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Measurement of element normalized level difference of small building elements with intensity technique

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ABSTRACT

A laboratory method to evaluate the sound insulation of small building elements was developed. In the method, sound intensity measurements are applied and the results are expressed in terms of the element normalized level difference. There are special requirements concerning the installation and operation of small building elements in measuring their sound insulation. The consequences of the requirements to the measurement method are taken into account. Also the special demands caused by the small size of the object are taken into account. A supplement, considering the general usefulness of the element normalized level difference (or unit sound insulation) in evaluating the sound insulation of partitions, is included in the method. The supplement can be applied also to ISO 140-10 and NT ACOU 037.

The classical form of the Waterhouse correction, the purpose of which is to take account of the higher energy density near room boundaries, has been developed to an improved formula, which is a function of room modal density. The Waterhouse correction can be determined for each room by measuring or calculating its modal density. The improved form of the Waterhouse correction normally differs from the traditional one at third octave bands with centre frequencies less than 100 Hz. There is a tendency for some measurement methods in building acoustics to be used in an extended frequency range down to a third octave band with a centre frequency of 50 Hz. With that kind of extended frequency range, the refinement of the Waterhouse correction has an obvious effect. The Waterhouse correction of the receiving room should be subtracted from the result of traditional measurements of the sound reduction index. This is especially important if the results are compared with those of intensity measurements. No Waterhouse correction is needed for the source room. The measurement of sound insulation by the intensity technique needs no Waterhouse corrections.

Experimental measurements were carried out according to this method and according to ISO 140-10. Both of the methods give quite similar results with an accuracy of 1 dB or better at a frequency range where the flanking transmission is not very important and where both of the methods give valid results. The effects of flanking transmission on the sound insulation measurement results can be diminished by using intensity technique. Very remarkable flanking transmission may, however, make the results of the intensity technique invalid.

PREFACE

This publication is based on the final report for the NORDTEST project no. 1065-92, titled "Measurement of element normalized level difference of small building elements using intensity technique". The goal of the project was to formulate a laboratory scanning method in accordance with the title. The project has been carried out by the following project group:

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The project was started in early 1993 and finished at the end of 1993. VTT acted as the responsible organization for the project. The project group held one meeting in November 1993 in Otaniemi, Finland. Besides the project group has communicated via letters and telefax. The comments of the Nordic circulation process at 1994 have been taken into account in the proposal for the NORDTEST method (Annex). The proposal has been approved as the NORDTEST method NT ACOU 093 at 1995-01 [11].

Espoo, May 1995

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CONTENTS

LIST OF SYMBOLS

A	absorption (area)
A_0	reference area (for the laboratory, $A_0 = 10\ \text{m}^2$)
C_W	Waterhouse correction (in dB)
c_0	speed of sound in unperturbed fluid
$D_{I,\text{n,e}}$	element normalized level difference, measured by intensity technique
$D_{\text{n,e}}$	element normalized level difference
E	energy
F	field indicator (pressure-intensity indicator)
f	frequency
I	sound intensity
I_{n1}	incident average normal sound intensity
I_{n2}	transmitted average normal sound intensity
L	total length of dimensions of a room
L_{In}	average sound intensity level over measurement surface (in receiver room)
L_p	average sound pressure level
L_{p1}	average sound pressure level in source room
n	modal density
P	sound power
P_1	sound power incident on test specimen
P_2	sound power transmitted through test specimen
P_{loss}	power loss
p	sound pressure (far from boundaries in diffuse fields)
R	sound reduction index
S	total area of a room, area of a test specimen
S_{m}	area of measurement surface
T	reverberation time
t	time
V	volume of a room
W	Waterhouse correction
δ_{pI0}	residual pressure-intensity indicator
η	total internal loss of room
λ	wavelength
ρ_0	density of unperturbed fluid
ω	angular frequency

1 INTRODUCTION

A laboratory method for evaluating the unit sound insulation of small building elements NT ACOU 037 [9], based on traditional sound insulation measurements between two reverberation rooms, was approved by Nordtest in 1982. Based on NT ACOU 037, an international standard ISO 140-10 [3] for evaluating the element normalized level difference (= unit sound insulation + 10 dB) of small building elements was approved. The methods apply to building elements, excluding windows and doors (ISO 140-10), with an area of less than 1 m^2 (ISO 140-10) and which occur in a certain number of discrete sizes with well-defined lateral dimensions and which transmit sound between two adjacent rooms, or between one room and the open air (ISO 140-10) independently of the adjoining building elements. Some examples of equipment covered by the methods are transfer air devices, airing panels (ventilators), outdoor air intakes, cable ducts and transit sealing systems.

One of the main problems of the methods is the flanking transmission through the partition built in the test opening between the rooms in which the object under test should be placed. The problem can be most clearly discovered in situations where the object has high sound insulation properties. In NT ACOU 037 and ISO 140-10, two ways of avoiding the effects of flanking transmission on the result are given: to correct mathematically the measurement result using the sound insulation of the flanking path; and to use more than one object in the test opening simultaneously to get the relative proportion of the flanking transmission smaller. The mathematical correction works only to a limiting value for the sound insulation of the object, the value depending on the flanking sound insulation; above this limit only a lower limit for the insulation will be achieved. Using more than one object has the disadvantage of possible interaction between the sound radiated by the objects at low frequencies (third octave bands below 400 Hz). The interaction tends to decrease the measured insulation. The interaction can be lowered only by increasing the distances between the objects, which is not always desirable for other reasons.

The main advantages of using sound intensity measurements in evaluating the sound insulation is the possibility to diminish the effects of flanking transmission on the measurement results and the ability to measure elements having very high sound insulation properties. In the traditional methods based on sound pressure measurements the sound reduction index based upon all paths between the source room and the receiving room is evaluated. The intensity based method evaluates the sound reduction index based upon the paths defined by the choice of measurement surface between the source room and the receiving room. This allows most of the flanking transmission paths to be isolated from the direct paths [12]. A laboratory method for using sound intensity measurements to evaluate the sound reduction index of building elements [10] was developed during Nordtest project 746-88 [6]. The method is primarily intended to be used when the traditional ISO 140-3 method fails because of remarkable flanking transmission. This may, for instance, be the case when measuring windows, doors or heavy constructions with high sound insulation. The method is quite general and, concerning the installation and operation of test objects, it has no special requirements for measuring small building elements. The special requirements for installation and operation may also lead to special requirements for the measurement method itself. Also the small size of the object and possible air stream cause special demands on the measurement procedure (measurement distance, scanning pattern etc.). Based on the method, a proposal for a field method for using sound intensity measurements to determine the sound reduction index of building elements in situ has being developed, too, at Nordtest project 879-90 [12].

In NT ACOU 037 there is a method of calculating the sound reduction index of a partition in which the object under test will be installed, the sound reduction of the partition and the unit sound insulation of the object as a starting point. According to the method in NT ACOU 037, the cross-sectional area of the object is not taken into account. This causes not very much error if the area is small. Problems may arise in other cases and especially in cases where more than one object are used in the partition.

In this project a laboratory method for using sound intensity measurements to evaluate the sound insulation of small building elements in terms of element normalized level difference was produced. The method has a supplement considering the general usefulness of the element normalized level difference (or unit sound insulation) in evaluating the sound insulation of partitions. The supplement can be applied also to ISO 140-10 and NT ACOU 037.

The consequences of the special requirements, concerning the installation and operation of test objects for measuring the sound insulation of small building elements, to the measurement method are taken into account. Also the special demands caused by the small size of the object are taken into account. Some experimental measurements according to the method have been performed.

2 SOME CONSIDERATIONS ABOUT THE MEASUREMENT METHOD

The method is based on NT ACOU 084 [10] (Nordtest method for using sound intensity measurements to evaluate the sound reduction index of building elements), ISO 140-10 [3] (international standard for evaluating the element normalized level difference of small building elements by traditional sound pressure measurements), NT ACOU 037 [9] (corresponding Nordtest method), and a Finnish Method description of VTT and TTL [1] (for determination of radiated sound power using intensity measurements). The method is based significantly also on the experience of the responsible organization for the project concerning the intensity measurement techniques.

2.1 BASIC QUANTITIES

The main quantity in the method of this report is the element normalized level difference $D_{\mathrm{n,e}}$. It is used to characterize the sound insulation of small building elements. It is defined as

$$D_{\mathrm{n,e}} = 10\lg\left(\frac{I_{n1} A_0}{I_{n2} S}\right), \tag{1}$$

where I_{n1} is the incident average normal sound intensity, I_{n2} is the transmitted average normal sound intensity, A_0 is the reference area (for the laboratory, A_0 = 10 m^2) and S is the area of the test specimen. The element normalized level difference is the ratio of the sound power incident on a reference area to the sound power transmitted through the test specimen in decibels. The incident average normal sound intensity on the reference area corresponds to the incident average normal sound intensity on the test specimen. If the transmitted intensity is measured by intensity technique, the element normalized level difference is denoted by $D_{I,\mathrm{n,e}}$ and it is given by

$$D_{I,\mathrm{n,e}} = L_{p1} - 6 - L_{In} + 10\lg\left(\frac{A_0}{S_{\mathrm{m}}}\right), \tag{2}$$

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 and S_{m} is the area of the measurement surface.

This element normalized level difference is evaluated from Eq. 5 assuming that the sound field in the source room is perfectly diffuse. For the purposes of ISO 140-10 the element normalized level difference is given in such a way that it is further assumed that the sound field is perfectly diffuse also in the receiving room and that the sound is transmitted only through the test specimen.

The formula connecting the element normalized level difference and sound reduction index is

$$R = D_{\mathrm{n,e}} - 10\lg\left(\frac{A_0}{S}\right). \qquad (3)$$

In intensity measurements the field indicator or pressure-intensity indicator

$$F = L_p - L_{In}\,, \qquad (4)$$

where L_p is time and surface averaged sound pressure level and L_{In} is time and surface averaged normal sound intensity level on the measurement surface, plays an important role as a quality factor of the measurement results. The lower the field indicator F is, the more reliable the results are. The residual pressure-intensity indicator δ_{pI0} is 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. It is a measure of the phase error between the two measurement channels. The smaller the phase error is, the higher the residual pressure-intensity indicator is. The higher the residual pressure-intensity indicator is, the higher the field indicator may be in the measurements.

2.2 SOME SPECIAL ASPECTS CONCERNING THE METHOD

Keeping the scanning speed and line density constant may be a difficult task for a long period. That is why the scanning time of each sub-area is restricted to maximum values in the method. The selected maximum values are based on simple personal experiments. For the same reasons in the method in the case of more than one sub-area, it is recommended to record the individual sub-area results and to calculate the final result afterwards. Doing so one is required to keep the scanning speed and line density constant only for individual subareas separately.

In the method there is a specific rule for the minimum number of scanning lines on any subarea. The rule is based on a minimum number of five lines on a square sub-area. If the sub-area is not square, the minimum number of scanning lines is dependent of the ratio of the dimensions of the sub-area so that the total length of the scanning pattern is proportional to the square root of the area.

In the method there is a possibility to use discrete probe positions in the case of very small sub-areas. This is because of a practical point of view: with a very small subarea a definite scanning pattern is impossible to be traced.

The method has special rules for adjusting the scanning speed in the case that the instrumentation allows only discrete integration times. That is the case with, e.g., FFT analyzers and some old real time analyzers. The rules give limits to the mismatch between the scanning and integration time. The limits are based on very simple error estimates and their purpose is to reject the error to less than 1 dB.

No dimensions of the sub-areas may exceed 1 m. With larger dimensions one is not able to scan properly according to the method. This requirement will be needed in cases where the object to be measured have large dimensions in the direction normal to the partition wall. That is the case, e.g., with cable ducts.

The requirement of less or equal than 1 dB difference between the results of the two scans and the requirements concerning the field indicator in the method proposal will be applied to the final result, not to the results of the individual sub-areas. That is due to that otherwise making more sub-areas may invalidate the results for some sub-areas having a low contribution to the final result. There is no sense in that the results of those sub-areas are able to invalidate the final result also, because the measurement result with less sub-areas may, however, be valid. If the requirements mentioned are applied to all sub-areas one-by-one, making more sub-areas may cause formally less accurate results although the result will actually become more accurate due to the diminished effect of scanning speed alteration.

If extra panels are used to simulate corner or edge positions, the average absorption coefficient for panels in the receiving room has to be less than 0.06. This requirement is to ensure that the reflecting panels do not absorb the sound energy too much. With the intensity technique the absorption of the panels to which the measurement surface is closed cannot be taken into account, and its effect is directly seen as an error in the measurement result.

In Annex C of the method, guidelines for the derivation of the overall sound reduction of composite partition constructions are given. The guidelines contain a correction to the case in which the area of the small elements on a partition is not small. That correction may be relevant in cases were the partition is very small or if there is many small elements mounted on the partition. Also the guidelines contain a rough estimate for the error caused by the acoustic interaction between the elements on the partition.

3 WATERHOUSE CORRECTION

Due to interference effects, the acoustic energy density in a room is higher near the boundaries than far away from them [13]. When estimating the total acoustic energy of a room by measuring the sound pressure far from the boundaries, the so-called Waterhouse correction must be applied to the results to take account of the higher energy density near the boundaries. An example of using the Waterhouse correction is sound power measurement in reverberation rooms according to, e.g., ISO 3741 [5]. Another example where the Waterhouse correction should be used is the measurement of the sound reduction index according to traditional methods; e.g., ISO 140-3 [2] and also ISO 140 series in general. In the latter example the correction is not normally applied. In the measurement of the sound reduction index using sound intensity techniques according to, e.g., Ref. [10], the Waterhouse correction is not needed. However, if the aim of that measurement is to simulate the traditional measurement methods (without the correction), a "negative correction" is proposed to be applied to the results [6, 10].

