (felt). The data are in principle only correct for heavy slabs. The sound reduction index improvement is 0 dB.

Frequency, Hz	1	2	3
100	2	1	2
125	2	1	2
160	2	1	2
200	2	1	2
250	2	1	2
315	2	1	3
400	2	1	4
500	2	2	6
630	2	3	8
800	3	4	11
1000	4	5	14
1250	5	7	18
2600	6	10	24
2000	8	13	30
2500	10	17	36
3150	12	23	42
ΔL_w	8	11	17

1 *Linoleum (SBI 172, Figure 3.23)*

2 *PVC on polyester (estimated data from Iceland)*

3 *Glued felt (estimated data from Iceland)*

Table 5.15. Reduction of impact sound pressure level ΔL by floorings

6. Conclusion

Input data for the coming European standard EN 12354 for estimation of sound insulation in buildings are proposed for common Nordic building constructions like monolithic elements, double plaster board walls, wooden floors, linings, floating floors, and floorings. The proposed data for transmission of vibration through junctions and a suitable procedure for determination of the structural reverberation time of monolithic elements agree with informative annexes of the standard. The other types of the proposed Nordic input data deviate from the guidelines of the annexes, or the constructions of interest are not included in the annexes of the standard.

With the proposed input data the sound insulation is in average overestimated by 0.0-0.5 dB.

The standard deviation of the difference between calculated and measured R'_w-values is 1.9-2.6 dB for monolithic basic elements and 3.1-3.2 dB for lightweight double constructions.

The standard deviation of the difference between calculated and measured $L'_{n,w}$-values for vertical transmission is 3.1 dB for monolithic slabs and 5.4 dB for lightweight floor constructions. Calculations for horizontal transmission of impact sound insulation have shown a much lower accuracy for both monolithic and lightweight double constructions.

The precision of the calculation results for airborne sound insulation is regarded as satisfactory. This is also the case for vertical transmission of impact sound insulation of monolithic floors with floating floors or floorings. The accuracy of the calculated impact sound insulation for lightweight floors is not regarded satisfactory. For horizontal transmission of impact sound the precision is even poorer.

In general, the calculated sound insulation of lightweight double constructions is sensitive to the choice of input data, especially concerning flanking transmission because the estimated sound insulation depends on correct values for the sound reduction indices of flanking elements as well as correct interpretations of the transmission paths through junctions. For lightweight building elements there is a need for relatively simple calculation methods to improve the available input data for the coming European standard.

During the project it appeared that comparisons of frequency curves for the calculated and measured sound insulation were useful for analyses of the calculation methods. The frequency curves were also very useful for validating data of the applied building materials as well as the quality of the workmanship. It is recommended that the result of the project is integrated in one or more computer programmes that will be commercially available and facilitate application of the detailed models of the coming EN 12354 part 1 and 2.

References

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Enclosures

There are 4 enclosures that belong to this report:

1. annex B of EN 12354-1
2. weighted sound insulations for building elements, comparisons between field measurements and calculated values according to EN 12354
3. third octave band sound insulation graphs for each comparison

Paper copies of the enclosures may be ordered from the Nordic Innovation Centre.