Method for the prediction of installation noise levels

ECMA

Standardizing Information and Communication Systems

Method for the prediction of installation noise levels

Brief History

In 1979 ECMA set up its Technical Committee TC26 for Acoustics. As a first task TC26 drafted a standard for determining the noise out-put of different categories of individual items of computer and business equipment. This Standard ECMA-74, was first issued in 1981, and was adopted by ISO/TC43 as the basis for International Standard ISO 7779:1988. ECMA-109 followed and covered the subject of Declared Noise Emission Values for Computer and Business Equipment. ECMA-109 was adopted by ISO TC43 as the basis for ISO 9296 and both are now widely used by the industry. ECMA-74. Edition 3, was adopted in 1993, slightly modified in 1994 and submitted to ISO TC43 for adoption under the fast-track procedure as new edition of ISO 7779.

Standard ECMA-74 facilitates the assessment of the NOISE EMISSION of a given piece of equipment, that is the level of noise emitted by this equipment when measured under standardised test conditions. In contrast, when several pieces of equipment are installed and operated in a room, the resulting sound pressure level is called INSTALLATION NOISE LEVEL that depends not only on the noise emitted by the installed equipment, but also on its arrangement in the room, on the acoustical properties of the room, and the location of interest.

Knowledge of the installation noise level is required in order to assess the NOISE IMMISSION level at workplaces in the room, that is the personal exposure to noise of people working in an installation. This personal exposure, the so-called RATING LEVEL, depends on the installation noise level and on the exposure duration of the individual person. Limits for the rating level have been set in a number of countries by law or regulation. ECMA TR/62 gives details of legislative and normative requirements applicable to computer and business equipment.

When planning an installation it is therefore important to be able to predict the likely installation noise level. This ECMA Technical Report describes a method for such prediction. It is based on mathematical models developed by KRAAK and JOVICIC (see annex C). For the purposes of this Technical Report applying to computer and business equipment, the method has been simplified to provide a practical tool for those concerned with machine and system installation as well as early installation planning.

Whilst actual calculations and measurements by members of TC26 have generally shown that the difference between the predicted and the actual measured levels is within 3 dB, users are cautioned that conditions unique to each installation may result in the measured values being more than 3 dB different from the predicted values. The principal reasons for this situation are as follows:

- In a given installation it is possible that the operation conditions are for a certain time more stringent than the standard operating conditions specified in ECMA-74.

- The predicted noise levels include steady background noise but do not include the additive effects of personal communication (speech, telephone, etc.).

It is the intention of TC26 to consider the experience made when applying the method described in this Technical Report with a view to issuing improved editions. Readers and users of this Technical Report are therefore invited to communicate their views to ECMA.

This ECMA Technical Report has been adopted by the ECMA General Assembly of June 1995

Table of contents

1.   Scope

This ECMA Technical Report specifies a method for the prediction of installation noise levels. This method takes into account the acoustical properties of the room in which computer and business equipment is installed, the location(s) of the noise emitting equipment and their noise emission level(s), determined in accordance with Standard ECMA-74, and the locations(s) of interest.

2   References

ECMA-74	Measurement of Airborne Noise emitted by Computers and Business Equipment.
ECMA-108	Measurement of High Frequency Noise Emitted by Computer and Business Equipment.
ECMA-109	Declared Noise Emission Values of Computer and Business Equipment.
ECMA-160	Determination of Sound Power Levels of Computer and Business Equipment.
ECMA TR/62	Product Noise Emission of Computer and Business Equipment.

3   Acoustical terminology

3.1   General

In noise control a variety of terms and definitions have been introduced during the past two decades of standardization. When dealing with acoustical values a basic understanding of the most commonly used expressions is essential. These definitions are listed in clause 4 of this ECMA TR.

An important area of understanding relates to the distinction between the noise level emitted by an individual machine or a piece of equipment operated under well defined standard conditions in a controlled acoustical room (called EMISSION), and the noise which may occur at a receiver's location in a given environment under actual working conditions as a result of the influence of multiple noise sources, and to which individuals are exposed during their daily work (called IMMISSION). This interrelationship is explained in clause 5 of this ECMA TR.

The following descriptions summarise some of the physical quantities which form the basis for noise measurements and noise ratings with regards to human hearing.