In this chapter an improved formula for the Waterhouse correction, as a function of modal density, is introduced, and some examples of the pertinent application of the correction are studied.

3.1 WATERHOUSE CORRECTION AND MODAL DENSITY

The Waterhouse correction *W* is [13]

$$W = 1 + \frac{S\lambda}{8V}, \qquad (5)$$

where S is the total area of the room, V its volume and λ the wavelength. In decibels the correction C_W is

$$C_W = 10\lg(W) = 10\lg\left(1 + \frac{S\lambda}{8V}\right). \qquad (6)$$

The modal density *n* of a room is, e.g., according to Ref. [7],

$$n = \frac{4\pi V}{c_0^3} f^2 + \frac{\pi S}{2 c_0^2} f + \frac{L}{8 c_0}, \tag{7}$$

where L is the total length of the linear dimensions of the room, f is frequency and c_0 is the speed of sound in unperturbed fluid. For further considerations one can write this as

$$n = \frac{4\pi f^2}{c_0^3} V \left(1 + \frac{S\lambda}{8V} + \frac{L\lambda^2}{32\pi V} \right). \tag{8}$$

Thus it can be seen that the modal density of a room is proportional to its volume, with a correction factor as a function of surface area and linear dimensions. If the last term in the correction factor is omitted, the factor has the same form as the Waterhouse correction. This is not coincidental. The original text of Waterhouse's consideration of the Waterhouse correction contains an extra term to the correction in Appendix 2 of Ref. [13], which can be averaged to exactly the same term as the last term in the modal density. Waterhouse stated about this term: "However, for small rooms, the initial assumption that at all points in them equal energy flows in all directions will not be true at the low frequencies for which the correction is significant. Thus, the interference patterns formed would differ from the reverberant interference patterns, and the correction computed for these latter patterns would not apply with accuracy." However, one may find some reasons to include the last term in the Waterhouse correction. This will be evident from the following.

By denoting the "complete" Waterhouse correction as

$$W = 1 + \frac{S\lambda}{8V} + \frac{L\lambda^2}{32\pi V}, \tag{9}$$

the modal density of the room can be expressed as

$$n = \frac{4\pi f^2}{c_0^3} VW. \tag{10}$$

The total acoustic energy E of the room is

$$E = \frac{p^2}{\rho_0 c_0^2} VW = \frac{p^2}{\rho_0 c_0} \frac{\lambda^2}{4\pi} n\,, \tag{11}$$

where p is the sound pressure measured far from the boundaries, and ρ_0 is the density of unperturbed fluid. The total acoustic energy is now proportional to the modal density of the room, and the energy per modal density is independent of the room geometry and size:

$$\frac{E}{n} = \frac{p^2}{\rho_0 c_0} \frac{\lambda^2}{4\pi}\,. \tag{12}$$

This makes sense, because in the S.E.A. (Statistical Energy Analysis) model, which is an extension of statistical diffuse field acoustics, basic quantities are input powers, energies, internal and coupling loss factors, and modal densities. All information concerning the room properties is included in the internal loss factor and the modal density of the room. It is the energy per modal density that tends to be equalized between subsystems in the S.E.A. model. So, if one uses statistical diffuse field theory, the modal density, rather than the room volume, is the correct basic quantity. This is equivalent to using the "Waterhouse-corrected room volume" instead of the physical room volume. The corrected room volume takes account of the fact that in small rooms the number of axial and tangential modes in proportion to oblique modes is higher than in large rooms. Inversely, if one accepts the basic assumptions of S.E.A. and supposes that the total acoustic energy is proportional to the modal density of the room rather than to its physical volume, the correct expression for the Waterhouse correction will be as stated in Eq. 9.

The foregoing examination can be seen to be useful by noticing that the Waterhouse correction is proportional to the modal density,

$$W = \frac{c_0^3 n}{4\pi V f^2}\,, \tag{13}$$

so it can be determined for each room by measuring its modal density. This is advantageous if the room is not a parallellepiped, in which case Eq. 8 is only an estimate of the modal density [8], and thus also Eq. 9 is an estimate of the Waterhouse correction.

At very low frequencies, the effects of the boundaries extend everywhere in the room, so there is nowhere "far from boundaries". In this situation the term p

(pressure far from boundaries) cannot be measured and it is a hypothetical quantity only. However, the preceding examination is still valid if this hypothetical sound pressure is accepted as a starting point. Also, the assumption of the diffuse field may be somehow misleading at very low frequencies, where the modal behaviour of the sound field should be taken into account. These facts and the statement of Waterhouse below Eq. 8 limit the usefulness of the theory presented. However, if statistical field theory is accepted as a starting point, these sources of error cannot be avoided. From this point of view, the dependence of the Waterhouse correction on modal density and the improved form of the Waterhouse correction can be seen as steps towards higher accuracy in the statistical field theory.

In practice, the last term in Eq. 9 is very small except at very low frequencies or in small rooms. The improved form of the Waterhouse correction normally differs from the traditional one at third octave bands with centre frequencies less than 100 Hz. In this project, the frequency bands below 100 Hz have not been treated, so the developed form of the classic Waterhouse correction has only little effect on the measurement results of this report. However, there is a tendency for some measurement methods in building acoustics to be used in an extended frequency range down to a third octave band with a centre frequency of 50 Hz. With that kind of extended frequency range the last term in Eq. 9 has an obvious effect on the Waterhouse correction. In Fig. 1 the traditional and improved Waterhouse corrections are presented for a room with dimensions of 5 m · 6.35 m · 4 m and with a volume of 129.4 m. This room has been used as the receiving room in the measurements of this project.

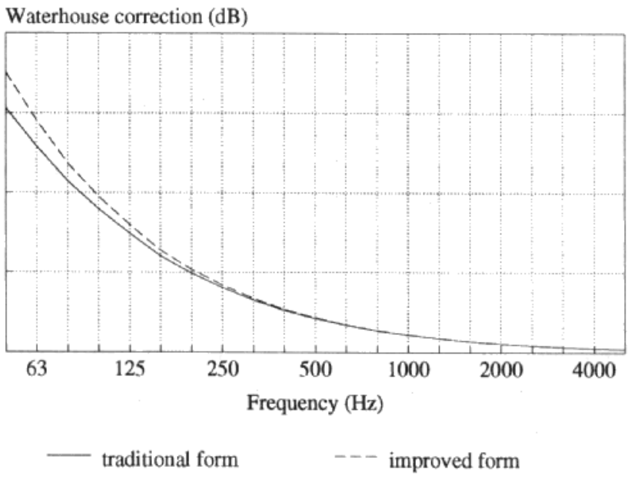


Fig. 1. Waterhouse correction for the receiving room.

The fact that the improved form of the Waterhouse correction differs from the traditional one mainly at low frequencies is advantageous when determining the correction by using the modal density according to Eq. 13. The modal density needs to be determined at low frequencies only. It is well-known that the measurement of the modal density of a room may be difficult, owing to diffuseness of the sound field, modal overlapping or problems concerning the excitation of modes. However, the above difficulties are not so severe at low frequencies. Nevertheless, there may be problems in the experimental estimation of the modal density at low frequencies too. If the problems cannot be overcome by very precise measurements, with narrowband excitation and analysis, and a large number of source and measurement positions, the modal density can be calculated by using, e.g., F.E.M. (Finite Element Method). In laboratory measurements, the modal density needs to be determined only once, if it is assumed that the room will remain unchanged, so one probably difficult measurement or calculation activity may be reasonable.

3.2 APPLICATIONS OF WATERHOUSE CORRECTION

The Waterhouse correction should be used every time one is considering the acoustic energy of a room as a function of the sound pressure (far away from the boundaries). The following examples are all based on this starting point.

3.2.1 Determination of sound power

If a sound source is turned off, the acoustic energy will decay according to

$$E = E_0 e^{-\eta\omega t}, \qquad (14)$$

where t is time, E is the energy, E_0 is the energy at time $t = 0$, η is the total internal loss factor of the room and ω is the angular frequency. The reverberation time is defined as the time during which the energy has decayed 60 dB from its initial value. So, the total internal loss factor can be presented as a function of the reverberation time as

$$\eta = \frac{3\ln(10)}{\pi f T}, \qquad (15)$$

where T is the reverberation time. The power loss can be expressed in terms of the acoustic energy as

$$P_{\mathrm{loss}} = \omega\eta E = \omega\eta \frac{p^2}{\rho_0 c_0^2} WV \, , \tag{16}$$

where the Waterhouse correction has now been applied to the relationship between the energy and the sound pressure of the room. In a stationary field the power loss is equal to the radiated power of the sound sources in the room. With Eqs. 15 and 16 taken into account, the sound power of a source in a reverberation room is

$$P = \frac{6 \ln(10) WV}{\rho_0 c_0^2} \frac{p^2}{T} \, , \tag{17}$$

where P is the sound power. In sound power measurements in reverberation rooms according to, e.g., ISO 3741 [5], the sound power is determined by using Eq. 17 by measuring the reverberation time and the sound pressure and applying the Waterhouse correction.

3.2.2 Determination of absorption

The one-sided diffuse field sound intensity is

$$I = \frac{p^2}{4 \rho_0 c_0} \, , \tag{18}$$

where I is the sound intensity and p is the sound pressure far from the boundaries. This equation is valid both far from the boundaries and near them; thus also in the latter case the quantity p means the sound pressure far from the boundaries. This is justified below.

In a diffuse field the magnitude of the one-sided intensity is independent of spatial variables, also near the boundaries. Although the sound pressure increases when going towards the boundaries, the active sound intensity does not, because the increase of the sound pressure due to interference is a purely reactive phenomenon. That phenomenon increases the energy density near the boundaries, but it does not have any effect on the propagating sound energy. It can be easily demonstrated by using a one-dimensional diffuse field of one frequency (meaning: having narrowband spectral content). It can be thought to be formed of two waves propagating in opposite directions, having equal expected values of amplitude, say p_1, and a random mutual phase difference. The total sound pressure is then

$$p = \sqrt{2}\, p_1 , \tag{19}$$

and the one-sided sound intensity is

$$I = \frac{p_1^2}{\rho_0 c_0} = \frac{p^2}{2\rho_0 c_0} . \tag{20}$$

Suppose there are two boundaries with a reflection coefficient of 1 and the field is between the boundaries. On the boundaries the two waves must have equal phases, because the wave outgoing from the boundary originates from the reflection of the wave coming towards the boundary. So, there is interference, and the total sound pressure at the boundary is

$$p_{\text{boundary}} = 2\, p_1 , \tag{21}$$

which is √2 times the value far away from the boundaries. The one-sided intensity, however, does not grow when approaching the boundary, but its value for waves propagating in both directions is obtained from the amplitude of the individual waves (p_1), and it is everywhere as stated in Eq. 20. Otherwise there would be active sources of sound near the boundary and that is not the case. This simple consideration can be easily generalized to three-dimensional spaces, so Eq. 18 is valid also near the boundaries. Thus no Waterhouse correction will be needed for the diffuse field sound pressure - sound intensity relation. The Waterhouse correction for the source room, which is included in the method proposed in Ref. [12], is unjustified therefore.

In this one-dimensional case the acoustic energy density is not higher at the boundaries than far from the boundaries. The potential energy density at the boundaries is twice the density far from the boundaries. The kinetic energy disappears at the boundaries, so the total energy density at the boundaries is the same as far from the boundaries. However, this is not the case with incidence angles other than normal to the boundaries, as shown by Waterhouse [13], because it is only the normal component of the particle velocity that disappears at the boundaries. So, with three-dimensional diffuse fields, the situation differs from that with one-dimensional fields in that also the total energy density near the boundaries is higher than far from the boundaries. The normal component of the sound intensity, with respect to boundaries, will nevertheless behave in three-dimensional space like the sound intensity in a one-dimensional space. So the one-sided normal intensity near the boundaries is the same as the one-sided intensity far from the boundaries.

Thus if the sound intensity is given by Eq. 18, in a stationary diffuse field the power loss can be represented as

$$P_{\mathrm{loss}} = \frac{p^2}{4\rho_0 c_0} A, \tag{22}$$

where P_{loss} is the power loss and A is the absorption of the room. By using Equations 15, 16 and 22, and assuming that the absorption is evenly distributed in the room, the absorption can be presented as a function of the reverberation time as

$$A = \frac{24\ln(10)}{c_0}\frac{WV}{T}. \tag{23}$$

This is one basic relation where the Waterhouse correction has to be used: i.e., when the absorption is determined by the reverberation time measurement. But it is remarkable that, e.g., in ISO 354 [4], where the absorption is determined by the reverberation time, the correction is not applied, since this is precisely the basic situation in which it is required. However, if the correction is applied, the result will represent the absorption in the measuring room, and if it is not applied, the result will represent the limiting case in which the room volume tends to infinity. So, the only way of getting a result that is independent of the measuring room geometry is not to use the Waterhouse correction. However, if the absorption determined is applied to a certain room (as in evaluating the reverberation time of the room), the measured absorption has to be corrected for that room by the Waterhouse correction. The fact that normally the absorption is not evenly distributed but rather concentrated at the walls, causes additional effects, which will not be treated here.

