TECHNICAL REPORT

ISO/TR 11690-3

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Acoustics — Recommended practice for the design of low-noise workplaces containing machinery —

Part 3:
Sound propagation and noise prediction in workrooms

Acoustique — Pratique recommandée pour la conception de locaux de travail à bruit réduit contenant des machines —

Partie 3: Propagation du son et prévision du bruit dans les locaux de travail

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Contents

Page

Annexes

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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 decice 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 Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.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 11690-3, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

ISO 11690 consists of the following parts, under the general title *Acoustics — Recommended practice for the design of low-noise workplaces containing machinery*:

— *Part 1: Noise control strategies*

— *Part 2: Noise control measures*

— *Part 3: Sound propagation and noise prediction in workrooms*

Introduction

This Technical Report is intended for use by all parties involved in noise reduction in workplaces and design of low-noise workplaces. The objective is:

- to make them aware of what is the current technical consensus regarding sound propagation and noise prediction in workrooms,
- to aid the interaction between them within a common technical framework,
- to promote the understanding of the desired noise control requirements.

This Technical Report provides the connection between the emission of sound sources e.g. machines and the sound pressure level at workstations caused by their operation in a workroom. Therefore, it allows an interchange of information between machine suppliers, who are responsible for noise emission values, and machine users, who require low noise immission values.

A further target is the assessment of the acoustical performance of a workroom.

These tasks are connected by the determination of the sound propagation descriptors of a workroom.

A methodology for noise prediction in workrooms is presented and a structure is given for the classification of prediction methods according to the level of detail of input parameters.

Acoustics — Recommended practice for the design of low-noise workplaces containing machinery — Part 3 : Sound propagation and noise prediction in workrooms

1 Scope

In this part of ISO 11690, sound propagation in a room is considered together with the prediction of sound pressure levels and of noise immission at the workplace.

Details of the description of the physical phenomena involved in a noise prediction scheme are strongly dependent on the situation being considered and the way this situation is modelled (input parameters, calculation techniques). This dependency is surveyed and the methodology for noise prediction is described. Recommendations are provided concerning the use of noise prediction as an aid for noise control in workrooms. Examples of use of noise prediction methods are given in annexes A to E.

2 References

References listed in ISO 11690-1 should also be consulted when using this Technical Report.

3 Definitions

Definitions given in ISO 11690-1 apply to this Technical Report.

4 Basic principles of sound propagation in rooms

4.1 Sound propagation descriptors

A basic element for noise prediction in workrooms is the prediction of the distribution of sound pressure levels caused by an omnidirectional point source. This distribution is influenced by :

- the shape and the volume of the room,
- the absorption of the surfaces,
- the fittings.

The resulting sound level distribution can be considered using a spatial sound distribution curve (see definition 3.4.11 of part 1 and figures 1 and 2 of this Technical Report). The information contained in this curve can be summarized, for a given distance range, by two quantities (see definitions 3.4.12 and 3.4.13 of part 1) :

- the rate of spatial decay of sound pressure level per distance doubling (DL2),
- the excess of sound pressure level with respect to a free field (DLf).

The spatial sound distribution curve and these two quantities are used to describe the acoustical characteristics of a room. The sound pressure level caused by a given source is indeed smaller if DLf is low and DL2 is high (see 6.3 of part 2). Annex D shows how the acoustical characteristics of a room can be described from spatial sound distribution curves.

The spatial sound distribution curve is determined on a free path with no obstacle between the source and the receiver. For its measurement, see 8.4 of part 2.

NOTES

1 An International Standard specific to the measurement of spatial sound distribution curves in rooms is in preparation (ISO 14257 presently at the stage of draft).

2 When sound sources (machines) with dimensions too large to be neglected are considered, the sound distribution curve may differ from that of a point source for distances less than the typical dimension of the machine.

4.2 Rooms with diffuse sound fields

If diffuse sound field conditions are met (see definitions 3.4.8 and 3.4.9 of part 1), at a certain distance from the source, sound pressure levels are nearly constant and independent of receiver position, as shown in figure 1.

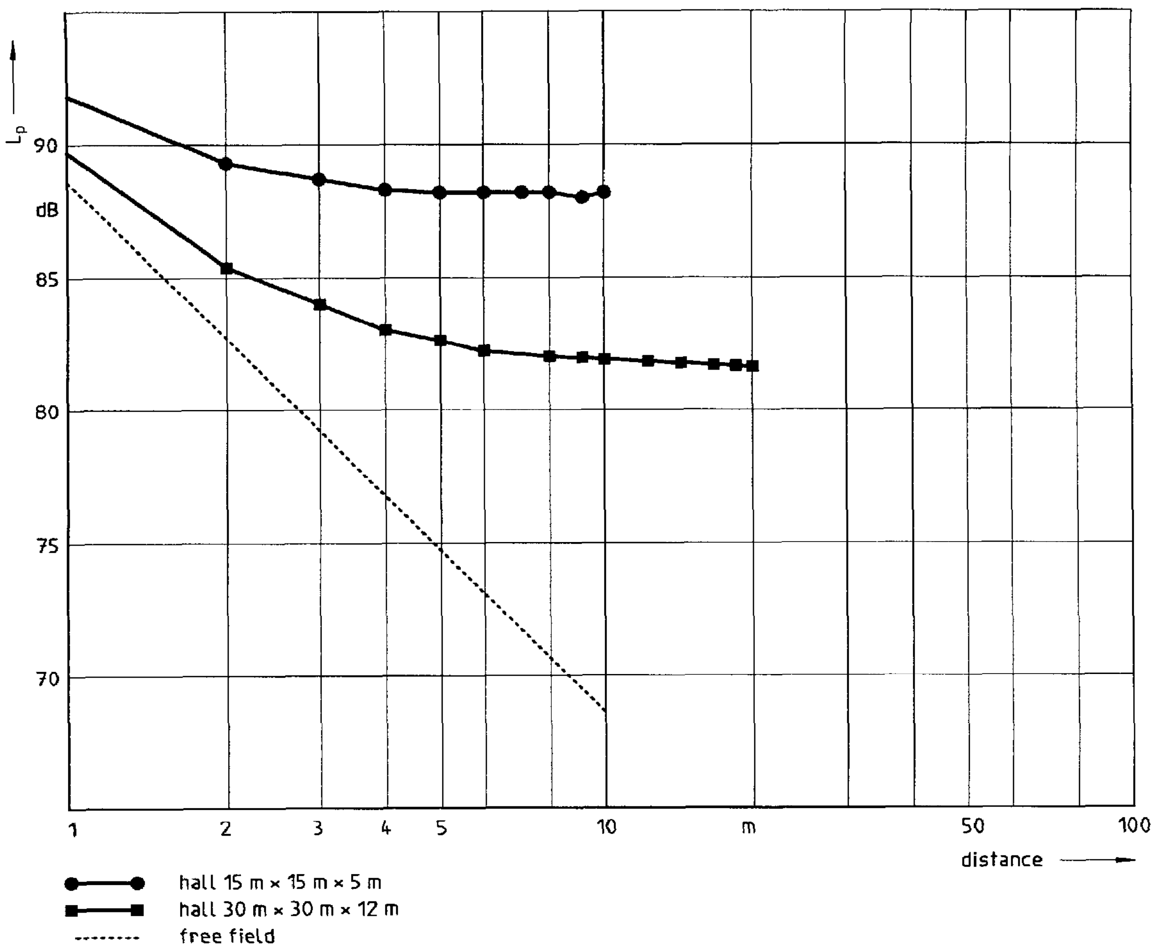

Figure 1 : Examples of spatial sound distribution curves for an omnidirectional point source and two rooms with different sizes, equal absorption coefficients and diffuse field. The dotted curve is the spatial sound distribution curve under total free field conditions. L_p denotes the sound pressure level at a given point when the sound power level of the source is 100 dB.

The sound pressure level of the diffuse field depends only on the total sound power level of all sources in the room and on the equivalent absorption area A. In rooms with a diffuse sound field, there is a direct connection between the reverberation time and the expected spatial sound distribution curve. It is therefore also possible to qualify such rooms by their reverberation time. In this case, noise prediction is relatively simple.

4.3 Rooms with uniform sound propagation

In many workrooms, diffuse sound field conditions cannot be assumed e.g. because the height of the room is less than one third of the length (flat rooms). In such rooms, even far from the source, the sound field depends on the position being considered and is characterized by a spatial sound distribution curve.

In many workrooms, it can be assumed that the absorption and the fitting density are similar in different parts of the room (this includes a room with an absorbing ceiling and a reflecting floor). In this case, a single spatial sound distribution curve along a free path (not close to walls or fittings) represents the sound propagation and the acoustical quality of the room.

As an example, figure 2 shows two typical spatial sound distribution curves in a flat room containing fittings.