3.2   The nature of sound

Mechanically vibrating bodies put the surrounding air particles into movement which eventually reaches the human ear. For computer and business equipment typical sound sources are printing mechanisms, moving paper, cooling devices, rotating disks, and transformers, which emit sound power ranging from about 10^{-8} watts to 10^{-2} watts.

Air pressure fluctuations in the frequency range of 20 Hz to 20000 Hz are perceived as sound. The sensitivity of the human ear is strongly frequency dependent: at 1000 Hz it is sensitive to sound pressure fluctuations as low as 20 micropascals, whereas at 100 Hz its sensitivity is reduced to 10 percent. It also perceives sound pressure fluctuations at about 20 pascals and above as painful. Because of this large range of sensitivity of the human ear it is common practice to use a logarithmic scale when dealing with sound pressure fluctuations.

3.3   The decibels scale

The rating of sound pressure fluctuations on a logarithmic scale yields the sound pressure level in decibels, abbreviated dB, and is being a dimensionless quantity. The audible sound pressure fluctuations range from 0 dB to about 120 dB. A sound pressure level change of 1 dB may be just detected by the human ear, 3 dB are clearly perceived and 6 dB are significant. If a sound pressure level is increased by 10 dB, the ear normally perceives it as a doubling in loudness. A decrease of 10 dB is similarly perceived as a halving in loudness.

Note 1

The decibel scale may be applied to both quantities, the total sound power emitted by a source, and the sound pressure, to which the human ear is sensitive. As this may easily lead to confusion, ECMA-109 reserves the decibel for sound pressure level measurement and declaration and uses the unit "bel" (1B = 10 dB) when declaring sound power levels.

4 Glossary

4.1 Sound pressure, *p*, in pascals

The sound pressure, *p* in pascals is the incremental variation in pressure above and below the static pressure at a given location in air. These variations are extremely small; e.g. for normal speech, they average about 0,1 pascals above and below atmospheric pressure at a distance of one metre from the speaker. For practical reasons the root-mean-square value (rms or effective value) of the instantaneous sound pressures averaged over a time interval is determined.

4.2 Sound pressure level, L_p, in decibels

4.2.1 Single machine

The sound pressure level, L_p in decibels is ten times the logarithm to the base 10 of the ratio of the square of the (rms) sound pressure, *p*, to the square of the reference sound pressure, p_0, of 20 micropascals (p_0 = 20 µPa, the approximate threshold of hearing at 1000 Hz):

$$L_p = 10 \log \frac{p^2}{p_0^2} = 20 \log \frac{p}{p_o} (dB)$$

4.2.2 Adding sound pressure levels

In many practical situations the emitted noise of several machines may be combined to obtain a total level. A simple rule of thumb is:

− Add two equal sources: The total value is 3 dB higher

− Add ten equal sources: The total value is 10 dB higher

A more detailed explanation is given in annex A.

4.3 Equivalent continuous sound pressure level, L_{peq}, in decibels

The equivalent continuous sound pressure level, L_{peq}, in decibels is equal to a steady sound pressure level which would produce the same sound energy over stated period of time as a specified time-varying sound, also known as time-averaged sound pressure level.

4.4 A-weighted sound pressure level, L_{pA}, in decibels

The A-weighted sound pressure level, L_{pA}, in decibels is a frequency weighted (equivalent continuous) sound pressure level, where the standardized A-weighting accounts for the frequency dependent hearing characteristics. the A-weighted sound pressure level is the commonly used value for noise measurements and noise ratings with regard to its influence on man. The correct terminology is to express the value of L_{pA} in decibels (dB) re 20 µPa, although it is commonly expressed in units of dB(A) or dBA.

4.5 C-weighted peak sound pressure level, L_{pCpeak}

The C-weighted peak sound pressure level, L_{pCpeak}, in decibels is the highest instantaneous value of the C-weighted sound pressure level determined over an operational cycle.

4.6 Sound power, *W*, in watts

The sound power, *W*, in watts is the rate per unit time at which airborne sound energy is radiated from a source into its environment. The sound power of a source is essentially independent of the environment.