3.2.3 Sound insulation measurements

In sound insulation measurement the aim is to determine the quantity

$$R = 10\lg\left(\frac{P_1}{P_2}\right), \tag{24}$$

where R is the sound reduction index, P_1 is the sound power incident on a test specimen and P_2 is the sound power transmitted through the specimen. If the measurement is done by traditional means (i.e., not with intensity measurements), e.g., by using ISO 140-3 [2], the transmitted sound power is determined by Eq. 22 (transmitted power is equal to the power loss in the receiving room), where the absorption of the receiving room is obtained by the reverberation time measurements according to Eq. 23. This procedure is equivalent to determining the sound power according to Eq. 17 exactly as stated in standards for sound power determination.

Whatever the starting point, the Waterhouse correction C_W (in dB) of the receiving room should be subtracted from the result. However, this correction is not normally applied, and the measurements thus yield overestimated values at low frequencies. The incident sound power is determined by the diffuse field sound intensity available from the sound pressure measurements, and the area of the specimen. These quantities are not affected by the interference effects near the boundaries, so no Waterhouse correction is needed for the source room. This is clear for the specimen area; justifications for the sound intensity are given in the text after Eq. 18.

In sound insulation measurement by the intensity technique the transmitted sound power is determined directly by sound intensity measurements, so no Waterhouse correction for the receiving room is needed. The incident sound power is determined similarly as in traditional methods, so no Waterhouse correction is needed for the source room either, according to the preceding examination. So sound insulation measurement by the intensity technique needs no Waterhouse corrections.

If one wants to compare the intensity measurement results with the results of the traditional methods, the Waterhouse correction C_W for the receiving room should be subtracted from the result of the traditional method before comparing, although the correction is not included in the traditional methods. The other and worse procedure is to add the Waterhouse correction of the receiving room to the intensity measurement result before comparing [6, 10]. Obviously, the difference between the methods is the same in both cases. In the second procedure the "right" intensity measurement result is made similarly erroneous as the result of the traditional method; in the first procedure the true error of the traditional method is corrected.

4 MEASUREMENTS

Experimental measurements were performed for two types of devices: ventilation valves and a cable duct. The intensity measurements were carried out according to the proposal of this report. The traditional measurements were carried out according to ISO 140-10.

4.1 MEASUREMENT EQUIPMENT AND ROOMS

A B&K two-microphone intensity probe type 3520 including an electret microphone pair of B&K 4183 was used with a two-channel real time 1/3 octave analyzer Norsonic 830. The equipment was calibrated and the residual pressure-intensity indicator was measured with the intensity calibrator B&K 3541.

In the measurements both 50 mm and 12 mm spacings were used. The finite difference approximation, used in the intensity measurements, causes underestimating to the sound intensity at high frequencies, the error being the higher the larger spacing is used in the probe. The 50 mm spacing works with an accuracy of 1 dB up to 1.25 kHz. The upper frequency limit for the 50 mm spacing was selected a little bit lower, as a frequency upwards from which it gives clearly lower intensity values than the 12 mm spacing. The lowest usable frequency for the 12 mm spacing was selected according to the rules concerning the field indicator and residual pressure-intensity indicator in the method. The limit frequency for using the different spacings was selected at about the middle of these two limits. According to this, a microphone spacing of 50 mm was used up to 400 Hz in the measurement of ventilation valves and up to 500 Hz in the measurement of the cable duct. A spacing of 12 mm was used at higher frequencies. The 12 mm spacing works with an accuracy of 1 dB up to 5 kHz. The error at high frequencies (near 5 kHz), due to the finite difference approximation, tends to overestimate the element normalized level difference and sound reduction index.

The sound insulation measurements were done between two reverberation rooms. The source and receiving room volumes were 99.1 m^3 and 129.4 m^3 respectively. For the intensity measurements the reverberation in the receiving room was minimized by adding absorbents and also by dismounting the roof of the receiving room.

In the source room only one loudspeaker position has been used, the same position for measurements according to ISO 140-10 and the proposal of this report.

4.2 VENTILATION VALVES

Three ventilation valves KIV-100 (Lapinleimu Oy) of diameter 200 mm were mounted on the partition wall between the measuring rooms. The valves have been measured mounted on a wall, near an extra reflecting panel and near two extra reflecting panels. The panels were mounted in the receiving room only. In the measurements according to ISO 140-10 the three valves were functioning simultaneously. In the measurement according to the proposal of this report the valves were open one at a time and each of the valves was measured separately. The measuring surface in the intensity measurements was box-shaped with five sub-areas in the case of no extra reflecting panels, and partially box-shaped with four or three sub-areas in the cases of one or two extra reflecting panels respectively. In the comparison between the results of intensity and ISO 140-10 measurements, Fig. 4, the intensity measurement results of the three valves have been averaged according to energy basis (the radiated sound power of the three valves added together), that is

$$D_{\mathrm{n,e}} = 10\lg\left(\frac{3}{\sum_{i=1}^{3} 10^{-D_{\mathrm{n,e}(i)}/10}}\right), \qquad (25)$$

because this gives comparable results with ISO method. In the comparison, the Waterhouse correction of the receiving room has been subtracted from the results of ISO 140-10 measurements.

Using more than one object in ISO 140-10 measurements has the disadvantage of possible interaction between the sound radiated by the valves at low frequencies (third octave bands below 400 Hz). The interaction tends to decrease the measured insulation.

The electret microphones of the probe got an electric shock of 200 V DC voltage just before the measurements. That kind of shock makes the residual pressure-intensity indicator very bad for a while; more than a week will be needed for the microphones to get over that. That is the main reason for that the results at lower frequencies than 100 Hz are invalid, so they are not presented in the figures.

The results and corresponding field indicators are presented on Figs. 2 and 3. In Fig. 2 it can be clearly seen that the different valves have differences in sound insulation at the lowest and highest frequencies, although they are similar in principle. The differences may be due to differences in mounting and differences of the valves due to tolerances in manufacturing. These sources of error are never totally avoidable; however, more reliable results may be obtained by measuring several objects and calculating confidence limits to the results. In Fig. 3 the effect of mounting the reflective panels

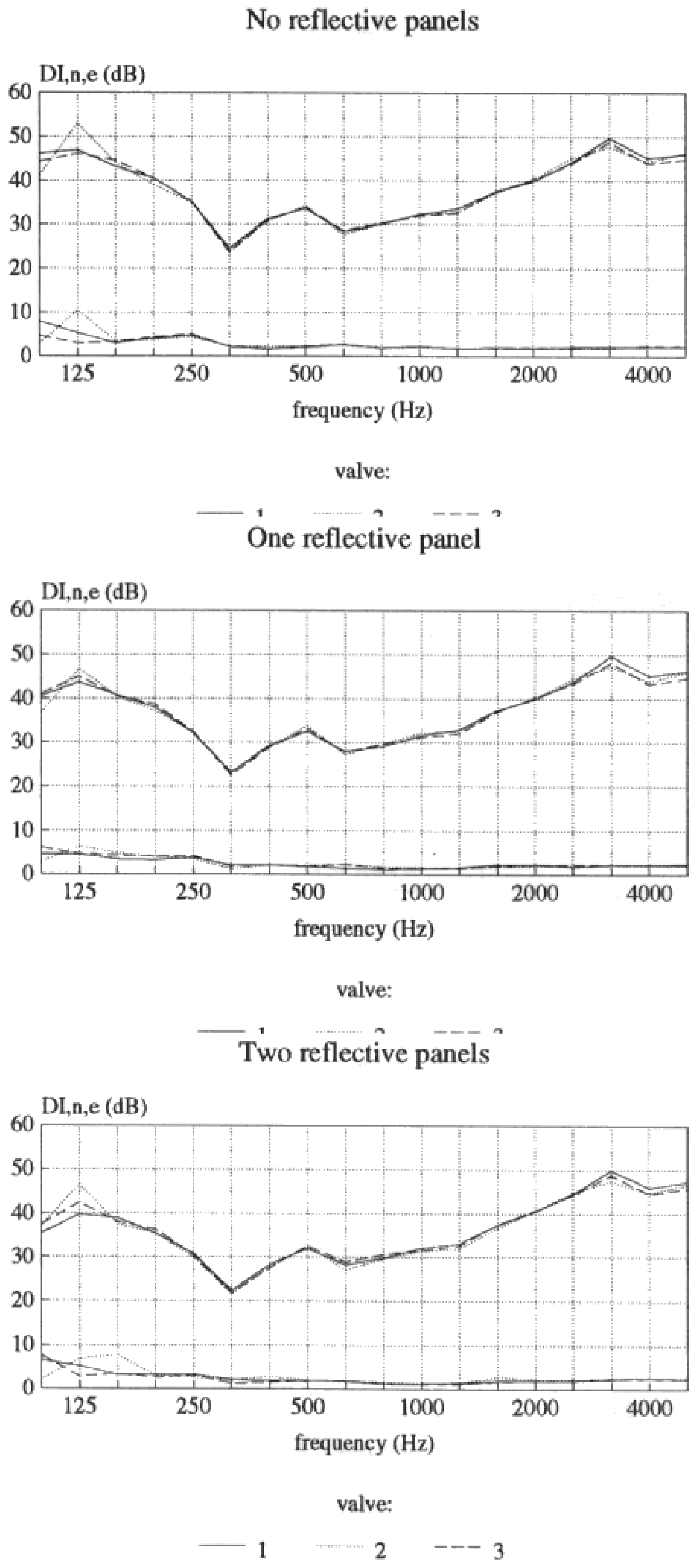
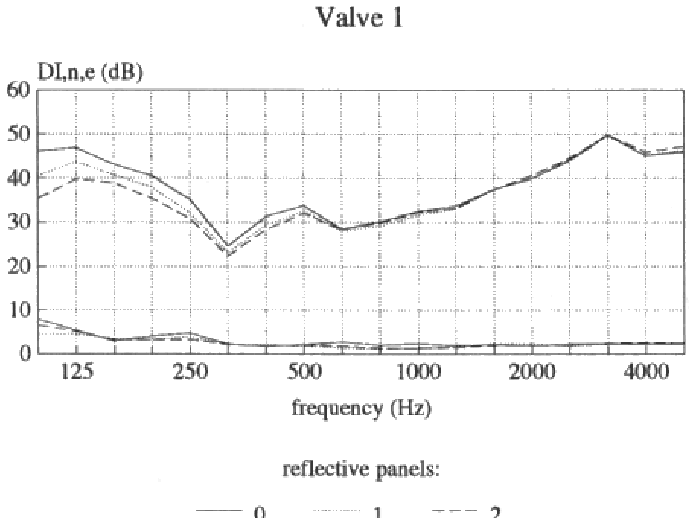
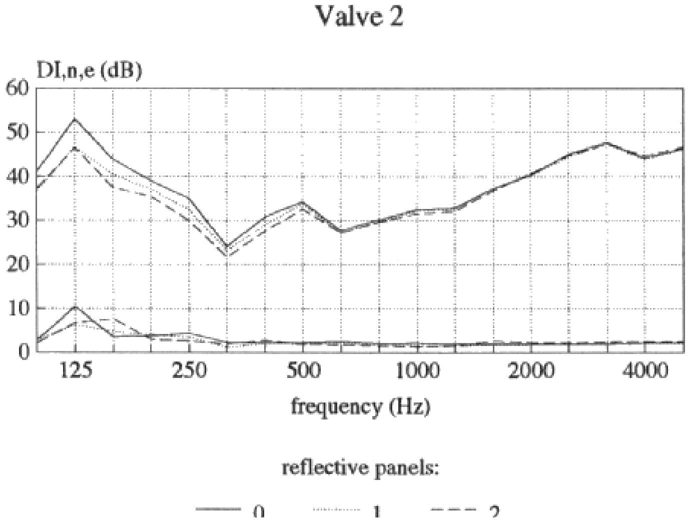


Fig. 2. Element normalized level difference and field indicator for different valves.


Valve 1


Valve 2

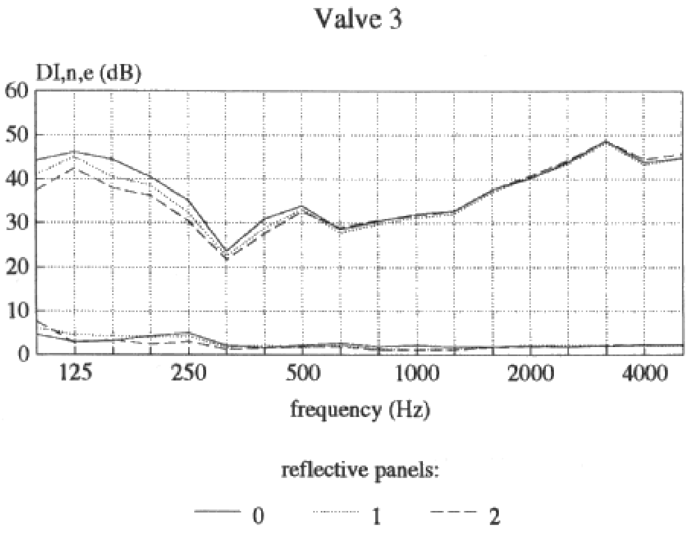

Valve 3

Fig. 3. Element normalized level difference and field indicator for different number of panels.