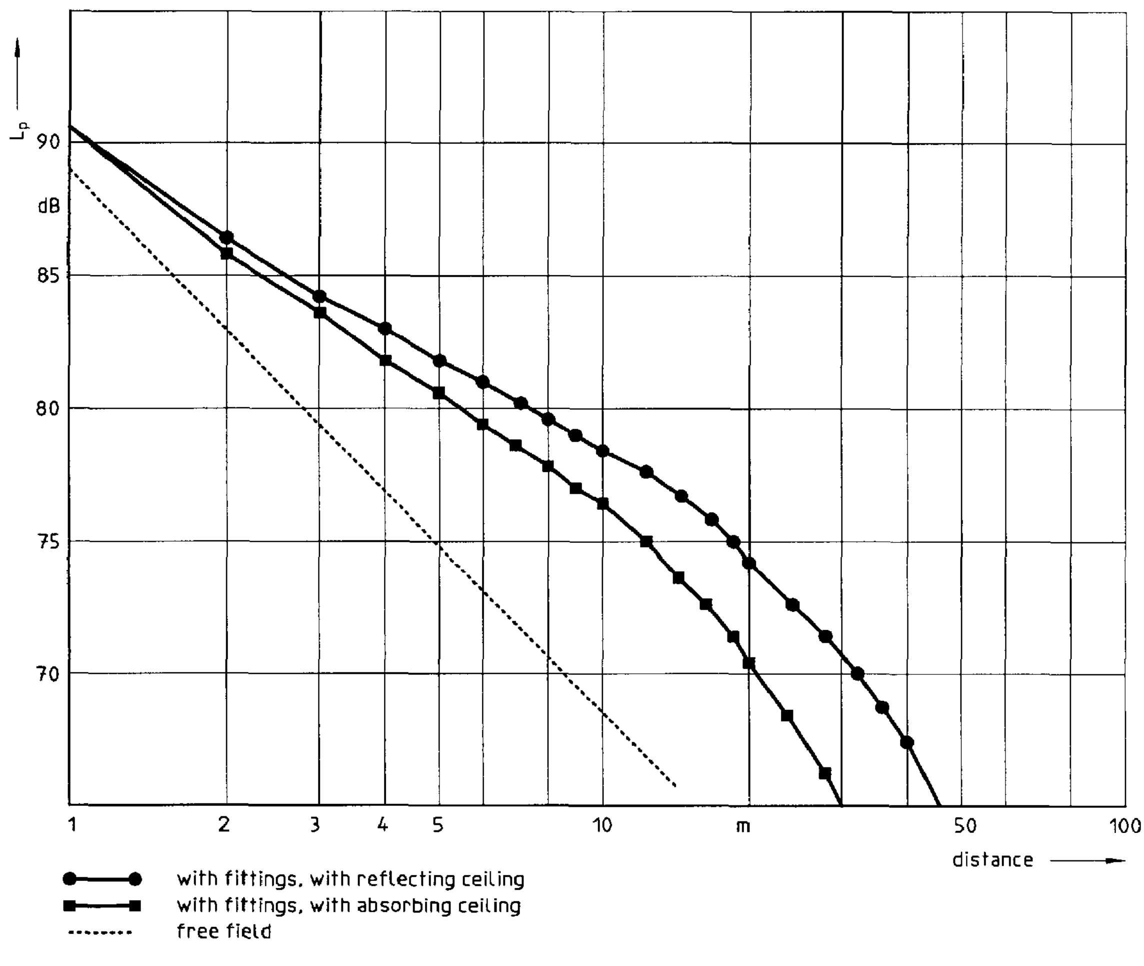

Figure 2 : Examples of typical spatial sound distribution curves for the same flat and fitted room, with and without sound absorbing ceiling. The dotted curve is the spatial sound distribution curve under total free field conditions. L_p denotes the sound pressure level at a given point when the sound power level of the source is 100 dB.

It is often useful to split the spatial sound distribution curve into three sections depending on the distance from the source (see 3.4.11 of part 1). The first section corresponds to the region near the source. In this region, the sound field is dominated by the direct field. The rate of spatial decay per distance doubling, DL2, is in most cases approximately 5 dB to 6 dB. Increasing the number of fittings in the vicinity of the source tends to increase the sound pressure level close to the source and to reduce it far from the source.

The second section of this curve corresponds to a middle region. In this region, DL2 lies in the range 2 dB to 5 dB and DLf in the range 2 dB to 10 dB.

In the far region (third part), scattering effects of fittings are important. The absorption of the walls, the density and the absorption of fittings have a dominant influence on the sound propagation far away from the source. Therefore, in this region, DL2 may be greater than 6 dB and DLf may be negative.

4.4 Rooms with non uniform sound propagation

In some situations, the room shape, absorption and fitting density differ from one part of the room to the other to such an extent that it is not possible to describe the sound propagation in the room with a single spatial sound distribution curve. In such situations, it may be necessary to describe the sound field in a way which takes into account the above factors. Fittings can also be considered individually.

5 Noise prediction in workrooms

Noise prediction in workrooms (see 9 of part 1) is an aid in making decisions regarding noise control measures. It allows calculation of the sound pressure level at any point and determination of sound propagation descriptors. It is therefore possible to compare these values with specified values or limits and to compare various solutions of a noise control programme. Although several noise prediction methods are available, all of them are based on a common procedure. This procedure is summarized in the flow chart shown in figure 3 and is outlined in the next clause.

6 Methodology for noise prediction in workrooms

Noise prediction in workrooms should follow five steps described below.

6.1 Objectives - Values to be achieved

At an early stage of a noise prediction scheme, acoustical descriptors must be chosen and target values defined by the parties involved, taking account of the various constraints associated with the project. Such descriptors can be sound pressure levels at workstations, immission and/or exposure data, spatial sound distribution curves, rates of spatial decay per distance doubling, excesses of sound pressure level, reverberation times etc.

6.2. Collection of input data

The level of detail of input parameters should be in accordance with the desired or possible value of the accuracy of the results. Different levels of detail in the description of the input parameters are shown in tables 1 to 3. The sound field that can be assumed in the room, the degree of knowledge of the input parameters and the acoustical description of the room are key factors for the selection of the prediction method.

6.2.1 Empty room description

The empty room is the space limited by the room surfaces such as the boundaries of the workroom (ceiling, floor, walls) and large internal surfaces which limit the space in it (screens, partitions, enclosures, cabins, etc.).

Prediction methods need the characteristics of the hall surfaces, such as their geometry (position, dimension, shape etc.), their absorption and reflection properties. Due to their complexity in real workrooms, room surfaces often need to be partitioned into sub-elements with different acoustical properties.

Absorption coefficients are also important parameters whose values affect the result of the prediction. Any prediction method should specify clearly the procedure to be used for estimating these parameters.

Table 1 shows several possible degrees of complexity in the description of the workroom.

Table 1 - Absorption and shape of the room

Level of detail of the description	Absorption and shape of the room
1	The room is characterized by its volume and by the mean absorption coefficient of its surfaces.
2	Box-like shape. Each surface is characterized by a single absorption coefficient.
3	Box-like shape. Sub-division of the room surfaces into elements of different absorption coefficients.
4	Actual room shape. Distribution of absorption and reflection properties of the room surfaces.

6.2.2 Description of room fittings

By fittings, it is meant any part of the lay-out of the hall which affects sound propagation. Fittings are machines, stocked goods, screens, pillars, ducts, partitions, cabins, etc. Fittings may either be introduced in the prediction model as a whole or subdivided into smaller parts with different acoustical properties.

Table 2 shows several possible levels of detail in the description of the room fittings.

NOTE 3 Fittings may be described by their density, q, which is defined as follows

$$q = S / 4V \quad \text{in } m^{-1}$$

where S is the total surface area of fittings, in m^2 and V is the volume, in m^3, of the room or the zone where fittings are located.

Table 2 - Room fittings

Level of detail of the description	Description of room fittings
1	Fittings are not taken into account.
2	Fittings are represented for the total room by one mean value for their density and one mean value for their absorption.
3	Fittings are represented for different parts of the room by one mean value for their density and one meanvalue for their absorption.
4	Actual shape and location of fittings are taken into account. Shielding by and reflection from these individual obstacles are taken into account.

NOTE: Levels 2, 3 and 4 in table 2 are not mutually exclusive.

6.2.3 Sources

Noise sources considered are machines, equipment and any noisy activity.

Noise emission can be characterized by the following descriptors (see ISO 3740 series, ISO 9614, ISO 11200 series, ISO 4871) :

- sound power level : A-weighted, in octave bands or third-octave bands,
- emission sound pressure level at workstation: A-weighted, in octave bands or in third-octave bands,
- time variation of emission, peak value etc.
- directivity or sound pressure level distribution on the measuring surface,
- distribution of noise sources on the machine structure,
- dimensions of the source.

Table 3 shows several possible levels of detail in the description of sources.

Table 3 - Sources

Level of detail of the description	Source description
1	Omnidirectional point sources
2	Point sources with a directivity pattern
3	Complex sources

For all the levels of detail in table 3, the sound power level and the emission sound pressure level at workstations are normally used. For levels of detail 2 and 3, the individual sound pressure level on the measuring surface and the directivity should also be known. The modelling of complex sources - level 3 in table 3 - requires the knowledge of the number, position and sound power level of all the elementary sources. Sound power level and emission sound pressure level at workstations are the main source descriptors. They can be measured either in laboratories or in-situ (see ISO 3740 series, ISO 9614 and ISO 11200 series) or found in noise emission declarations (see ISO 4871). Operating and mounting conditions strongly affect the noise emission from machines. The type and rate of the process must therefore also be taken into account.

NOTE 4: The description of the source should be of a high level of detail when the direct sound in the vicinity of the source is more important than the reflected sound.

6.2.4 Reference data

Reference data are collected either from previously studied similar workrooms or from the workroom itself if it already exists. The reference data can be parameters such as absorption coefficients, sound emissions of sources and/or data such as sound pressure levels, noise maps, spatial sound distribution curves, etc. The knowledge of these quantities helps the noise specialist to choose the most appropriate prediction method.

