TECHNICAL REPORT

ISO/TR 140-13

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Acoustics — Measurement of sound insulation in buildings and of building elements —

Part 13:
Guidelines

Acoustique — Mesurage de l'isolement acoustique des immeubles et des éléments de construction —

Partie 13: Lignes directrices

Reference number
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Foreword

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

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 140-13, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 2, *Building acoustics*.

ISO 140 consists of the following parts, under the general title *Acoustics — Measurement of sound insulation in buildings and of building elements*:

— *Part 1: Requirements for laboratory test facilities with suppressed flanking transmission*

— *Part 2: Determination, verification and application of precision data*

— *Part 3: Laboratory measurements of airborne sound insulation of building elements*

— *Part 4: Field measurements of airborne sound insulation between rooms*

— *Part 5: Field measurements of airborne sound insulation of façade elements and façades*

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— *Part 6: Laboratory measurements of impact sound insulation of floors*

— *Part 7: Field measurements of impact sound insulation of floors*

— *Part 8: Laboratory measurements of the reduction of transmitted impact noise by floor coverings on a solid standard floor*

— *Part 9: Laboratory measurement of room-to-room airborne sound insulation of a suspended ceiling with a plenum above it*

— *Part 10: Laboratory measurement of airborne sound insulation of small building elements*

— *Part 11: Measurement of impact sound improvement of light-weight floors*

— *Part 12: Laboratory measurement of room-to-room airborne and impact sound insulation of an access floor*

— *Part 13: Guidelines*

Introduction

This Technical Report is identical with Nordtest Technical Report NT TECHN REPORT 203, *Measurements of the acoustical properties of buildings — Additional guidelines* (approved 1992-11), which is the result of a Nordtest-financed project carried out by a Nordic project group.

The reason for publishing the Nordtest Report as an ISO Technical Report is to spread the report widely, in order to gain as much experience as possible before considering implementation of the guidelines in existing standards.

Acoustics — Measurement of sound insulation in buildings and of building elements —

Part 13:
Guidelines

1 Scope

This part of ISO 140 gives guidelines on building acoustical field measurements, based on ISO 140 parts 4 and 7.

2 Guidelines

Guidelines are given in Nordtest Technical Report NT TECHN REPORT 203, *Measurements of the acoustical properties of buildings — Additional guidelines*, 1992, which is adopted as ISO/TR 140-13.

nordtest report

NT TECHN REPORT 203
Approved 1992-11

MEASUREMENTS OF THE ACOUSTICAL PROPERTIES OF BUILDINGS – ADDITIONAL GUIDELINES

Henrik S. Olesen

NORDTEST

TASKS

The tasks of Nordtest are to promote the safety of life, health, environment and material values, and to encourage the free exchange of trade. The approach adopted by Nordtest to achieve these objectives is:

- to develop, adopt and recommend test methods and to promote the use of these by industry and the authorities, and also in standardisation work
- to obtain international recognition of test results and the competence of the Nordic countries, for instance by quality assurance and verification of testing activity
- to endeavour to ensure that tests and the approval of test results are made in a resource and cost effective manner
- to promote the technical testing infrastructure in the Nordic countries by means of research, development of competence and collaboration, and
- to participate in the European and international development of testing and to promote Nordic interests.

ORGANISATION

The organisation of Nordtest consists of a board, a secretariat and nine technical groups. These groups are Acoustics and Noise, Building, Electronics, Environment, Fire, Mechanical Building Services (VVS), Mechanics, Polymers and Quality Assurance.

The work is directed by the Board which comprises representatives of all the Nordic countries. The members are appointed by the government or appropriate department of the country concerned.

The technical groups initiate and evaluate projects. The projects are often structured in such a way that they can be used as catalysts for the development of the combined technical competence in the Nordic countries. At present, about 250 Nordic projects are being carried out in some 40 firms and institutions.

The board and the technical groups are assisted by the secretariat which is responsible for day to day activity. The secretariat is located at Espoo, Finland.

FINANCIAL FRAMEWORK

The cost of the Nordtest secretariat and a large proportion of project activity is financed from the budget of the Nordic Council of Ministers. The grant for 1992 is approx 1,5 millions ECU. The work of the board and the technical groups is financed by the participating organisations.

PUBLICATIONS

Nordtest publishes test methods, technical reports and a register of test methods and technical reports.

NT TECHN REPORT 203

Approved 1992-11

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Title (English): --	
Title (Original): Measurements of the acoustical properties of buildings - additional guidelines	

Abstract:

Requirements of the acoustical quality of buildings are normally stated in the building code regulations of the individual countries. The building code regulations normally prescribe minimum requirements concerning airborne sound insulation, impact sound insulation, reverberation time and noise from technical installations.

Basic methods for measuring these quantities are given in international standards and Nordtests Methods. However, acoustical measurements in buildings are quite complicated, especially regarding airborne and impact sound insulation. The standards presume ideal acoustical behavior of the rooms, which is in practical measurement situations almost impossible to achieve.

The standards prescribe the principles of the measurements, but often they give only little detailed information on how to establish a suitable measurement set-up in rooms differing from simple box-shaped rooms of normal living room size.

Often in field situations it can be very difficult to choose an optimal measurement set-up. On this background the purpose of this project is to prepare additional guidelines to be used together with the basic standards. The guidelines include proposals for suitable measurement set-ups in typical as well as atypical rooms.

The guidelines have been prepared partly based on theoretical consideration and experimental results and partly on practical experience from performing a great number of field measurements. A detailed experimental evaluation of the guidelines would be very comprehensive and would also widely exceed the limits of this project. Therefore, the proposed guidelines should not be regarded as recommendations at the same level of try out as the basic standards.

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FOREWORD

This project has been financial supported by Nordtest, project 963-91.

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1. SUMMARY

Requirements of the acoustical quality of buildings are normally stated in the building code regulations of the individual countries. The building code regulations normally prescribe minimum requirements concerning airborne sound insulation, impact sound insulation, reverberation time and noise from technical installations.

Basic methods for measuring these quantities are given in international standards and Nordtest Methods. However, acoustical measurements in buildings are quite complicated, especially regarding airborne and impact sound insulation. The standards presume ideal acoustical behaviour of the rooms, which is in practical measurement situations almost impossible to achieve.

The standards prescribe the principles of the measurements, but often they give only little detailed information on how to establish a suitable measurement set-up in rooms differing from simple box-shaped rooms of normal living room size.

Often in field situations it can be very difficult to choose an optimal measurement set-up. On this background the purpose of this project is to prepare additional guidelines to be used together with the basic standards. The guidelines include proposals for suitable measurement set-ups in typical as well as atypical rooms.

The guidelines have been prepared partly based on theoretical consideration and experimental results and partly on practical experience from performing a great number of field measurements. A detailed experimental evaluation of the guidelines would be very comprehensive and would also widely exceed the limits of this project. Therefore, the proposed guidelines should not be regarded as recommendations at the same level of try out as the basic standards.

2. INTRODUCTION

2.1. BACKGROUND

Verification of the internal acoustical quality of buildings typically comprises measurement of the following quantities:

1. Airborne sound insulation

2. Impact sound insulation

3. Reverberation time

4. Noise from technical installations

(Measurements of noise from the outside transmitted into the building are not included in the scope of this project.)

In the Nordic countries methods for measurement of airborne and impact sound insulation is basically performed according to the international standards ISO 140 Part 4 and 7, respectively. Regarding methods for measurements of reverberation time in rooms for normal use and noise from technical installations no suitable international standards exist at present. Measurements of reverberation time and noise from technical installations are carried out in accordance with procedures prescribed in the individual building code regulations. These procedures are usually based on the Nordtest Methods NT ACOU 053 concerning reverberation time and NT ACOU 042 concerning noise measurements or alternatively the international standards ISO 3382 and ISO/R 1996.

In Norway and Sweden additional standards have been worked out giving some instructions and modifications in relation to the basic standards (ref. [15], [16],[17]).

Especially for measurements of airborne and impact sound insulation it can often be very difficult to choose a suitable measurement set-up in atypical rooms exclusively based on the test procedures prescribed in the basic standards.

To improve the reproducibility of building acoustic field measurements there is a need for additional guidelines to be used together with the basic standards.

2.2. OBJECTIVE

The objective of this project is to prepare additional guidelines to basic standards for building acoustic field measurements.

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The use of the guidelines should contribute to improvement of the reproducibility of building acoustic field measurements and furthermore, hopefully, facilitate the performance of measurements by avoiding time consuming consideration in actual measurement situations.

2.3. APPROACH

As mentioned detailed theoretical and experimental investigations covering the measurements dealt with in this project would be very comprehensive and would widely exceed the limits of the project. Therefore the guidelines have been prepared based on simple theoretical consideration, some experimental results and experience from a great number of field measurements.

The requirements of airborne and impact sound insulation in building code regulations are usually stated in form of the single number values R'_w and $L'_{n,w}$. These quantities are calculated from the sound reduction index determined for 1/3 octave bands in the frequency range 100-3150 Hz. It has been decided to work out the guidelines with the purpose of improving the accuracy of the determination of the sound reduction indices. The single number values have not directly been taken into consideration.

The proposed guidelines are primarily applicable for measurements in rooms in dwellings, schools, hotels etc. with volumes less than approximately 250 m³.

The basic idea of the guidelines is that examples of suitable measurement set-ups in typical as well as atypical rooms are shown on diagrammatic sketches. For actual measurement situations not directly covered by the examples it should be possible to derive a suitable set-up from the examples given.

It shall be stressed that the proposed additional guidelines are not recommendations at the same level of try out as the basic standards.

3. BASIC STANDARDS

The standards related directly to the guidelines are:

ISO 140, Part 4: Acoustics - Measurement of sound insulation in buildings and of building elements. Field measurements of airborne sound insulation between rooms.

ISO 140, Part 7: Acoustics - Measurement of sound insulation in buildings and of building elements. Field measurement of impact sound insulation of floors.

Note - ISO 140 Part 4 and 7 are for the time being under revision. In this project the committee drafts of 5. May 1992 have been used. In all probability the standards will be approved in the present form within a short time.

Nordtest Method NT ACOU 042, Rooms: noise level (Approved 1983-09).

Nordtest Method NT ACOU 053, Rooms: reverberation time. (Approved 1986-02).

Nordtest Method NT ACOU 069, Doors in buildings: airborne sound insulation. (Approved 1988-09).

4. AIRBORNE SOUND INSULATION

4.1. INTRODUCTION

A measurement of the airborne sound insulation (sound reduction index) includes determination of the space and time average sound pressure level in the source room and the receiving room respectively, and the space average reverberation time in the receiving room.

The sound reduction index is given by

$$R = L_1 - L_2 + 10 \log \frac{S}{A} \ [\mathrm{dB}]$$
$$A = 0.163 \cdot \frac{V}{T} \ [\mathrm{m}^2] \qquad (4.1)$$

where L_1 = sound pressure level in the source room [dB]
L_2 = sound pressure level in the receiving room [dB]
S = area of the test object [m^2]
A = equivalent absorption area of the receiving room [m^2]
V = volume of the receiving room [m^3]
T = reverberation time of the receiving room [s]

If the individual sources of errors are assumed to be uncorrelated, the normalized variance of the sound reduction index can be estimated from

$$\varepsilon^2(R) = \varepsilon^2(L_1) + \varepsilon^2(L_2) + \varepsilon^2(T) \qquad (4.2)$$

where $\varepsilon^2(L_1)$ = normalized variance of the average sound pressure in the source room

$\varepsilon^2(L_2)$ = normalized variance of the average sound pressure in the receiving room

$\varepsilon^2(T)$ = normalized variance of the average reverberation time

Determination of the sound reduction index according to equation 4.1 assumes diffuse sound fields in the source and receiving room, respectively. In empty rooms with normal living room size the sound field will normally be approximately diffuse apart from the lowest measurement frequencies observed. Serious problems with non-diffuse sound fields especially occur in very small rooms - e.g. bath rooms - and in large rooms with a short reverberation time.

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Detailed knowledge of the influence on the measurement accuracy of the room volume, reverberation time, number of loudspeaker and microphone positions etc. is an important basis for preparation of additional guidelines to ISO 140 Part 4.

In the following chapters 4.2-4.11 calculations and consideration concerning the accuracy of measurements of airborne sound insulation in different types of rooms are presented. Chapter 4.12 is a summary of ISO 140 Part 4. Based on the chapters 4.2-4.11 principle aspects regarding additional guidelines are considered in chapter 4.13. A proposal for additional guidelines is presented in chapter 4.14.

When possible, measurements and calculations have been carried out in the frequency range 50-5000 Hz. In cases where the frequencies 50-80 Hz and 4000-5000 Hz have not been included this is due to either a lack of data, because measurement results from former investigations not performed in the extended frequency range have been used, or because the theories used in the calculations are not valid at low frequencies.

tandard deviations presented in this chapter calculated from measurement results are determined as the sample standard deviation.

4.2. STATISTICAL ROOM ACOUSTICS

This chapter deals with statistical consideration concerning random errors of the determination of the average sound pressure level in a room. The calculations in this chapter are mainly based on theories from the references [1], [2] and [3].

4.2.1. Schröder cut-off frequency

Statistical consideration on the sound field in a room is valid, when the sound field is diffuse. Schröder has suggested that the sound field can be regarded as diffuse if the modal overlap index is greater than 3. Based on this condition an approximation of the lowest frequency at which diffuse sound fields occur can be calculated. The so-called Schröder cut-off frequency is given by the equation (ref. [1]):

$$f_s = 2000\sqrt{\frac{T}{V}} \text{ [Hz]} \qquad (4.3)$$

where T = reverberation time of the room [s]
V = volume of the room [m³]

The Schröder cut-off frequency as a function of the room volume has been calculated for rooms with typical living room size. The reverberation time used in the calculation is estimated from figure A1 in Annex A. From figure 4.1 it is seen that for a typical minor living room with a volume of 30 m³ a diffuse sound field - in regard of the Schröder definition - does not occur at frequencies below approximately 500 Hz.

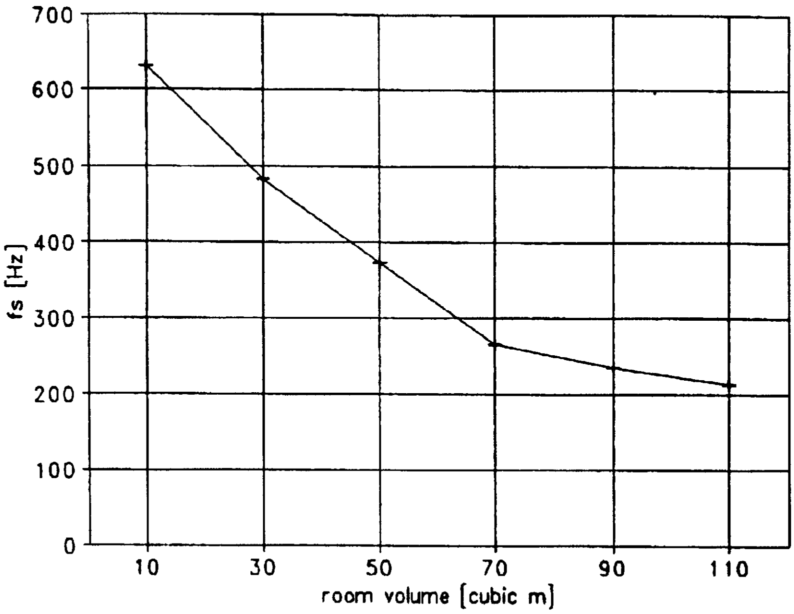


Figure 4.1. Schröder cut-off frequency as a function of the room volume.

4.2.2. Normalized standard deviation of sound pressure measurements due to spatial variations in the sound field

The sound pressure level varies with the position in a room. Lubman, (ref. [1], [3]), has derived equations approximating this position variance, even at frequencies below the Schröder cut-off frequency. It is assumed that the sound field is generated by a point source in one position.

According to Lubman the normalized spatial variance of the mean square sound pressure due to varying positions can be determined by the following equations (f_s is the Schröder cut-off frequency):

$0.2 \cdot f_s \leq f \leq 0.5 \cdot f_s$:

$$\varepsilon^2(p^2) = \frac{1}{1 + \frac{\eta(f) \cdot B}{\pi}} \tag{4.4}$$

where B = bandwidth of the filters [Hz] $(0.23 \cdot f)$

f = centre frequency of 1/3 octave band [Hz]

$\eta(f)$ = modal density for rectangular rooms

$$= \frac{4\pi \cdot V}{c^3} \cdot f^2 + \frac{\pi \cdot S}{2 \cdot c^2} \cdot f + \frac{L}{8 \cdot c}$$

where c = speed of sound in the air [m/s]
V = room volume [m^3]
S = total area of the room surfaces [m^2]
L = $4 \cdot (l_x + l_y + l_z)$ [m]
(l_x,l_y,l_z length of the room edges)

<u>$f_t \leq f$:</u>

$$\varepsilon^2(p^2) = \frac{1}{1 + 0.145 \cdot B \cdot T} + \frac{1}{160^2 \cdot n} \cdot \left(\sqrt{A} \cdot \frac{S}{V}\right)^3 \tag{4.5}$$

where B = bandwidth of the filters [Hz] $(0.23 \cdot f)$
f = centre frequency of 1/3 octave bands [Hz]
T = reverberation time [s]
V = room volume [m^3]
S = total area of the room surfaces [m^2]
A = absorption area of the room surfaces [m^2]
$= \frac{0.163 \cdot V}{T}$

n = shortest distance between any microphone position and the sound source in units of the reverberation distance, r_H.

$$r_H = 0.056 \cdot \sqrt{\frac{V}{T}} \text{ [m]}$$

A modification of equation 4.4 is proposed in ref. [2]. By this modification it seems that the agreement between measured and calculated results is improved. Furthermore the frequency range in which the equation is valid is extended from half the Schröder cut-off frequency to f_t. (It is stressed in [2] that the proposed modification shall be taken with reservation because of the limited documentation). The modified equation is:

$$\varepsilon^2(p^2) = \frac{1}{1 + \frac{\eta(f) \cdot B}{8.5}} \qquad (4.6)$$

In the following the equations 4.5 and 4.6 are used.

From the normalized standard deviation $\bar{s}(x)$ of a sample x it is possible to calculate a first order approximation of the standard deviation of x in decibels by the equation (ref. [1]):

$$s(10 \log x) \approx 4.34 \cdot \bar{s}(x) \qquad (4.7)$$

For the purpose of this project the approximation in 4.7 is estimated to be sufficiently good for standard deviations $\bar{s}(x)$ less than 0.75.

As a check of the validity of the equations 4.5 and 4.6 calculation and measurement results have been compared for four different rooms having the following data:

Room no	length • width • hight m	Volume m^3	Reverberation time, s		
			100 Hz	1000 Hz	3150 Hz
1	2.88 • 1.53 • 2.51	11.1	1.3	1.1	0.8
2	5.05 • 4.00 • 3.21	64.8	1.6	2.0	1.7
3	5.34 • 5.02 • 2.58	69.2	1.2	0.7	0.6
4	4.87 • 8.12 • 2.58	102.0	1.0	0.6	0.5

Table 4.1. Data of rooms used for comparison of measured and calculated spatial standard deviation of the sound pressure level.

Room 1: Toilet with hard room boundaries.

Room 2: Laboratory room with absorbers evenly distributed over the wall surfaces and the ceiling. Suspended diffusing elements.

Room 3: Furnished meeting room with carpet.

Room 4: Furnished living room with carpet.

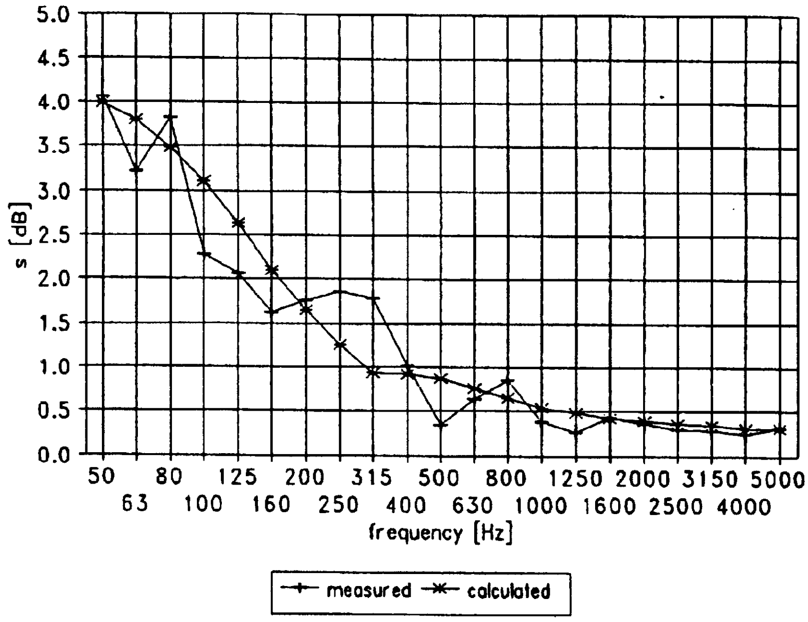


Figure 4.3. Measured and calculated spatial standard deviation of the sound pressure level in room 2.

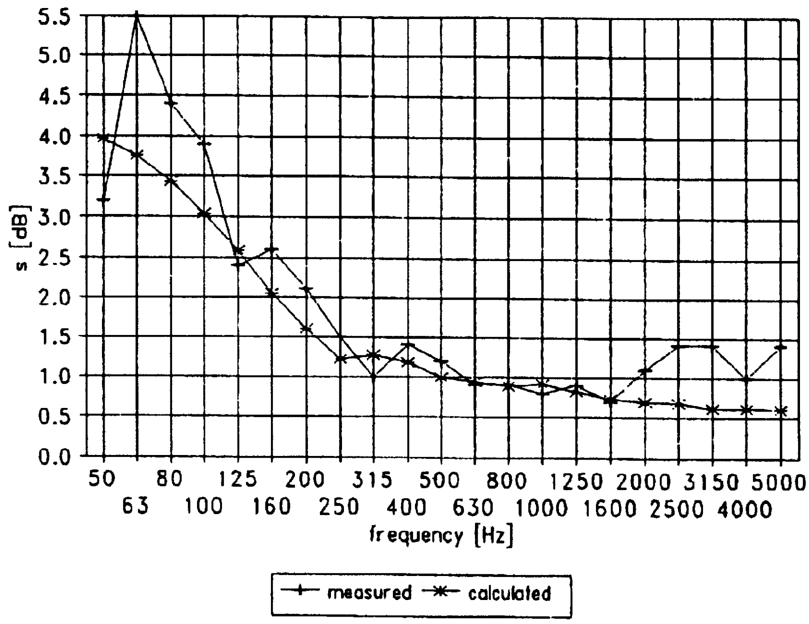


Figure 4.4. Measured and calculated spatial standard deviation of the sound pressure level in room 3.

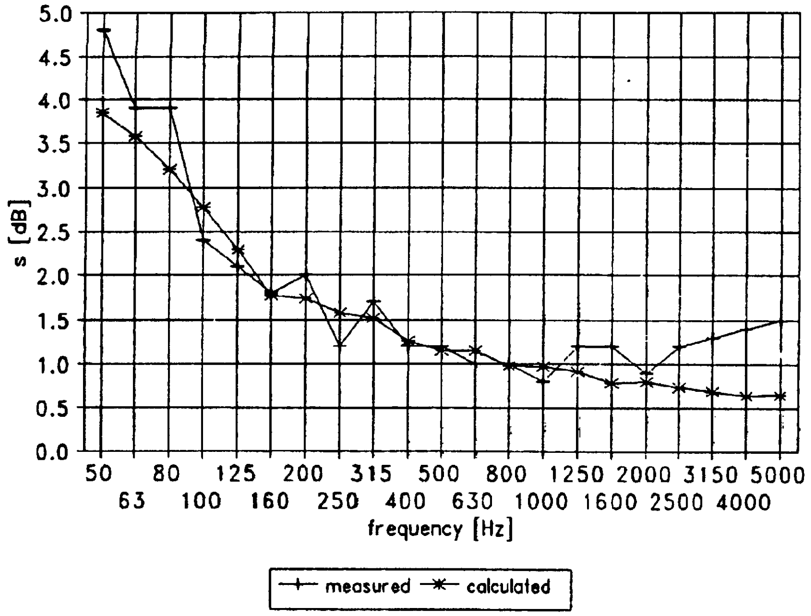


Figure 4.5 Measured and calculated spatial standard deviation of the sound pressure level in room 4.

To illustrate the spatial standard deviation for the sound pressure level in typical empty living rooms calculations have been carried out for five different rooms with volumes from 10 m³ to 100 m³. The results are shown in figure 4.6. The reverberation time has been estimated from Annex A. For the 100 m³-room an additional calculation has been carried out assuming that the reverberation time in the entire frequency range is 0.4 s. It is seen that in this extremely damped room the standard deviation is increased considerably.

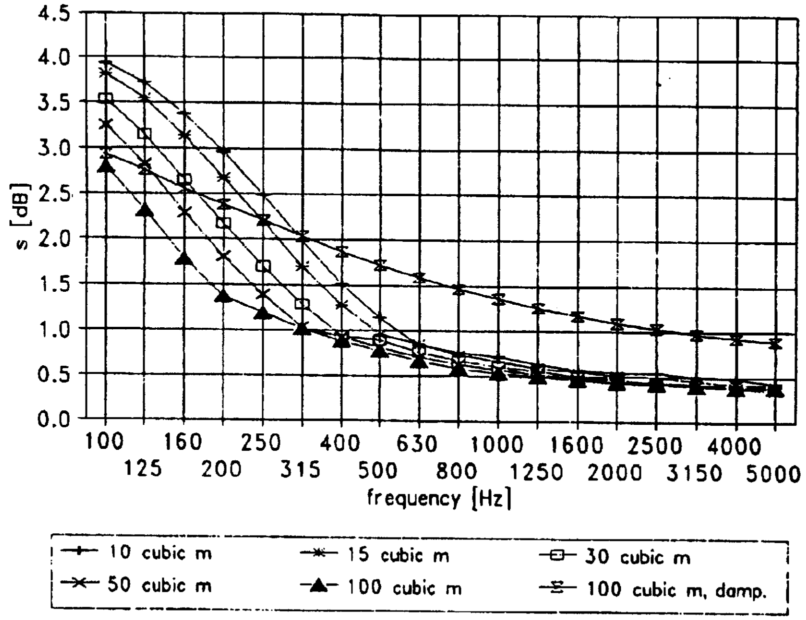


Figure 4.6. Spatial standard deviation calculated for rooms with typical living room dimensions and with volumes in the range 10 m³ to 100 m³.

4.3. LOW FREQUENCY LIMITATIONS

At frequencies below the lowest eigenfrequency of a room, wave patterns do not occur. The room is to be considered as a pressure chamber with a uniform sound pressure level distribution. The lowest eigenfrequency of a rectangular room can be calculated from the equation:

$$f = \frac{c}{2\ell} \text{ [Hz]} \qquad (4.8)$$

where c = speed of sound in the air [m/s]
ℓ = longest dimension of the room [m]

If e.g. the longest dimension of a room is 2 m wave patterns cannot occur at frequencies below 86 Hz.

At frequencies below the lowest eigenfrequency the spatial standard deviation is expected to decrease considerably.

4.4. EQUIVALENT NUMBER OF MICROPHONE POSITIONS, LOUD-SPEAKER POSITIONS AND TEST OBJECT POSITIONS

In a diffuse sound field microphone and loudspeaker positions, respectively, can be regarded as uncorrelated if the distance between them is more than half a wavelength corresponding to the lowest frequency of interest. Assuming diffuse sound fields it is possible to estimate the equivalent number of uncorrelated positions in situations where the distance between the actual positions is less than half a wavelength.

4.4.1. Rotating microphone

For a continued averaging along a circle an estimate of the equivalent number of uncorrelated fixed microphone positions can be calculated from the equation (ref. [1]):

$$N_{eq,rot.mic.} = \frac{2L}{\lambda} + \frac{1}{1 + (2L/\lambda)} \qquad (4.9)$$

where λ = the wavelength [m]
L = the length of the perimeter of the circle path [m]

In figure 4.7 the equivalent number of uncorrelated fixed microphone positions is shown for different circular microphone paths as a function of the frequency in the range 50-315 Hz.