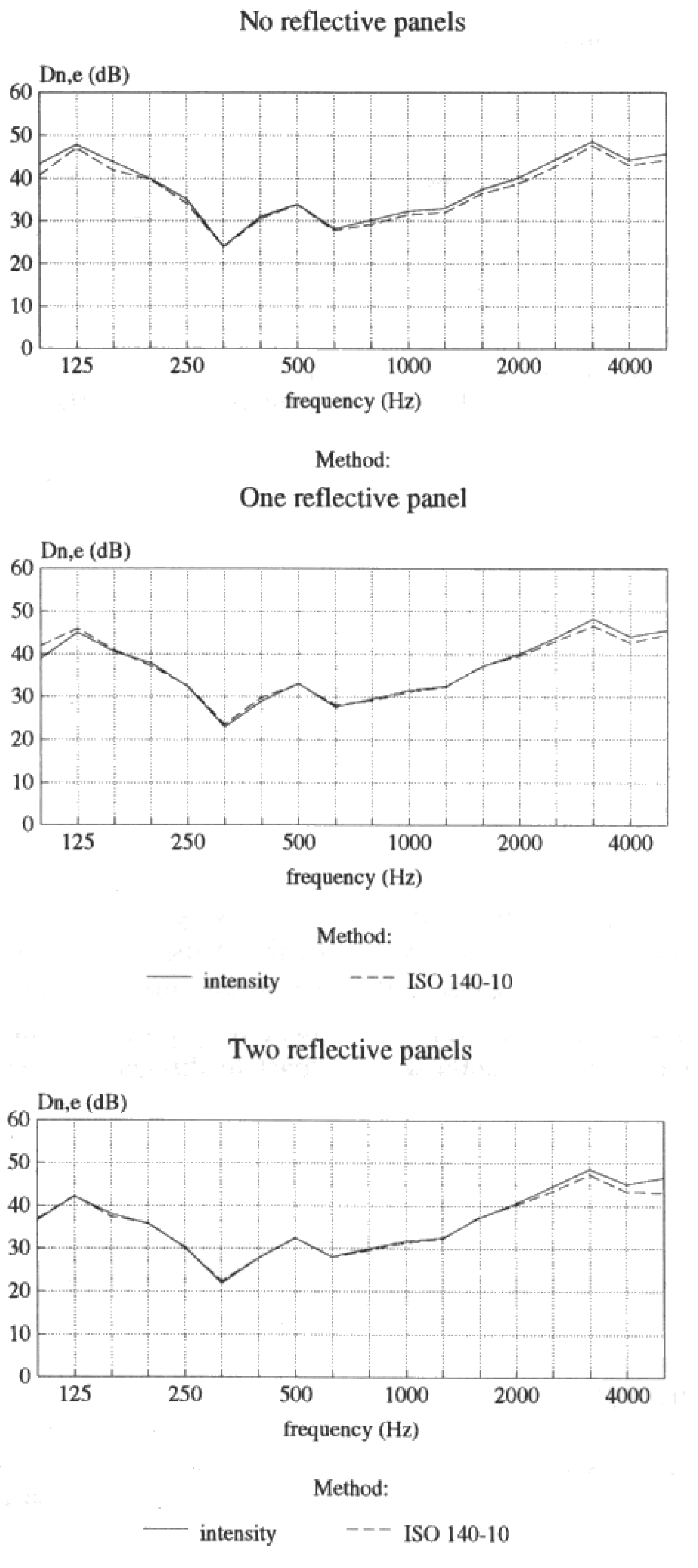


Fig. 4. Element normalized level difference of the valves, comparison of methods.

can be seen. As could be expected, the panels increase the sound power coming out of the valves thus decreasing their sound insulation at low frequencies (below 630 Hz).

In Fig. 4 the difference between the results of this method and ISO 140-10 can be seen. Both of the methods give quite similar results with an inaccuracy of much less than 1 dB, except at very low and high frequencies. At high frequencies the difference is partly due to the error caused by the finite difference approximation of intensity measurements. This could be lowered by using smaller than 12 mm spacing in the probe. However, that error does not explain totally the difference between the results of the methods at high frequencies. Another cause of difference is that the results should be different due to flanking transmission, which is present in the results of ISO 140-10 but not in the intensity measurement results. At low frequencies with no reflective panels, the difference in the results is mainly caused by the interaction between the sound radiated by the three valves simultaneously in ISO 140-10 measurements. That effect cannot be seen in the results with reflective panels. Also the flanking transmission may have an effect on ISO 140-10 results at low frequencies. Very curious and not very easily explainable is that the intensity measurements give lower element normalized level difference than ISO 140-10 measurements at the lowest frequencies with one reflective panel. One explanation may be that in ISO 140-10 measurements there was deviation in ideal diffuse field conditions in the receiving room at low frequencies.

As a conclusion, the differences between the two methods are due to errors in ISO 140-10 measurements (errors due to flanking transmission, interaction between elements and deviation in ideal diffuse field conditions). An exception to above is the finite difference approximation error in intensity measurement results (which can be eliminated by proper spacing selection). So the intensity measurements will, at least in this case, have an accuracy which is better than in traditional measurements. One remarkable point of view is that the differences between the results of different valves are of the same order, and at low frequencies even higher, than the differences between the results of different methods.

4.3 CABLE DUCT

One cable duct of lateral dimensions of 134 mm · 62 mm, constructed of aluminium profile, with a length of 2.1 m in both the source and receiving rooms and having six cables inside was mounted through the partition wall between the measuring rooms, on an reflecting panel in both rooms. In the intensity measurements the measurement surface was divided into 10 subareas. The measurement results are shown in Fig. 5. The Waterhouse correction of the receiving room has been subtracted from the results of ISO 140-10 measurements.

The effect of flanking transmission is very high in this case. So it is expected that ISO 140-10 will clearly underestimate the element normalized level difference. In Fig. 4 also the element normalized level difference of the partition wall, measured using ISO 140-10, is presented. In the figure it can be seen that at frequencies below 315 Hz, between 800 and 1000 Hz, and over 2500 Hz the measurement result of the cable duct is clearly dominated by the wall sound transmission properties. The traditional method fails and the intensity method should give much more reliable results at these frequencies. That can also be seen except at low frequencies, below 315 Hz.

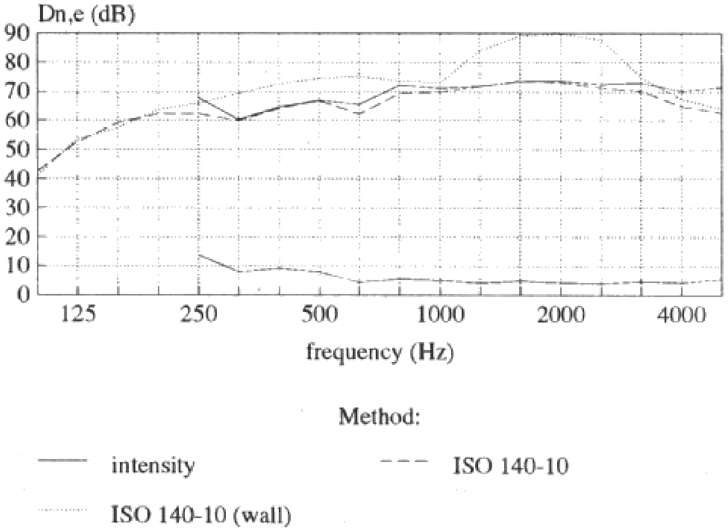


Fig. 5. Element normalized level difference and field indicator for the cable duct.

The sound insulation of the partition wall between the measuring rooms gives limitations to the valid frequency range at low frequencies for intensity measurements also, as can be seen. This is due to the fact that the sound transmitted through the wall makes the field indicator very high at low frequencies. Another reason for the high field indicator at low frequencies is the flanking transmission of sound originating from the source room through the dismounted roof. The valid frequency range for the intensity measurement results in this case, according to the method proposal, begins from the third-octave with centre frequency of 315 Hz.

It can be seen that at the valid frequency range of both of the methods, they give the same results within an accuracy of about 1 dB or better. The difference is higher at frequencies where one or both of the methods do not work properly.

It can be clearly seen from this measurement example that the effects of flanking transmission on the sound insulation measurement results can be diminished by using intensity technique. Also it can be seen that very high flanking transmission may, however, make the results of the intensity technique invalid. This effect can be very easily noticed from the values of field indicator. If the field indicator is within the limits of the method of this report, one can be assured that that kind of high flanking transmission problem does not exist.

The only way to avoid the high flanking transmission problem is to increase the sound insulation of the flanking paths. Using more than one object in connection with the intensity technique does not make the situation better, because in the intensity technique the individual objects have to be measured one-by-one. If one gives himself a possibility to deviate from the requirements of the method of this report, one way of avoiding the high flanking transmission problem somehow is to use very accurately phase-matched microphones (very low residual pressure-intensity indicator) and to ignore the requirement of the highest field indicator of 10 dB. This must be done with ultimate care and it is not recommended for non-experts in acoustics. Anyhow, this is beyond the scope of the method of this report.

5 CONCLUSIONS

In this project a laboratory method to evaluate the sound insulation of small building elements was developed. In the method, sound intensity measurements are applied and the results are expressed in terms of the element normalized level difference. The method has a supplement considering the general usefulness of the element normalized level difference (or unit sound insulation) in evaluating the sound insulation of partitions. The supplement can be applied also to ISO 140-10 and NT ACOU 037.

There are special requirements concerning the installation and operation of small building elements in measuring their sound insulation. The consequences of the requirements to the measurement method are taken into account. Also the special demands caused by the small size of the object are taken into account. Some experimental measurements according to the method have been performed.

The main special features of this method are: The scanning time of each sub-area has a recommendation for maximum value and in the case of more than one sub-area, it is recommended to record the individual sub-area results and to calculate the final result afterwards. That is to avoid errors due to scanning speed and line density alteration. A specific rule for the minimum number of scanning lines on any subarea is given, in which the number is dependent of the shape of the sub-area. Special rules for adjusting the scanning speed in the case that the instrumentation allows only discrete integration times are given, to give limits to the mismatch between the scanning and integration time. The requirement of less or equal than 1 dB difference between the results of the two scans and the requirements concerning the field indicator in the method will be applied to the final result, not to the results of the individual sub-areas. If extra panels are used to simulate corner or edge positions, the average absorption coefficient for panels in the receiving room has to be less than 0.06.

The guidelines for the derivation of the overall sound reduction of composite partition constructions contain a correction to the case in which the total area of the small elements on a partition cannot be considered to be small compared with the area of the partition. That correction may be relevant in cases where the partition is very small, or if there is many small elements mounted on the partition. The guidelines contain also a rough estimate for the error caused by the acoustic interaction between the elements on the partition.

The classical form of the Waterhouse correction, the purpose of which is to take account of the higher energy density near the room boundaries, has been developed to an improved formula, which is a function of room modal density. The corrected room volume takes account of the fact that in small rooms the number of axial and tangential modes in proportion to oblique modes is higher than in large rooms. The Waterhouse correction may be determined for each room by measuring or calculating its modal density. This is advantageous if the room is not a parallellepiped, in which case the accuracy of the classical form of the Waterhouse correction is worse. The improved form of the Waterhouse correction normally differs from the traditional one at third octave bands with centre frequencies less than 100 Hz. There is a tendency for some measurement methods in building acoustics to be used in an extended frequency range down to a third octave band with a centre frequency of 50 Hz. With that kind of extended frequency range, the refinement of the Waterhouse correction has an obvious effect.

If absorption is determined by measuring the reverberation time as in ISO 354 and the Waterhouse correction is not applied, the result will represent the limiting case in which the room volume tends to infinity. If the absorption determined is applied to a certain room (as when evaluating the reverberation time of the room), the measured absorption must be corrected for that room by the Waterhouse correction.

The Waterhouse correction of the receiving room should be subtracted from the result of traditional measurements of the sound reduction index. This is especially important if the results are compared to those of intensity measurements. However, this correction is not normally applied, and the measurements thus yield overestimated values at low frequencies. No Waterhouse correction is needed for the source room. The measurement of sound insulation by the intensity technique needs no Waterhouse corrections.

Experimental measurements were performed for two types of devices: ventilation valves and a cable duct. The intensity measurements were carried out according to the proposal of this report. The traditional measurements were carried out according to ISO 140-10. Both of the methods give quite similar results with an accuracy of 1 dB or better at a frequency range where the flanking transmission is not very important and were both of the methods give valid results. The other reasons for differences are the finite difference approximation error in intensity measurement results, the interaction of different objects at low frequencies, and deviations in ideal diffuse field conditions in the receiving room at low frequencies. Except for the finite difference approximation error, which can be eliminated by proper spacing selection, the differences between the two methods are due to errors in ISO 140-10 measurements (errors due to flanking transmission, interaction between elements and deviation in ideal diffuse field conditions). So the intensity measurements will have at least as good an accuracy as the traditional measurements. The differences between the results of similar objects, due to mounting and manufacturing tolerances, are of the same order as the differences between the results of the different methods, i.e., the difference between the two methods lies well within the repeatability of the methods.

The effects of the flanking transmission on the sound insulation measurement results can be diminished by using the intensity technique. Very high flanking transmission may, however, make the results of the intensity technique invalid. This effect can be very easily noticed from the values of field indicator. If the field indicator is within the limits of the method of this report, one can be assured that that kind of high flanking transmission problem does not exist. The only way to avoid the high flanking transmission problem, according to this method, is to increase the sound insulation of the flanking paths (i.e., partition wall).

In the cases where flanking transmission causes no problems for traditional measurements, ISO 140-10 method is preferable because measurements according to it may be carried out with much less time than measurements according to the method of this report.

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ANNEX: PROPOSAL FOR NORDTEST METHOD

SMALL BUILDING ELEMENTS:
ELEMENT NORMALIZED LEVEL DIFFERENCE

A laboratory method based on
scanned sound intensity measurements

CONTENTS

1 SCOPE AND FIELD OF APPLICATION

This NORDTEST method specifies a laboratory sound intensity scanning method of measuring the airborne sound insulation of such small building elements as are defined below. This method also establishes directions about reporting and applying such test data.