6.3 Choice of the prediction method

Table 4 presents two important categories of prediction methods.

Table 4 - Categories of prediction methods

Category	Prediction methods	
1	Diffuse field	
2a	Geometrical	Rooms that can be approximated by one mean absorption coefficient for each wall and one mean density for the fittings.
2b	Geometrical	Rooms that can be approximated by one mean absorption coefficient for each room surface and one mean density for the fittings in each zone of the room.
2c	Geometrical	Rooms for which individual distribution of absorption and fittings has to be considered.

Recommendations regarding the use of the different prediction methods are given in annex E. Some basic literature on sound propagation in rooms and indoor noise prediction methods is given in annex F.

6.3.1 Diffuse field methods

With these methods, noise prediction is relatively simple. The sound pressure level at a point is obtained by summing the contributions of the direct and reflected fields, the latter field being assumed diffuse. In some cases, although diffuse field conditions are not exactly met, the sound distribution that is specific to a diffuse field may be regarded as an acceptable approximation. This is often the case in highly reverberant rooms with acoustically hard surfaces and many fittings (see annex A).

If the sound field in a room is not diffuse, the calculation of sound pressure levels using the diffuse field method generally leads to an overestimation. When the objective is to predict whether or not noise immission limits are likely to be exceeded, the diffuse field method can be used as a first step calculation. Only when desired sound pressure levels are exceeded by the calculated levels it is necessary to use more precise methods.

Position and sound emission of the sources and total absorption in the room are the only input parameters that are required for predicting sound pressure levels according to these methods. If it is known, the directivity of the source(s) can be taken into account.

An example of use of a diffuse field method is given in annex A. Literature on diffuse field methods is given in annex F.

6.3.2 Geometrical methods

Geometrical methods are based on a geometrical representation of sound propagation in a room in which sound is assumed to propagate along straight lines. Reflections at boundaries are supposed to be specular or diffuse. The scattering effects can be taken into account by estimating the density of fittings in the room (see levels of detail 2 and 3 in table 2) or by taking into account the actual shape and location of scattering obstacles (see level of detail 4 in table 2), if practicable. Geometrical methods include ray tracing, source image and diffuse reflection techniques (see table 4).

An example of use of a geometrical method is given in annex A. Literature on geometrical methods is given in annex F.

6.3.3 Accuracy and validation of a prediction method

Before using any prediction method, it may be required to verify that the approximations which are inherent to the method selected will not invalidate the results.

When the workroom exists, a validation step based on the comparison of the calculated data with values measured in the initial situation (before applying noise control measures) is required. From this comparison, it can be decided whether or not the model selected is appropriate to the particular situation. A decision may have to be made that the level of detail of the input parameters should be changed or that the approximations inherent to the selected model make it inapplicable to the case under study.

In practice, the complexity of the situation generally requires a compromise between the level of detail, the accuracy of input parameters and the accuracy of the calculated results.

For workrooms at the design stage, comparison of calculated and measured data is not possible. However, if experience is available that indicates that details of a known situation and the details of the new room can be assumed to be comparable in acoustical terms, the validation of the prediction can be carried out in the known workroom; in such a case, the accuracy of the method used is known. If this is not the case, the validation is made on the basis of the experience in the type of industry concerned and of information gathered from available data banks and technical literature.

6.4 Predictive calculation

Once the prediction method and the suitable level of detail of its input parameters are chosen, the prediction method is first used to calculate e.g. sound pressure levels at workstation(s) and spatial sound distribution curve(s) for the given input data of the workroom. Annex B shows one practical application of noise prediction i.e. the determination of the noise impact of new machines in existing workrooms. In a second step, the repeated calculation with changes in input parameters due to noise control measures (see part 2) shows the effect of these measures on the sound pressure level at workstation(s) and on the spatial sound distribution curve(s).

The sound pressure level in the vicinity of a machine operating in a room is influenced by reflections and is therefore higher than the emission sound pressure level at the workstation of the machine. This level increase depends on the sound power of the machine and the characteristics of the room. A practical way to calculate the sound pressure level at the workstation of a machine operating in a room (with no other noise sources in operation) is described in annex C.

6.5 Results and conclusions

The prediction method provides sound pressure levels, noise immission or exposure levels, spatial sound decay curve(s) (DLf and DL2) or reverberation time(s) for each solution considered.

Values may be displayed as :

- spatial sound distribution curves,

- noise maps showing noise immission or exposure levels,

- curves of percentage area above a given sound pressure level,

- tables.

The results (curves, maps, values in tables) can be compared with given limits or recommended values for sound pressure level at workstations or for spatial sound decay. The differences between the calculated values for the initial and predicted situations help to evaluate the various solutions. This comparison should also take into account operating constraints.

On the basis of the advantages and disadvantages of each solution, the most effective one can be chosen.

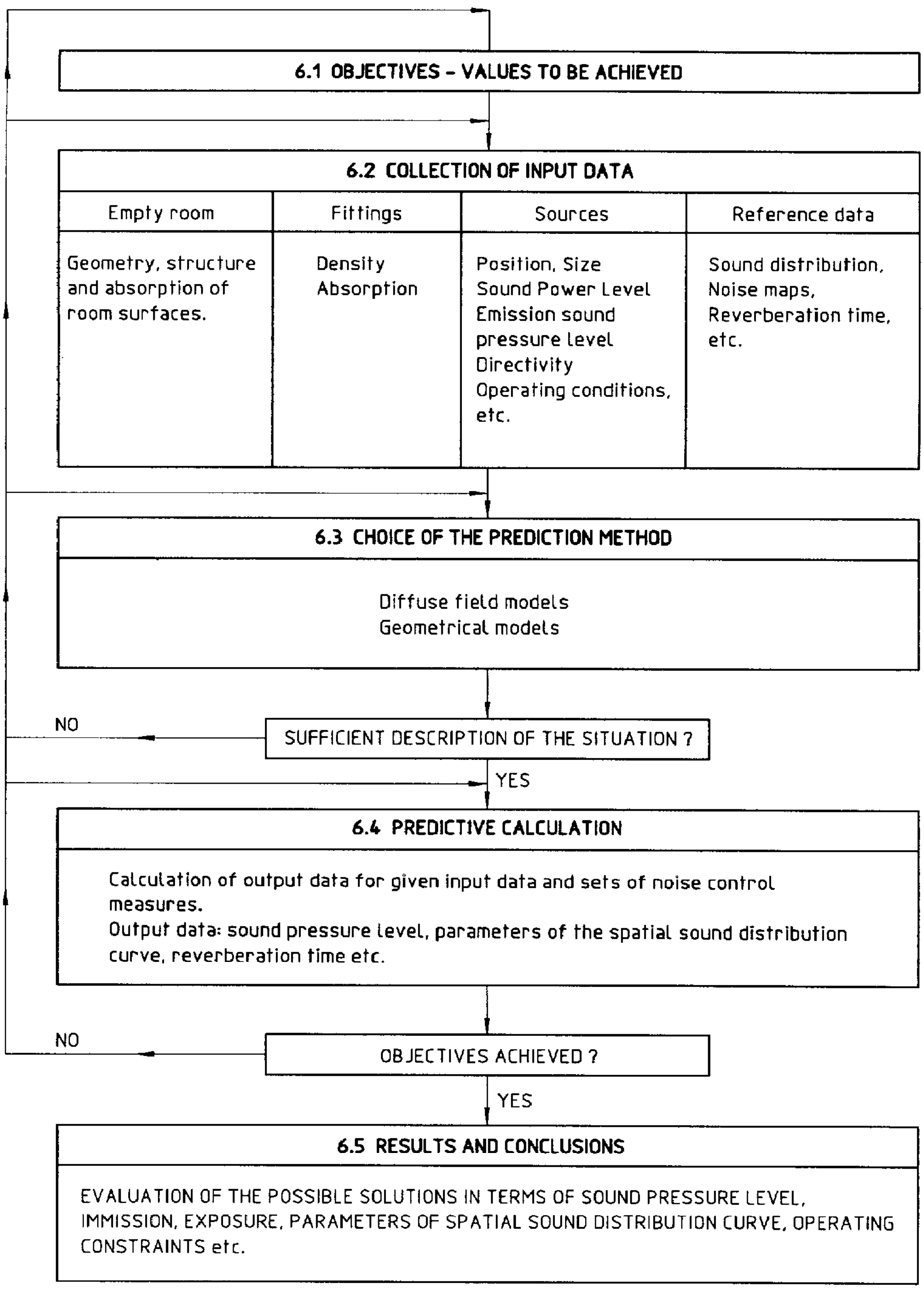

Figure 3 : General flow chart for noise prediction in workrooms.

7 Further aspects of noise prediction.

Noise prediction in workrooms often requires input data describing the noise emission of machines and other noise-producing elements, the acoustical properties of room surfaces and structures and an appropriate calculation procedure. Whatever prediction model is used, there will be some uncertainty regarding the input parameters. It is therefore not recommended to search for a detailed description of a specific input parameter if the others can only be known approximately. The use of the most appropriate data depends on each individual case, but to consider the overall effect of effort, complexity of calculation procedure and accuracy, there needs to be some consideration of the value of the outcome on the problem being dealt with.