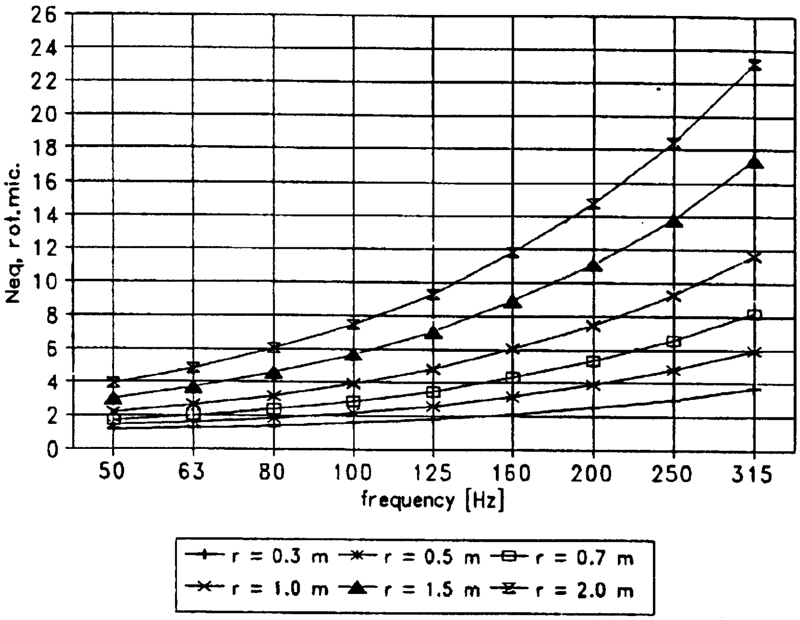


Figure 4.7. Equivalent number of uncorrelated fixed microphone positions as a function of the frequency and the radius (r) of a rotating microphone.

According to ISO 140 Part 4 the radius of a rotating microphone must not be less than 0.7 m. From figure 4.7 it is seen that in a diffuse sound field a radius of 0.7 m corresponds to three uncorrelated fixed positions at 100 Hz and less than two positions at 50 Hz.

4.4.2. Fixed microphones

For fixed microphones in a diffuse sound field with a distance between the positions less than half a wavelength the equivalent number of uncorrelated positions can be estimated from the equation (ref. [2], [3]):

$$N_{eq,disc.mic.} = \frac{N}{1 + \frac{1}{N}\sum_i \sum_j R^2(kx_{ij})} \quad (i \neq j) \qquad (4.10)$$

where N = the actual number of positions

R = correlation coefficient for a diffuse sound field

$= \frac{\sin(kx)}{kx}$

k = wave number [1/m]

$= \frac{2\pi \cdot f}{c}$

f = Centre frequency of 1/3 octave band [Hz]

c = speed of sound in the air [m/s]

x_{ij} = actual distance between the i´th and the j´th discrete microphone position [m]

Calculations have been carried out for five positions with a mutual distance between all positions of 0.4 m, 0.7 m, 1.0 m and 1.5 m, respectively. Furthermore calculations have been carried out for ten positions with a mutual distance of 0.4 m. The result of the calculations in the frequency range 50-500 Hz is shown in figure 4.8.

According to ISO 140 Part 4 the minimum allowable distance between fixed microphone positions is 0.7 m and the minimum number of positions is five. From figure 4.8 it can be seen that five positions with a mutual distance of 0.7 m at 100 Hz correspond to 2.4 uncorrelated positions. (The same distance between all positions has been assumed to facilitate the calculations. Of course this cannot be achieved precisely in practice.)

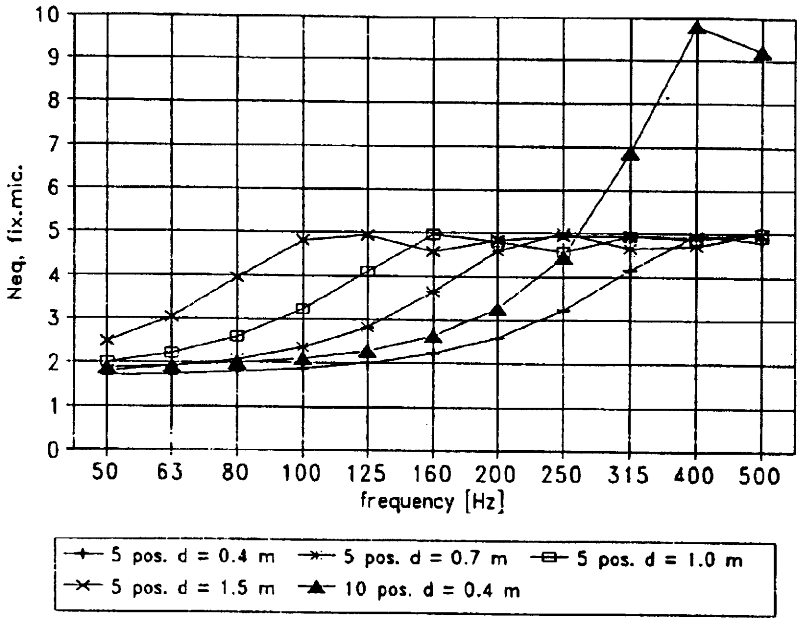


Figure 4.8. Number of uncorrelated microphone positions as a function of the frequency and the mutual distance between the actual number of fixed positions (d).

4.4.3. Test object

The test object is defined as the part of the partition wall common to source and receiving room.

The test object can be equivalated with a number of uncorrelated point sources by the following equation, ref. [1]:

$$N_{eq,testobject.} = 1 + \left(\frac{\sqrt{S}}{\lambda/2}\right)^2 \qquad (4.11)$$

where S = surface area of test object [m^2]
λ = wavelength [m]

In figure 4.9 is shown the equivalent number of point sources as a function of the frequency and the area of a test object.

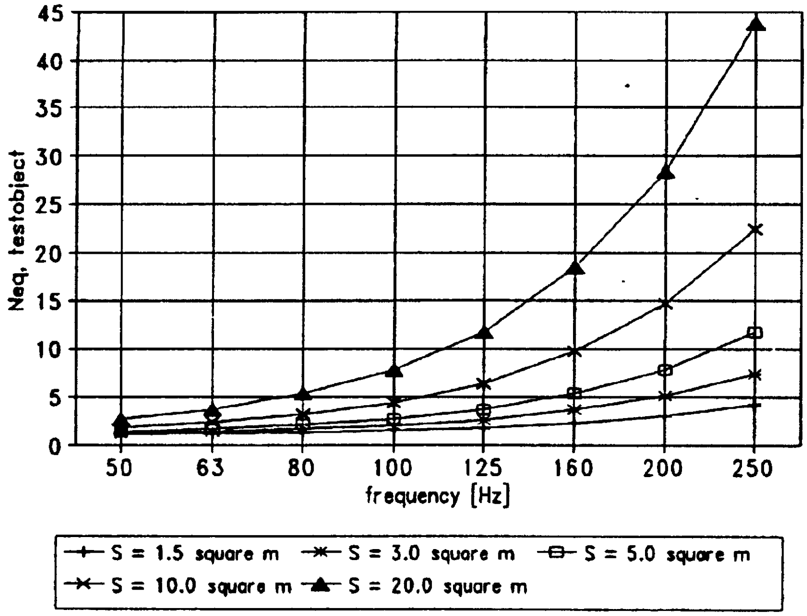


Figure 4.9 Equivalent number of uncorrelated point sources corresponding to the area (S) of a test object as a function of the frequency.

To investigate the validity of equation 4.11 an experiment was carried out in two adjacent rooms with the volumes of 69 m^3 and 102 m^3. The common partition wall (the test object) is made of solid bricks and the area is 13 m^2. The rooms were furnished.

In the 69 m^3-room a loudspeaker was placed close to the wall opposite the test object and another loudspeaker was placed in the 102 m^3-room. The sound pressure level was measured in ten microphone positions in the 102 m^3- room with the two loudspeakers successively. When the loudspeaker in the 69 m^3-room is used the test object is excited and acts as sound source. The standard deviation of the sound pressure level in the ten positions has been calculated for both measurements. The complete experiment was repeated for the opposite measuring direction.

The results are shown in figure 4.10. If the theory of equivalating the wall with a number of uncorrelated point sources is valid it should be expected that the standard deviation of the ten measurements should decrease when the wall is radiating the sound into the rooms compared with the results where only one source position - the loudspeaker - has been used. Apart from the lowest frequencies in the measurement from the smaller to the bigger room, this effect does not clearly appear.

At medium and high frequencies where the equivalent number of uncorrelated point sources for the wall is high a considerable decrease in the standard deviation should be expected, but does not occur.

The results of this experiment indicate that in practice equation 4.11 may overestimate the number of equivalent point sources.

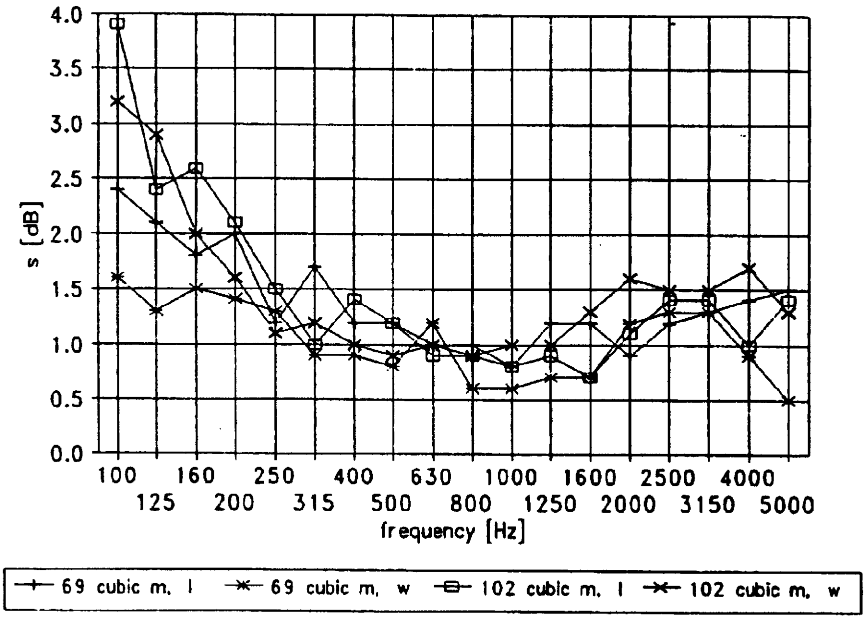


Figure 4.10. Standard deviation of the sound pressure level in ten microphone positions partly with a loudspeaker in one position as sound source (l), and partly with sound radiated from a 13 m² wall made of solid bricks (w).

4.4.4. Loudspeakers

Theoretically the loudspeaker positions can be assumed uncorrelated if the distance between them is greater than half a wavelength. At 100 Hz the minimum distance fulfilling this requirement is 1.7 m. Often two loudspeaker positions are used and - even in case of a small source room - it will normally be possible to place the loudspeaker in positions separated at least approximately 1.7 m. Therefore consideration concerning the equivalent number of uncorrelated loudspeaker positions has been omitted. It shall be mentioned that experimental results in ref. [7] show that even at a distance between loudspeaker positions of a quarter of a wavelength the positions can be considered approximately uncorrelated in a fairly reverberant room.

To investigate if the number of loudspeaker positions should be varied depending on the size of the rooms a statistical evaluation has been carried out on measurement results from routine field measurements carried out by the Danish Technological Institute (DTI).

The standard test procedure used by DTI includes two loudspeaker position and a rotating microphone in the source and receiving room, respectively. Source room level and receiving room level are measured simultaneously. For each loudspeaker position the level difference is determined separately. The paths of the two rotating microphones are not changed during the measurement.

Results from 45 field routine measurements carried out by DTI have been analyzed by calculating the difference between the measured sound pressure level difference for each of the two loudspeaker positions. Horizontal as well as vertical measurements have been included and the volumes of the rooms are in the range of 11 m^3 to 122 m^3. For some of the measurements the dimensions of the source and receiving rooms are identical; for others they are very different. Normally the larger room is used as source room. For horizontal measurements the loudspeakers are placed on the floor close to the corners opposite the test object. For vertical measurements the lower room is the source room and the loudspeaker positions are as far as possible chosen to be in the corners opposite the facade.

In figure 4.11 the following results are shown:

- The mean value of the difference between the sound pressure level difference measured with the two loudspeakers in the frequency range 100-3150 Hz for the 45 measurements. ("mean value").

- Values below which 50% of the results are lying. ("50% limit").

- Values below which 90% of the results are lying. ("90% limit").

- The maximum difference observed ("max. value").

It is seen that for 90% of the measurements the difference between the results obtained with the two loudspeakers is less than 3-6 dB at frequencies below 400 Hz and less than 3 dB at frequencies above 400 Hz.

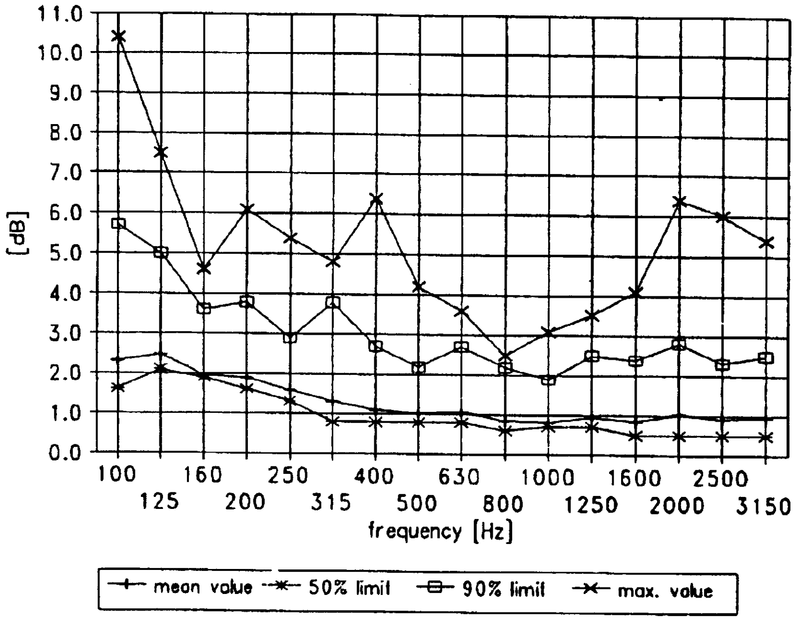


Figure 4.11. Difference between the sound pressure level difference obtained with two loudspeaker positions in 45 in-situ routine measurements.

To investigate the correlation between the volume of the source room and the difference between the sound pressure level difference measured with the two loudspeakers a linear regression analysis has been carried out. The coefficient of determination turns out to be less than 0.05 in the entire frequency range. In spite of the relatively limited statistical basis this result indicates that there is no significant correlation between the source room volume and the sound pressure level difference obtained from measurement with the two loudspeakers.

4.5. MINIMUM DISTANCE BETWEEN LOUDSPEAKER AND MICROPHONE POSITIONS

Near-field influence from the loudspeaker at any microphone position shall be avoided. The near-field influence depends on the room volume, the reverberation time and the radiation characteristic of the loudspeaker. By equation 4.12 the minimum distance from an omnidirectional loudspeaker where the influence from the near-field is negligible can be calculated. (3 times the reverberation distance):

$$d = 0.16 \sqrt{\frac{V}{T}} \text{ [m]} \tag{4.12}$$

where T = reverberation time [s]
V = room volume [m³]

Figure 4.12 shows calculation results of d as a function of the reverberation time and the room volume. If the loudspeaker is placed close to the room boundary - e.g. in a corner of the room - the required minimum distance estimated by equation 4.12 shall be increased by a factor 2-3. For loudspeakers which are not omnidirectional the distance must be increased further to avoid near-field influence.

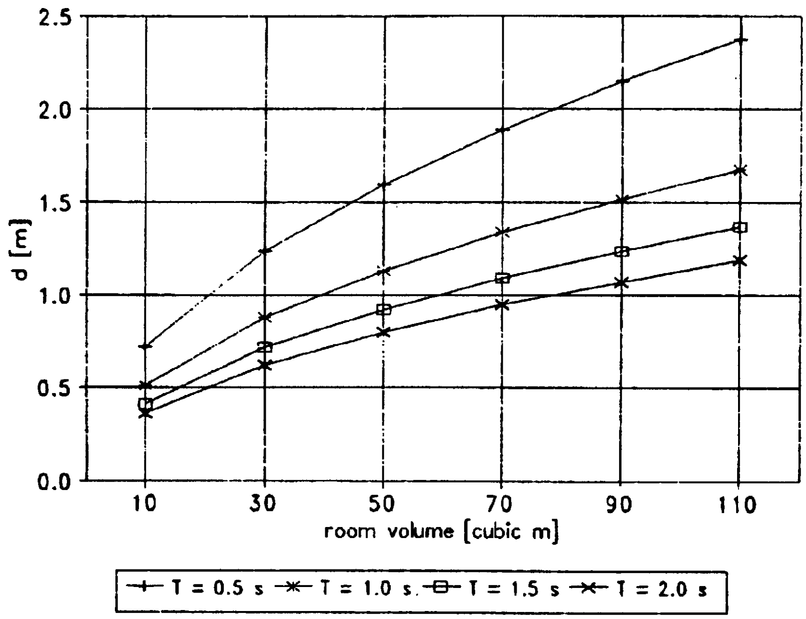


Figure 4.12. Minimum distance between an omnidirectional loudspeaker and a microphone position as a function of the reverberation time (T) and the room volume.

4.6. AVERAGING TIME

If errors due to time averaging shall be negligible compared with the position variance in the room the averaging time in each microphone position shall fulfil the following condition (ref. [2]):

$$t > 0.29 \cdot T + \frac{2}{B} \ [s] \qquad (4.13)$$

where T = reverberation time [s]
B = bandwidth of the filters [Hz] (0.23·f)
f = centrefrequency of 1/3 octave bands [Hz]

As the last term in the equation is small compared with the first one it can be derived from equation 4.13 that the averaging time in each frequency band shall be at least 3 times the reverberation time (~ 10 times 0.29 T). ISO 140 Part 4 prescribes an averaging time in each microphone position of at least 6 s at frequencies below 400 Hz and at least 4 s at higher frequencies.

4.7. SMALL ROOMS

In small rooms - typically bath rooms and entrance halls - with volumes in the range 8-15 m^3 the following problems occur causing considerable measurement inaccuracy especially at low frequencies:

- The modal overlap is small (the Schröder cut-off frequency typically 400-600 Hz).

- Room dimensions are so small that it is impossible to achieve a sufficient distance between individual microphone positions or a sufficient radius of a rotating microphone. From figure 4.7 in paragraph 4.4.1 it appears that a rotating microphone with a radius of e.g. 0.3-0.4 m corresponds to less than two uncorrelated microphone positions at 100 Hz. From figure 4.8 in paragraph 4.4.2 it appears that e.g. five fixed microphone positions with a mutual distance of 0.4 m also correspond to less than two uncorrelated positions at 100 Hz.

- It is difficult to achieve a sufficient distance between loudspeaker and microphone positions so near field influence is avoided. From figure 4.12 it can be seen that in a 10 m^3 room with a reverberation time of 0.5 s the minimum distance between loudspeakers and microphones shall be approximately 0.75 m to avoid near field influence. In small rooms it is necessary to place the loudspeakers close to the corners. This means that the minimum distance estimated according to figure 4.12 should at least be doubled.

- Often it is impossible to achieve sufficient distance between the loudspeaker positions.

It can be estimated that if the measurement accuracy of the mean sound pressure level in e.g. a 10 m^3-room and a 100 m^3- room shall be of the same magnitude at low frequencies, the number of uncorrelated microphone positions in the 10 m^3-room shall be increased with approximately a factor 10 compared with the number used in the 100 m^3-room.

The increase in the position variance of the sound pressure level in small rooms with volumes of 8-15 m^3 might imply that the number of loudspeaker and/or microphone positions should be increased to achieve a measurement accuracy of the mean value comparable to that obtained in bigger rooms. However, the small room volume makes it impossible to fulfil the requirements to minimum distances stated in ISO 140 Part 4. Furthermore, the number of positions required, if the measurement accuracy shall be improved considerably will be so high that the guidelines will be inapplicable for ıtine measurements. Therefore it is suggested that it generally is accepted that the measurement accuracy is decreased in small rooms in which the ISO 140-procedure cannot be fulfilled.

Especially the use of a rotating microphone is problematic if the minimum radius and the minimum distance to the room boundaries shall be fulfilled.

4.8. DAMPED ROOMS

In typical living rooms with volumes of 50-100 m^3 the sound field normally can be regarded as approximately diffuse provided that the room surfaces are made of normal building materials such as plasterboard, bricks, concrete and wood. Even if the floor is covered with a carpet, the measurement conditions still normally will be sufficiently good. This means that averaging the sound field by measuring in several microphone positions distributed in the room will give a fairly good mean value of the sound pressure level for the determination of the sound reduction index.

ıne equation used for calculating the sound reduction index assumes that the incident sound power on the test object and the total sound power radiated into the receiving room are determined from averaging the sound pressure levels in a diffuse field in source room and receiving room, respectively. Under ideal conditions the purpose of the averaging is just to reduce the influence on the measurement result of unavoidable random variations in the sound field.

However, in rooms with high absorption as e.g. furnished living rooms, offices, classrooms, auditoria, corridors and industrial halls the sound pressure level often decreases considerably with increasing distance to the sound source. This phenomenon causes measurement problems, especially in big rooms or rooms where the width of the room is small compared to the length. In such rooms a correct estimate of the incident and radiated sound power is not possible.

In the free-field region close to a sound source the sound pressure level will decrease by 6 dB per doubling of the distance to the sound source. In the diffuse-field region no systematic decrease in the sound pressure level far away from the loudspeaker will occur if the distance to the sound source is increased. In strongly damped rooms the decay rate of the sound pressure level far away from the loudspeaker can typically be 3-4 dB per doubling of the distance from the source.

To get an impression of the magnitude of the sound decay rate in damped and non-damped rooms with different shapes, a few calculations of the sound pressure level distribution have been carried out by use of the computer programme "Odeon" developed by the Acoustical Laboratory at the Technical University in Denmark. The size of the rooms in the calculations have been chosen corresponding to "big living rooms". The calculation results are presented in Annex B. From the calculation examples it is seen that with high absorption of ceiling and floor a considerable decay of the sound pressure level occurs.

In ISO 140 Part 4 it is stated that the microphone positions shall be distributed within the maximum permitted space throughout the room, taken in the room space uniformly. ISO 140 Part 4 assumes diffuse sound fields and nothing is stated explicit concerning loudspeaker and microphone positions in damped rooms.

If a logarithmic averaging of the sound pressure level in positions spread over the entire volume is used in a big damped receiving room, the positions in the part of the room closest to the test object will dominate the average value. This average value, however, equals to some extent the average sound pressure level in "the same room" determined under diffuse field conditions. Consequently, averaging over the entire volume in damped receiving rooms leads to a fairly good approximation of the sound power radiated into the room.

In the source room the problems are different. From the average sound pressure level the incident sound power on the test object is determined. In big, damped rooms averaging over the entire room volume often will lead to considerable errors. This can be illustrated by an example:

The sound insulation is measured horizontal between two rooms. The source room is big, with a highly absorbing ceiling and floor and the width of the room is assumed much less than the length (e.g. the corridor in example 1, Annex B.3). Loudspeaker positions are chosen close to the corners at the back wall of the room opposite the test object, which is assumed to be the wall designated "2,50 m" in Annex B.3. The sound pressure level is measured in positions distributed evenly in the total room volume, which means that the sound pressure level measured at the positions close to the loudspeaker will be dominating the average sound pressure level. In example 1, Annex B.3, the mean sound pressure level averaged over the entire room volume is estimated to be 7 dB higher than the sound pressure level in the part of the room close to the test object. It appears from this example that averaging over the total volume in big, damped source rooms leads to a bad estimate of the incident sound power on the test object.

If the flanking transmission between the rooms in the example is considerable, another problem arises. Because of the loudspeaker positions far away from the test object and at the same time close to the flanking walls, the excitation of these will be high compared with the excitation of the test object. In the extreme situation, exclusively the flanking transmission will be determined based on near-field influence from the loudspeaker and the contribution of the sound transmitted directly through the test object will have an unrealisticly low influence on the measurement result.

In the extreme situation where the source room can be approximated with free-field conditions, the measured sound reduction index will be different for each angle of incidence of sound upon the test object. Especially at frequencies in the coincidence region the results are expected to be too high compared with results from diffuse-field measurements. (Incident sound parallel to the test object is reduced under free-field conditions.)

As a consequence of the consideration above it might be a possibility to improve the measurement conditions in big source rooms by moving the loudspeaker positions towards the test object. Averaging in a limited part of the room not too far away from the test object will reduce the error because of the spatial sound decay in the room, and furthermore ensure an equal weighting of the incident sound power on the test object and the flanking walls, respectively.

In very damped rooms which imply free-field conditions, measurements should not be carried out according to the ISO 140 procedures. The intensity measurement technique is a suitable alternative for the determination of the sound power radiated into the receiving room. (Nordtest Method NT ACOU 084 can be used.)

For vertical measurements between damped rooms, the problems are not so serious because the sound pressure level decay in vertical direction is limited to a distance equal to the height of the rooms.

4.9. BIG ROOMS AND ROOMS WITH NON-REGULAR SHAPE

When measuring the sound insulation between regular box-shaped rooms with typical living room size, not too different in size and not too "staggered", the selection of loudspeaker and microphone numbers and positions does not normally cause particular problems. However, in case of big rooms, staggered rooms or rooms with non-regular shapes, it often can be rather difficult to choose a suitable measurement set-up. Non-regular room shapes are frequently seen in modern dwellings.

The question can typically be if the minimum number of loudspeaker and microphone positions stated in ISO 140 Part 4 shall be increased in big rooms, and where to place the loudspeaker and the microphones in a room with non-regular shape e.g. an angular shaped room, a room partly divided by a wall or a very long, narrow room. A detailed theoretical or experimental investigation of the measurement accuracy in such rooms is extremely complicated and in excess of the scope of this project. Principles for the choice of suitable measurement set-ups in non-regular rooms have therefore been worked out partly based on the consideration and results in the previous chapters and partly on practical experience.

Some typical non-regular shaped room configurations are shown in Annex C. The loudspeaker and microphone positions indicated in Annex C are described in chapter 4.14.

4.10. DETERMINATION OF ROOM VOLUME AND AREA OF THE TEST OBJECT

In regular box-shaped rooms without any fixtures the determination of the volume of the receiving room and the area of the test object is self-evident. However, in rooms such as kitchens, sculleries and bathrooms with fixtures like cabinets, wardrobes and installation shafts the calculation of volume and area require some attention.

The problem is to decide whether fixtures can be neglected or not. Figure 4.13 shows calculation results of the error introduced on the sound reduction index measurement, as a function of the ratio in percentages between two room volumes or two test object areas. If e.g the volume used in the calculation is 10% too big because the volume of the fixtures has not been subtracted, the measurement result will be 0.5 dB too low. If a reduced test object area is used in the calculation e.g. because fixed cabinets are covering a part of the wall, the measurement result will be lower than the result obtained if the entire wall area is used.

In a minor kitchen with a volume of 35 m^3 the cabinets etc. will often reduce the total room volume with 5-6 m^3. If the total volume is used in the calculation the error will be approximately 1 dB.

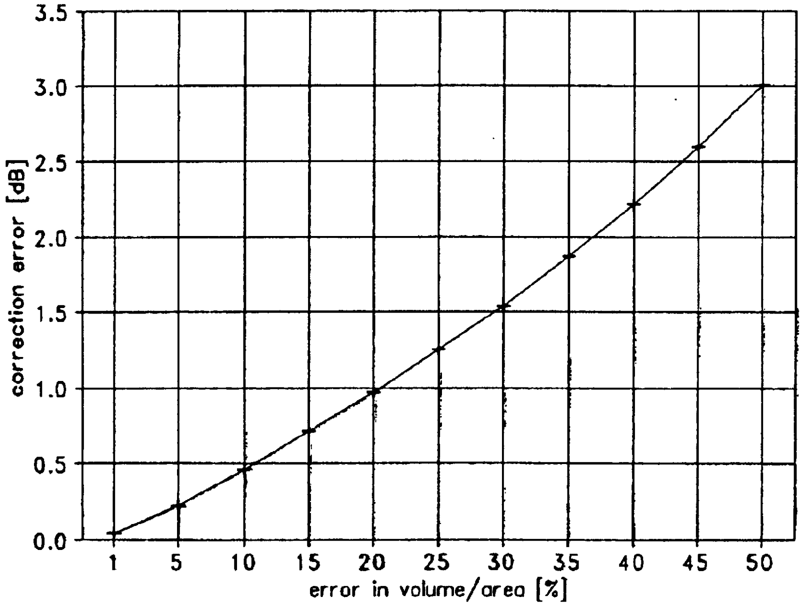


Figure 4.13. Measurement error as a function of error in room volume or test object area expressed in percentages.