ISO 140-10 specifies a laboratory method of measuring airborne sound insulation of small building elements under diffuse field conditions. This NORDTEST method is primarily intended to be used instead of ISO 140-10 whenever the flanking transmission prevents accurate measurements according to ISO 140-10. The correction of flanking transmission, used in ISO 140-10, is not needed in this NORDTEST method. Increasing the number of test objects to avoid inaccuracy due to flanking transmission, used in ISO 140-10, is not used in this NORDTEST method. Increasing the number of test objects may, however, be used to evaluate the standard deviation of the results and to increase the accuracy of the results. ISO 140-10 is to be preferred to this NORDTEST method when it is not possible to get a low enough field indicator in the receiving room, when the air flow from the building elements to be measured prevents accurate intensity measurements or when the flanking transmission causes no problems.

It is intended that the results obtained will be used to develop building elements with appropriate acoustical properties, to classify such elements according to their sound insulation properties and to estimate their influence on the sound insulation of partition constructions in buildings.

This NORDTEST method applies to building elements with an area of less than 1 m^2 which occur in a certain number of discrete sizes with well-defined lateral dimensions. The elements are such that they transmit sound between two adjacent rooms or between one room and the open air independently of the adjoining building elements. The method does not apply to windows and doors, and elements with air flows over 2 m/s through the measurement surface.

Some examples of equipment covered by this NORDTEST method are

transfer air devices
airing panels (ventilators)
outdoor air intakes
electrical cable ducts
transit sealing systems (e.g., sealing systems for passings through walls or slabs).

This method is not primarily intended for components that constitute part of an integrated unit for which the associated sound transmission might depend on an interplay of components.

2 REFERENCES

The following standards contain provisions which, through reference in this text, constitute provisions of this NORDTEST method. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this NORDTEST method are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 140-1:1990, Acoustics - Measurement of sound insulation in buildings and of building elements - Part 1: Requirements for laboratories.

ISO 140-3:1978, Acoustics - Measurement of sound insulation in buildings and of building elements - Part 3: Laboratory measurements of airborne sound insulation of building elements. (Under revision.)

ISO 140-10:1991, Acoustics - Measurement of sound insulation in buildings and of building elements - Part 10: Measurement of sound insulation of small building elements.

ISO 717-1:1982, Acoustics - Rating of sound insulation in buildings and of building elements -Part 1: Airborne sound insulation in buildings and of interior building elements. (Under revision.)

ISO 717-3:1982, Acoustics - Rating of sound insulation in buildings and of building elements -Part 3: Airborne sound insulation of facade elements and facades. (Under revision, to be subjoined to ISO 717-1.)

ISO 3741:1988, Acoustics - Determination of sound power levels of noise sources - Precision methods for broad-band sources in reverberation rooms.

ISO 9614-1:1993, Acoustics - Determination of sound power levels of noise sources using sound intensity - Measurement at discrete points.

ISO 9614-2, Acoustics - Determination of sound power levels of noise sources using sound intensity - Measurement by scanning. (At present at the stage of draft.)

IEC 942:1988, Sound calibrators.

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

NT ACOU 084:1992, Building elements: Sound insulation, intensity. Scanning under laboratory conditions.

3 DEFINITIONS

For the purposes of this NORDTEST method, the following definitions apply.

3.1 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. The average sound pressure is given by:

$$L_p = 10 \lg \left(\frac{p_1^2 + p_2^2 + \ldots + p_n^2}{n\, p_0^2} \right) \mathrm{dB} \tag{1}$$

where

$p_1, p_2, \ldots, p_n$ are the time average (r.m.s.) sound pressures at n different positions in the room, in pascals;

$p_0 = 20\ \mu\mathrm{Pa}$ is the reference sound pressure.

3.2 SOUND INTENSITY, I

Time average rate of flow of sound energy per unit area. The orientation of the unit area is such that the local particle velocity is normal to it. The sound intensity is a vectorial quantity which is equal to

$$\bar{I} = \frac{1}{T} \int_0^T p(t)\vec{u}(t)dt\ \mathrm{W/m^2}, \tag{2}$$

where

$p(t)$	is the instantaneous sound pressure at a point, in pascals;
$u(t)$	is the instantaneous particle velocity at the same point, m/s;
T	is the averaging time, in seconds.

3.3 NORMAL SOUND INTENSITY, I_n

Sound intensity component in the direction normal to the measurement surface. If the normal sound intensity is positive, the acoustic energy flows out from the measurement surface, and if it is negative, the energy flows towards the measurement surface. The absolute value of I_n is denoted by $|I_n|$.

3.4 NORMAL SOUND INTENSITY LEVEL, L_{In}

Ten times the common logarithm of the ratio of the absolute value of normal sound intensity $|I_n|$ to the reference intensity I_0 as given by:

$$L_{In} = 10 \lg\left(\frac{|I_n|}{I_0}\right) \mathrm{dB}, \qquad (3)$$

where

$I_0 = 10^{-12}$ W/m^2 .

3.5 PRESSURE-INTENSITY INDICATOR OR FIELD INDICATOR, F

The difference between time and surface averaged sound pressure level, L_p, and the normal sound intensity level, L_{In}, on the measurement surface given by:

$$F = L_p - L_{In} \, \mathrm{dB}. \qquad (4)$$

Note In ISO 9614-1 the notation F_2 is used.

3.6 RESIDUAL PRESSURE-INTENSITY INDICATOR, δ_{pI0}

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).

3.7 ELEMENT NORMALIZED LEVEL DIFFERENCE, $D_{\mathrm{n,e}}$

Ten times the common logarithm of the ratio of the sound power incident on a reference area to the sound power transmitted through the test specimen. The incident average normal sound intensity on the reference area corresponds to the incident average normal sound intensity on the test specimen. The element normalized level difference is denoted by $D_{\mathrm{n,e}}$ and is expressed in decibels:

$$\Delta_{\mathrm{n,e}} = 10 \lg\left(\frac{I_{v1} A_0}{I_{v2}\, \Sigma}\right) \mathrm{dB}\,, \qquad (5)$$

where

I_{n1}	is the incident average normal sound intensity, in W/m^2;
I_{n2}	is the transmitted average normal sound intensity, in W/m^2;
A_0	is the reference area, in square metres (for the laboratory, A_0 = 10 m^2);
S	is the area of the test specimen, in square metres.

For the purposes of this test method, the element normalized level difference is given by equation 6. It is denoted by $D_{I,\mathrm{n,e}}$ and is expressed in decibels:

$$D_{I,\mathrm{n,e}} = L_{p1} - 6 - L_{In} + 10 \lg\left(\frac{A_0}{S_{\mathrm{m}}}\right) \mathrm{dB}\,, \qquad (6)$$

where the reference area A_0 is defined above and

L_{p1}	is the average sound pressure level in the source room, in decibels;
L_{In}	is the average sound intensity level over the measurement surface in the receiver room, in decibels;
S_{m}	is the area of the measurement surface, in square metres.

This element normalized level difference is evaluated from Eq. 5 assuming that the sound field in the source room is perfectly diffuse. For the purposes of ISO 140-10 the element normalized level difference is given in such a way that it is assumed further that the sound field is perfectly diffuse also in the receiving room and that the sound is transmitted only through the test specimen.

Note If the level of the sound power transmitted through the element to the receiving room is known, the element normalized level difference may also be obtained according to:

$$D_{I,\mathrm{n,e}} = L_{p1} - L_W + 4\ \mathrm{dB}\,, \tag{7}$$

where the reference area of 10 m^2 is supposed, L_{p1} is as above and L_W is the sound power level, in decibels.

3.8 CORRECTED ELEMENT NORMALIZED LEVEL DIFFERENCE, $D_{\mathrm{n,e,c}}$

If the measurement result $D_{I,\mathrm{n,e}}$ is to be compared to a result obtained by the traditional measurement method ISO 140-10 the corrected element normalized level difference

(8)

should be used instead of the result of ISO 140-10, where

$D_{\mathrm{n,e}}$	is the element normalized level difference, in decibels, measured according to ISO 140-10;
S_{b2}	is the area of all the boundary surfaces in the receiving room, in square metres;
V_2	is the volume of the receiving room, in cubic metres;
λ	is the wavelength at the centre frequency of the one-third octave band, in metres.

In the measurements according to ISO 140-10 the sound field in the receiving room is not perfectly diffuse, as it is assumed, which thus underestimates the sound power radiated into the receiving room. The correction term in Eq. 8, called Waterhouse correction, compensates for that effect concerning the higher energy density near the room boundaries.

Note In Annex D a refined form of Waterhouse correction is presented. By using it, the correction can be determined experimentally by measuring the modal density of the receiving room.

3.9 SOUND REDUCTION INDEX, R

Ten times the common logarithm of the ratio of the sound power incident on a test specimen to the sound power transmitted through the specimen. This quantity is denoted by R and it can be expressed in decibels using the element normalized level difference:

$$R = D_{\mathrm{n,e}} - 10\lg\left(\frac{A_0}{S}\right)\mathrm{dB}\,, \tag{9}$$

where

$D_{\mathrm{n,e}}$	is the element normalized level difference, in decibels;
A_0	is the reference area, in square metres (for the laboratory, $A_0 = 10\ \mathrm{m}^2$);
S	is the area of the test specimen, in square metres.

If the element normalized level difference is determined by intensity measurements, using Eq. 6, it is denoted by $D_{I,\mathrm{n,e}}$. If this is substituted for $D_{\mathrm{n,e}}$ in Eq. 9, the result is called intensity sound reduction index and denoted by R_I.

3.10 WEIGHTED ELEMENT NORMALIZED LEVEL DIFFERENCE, $D_{\mathrm{n,e,w}}$

Element normalized level difference $D_{\mathrm{n,e}}$ weighted according to ISO 717-1, similar weighting as for the level difference D in that standard. If the element normalized level difference $D_{I,\mathrm{n,e}}$ according to Eq. 6 is weighted, the result is denoted by $D_{I,\mathrm{n,e,w}}$. The spectrum adaptation terms C and C_{tr} may be stated with the weighted element normalized level difference in parentheses behind the single number quantity as $D_{\mathrm{n,e,w}}(C;C_{\mathrm{tr}})$, according to ISO 717-1 (Draft).

3.11 WEIGHTED SOUND REDUCTION INDEX, R_{w}

Sound reduction index R weighted according to ISO 717-1. If the intensity sound reduction index R_I is weighted, the result is weighted intensity sound reduction index $R_{I,\mathrm{w}}$. The spectrum adaptation terms C and C_{tr} may be stated with the weighted sound reduction index in parentheses behind the single number quantity as $R_{\mathrm{w}}(C;C_{\mathrm{tr}})$, according to ISO 717-1 (Draft).

3.12 MEASUREMENT SURFACE

Surface totally enclosing the test specimen on the receiving side, scanned by the probe during the measurements.

3.13 SUB-AREA

Part of the measurement surface being measured in one continuous sub-scan.

3.14 MEASUREMENT DISTANCE

The shortest distance between the measurement surface and the specimen to be measured.

4 INSTRUMENTATION

4.1 GENERAL

The measurement equipment shall be suitable for meeting the requirements of clause 7. The intensity measuring instrumentation shall comply with IEC 1043 and be able to measure sound intensity and sound pressure levels in decibels in one-third octave bands. It is preferred that the analysis is performed in real time. A probe windscreen shall be used if the element to be measured generates air flow through the measurement surface.

Note It is advantageous to have a reasonably flat spectrum in the receiving room. The most effective method of achieving this aim is to equalize the measuring signal fed to the loudspeakers in the source room. If an equalizer is not available, some benefit may be gained by using white rather than pink noise or by measuring at one or a few one-third octave bands at a time, for situations with high sound reduction indices at high frequencies.

The residual pressure-intensity indicator δ_{pI0} of microphone probe and analyzer shall be higher than F + 10 dB at each third octave band used in the measurements.

Note In cases where the residual pressure-intensity indicator of the probe and analyzer is lower than 20 dB in any frequency bands of interest, it may be advantageous before the measurements to write out a table of maximum allowed field indicator as a function of frequency separately for each microphone spacing used. This can be done as follows: Measure the residual pressure-intensity indicator. Subtract 10 dB from the results. This will give the maximum allowed field indicator so that the above criterion for the residual pressure-intensity indicator is always satisfied. If the maximum allowed field indicator is known for spacing d_1, it can be calculated for another spacing d_2 using

$$F_{\max,2} = 10 \lg\left(\frac{d_2}{d_1}\right) \bullet F_{\max,1} , \qquad (10)$$

where

$F_{\max,1}$	is the maximum allowed field indicator for spacing d_1;
$F_{\max,2}$	is the maximum allowed field indicator for spacing d_2;

supposing that the same probe (and microphones) are used. In Clause 7.4.4 a criterion for the maximum allowed field indicator of 10 dB is given in the case of a sound reflecting specimen. The final maximum of the field indicator will be either 10 dB or the value obtained in the procedure above, whichever is lower. So the table will have the factors

$$\min(10, F_{\max})\ \mathrm{dB} \qquad (11)$$

as functions of frequency for each microphone spacing used.

Note In the case of a test specimen with sound absorbing surface in the receiving room the criterion for the maximum allowed field indicator is 6 dB instead of 10 dB in Clause 7.4.4. In that case 10 must be replaced by 6 in Eq. 11.

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.

4.2 CALIBRATION

Calibrate the instrument and the probe at least at one frequency in the range from 200 to 1000 Hz in accordance with the calibration procedure and at intervals specified by the manufacturer.

Carry out the following field checks to test the instrument before each series of measurements:

a) Carry out a field check according to the instrument manufacturer's specifications.