Special consideration has to be given to the following aspects:

a) large machines should be modelled as multi-point noise sources to come to a sufficient accuracy at distances shorter than the typical machine dimension,

b) although the progress of computer technology reduces computation time, it remains necessary to limit the number of rays, reflections or images considered in the prediction and to reduce the level of detail of the description of scattering objects. The calculation of the scattering effect of every individual object in the room (machines, screens, etc.) is time consuming. Fortunately, it is often possible to make approximations that simplify the problem and still lead to a sufficient description of the phenomena observed. Examples of such approximations are:

- the sound field is diffuse (see 6.3.1 of this Technical Report and 6.3 and annex F of part 2),

- uniform distribution of fittings in the whole workroom (see 6.3.2) or in part of it (a large workroom may be divided into several zones).

Annex A

Three case studies relating to noise prediction in workrooms

This annex illustrates the practical use of noise prediction in workrooms by three case studies. The objective of each case study is the prediction of noise immission at workstations.

A.1 General approach

The approach is identical in the three cases studied. Each differs in the noise prediction method and the necessary level of detail of input parameters. For each case, the category of prediction method and the level of detail of input parameters are described by numbers taken from tables 1 to 4. After establishing the initial situation in terms of sound pressure levels at workstations, the effect of noise control measures, e.g. quieter machines, enclosures, absorbing ceiling etc., on the sound pressure level at workstations can be evaluated. In these case studies, A-weighted emission and immission sound levels are considered; values of absorption coefficient are for the 500 Hz octave band.

In cases 1 and 2, as a first step and depending on the configuration, one or several spatial sound distribution curves are determined using a selected calculation procedure. As a second step, sound pressure levels at workstations are calculated from the source data and the spatial sound distribution curves. In case 3, sound pressure levels are calculated directly without using spatial sound distribution curves.

NOTE: The procedures outlined in this annex may be used for any frequency band or frequency weighting. Noise emission values available are normally A-weighted.

A.2 Case study 1

Description of the situation for noise prediction purposes:

Table A.1 - Level of detail of input parameters

Category of method	Absorption and shape of the room	Room fittings	Source description
1	1	1	1

It is assumed that the sound field in the room is diffuse because:
- dimensions of the room have the same order of magnitude,
- the absorption coefficient of the room is small.

Input data: Workroom, source and workstation data.

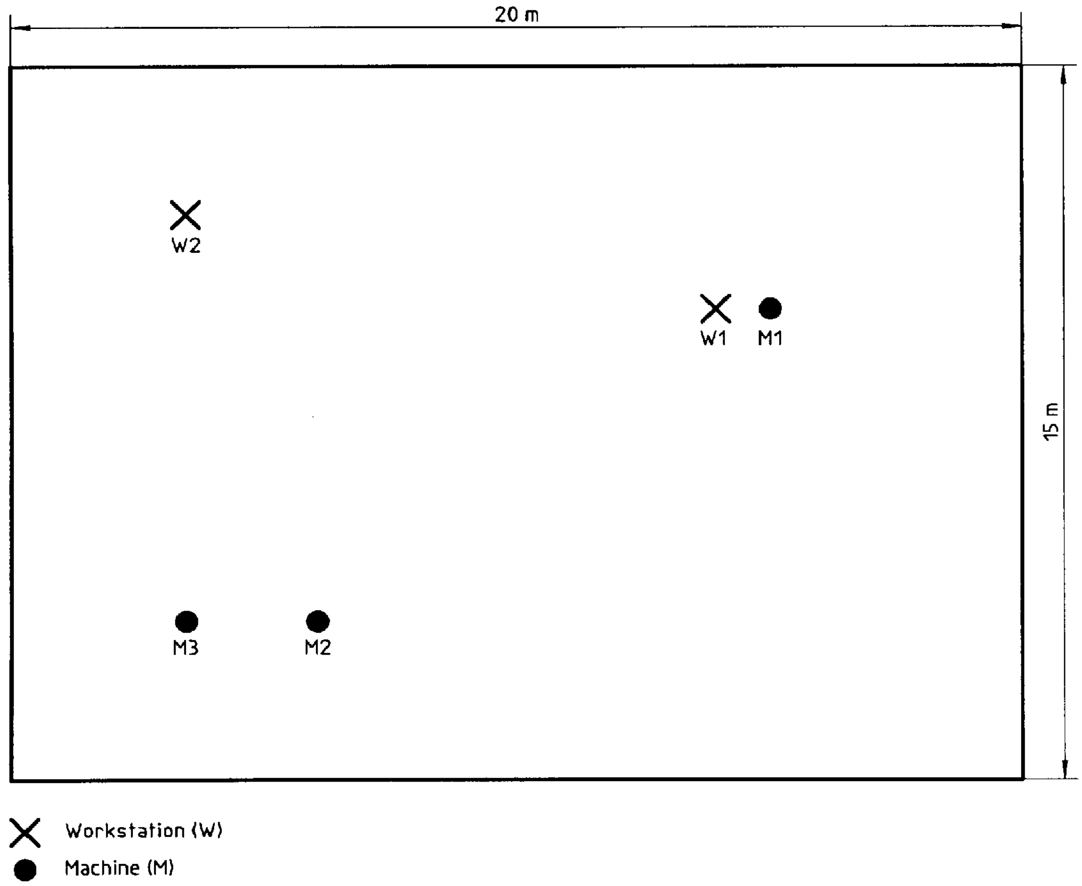

Figure A.1 - Location of machines and workstations in the workroom

Table A.2 - Room shape and dimensions

Box-shaped workroom	Lx = 20 m Ly = 15 m Lz = 7 m

Table A.3 - Absorption of the room

Uniform absorption of all surfaces
Mean absorption coefficient : $\overline{\alpha} = 0{,}2$

Table A.4 - Source data

Machine	L_W in dB	L_p in dB	x in m	y in m	z in m
M1	95	86	15	10	1
M2	100	(90)	6	3	1
M3	102	(91)	3	3	1

( ) : value not used in the calculation.
L_p is the emission sound pressure level at the workstation.

Table A.5 - Workstation data

Workstation	x in m	y in m	z in m
W1	14	10	1,6
W2	3	12	1,6

Output data:

Step 1: calculation of the spatial sound distribution curve (figure A.2).

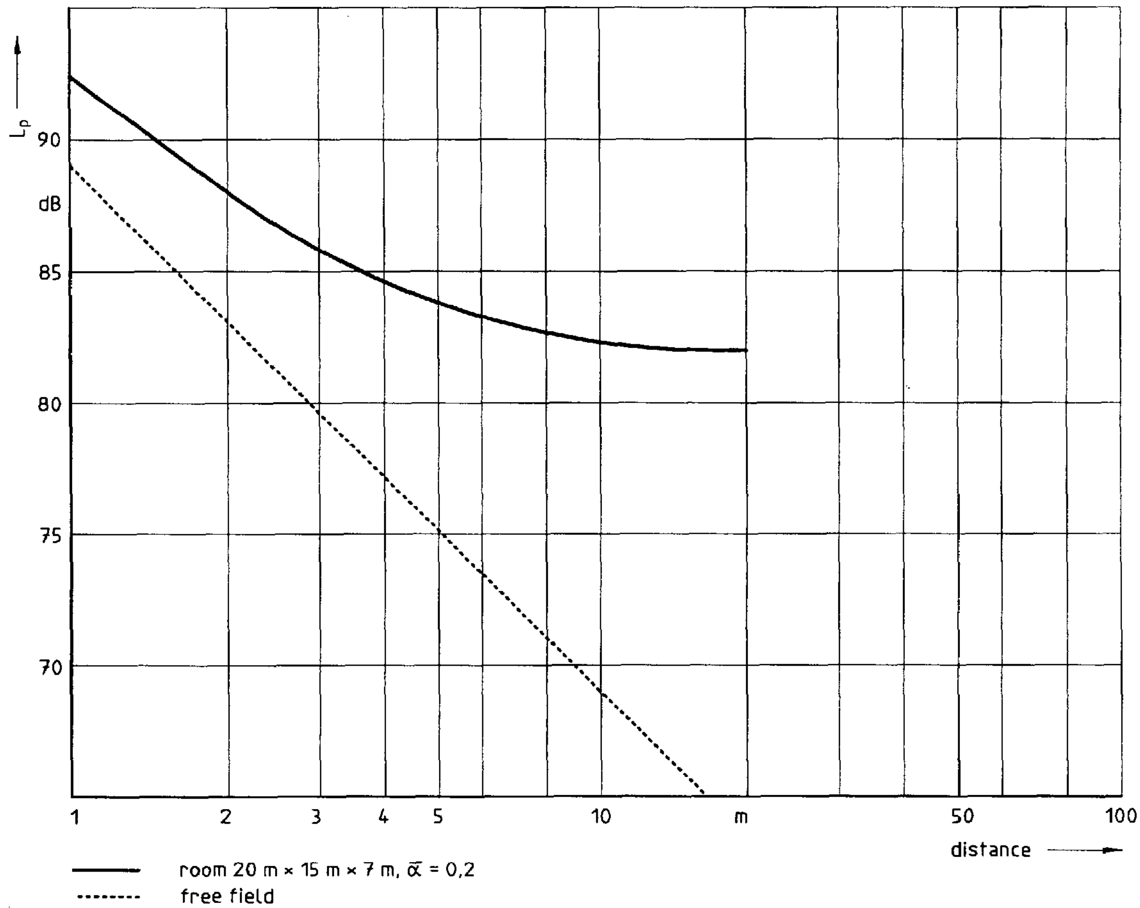

Figure A.2 - Calculated spatial sound distribution curve. L_p is the sound pressure level at a given point when the sound power level of the source is 100 dB

Step 2: Calculated immission sound pressure levels L_p at workstations (table A.6):

Table A.6 - Workstation noise data

Workstation	L_p in dB
W1	89,9
W2	87,7

NOTE: For workstation W1 of machine M1, the contribution of M1 to L_p at W1 is determined using the procedure described in annex C taking account of the noise emission values of this machine (sound power level and emission sound pressure level at the workstation).