For a room to some extent separated by a wall it often can be difficult to decide if the room shall be regarded as one or two volumes. This type of rooms typically will be a combined living room and kitchen where the kitchen section is partly separated from the living room by a wall.

In special cases it can be almost impossible to define the room volumes to be used for the measurements. This is e.g. the situation where two or three rooms with complicated ground planes are situated on displaced storeys and more or less coupled together by openings for stairs etc.

4.11. REVERBERATION TIME

For the determination of the sound reduction index the reverberation time in the receiving room shall be determined.

In ISO 140 Part 4 the requirements concerning measurement of the reverberation time are based on ISO 354, in which it is prescribed that as a minimum three microphone positions shall be used. At frequencies below 300 Hz at least two loudspeaker positions are required. The minimum number of measurements required for each frequency band is twelve decays at frequencies from 100-250 Hz, nine decays from 315-800 Hz and six decays from 1000-5000 Hz.

In ISO 140 Part 4 the requirements in ISO 354 have been somewhat modified and it is required that at least one loudspeaker position and three microphone positions with two excitations in each position shall be used. The six readings can alternatively be taken on a rotating microphone path with a traverse time not less than 30 s.

To asses the accuracy of the reverberation time measurement according to ISO 140 Part 4 a comparison between the spatial standard deviation of the sound pressure level and the reverberation time has been estimated from measurements in room 2, described in table 4.1, chapter 4.2.2. The sound pressure level as well as the reverberation time were measured in the same ten microphone positions (five for each of the two loudspeaker positions). In each microphone position two reverberation decays were taken. The standard deviation of the reverberation time measurement has been approximated in decibels (10log(T)) by means of equation 4.7.

Figure 4.14 shows the measurement result. It appears that at frequencies below 500 Hz the standard deviation of the reverberation time measurement is much less than the standard deviation of the sound pressure level measurement. At 500 Hz and higher frequencies the difference between the standard deviations is decreased considerably, but still inaccuracy due to the sound pressure level measurement is predominant. From figure 4.14 the standard deviations of the sound pressure level difference and the reverberation time, respectively, have been estimated based on the number of microphone positions used in a realistic measurement situation. This does not cause essential change in the ratio between the two standard deviations.

Thus the results in figure 4.14 indicate that the modification of ISO 354 requirements used in ISO 140 Part 4 is reasonable, and the inaccuracy due to the reverberation time measurement is normally small compared with the inaccuracy of the sound pressure level measurements.

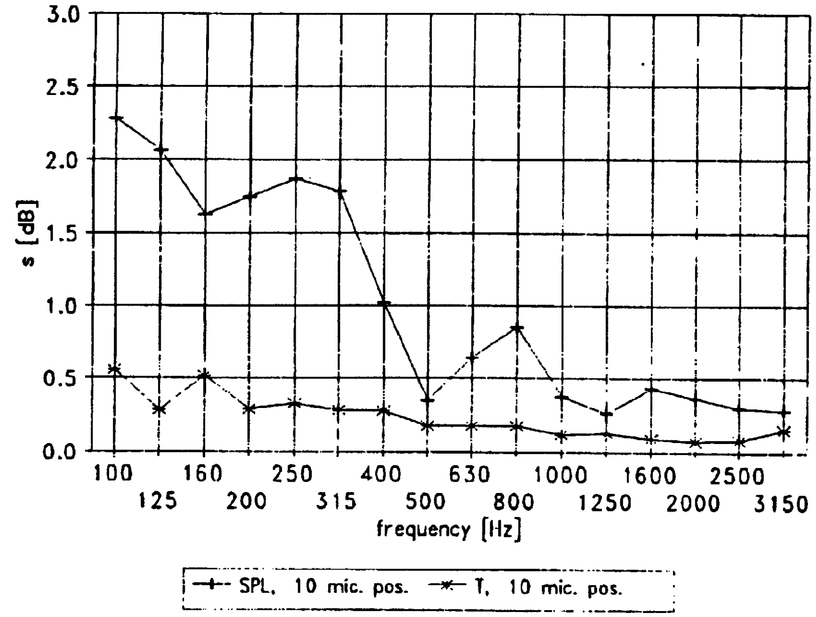


Figure 4.14 Spatial standard deviation of the sound pressure level and the reverberation time measured in ten positions in a 65 m³ room. Two excitations in each position for the reverberation time measurement.

4.12. SUMMARY OF REQUIREMENTS IN ISO 140 PART 4 CONCERNING LOUDSPEAKER- AND MICROPHONE POSITIONS

Summary of the requirements in ISO 140 Part 4 concerning number and position of sound source and microphones:

- One loudspeaker may be moved from position to position or several loudspeakers may be operating simultaneously provided that they are driven by uncorrelated noise generators and different power amplifiers.

- At least two loudspeaker positions shall be used.

- The distance between different loudspeaker positions shall be not less than 0.7 m. At least two positions must be situated not less than 1.4 m from each other.

- The distance between room boundaries and the loudspeaker shall be not less than 0.5 m. Small irregularities of the room boundaries may be neglected.

- Different loudspeaker positions may not be situated within the same planes parallel to the room boundaries.

- Especially in small rooms often it is an advantage for the practical execution of the measurement to use loudspeaker positions in the corners of the source room. Special care must be taken in regard to possible influence on the flanking transmission and in regard to unwanted increase of level fluctuations in the source room.

- If the rooms are of different volumes the larger one should be chosen as source room when the standardized level difference is to be evaluated and no contradictory procedure is agreed upon.

- In order to evaluate the apparent sound reduction index the loudspeaker positions may be in the same room or the measurement may be repeated in the opposite direction by changing source and receiving rooms with one or more positions in each room.

- The loudspeaker should be placed so as to give a sound field as diffuse as possible and at such a distance from the partition element and the flanking elements influencing the sound transmission, that the direct radiation on these is not dominant.

- The average sound pressure level can be obtained by using a single microphone moved from position to position, by an array of fixed microphones, by a continuously moving microphone or by swinging a microphone. The sound pressure level at the different microphone positions shall be averaged on an energy basis for all sound source positions.

- As a minimum five microphone positions shall be used being distributed within the maximum permitted space throughout each room taken in the room space uniformly.

- When using a moving microphone the sweep radius shall be not less than 0.7 m. The plane of the traverse shall be inclined in order to cover a large proportion of the permitted room space and shall not lie in any plane within 10° of a room surface. The duration of a traverse period shall be not less than 15 s.

- The following separation distances are minimum values and should be exceeded where possible:

  0.7 m between microphone positions.

  0.5 m between any microphone position and room boundaries or diffusers.

  1.0 m between any microphone position and the sound source.

- It must be ensured that the microphone positions are outside the direct sound field of the source. Each fixed microphone position shall lie outside the region in which levels increase significantly with distance from the source. For a moving microphone, no significant level increase shall occur when the path comes close to the source.

4.13. PRINCIPLES OF ADDITIONAL GUIDELINES

The combinations of source and receiving rooms with different volumes, absorption and shape are infinite. Because of that it is impossible to prepare specific guidelines concerning the number and position of loudspeakers and microphones covering every individual case. Consequently, it has been decided to show the principles of the proposed positions on diagrammatic sketches of typical as well as special room configurations. Efforts have been made to select examples from which it should be possible to derive a suitable measurement set-up for practically any measurement situation.

In addition to the examples a simple method for evaluation of the sound field in source and receiving room is proposed. The principle of the method is based on an experimental estimate of the spatial standard deviation of the sound pressure level in the room. The sound pressure level is measured in ten microphone positions and the standard deviation is compared with a theoretical value calculated by equations 4.5 and 4.6. Reverberation time estimates used in the calculation have been taken from Annex A. Near-field influence from the loudspeaker has been considered small. The theoretical results have been corrected to take into account the limited number of samples of 10.

The evaluation procedure may be used whenever incomprehensible measurement results appear or previous to a measurement where non-diffuse sound fields are expected to cause problems. Based on the result of the evaluation procedure it may be decided to use additional loudspeaker and microphone positions.

4.14. ADDITIONAL GUIDELINES - AIRBORNE SOUND INSULATION

Basic standard: ISO 140 Part 4, "Field measurements of airborne sound insulation between rooms" (Committee draft of 11. May 1992)

The complete basic standard should be studied carefully previous to implementation of the additional guidelines in the measurement procedure. The additional guidelines are closely related to the basic standard and should never be used as a solitary document.

In measurement situations with a big and damped source room, a discrepancy might be observed between results obtained according to the additional guidelines and the basic standard, respectively.

The guidelines primarily are applicable for measurements in the frequency range 100-3150 Hz in empty rooms with volumes not exceeding 250 m^3. However, the guidelines may also be useful for measurements between rooms not fulfilling these limitations.

4.14.1. Loudspeaker positions

The part of the separating partition common to both source and receiving room is named the "test object". The total surface of the separating partition is named the "partition wall" for horizontal measurements and "partition" for vertical measurements (see Annex C.18, definition). The symbols used in the diagrammatic sketches are defined in Annex C.2.

General:

- Preferably measurements are carried out in one direction only and the largest room is chosen to be the source room. If one of the rooms is regular with a well-defined volume, while the other has a complicated geometry, the well-defined room should be used as receiving room, even if it is the larger of the two rooms. For vertical measurements the lower room should preferably be used as the source room.

  Note: According to ISO 140 alternatively two measurements can be carried out in opposite directions and finally be averaged. However, measurements in two directions are quite time-consuming because two complete measurement set-ups shall be established and the reverberation time must be measured twice.

  The upper room may be the source room in vertical measurements provided that an omnidirectional loudspeaker is used - situated at a sufficient distance above the floor to prevent incidence of direct sound.

- Two loudspeaker positions are used in regular shaped rooms with floor areas up to 100 m^2. In rooms with floor areas exceeding 100 m^2 and in irregular rooms 3-4 positions are chosen depending on the size of the room and the degree of irregularity.

Horizontal measurements:

- The loudspeaker positions are normally chosen as close as possible, regarding the minimum distances stated in ISO 140 Part 4, to the two corners at the back wall of the source room opposite the test object.

- The loudspeakers should not be placed at a distance from the test object exceeding 10 m or 2.5 times the width of the partition wall in the source room. The criteria of the two giving the shortest distance shall be chosen. (See Annex C, examples 2 and 3).

- If the width of the test object is less than half the width of the partition wall in the source room, the distance between the loudspeaker positions should be reduced to approximately 2.5 times the width of the test object. (Relevant if the receiving room is much smaller than the source room or if the rooms are staggered). The positions shall be chosen in the area of the room closest to the test object. The distance should not be reduced to less than 5 m. (Loudspeaker positions on the symmetric lines of the room shall be avoided). (See Annex C, examples 4 and 5). If the rooms are completely staggered (no common partition) the distance between the loudspeakers should not be reduced. (See Annex C, example 6.)

- If a room is partly divided by a wall, a "rule-of-thumbs" can be that the room is considered as two individual rooms if the area of the opening is equal to or less than 1/3 of the total area of the vertical section of the room in the plane containing the dividing wall. Examples 9-13 show proposals for loudspeaker positions in rooms partly divided by a wall. If the room is considered as one room volume the loudspeaker positions shall be situated to "cover" the entire test object area as complete as possible. (Preferably the entire test object shall be visible from both loudspeaker positions). The principles above are also applicable to room-dividing walls with a height less than the height of the room. (In situations where source and/or receiving room is considered as two rooms only an example of a measurement set-up for one of the possible measurements is given in Annex C.)

  In some situations the principles above must be modified in the source room. (See e.g. Annex C, example 11.)

  Note - If practicable, an opening between two coupled rooms should always be totally covered by plates of e.g. plywood or gypsum board to achieve well-defined volumes.

<u>Vertical measurements</u>:

(The lower room is assumed to be the source room.)

- The loudspeaker positions are chosen as close as possible, regarding the minimum distances stated in ISO 140 Part 4, to the corners opposite the facade.

- If the receiving room is smaller than the source room or the rooms are staggered the loudspeakers should be situated in the part of the source room closest to the test object if the floor-area of the source room exceeds 50 m^2. For measurements between staggered rooms the loudspeakers should not be placed closer to the end wall (see definition, Annex C.18) of the source room than 2.5 times the width of the source room or 10 m. The criteria of the two giving the shortest distance should be used. (See Annex C, examples 17, 21 and 23.)

- If one or both rooms are partly divided by a wall the same principles as mentioned in connection with horizontal measurements shall be used. (See Annex C, examples 26-28.)

<u>Measurements on doors</u>:

- For doors mounted between two regular rooms e.g. hotel rooms or class rooms the guidelines stated above can be used.

- Measurement on doors mounted between a corridor or a staircase and an entrance hall should be carried out according to the Nordtest Method NT ACOU 069 "Doors in buildings: airborne sound insulation". Two loudspeaker positions shall be used for all measurements on doors. If no corners are available in a corridor two positions placed with a distance of approximately 6 m should be used. To avoid symmetry the positions should be displaced so one position is situated e.g. 2.5 m to the right of the door and the other 3.5 m to the left. (See Annex C, example 14.)

In narrow staircases without suitable corners the two loudspeakers are preferably placed half a storey up and half a storey down, respectively, either on the stairflight or on a landing.

4.14.2. Microphone positions

In the following it is assumed that either fixed microphones or a rotating microphone are used. Proposals of suitable microphone positions are shown in Annex C.

The recommended number of microphone positions in the source and receiving room is stated in table 4.2.

		Number of loudspeaker and microphone positions		
Measurement set-up	Floor area of the room, m^2	Loudspeakers	Fixed microphones	Rotating microphones
1	< 50	2	5 (10)	1 (2)
2	50-100	2	10 (10)	2 (2)
3	> 100	3	15 (15)	3 (3)

Table 4.2. Number of microphone and loudspeaker positions depending on the floor area of the source or receiving room. The numbers in brackets are the total number of sound pressure level measurements to be carried out in the room.

Comments to table 4.2:

If the floor area is less than 50 m^2 and the distance between the loudspeakers is at least 1.4 m the same five microphone positions or the same path of a rotating microphone can be used for both loudspeakers (measurement set-up no 1). If the requirements in ISO 140 Part 4 concerning the distance between loudspeaker positions cannot be fulfilled, measurement set-up no 2 should be used.

If the floor area is in the range 50-100 m² the same five fixed microphone positions or the same position of the rotating microphone should not be used for both loudspeakers. This means that a total of ten fixed microphone positions or two positions of a rotating microphone is required. (Measurement set-up no. 2.)

Measurement set-up no 2 should, if suitable, also be used if the shape of the room is non-regular or if the room is partly divided by a wall, but considered as one room.

Note - To achieve the highest obtainable accuracy under all measurement conditions it should be considered generally to use measurement set-up no 2, also for rooms with volumes less than 50 m².

If the floor area exceeds 100 m² it is recommended to use three loudspeaker positions, 15 fixed microphone positions or alternatively three positions of a rotating microphone.

It is assumed that the height of the rooms covered by table 4.2 is in the range pproximately 2.3-3.5 m. In rooms with a height exceeding 3.5 m it should be considered to increase the number of loudspeaker and microphone positions given in the table.

In the source room the microphone positions are distributed evenly in the volume of the room defined as the source room (see chapter 4.14.1.). If a limited source room volume is used the floor area corresponding to this volume shall be used when selecting the number of positions from table 4.2.

In the receiving room fixed microphone positions shall be evenly distributed over the entire volume and in case of a rotating microphone the position shall be chosen to cover the entire room volume as far as possible. If the receiving room is partly divided by a wall the method described in chapter 4.14.1 is used to decide whether the room shall be considered as one room or two rooms. In some situations, e.g. in very damped rooms, the screening effect of the room-dividing wall can be essential. In such situations the receiving room volume should be decreased. As a guideline a criterion may be that parts of the receiving room is omitted where the sound pressure level is 6 dB or more below the level in the part of the room closest to the test object. This criterion is also used in situations where the height of the room-dividing wall is less than the height of the room. (A limitation of the volume might be relevant in a receiving room as shown in Annex C, example 10.)

In small rooms with volumes less than 10 m³ a maximum number of uncorrelated microphone positions are obtained by the use of fixed microphone positions.

The height above floor level of the different microphone positions shall be varied within the permitted volume.

For measurements on doors the microphone positions shall be dispersed as much as possible on the landing or in case of measuring from a corridor at distances not exceeding approximately 3 m at both sides of the door. (See Annex C, example 14.)

4.14.3. Diffuse-field evaluation procedure

This procedure may be used for evaluation of incomprehensible measurement results or previous to measurements whenever non-diffuse sound fields are expected to cause problems.

The sound pressure level is measured in ten fixed microphone positions by means of two loudspeakers (five microphone positions for each loudspeaker). In the source room the position of the two loudspeakers should be chosen equal to those used for the sound insulation measurement. In the receiving room the measurement can be carried out by means of two loudspeakers or by sound radiated from the building structures when the loudspeakers in the source room are in operation. The microphone positions shall be carefully distributed evenly in the total room volume.

The sample standard deviation of the ten measurements is determined and compared with the theoretical expected values in figure 4.15. (The curves are showing the upper limit of the 90% confidence interval of the standard deviation). Numerical values are given in Annex D.1.

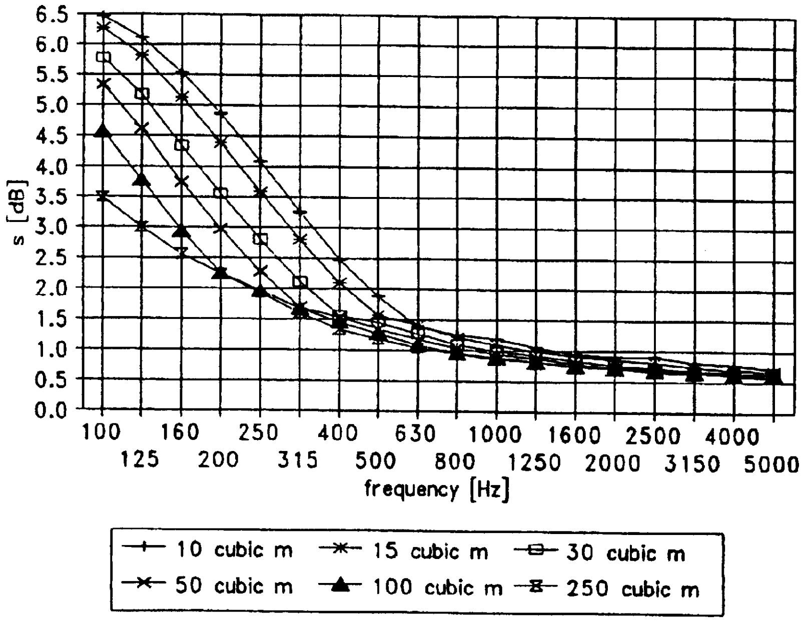


Figure 4.15. Theoretical values of the spatial standard deviation of the sound pressure level measured in ten microphone positions in empty rooms with different volumes. Near-field influence from the loudspeaker has been considered negligible.

If the theoretical values are exceeded the following should be considered:

- If excess is observed at low frequencies the reason may be that "unfavourable" loudspeaker positions have been chosen. Therefore the measurement should be repeated with new loudspeaker positions. If this does not cause any improvement it should be considered to increase the number of loudspeaker/microphone positions.

- The limits have been determined for empty rooms with a reverberation time estimated from the results in Annex A. In rooms with a reverberation time which is shorter than in empty rooms - e.g rooms with an absorbing ceiling - the spatial standard deviation will increase and the theoretical values may be exceeded, especially at higher frequencies.

- In the mid and high frequency range excess of the limits may be caused by a spatial sound pressure level decay in damped rooms. This can easily be checked by a systematic measurement of the sound pressure level at different positions in the room on a line perpendicular to the test object in the receiving room, or in positions with increasing distance to the loudspeaker in the source room. If a considerable sound level decay appears, additional loudspeaker and microphone positions should be used.

- Especially in small, damped rooms influence from the near field of the loudspeaker is a risk. If this turns out to be the reason the microphone positions must if possible be moved further away from the loudspeaker. (The near-field influence is considered negligible in figure 4.15.)

- In a room partly divided by a wall the limits can be exceeded because the dividing wall acts as a sound screen in some of the microphone positions.

4.14.4. Extremely complicated room configurations

No detailed guidelines can be stated for measurements between rooms with extremely complicated room geometry. As an example can be mentioned measurement between open-planned, split-level dwellings each consisting of several more or less coupled rooms. In such situations it can be almost impossible to state the volume of the receiving room and the test object area. Furthermore selection of loudspeaker and microphone positions often is very difficult.

A principal rule in such situations can be that the loudspeakers shall be placed in the part of the dwelling closest to what has been defined to be the test object. Often 3-4 loudspeaker positions are required. In the receiving room averaging shall take place in the entire available volume. The receiving room volume should be limited according to the 6 dB-rule described in chapter 4.14.2.

4.14.5. Calculation of room volume and area of the test object

The volume of objects with closed non-absorbing surfaces, such as wardrobes, cabinets and installation shafts, shall be subtracted from the total volume of the receiving room.

The total area of the test object shall be used when calculating the sound reduction index. The area shall not be reduced if fixed cabinets, wardrobes etc. are covering a part of the test object.

4.14.6. Measurement of reverberation time

Measurement of the reverberation time in the receiving room is carried out as prescribed in ISO 140 Part 4. At least three microphone positions and one loudspeaker position shall be used with two excitations in each position. Alternatively, measurements can be carried out in six microphone positions with one excitation in each position. If a rotating microphone is used the measurements may be carried out while the microphone boom is rotating, provided that the measurement positions are evenly distributed over the path.

For field measurements a sound pressure level decay of 20 dB should preferably be used.

Normally the position of the loudspeaker is uncritical. A suitable position is close to a corner of the room. In a room partly separated by a wall where the absorption is different in the two parts of the room the reverberation time should be measured according to the above mentioned procedure in both parts. If the coupled rooms are considered to be one room, the mean value of these measurements shall be used in the calculation of the sound reduction index.

In rooms with floor areas exceeding 50 m^2 two loudspeaker positions and six fixed microphone positions or two positions of a rotating microphone should preferably be used. (12 fixed microphone positions if only one excitation in each position.)

5. IMPACT SOUND INSULATION

5.1. INTRODUCTION

A measurement of the impact sound insulation (the normalized impact sound pressure level) includes determination of the time and space average sound pressure level in the receiving room generated by a standardized tapping machine placed on the floor of the source room and the space average reverberation time in the receiving room.

The normalized impact sound pressure level is given by:

$$L_n = L_i + 10 \log \frac{A}{A_0} \text{ [dB]}$$
$$A = 0.163 \cdot \frac{V}{T} \tag{5.1}$$

where l_i = sound pressure level in the receiving room [dB]
A = equivalent absorption area of the receiving room [m^2]
A_0 = 10 [m^2]
V = volume of the receiving room [m^3]
T = reverberation time of the receiving room [s]

If the individual sources of errors are considered to be uncorrelated, the normalized variance of the impact sound pressure level can be estimated from:

$$\varepsilon^2(L_n) = \varepsilon^2(L_i) + \varepsilon^2(T) \tag{5.2}$$

where $\varepsilon^2(L_i)$ = normalized variance of the average impact sound pressure in the receiving room

$\varepsilon^2(T)$ = normalized variance of the average reverberation time

Determination of the impact sound pressure level according to equation 5.1 assumes a diffuse sound field in the receiving room. The consideration concerning the receiving room conditions presented in chapter 4 is valid for impact sound pressure level measurements too.

The variance of the sound pressure level in the receiving room due to different tapping machine positions depends on the size and mechanical properties of the floor, mounting and edge restraints, stiffness and internal damping. Because of this rather complicated combination of different parameters the position variance of the tapping machine can not be estimated in a simple theoretical way.

The following chapters 5.2-5.9 comprise consideration on the accuracy of impact sound insulation measurements. Chapter 5.10 contains a summary of ISO 140 Part 7. Basic aspects regarding preparation of additional guidelines are considered in chapter 5.11 and a proposal for additional guidelines is presented in chapter 5.12.

Standard deviations presented in this chapter calculated from measurement results are determined as the sample standard deviations.

5.2. FLOOR CONSTRUCTIONS

In this chapter a short description of typical floor-constructions shall be given.

Floor constructions can be divided into two main categories: isotrope and anisotrope floors.

The most common type of an isotrope floor-construction consists of solid reinforced concrete with a thickness of 120-250 mm, and a weight per m^2 of approximately 275-375 kg. Another type of solid concrete partition is constructed from elements of clinker concrete with a thickness of 180-220 mm and a weight per m^2 of 300-400 kg. (Clinker concrete elements are not pure isotrope constructions).

Typical anisotrope constructions are hollow concrete slabs or solid concrete slabs reinforced by beams or ribs. The weight per m^2 of such constructions are typically 300-350 kg. Another very common type of anisotrope construction is timber joist floors with a weight per m^2 of typically 40-150 kg.

5.3. FLOOR COVERINGS

The basic floor constructions described above are normally supplied with some kind of floor covering.

Concrete partitions are usually supplemented with boards/parquet on either joist or on a thin, soft underlayer. Clinker floors either directly on the partition or on a floating concrete slab on e.g. mineralwool is another very common floor construction.

In case of board or parquet floors on joists normally bricks of soft fibre board are placed between the joists and the concrete underlayer. Carpets, linoleum or different types of vinyl are the most common floor coverings.

The upper surface of timber joist floors often consists of boards without any supplementary covering. Alternatively the surface is made of a material - e.g. chip board - intended for an additional covering.

5.4. STAIRS

A stairway in an apartment house normally consists of a landing at each storey and often a supplementary landing between the storeys.

The landings are fixed directly to the walls of the staircase e.g. by means of soft interlayers between the fixtures and the wall. The stairflights can be fixed exclusively on the landings or in addition to the walls of the staircase.

Landings and stairflights in apartment houses are normally made of concrete while the most common material for internal stairs in dwellings is wood.

5.5. IMPACT SOUND INSULATION CHARACTERISTICS OF DIFFERENT FLOOR-CONSTRUCTIONS

The smallest position variance due to different tapping machine positions is normally obtained from a wooden floor on joists on a heavy isotrope concrete partition. Larger variations are seen for wooden floors on joists on clinker concrete partitions. Also floating clinker floors on concrete partitions show an increased position variance compared with wooden floors on joists, especially in the frequency range 100-500 Hz.

The position variance for anisotrope partitions generally is higher than for isotrope constructions. Especially for timber joist partitions this seems to be marked.

Nothing general can be stated concerning the position variance for measurement on stairs and landings. The variance very much depends on the type of construction and the degree of isolation from the building structures.

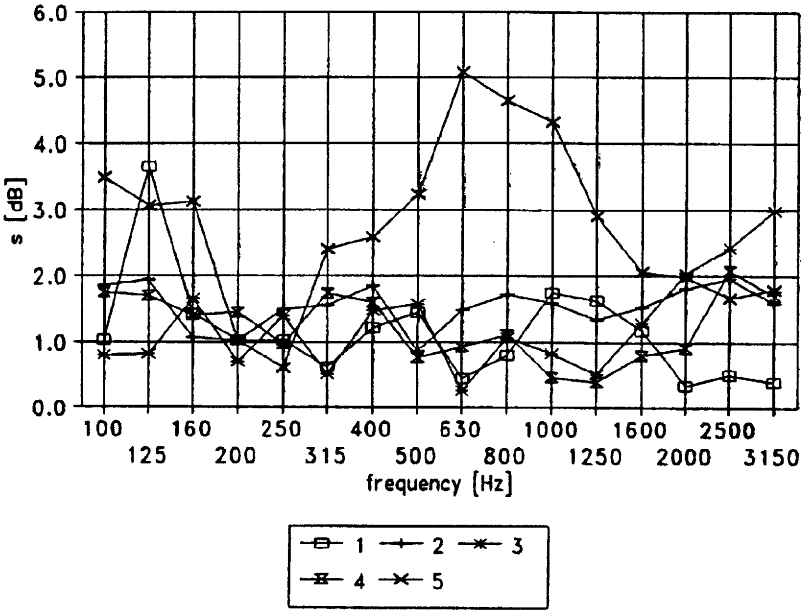
5.6. EXPERIMENTAL RESULTS

Based on results from routine measurements carried out by the Danish Technological Institute (DTI) and the Swedish National Testing and Research Institute (SP) calculations of the position variance (standard deviation) of the tapping machine placed on different floor constructions have been performed. The results are shown in the figures 5.1-5.6.