If no field check is specified by the instrument manufacturer, check the instrument according to b) and c):

b) Sound pressure level: Check each pressure microphone of the intensity probe for sound pressure level using a class 1 calibrator or better in accordance with IEC 942.

c) Intensity: Carry out a calibration using an intensity calibrator. If such a calibrator is not available or if the construction of the probe does not allow it, make a rough field check to indicate anomalies within the measuring system, according to the following: Place the intensity probe on the measurement surface, with the probe axis oriented normal to the surface, at a position where the noise from the source is characteristic for that source. The intensity probe should be mounted on a stand to retain the same position while carrying out the measurement check. Measure the normal sound intensity level. Rotate the intensity probe through 180 ° about a normal to its measurement axis in the same position as the first measurement. Measure the normal sound intensity level again. For the highest sound intensity level measured in one-third octave or octave bands the unsigned difference between the two sound intensity levels shall be less than 1.5 dB, and the direction indicated for the intensity shall differ, for the measurement instrumentation to be acceptable.

Note This test may not be completely appropriate for pressure-velocity probes for which the manufacturer's instruction should apply.

5 LABORATORY REQUIREMENTS

5.1 ROOMS

Laboratory test facilities shall comply with the requirements given for laboratory test facilities in ISO 140-1, concerning the source room. The receiving room may be any room meeting the requirements of the field indicator and the background noise, see 7.4.3 and 7.4.5. All the measurement results within the same measurements have to correspond to similar reflecting and absorbing properties of the receiving room.

5.2 PARTITIONS

The test object is usually much smaller than the available test opening. A partition of sufficiently high sound insulation shall be built in the test opening: the object shall be placed in this partition.

If the sound insulation of the partition is expected not to be sufficient, it may be advantageous to measure it. This measurement can be carried out before making the opening for the test object or with plates having a high sound insulation on both sides of the opening. It is convenient to express this sound insulation in terms of the element normalized level difference according to equation 5.

6 INSTALLATION AND OPERATION OF TEST OBJECTS

6.1 GENERAL

As the sound insulation of small building elements depends on their dimensions, reliable values can be obtained only by testing every actual size.

6.2 MOUNTING OF TEST OBJECTS

Ensure that the test object is installed in a manner representative of field practice with a careful simulation of normal connections and sealing conditions at the perimeter and at joints within the unit.

If the test object is intended to be openable, install it for test so that it can be opened and closed in the normal manner. Open and close it at least ten times immediately before testing.

In order to achieve a realistic wall thickness around the element, it might be practical or necessary either to increase or decrease the thickness of the partition wall in the area around the element. Rules for increasing or decreasing the thickness locally are given in Annex A.

6.3 LOCATION OF TEST OBJECTS

6.3.1 Mounting locations

When a small building unit is mounted near one or more reflecting planes, the sound transmission may differ appreciably from that obtained when the unit is mounted through a partition but away from any adjoining room surface. Therefore, mount the equipment to be tested through the partition in locations representative of normal usage. On devices which can be used at several different locations, carry out measurements at least with an edge present in both rooms.

For transfer air devices and cable ducts which are normally mounted near an adjoining reflective wall, the specific mounting locations are stated in 6.4 and 6.5. For other types of equipment the rules given in 6.3.1.1 to 6.3.1.3 shall be observed. If the small building unit is mounted in a niche, the frames of the niche are not considered to be reflective planes in Clauses 6.3. - 6.5.

6.3.1.1 Equipment used away from wall

Install equipment mounted through a partition but normally located away from an adjoining wall, floor or ceiling in such a manner that no part is within 1.00 m of a surface at right angles to the mounting surface.

6.3.1.2 Equipment used near an edge

Locate equipment mounted through a partition and normally located near an adjoining wall, floor or ceiling, and away from a corner, at least 1.00 m from the nearest wall not being a part of the edge. Unless otherwise specified by the manufacturer, locate the edge of the equipment 0.1 m from the edge of the wall.

6.3.1.3 Equipment used near a corner

Locate equipment mounted through a partition and normally located near a corner at the distance from a corner recommended by the manufacturer.

If natural corners or edges are not available in the test opening, it is essential to simulate such mounting conditions by attaching reflective panels at right angles to the partition wall, as illustrated in Annex B. Ensure that the simulation takes place both in the receiving and the source room.

6.3.2 Number of locations

The building elements are small and, in combination with the spatial variations of the sound field in the test room, this leads to a significant location dependency. Use preferably three locations for the mounting of the test object in the partition wall. These locations shall either

a) be simulated as described in 6.3.1 or

b) they shall be located at least 1.2 m from each other.

Note A location dependency also exists for apparently equivalent corners which makes it necessary to use more than one corner to achieve an acceptable precision.

Note When simulating corner or edge locations by attaching reflective panels, it is possible to achieve the necessary location averaging by changing the locations and orientations of the additional panels.

6.4 INSTALLATION OF TRANSFER AIR DEVICES

Install the test objects in a manner representative of field practice and in typical locations with respect to the room surfaces as given in the installation rules above. Mount transfer air devices which are normally mounted near an adjoining ceiling in a location close to a reflective surface at right angles to the partition, but at least 1.00 m from any corner. The distance between the closest part of the device and the adjoining surface shall be 0.1 m. Accessories normally used shall be included. Set and fix these accessories in accordance with the manufacturer's directions.

If the device is provided with some airflow control, ensure that the equipment is operated in a specified manner typical of normal usage. If the specified manner is not the fully open condition, include this condition in the test sequence.

If the device is continuously adjustable to various wall thicknesses, ensure that the tests comprise at least the two extreme wall thicknesses for which the device is stated to be suitable.

6.5 INSTALLATION OF CABLE DUCTS

Install the test object in a manner representative of field practice and in typical locations with respect to the room surfaces. Mount cable ducts which are normally mounted directly on walls on a reflective surface at right angles to the partition and in accordance with the manufacturer's directions. Include accessories normally used. Install these accessories in accordance with the manufacturer's instructions.

Install the test object with an exposed continuous duct length of at least 2 m, both in the source and in the receiving room. Provide the exposed duct ends with standard end covers.

Soundproofing accessories to be used in installations through partition walls are often available in cable ducts. To test practical sealing and insulating properties of such soundproofing accessories, it is recommended that the cable duct be filled to its rated capacity with cables.

Note The acoustical performance can vary with the number of cables.

If the edge mounting is simulated with additional panels, ensure that the panel length is at least as large as the duct length.

7 TEST PROCEDURE AND EVALUATION

7.1 GENERAL

Measure the average sound pressure level in the source room and the average sound intensity level on a measurement surface in the receiving room. Provided that the field indicator is satisfactory calculate the element normalized level difference and, if needed, the intensity sound reduction index.

Unless otherwise stated in this standard, the laboratory procedures shall comply with the relevant clauses of ISO 140-3, concerning the sound generation and measurement in the source room.

7.2 GENERATION OF SOUND FIELD IN THE SOURCE ROOM

The sound generated in the source room should be steady and have a continuous spectrum in the frequency range considered. Filters with a bandwidth of at least one-third octave may be used.

The sound power should be sufficiently high for the sound pressure and sound intensity level in the receiving room to be at least 10 dB higher than the corresponding background level in any third-octave band.

If the sound source contains more than one loudspeaker operating simultaneously, the loudspeakers should be contained in one enclosure, the maximum dimension of which should not exceed 0.7 m. The loudspeakers should be driven in phase. Multiple sound sources may be used simultaneously providing they are of the same type and are driven at the same level by similar, but uncorrelated signals. Continuously moving sound sources may not be used. When using a single sound source it shall be operated in at least two positions.

The loudspeaker enclosure should be placed to give a sound field as diffuse as possible and at such a distance from the test specimen that the direct radiation upon it is not dominant.

7.3 MEASUREMENT OF AVERAGE SOUND PRESSURE LEVEL IN THE SOURCE ROOM

The average sound pressure level may be obtained by using a number of fixed microphone positions or a continuously moving microphone with an integration of sound pressure squared (p^2). As a minimum, five microphone positions shall be used.

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. The measurement surface forms a closed surface over/in front of the element to be measured. If the test specimen generates air flow in the receiving room the speed of flow must not exceed 2 m/s on the scanning paths through the measurement surface.

If the test specimen is mounted in a niche, the measurement surface is normally one face, the face consisting of the flat surface of the niche opening flush with the wall in the receiving room. If the opening is large, the measurement surface can be made smaller by closing the surface into the opening by using a box-shaped or partial box-shaped measurement surface, see Figs. 1 and 3. The box-shaped surface consists of five faces, see Fig. 1, and the number of faces of a partial box-shaped surface is more than one but less than five, see Figs. 2 and 3. If the test specimen is not mounted in a niche or if the depth of the niche is less than 0.1 m a box-shaped measurement surface has to be used. A box-shaped measurement surface may also be used to avoid too high speeds of flow on the measurement surface. If the building element is mounted near one or more reflecting planes excluding the wall between measuring rooms (see Clause 6), the reflective planes shall be used as boundaries of the measurement surface, the measurement surface thus being replaced by a partial one, see Fig. 2. Especially considering the box-shaped or partial box-shaped surfaces, if any reflecting plane (even small) is nearer than 1 m to any part of the measurement surface, the angle between them shall be at least 30 °. The reflecting planes above do not mean those of the element to be measured, the wall between the measuring rooms and other surfaces on which the measurement surface is closed. The former requirement is not applied to the frames of a niche when using box-shaped or partial box-shaped measurement surfaces provided that the field indicator is valid according to Clause 7.4.4 at the side faces of the measurement surface in the niche opening.

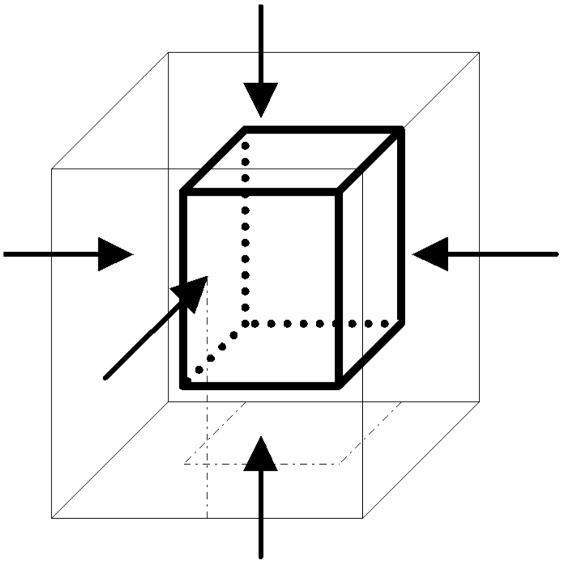


Fig. 1. Box-shaped measurement surface. The arrows point towards the faces of the measurement surface.

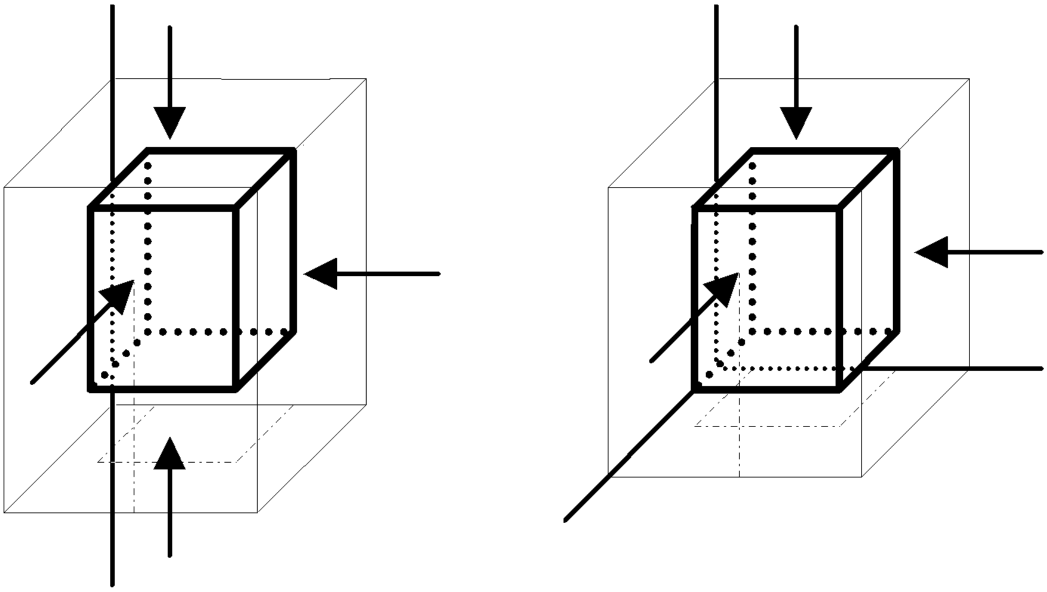


Fig. 2. Examples of partial box-shaped measurement surfaces. The arrows point towards the faces of the measurement surface.