A.3 Case study 2

Description of the situation for noise prediction purposes:

Table A7 - Level of detail of input parameters

Category of method	Absorption and shape of the room	Room fittings	Source description
2a	2	2	1

Input data: Workroom, source and workstation data.

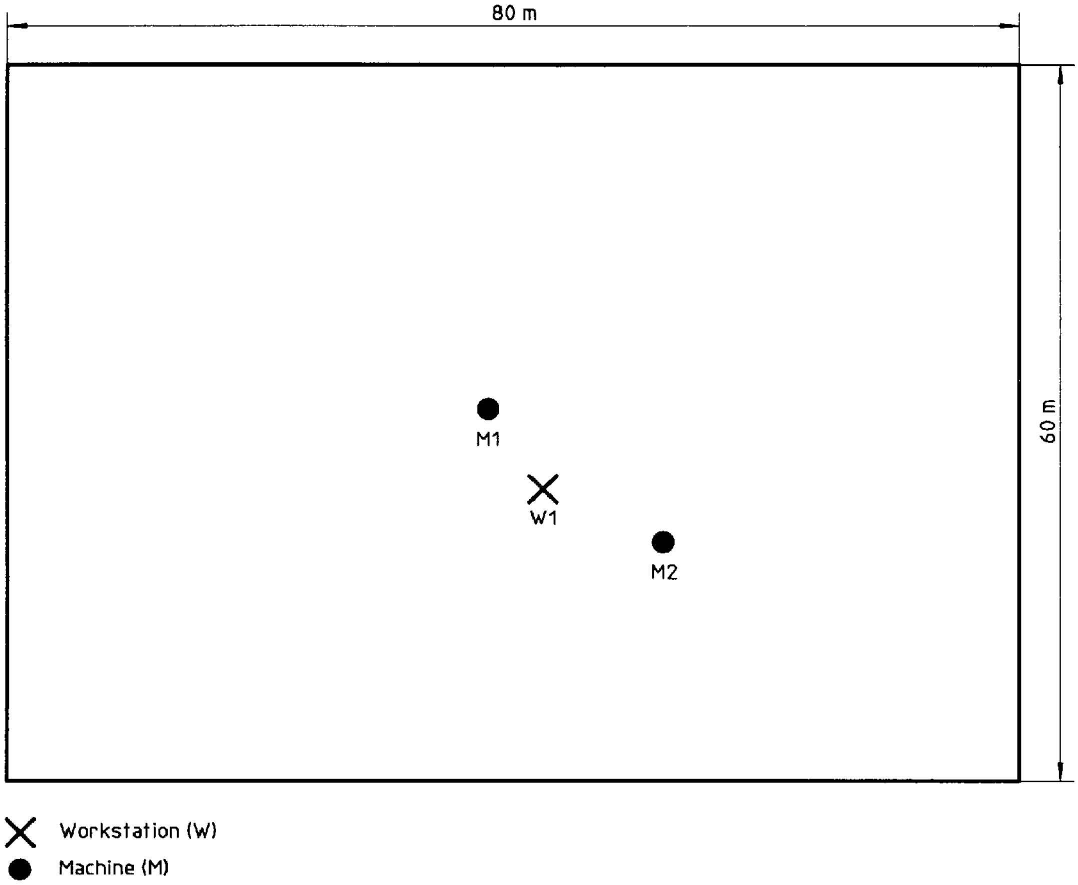

Figure A.3 - Location of machines and workstations in the workroom.

Table A.8 - Room shape and dimensions

Box-shaped workroom	Lx = 80 m, Ly = 60 m, Lz = 7 m

Table A.9 - Absorption of the room

Mean absorption coefficient	Wall 1 $\alpha_1 = 0{,}08$ Wall 2 $\alpha_2 = 0{,}15$ Wall 3 $\alpha_3 = 0{,}12$	Wall 4 $\alpha_4 = 0{,}12$ Ceiling $\alpha_5 = 0{,}45$ Floor $\alpha_6 = 0{,}15$

Table A.10 - Room fittings (scattering objects, see 6.2.2)

Fitting density (see 6.2.2)	$q = 0{,}05\ m^{-1}$
Absorption coefficient	$\alpha = 0{,}08$

Table A.11 - Source data

Machine	L_W in dB	L_p in dB	x in m	y in m	z in m
M1	105	(88)	36	28	1
M2	98	(84)	50	17	1

( ) : value not used in the calculation.
L_p is the emission sound pressure level at the workstation.

Table A.12 - Workstation data

Workstation	x in m	y in m	z in m
W1	40	22	1,6

Output data:

Step 1: calculation of the spatial sound distribution curve (figure A.4).

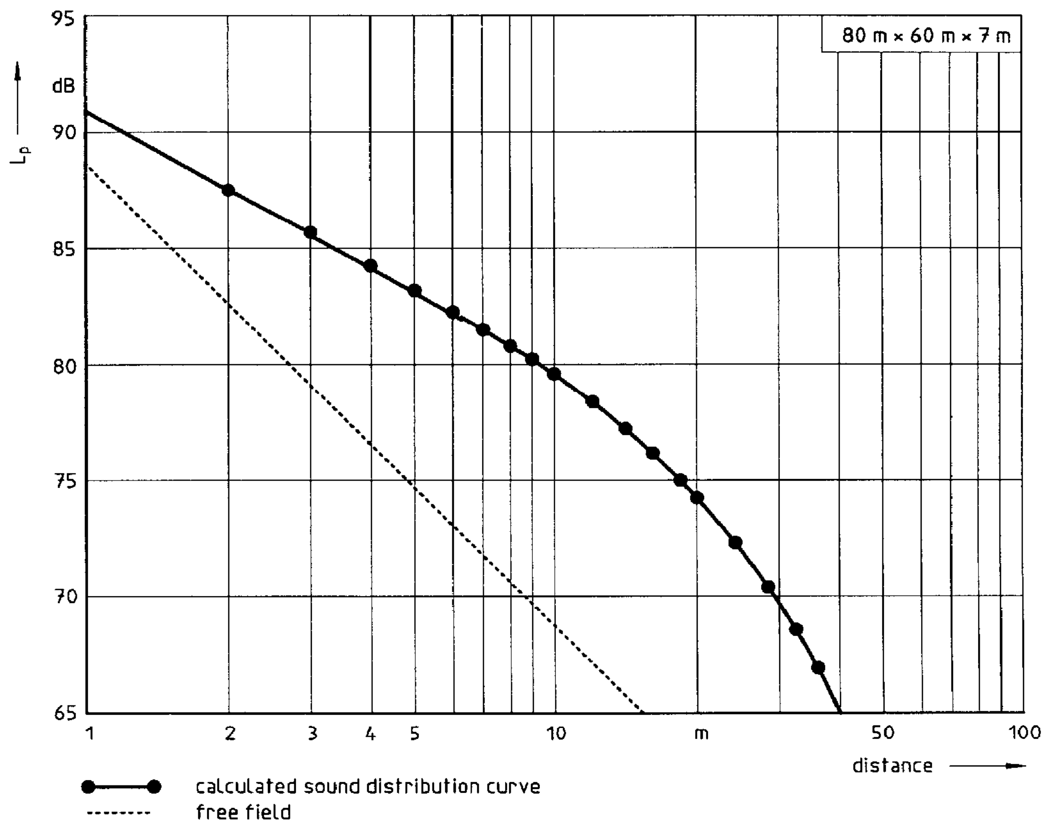

Figure A.4: Calculated spatial sound distribution curve. L_p denotes the sound pressure level at a given point when the sound power level of the source is 100 dB.

Step 2: calculated immission sound pressure level at the workstation (table A.13).

Table A.13 - Calculated immission sound pressure level at the workstation.

Workstation	L_p in dB
W1	85,4

A.4 Case study 3

Description of the situation for noise prediction purposes:

Table A.14 - Level of detail of input parameters

Category of method	Absorption and shape of the room	Room fittings	Source description
2b	4	3	1

Input data: Workroom, source and workstation data.