The DTI-measurements are carried out with four tapping machine positions distributed evenly over the total floor area. The averaging time in each position is 32 s. The sound pressure level is measured in the receiving room by means of a rotating microphone. The same path of the microphone is used for all tapping machine positions. This means that the calculated position variance exclusively is caused by the variation of the tapping machine position.

The SP-measurements are performed with five or six positions of the tapping machine. The averaging time in each position is 16 s. The sound pressure level in the receiving room is measured by means of a rotating microphone in the same position for all tapping machine positions.

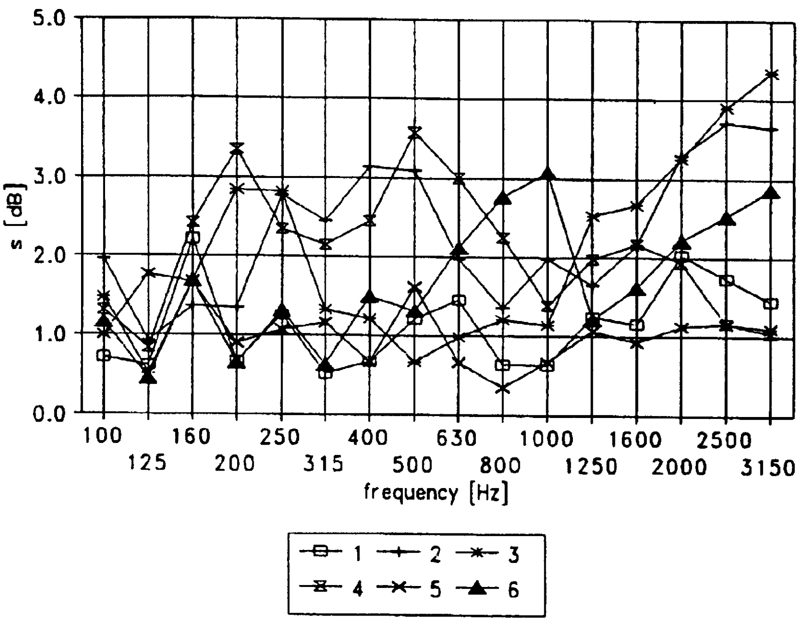
Unless otherwise stated the measurement have been carried out in vertical direction.



1. 150 mm solid concrete (60 m² / 53 m³)
2. 180 mm solid concrete (32 m² / 69 m³)
3. 220 mm hollow concrete (27 m² / 69 m³)
4. 220 mm hollow concrete (10 m² / 26 m³)
5. 200 mm solid concrete (34 m² / 85 m³)

1-4: Wooden floor on joists
5: Wooden floor on mineralwool (suspended ceiling in the receiving room)

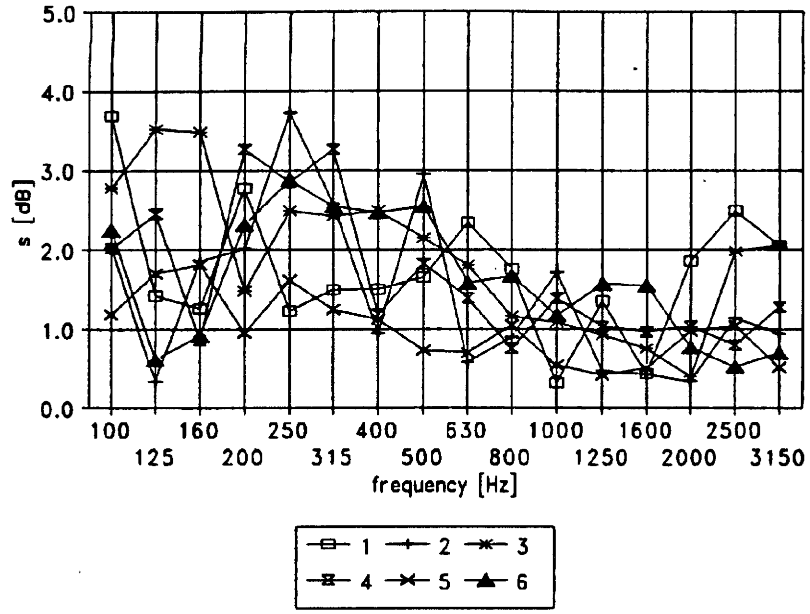
Figure 5.1. Standard deviation of four tapping machine positions on different wooden floors on solid reinforced concrete partitions and hollow concrete partitions. (The area of the floor and the volume of the receiving room, respectively, are stated in brackets).



1. 180 mm clinker concrete	(40 m^2 / 97 m^3)
2. 240 mm clinker concrete	(33 m^2 / 78 m^3)
3. 240 mm clinker concrete	(11 m^2 / 28 m^3)
4. 120 mm clinker concrete	(17 m^2 / 53 m^3)
5. 240 mm clinker concrete	(33 m^2 / 78 m^3)
6. 240 mm clinker concrete	(4 m^2 / 25 m^3)

1-3: Vertical measurements
4-6: Horizontal measurements

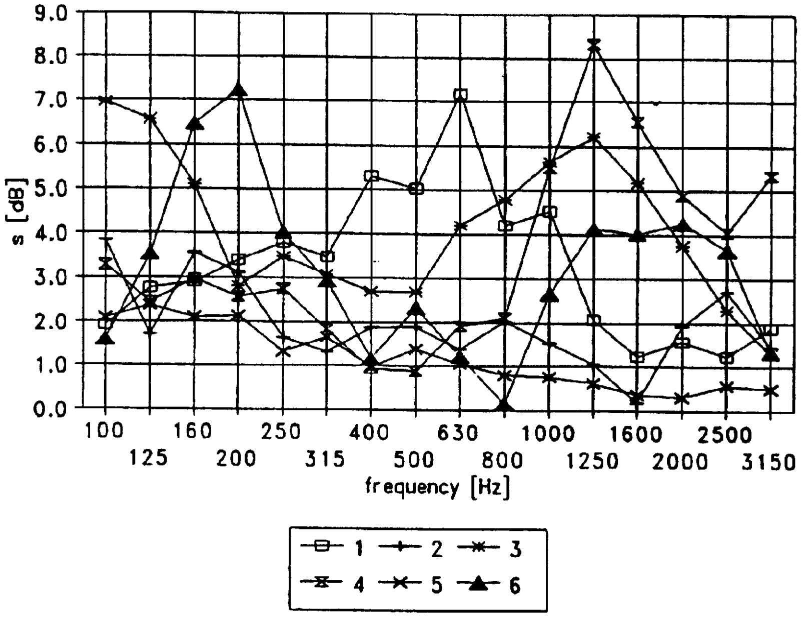
Figure 5.2. Standard deviation of four tapping machine positions on board/parquet floors on joists on clinker concrete partitions.



1. 180 mm clinker concrete (6 m² / 97 m³)
2. 200 mm clinker concrete (4 m² / 51 m³)
3. 220 mm hollow concrete (5 m² / 69 m³)
4. 220 mm hollow concrete (5 m² / 69 m³)
5. 180 mm clinker concrete (5 m² / 30 m³)
6. 180 mm clinker concrete (6 m² / 32 m³)

1-3: Vertical measurements
4-6: Horizontal measurements

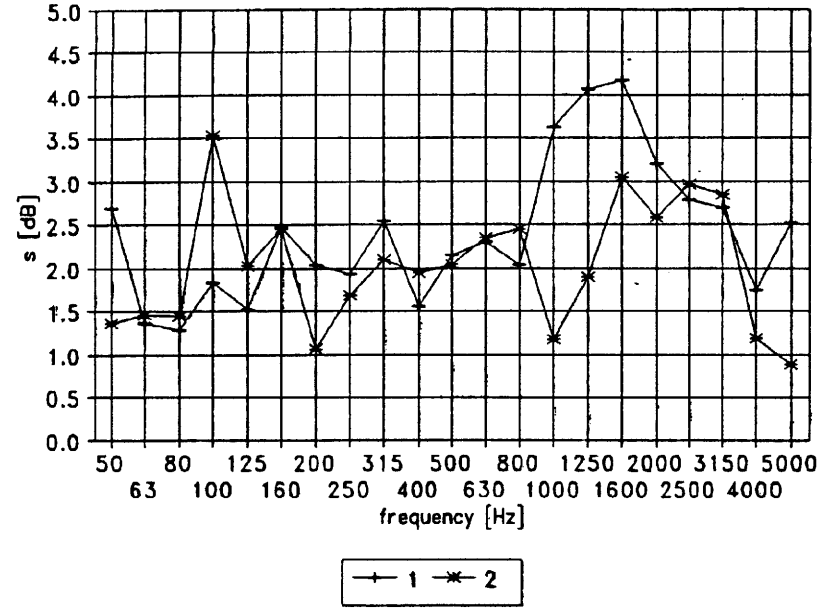
Figure 5.3. Standard deviation of four tapping machine positions on floating clinker floors on clinker and hollow concrete partitions, respectively.



1. Carpet and suspended ceiling (38 m² / 102 m³)
2. Boards (17 m² / 42 m³)
3. Linoleum (9 m² / 33 m³)
4. Boards (15 m² / 66 m³)
5. Vinyl (6 m² / 15 m³)
6. Boards (33 m² / 150 m³)

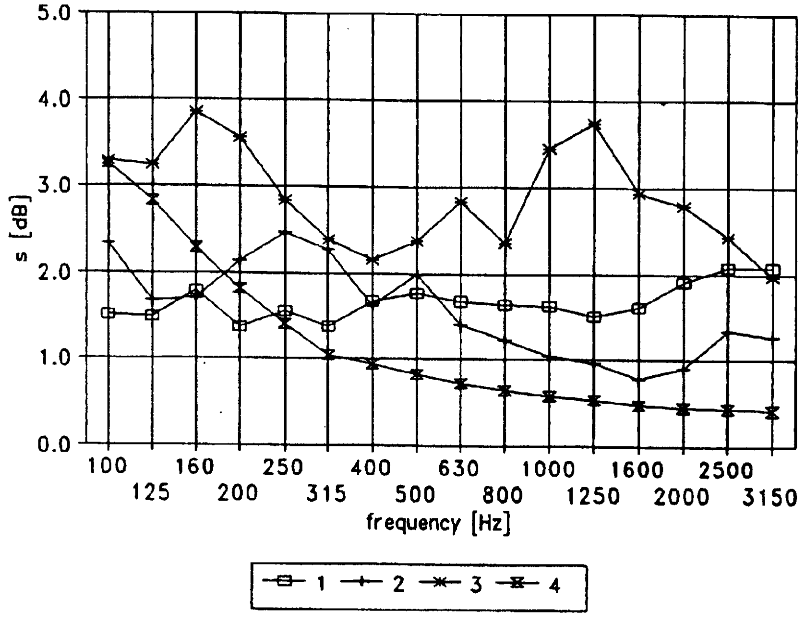
1-4: Vertical measurements
5-6: Horizontal measurements

Figure 5.4. Standard deviation of four tapping machine positions on different timber joist partitions with different types of floor coverings.



1. Without covering (10 m² / 24 m³)
2. With a soft-layer covering (no adhesive)

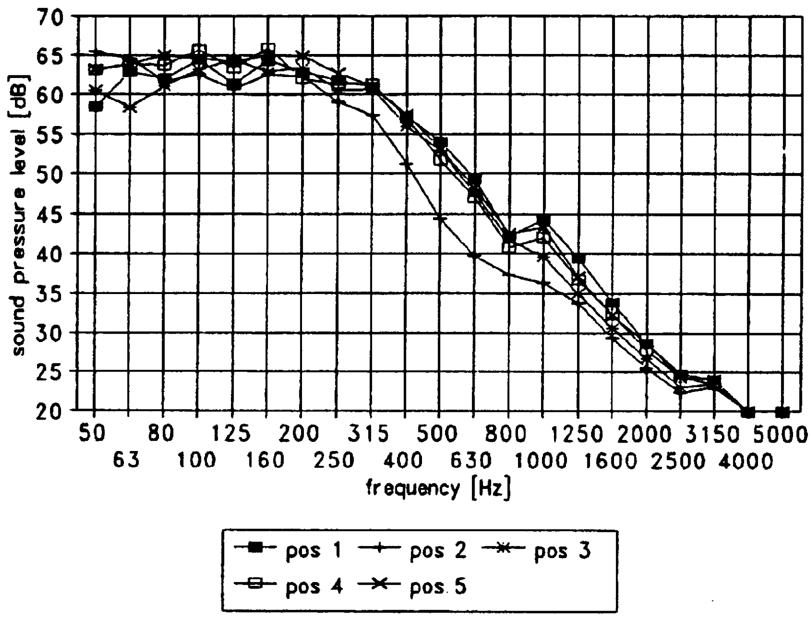
Figure 5.5. Standard deviation of six tapping machine positions on a timber joist partition with and without a soft floor covering. (The measurement has been carried out by SP.)



1. Average of the results in the figures 5.1 and 5.2 (measurement no. 5 in figure 5.1 has been excluded)
2. Average of the results in figure 5.3
3. Average of the results in figure 5.4
4. Estimate of the spatial standard deviation of the sound pressure level in a 50 m^3-room.

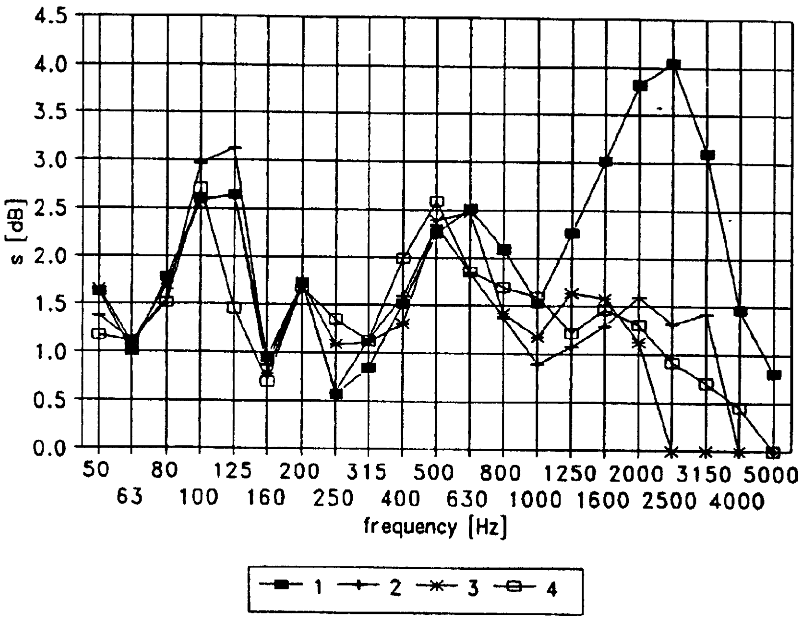
Figure 5.6. Average values of the results in the figures 5.1-5.4 compared with the spatial standard deviation of the sound pressure level in a typical living room.

In figures 5.7 and 5.8 results are shown from measurements on a special lightweight partition consisting of 70 mm concrete elements supporting a wooden floor of chip board on joists. The height of the joists is approximately 200 mm and the mutual distance between the joists is 600 mm. Measurements have been performed partly with different positions of the tapping machine related to the positions of the joists and partly on different floor coverings on the chip board.



1. On a joist (tapping machine parallel to the joist)
2. Between two joists (tapping machine parallel to the joists)
3. On a joist (tapping machine perpendicular to the joist)
4. Between two joists (tapping machine parallel to the joists)
5. Between two joists (tapping machine rotated 45° related to the direction of the joists)

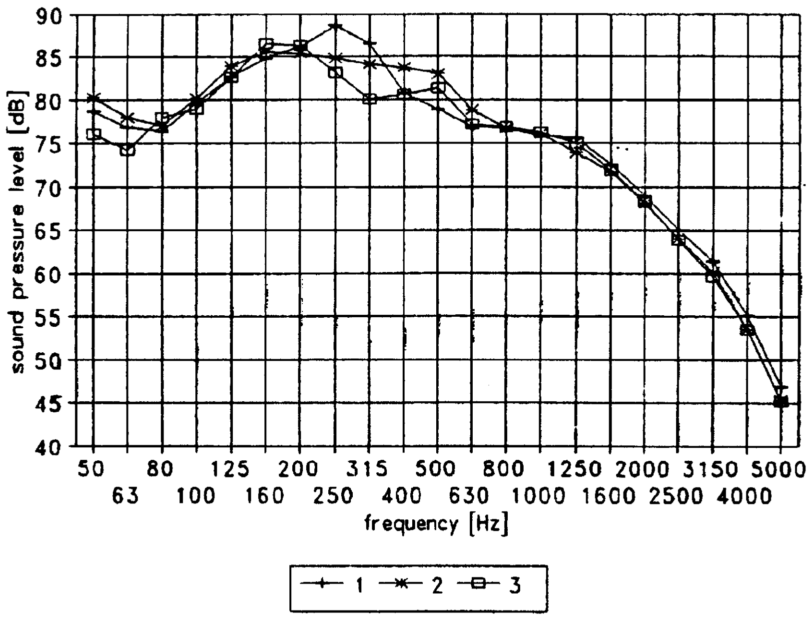
Figure 5.7. Sound pressure level from the tapping machine in different positions on a partition consisting of 70 mm concrete elements with a chip board floor on joists. (The measurement has been carried out by SP.)



1. chip board without covering
2. As 1 + 2 mm linoleum
3. As 1 + a soft layer covering
4. As 1 + 15 mm boards on 2 mm soft underlayer.

Figure 5.8. Standard deviation of five tapping machine positions on different floor coverings on a partition consisting of 70 mm concrete elements with a chip board floor on joists. (The measurements has been carried out by SP.)

A measurement series with different tapping machine positions in relation to the direction of the joists have been performed on a simple timber joist partition consisting of 100•200 mm joists with a distance of 600 mm. The floor and the ceiling are made of boards with a thickness of 16-22 mm. The results are shown in figure 5.9.



1. On a joist 0.3 m from the facade
2. Between two joists 1.2 m from the facade
3. On a joist 1.5 m from the facade

Figure 5.9 Sound pressure level from the tapping machine in different positions on a timber joist partition.

Figure 5.10 shows the results from a horizontal measurement with the tapping machine placed in five positions with increasing distance to the wall between source and receiving room. The impact sound pressure level for all tapping machine positions was measured on the same rotating microphone path. In both rooms the partition is made of solid reinforced concrete elements with a thickness of 180 mm and a width of 2.4 m supplied with a linoleum covering. The dimensions of the floor in the source room are 4.7 m · 7.4 m. The direction of the elements is parallel to the wall between the two rooms, which is built as a lightweight gypsum wall.

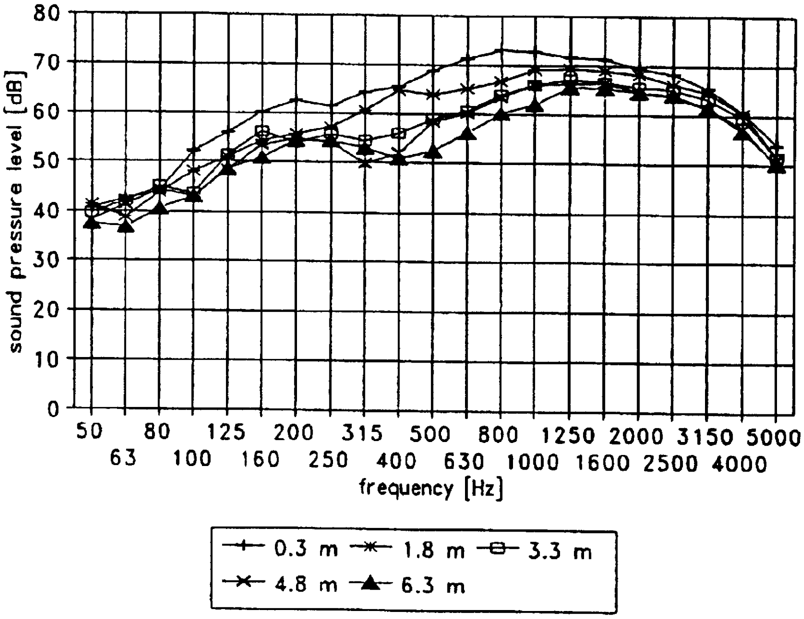


Figure 5.10. Horizontal measurement of the sound pressure level from the tapping machine in 5 positions with increasing distance to the separating wall between source and receiving room.

In spite of the limited number of measurements the following indications can be deduced from the experimental results in the figures 5.1-5.10:

The results in figure 5.1 indicate that the position variance for measurements on heavy concrete partitions with wooden floor on joists is below 2 dB in the frequency range 200-2500 Hz. The measurement on a wooden floor on mineralwool supplemented with a suspended ceiling in the receiving room shows a considerable increased standard deviation in the frequency range 500-1250 Hz.

From figure 5.2 it appears that for wooden floors on joists on a clinker concrete partition the standard deviation generally seems a little higher than for the heavy concrete partitions in figure 5.1.

The results in figure 5.3 are from measurements on floating clinker floors in bathrooms with floor areas in the range 4-6 m^2. An essential standard deviation is seen especially at frequencies below 500 Hz.

The standard deviation for measurements on timber joist partition shown in figure 5.4 show a considerably increased standard deviation compared with the measurements on different concrete partitions. However, there seems to be no clear correlation between the standard deviation and the type of the partition/floor covering.

Figure 5.5 shows results from measurements on a timber joist partition with and without a soft floor covering. It appears that with the covering the standard deviation decreases considerably in the frequency range 1000-2000 Hz.

Comparing results in figures 5.1-5.5 from measurements on the same category of construction with different floor areas indicates that no correlation between the standard deviation and the floor area exists.

To get an overview of the position variance of the tapping machine for different types of partitions the average value of all measurement results for the same category has been calculated and are shown in figure 5.6. Furthermore the estimated spatial standard deviation of the sound pressure level in a typical living room with a volume of 50 m^3 is shown in the figure.

From figure 5.6 it is seen that for concrete partitions with wooden floor on joists (curve no 1) or clinker concrete partitions with floating concrete floors (curve no 2) the average standard deviation is in the range 1-2 dB. The average standard deviation for timber joist partitions seems considerably higher especially at low frequencies and in the frequency range 1000-1600 Hz.

The result in figure 5.6 shows that the spatial standard deviation of the sound pressure level in a typical living room is lower than the position variance of the tapping machine in the entire frequency range for timber joist partitions and at frequencies above 250 Hz for concrete partitions. At frequencies below 250 Hz the spatial standard deviation of the sound pressure level is higher than the position variance of the tapping machine for concrete partitions.

If the standard deviation for measurements with 4 tapping machine positions on concrete partitions with wooden floor on joists is chosen as a reference it can be roughly estimated from the results in figure 5.6 that the number of tapping machine positions on timber joist partitions should be increased to approximately 11 to give the same accuracy on the mean value of all tapping machine positions.

From figure 5.7 it is seen that in the frequency range 250-1250 Hz the result from measurement no 2 with the tapping machine situated between the joists deviates considerably from the other results. However, measurement no 4 is also performed with the tapping machine placed between the joists and this results corresponds well to the others. Figure 5.9 shows a difference in the frequency range 200-630 Hz depending on the tapping machine position. No significant correlation between the standard deviation and the position of the tapping machine related to the joists can be seen from these measurements.

From figure 5.8 it is seen that the standard deviation in the frequency range 1250-3150 Hz for measurement no 1 without any floor covering significantly exceeds the results from measurements with different coverings.

A surprising dependence of the positions of the tapping machine appears from figure 5.10. In the mid-frequency range a difference in the sound pressure level of up to approximately 16 dB is seen for measurements taken at distances of 0.3 m and 6.3 m, respectively, from the wall between source and receiving room.

5.7. AIRBORNE SOUND CONTRIBUTION FROM THE TAPPING MACHINE

When measuring the impact sound insulation from e.g. a wooden floor on a concrete partition the sound pressure level in the source room can be rather high. If the airborne sound insulation between source and receiving room is pure while the impact sound insulation is high, airborne sound from the tapping machine can be transmitted to the receiving room and influence the measurement result.

The airborne noise contribution can be evaluated by comparing the sound pressure level difference between source and receiving room partly determined by the tapping machine and partly by use of an airborne sound source, e.g. a loudspeaker.

5.8. RECEIVING ROOM CONDITIONS

Consideration concerning the influence of the receiving room characteristics on the measurement result stated in chapter 4 is in general valid for impact sound insulation measurements too (chapters 4.2, 4.3, 4.4, 4.6, 4.7-4.10).

5.9. REVERBERATION TIME

From the results in figure 4.14 and figure 5.6 it can be concluded that inaccuracy due to the reverberation time measurement can be neglected as an appreciable source of error in impact sound insulation measurements.

5.10. SUMMARY OF REQUIREMENTS IN ISO 140 PART 7 CONCERNING POSITIONS OF TAPPING MACHINE AND MICROPHONES

- Minimum four tapping machine positions unsymmetrically distributed on the floor during test shall be used.

- The distance between tapping machine positions and the walls shall be at least 0.5 m.
- In case of anisotrope floor constructions (ribs, beams) an increased number of positions may be necessary.
- The hammer connecting line should be oriented at 45° to the direction of the beams or ribs.
- As a minimum four microphone positions shall be used, all distributed within the maximum permitted space in the room taking in the room space uniformly. At least a pair of them may be used in each case with two tapping machine positions and the other pair with the other two, so that eight sound pressure level readings are taken as a minimum.
- When using a rotating microphone the sweep radius shall be at least 0.7 m. The plane of the traverse shall be inclined in order to cover a large proportion of the permitted room space and shall not lie in any plane within 10° of a room surface. The duration of a traverse period shall be at least 15 s.
- The following separating distances are minimum values and should be exceeded where possible:

  0.7 m between microphone positions.

  0.5 m between any microphone position and room boundaries or diffusers (e.g. furniture).

  1.0 m between any microphone position and the test object.

5.11. PRINCIPLES OF ADDITIONAL GUIDELINES

It is not possible on a theoretical basis to estimate the position variance for a number of tapping machine positions on different types of floor constructions. Furthermore the number of experimental results in the literature are very limited and not sufficient for clear conclusions. Consequently, the guidelines concerning tapping machine positions presented in chapter 5.12 have been prepared from simple consideration to some extent based on the measurement results in chapter 5.6.

The proposed guidelines are based on the following:

1. The minimum number of tapping machine positions stated in ISO 140 Part 7 is increased for measurements on timber joist partitions and concrete partitions with beams or ribs. Additional tapping machine positions are used on all types of partitions if the floor area exceeds a certain limit.

2. For big floor areas a limitation of the distance between the tapping machine positions and the receiving room is proposed.

In ISO 140 Part 7 it is stated that as a minimum four tapping machine positions and four fixed microphone positions, alternatively one rotating microphone position, shall be used. For the fixed microphone two of them may be used with two of the tapping machine positions. This leads to a minimum of eight sound pressure level measurements. To get a highly applicable procedure it has been the assumption in the preparation of the additional guidelines that the number of eight measurements should normally not be exceeded.

The proposed limitation of the floor area to be used for the tapping machine position is quite restrictive. For horizontal measurements in general and for vertical measurements in situations where the part of the partition common to both source and receiving room is less than 20 m^2, it is proposed that the area to be used for the positions of the tapping machine is limited to approximately 20 m^2.

The number of microphone positions is increased from the minimum of four to eight in rooms with floor areas exceeding 50 m^2. The proposed positions are for typical as well as special room configurations shown on diagrammatic sketches (Annex C).

From a corridor a measurement will normally be carried out to a room in an apartment. A corridor typically has a width of 2-4 m. The tapping machine should be placed on the area of the corridor in front of the receiving room. The area of the floor should be limited to approximately 10 m^2.

A stairway in an apartment house consists of stairflights mounted between landings at each storey level. Often there are supplementary landings between the storeys.