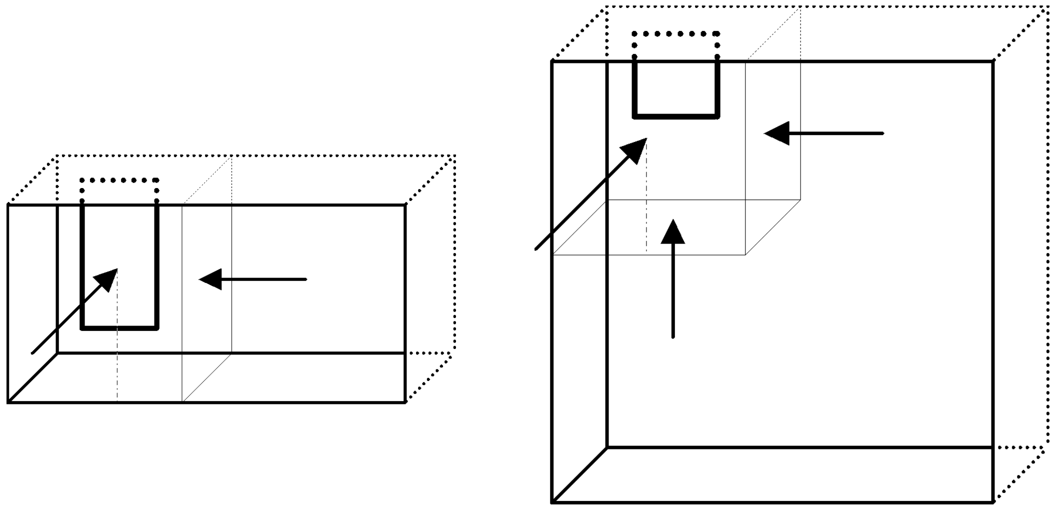


Fig. 3. Examples of partial box-shaped measurement surfaces on a niche. The arrows point towards the faces of the measurement surface.

The measurement surface may be a hemisphere (or part thereof if the test object is mounted close to the ceiling, on the floor or in a corner) if all dimensions of the test object inside the receiving room are less than half the chosen measurement distance. In that case the surface consists of only one face. The measurement surface may be a cylinder (or part thereof) if only two dimensions of the test object inside the receiving room are less than half the chosen measurement distance. In that case the cylindrical shell part forms one face of the surface and the ends (two or one) of the cylinder form other faces.

Avoid measurement distances smaller than 0.1 m because of the complicated near field of the vibrating element. In the near field the intensity tends to change sign on a very short spatial scale. The sound field is also normally more uniform in the niche opening than inside the niche. Avoid measurement distances greater than 0.3 m. However, to avoid too high speeds of flow on the measurement surface, larger measurement distances can be used provided that the field indicator remains in its valid range.

7.4.2 Sub-areas

If the measurement surface consists of one face, it is normally not divided into distinct sub-areas. If a box-shaped, partial box-shaped or cylindrical measurement surface is used, the measurement surface is normally divided into sub-areas, one sub-area for each face of the surface.

If the maximum recommended scanning time of a sub-area is going to be exceeded, the measurement surface has to be divided further into sub-areas. Subdivision can also be carried out if other aspects in the scanning procedure (see Clause 7.4.3) favour it. In that case use the following principles:

The division into sub-areas can be based on the shape, size and other factors of the partition to be measured, to make the scanning patterns easier to follow with a steady speed and line density. Also other constructional details of the partition, including the thicknesses and edges of plate-like parts, other natural boundaries, natural obstacles (e.g., pipes), leakages etc. can be used as the basis for defining the sub-areas. No dimensions of the sub-areas may exceed 1 m. The sub-areas can be of different size. It is recommended that strongly (and weakly) radiating parts of the partition should have their own sub-areas, as should also parts with negative intensity.

In the case of more than one sub-area, it is recommended to record the individual sub-area results and to calculate the final result afterwards, to avoid errors due to scanning speed alteration.

7.4.3 Scanning procedure

Always hold the probe normal to the measurement surface while scanning and direct it to measure the positive intensity outwards from the building element under test. The operator should disturb the acoustic field to be measured as slightly as possible. If possible, this can be ensured by the operator by having larger viewing angles than 45 ° (if forward looking is assumed) in respect to the normal of the surface to be measured.

Scan at a steady speed between 0.1 and 0.3 m/s. Each flat sub-area is scanned using parallel equidistant lines turning at each edge as shown in Fig. 4. Scanning patterns of the same kind are applied to hemispherical and semicylindrical subareas. With the latter, the scanning direction may be axial or circumferential. The scanning line density depends on the irregularity of the sound radiation. A large number of irregularities such as leakages requires a higher line density. Normally select the line density so that the distance between adjacent lines is equal to or less than the measurement distance. Besides, it is preferred that each square or nearly square sub-area has at least 5 scanning lines. With other sub-area shapes the foregoing recommendation is modified so that the product of the number of scanning lines in two mutually perpendicular directions (with the same distance between lines) is at least about 25 (i.e., 5 and 5, or 4 and 6, or 3 and 8, etc.).

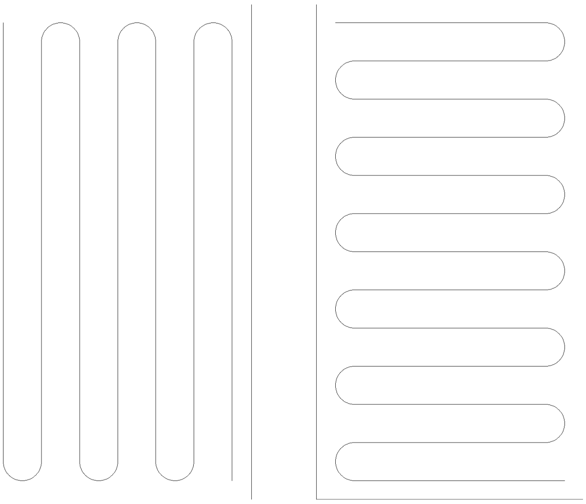


Fig. 4. Scanning patterns for the two scans.

Note The last recommendation regarding the minimum number of scanning lines will guarantee that the (minimum) total path length of the scanning lines is independent of the sub-area shape. In fact, the minimum path length according to the recommendation will be 5 times the square root of the area.

If the speed of flow is not constant on the measurement surface, the areas of high speed of flow may be avoided in some degree by proper selection of the scanning pattern.

If the individual sub-area results are recorded for later calculation, the line density may be different on different sub-areas. Those sub-areas that have small dimensions can be measured using discrete probe positions in the middle of the sub-areas. The dimensions are small if a definite scanning pattern is difficult or impossible to be traced.

Avoid stops other than interruptions when passing from one sub-area to another.

If the individual sub-area results are not recorded for later calculation, the scanning time of each sub-area shall be proportional to the size of the area. For the sake of steady scanning speed and line density, it is recommended that the maximum scanning time is about 1 min for each sub-area unless scanning is carried out by an automatic system.

Note The recommendation regarding the maximum scanning time together with the other recommendations and requirements above may lead to maximum recommended sub-area sizes.

If the instrumentation is such as to allow only discrete integration times, take into account the following special rules:

Adjust the scanning speed and integration time of each sub-area so that the scanning time is as near to the integration time as possible. If the scanning time of a sub-area is about 20 % or more longer than the integration time or if the integration time is about 20 % or more longer than the scanning time, rescan the sub-area. If it can be expected that the intensity level is at least 6 dB higher in the part of the scanning pattern not integrated, rescan the sub-area (although otherwise within the limits above). If the integration time is longer than the scanning time (within the above limits), i.e., the scanning will be ended before all the integration time has elapsed, continue scanning from the end of the scanning path towards the beginning, with decreased line density, until the integration time ends. Always record the individual sub-area results and calculate the final result afterwards.

If the measurement surface is not one flat surface, it is important to pay particular attention to the areas close to the intersection between the surface and the partition wall in which the test specimen is mounted. The measurement surface must be closed properly around the outer edge of the measuring surface, that is, it is essential to scan as close as possible to the partition wall. For measuring surfaces that are divided into several sub-areas, these do not need to be closed onto the physical surface at the joints between two sub-areas as long as there is no gap between them.

7.4.4 Sound intensity measurement

During the scan measure the time and space integrated sound intensity level L_{In}. If possible measure the time and space integrated sound pressure level L_p simultaneously. If the sound pressure level is not measured simultaneously, measure it using scanning similar to that for sound intensity. If the measurement surface is divided into several sub-areas, each of area S_i and each scanned individually, the total sound intensity level L_{In} and sound pressure level L_p must be evaluated from

$$\begin{aligned} L_{In} &= 10\,\mathrm{lg}\left(\sum S_i I_i\right) - 10\,\mathrm{lg}\left(\sum S_i\right)\ \mathrm{dB} \\ L_p &= 10\,\mathrm{lg}\left(\sum S_i 10^{L_{pi}/10}\right) - 10\,\mathrm{lg}\left(\sum S_i\right)\ \mathrm{dB}\,, \end{aligned} \tag{12}$$

where I_i is positive for sound intensity with positive direction

$$I_i = 10^{L_{Ii}/10}\ \text{, energy flow out from the test surface} \tag{13}$$

and negative for sound intensity with negative direction

$$I_i = -10^{L_{Ii}/10} \text{, energy flow towards the test surface .} \qquad (14)$$

Calculate the field indicator according to Eq. 4. 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 receiving room, improve the measurement environment. First try to increase the measurement distance by 5 ... 10 cm. If this fails add sound absorbing material to the receiver room. The field indicator requirement shall be satisfied for each scan and each loudspeaker position at each third octave band used in the measurements. However, it shall be satisfied only for the total measurement surface and not for individual sub-areas.

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

Note The criterion for the residual pressure-intensity indicator δ_{pI0} in respect to F may lead to more stringent upper bounds than 10 or 6 dB to F, see Clause 4.1.

Once the measurement environment is satisfactory carry out two complete scans and compare the results. Turn the scanning path 90 degrees between the two scans. If a sub-area is such that its dimension is small in one direction (of the same order or smaller than the chosen distance between lines), both the scans will be performed with lines parallel to the larger dimension. If the difference between the two measurements is less than or equal to 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 satisfied. The requirement for the level difference concerns the final result, not the results of individual subareas. If the requirement cannot be satisfied, change the scanning pattern, measurement surface or measurement environment and repeat the measurements until the requirement is satisfied. 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 provided that all deviations from the requirements of this method are clearly stated.

If two or more loudspeaker positions are used carry out a pair of scans in each position, each pair of scans complying with the above requirements. All results, including element normalized level difference and field indicator, are given by the arithmetic mean of all valid scans carried out.

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 by 10 dB. If *F* is changed by less than 1 dB then the requirements are satisfied. Carry out the procedure at point(s) representative for the actual measurements.

7.5 FREQUENCY RANGE OF MEASUREMENTS

Measure the sound pressure level and the sound intensity level 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 use third octave band filters with the following centre frequencies:

50 63 80.

The response of the filters should be in accordance with IEC Publication 225.

8 PRECISION

The precision is expected to be equivalent to that given in ISO 140-3 in the frequency range valid according to the measurement method.

It is required that the measurement procedure should give satisfactory repeatability. This can be determined in accordance with the method shown in ISO 140-2 and should be checked from time to time, particularly when a change is made in procedure or instrumentation.

9 EXPRESSION OF RESULTS

For the statement of the airborne sound insulation of the test specimen, give the values of element normalized level difference and, if needed, the intensity sound reduction indices at all frequencies of measurement to one decimal place in tabular form and/or in the form of a curve. In addition always give a curve of the pressure-intensity indicator in the graph. Indicate clearly any deviations from the basic requirement that the difference between two scans must not exceed 1 dB. For graphs with the level in decibels plotted against frequency on a logarithmic scale, use the following dimensions:

5 mm for the one-third octave band;

20 mm for 10 dB.

If weighted element normalized level difference $D_{I,\mathrm{n,e,w}}$ or weighted sound reduction index $R_{I,\mathrm{w}}$ is to be given, calculate it as specified for single-number quantities in either ISO 717-1 or ISO 717-3. The spectrum adaptation terms C and C_{tr} may also be stated as in Clauses 3.10 and 3.11.

10 TEST REPORT AND RECORD

10.1 INFORMATION TO BE REPORTED

The test report shall state:

a) reference to this NORDTEST method;

b) name and address of the testing laboratory;

c) identification number of the test report;

d) name and address of the organization or the person who ordered the test (optional);

e) purpose of the test;

f) name and address of manufacturer or supplier of the test object;

g) name or other identification marks of the tested object;

h) description of the tested object (test specimen), including type and size, with sectional drawing and operating conditions;

i) identification of the test equipment and instruments used including the probe type or probe configuration; if more than one probe type or configuration is used, the frequency range used for each of these; methods and instruments used in calibration and field check;

j) description of mounting conditions, including the location of the test object in the partition wall and the distances to adjoining walls, floor, ceiling and reflective panels;

k) element normalized level difference of the test specimen as a function of frequency; intensity sound reduction index, if needed, and pressure-intensity indicator of test specimen as a function of frequency including a clear indication of any deviations from this method;

l) single number rating according to ISO 717, if needed; also the spectrum adaptation terms as in Clauses 3.10 and 3.11, if needed;

m) limit of measurement in case of background noise;

n) brief description of details of procedure;

o) date of test, and signature of person responsible.

10.2 INFORMATION TO BE RECORDED

Information to be recorded includes, in addition to the information to be reported, also:

a) results of the different sub-areas;

b) measurement distance, shape of measurement surface and dimensions of sub-areas;

c) scanning time of each sub-area;

d) deviations of method concerning e.g., scanning patterns, scanning speeds, scanning times etc.

11 APPLICATION OF SOUND INSULATION DATA

When predicting the resulting performance of complex partition constructions, it is necessary to identify the important transmission paths, to estimate the sound insulation properties of the individual partition elements and to add their individual transmission contributions. A typical situation could be that one is interested in the sound insulation of a facade consisting of a wall, a window and an outdoor air intake. Guidelines for the derivation of the resulting sound insulation of a partition construction consisting of a partition wall and a small building element are presented in Annex C.

