Hans G. Jonasson

Measurements of sound reduction index with intensity technique
Nordtest Project 746-88
Abstract

Measurement of sound insulation with intensity technique

The sound intensity technique has been tested on sound insulation measurements under laboratory conditions. It is shown that the agreement with traditional measurements of the sound reduction index is excellent. If the Waterhouse correction is applied in the receiving room the weighted sound reduction index $R_W$ is overestimated by about 0.5 dB with a standard deviation of 1.0 dB. Without this correction there is a small underestimate.

A Nordtest method is proposed. In this method the sound intensity is determined by scanning a closed surface on the receiving side of the test specimen. At least two scans with different scanning patterns shall be carried out and the maximum difference between these two scans must not exceed 1.0 dB for any frequency band. The field indicator, that is the difference between the sound pressure level and the sound intensity level averaged over the measurement surface must not exceed 10 dB and 6 dB for a test specimen which is sound reflecting and sound absorbing respectively on the receiving side. The Waterhouse correction shall be applied in the receiving room when comparing with traditional measurements.

About 30 different measurements have been carried out in 3 different laboratories to get an estimate of the precision of the intensity method when comparing with the traditional measurement technique. In addition measurements illustrating the influence of different parameters such as measurement distance, microphone spacing and measurement environment are described.

Key words: measurements, sound reduction index, sound insulation, intensity, scanning

SP
SP RAPPORT 1991: 23
ISBN 91-7848-280-1
ISSN 0284-5172
Borås 1991

Swedish National Testing and Research Institute
SP REPORT 1991: 23

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Foreword

This project has been financed by Nordtest, project 746-88. The project has been carried through by a project group consisting of

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The project would not have been possible without the kind cooperation of the above individuals and institutes. Thank you!

Hans G. Jonasson
1 Introduction

1.1 Background

Measurement of sound reduction index in the laboratory is indeed one of the most usual acoustical measurements. Ideally these measurements are carried out without flanking transmission. On measurements on small building elements, however, it is often impossible to avoid all flanking transmission. This fact has been recognized by ISO in recent standardization in the ISO 140 series. It has been proposed to make corrections for flanking transmission. However, even with these corrections many small building elements with high sound insulation will still be difficult to handle. A solution to this problem is the new sound intensity technique which has been under strong development during the past 15 years, [1].

Although it has been shown by many researchers, i.e. [2, 3], that it is possible to get good agreement between traditional measurements and intensity measurements there is not yet any standard or proposal on the subject.

1.2 Aim

The aim of this project is to propose a Nordtest method to measure the sound reduction index using the sound intensity technique. The method is primarily aiming at being used in acoustical laboratories for measurements on building elements, particularly small elements, with very high sound insulation. This does not prevent the method to become useful also for field applications. Because the results will be used together with traditional measurements it is of particular interest to study the difference between the two measurement methods. Thus it is not the aim of this project, to evaluate which method is the best one to evaluate the "true" sound reduction index.

1.3 Disposition

The discussions are, to some extent, carried out in section 2. Many details have been left out because the background is not as important as the result. Some results from measurements carried out before the first draft proposal for Nordtest method was made are accounted for in section 3. This draft version was then been used for a number of measurements in 3 different Scandinavian laboratories. These results are accounted for in section 4 and they also provide the necessary statistics to evaluate the differences between the intensity method and the traditional method. Experiences from these tests also caused some editorial change in the final Nordtest proposal which is accounted for in clause 7.
2 Some considerations

2.1 What do we want to measure?

In the ISO 140 series the sound reduction index R is defined as

\[ R = 10 \log(W_1/W_2) \]  \hspace{1cm} (2.1)

where \( W_1 \) = the sound power incident on the test specimen,
\( W_2 \) = the sound power transmitted through the test specimen.

Assuming a perfectly diffuse sound field in the source room we get

\[ W_1 = p_1^2 S / 4 \rho c \]  \hspace{1cm} (2.2)

where \( S \) = the area of the test specimen,
\( \rho c \) = the specific acoustic impedance of air,
\( p_1 \) = the sound pressure in the source room.

With the same conditions in the receiving room the power balance gives

\[ W_2 = p_2^2 A / 4 \rho c \]  \hspace{1cm} (2.3)

where \( A \) = the sound absorption area of the receiving room,
\( p_2 \) = the sound pressure in the receiving room.

(2.1) - (2.3) now gives the well-known ISO 140/3 standard formula

\[ R = L_1 - L_2 - 10 \log(A/S) \]  \hspace{1cm} (2.4)

where \( L_1 \) and \( L_2 \) = the time and space averaged sound pressure levels in the source and receiving room respectively;

The sound pressure levels \( L_1 \) and \( L_2 \) in (2.4) are average sound pressure levels where the averaging takes place outside room volumes close to the boundary surfaces. If, by measuring in the middle of the room only, we want a true average over the whole room volume we have to add corrections accounting for the higher energy density close to the room boundaries. This has been done in the ISO 3741 standard for determining sound power levels in a reverberation room by adding, to the measured sound pressure level, the Waterhouse correction

\[ C_{\text{Waterhouse}} = 10 \log \left(1 + \frac{S_b \lambda}{8V} \right) \]  \hspace{1cm} (2.5)

where \( S_b \) = the total area of the boundary surfaces of the room;
\( \lambda \) = the wavelength of the midband frequency;
\( V \) = the volume of the test room.