Because of the varying combinations of fixation and the use of vibration isolating materials the impact sound pressure level from the flights and the landings, respectively, can vary considerably. Furthermore different covering may be used on flights and landings, respectively. Therefore measurements should be taken from the flights and the landings separately.

A simple check procedure is proposed to be used for evaluation of the airborne sound contribution from the tapping machine.

5.12. ADDITIONAL GUIDELINES - IMPACT SOUND INSULATION

Basic standard: ISO 140 Part 7, "Field measurements of impact sound insulation of floors" (Committee draft of 11. May 1992)

The complete basic standard should be studied carefully previous to implementation of the additional guidelines in the measurement procedure. The additional guidelines are closely related to the basic standard and should never be used as a solitary document.

In measurement situations with a big floor area, a discrepancy might be observed between results obtained according to the additional guidelines and the basic standard, respectively.

5.12.1. General

The room in which the tapping machine is placed is named the source room. For vertical measurements the upper room is the source room and the lower room the receiving room.

The examples of tapping machine positions in Annex C are all shown for a partition type 2 as defined in table 5.1. If the actual partition is of type 1 the number of tapping machine positions must be increased according to table 5.1 (table 5.1 is explained in chapter 5.12.2).

If in the same room different floor coverings are used e.g. in a kitchen section and a living room section in the same room measurements must be performed from the two types of floors separately. The guidelines in the following must then be used on each of the two floor areas.

In the following the designations "test object", "partition wall" and "partition" are used. (See Annex C.18 "definitions".)

5.12.2. Number of tapping machine and microphone positions

The number of tapping machine positions and microphone positions is determined according to the table below:

Floor area of the source room, m^2	Number of positions of:	Floor area of the receiving room, m^2			
		≤ 50		> 50	
		Partition type 1	Partition type 2	Partition type 1	Partition type 2
< 10	Tapping machine	4	4	4	4
	Fixed microphones	4	4	8	8
	Rotating microphone	1	1	2	2
10-50	Tapping machine	8	4	8	4
	Fixed microphones	4	4	8	8
	Rotating microphone	1	1	2	2
> 50	Tapping machine	8	8	8	8
	Fixed microphones	4	4	8	8
	Rotating microphone	1	1	2	2

Table 5.1. Number of tapping machine positions and microphone positions determined from the floor area of source and receiving room, respectively.

The combinations of tapping machine positions and microphone positions prescribed in the table are shown on diagrammatic sketches in Annex C.17.

Comments to table 5.1:

Partition type 1: Timber joist partitions, concrete partition with ribs or beams and solid concrete partitions with a thickness less than 100 mm. Any kind of floor covering.

Partition type 2: Solid concrete partitions with a thickness equal to or greater than 100 mm, clinker concrete elements and hollow concrete elements. Any kind of floor covering.

For very small floor areas e.g. in bathrooms the minimum requirement for the distance between tapping machine and the edges of the floor leads to a very limited area left for the four positions. However, the minimum number of tapping machine positions stated in table 5.1 should still be used. The tapping machine must be placed within the permitted area and the direction of the hammer connecting line should be changed between each measurement.

It is assumed that the height of the receiving room covered by the table is in the range approximately 2.3-3.5 m. In rooms with a height exceeding 3.5 m it should be considered to increase the number of microphone positions given in the table.

For rooms partly divided by a wall the room is considered to be two rooms if the area of the opening is less than 1/3 of the total area of the vertical section of the room in the plane containing the wall. (See Annex C, examples 30 and 31.)

General guidelines concerning the microphone positions: see chapter 4.14.2.

5.12.3. Vertical measurements

In the following "non-staggered rooms" means rooms where the horizontal contour of the smaller room can be totally contained in the horizontal contour of the bigger room.

5.12.3.1. Non-staggered rooms. The floor area of the source room equal to or less than the floor area of the receiving room

The number of tapping machine positions and microphone positions are chosen directly from table 5.1. The tapping machine positions shall be distributed to cover the total floor area.

(See Annex C, example 29.)

5.12.3.2. Non-staggered rooms. The floor area of the source room greater than the floor area of the receiving room

If the floor area of the source room is equal to or less than 20 m² table 5.1 is used directly. If the floor area of the source room exceeds 20 m² and the area of the test object is equal to or less than 20 m² a limited floor area of 20 m² should be used for the measurements. The tapping machine is placed exclusively in this area. (See Annex C, example 32). If the area of the test object exceeds 20 m² the tapping machine positions shall be distributed over the total area of the test object.

5.12.3.3. Staggered rooms

If the area of the test object is greater than 20 m² the guidelines in 5.12.3.1. and 5.12.3.2 are used.

If the area of the test object is equal to or less than 20 m² - or if there is no common part - a limited area of 20 m² is used.

(See Annex C, examples 33-35.)

5.12.4. Horizontal measurements

If the floor area of the source room is equal to or less than 20 m² table 5.1 can be used directly. If the floor area exceeds 20 m² a limited area of 20 m² is used. The dimension of the limited floor area perpendicular to the partition wall in the source room should not be reduced to less than half the width of the partition wall in the source room. The other dimension of the limited area shall not be less than the width of the partition wall in the receiving room (These requirements shall always be fulfilled. In some special cases this implies that it will not be possible to limit the floor area to 20 m².)

(See Annex C, examples 36-44.)

5.12.5. Measurements of impact sound insulation from a corridor

Impact sound insulation measurements from a corridor to a room on the same storey or the storey below is carried out by placing the tapping machine on a limited area of the corridor close to the receiving room. The area used shall be the full width of the corridor and a length corresponding to an area of approximately 10 m².

Four tapping machine positions are used and the number of microphone positions can be chosen according to table 5.1. (See Annex C, example 45.)

5.12.6. Measurements of impact sound insulation from staircases in apartment houses and internal stairs in apartments and terrace houses

Measurements are carried out for the landings and the flights separately. Four tapping machine positions are used on the landings as well as on the flights. The number of microphone positions can be chosen according to table 5.1.

The four tapping machine positions on the flights are placed with one at step number two from the top of the flight and one at step number two from the bottom. Two positions are evenly distributed in between the top- and bottom positions.

Note - It sometimes may be problematic to place the tapping machine on narrow steps. A special support device can be used to extend the supporting legs at one side of the tapping machine. This allows the machine to stand on two steps. If such a modification is used this should be mentioned in the report.

The impact sound pressure level from a landing is normally measured in an adjoining room in which the highest level is expected. If the floor in the adjoining rooms of the same storey as the landing consist of e.g. boards on joists on a concrete partition, the impact sound pressure may be at its highest level in a room at the storey below the landing, because the wooden floor is reducing the sound radiation from the concrete partition into the upper room. If the flights are not fixed to the walls of a staircase the impact sound pressure level from the flights should be measured in the same room as used for the measurement from the landings. If the flight is fixed to the wall, the receiving room used for measurements from the flight should be chosen as the room closest to the fixations.

The guidelines stated above are also applicable for measurements on internal stairs.

5.12.7. Remarks concerning different floor coverings

Measurements on soft floor coverings such as carpets and PVC-layers can be performed on a small sample of e.g. 1 m^2 which is moved between the different tapping machine positions. It should be noticed that if the covering is going to be fastened by an adhesive, the results from a measurement without adhesive can be misleading.

The use of a small sample of a heavy carpet with significant weight on a lightweight timber joist partition should be avoided since it may not take into account a damping or restraining effect on the flexural motions of the partition, which occurs when the total area is covered.

When a small sample is used this should always be mentioned in the report.

For soft coverings it should be noticed that some materials have an impact sound insulation which is dependent on the temperature. The temperature dependence should be evaluated if measurements are carried out under temperature conditions differing from normal room temperature.

When measuring on rough clinker-floors the positions of the tapping machine should be adjusted so the hammers are not tapping on the edges of the clinkers. This would prevent partly that the clinkers are damaged and partly that the measurement result is influenced by an uncharacteristic excitation of the floor.

5.12.8. Airborne sound contribution from the tapping machine

The airborne sound contribution from the tapping machine can be evaluated in the following way:

1. The sound pressure level difference between source and receiving room is determined by means of a pink noise signal from a loudspeaker placed in the source room ($L_{D,spk}$).

2. The sound pressure level in the source room from the tapping machine is measured ($L_{S,tm}$).

3. The sound pressure level in the receiving room from the tapping machine is measured ($L_{R,tm}$).

If the difference ($L_{S,tm}$ - $L_{D,spk}$) is 10 dB or more below $L_{R,tm}$ at any frequency band of interest the influence of the airborne sound from the tapping machine can be regarded negligible.

5.12.9. Determination of room volume and reverberation time

Determination of the volume of the receiving room: see chapter 4.14.5.

Determination of the reverberation time of the receiving room: see chapter 4.14.6.

6. REVERBERATION TIME MEASUREMENTS

6.1. INTRODUCTION

This chapter concerns reverberation time measurements to be used for verification of the fulfilment of requirements e.g. in the building code regulations.

Only the interrupted noise method is considered. This method is accurate and practicable and seems to be most suitable for verification measurements. However, the method is not applicable for measurements in concert halls and other rooms where a very detailed and precise evaluation of the room acoustical properties is required.

An applicable and suitable measurement procedure is given in Nordtest Method NT ACOU 053 "Rooms: reverberation time". (Approved 1985-05.)

Standard deviations presented in this chapter calculated from measurement results are determined as the sample standard deviations.

6.2. ACCURACY OF REVERBERATION TIME MEASUREMENTS

The reverberation time is normally determined by averaging a number of measurements in different positions in the room.

The statistics of the decaying sound field in a room has been treated by Davy (ref. [6]) and the theories are summarized in ref. [1] and [5]. The theory takes into account the variance in fixed positions as well as the spatial variance in a room.

The total spatial variance of the reverberation time can be calculated from the following equation:

$$\varepsilon_T^2(T) = \left[\varepsilon_r^2(T) + \frac{\varepsilon_e^2(T)}{N}\right] \qquad (6.1)$$

where $\varepsilon_r^2(T)$ = spatial variance in the room
$\varepsilon_e^2(T)$ = variance of repeated measurements in one position in the room
N = number of excitations in each position

Equation 6.1 assumes a diffuse sound field. Furthermore the damping shall be the same for all modes within each frequency band.

To evaluate equation 6.1 a comparison between calculated and measured standard deviation has been performed. In this and the following calculation examples it has been assumed that the reverberation time is measured using exponential averaging with a fall time of the measuring system of 1/4 of the decay time of the sound. The

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reverberation time is assumed to be determined from a sound pressure level decay of 30 dB. Under these assumptions equation 6.1 according to ref. [5] can be given as:

$$\varepsilon_T^2(T) = \left(1.31 + \frac{1.94}{N}\right) \cdot \frac{T}{f} \;[s] \qquad (6.2)$$

where T = reverberation time [s]
N = number of excitations in each position
f = 1/3 octave band centre frequency [Hz]

The calculated result has been compared with the result of a measurement carried out in a room with a volume of 65 m^3 and a reverberation time in the entire frequency range of approximately 2 s.

For each of two loudspeaker positions the reverberation time was measured in six fixed icrophone positions. In each of the twelve positions two excitations were performed. In figure 6.1 the measured and calculated spatial standard deviations are shown. A good agreement between measurement and calculation results is observed.

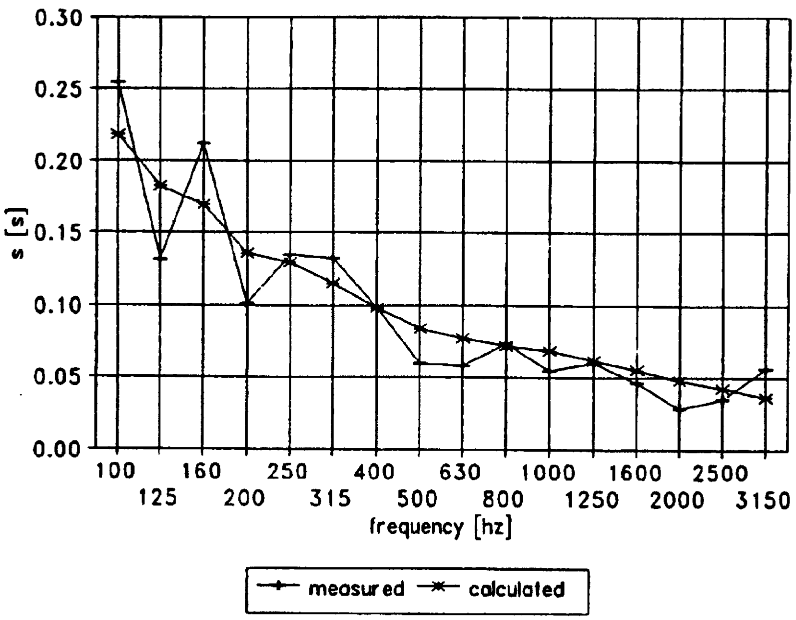

Figure 6.1. Measured and calculated total spatial standard deviation of the reverberation time in a 65 m^3 room.

Figure 6.2 shows the calculated total spatial standard deviation as a function of the frequency and the number of excitations in each position. The reverberation time is assumed to be 1 s in the entire frequency range. A considerable decrease of the standard deviation is seen when the number of excitation in each position is increased from one to ten. Further measurement positions do not cause any essential improvement of the measurement accuracy.

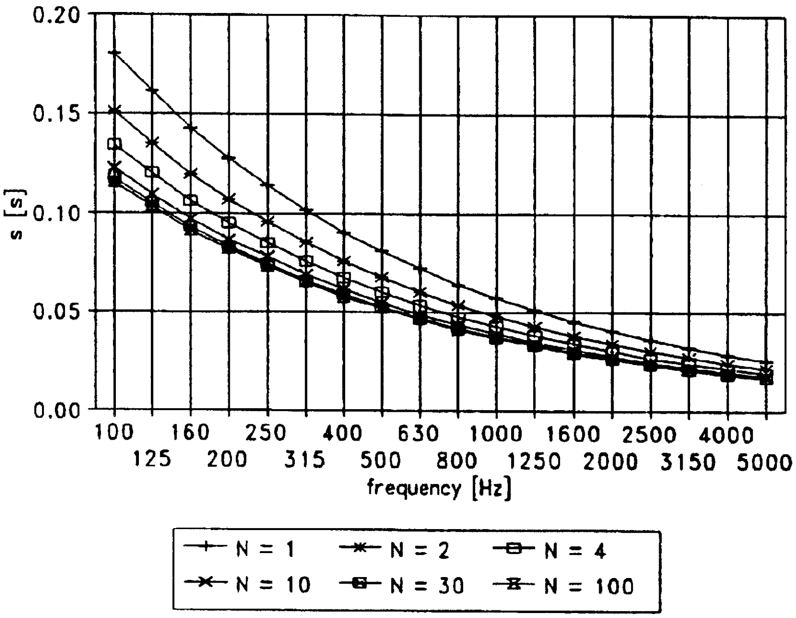

Figure 6.2. Total spatial standard deviation of the reverberation time as a function of the frequency and the number of excitations in each position in a room with a reverberation time of 1 s at all frequencies.

With two excitations in each position the spatial standard deviation has been calculated for measurement in rooms with different reverberation time. From figure 6.3 it is seen that the spatial standard deviation is increasing with increasing reverberation time.

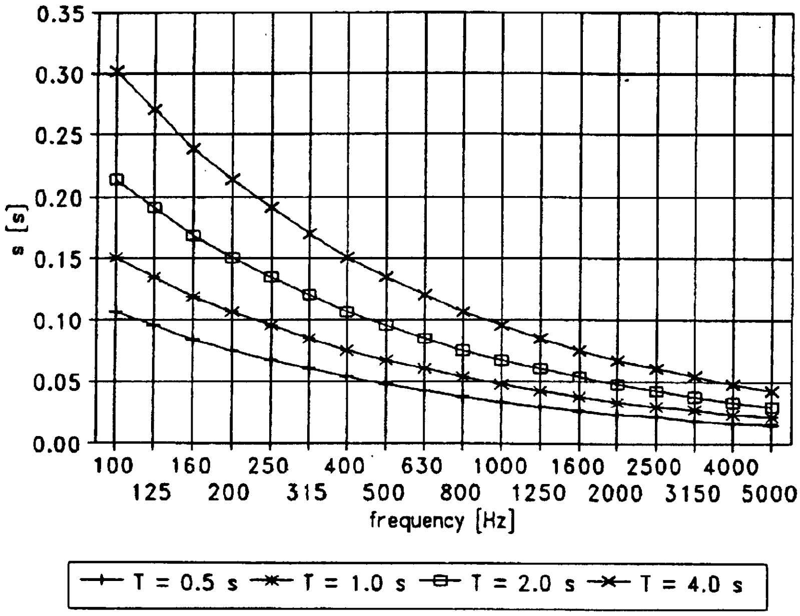

Figure 6.3. Total spatial standard deviation as a function of the frequency and the reverberation time.

According to the results in figure 6.2 an optimized measurement procedure should comprise approximately ten excitations in each position if the positions variance should be negligible compared with the spatial variance. (The calculation result for N = 100 in figure 6.2 roughly corresponds to the spatial variance. See equation 6.1.)

According to the results in figure 6.3 the number of microphone positions should be increased with increasing reverberation time to have the same standard deviation on the average value. From figure 6.3 it can be estimated that if the reverberation time is measured in two rooms with a reverberation time of 0.5 s and 2 s, respectively, the number of positions in the room with the longer reverberation time shall be approximately 4 times the number used in the room with the lower reverberation time to have the same standard deviation on the average value. (However, it may be discussed if it is the absolute accuracy or the relative accuracy (normalized standard deviation) which is relevant for measurements of the reverberation time.)

The number of sound source and microphone positions in existing test procedures normally is determined based on the room volume. As it appears from the calculation examples above that it would in fact be more correct to use the reverberation time as the parameter for determination of the number of positions, since the total spatial variance is independent of the room volume.

6.3. SUMMARY OF NORDTEST METHOD ACOU 053

In the Nordtest Method the following minimum requirements are stated concerning sound source and microphone numbers and positions:

- Three source positions shall be used (one of them in a corner).
- Rooms with a volume less than 250 m^3: three fixed microphone positions or one position of a rotating microphone with a radius of at least 0.8 m for each source position.
- Rooms with a volume equal to or larger than 250 m^3: six fixed microphone positions or two positions of a rotating microphone with a radius of at least 0.8 m for each source position.
- At frequencies below 500 Hz at least two excitations in each microphone position.
- At frequencies equal to or more than 500 Hz at least one excitation for each microphone position.
- The microphone positions should be evenly distributed in the room. Minimum distance between microphones 1.5 m.
- Minimum distance to room boundaries 0.5 m.
- If a rotating microphone is used the three measurements shall be evenly distributed on the path.
- In case only a limited part of a room is normally used, the averaging should take place in this area only.

6.4. PRINCIPLES OF ADDITIONAL GUIDELINES

The nordtest Method NT ACOU 053 is quite clear, and there seems to be a need for only few additional guidelines.

The Nordtest Method prescribe that in rooms with volumes less than 250 m^3 at least three loudspeaker positions and three microphone positions shall be used. For rooms with volumes equal to or greater than 250 m^3 at least three loudspeaker positions and six microphone positions are prescribed.

Based on the results in figure 6.3 a new criteria taking into account the reverberation time is introduced.

From experimental results in ref. [4] it is indicated that in big rooms (volumes exceeding 1000 m^3) the spatial variation of the reverberation time is more sensitive to varying the loudspeaker positions than to varying the microphone positions. To improve the measurement accuracy in very big rooms (e.g. in gymnasiums and swimming baths) it is proposed that if the room volume exceeds 1000 m^3 six loudspeaker positions and six microphone positions are used.

Normally a sound pressure level decay of 20-30 dB is used for the determination of the reverberation time. 30 dB is proposed to be the preferred range. If problems appear concerning the dynamic range because of background noise, the level decay is decreased to 20, 15 or 10 dB.

6.5. ADDITIONAL GUIDELINES - REVERBERATION TIME

6.5.1. General

asic standard: Nordtest Method NT ACOU 053 "Rooms: reverberation time". (Approved 1985-05.)

The complete basic standard should be studied carefully previous to implementation of the additional guidelines in the measurement procedure. The additional guidelines are closely related to the basic standard and should never be used as a solitary document.

6.5.2. Number and positions of loudspeakers and microphones

The number of loudspeaker and microphone positions depending on the room volume is selected from table 6.1.

		Number of loudspeaker and microphone positions		
Measurement set-up	Room volume, m^3	Loudspeakers	Fixed microphones	Rotating microphones
1	< 250	3	3 (9/18)	1 (9/18)
2	250-1000	3	6 (18/32)	2 (18/32)
3	> 1000	6	6 (36/72)	2 (36/72)

Table 6.1. Number of loudspeaker and microphone positions depending on the room volume. (The values in brackets are the total number of decays to be recorded. The two numbers are for one and two excitations in each position, respectively.)

Comments to table 6.1:

Measurement set-up no 2 should also be used in rooms with a volume less than 250 m³ if the reverberation time in the 500 Hz 1/3 octave band is 2 s or more.

The radius and the position(s) of a rotating microphone should be selected to cover the entire room volume as far as possible.

The height above floor level of the microphone positions should be limited to 2.5 m in rooms with heights exceeding 3 m.

The distance between an omnidirectional sound source and any microphone positions should exceed 3 times the reverberation distance of the room. The minimum distance can be approximated by the equation:

$$d_{min} = 0.16 \cdot \sqrt{\frac{V}{T}} \qquad (6.3)$$

where V = the room volume [m²]
T = the reverberation time [s]

If the loudspeaker is placed close to a room boundary or in a corner, the minimum distance determined by equation 6.3 shall be increased by a factor 2-3.

For measurement of the reverberation time of a staircase three loudspeaker positions placed on three landings distributed to cover the entire volume of the staircase should be used. For each loudspeaker position the three microphones positions are placed at the landings half a storey down and half a storey up and if possible regarding the minimum distance between loudspeaker and microphone on the landing where the loudspeaker is placed. Alternatively the 3rd position may be a full storey up or down. For measurements in staircases fixed microphones are to be preferred.

In rooms partly divided by a wall separate measurements shall be carried out in each part of the room if the surfaces are different regarding absorption in the two parts of the room.

Note - ISO 3382-1975, "Acoustics - Measurement of reverberation time in auditoria", is for the time being under revision. As a new item the new edition will include the integrated impulse response method, which is useful for e.g. measurements of very short reverberation times.

6.5.3. DECAY RATE

Preferably a decay of the sound pressure level of 30 dB should be used. If this appears to be impossible because of background noise, a decreased decay of 20, 15 or 10 dB can be chosen. The results are designated T_{30}, T_{20}, T_{15} and T_{10}.

Note - In case of curved decays the measured reverberation time may differ depending on the chosen sound pressure level decay.

7. NOISE FROM TECHNICAL INSTALLATIONS

7.1. INTRODUCTION

A measurement of noise from technical installations usually consists of the determination of the A-weighted sound pressure level in a room due to the operation of the installation in question. The installation can belong to the dwelling in which the measurement is performed, to an adjacent dwelling or the noise source can be a part of an installation common to all dwellings in e.g. an apartment house.

The sound pressure level is usually determined as the A-weighted, equivalent, continuous sound pressure level or the A-weighted maximum level measured with time weighting "F". Furthermore the measurement result may be corrected to the reference measurement condition, which is normally an empty room ready for use.

In some countries a correction of the measurement result with typically + 5 dB is required, if the noise includes distinct audible tones or impulses.

If the individual sources of errors are considered uncorrelated, the variance of the sound pressure level can be estimated from:

$$e^2(L_A) = e^2(L_m) + e^2(F) \tag{7.1}$$

where $e^2(L_m)$ = spatial variance of the sound pressure in the receiving room
$e^2(F)$ = variance due to fluctuations in the sound pressure level from the installation

The A-weighted spectrum of noise from technical installations typically has its maximum in the frequency range 500-2000 Hz. For noise with an approximately flat spectrum in this frequency range it can be estimated by equation 4.5 that the spatial standard deviation of the sound pressure level in a room with a reverberation time of 1 s is 0.3 dB. If the final result is determined as an average value of measurements in three uncorrelated positions as required in Nordtest Method NT ACOU 042 "Rooms: noise level", it can be estimated that the 95% confidence interval of the average value is ± 0.4 dB. This is the estimated accuracy of measurements on broad band noise sources with a constant sound pressure level. For installations from which the sound pressure level is fluctuating, the variance due to this must of course be added to the spatial variance of the room.

Averaging the sound pressure level determined in three microphone positions seems to be sufficient for the accuracy needed for evaluation of the fulfilment of requirements in e.g. building code regulation.

7.2. TYPES OF INSTALLATIONS

The most common installations from which noise problems frequently occur are water appliances and ventilation systems.

Usually a high noise level from water installations usually is caused by fixation of the appliances and pipes directly to the partitions or possibly because the pipes have been built into the wall.

Noise from ventilation systems is normally caused either by noise directly from the fan or by air turbulence in the vent.

Concerning additional guidelines the following installations are considered:

- Water taps over sinks
- Shower cabins
- Baths (tubs)
- Water closets
- Ventilation systems
- Lifts

7.3. SUMMARY OF NORDTEST METHOD NT ACOU 042

Summary of the requirements for measurements in the far-field of noise sources stated in Nordtest Method NT ACOU 042, "Rooms: noise level".

- In rooms with volumes less than 75 m^3 three fixed microphone positions or one position of a rotating microphone shall be used. The radius of a rotating microphone should be at least 0.8 m. For rooms with volumes equal to or greater than 75 m^3 more than three microphone positions should be used.

- The distance between the microphone positions should be greater than 1.5 m and no single position should be closer to the room boundaries than 0.5 m.

- The measurement time shall be sufficiently long to include a full cycle of fluctuations, if any. For constant noise a suitable measurement time is 30 s in each microphone position.

- The A-weighted, equivalent, continuous sound pressure level is measured over the chosen measurement period.

- For noise of short duration - e.g. noise from start and stop of a lift - the A-weighted maximum sound pressure level with time weighting "F" shall be measured.

Note - A special procedure is prescribed in Nordtest Method NT ACOU 042 concerning measurement of low-frequency noise.

7.4. PRINCIPLES OF ADDITIONAL GUIDELINES

The Nordtest Method NT ACOU 042, "Rooms: noise level", is the basic standard to which the additional guidelines are related.

Measurements of noise from technical installations are carried out according to different basic standards in the individual countries. In some countries the maximum sound pressure level observed during the measurement period is the measure to be used, while others are using the equivalent, continuous sound pressure level determined by averaging over a period depending on the type of installation in question. The present guidelines are prescribing the operating conditions of the installations as well as suitable measurement periods. If the maximum value is wanted it should be determined within the proposed measurement period.

7.5. ADDITIONAL GUIDELINES - NOISE FROM TECHNICAL INSTALLATIONS

Basic standard: Nordtest Method NT ACOU 042, "Rooms: noise level"

The complete basic standard should be studied carefully previous to implementation of the additional guidelines in the measurement procedure. The additional guidelines are closely related to the basic standard and should never be used as a solitary document.

7.5.1. General

The measurement period to be used for the determination of the equivalent, continuous sound pressure level is in the following named the "the observation period". The maximum sound pressure level is the maximum value observed during the observation period.

Generally the measurement shall be carried out in the room mostly affected by noise from the installations considered. Doors and windows shall be closed.

The measurements are preferably carried out in empty rooms ready for use. If measurements are carried out in furnished room the measurement result must be corrected according to the method stated in NT ACOU 042.

The individual installations shall be considered separately.

7.5.2. Microphone positions

In rooms with volumes less than 75 m^3 three fixed microphone positions or one position of a rotating microphone shall be used. The radius of a rotating microphone shall be at least 0.8 m. The positions are chosen in the middle part of the room. (The distance between the positions should preferably not be less than 1.5 m and no position must be situated on the symmetric lines of the room).

If the room volume is in the range 75-250 m^3 five positions of fixed microphones or one position of a rotating microphone are used. The radius of the rotating microphone path should be chosen to cover the entire room volume as far as possible. In rooms with volumes exceeding 250 m^3 the number of positions must be increased regarding the characteristics of the actual room such as reverberation time and shape.

In rooms partly divided by a wall the measurement should be carried out in the part of the room with the highest noise level. If e.g. a kitchen section is partly separated from a living room section it often can be difficult to state the limit between the two sections. If the requirements for kitchens and living rooms in the building code regulations are differing a measurement should be carried out in both sections. If the noise source is placed in the kitchen section - e.g. a cooking hood - the measurement in the living room should be carried out in the part of the room closest to the kitchen.