ANNEX A: LOCAL CHANGE IN WALL THICKNESS

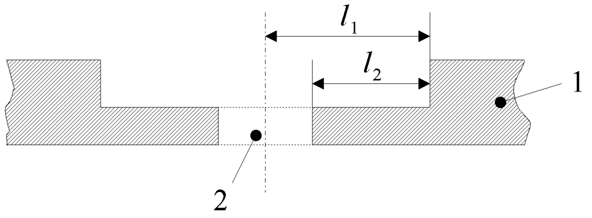
(normative)

A.1 LOCAL INCREASE OF WALL THICKNESS

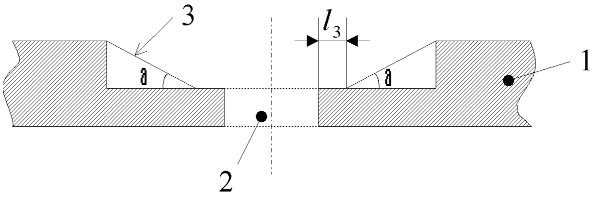
Instead of changing the thickness of the complete partition wall, simulate various wall thicknesses by adding extra panels to the original partition construction. The edges of such additional panels shall be at least 0.5 m from any part of the test object.

A.2 LOCAL DECREASE OF WALL THICKNESS

If a thick partition wall is needed to ensure sufficiently high flanking transmission loss, create a realistic wall thickness around the test device by locally reducing the thickness. This shall be done according to Fig. A.1.



alternative:



1 Partition between test rooms
2 Test specimen
3 Auxiliary transition panels with mass per unit area more than 10 kg/m^2 and an inclination of $\alpha < 30°$. (The panels shall be sealed with tape along edges.)

Fig. A.1. Local decrease of wall thickness.

The following relations shall hold:

$$\begin{aligned} l_1 &\geq 0.6\ \mathrm{m} \\ l_2 &\geq 0.1\ \mathrm{m} \\ l_3 &\geq 0.1\ \mathrm{m} \\ \alpha &< 30^\circ\,. \end{aligned} \tag{A.1}$$

ANNEX B: SIMULATION OF CORNER AND EDGE LOCATIONS

(normative)

The simulation of a corner is shown in Fig. B.1. To simulate an edge, it is sufficient to use only one panel, the dimensions of which shall be at least 1.2 x 2.4 m. The minimum dimensions are valid at and above the third octave with the centre frequency of 100 Hz. If a frequency range down to 50 Hz is used, the minimum panel dimensions shall be doubled. The panels shall not be mounted parallel to the boundary surfaces of the room.

If it is necessary to use additional panels in both the source room and the receiving room, ensure that the locations and orientations of the panels are the same in both rooms.

The mass per unit area of the panels shall exceed 7 kg/m^2. Above 100 Hz, the sound absorption coefficient shall be less than 0.1 at every frequency band of interest. The sides of the panels facing to the small element in the receiving room shall have the average absorption coefficient less than 0.06, calculated over the total frequency range of interest above 100 Hz.

Note The requirements concerning the absorption coefficient can be satisfied if, e.g., wooden panels with steel coverings are used.

Seal the connections between the panels and the partition wall with, for example, a heavy adhesive tape. As the mounting of additional panels to the partition wall might influence its transmission characteristics, include the various panel arrangements in the measurements of the flanking transmission.

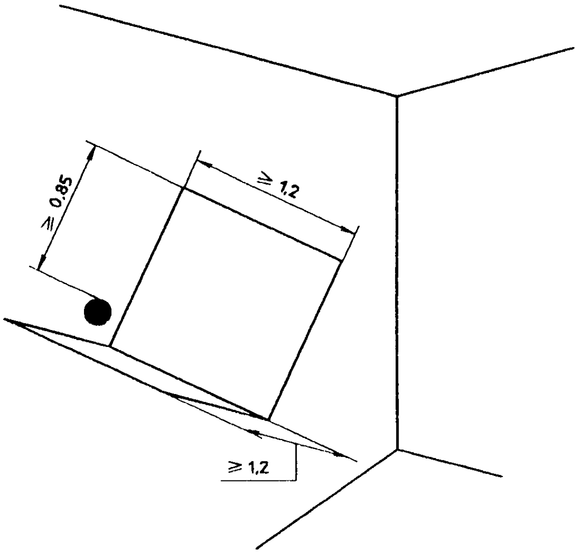


Fig. B.1. Drawing showing the principle of simulating a corner location by attaching reflective panels at right angles to the partition wall mounted in the test opening.

ANNEX C: GUIDELINES FOR THE DERIVATION OF THE OVERALL SOUND REDUCTION OF COMPOSITE PARTITION CONSTRUCTIONS

If a small building element is installed in a partition, the resulting sound insulation is given by

$$R_p = 10\lg\left(\frac{1}{10^{-R/10} + (A_0/S)10^{-D_{\mathrm{n,e}}/10}}\right)\mathrm{dB}, \tag{C.1}$$

where

R is the sound reduction index of the partition wall, in decibels;

$D_{\mathrm{n,e}}$ is the element normalized level difference of the small building element, in decibels;

A_0 is the reference area, in square metres (for the laboratory, $A_0 = 10$ m^2);

S is the total area of the partition, in square metres.

If more than one unit of a specific building element is installed in a partition, the second term in the denominator in Eq. 1 has to be multiplied by the number of the elements. If more than one, mutually different units are installed in a partition, Eq. 1 will be replaced by

$$R_p = 10\lg\left(\frac{1}{10^{-R/10} + (A_0/S)\sum 10^{-D_{\mathrm{n,e},i}/10}}\right)\mathrm{dB}, \tag{C.2}$$

where the summation takes place over i; R, A_0 and S are as above, and

$D_{\mathrm{n,e},i}$ is the element normalized level difference of the i:th small building element, in decibels.

The above extensions to Eq. 1 presuppose that the acoustical interaction between the elements has no effect on the total radiated sound power. The interaction can be seen at low frequencies so that the total sound power radiated by the elements at the same time is not equal to the sum of the sound powers of the elements when they are radiating separately. This usually tends to decrease the total sound insulation. If two elements that can be considered as similar constant volume velocity sources are mounted at a distance d, the difference between the total radiated sound power compared to the sum of individual powers is

$$\Delta L_w = 10\lg\left(1 + \frac{\sin(2\pi d / \lambda)}{2\pi d / \lambda}\right)\mathrm{dB}, \tag{C.3}$$

where

ΔL_w is the difference between the total radiated sound power and the sum of individual powers, in decibels;

λ is the wavelength, in metres (c/f, c = speed of sound, f = frequency);

which can be considered to be the same as the difference in sound insulation (with different sign) if the sound reduction index of the partition is high compared with the element normalized level difference of the elements. If the sound reduction index of the partition wall is low the difference is lower. There are two situations where the problem of interaction is overcome. The first is that the measurement has been made for the total sound insulation of the elements mounted in a way similar to their final mounting. The other is that the elements are mounted far enough from each other to avoid the interaction. If two elements are considered according to Eq. 3 an error of 1 dB at the lower limiting frequency of third octave of 100 Hz will give the minimum distance of the elements to be 1.5 m. At the lower limiting frequency of third octave of 50 Hz the minimum distance is 3 m. Corresponding minimum distances for an error of 0.5 dB are 5 m (100 Hz) and 10 m (50 Hz). If it is not possible to overcome the problem, i.e., if one has to evaluate the resulting sound insulation of a partition having more than one small element with distances of less than 1.5 m between them, based on the measurement results of the element normalized level differences of individual elements, an upper bound for the resulting error can be got from

$$\Delta R_p \approx \Delta L_w + 10\lg(n-1), \tag{C.4}$$

where

ΔL_w is given by Eq. 3, in decibels, with d taken as the average distance of any element from the element nearest to it;

n is the number of small elements.

In Eq. 4 it has been assumed, besides the assumptions for Eq. 3, that any element interacts only with the element nearest to it.

If the total physical area of the small element(s) ΣS_i (in the plane of the partition) is not small compared with the area of the partition, Eqs. 1 and 2 give an underestimate of the resulting sound insulation. The error depends on the sound reduction index of the partition wall compared with the element normalized level difference of the elements; the lower the sound reduction index of the partition wall, the higher this is. If the sound reduction index of the partition wall is very low, the error can be about 1 dB if ΣS_i is about 20 % of the total area, 0.5 dB if ΣS_i is about 10 % of the total area and 0.1 dB if ΣS_i about 2 % of the total area. The error is lower than stated above if the sound reduction index of the partition wall is high. The error can be compensated for by changing the term $10^{-R/10}$ according to

$$10^{-R/10} \rightarrow \left(1 - \frac{\Sigma S_i}{S}\right) \bullet 10^{-R/10} \qquad \text{(C.5)}$$

in Eqs. 1 and 2. To compensate for the error it is required that the total physical area of the small elements is known.

Example. Let R_m be the minimum allowed value for the total sound reduction index of a partition with n identical small elements. Let the sound reduction index R of the partition be expressed as

$$R = R_\mathrm{m} + \Delta R \,\mathrm{dB}\,.$$

Using Eqs. 1 and 5 the element normalized level difference of each small element has to satisfy:

$$D_\mathrm{n,e} \geq R_\mathrm{m} + 10\,\mathrm{lg}\left(\frac{n\,A_0/S}{1-(1-n\,S_1/S)\bullet 10^{-\Delta R/10}}\right)\mathrm{dB}\,,$$

where S_1 is the area of one element. For two extreme cases, when ΔR tends to zero or infinity, the requirement will be

$$D_\mathrm{n,e} \geq R_\mathrm{m} + 10\,\mathrm{lg}(A_0/S_1)\,\mathrm{dB}\,, \Delta R \rightarrow 0$$
$$D_\mathrm{n,e} \geq R_\mathrm{m} + 10\,\mathrm{lg}(n\,A_0/S)\,\mathrm{dB}\,, \Delta R \rightarrow \infty\,.$$

In the first case, an alternative way of stating the requirement is that if the sound reduction index of the partition just satisfies the requirement, the sound reduction index of each small element has to be equal to or higher than the requirement (see the relation between the sound reduction index and element normalized level difference, Eq. 9). In the second case the sound reduction index of the partition is so high that the total sound reduction index is determined only by the elements. If the area of the partition is $S = A_0 = 10\ \mathrm{m}^2$, the requirement in the second case can be written as

$$D_{\mathrm{n,e}} \geq R_{\mathrm{m}} + 10\lg(n)\ \mathrm{dB}\ ,\ S = A_0 = 10\,\mathrm{m}^2,\ \Delta R \rightarrow \infty$$

$$= \begin{cases} R_{\mathrm{m}} & \mathrm{dB}\ ,\ n = 1 \\ R_{\mathrm{m}} + 3.0 & \mathrm{dB}\ ,\ n = 2 \\ R_{\mathrm{m}} + 4.8 & \mathrm{dB}\ ,\ n = 3 \\ R_{\mathrm{m}} + 6.0 & \mathrm{dB}\ ,\ n = 4 \end{cases}$$

$$\text{etc.}$$

The acoustical interaction between the elements is not taken into account in this example.

ANNEX D: REFINED FORM OF WATERHOUSE CORRECTION

The Waterhouse correction, used in Eq. 8, can be presented more precisely by using the modal density of the room instead of the room geometry. By doing so the corrected element normalized level difference $D_{\mathrm{n,e,c}}$ (for the result of ISO 140-10 measurement) can be written as

$$D_{\mathrm{n,e,c}} = D_{\mathrm{n,e}} - 10\lg\left(1 + \frac{S_{\mathrm{b2}}\lambda}{8V_2} + \frac{L_2\lambda^2}{32\pi V_2}\right)\ \mathrm{dB} \quad , \qquad \text{(D.1)}$$

where

$D_{\mathrm{n,e}}$	is the element normalized level difference, in decibels;
n_2	is the modal density of the receiving room, in modes/hertz;
V_2	is the volume of the receiving room, in cubic metres;
f	is the centre frequency of the one-third octave band, in hertz.

This formula has the advantage that the Waterhouse correction can be determined experimentally by measuring the modal density of the receiving room.

This formula can be written using geometrical quantities as

$$D_{\mathrm{n,e,c}} = D_{\mathrm{n,e}} - 10\lg\left(\frac{n_2}{f^2 V_2}\right) - 65.1\ \mathrm{dB} \quad , \qquad \text{(D.2)}$$

where $D_{\mathrm{n,e}}$ is as above and

S_{b2}	is the area of all the boundary surfaces in the receiving room, in square metres;
V_2	is the volume of the receiving room, in cubic metres;
L_2	is the total length of the linear dimensions of the receiving room, in metres (if the room is rectangular with dimensions a, b and c, $L_2 = 4 \cdot (a + b + c)$);
λ	is the wavelength at the centre frequency of the one-third octave band, in metres.

The formula 2 is identical to Eq. 1 with rectangular rooms; for other room shapes Eq. 2 is an approximation. The last (third) factor in the correction term in Eq. 2 is not presented in the traditional Waterhouse correction in Eq. 8. Normally it has significance only at frequencies below 100 Hz, typically about or less than 0.5 dB.

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A laboratory method to evaluate the sound insulation of small building elements using sound intensity technique was developed. A supplement, considering the general usefulness of the element normalized level difference in evaluating the sound insulation of partitions, is included in the method. The method gives similar results as ISO 140-10 with an accuracy of 1 dB or better at a frequency range where both of the methods give valid results. The effects of flanking transmission on the sound insulation measurement results can be diminished by using intensity technique unless the flanking transmission is very remarkable. An improved form has been developed to the Waterhouse correction. The Waterhouse correction can be determined for each room by measuring or calculating its modal density. The Waterhouse correction of the receiving room should be subtracted from the result of traditional measurements of the sound reduction index. No Waterhouse correction is needed for the source room. The measurement of sound insulation by the intensity technique needs no Waterhouse corrections.