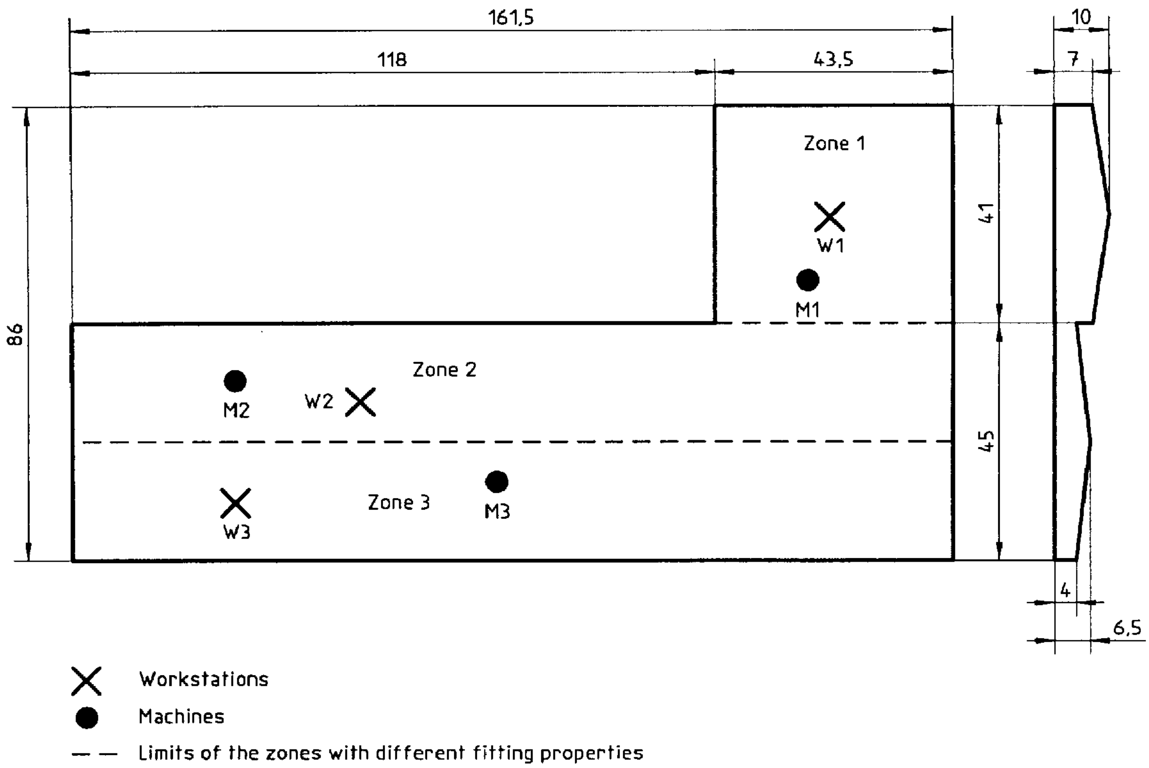

Figure A.5 - Sketch of the workroom and location of machines and workstations.

Table A.15 - Absorption of the room

Mean absorption coefficient	Walls $\alpha = 0{,}15$ Ceiling $\alpha = 0{,}25$ Floor $\alpha = 0{,}10$

Table A.16 - Room fittings (scattering objects, see 6.2.2)

Zone	Density of fittings q in m-1	Absorption coefficient of fittings
1	0	/
2	0,05	0,10
3	0,15	0,10

Table A.17 - Source data

Machine	L_W in dB	x in m	y in m	z in m
M1	114	138	49	1
M2	118	45	36	1
M3	111	94	15	1

Table A.18 - Workstation data

Workstation	x in m	y in m	z in m
W1	139	60	1,6
W2	60	30	1,6
W3	45	10	1,6

Output data:

In this case, there is one spatial sound distribution curve for each zone. From each curve, the acoustical performance of the zone concerned can be evaluated. Output data are given in figure A.6 and table A.19.

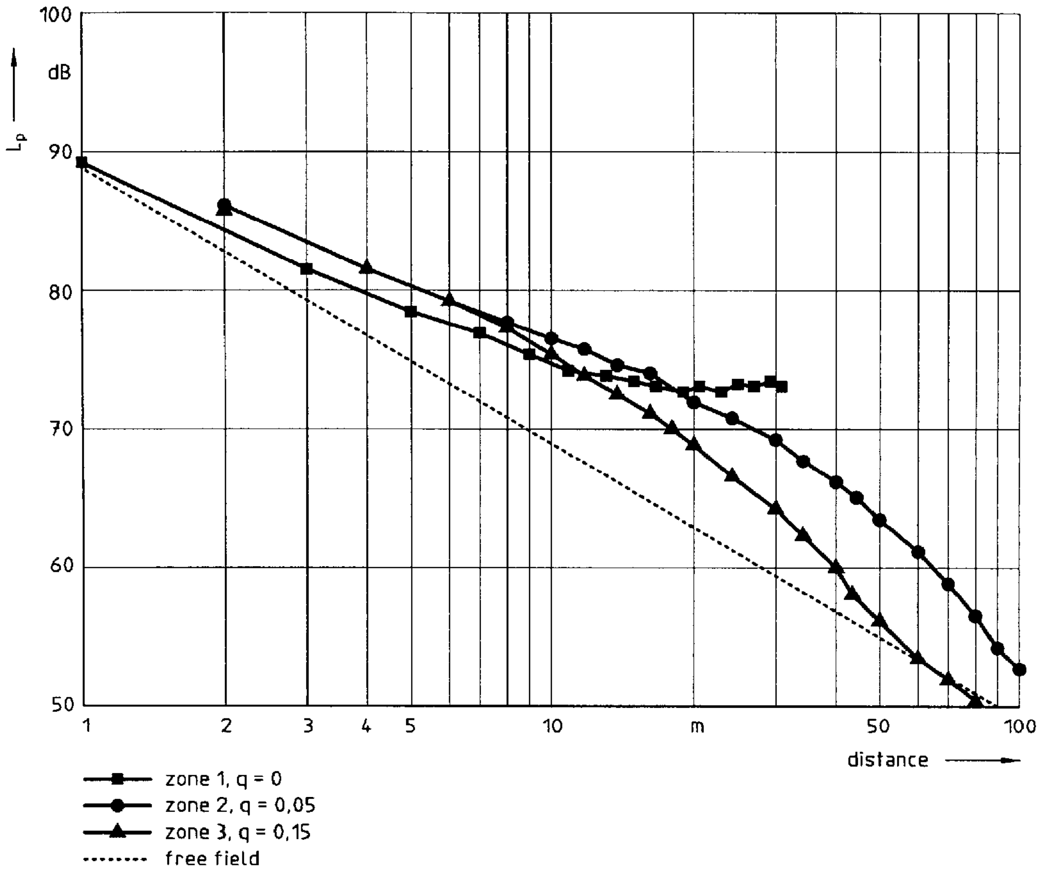

Figure A.6: Calculated spatial sound distribution curves. L_p denotes the sound pressure level at a given point when the sound power level of the source is 100 dB.

Table A.19 - Calculated immission sound pressure levels L_p at workstations

Workstation	L_p in dB
W1	95
W2	92
W3	86,5

NOTE: In situations with zones of different fitting properties, the sound pressure level at workstations cannot be obtained directly from the sound distribution curves.

Annex B

Prediction of the noise impact of new machines in existing workrooms

This Annex shows how the noise prediction tool can be used to estimate the influence of the sound emission of new machines on the sound immission in an existing workroom.

Procedure:

The procedure for predicting the noise impact of new machines is described by the following example for a room with diffuse field conditions. The diffuse field assumption is made because:

- the dimensions of the room are of the same order of magnitude,

- the absorption coefficient of the room surfaces is small.

Step 1: Calculation of the spatial sound distribution curve.

The level of detail of the calculation, as chosen from the selection offered in tables 1 to 4, is as shown in table B.1.

Table B.1 - Level of detail of input parameters

Category of method	Absorption and shape of the room	Room fittings	Source description
1	1	1	1

Input data: Workroom data

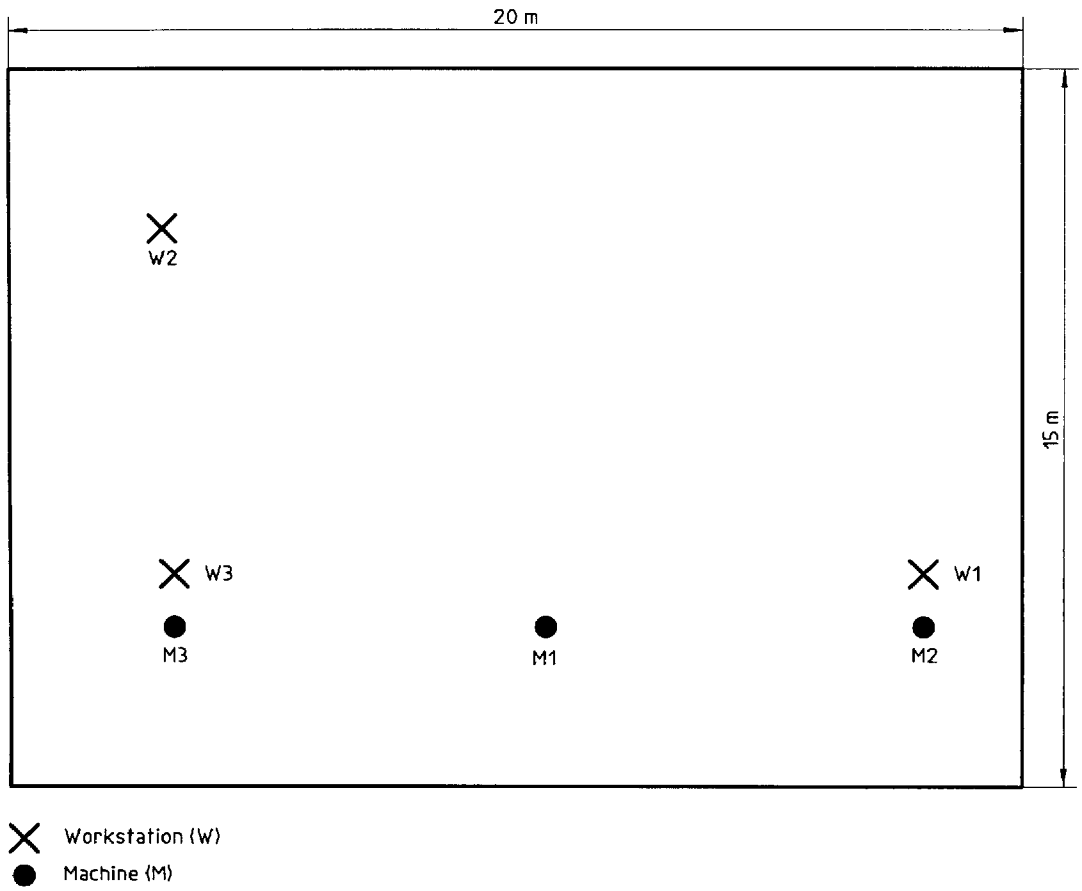

Figure B.1: Location of machines and workstations in the workroom.