If the noise source is placed in the room the measurement is performed as described above. In addition a measurement should be carried out at a distance of approximately 1 m from the vertical projection of the noise source on the floor and 1.2-1.5 m above floor level. Noise sources in the room are typically exhaust units in the ventilation system or a cooker hood. If the unit is mounted flush with the wall the microphone positions shall be placed 1 m from the wall. Three measurements are performed in microphone positions varied in the height within the limits 1.2 to 1.5 m and with a horizontal distance between the positions of approximately 0.5 m.

7.5.3. Operating conditions

7.5.3.1. Water taps

Water taps above sinks in toilets, kitchens and sculleries usually consist of either two individual taps, one for hot and cold water respectively, or one single tap for mixing hot and cold water.

In case of individual taps the noise should be measured from each tap separately. The measurement is performed with the tap in the position causing the highest noise level in the room where the measurement is performed. Normally the maximum noise level is observed with the tap fully opened. However, occasionally the maximum level occurs at a position different from fully opened.

Note - Erroneous measurement results will occur if the shut-off valves and the check valves are not in their maximum opened positions or if the waterpressure is not correctly adjusted.

For mixing taps a measurement is carried out with the tap in the hot-position and the cold-position, respectively. If a position can be found in between where the noise level is higher than in the hot and cold positions, a measurement shall be carried out in this position too.

An observation period of approximately 30 s is recommended.

Emptying the sink should take place simultaneously with the measurement.

7.5.3.2. Showers

The measurement is performed according to 7.5.3.1. The shower shall be placed in the wall fixture at its highest position above floor level and the shower shall be directed towards the floor of the shower cabin.

An observation period of approximately 30 s is recommended.

7.5.3.3. Baths (tubs)

The measurement is performed according to 7.5.3.1 and 7.5.3.2. If the tap of the bath is a combination of a nozzle exclusively for filling the bath and a shower, the two function shall be regarded separately.

The shower shall be directed towards the bottom of the bath. If there is no fixture at the wall the shower should be held at a height above the bottom of the bath of approximately 1.5 m while carrying out the measurement. Emptying the bath should take place simultaneously with the measurement.

An observation time of approximately 30 s is recommended.

The noise from filling the bath is measured during an observation period corresponding to the time it takes to fill the bath to approximately one third of the total capacity. The noise from draining the bath is measured while the water is flushing out.

Measurements of noise from filling and draining the bath are quite time consuming. Therefore, averaging in different positions in the room should take place during only one filling/draining.

7.5.3.4. Water closets

The noise from a water closet consist partly of the noise from flushing out the water and partly of the noise generated when the cistern is re-filled. The two contributions should be considered separately.

The observation period for measuring the flushing out-noise starts when the toilet is operated and stops when the flushing has finished. The water closet is operated 3 times, one for each of the three microphone positions, and the mean value on energy basis is calculated. In rooms where an increased number of microphone positions are required it may be suitable also to increase the number of operations of the water closet accordingly.

The observation period for measuring the noise from re-filling the cistern is the time needed for the re-fill.

Note - Annoyance from water closets in adjoining dwellings frequently is caused by the noise generated by "standing, urinating males".

A standardized measurement procedure for the determination of the sound pressure level of this "event" could be the following:

A special device is constructed from a PVC-tube with a length of 750 mm and an inside diameter of 36.8 mm. (A tube with an outside diameter of 40 mm and the pressure class PN6 should be suitable). One end of the tube is closed by a rubber plug. (A suitable plug is conic with maximum and minimum diameter of 40 mm and 34-35 mm, respectively. The length of the plug should be 35 mm). In the middle of the plug shall be a hole with a diameter of 5 mm. The tube is filled with water, and it is checked that emptying the tube through the hole in the plug takes 20 s. The time of emptying the tube can be adjusted a little by fastening or loosening the plug in the tube.

The measurement is performed by emptying the tube directly towards the water surface in the closet. The distance between the rubber plug and the water surface shall be 1 m.

The observation period is 20 s.

The final results should be the average value on energy basis of three measurements.

7.5.3.5. Ventilation systems

The part of a ventilation system placed in the dwelling normally consists of vents in living rooms and toilets for comfort ventilation, or cooker hoods in kitchens.

Generally, manually operated systems shall be set to the position with the highest noise level, normally the maximum speed or fully opened position of the vent.

Note - especially cooker hoods connected to a common ventilation system can generate a considerable noise, even when the vent is fully closed. Previous to a measurement is should be checked that the system has been adjusted to the correct air-flow.

An observation period of approximately 30 s is recommended.

7.5.3.6. Lifts

The lift is operated between the two storeys closest to the room in which the noise level is measured. The observation period shall include one opening and closing of the doors, one start and one stop of the lift, and the operation in between. Three measurements are carried out. If an increased number of microphone positions is used it may be suitable to increase the number of operations of the lift accordingly.

7.5.4. Correction for background noise

If the background noise level is 4-10 dB below the sound pressure level of the installation, the measurement result shall be corrected. A difference of 4 dB corresponds to a correction value of 2.2 dB. If the difference is less than 4 dB, the correction value should be limited to 2.2 dB, and in the report it shall be stated that the measurement result is influenced by background noise.

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ANNEX A.1

REVERBERATION TIME IN ROOMS IN TYPICAL DWELLINGS

For some of the calculations in this report the reverberation time is needed. However, theoretical calculations of the reverberation time in typical rooms in dwellings are very inaccurate, especially at low frequencies, where the absorption coefficient of e.g. lightweight building constructions is difficult to estimate.

As realistic values of the reverberation time measurement results from 51 routine measurements carried out by the Danish Technological Institute have been analyzed. The measurements have been performed in empty rooms with volumes in the range 5-122 m^3. One loudspeaker position and six microphone positions were used and two decays were recorded in each microphone position.

Most of the rooms with volumes below 15 m^3 were bathrooms with clinker floors. The majority of the rooms with volumes of 15-122 m^3 were living rooms or kitchens with wooden floors. In some of the kitchens clinker floors have been used.

In figure A1 is shown the mean reverberation time for groups of rooms with volumes as stated below the figure.

The following numbers of measurement results have been used in the calculated average reverberation time in the different groups:

5- 14 m^3:	15 measurements
15- 24 m^3:	9 measurements
40- 60 m^3:	11 measurements
65-122 m^3:	16 measurements

ANNEX A.2

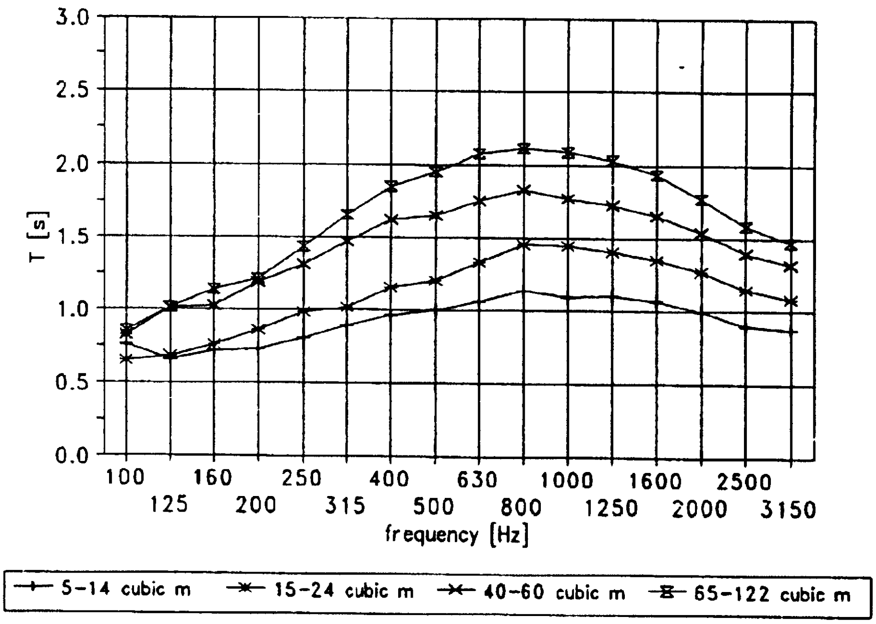


Figure A1. Reverberation time measured in empty rooms in dwellings as a function of the frequency.

ANNEX B.1

CALCULATIONS OF THE SOUND PRESSURE LEVEL DISTRIBUTION IN DIFFERENT ROOMS

To get an impression of the magnitude of the sound pressure level decay in reverberant and damped rooms respectively, calculations have been carried out by the computer programme "Odeon", version 1.0, developed by the Acoustical Laboratory of the Technical University of Denmark.

The version of the programme used in these calculations does not take into account scattering of reflections from the surfaces. Furthermore, all surfaces reflect with zero phase shift. To estimate the calculation errors because of these simplifications calculation results and measurement results have been compared for a hard walled room and for a long corridor with high absorbing floor and ceiling.

Calculations have been carried out for the following rooms:

1. Corridor with Annex and high absorbing ceiling and floor. (Comparing calculations and measurements)

2. Office with medium absorbing ceiling and reflecting floor. (Comparing calculations and measurements)

3. Right-angled room

   a. Reflecting boundaries
   b. Highly absorbing ceiling and floor

4. Rectangular room

   a. Reflecting boundaries
   b. Highly absorbing ceiling and floor

5. Rectangular room partly divided by a wall with a length of 2 m

   a. Reflecting boundaries
   b. Highly absorbing ceiling and floor

6. Rectangular room partly divided by a wall with a length of 4 m

   a. Reflecting boundaries
   b. Highly absorbing ceiling and floor

In calculation examples 1 and 2 a point source has been placed close to a corner of the room at the same positions as used in the measurements for the loudspeaker.

ANNEX B.2

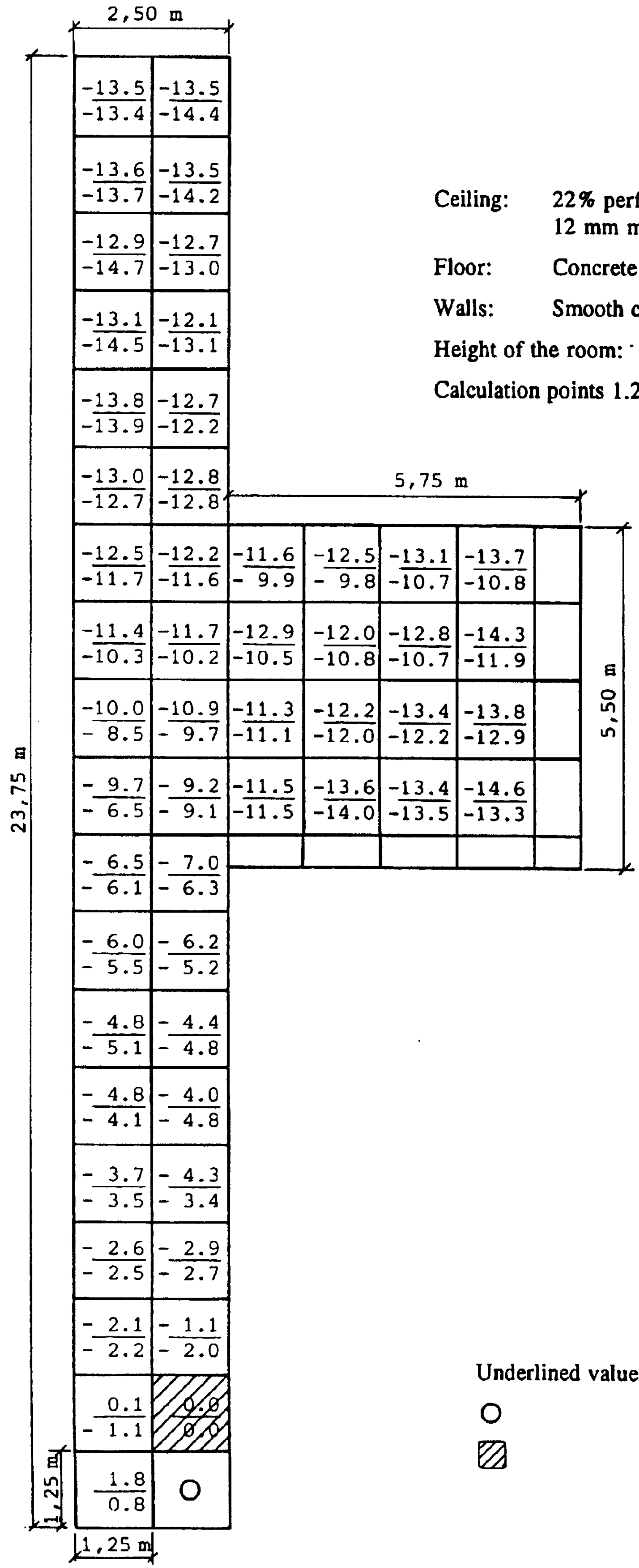
In the enclosed forms B3-B8 showing the calculation/measurement results a point close to the sound source has been chosen as a reference point (the square marked with hatching). All other sound pressure levels are given with reference to this point.

Exclusively results for the 1000 Hz 1/3 octave band are presented.

It can be seen from calculation examples 1 and 2 that the agreement between calculations and measurements is good.

ANNEX B.3

Example 1



Ceiling: 22% perforated steelpanels with 12 mm mineralwool in the cavity

Floor: Concrete + 5 mm needle felt

Walls: Smooth concrete, painted

Height of the room: 2.8 m

Calculation points 1.2 m above floor level

Underlined values = measurement results

○ = sound source

▨ = reference position

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ANNEX B.4

Example 2

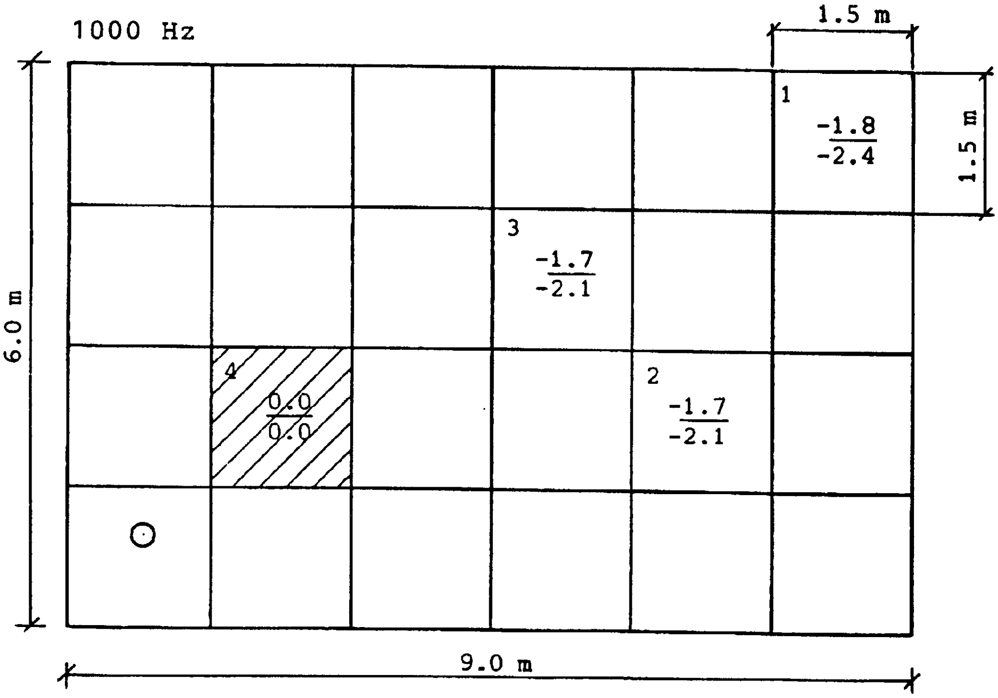
Ceiling: 14% perforated plasterboard with 15 mm mineralwool in the cavity

Floor: Concrete + linoleum

Walls: Smooth brickwork with flush pointing, painted

Height of the room: 3.0 m

Calculation points 1.2 m above floor level



Underlined values = measurement results

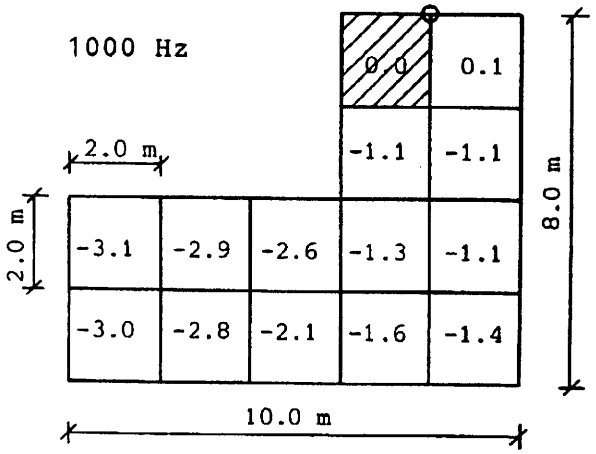
○ = sound source

▨ = reference position

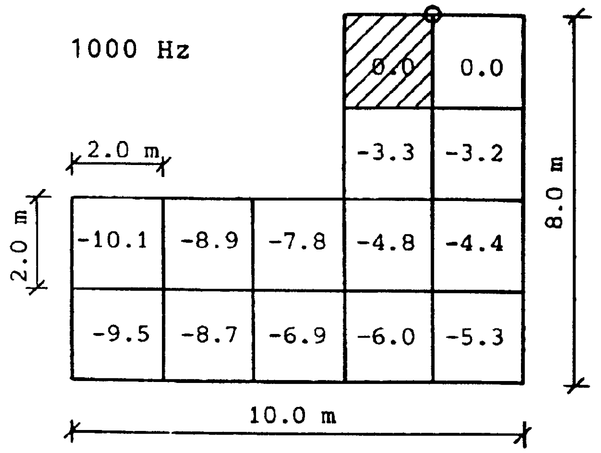
ANNEX B.5

Example 3

Ceiling: 13 mm plasterboard
Floor: Wooden floor on joists
Walls: Smooth brickwork with flush pointing
Height of the room: 2.5 m
Calculation points 1.10 m above floor level



Ceiling: Suspended mineralwool ($\alpha = 0.8$ in the entire frequency range)
Floor: Wooden floor on joists + carpet
Walls: Smooth brickwork with flush pointing
Height of the room: 2.5 m
Calculation points 1.10 m above floor level



O = sound source
▨ = reference position

ANNEX B.6

Example 4

Ceiling: 13 mm plasterboard

Floor: Wooden floor on joists

Walls: Smooth brickwork with flush pointing

Height of the room: 2.5 m

Calculation points 1.10 m above floor level

1000 Hz

-2.1	-1.9	-1.9	-1.4	-1.4	-1.1
-2.0	-2.1	-1.8	-1.7	-1.2	0.0
-2.0	-1.9	-2.0	-1.7	-1.2	-0.1
-2.0	-1.9	-1.8	-1.8	-1.4	-1.3

1.5 m; 1.5 m; 6.0 m; 9.0 m

Ceiling: Suspended mineralwool ($\alpha = 0.8$ in the entire frequency range)

Floor: Wooden floor on joists + carpet

Walls: Smooth brickwork with flush pointing

Height of the room: 2.5 m

Calculation points 1.10 m above floor level

1000 Hz

-5.8	-5.6	-5.3	-4.8	-4.1	-3.2
-5.7	-6.0	-5.3	-4.8	-3.5	0.0
-5.9	-5.7	-5.6	-4.9	-3.5	-0.1
-6.0	-5.7	-5.3	-5.3	-4.1	-3.2

1.5 m; 1.5 m; 6.0 m; 9.0 m

○ = sound source

▨ = reference position

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ANNEX B.7

Example 5

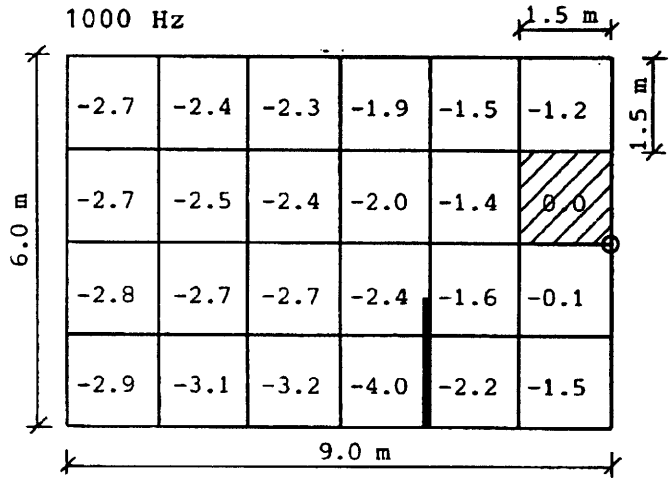
Ceiling: 13 mm plasterboard

Floor: Wooden floor on joists

Walls: Smooth brickwork with flush pointing

Height of the room: 2.5 m

Calculation points 1.10 m above floor level



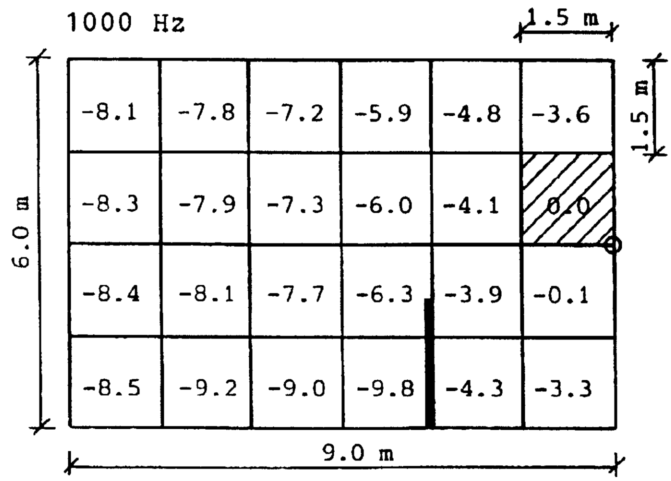
Ceiling: Suspended mineralwool ($\alpha = 0.8$ in the entire frequency range)

Floor: Wooden floor on joists + carpet

Walls: Smooth brickwork with flush pointing

Height of the room: 2.5 m

Calculation points 1.10 m above floor level



O = sound source

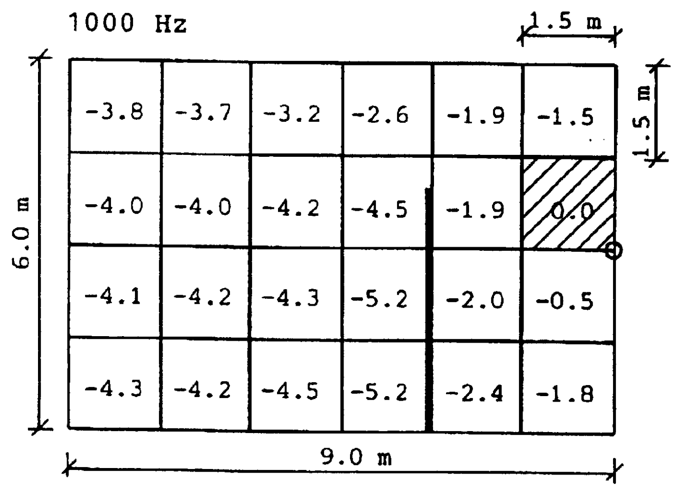
▨ = reference position

❙ = wall partly dividing the room

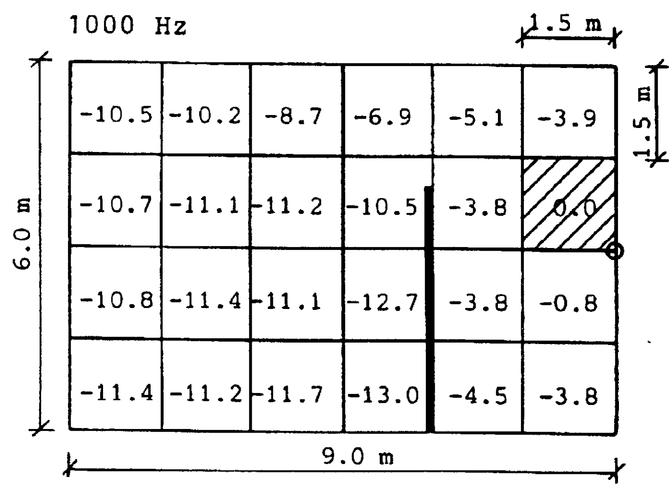
ANNEX B.8

Example 6

Ceiling: 13 mm plasterboard
Floor: Wooden floor on joists
Walls: Smooth brickwork with flush pointing
Height of the room: 2.5 m
Calculation points 1.10 m above floor level



Ceiling: Suspended mineralwool (α = 0.8 in the entire frequency range)
Floor: Wooden floor on joists + carpet
Walls: Smooth brickwork with flush pointing
Height of the room: 2.5 m
Calculation points 1.10 m above floor level



○ = sound source
▨ = reference position
❙ = wall partly dividing the room

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ANNEX C.1

DIAGRAMMATIC SKETCHES OF LOUDSPEAKER AND MICROPHONE POSITIONS IN ROOMS WITH DIFFERENT SHAPES

Efforts have been made to present examples - some very realistic and some very unusual - which as a whole should permit one to select an example based on which a suitable measurement set up can be established in nearly all field situations.

The loudspeaker, tapping machine and microphone positions indicated on the sketches should only be considered as a guidance with the purpose to show in which part of the rooms the positions should be placed. All requirements in ISO 140 Part 4 concerning distances to room boundaries, displacement of the loudspeakers in relation to planes parallel to room boundaries etc. shall of course be fulfilled.

ANNEX C.2

SYMBOLS:

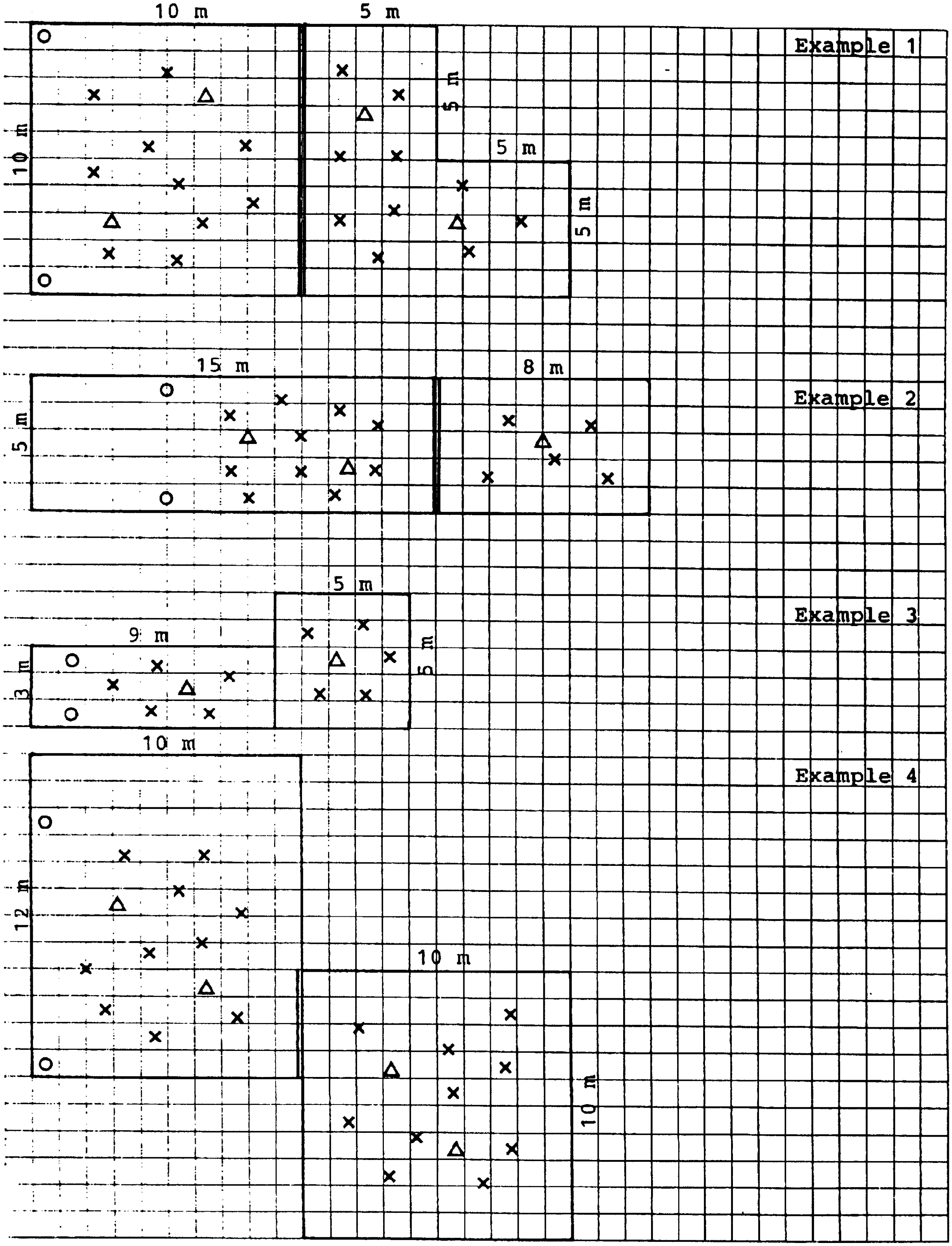
○	=	Loudspeaker
●	=	Tapping machine
×	=	Fixed microphone
△	=	Rotating microphone
———	=	Contour of rooms (U = upper room, L = lower room)
– – – –	=	Contour of lower room with correct placing related to upper room
═══	=	Test object
— · —	=	Limitation of floor area

All examples are horizontal sections.