The size of this correction is given for two typical laboratory room sizes in Fig. 2.1. The dimensions of the rooms are
200 m\(^3\): 8,0 m \(\times\) 6,0 m \(\times\) 4,2 m, \(S_b = 213,6 \text{ m}^2\)
100 m\(^3\): 6,0 m \(\times\) 5,0 m \(\times\) 3,3 m, \(S_b = 132,6 \text{ m}^2\)
50 m\(^3\): 5,0 m \(\times\) 4,0 m \(\times\) 2,5 m, \(S_b = 85,0 \text{ m}^2\)

**Figure 2.1** The Waterhouse correction for 3 typical laboratory rooms.

If we now measure the sound intensity \(I\) over a measurement surface \(S_m\) completely enclosing the surface \(S\) of the test specimen we get with eq. (2.3) and the Waterhouse correction in the receiving room(index 2)

\[
W_2 = I S_m = p_2^2 (1 + \frac{S_b 2 \lambda}{8 V_2^2}) \frac{A}{4 \rho c}
\]

(2.6)

or in the usual logarithmic form after division with the reference sound pressure \(p_0 = 2 \times 10^{-5} \text{ Pa}\) and the reference sound intensity \(I_0 = 10^{-12} \text{ W/m}^2\).

\[
L_2 = L_I + 10 \log(S_m) - 10 \log(A) + 6 - 10 \log(1 + \frac{S_b 2 \lambda}{8 V_2^2})
\]

(2.7)

where \(L_I\) = the sound intensity level \(10 \log(I/I_0)\),

which together with (2.4) gives

\[
R = L_I - L_2 + 10 \log(S/S_m) - 6 - 10 \log(1 + \frac{S_b \lambda}{8 V_2})
\]

(2.8)

A problem with the Waterhouse correction in Eq. (2.8) is that it can only be calculated when the receiving room is known. If the receiving room is not defined it should, because of reciprocity, be preferable to apply the Waterhouse correction in the source room.

Equation (2.8) can't be expected to give the whole truth. The Waterhouse correction assumes diffuse field conditions in the middle of the room and takes no account of the modal behaviour of the sound field. This is particularly serious as the Waterhouse correction has its major importance at low frequencies where the modal density has its minimum.
2.2 Scanning versus discrete measurement points

Scanning works! Although it is still possible to find some sceptics who are of the opinion that manual scanning is too risky to use and that we, for the time being, have to restrict ourselves to discrete point sampling, everybody who has used manual scanning seem to agree that it is the best way to do the surface averaging with. Some references that support this are [4], [5] and [6]. In Fig. 2.2 an example of the repeatability of the scanning method is shown. The repeatability may be worse under more complicated situations. The results refer to single scans and can be improved by averaging over several scans.

![Graph showing repeatability of scanning](image)

**Figure 2.2** Repeatability of a single scan. 8 measurements and 2 operators. Window with area 1.5 m². Measurement distance 0.1 m.

The scanning speed used in Fig. 2.2 was 0.14 m/s. Normal speeds successfully used in the literature are 0.1-0.3 m/s. In the Nordtest method for sound power measurements, [7], it is recommended to scan with speeds <0.24 m/s. In France CSTB recommends 0.05 m/s, [8].

2.3 Measurement environment

2.3.1 Reflecting test specimen

In order to be able to measure the sound intensity correctly certain requirements have to be fulfilled. In [6] a number of sound field indicators have been introduced in order to make it possible to validate the quality of sound intensity measurements to determine the sound power level. Unfortunately most of these indicators can, with commercially available instrumentation, not be evaluated while carrying out real time scanning. However, it has been shown, i.e [8], that the time and space averaged pressure-intensity indicator $L_p - L_I$ normally is the most important indicator to evaluate the quality of the measurements.

In [7] it is stated that engineering accuracy according to ISO can be achieved if

$$L_p - L_I < 10 \text{ dB}$$

(2.9)

assuming the sound source is not absorbing incoming sound. Although this limit of 10 dB cannot be verified theoretically there are numerous examples that it does work well. One nice example is given in Fig. 2.3 which shows that the measured values of $L_I$ in
front of a reflecting wall seem to coincide as soon as $L_p - L_I < 10$ dB.

![Graph showing dB Sound intensity level and $L_p - L_I$ respectively.](image)

**Figure 2.3** Measurements in front of a 11 m$^2$ reflecting wall in a 107 m$^3$ reverberation room. Measurement surface in niche opening 0,1 m from the wall.(RT= reverberation time).

In [11] it is shown that the pressure-intensity indicator in a diffuse sound field in front of a surface $n$ is given by

$$L_p - L_{In} = 10 \lg(8 \ W \ S_n/A/W_n) = 9 + 10 \ lg(W/W_h) + 10 \ lg(S_n/A)$$  \hspace{1cm} (2.10)

where

- $A =$ total absorption area in receiving room;
- $W =$ total power injected into receiving room;
- $S_n =$ area of surface $n$;
- $W_h =$ power injected into receiving room by surface $n$.

If all the power is injected through surface $n$ we get

$$L_p - L_I = 9 + 10 \ lg(S_n/A)$$  \hspace{1cm} (2.11)

Thus the requirement for a suitable environment becomes

$$S_n/A < 1.25$$  \hspace{1cm} (2.12)
In a room with volume $V$ this means that the reverberation time

$$ T < 0.2 \frac{V}{S_n} $$  \hspace{1cm} (2.13)

The restriction in eq. (2.13) gets tougher the more flanking transmission we have and the larger the area of the test specimen is.

2.3.2 Absorbing test specimen

When the test specimen is sound absorbing on the receiver side where the sound intensity is measured an additional measurement error is introduced. The measured intensity will become too low because the energy coming from the receiving room will only partially be reflected back to the room. As shown in [11] the error is given by

$$ e_n = 10 \log(1 - \frac{A_n}{A} \frac{W}{W_n}) $$  \hspace{1cm} (2.14)

where $A_n = \text{absorption area of the surface } n$. Also in this case the problem increases with the flanking transmission, that is a large $W/W_n$-ratio. However, even without flanking transmission the error can become quite large if the test specimen supplies a significant part of the total sound absorption in the receiving room. An example of this is shown in Fig. 2.4. In this example it is not sufficient to have a pressure-intensity indicator less than 10 dB. Although the flanking transmission is negligible it is necessary also to decrease the $A_n/A$-ratio by adding sound absorption to the receiver room.