Table B.2 - Room shape and dimension

Box-shaped workroom	Lx = 20 m, Ly = 15 m, Lz = 7 m

Table B.3 - Absorption of the room

Uniform absorption of all surfaces
Mean absorption coefficient : $\overline{\alpha}$ = 0,15

Output data: Calculated spatial sound distribution curve.

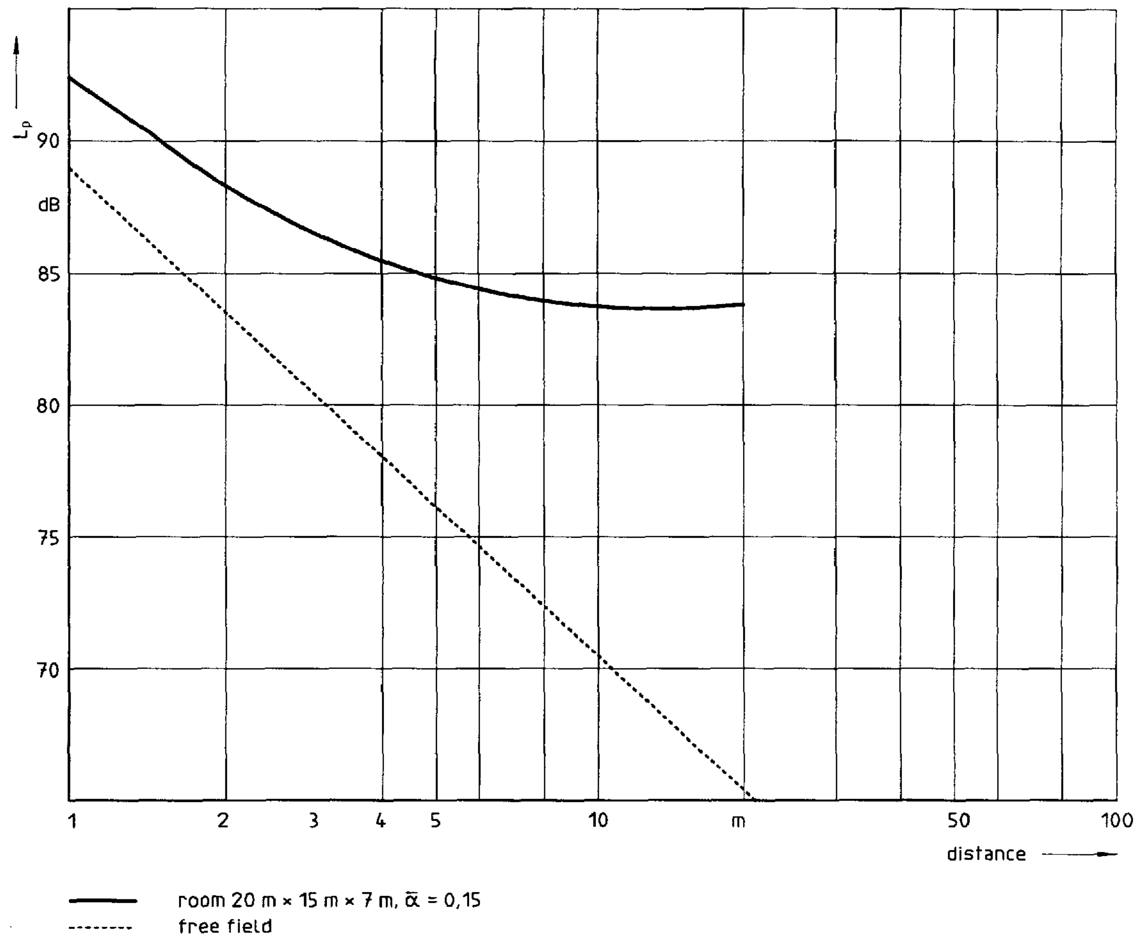

Figure B.2 - Calculated spatial sound distribution curve. L_p denotes the sound pressure level at a given point when the sound power level of the source is 100 dB.

Step 2: Calculation of the noise impact of new machines from the calculated spatial sound distribution curve.

The principle of the calculation is as follows. At each workstation, the sound pressure level due to each new machine is calculated from the spatial sound distribution curve. These sound pressure levels and the existing sound pressure level are added up on an energy basis to yield the total sound pressure level at each workstation after installation of the new machines. The contribution of a machine to the total sound pressure level at its workstation can be determined using the method described in annex C taking account of the sound power level of the machine and the emission sound pressure level at its workstation.

This step is illustrated by two cases relating to the workroom considered in step 1.

Case A: The workroom has initially one workstation, W1, and no machine. Two new machines, M1 and M2, are installed and one new workstation, W2 (the workstation of M2), is implemented.

Input data:

Table B.4 - Source data

	Noise emission values		Source location		
Machine	L_W in dB	L_p in dB	x in m	y in m	z in m
M1	95	(80)	10	3	1
M2	90	77	17	3	1

( ) : value not used in the calculation.

Table B.5 - Workstation data

Workstation	Position			Immission sound pressure level, L_p, in dB
	x in m	y in m	z in m	
W1 (existing)	3	12	1,6	50 (background noise)
W2 (new)	17	4	1,6	to be determined

Output data: Calculated immission sound pressure levels at workstations after installation of the new machine (table B.6).

Table B.6 - Calculated immission sound pressure levels at workstations

Workstation	L_p in dB	
	before	after
W1	50	82,1
W2	/	80,3

Case B: The workroom has initially two machines, M1 and M2, and two workstations, W1 and W2. One new machine, M3, is to be bought from a choice of two. One new workstation, W3, is implemented (that of the new machine).

Input data :

Table B.7 - Source data

Machine	Noise emission values		Source location		
	L_W in dB	L_p in dB	x in m	y in m	z in m
M1	95	(80)	10	3	1
M2	90	77	17	3	1
M3 first choice	100	87	3	3	1
M4 second choice	95	82	3	3	1

( ) : value not used in the calculation.

Table B.8 - Workstation data

Work station	Position			Immission sound pressure level, L_p, in dB
	x in m	y in m	z in m	
W1	3	12	1,6	82
W2	17	4	1,6	80
W3	3	4	1,6	/

Output data: Calculated immission sound pressure levels at the workstations after one of machines M3 or the other is installed (table B.9).

Table B.9 - Calculated immission sound pressure levels, Lp in dB, at workstations

Workstation	before	after with first choice machine	after with second choice machine
W1	82,1	86,2	83,8
W2	80,3	85,7	82,8
W3	/	89,4	85,4

The benefit of buying the less noisy machine is quantified in the above table.

Annex C

Determination of the sound pressure level at the workstation of a machine in a workroom

C.1 Procedure

The emission sound pressure level, L_p, at the workstation of a machine relates to free field conditions with the machine operating on a reflecting floor without other reflecting surfaces.

When the machine operates in a workroom, the sound pressure level at the workstation, L'_p, is higher because of the room influence. This increase, ΔL, of the sound pressure level:

$$\Delta L = L'_p - L_p$$

is identical to the K_3 correction (see ISO 11204) and is associated with the two basic noise emission values i.e.

- the sound power level, L_W (A-weighted or in frequency bands), and

- the emission sound pressure level, L_p (A-weighted or in frequency bands),

and with the room quality. The latter can be expressed as:

- the equivalent absorption area A in m^2 or

- the room correction, K_2 (see ISO 3744), measured, for a given surface of area S surrounding the source, using a reference sound source with a well-known sound power level or

- the excess of sound pressure level and/or the sound pressure decay per distance doubling determined from the sound distribution curve in a certain distance range (e.g. 1 m to 5 m).

The following steps show how the sound pressure level at the workstations in a room can be determined from the emission values, if the room quality can be described by the equivalent absorption area A in m^2.

The increase of sound pressure level, ΔL_A, at the workstation of the machine can be determined from the above quantity. The flow chart of figure C.1 shows this increase as a function of the equivalent absorption area, A, of the room with the difference $L_{WA} - L_{pA}$ as parameter.

With the help of this flow chart, the immission sound pressure level, L'_{pA} , at the workstation of each machine, when this machine - and only this one - operates in the workroom considered, can be determined from the value of ΔL_A.