AIRBORNE SOUND INSULATION

ANNEX C.3

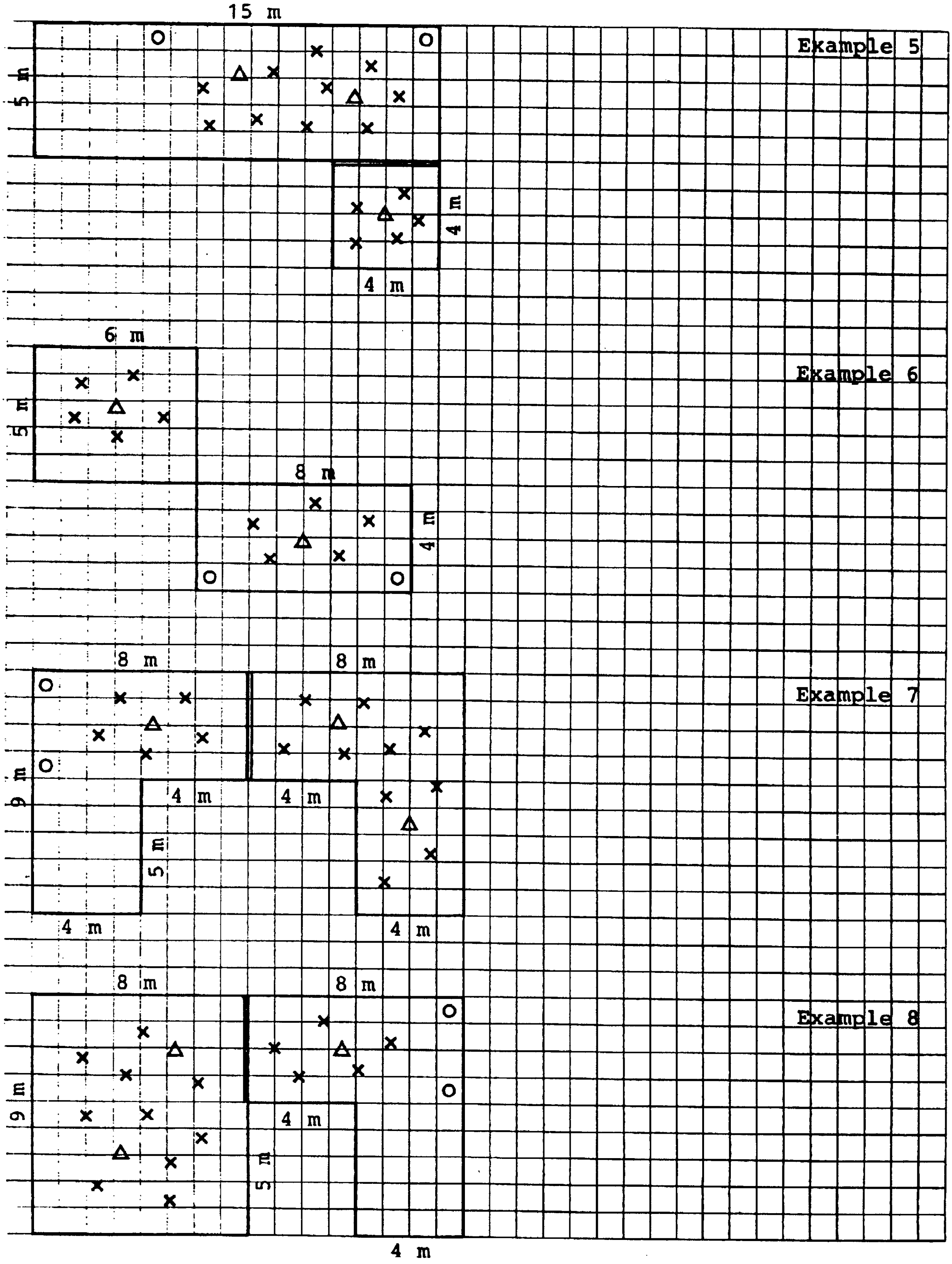
Horizontal measurements, scale 1:200



AIRBORNE SOUND INSULATION

ANNEX C.4

Horizontal measurements, scale 1:200



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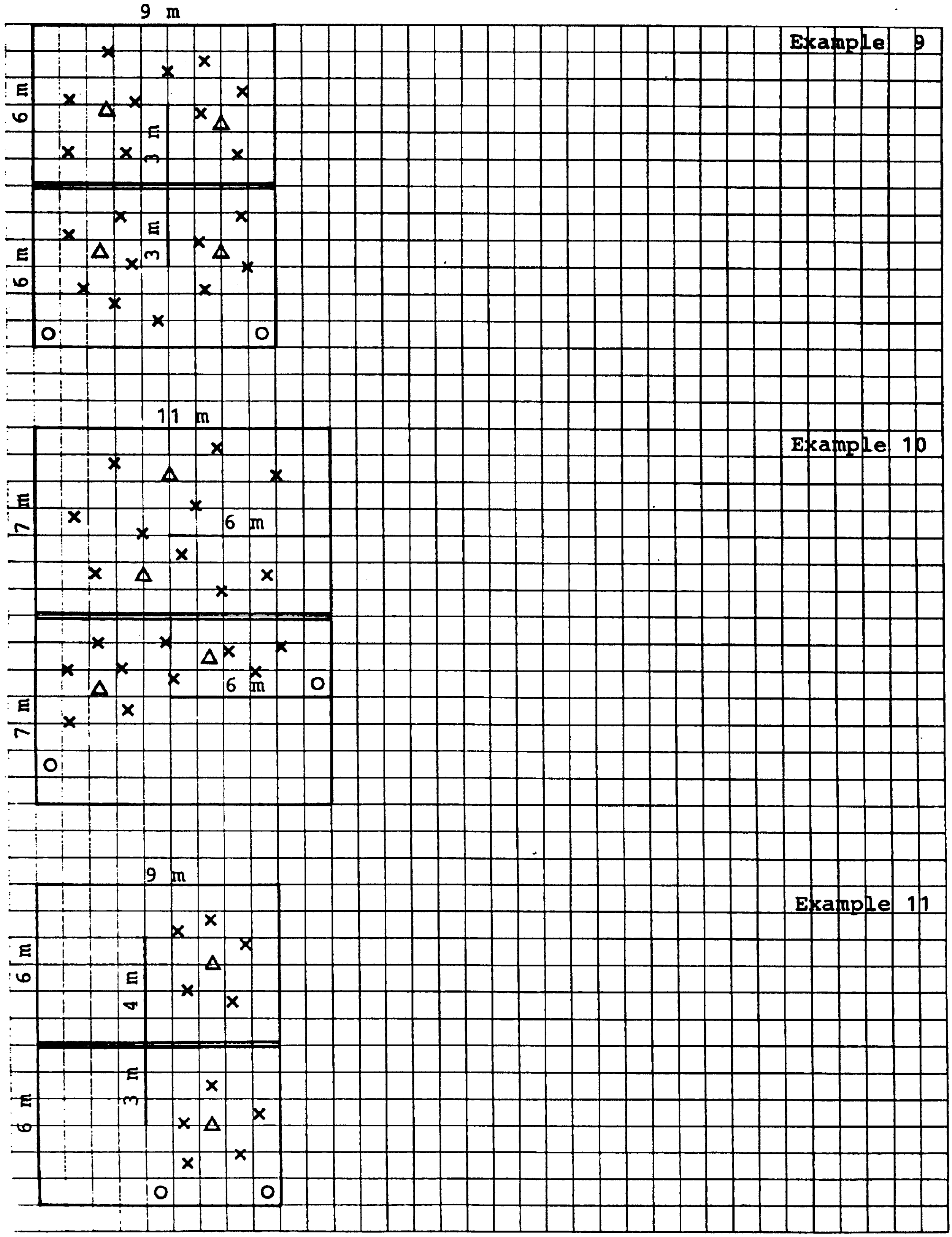
AIRBORNE SOUND INSULATION **ANNEX C.5**

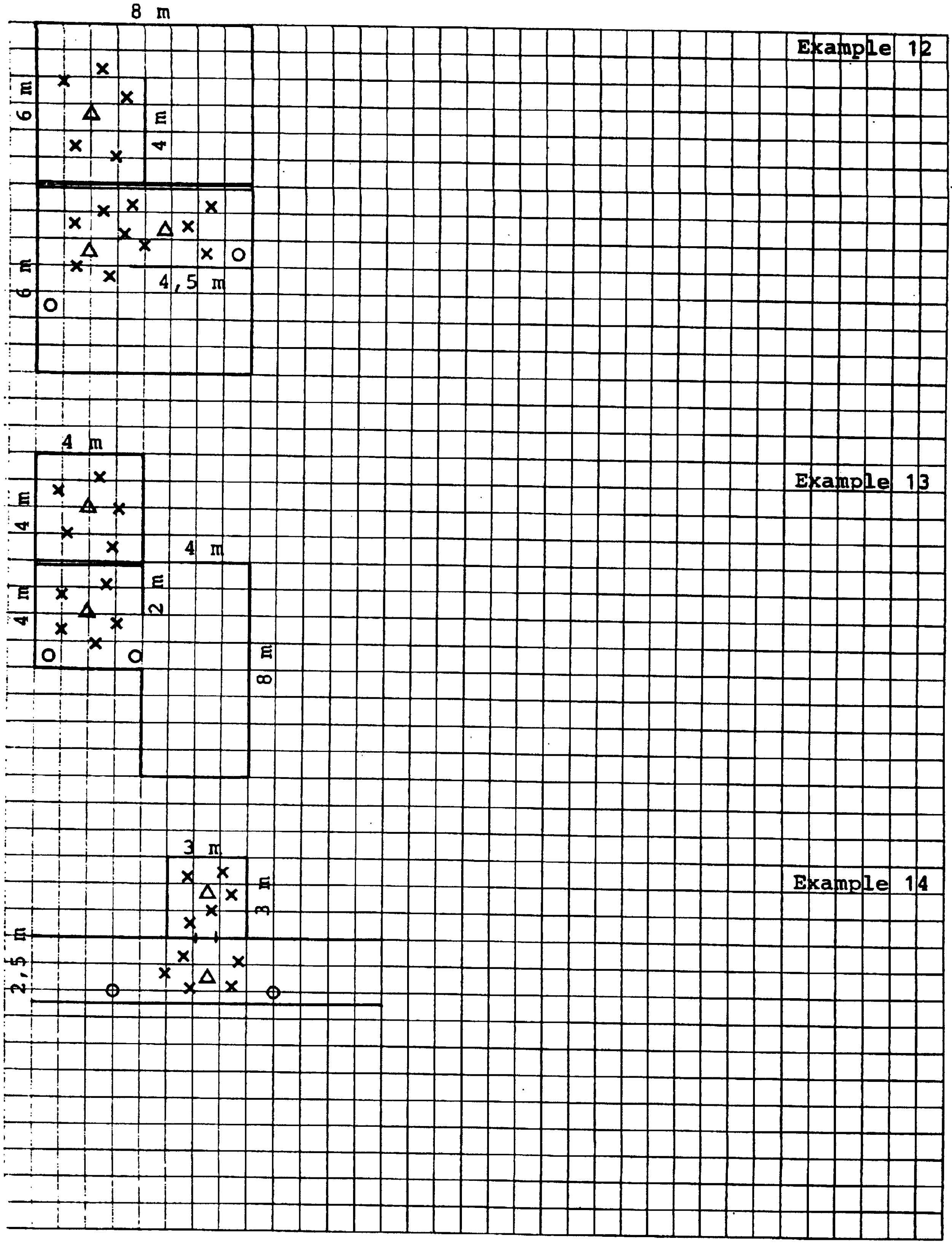
Horizontal measurements, scale 1:200



AIRBORNE SOUND INSULATION

ANNEX C.6

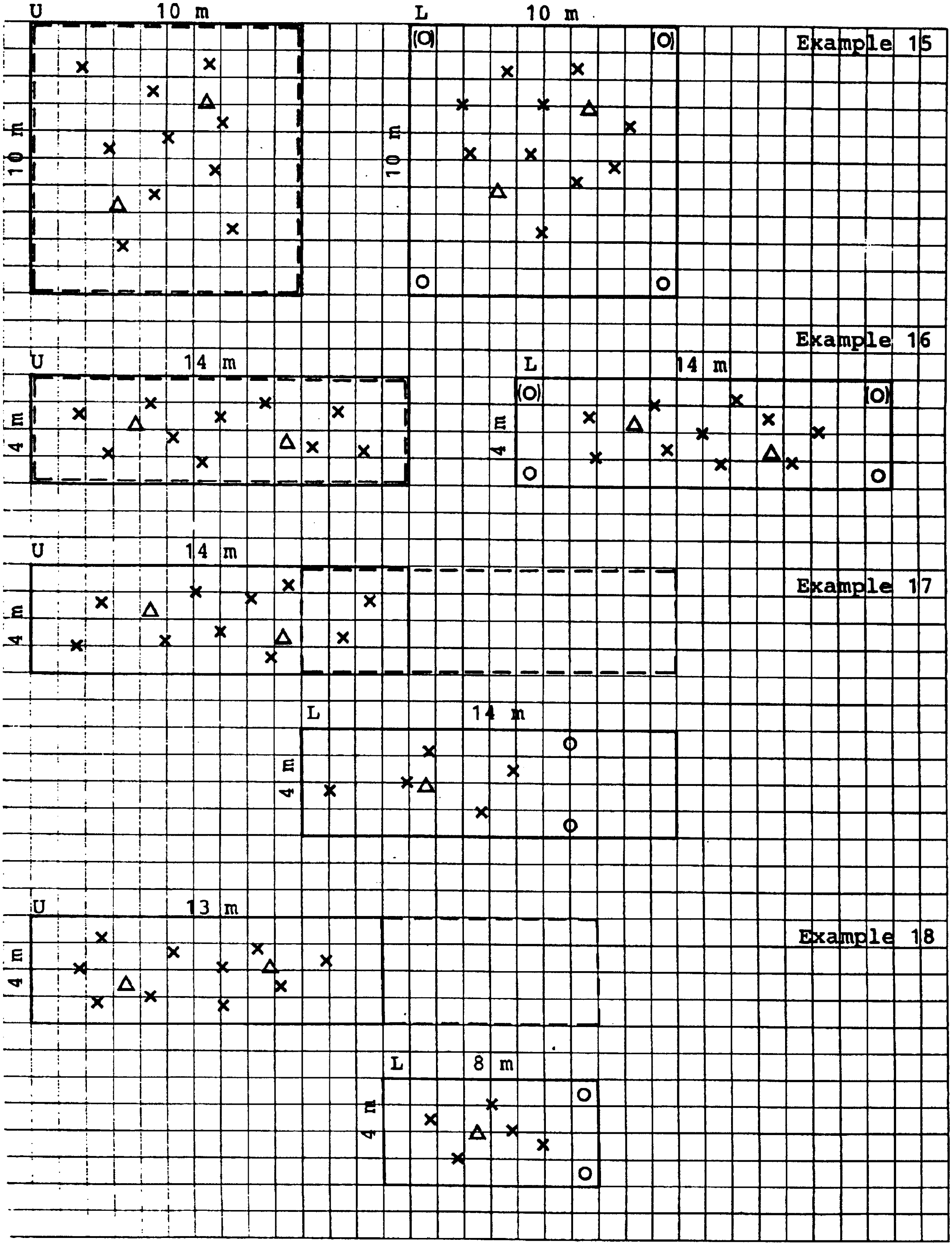
Horizontal measurements, scale 1:200



AIRBORNE SOUND INSULATION **ANNEX C.7**

Vertical measurements, scale 1:200

(Alternative loudspeaker positions are shown in brackets)

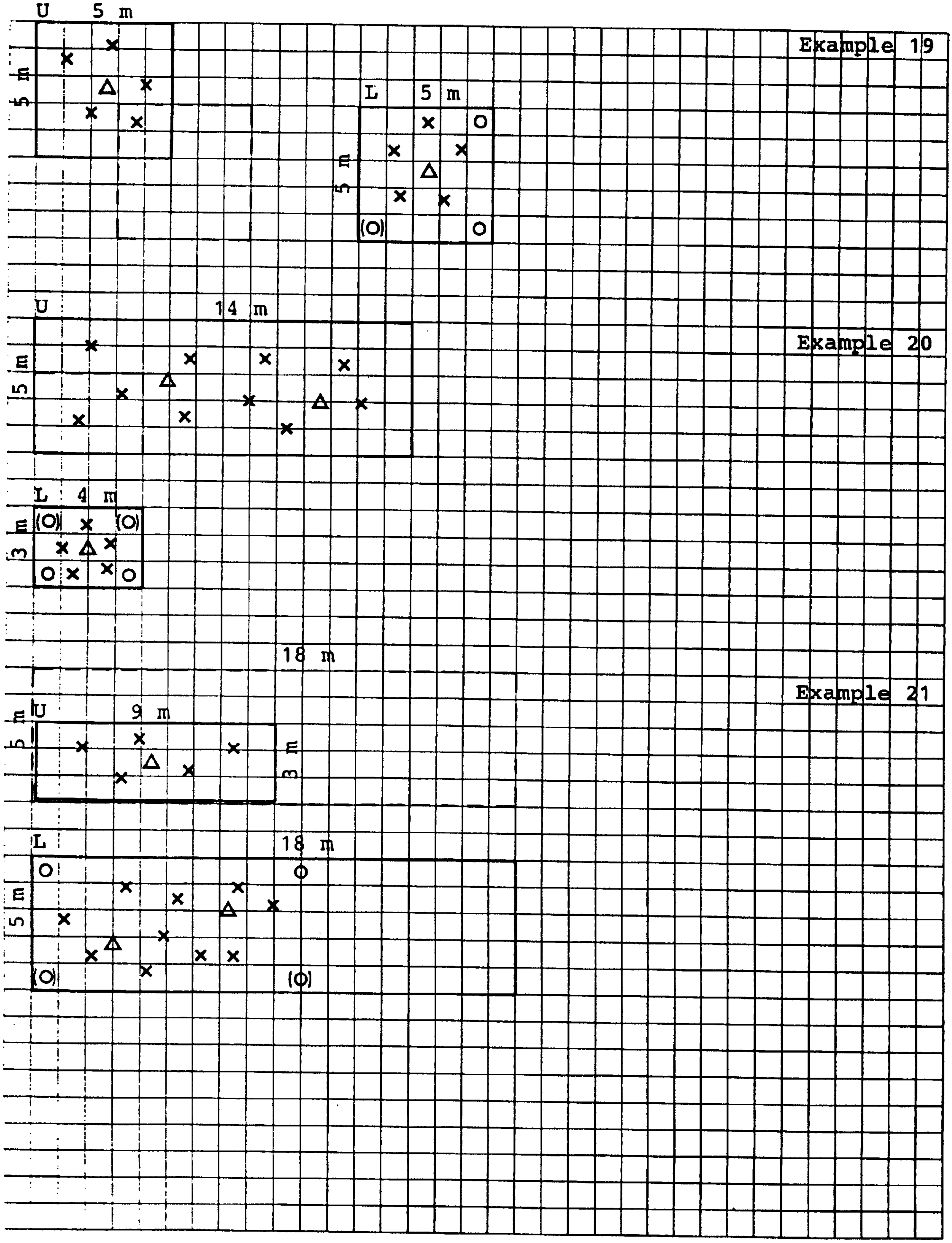


AIRBORNE SOUND INSULATION

ANNEX C.8

Vertical measurements, scale 1:200

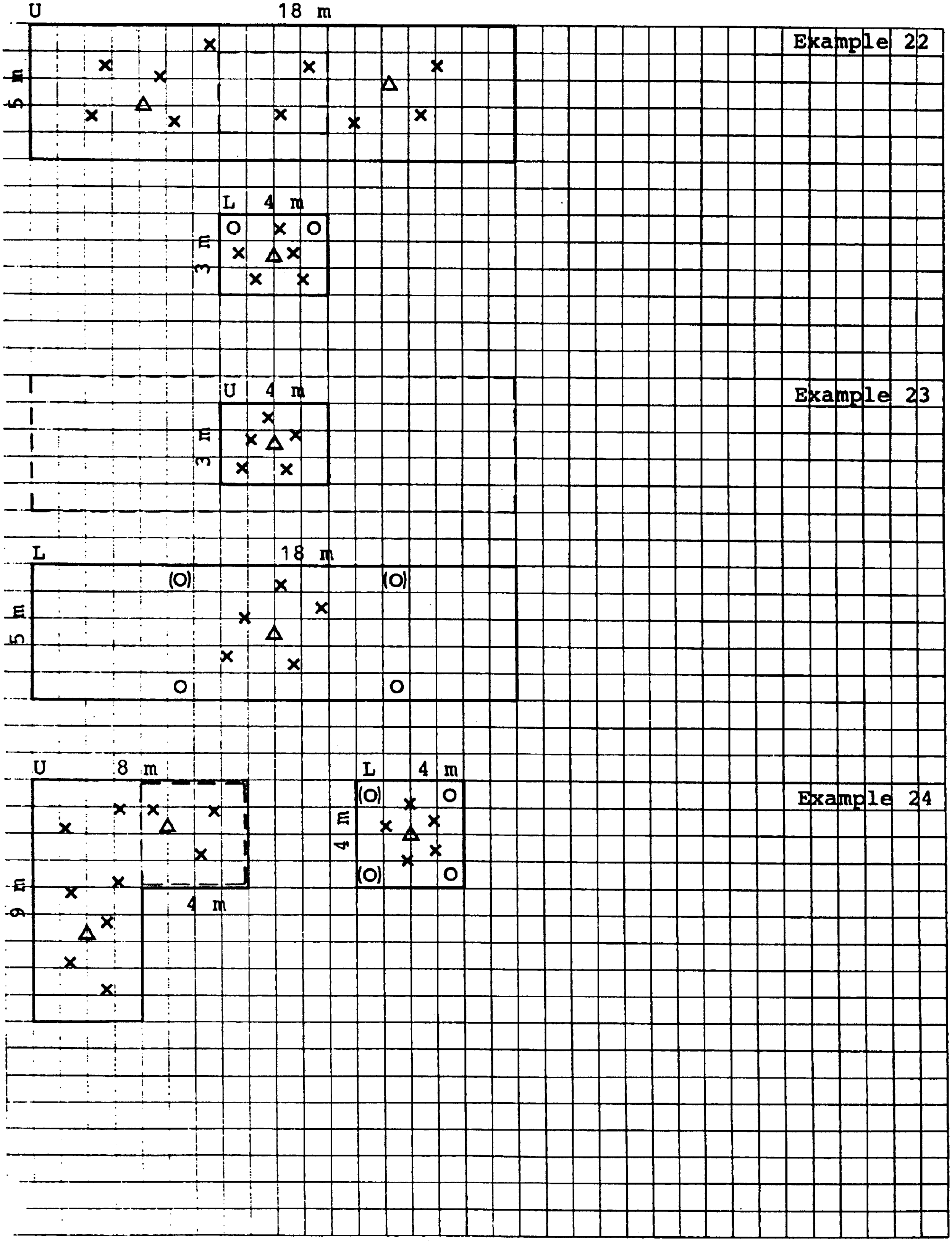
(Alternative loudspeaker positions are shown in brackets)



AIRBORNE SOUND INSULATION **ANNEX C.9**

Vertical measurements, scale 1:200

(Alternative loudspeaker positions are shown in brackets)



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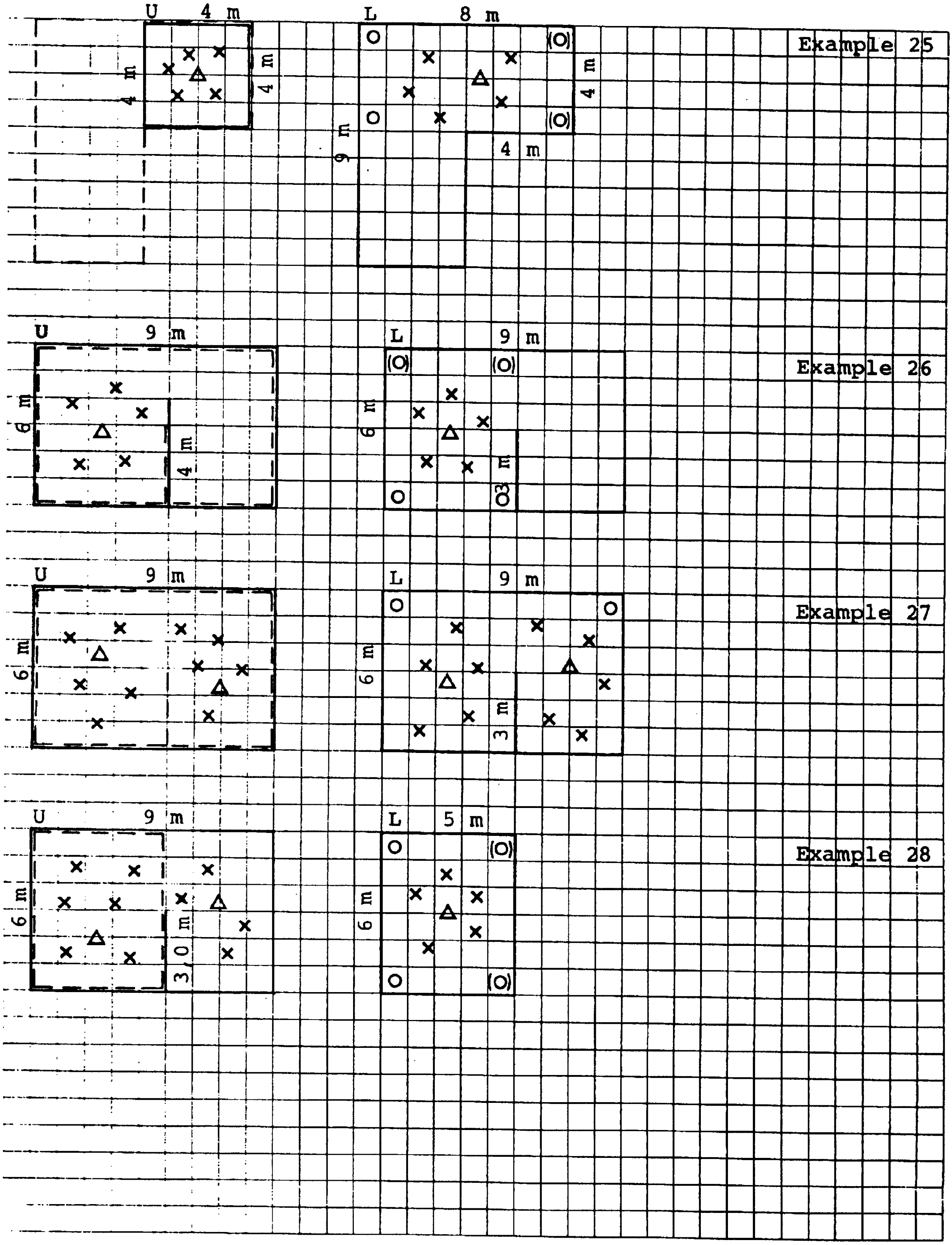
AIRBORNE SOUND INSULATION **ANNEX C.10**