In Figure 2.4 the agreement between the traditional method and the intensity method seems to be "normal" when the field indicator

$$ L_p - L_I < 6 \text{ dB} $$  \hspace{1cm} (2.15)

As the wall in this example was very highly absorbing and as the measurement room had very little absorption it is not unlikely that eq. (2.15) will be a satisfactory general requirement.
2.4 Measurement distance and measurement surface

Numerous investigations, such as [12] and [1], have shown that the sound field very close to a sound radiating plate is very complicated because of the energy flow parallel to the plate in the near field. Normally, the problems get serious when the distance is smaller than about 50 mm. In this respect, the coincidence frequency of the plate is an important parameter. When scanning the critical minimum distance is often easy to find. As soon as the intensity starts changing, the sign very often the probe is likely to be too close to the plate. In building acoustics, a suitable measurement distance seems to be about 100 mm. The experiences from this project indicate that, when measuring in a niche, it is preferable to measure in the niche opening flush with the wall in the receiving room. The sound field there is normally much better than inside the niche itself even if the measurement distance exceeds 100 mm.

As to the choice of a suitable measurement surface it has been shown, i.e. [5], that it is extremely important to "close" the edges of the surface properly. The practical implication of this is that a flat measurement surface, such as a niche opening, is to prefer to a box shaped surface which often is quite difficult to "close". An example of the
problems is given in Fig. 2.5., which shows some measurements on a door with area 1.72 m² and thickness 40 mm.

Figure 2.5 Different measurement surfaces on a door with area 1.72 m² (op = operator).

2.5 Microphone spacing

When using a p-p probe the microphone spacing required depends not only on the frequencies of interest but also on the quality of the equipment used. Recently better microphones have been introduced and it is now possible to go further down in frequency when using small microphone spacing. As the low frequency limit is so equipment dependent the limits for different spacings must be determined by the individual user.

For the high frequencies the maximum separation to give a maximum systematic intensity error of -0.5 dB is as follows (from [1]):

Microphone spacing Maximum frequency

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12 mm</td>
<td>3500 Hz</td>
<td></td>
</tr>
<tr>
<td>50 mm</td>
<td>1000 Hz</td>
<td></td>
</tr>
</tbody>
</table>

In Fig. 2.6 a comparison is given between the two most common microphone spacings 12 and 50 mm. We can see that the agreement is very good within the range 100-2500 Hz. In fact, this example and others tend to yield better agreement than would be expected from theoretical considerations. It is not unusual to have very good agreement within the range 63-3150 Hz. However, the lower frequency limit is strongly dependent on the equipment used.
Figure 2.6  Different microphone spacings. Test object: 11 m² wall in the laboratory
3 Some comparisons with ISO 140

In the literature numerous comparisons have been made between the intensity technique and the traditional ISO 140/3. The most common result is that the intensity technique yields systematically lower values in the low frequency region and systematically higher values in the high frequency region, i.e [13]. The agreement has been reported to become better after the introduction of the Waterhouse correction. A problem with earlier comparisons is that the measurement procedure has not been described in detail and that different people normally have carried out their intensity tests differently.

All tests reported here have been carried out at the Swedish National Testing and Research Institute. The traditional tests have been carried out according to ISO 140/3 using one loudspeaker position only. The same position was used for all intensity tests.

For the intensity measurements eq. (2.8) was used for all evaluations. A B&K p-p-probe with the new, improved 13 mm matched microphones was used with a Norwegian Electronics 830 analyzer. Before each test the equipment was calibrated with the B&K intensity calibrator. The microphone spacing was 50 mm below 100 Hz and 12 mm for the other frequencies. Each test object was scanned twice with each spacing. If the result of two scans differed by more than 0.5 dB for any single frequency in the frequency range 100-3150 Hz new and even more careful measurements were carried out. The result was then taken as the arithmetic average of two "successful" scans. In Fig. 2.7 a typical example is given showing good agreement but a little low and high values in the low and high frequency regions respectively. Other examples are shown in Fig. 2.8 and 2.9.

![Graph showing dB Sound reduction index and Lp - L1 respectively](image)

**Figure 2.7** 40 mm thick door with mass 27,5 kg and area 1,72 m². Source room:106 m³. Receiving room:129 m³. 12 mm probe only.
Figure 2.8  Window with 6 mm glass+63 mm air+ D4-12 with area 1.48 m². Source room:106 m³, receiving room:129 m³. (Figure scale 85%)

Figure 2.9  Steel element wall with window. Area: 11 m². Source room:107 m³ Receiving room:129 m³. Measurement distance: 0.4 m in a niche opening. (Figure scale: 85%)
In Fig. 2.10 an example is given of a wall which is sound absorbing on the source side. This is a difficult example because we don't know the precision of ISO 140 as good as we do for more normal constructions. However, as the source room was equipped with diffusors the precision is probably close to the "normal". The wall is the same one as in Fig. 2.4 although measured in the reverse direction.