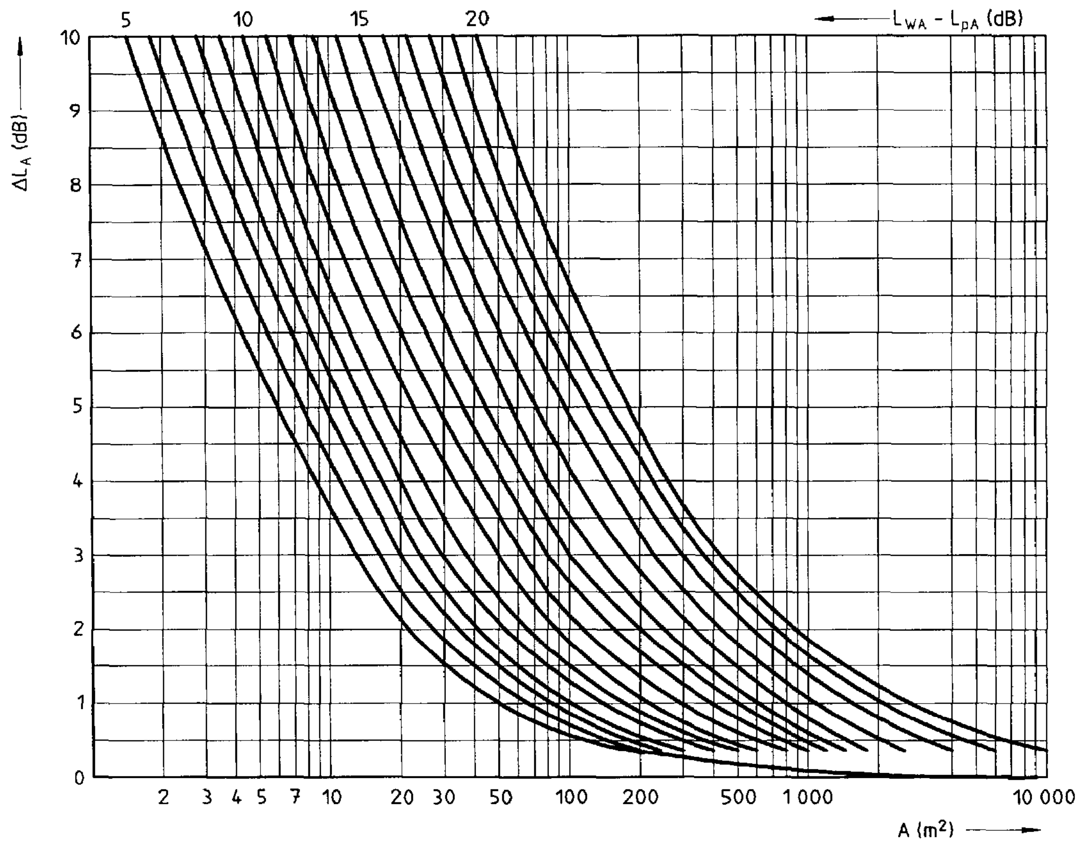

Figure C.1 - Diagram for the determination of the sound pressure level increase at the workstation of a machine.

The procedure is illustrated using an example dealing with the installation of new machines in a plant.

C.2 Input data

C.2.1 Machine data

For each machine, the two basic sound emission values (sound power level L_W and emission sound pressure level L_p) must be known. In this example, A-weighted quantities are considered.

Table C.1 - Source data

Machine	A-weighted noise emission values	
	L_{WA} in dB	L_{pA} in dB
M1	105	79
M2	98	81
M3	107	87
M4	94	82
M5	102	84
M6	96	82
M7	101	84
M8	107	78

C.2.2 Workroom data

In this example, the room has a total absorption area A equal to 195 m^2.

C.2.3 Determination of the sound pressure level increase

Values of L'_{pA} for the example given are shown in table C.2.

Table C.2 - Sound pressure level determination

Machine	$L_{WA} - L_{pA}$ in dB	ΔL_A in dB	L'_{pA} in dB
M1	26	9,5	89
M2	17	3	84
M3	20	5	92
M4	12	1	83
M5	18	4	88
M6	14	2	84
M7	17	3	87
M8	29	10	88

Each value L'_{pA} in the last column of table C.2 is the sound pressure level at the workstation of the machine, considered with this machine running and all other machines off. To determine the sound pressure level at a workstation with all machines running, the contribution of each machine in the room has to be evaluated for this workstation with the procedure given in annex A or B and added on an energy basis.

Annex D

Evaluation of the acoustical quality of a workroom

This annex shows how the acoustical quality of a workroom can be evaluated by calculation of the spatial sound distribution curve and its derived parameters (DLf and DL2). In the example used, an empty room with and without absorbing ceiling is considered.

D.1 Evaluation method

Description of the situation for noise prediction purposes:

Table D.1 - Level of detail of input parameters

Category of method	Absorption and shape of the room	Room fittings	Source description
2a	2	1	1

Figures in the above table are taken from tables 1 to 4.

D.2 Input data

Workroom data :

Table D.2 - Shape and dimensions

Box-shaped room
Dimensions : Lx = 75 m, Ly = 50 m, Lz = 10 m

Table D.3 - Absorption of the room

Absorption coefficient in the frequency range of interest	Ceiling	without treatment $\alpha = 0{,}10$
		with treatment $\alpha = 0{,}85$
	Other surfaces $\alpha = 0{,}10$	

D.3 Output data

Calculated spatial sound distribution curve (sound pressure levels (L_p) for a sound power level of the source L_W = 100 dB)

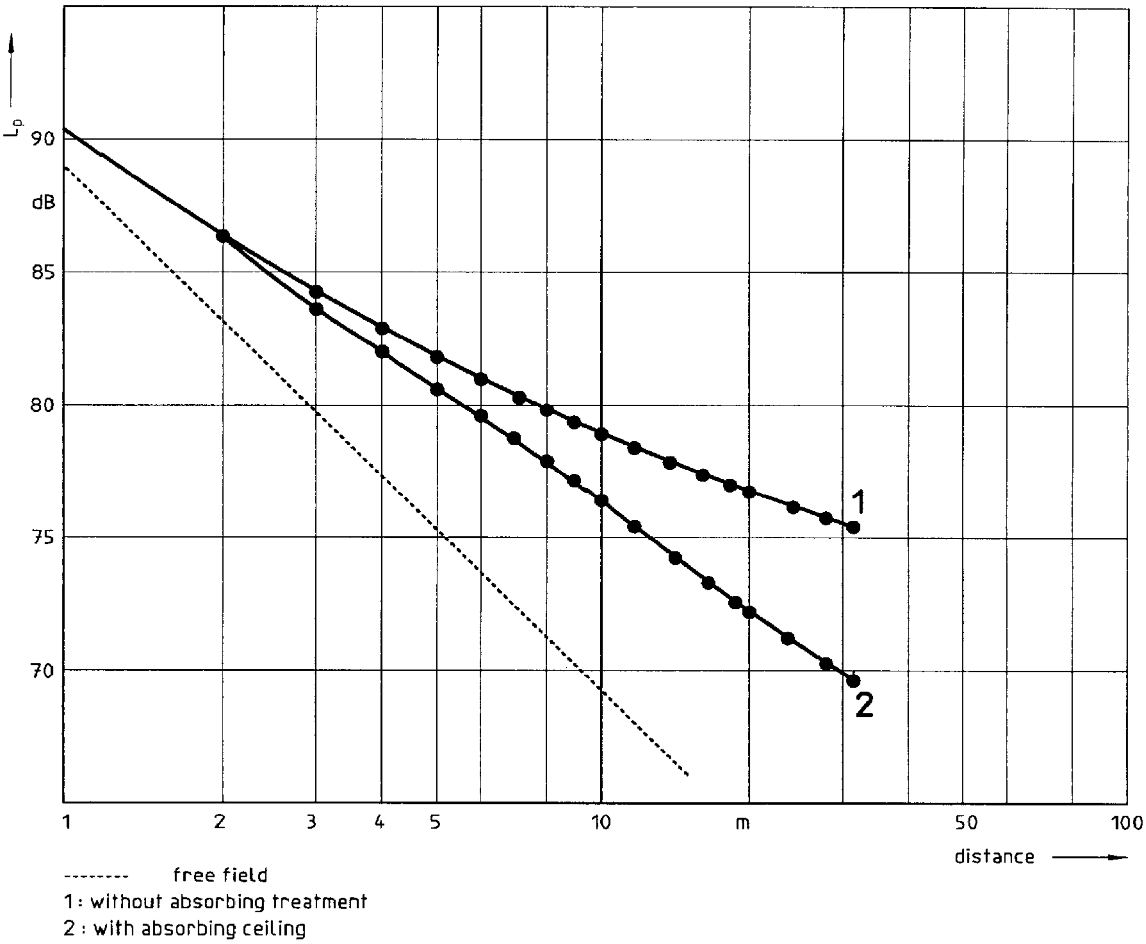

Figure D.1 - Calculated spatial sound distribution curves

Derived room parameters:

DL2 and DLf are calculated here for the medium range of distances from the source (chosen as the 5 m to 15 m range).

Table D.4 - Calculated values of excess of sound pressure level, DLf, and sound pressure decay per distance doubling, DL2

Room treatment	DL2 in dB	DLf in dB
No treatment	2,5	6,9
Absorbing ceiling	4,4	4,5

The benefit of treating the ceiling is quantified in the above table (see figure 10 of part 2) and also shown in the spatial sound distribution curves of figure D.1.

Annex E

Recommendation for the use of noise prediction methods

The following table gives the recommended range of levels of detail of input parameters for each category of noise prediction method.

Table E.1 - Recommended range of levels of detail of input parameters for each category of noise prediction method

	Level of detail of input parameters		
Category of prediction method (see table 4)	Absorption and shape of the room (see table 1)	Room fittings (see table 2)	Source description (see table 3)
1	1	1	1 to 3
2a	1 ; 2	1 ; 2	1 to 3
2b	1 to 3	1 to 3	1 to 3
2c	1 to 4	1 to 4	1 to 3

Annex F

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