Vertical measurements, scale 1:200

(Alternative loudspeaker positions are shown in brackets)



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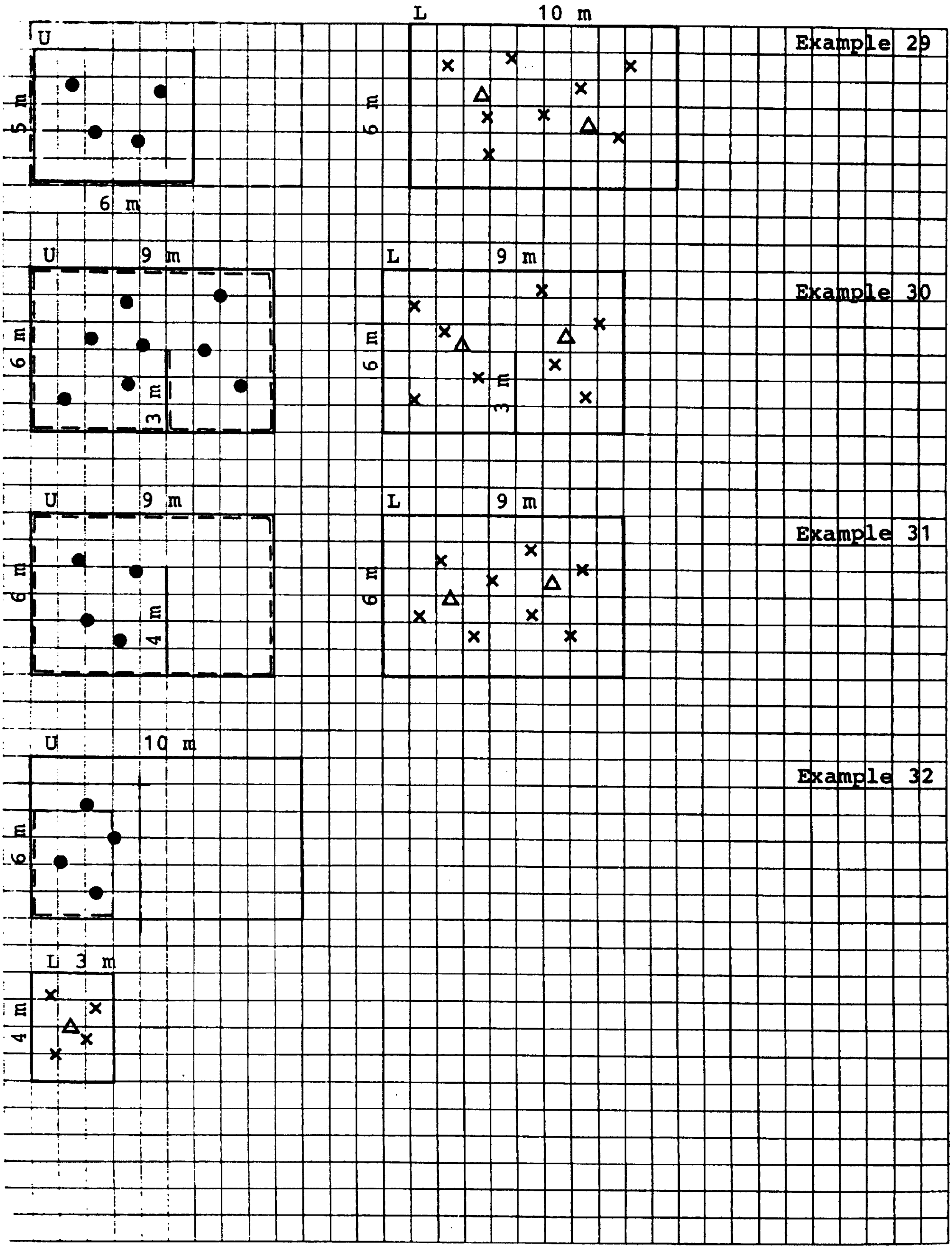
IMPACT SOUND INSULATION **ANNEX C.11**

Vertical measurements, scale 1:200



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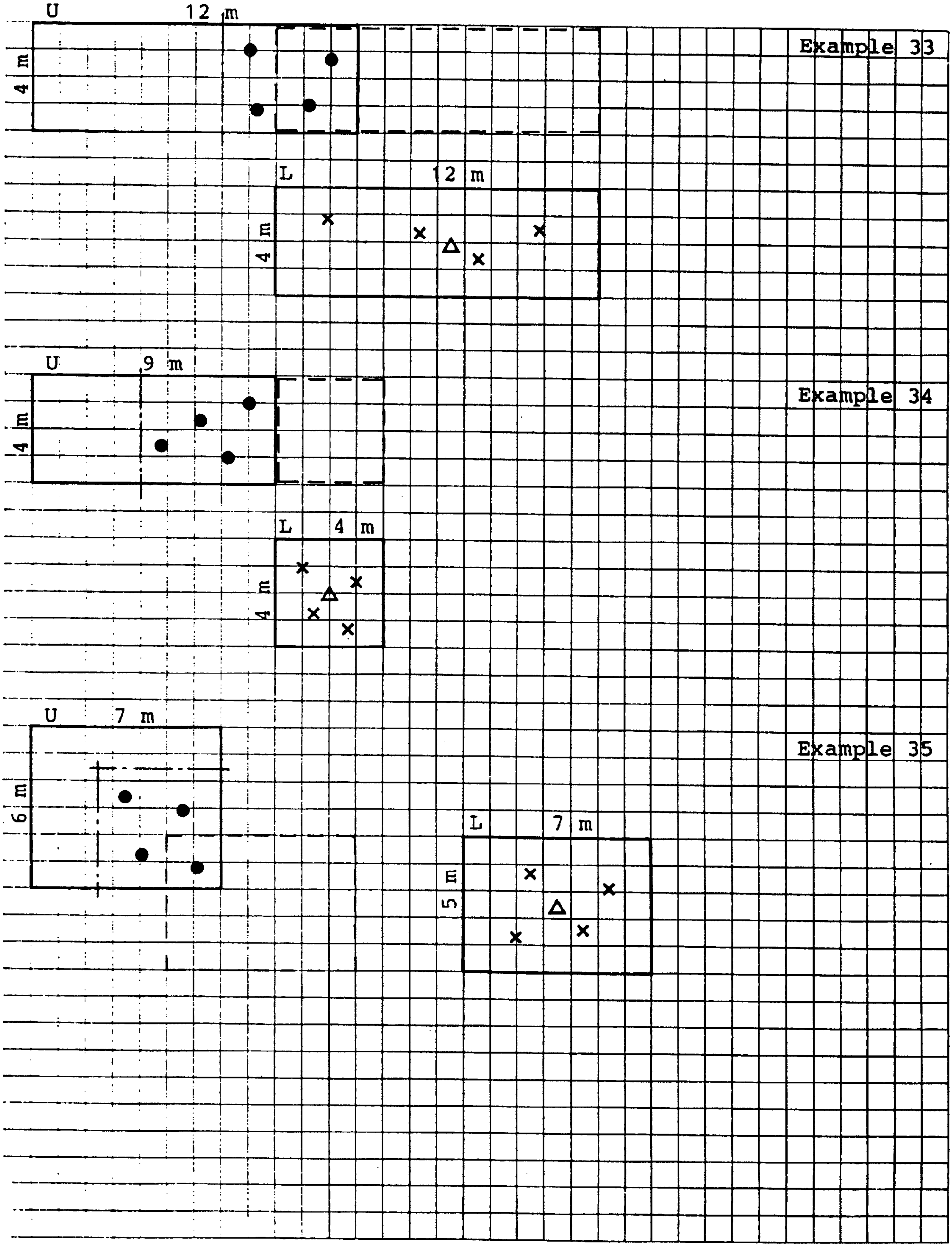
IMPACT SOUND INSULATION **ANNEX C.12**

Vertical measurements, scale 1:200



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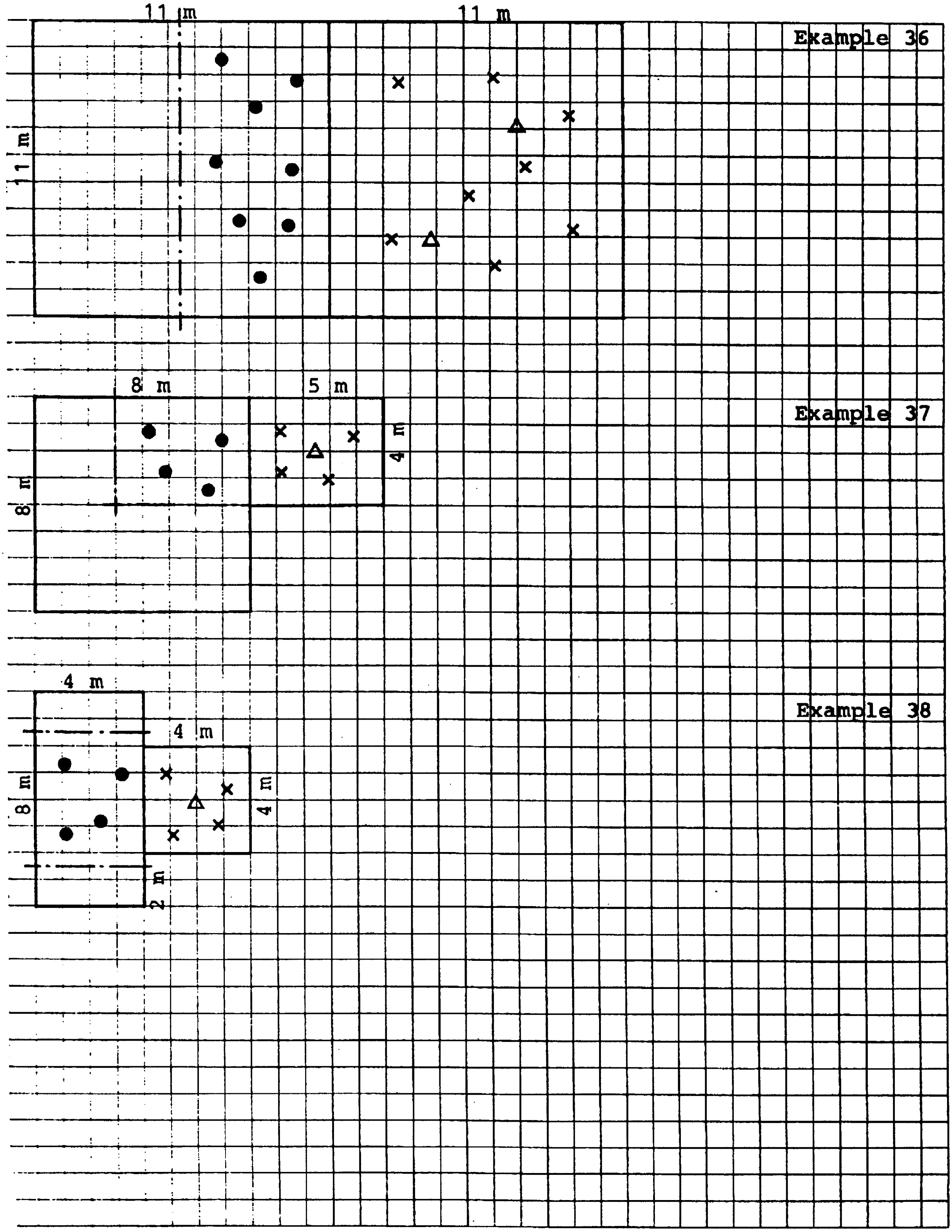
IMPACT SOUND INSULATION **ANNEX C.13**

Horizontal measurements, scale 1:200



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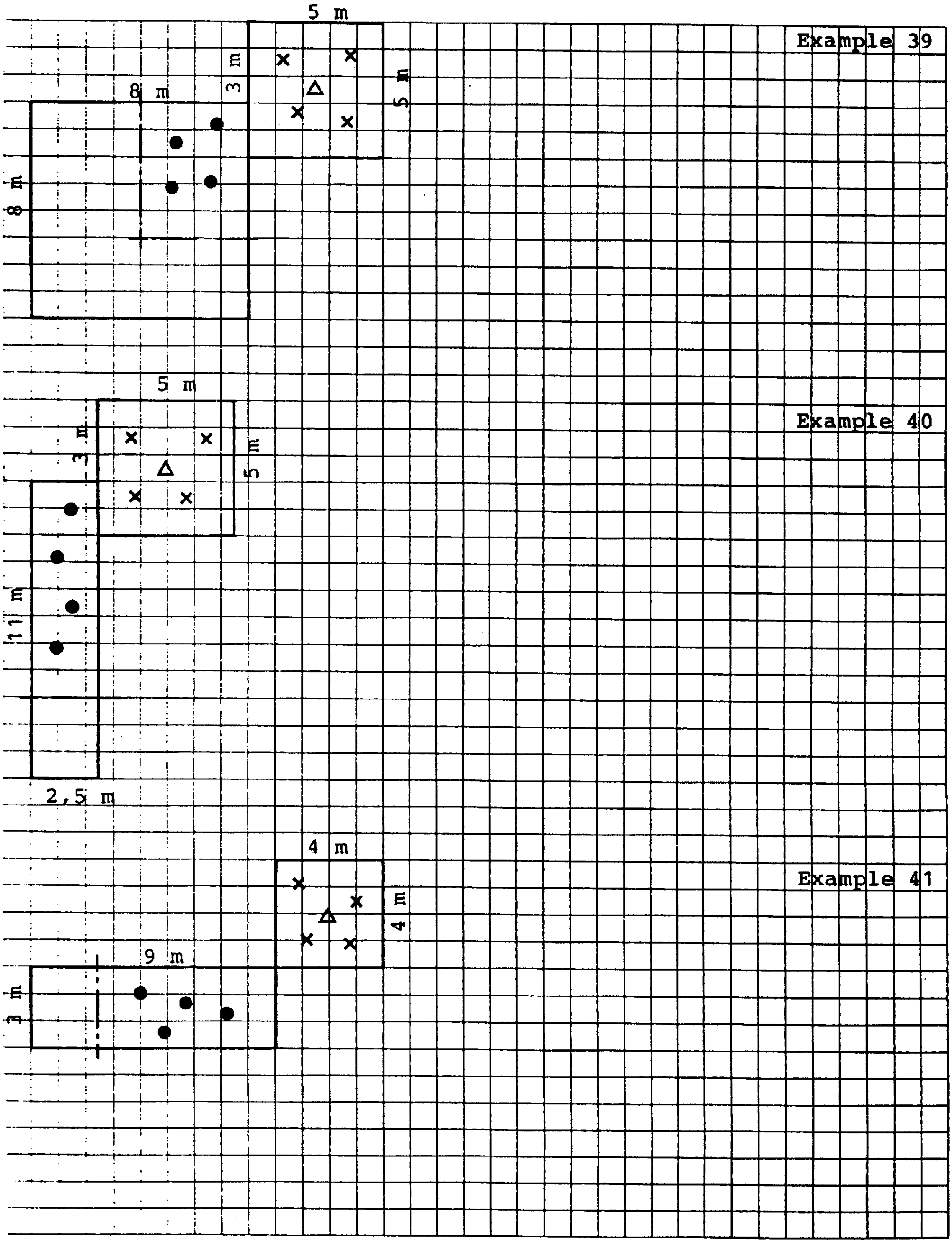
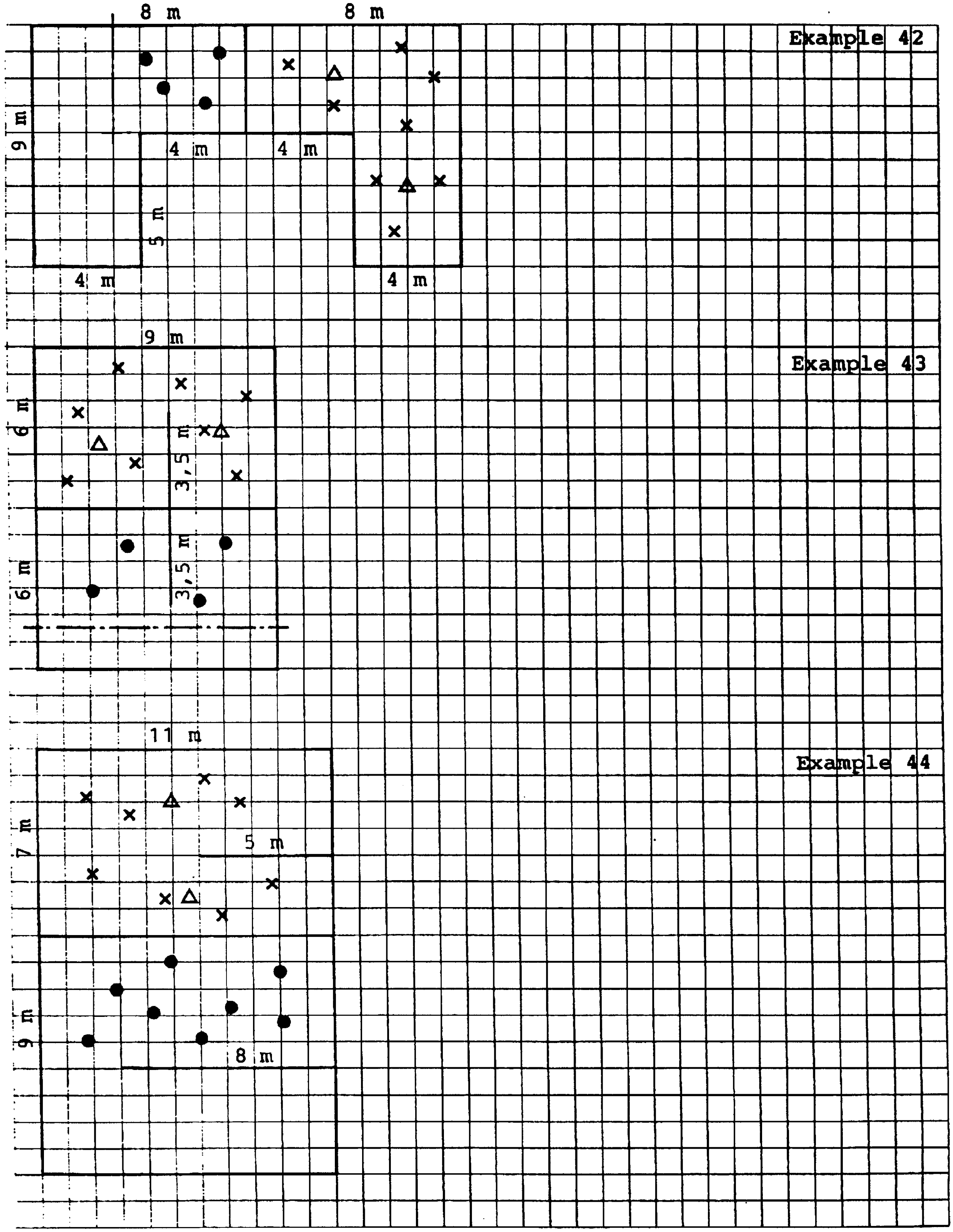
IMPACT SOUND INSULATION **ANNEX C.14**

Horizontal measurements, scale 1:200



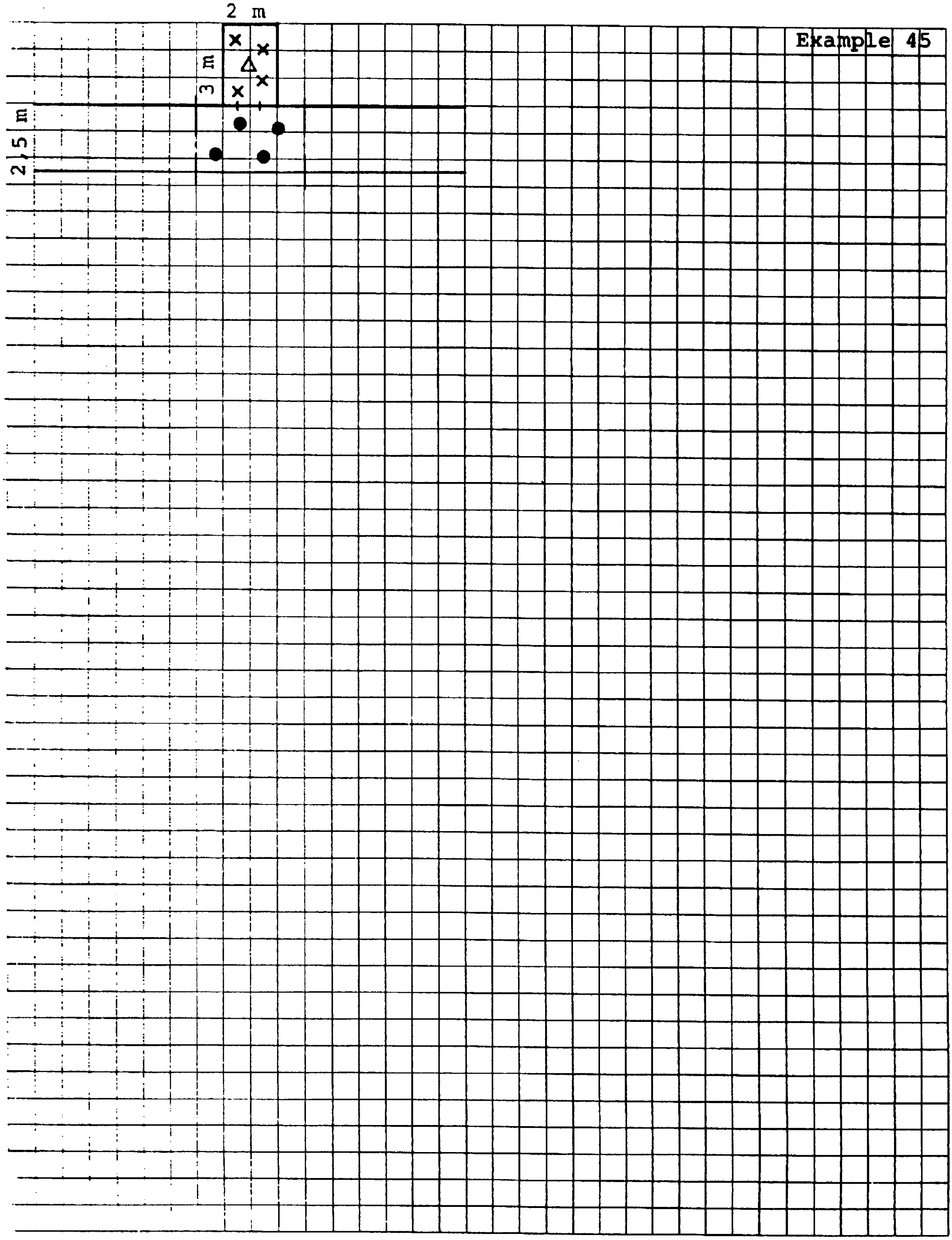
IMPACT SOUND INSULATION **ANNEX C.15**

Horizontal measurements, scale 1:200



IMPACT SOUND INSULATION **ANNEX C.16**

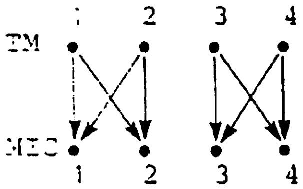
Horizontal measurements, scale 1:200



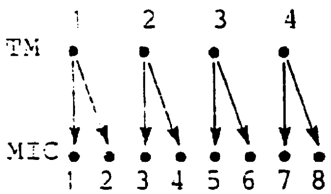
ANNEX C.17

Fixed microphone

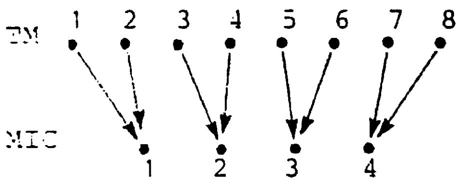
(4/4)



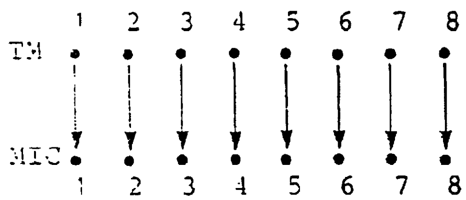
(4/8)



(8/4)

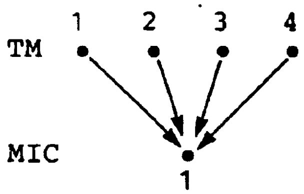


(8/8)

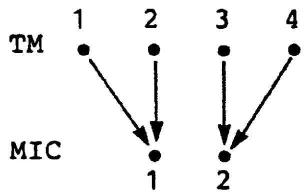


Rotating microphone

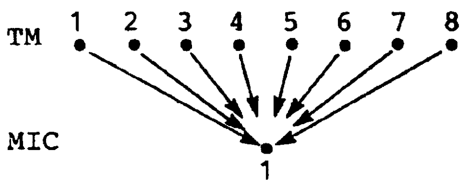
(4/1)



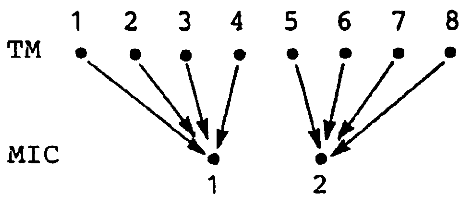
(4/2)



(8/1)



(8/2)



TM = tapping machine position

MIC = microphone position

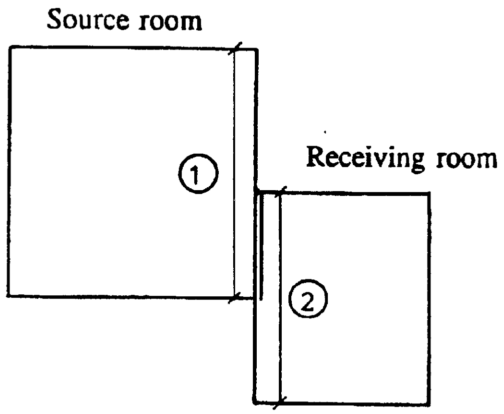
(x/x) = (number of tapping machine positions/number of microphone positions)

(4/4) = minimum number of positions stated in ISO 140 Part 7

ANNEX C.18

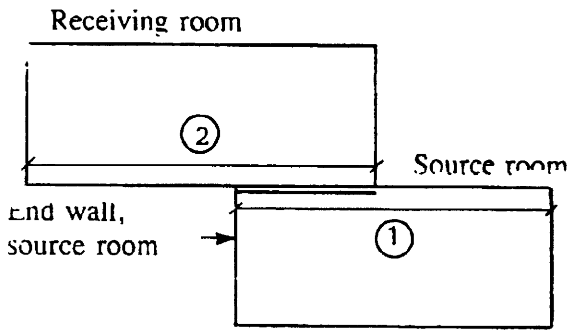
DEFINITIONS

For horizontal measurements the following definitions are used (horizontal section):



═══	Test object
①	Partition wall, source room
②	Partition wall, receiving room

For vertical measurements the following definitions are used (vertical section):



═══	Test object
①	Partition, source room
②	Partition, receiving room

ANNEX D.1

NUMERICAL VALUES OF THE CURVES IN FIGURE 4.15

Frequency Hz	Volume, m³					
	10	15	30	50	100	250
100	6.46	6.26	5.78	5.34	4.58	3.49
125	6.11	5.81	5.17	4.62	3.79	3.00
160	5.54	5.14	4.35	3,75	2.94	2.56
200	4.86	4.39	3.55	2.98	2.26	2.25
250	4.08	3.59	2.80	2.29	1.96	1.92
325	3.26	2.80	2.11	1.70	1.66	1.59
400	2,48	2.10	1.55	1.52	1.45	1.33
500	1,88	1.57	1.46	1.33	1.27	1.16
630	1,38	1.41	1.27	1.16	1.09	1.03
800	1,25	1.21	1.10	1.04	0.95	0.93
1000	1,18	1.09	0.99	0.94	0.88	0.85
1250	1.06	0.98	0.92	0.87	0.81	0.80
1600	0.94	0.91	0.82	0.78	0.75	0.74
2000	0.89	0.85	0.77	0.73	0.70	0.72
2500	0.90	0.81	0.72	0.71	0.68	0.67
3150	0.81	0.73	0.68	0.67	0.65	0.64
4000	0.78	0.70	0.65	0.61	0.61	0.64
5000	0.71	0.68	0.62	0.58	0.62	0.66

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