![Graph](image)

**Figure 2.10** Steel element wall with 11 m² area. Source room: 129 m³, receiving room: 107 m³
Finally in Fig. 2.11 an example is given for a case where the requirements on the pressure-intensity indicator was not fulfilled. Only a 12 mm probe was used.

dB Sound reduction index and $L_p - L_I$ respectively

**Figure 2.11** A 200 mm + 100 mm double concrete slab with area 12 m$^2$. Source room:138 m$^3$, receiving room:129 m$^3$. 
4 Final measurement results

4.1 Within laboratory comparisons

3 different laboratories have used the Nordtest proposal to test about 10 different building elements each in their respective laboratories. The three laboratories were the Swedish National Testing and Research Institute (SP) in Borås, The Acoustic Research Center (DELAB) in Trondheim and the Danish Technological Institute (DTI) in Aarhus. All the three laboratories used the Norwegian Electronics 830 analyzer with Brüel & Kjær 2 microphone probes. Other information is summarized below:

**SP:** Source and receiving room volumes: 106 m$^3$ and 129 m$^3$ respectively. Measurements on 1 slab, 4 doors, 1 wall element, 4 normal windows and the two specially constructed steel windows used in the Round-Robin reported in 4.2.

**DELAB:** Source and receiving room volumes: 110 m$^3$ and 267 m$^3$ respectively. Measurements on 1 wall, 5 windows and 2 doors.

**DTI:** Source and receiving room volumes: 118 m$^3$ and 65 m$^3$ respectively. Measurements on 5 walls, 3 normal windows, 1 door and the same two steel windows as SP.

The instruction to the laboratories was to measure both with their traditional test procedure and with the proposal given in this report. Complete measurement results are given in [14], [15] and [16]. A summary of the results is given in Table 4.1 and Figure 4.1. The results are given with different use of the Waterhouse correction.

![Figure 4.1](image)

**Figure 4.1** Summary of the $R_w$-results of the 31 measurements, including some measurements not fully complying with the proposed method.

Figure 4.1 which includes all the measurements from Table 4.1, including those with some unreliable frequencies, shows that the agreement between the traditional method and the intensity method is good. There is little difference in accuracy between $R_{I,w}$ with W-h and $R_{I,w}$ without W-h. To have the Waterhouse correction tends to overestimate and not to have it tends to underestimate the sound insulation. If we remove the doubtful measurements not fully complying with the proposed method we get Figure 4.2.
Figure 4.2  Summary of 26 of the $R_w$-results of the measurements, excluding measurements not fully complying with the proposed method.

Also from Figure 4.2 it is quite obvious that no firm conclusions can be drawn as to whether the agreement improves with the Waterhouse correction. With and without the correction the difference between the traditional and the intensity method becomes 0.4 dB and -0.1 dB respectively with the corresponding standard deviations 0.9 and 0.8 dB. Thus the result seems to be slightly better without the Waterhouse correction! In Figure 4.3 the results of all frequencies of the measurements reported in Figure 4.2 are summarized.

Figure 4.3  Results from 26 measurements with Waterhouse correction in the receiving room.
<table>
<thead>
<tr>
<th>Test specimen</th>
<th>$R_{W\text{, traditional}}$</th>
<th>$R_{I,w\text{, no\text{W}}c}$</th>
<th>$R_{I,w\text{, Wc in rec}}$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wall, 10.9 m$^2$.</td>
<td>45 dB</td>
<td>42 dB</td>
<td>43 dB</td>
<td>DTI, more than 1 dB between scans. Box surface.</td>
</tr>
<tr>
<td>2. Wall, 10.9 m$^2$.  = 1, reversed direction.</td>
<td>43 dB</td>
<td>42 dB</td>
<td>43 dB</td>
<td>DTI, more than 1 dB between scans. Box surface.</td>
</tr>
<tr>
<td>3. Window, 1.46 m$^2$.</td>
<td>43 dB</td>
<td>43 dB</td>
<td>43 dB</td>
<td>DTI</td>
</tr>
<tr>
<td>4. Wall, 10.9 m$^2$.</td>
<td>52 dB</td>
<td>49 dB</td>
<td>51 dB</td>
<td>DTI, more than 1 dB between scans at 3 freq.</td>
</tr>
<tr>
<td>5. Wall, 10.9 m$^2$.</td>
<td>37 dB</td>
<td>37 dB</td>
<td>38 dB</td>
<td>DTI</td>
</tr>
<tr>
<td>6. Window, 1.46 m$^2$.</td>
<td>47 dB</td>
<td>47 dB</td>
<td>48 dB</td>
<td>DTI</td>
</tr>
<tr>
<td>7. Window, 1.46 m$^2$.</td>
<td>36 dB</td>
<td>36 dB</td>
<td>37 dB</td>
<td>DTI</td>
</tr>
<tr>
<td>8. Door, 1.9 m$^2$.</td>
<td>32 dB</td>
<td>33 dB</td>
<td>34 dB</td>
<td>DTI</td>
</tr>
<tr>
<td>9. Wall, 10.9 m$^2$.</td>
<td>56 dB</td>
<td>56 dB</td>
<td>56 dB</td>
<td>DTI, high background noise at high freq.</td>
</tr>
<tr>
<td>10. Window, 1.46 m$^2$.</td>
<td>39 dB</td>
<td>40 dB</td>
<td>40 dB</td>
<td>DELAB</td>
</tr>
<tr>
<td>11. Window, 1.46 m$^2$.</td>
<td>39 dB</td>
<td>39 dB</td>
<td>40 dB</td>
<td>DELAB</td>
</tr>
<tr>
<td>12. Window, 1.46 m$^2$.</td>
<td>38 dB</td>
<td>38 dB</td>
<td>38 dB</td>
<td>DELAB</td>
</tr>
<tr>
<td>13. Door, 1.92 m$^2$.</td>
<td>45 dB</td>
<td>45 dB</td>
<td>46 dB</td>
<td>DELAB</td>
</tr>
<tr>
<td>14. Window, 1.46 m$^2$.</td>
<td>42 dB</td>
<td>41 dB</td>
<td>42 dB</td>
<td>DELAB</td>
</tr>
<tr>
<td>15. Window, 1.46 m$^2$.</td>
<td>42 dB</td>
<td>42 dB</td>
<td>42 dB</td>
<td>DELAB</td>
</tr>
<tr>
<td>16. Steel deck, 10.5 m$^2$.</td>
<td>35 dB</td>
<td>36 dB</td>
<td>36 dB</td>
<td>DELAB, more than 1 dB between scans, box surface.</td>
</tr>
<tr>
<td>17. Door, 4.2 m$^2$.</td>
<td>40 dB</td>
<td>39 dB</td>
<td>40 dB</td>
<td>DELAB</td>
</tr>
<tr>
<td>18. Window, 2.94 m$^2$.</td>
<td>42 dB</td>
<td>41 dB</td>
<td>42 dB</td>
<td>SP</td>
</tr>
<tr>
<td>19. As 18, partly open</td>
<td>22 dB</td>
<td>20 dB</td>
<td>20 dB</td>
<td>SP</td>
</tr>
<tr>
<td>20. Door, 1.89 m$^2$.</td>
<td>37 dB</td>
<td>38 dB</td>
<td>39 dB</td>
<td>SP</td>
</tr>
<tr>
<td>21. Door, 1.89 m$^2$.</td>
<td>40 dB</td>
<td>40 dB</td>
<td>40 dB</td>
<td>SP</td>
</tr>
<tr>
<td>22. Door, 1.89 m$^2$.</td>
<td>35 dB</td>
<td>37 dB</td>
<td>37 dB</td>
<td>SP</td>
</tr>
<tr>
<td>23. Wall element, 1.0 m$^2$.</td>
<td>18 dB</td>
<td>17 dB</td>
<td>17 dB</td>
<td>SP</td>
</tr>
<tr>
<td>24. Window, 1.44 m$^2$.</td>
<td>44 dB</td>
<td>44 dB</td>
<td>44 dB</td>
<td>SP</td>
</tr>
<tr>
<td>25. Window, 1.2 m$^2$.</td>
<td>40 dB</td>
<td>39 dB</td>
<td>40 dB</td>
<td>SP</td>
</tr>
<tr>
<td>26. As 25, partly open</td>
<td>28 dB</td>
<td>27 dB</td>
<td>27 dB</td>
<td>SP</td>
</tr>
<tr>
<td>27. Concrete slab, 12 m$^2$.</td>
<td>53 dB</td>
<td>55 dB</td>
<td>56 dB</td>
<td>SP, probably some flanking transmission</td>
</tr>
<tr>
<td>28. Single steel window</td>
<td>37 dB</td>
<td>37 dB</td>
<td>37 dB</td>
<td>SP</td>
</tr>
<tr>
<td>29. = 28</td>
<td>37 dB</td>
<td>37 dB</td>
<td>37 dB</td>
<td>DTI</td>
</tr>
<tr>
<td>30. Double steel wind.</td>
<td>54 dB</td>
<td>54 dB</td>
<td>55 dB</td>
<td>SP</td>
</tr>
<tr>
<td>31. = 30</td>
<td>53 dB</td>
<td>53 dB</td>
<td>54 dB</td>
<td>DTI</td>
</tr>
</tbody>
</table>

**Table 4.1** Summary of the measurements at the three different laboratories
The results shown in Figure 4.2 and 4.3 are summarized in Table 4.2.

<table>
<thead>
<tr>
<th>Frequency, Hz</th>
<th>Average overestimate</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Hz</td>
<td>5 dB</td>
<td>6 dB</td>
</tr>
<tr>
<td>63 - 80</td>
<td>1.5 dB</td>
<td>3 dB</td>
</tr>
<tr>
<td>100 Hz</td>
<td>1 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td>125 - 400 Hz</td>
<td>1 dB</td>
<td>1.5 dB</td>
</tr>
<tr>
<td>500 - 1600 Hz</td>
<td>0.5 dB</td>
<td>1.5 dB</td>
</tr>
<tr>
<td>2000 - 3150 Hz</td>
<td>1 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>1.5 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td>5000 Hz</td>
<td>1.5 dB</td>
<td>3 dB</td>
</tr>
<tr>
<td>100 - 3150 Hz, R_w</td>
<td>0.5 dB</td>
<td>1 dB</td>
</tr>
</tbody>
</table>

Table 4.2 Estimation of the precision with which the proposed intensity method will reproduce the traditional ISO 140/3 method.

It may be of interest to compare the values in Table 4.2 with the repeatability requirements for measurements according to ISO 140/3 which are given in ISO 140/2, see Table 4.3. As we can see the average differences in Table 4.2 are well within the repeatability requirements.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Repeatability</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 200 Hz</td>
<td>5 dB</td>
</tr>
<tr>
<td>250 Hz</td>
<td>3 dB</td>
</tr>
<tr>
<td>315 - 500 Hz</td>
<td>2 dB</td>
</tr>
<tr>
<td>630 - 1250 Hz</td>
<td>1 dB</td>
</tr>
<tr>
<td>1600 - 3150 Hz</td>
<td>2 dB</td>
</tr>
</tbody>
</table>

Table 4.3 Repeatability requirements for sound reduction index measurements according to ISO 140/2.

In Figure 4.4 - 4.6 the individual sound reduction index curves for the three participating laboratories are given. Generally the results look very good. Some comments:

It is remarkable that DTI has a different tendency than SP and DELAB in the low frequency region. One explanation may be that DTI has used the old type of B&K intensity microphones. These are not as good as the new type used by SP and DELAB. Another reason may be that DTI has carried out more measurements on walls. One problem is that we have a limited experience from low frequency measurements with the traditional method.

It is also remarkable that DELAB has managed to get so much better results for the high frequencies than the other two laboratories. All laboratories have used the same type of probe with the same 12 mm microphone spacing. Theoretically this spacing is rather large for 5000 Hz. Maybe it is possible to get better results by using a smaller microphone spacing? On the other hand the results seem to be good enough.

DTI in Figure 4.5 has one curve deviating significantly from the others. That measurement was on a good double wall of lightweight concrete.
Figure 4.4 9 measurements at SP. With Waterhouse correction in receiving room.

Figure 4.5 All 9 measurements at DTI. With Waterhouse correction in receiving room.

Figure 4.6 All 9 measurements at DELAB. With W-h correction in receiving room.
4.2 Round - Robin tests

Unfortunately it was not possible to make a complete Round - Robin test on the same test specimen. However, two steel windows, one single and one double metal leaf, which previously had been used in an European Round - Robin test were finally circulated for testing with both the traditional ISO 140 method and the proposed intensity method. The results are given in Figure 4.7-4.8. It should be observed that the double window has a very extreme sound insulation. In the traditional ISO method two source positions have been used by DELAB and DTI. SP used a moving loudspeaker.

![dB Sound reduction index according to ISO/DIS 140-3, 1991](image)

**Figure 4.7** Interlaboratory comparisons according to ISO 140-3 for a single metal leaf window(lower curves) and a double metal leaf window(upper curves)
Figure 4.8  Interlaboratory comparisons for a single metal leaf window(lower curves) and a double metal leaf window(upper curves)

The results show an excellent agreement both for the traditional method and the proposed intensity method. The small differences between the laboratories seem to be the same for both methods. For the best window all laboratories get a 1-2 dB higher $R_W$ with the intensity technique. This may depend on some flanking transmission. It is difficult to measure with the traditional method on such a good window.
5 Conclusions

Measurement of the sound reduction index as defined in ISO 140/3 can be carried out with good accuracy by using the method proposed in section 7. This method will on the average overestimate $R_w$ by about 0.5 dB with the standard deviation 1.0 dB.

Without Waterhouse correction in the receiving room the intensity method will yield a small underestimate of the traditional sound reduction index. With Waterhouse correction a small overestimate will occur.

The sound intensity method can be regarded to be equivalent to the traditional method. Actually the difference between the two methods lie well within the repeatability of the traditional method.

For constructions with high sound insulation the intensity method is probably more reliable and more accurate than the traditional method because it is less sensitive to flanking transmission.
6 References

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[8] CSTB:s quality manual on sound intensity measurements

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Sound insulation measurements with intensity technique
SP Internal report

Intensity measurements of sound intensity
DELAB, Journal no: AN90262 Memo 3-90

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Measurement of sound reduction indices with sound intensity technique
DTI, Ref no: 260 0 8008
7 Proposal for Nordtest method

Building elements:
Sound insulation measurements with an intensity scanning method under laboratory conditions
0 Introduction

The ISO 140 series specifies methods to measure the sound reduction index of building elements in the laboratory. This NORDTEST method is primarily aiming at being a supplement to ISO 140 to be used whenever the flanking transmission prevents accurate measurements according to that standard.

1 Scope

This NORDTEST method specifies a sound intensity scanning method to determine the sound reduction index, as defined by ISO 140/3, of a building element.

2 Field of application

2.1 General

This NORDTEST method is primarily intended to be used in the laboratory when the traditional ISO 140/3 method fails because of high flanking transmission. This may, for instance, be the case when measuring on windows, doors or heavy constructions with high sound insulation.

Relevant parts of the method can of course also be used for measurements on facade elements, suspended ceilings and small building elements according to ISO 140 Parts 5, 9 and 10 respectively.

2.2 Precision

The absolute precision of this Nordtest method is not known. As the method will primarily be used in parallel with the traditional ISO 140/3 method and not as a self standing method the estimated precision in relation to this traditional method is given in Table 1.

<table>
<thead>
<tr>
<th>Frequency, Hz</th>
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<td>0,5 dB</td>
<td>1 dB</td>
</tr>
</tbody>
</table>

Table 1 Estimation of the precision with which this Nordtest method will reproduce the traditional ISO 140/3 method.

Note - The estimates in Table 1 are based on about 30 comparison measurements carried out in three different Scandinavian laboratories.
3 References


ISO 140/5, Acoustics - Measurement of sound insulation in buildings and of building elements - Part 5: Field measurements of airborne sound insulation of facade elements and facades.

ISO 140/9, Acoustics - Measurement of sound insulation in buildings and of building elements - Part 9: Laboratory measurement of room-to-room airborne sound insulation of suspended ceiling with a plenum above it.


ISO 717, Rating of sound insulation in buildings and of building elements.

ISO 3741, Acoustics - Determination of sound power levels - Precision method in a reverberation room

IEC 942, Sound calibrators

IEC 1043, Instruments for the measurement of sound intensity (at present at the stage of draft).

4 Definitions

4.1 average sound pressure level in a room, \( L_p \):
10 times the common logarithm of the ratio of the space and time average of the sound pressure squared to the square of the reference sound pressure, the space average being taken over the entire room with the exception of those parts where the direct radiation of a sound source or the near field of the boundaries (wall, etc.) is of significant influence.

4.2 sound intensity, \( I \):
Time averaged rate of flow of sound energy per unit area oriented normal to the local particle velocity. This is a vectorial quantity which is equal to

\[
\hat{I} = \frac{1}{T} \int_{0}^{T} p(t) \hat{u}(t) \, dt \quad \text{W/m}^2
\]  

where

\( p(t) \) is the instantaneous sound pressure at a point, in pascals;

\( \hat{u}(t) \) is the instantaneous particle velocity at the same point, m/s;

\( T \) is the averaging time, in seconds;

4.3 normal sound intensity, \( \hat{I}_n \):
Sound intensity component in the direction normal to the measurement surface. The signed magnitude of \( \hat{I}_n \) is denoted by \( I_n \) and the unsigned magnitude by \( |I_n| \).
4.4 normal sound intensity level, \( L_{ln} \):
Ten times the common logarithm of the ratio of the unsigned value of the normal sound intensity to the reference intensity \( I_0 \) as given by:

\[
L_{ln} = 10 \lg \left( \frac{I_n}{I_0} \right) \quad \text{dB}
\]

where

\( I_0 = 10^{-12} \text{ W/m}^2 \)

4.5 pressure-intensity indicator or field indicator, \( F \):
The difference between time and surface averaged sound pressure level and sound intensity level on the measurement surface given by:

\[
F = L_p - L_{ln} \quad \text{dB}
\]

4.6 residual pressure-intensity indicator, \( F_0 \):
The difference between indicated sound pressure level and sound intensity level when the probe is placed in a sound field in such an orientation that the particle velocity in the direction of the probe measurement axis is zero (e.g. in an acoustic coupler or transverse to the direction of propagation of a plane sound wave).

4.7 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. This quantity is denoted by \( R \):

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

For the purpose of ISO 140/3 the sound reduction index is evaluated from

\[
R = L_{p1} - L_{p2} + 10 \lg \left( \frac{S}{A} \right) \quad \text{dB}
\]

where
\( L_{p1} \) is the average sound pressure level in the source room;
\( L_{p2} \) is the average sound pressure level in the receiver room;
\( S \) is the area of the test specimen, which is normally equal to the free test opening;
\( A \) is the equivalent absorption area in the receiving room.

Note - The deduction from eq. (4) to eq. (5) assumes that the sound fields are perfectly diffuse including a diffuse sound incident and that the sound is transmitted only through the test specimen.

4.8 intensity sound reduction index, \( R_I \):
This index is evaluated from eq.(5) assuming that the sound fields are not perfectly diffuse and that the average sound pressure level in a room must include corrections for a higher energy density close to the boundaries as given in ISO 3741. In that case
\[
R_I = L_{p1} - 6 - L_{In} + 10 \log(1 + \frac{S_b \lambda}{8 V_2}) - 10 \log(S_m / S)
\]  

where

- \(L_{p1}\) is the average sound pressure level in the source room;
- \(L_{In}\) is the average sound intensity level over the measurement surface in the receiver room;
- \(S_b\) is the area of all the boundary surfaces in the receiving room;
- \(\lambda\) is the wavelength of the midband frequency;
- \(V_2\) is the volume of the receiving room;
- \(S_m\) is the area of the measurement surface;
- \(S\) is the area of the test specimen.

If the receiving room is not defined the room correction 10 \(\log(1 + \frac{S_b \lambda}{8 V_2})\) shall be applied to the source room instead.

Note - The room correction 10 \(\log(1 + \frac{S_b \lambda}{8 V_2})\) must be used in order to simulate the same result as the traditional method.

### 4.9 Weighted Intensity Sound Reduction Index, \(R_{I,w}\):

Intensity sound reduction index \(R_I\) weighted according to ISO 717/1.

### 5 Instrumentation

#### 5.1 General

The intensity measuring instrumentation shall comply with IEC 1043 and be able to measure intensity levels re 10^-12 W/m^2 in decibels in one-third octave bands. The intensity shall be measured in real time.

The residual pressure-intensity indicator \(F_0\) of microphone probe and analyzer shall be higher than 10+10 dB.

The equipment for sound pressure level measurements shall meet the requirements of ISO 140/3. In addition the microphone in the source room must give a flat frequency response in a diffuse sound field.

Note - A 13 mm pressure microphone will normally yield satisfactory frequency response.

#### 5.2 Calibration

In a p-p-probe both microphones shall be sound pressure level calibrated before and after each measurement series using a class 2 or better acoustical calibrator in accordance with IEC Publication 942. It is also recommended to make a corresponding intensity calibration providing such a calibrator is available and the probe build up allows it.
p-n-probes should be calibrated according to the manufacturer's instructions.

6 Arrangement

6.1 Rooms

The source room shall meet the requirements of the respective standard in the ISO 140 series. The receiving room can be any room meeting the requirements of the field indicator and the background noise, see 7.4.3 and 7.4.5.

6.2 The test specimen

The test specimen shall meet the requirements of the respective ISO-standard.

6.3 Mounting conditions

Mount the test specimen according to the requirements of the respective ISO standard.

7 Test procedure

7.1 General

The average sound pressure level in the source room and the average sound intensity level on a measurement surface in the receiver room are measured. Providing the field indicator is satisfactory the intensity sound reduction index can then be calculated.

7.2 Generation of sound field in the source room

Loudspeaker, noise and loudspeaker position(s) shall meet the requirements of the respective standard in the ISO 140 series.

7.3 Measurement of average sound pressure level in the source room

This procedure shall meet the requirements of the respective standard in the ISO 140 series.

7.4 Measurements on the measurement surface in the receiving room

7.4.1 Measurement surface

The acoustical measurements in the receiving room shall take place on a measurement surface totally enclosing the test opening.

If the test specimen is mounted in a niche the measurement surface is normally the flat surface of the niche opening flush with the wall in the receiving room. If the test
specimen is not mounted in a niche or if the depth of the niche is less than 0.1 m a boxshaped measurement surface has to be used.

Measurement distances shorter than 0.1 m shall be avoided because of the complicated near field of the vibrating element. In the near field the intensity tends to change sign very often. The sound field is also normally more uniform in the niche opening than inside the niche. When using box-shaped measurement surfaces measurement distances longer than 0.3 m shall be avoided.

7.4.2 Scanning procedure

The probe shall always be held normal to the measurement surface while scanning and it shall be directed to measure the positive intensity outwards from the building element under test.

The measurement surface shall be divided into one or more subareas. The scanning time of each subarea shall be proportional to the size of the area. The scanning shall be made with a steady speed between 0.1 and 0.3 m/s. The measurements may be interrupted when going from one subarea to another. Other stops shall be avoided.

Each subarea shall be scanned using parallel lines turning at each edge as shown in Fig. 1. The scanning line density depends on how irregular the sound radiation is. A large amount of irregularities such as leakages requires a higher line density. Normally the line density is chosen to be equal to the measurement distance.

![Figure 1 Scanning patterns for the two scans.](image)

If the measurement surface is box shaped as shown in Figure 2 particular care should be given to the areas close to the intersection between the box surface and the partition wall in which the test specimen is mounted. The measurement surface must be "closed" properly, that is it is essential to scan as close as possible to the partition wall.
7.4.3 Sound intensity, one scan area

During the scan the time and space integrated sound intensity level $L_I$ is measured. If possible the time and space integrated sound pressure level $L_P$ is measured simultaneously. Then the field indicator is calculated from

$$ F = L_P - L_I $$  \hspace{1cm} (7) 

If the measured intensity is negative or if $F$ is not satisfactory, that is if $F > 10$ dB for a sound reflecting test specimen or if $F > 6$ dB for a test specimen with a sound absorbing surface in the receiver room, the measurement environment must be improved. First try to increase the measurement distance 5-10 cm. If this fails, add sound absorbing material to the receiver room. The field indicator requirement is valid for each scan and each loudspeaker position. However, it is only valid for the total measurement surface and not for individual sub-surfaces, see 7.4.4.

Note - As a rule of thumb $F < 10$ dB requires $S / A < 1.25$ where $S$ is the area of the measurement surface, $A$ is the sound absorption area of the receiving room. The more flanking transmission the more $A$ must be increased.

Once the measurement environment is satisfactory two complete scans are carried out and the results are compared. The scanning path shall be turned 90 degrees between the two scans. If the difference between the two measurements is less than 1,0 dB for any one frequency band the measurement result is given by the arithmetic average of the two measurements. If the difference is larger than 1,0 dB the measurements are not valid and new scans must be carried out until the requirement is fulfilled. If the requirement cannot be fulfilled, scanning pattern, measurement surface or measurement environment must be changed and the measurements repeated until the requirement is fulfilled. If, despite these efforts, it turns out to be impossible to comply with these requirements, the results may still be given in the test report providing that all deviations from the requirements of this method are clearly stated.

If two or more loudspeaker positions are used a pair of scans shall be carried out in each position. Each pair of scans shall comply with the requirements above. All results, including sound reduction index and field indicator, are given by the arithmetic mean of all scans carried out.
7.4.4 Sound intensity, several sub scan areas

If the measurement surface is divided into several sub areas, each with the area $S_i$ and each being scanned individually, the total sound intensity $L_{in}$ must be evaluated from

$$L_{in} = 10 \lg(\Sigma S_i \cdot 10^{L_{ii}/10}) - 10 \lg(S)$$ (8)

where $S = \Sigma S_i$. If the sound intensity for a subarea has a negative direction, that is the flow of energy is in the direction towards the test object a minus-sign shall be inserted before the respective $L_{ii}$ in eq. (8).

To calculate the field indicator $L_p$ and $L_i$ are given by the following equations:

$$L_i = 10 \lg(\Sigma S_i \cdot I_i) - 10 \lg(\Sigma S_i)$$ (9)

$$L_p = 10 \lg(\Sigma S_i \cdot 10^{L_{pi}/10}) - 10 \lg(\Sigma S_i)$$ (10)

where

$$I_i = 10^{L_{ii}/10}$$, energy flow out from the test surface (11)

or

$$I_i = -10^{L_{ii}/10}$$, energy flow towards the test surface (12)

For different loudspeaker positions or scans the procedures of 7.4.3 are then applicable.

7.4.5 Background noise

Both sound pressure level and sound intensity level shall be at least 10 dB higher than the background noise.

Note - These requirements may be tested by applying the following procedure:
If the field indicator $F<10$ dB then lower the source level 10 dB. If $F$ is changed less than 1 dB then the requirements are fulfilled.

7.5 Frequency range of measurements

The sound pressure level and the sound intensity level shall be measured using one-third octave band filters having at least the following centre frequencies in hertz:

$100$ $125$ $160$ $200$ $250$ $315$ $400$ $500$ $630$ $800$ $1000$ $1250$ $1600$ $2000$ $2500$ $3150$ $4000$ $5000$

If additional information in the low frequency range is required then third octave band filters with the following centre frequencies should be used:

$50$ $63$ $80$
8 Expression of results

For the statement of the airborne sound insulation of the test specimen, the intensity sound reduction indices shall be given at all frequencies of measurement to one decimal place in tabular form and in the form of a curve. In addition a curve of the pressure-intensity indicator shall always also be given in the graph. Any deviations from the basic requirement that the difference between two scans must not exceed 1 dB shall be clearly indicated. For graphs with the level in decibels plotted against frequency on a logarithmic scale, the following dimensions shall be used:

5 mm for a one-third octave,
20 mm for 10 dB.

9 Test report

With reference to this NORDTEST method the test report shall state:

a) name of organization that has performed the measurements;
b) date of test;
c) manufacturer's name and product specification;
d) description of test specimen;
e) description of details of the test opening;
f) volumes of both measurement rooms

g) air temperature in the measuring rooms (if relevant);h) intensity sound reduction index and pressure-intensity indicator of test specimen as a function of frequency including a clear indication of any deviations from this method.;
i) brief description of details of procedure and equipment;
j) limit of measurement in case of background noise;
k) single number rating according to ISO 717
l) measurement distance and shape of measurement surface.