4.7 Sound power level, L_W, in decibels

The sound power level, L_W, in decibels is a logarithmic quantity of the measured sound power of a source with reference to 1 picowatt (W_0=10^{-12} watts):

$$L_W = 10 \log \frac{W}{W_o} (dB)$$

4.8 A-weighted sound power level, L_{WA}, in decibels

The A-weighted sound power level, L_{WA}, in decibels is a frequency weighted sound power level, using the standardized A-weighting. The A-weighted sound power level is used to describe the total emitted sound power of a source, being independent of its environment.

The relevant standard for computer and business equipment, ECMA-109 (ISO 9296) specifies this level as the major quantity for product noise emission declaration.

4.9 Noise emission

For computer and business equipment the standards for determining noise emissions are ECMA-74 (ISO 7779), ECMA-108 (ISO 9295), and ECMA-160 (ISO 9614-2). They describe the acoustical noise emitted by a sound source under well defined conditions. These conditions include the installation and operation of the source (equipment), the acoustical properties of the test environment, and the measurement and evaluation method to be used.

These conditions are generally specified in basic International Standards which are supplemented by test codes for specific machinery and equipment categories. A summary and interrelationship of these International Standards is given in annex B.

4.10 Emission sound power level and sound pressure level

The emission sound power level and sound pressure level are quantities to describe the noise emitted by a source, e.g. computer and business equipment. Major noise emission quantities are the A-weighted sound power level, L_{WA}, and the A-weighted sound pressure level at the operator or bystander positions, L_{pA}. These values are to be determined under standardized installation and operating conditions in an acoustically well defined environment. The A-weighted sound power level is the primary quantity when declaring noise emission values for computer and business equipment. the A-weighted sound pressure level is used for standard emission measurements at a defined operator position or at positions on a path around the equipment (bystander positions).

Note 2

The C-weighted peak sound pressure level L_{pCpeak}, in decibels, is also a noise emission quantity, which is mainly used if its value exceeds 130 dB. For computer and business equipment, such high levels are unusual, and are not included in this Technical Report.

4.11 Declared noise emission values

Declared noise emission values are emission sound power and sound pressure levels specified and/or reported for a specific piece of equipment or for a mass produced machine family. ECMA-109 (ISO 9296) defines these values.

4.11.1 Declared sound power level, L_{WAd}, in bels

The declared sound power level, L_{WAd} in bels includes statistical quantities accounting for measurement uncertainties and production variability. For computer and business equipment, declared A-weighted sound power levels, expressed in bels (B), are "statistical maximum" values for a given machine family or a batch of manufactured units. The sound power emitted by a product is the same both in an acoustical laboratory as it is in the user's actual environment, if the product is operating identically in both environments.

Note 3

Why use Bels? *The computer and business equipment industry has a long tradition in publishing product noise emission values. For more than 25 years the A-weighted sound pressure level in decibels has been used as the noise descriptor, whereas other industries have used the A-weighted sound power level, also in decibels, as the declaration value. When introducing the sound power level for declaring the noise emission of computer and business equipment in the early 1980's, it was not well received because of the confusion with sound pressure levels, when both were given in decibels, albeith with different reference values. A breakthrough was achieved with the publication of ECMA-109 in 1985 and the resulting ISO 9296 in 1988, which clearly separates the two quantities by declaring the A-weighted sound power level in bels (1 B = 10 dB), and no longer confuses the user between sound power and sound pressure.*

World-wide experience gained with these standards in years since their introduction has confirmed the importance of the decision to use the bel. The computer and business equipment industry uses these standards which provide a clear basis of communication in product noise declaration.

4.11.2 Declared sound pressure level, L_{pAm}, in decibels

Declared sound pressure level, L_{pAm}, in decibels are production mean values as defined in ECMA-109 (ISO 9296).

4.12   **Noise immission**

Noise immission describes the noise received by humans. Rating of immission may be performed with respect to hearing impairment, annoyance or interference with speech or work.

Immission in general depends on the noise emitted by the installed equipment in operation during the workshift as well as other influences such as the acoustical properties of the room, number of machines contributing to the total immission, and the background noise which may be due to air conditioning systems, outside traffic etc. Since in real life the noise in environments varies with time, the A-weighted equivalent continuous sound pressure level L_{pAeq} is used for immission measurements.

**4.13**   **Rating sound level, L_r, in decibels**

The rating sound level, L_r, in decibels is used for rating noise immission of a person at a work-station. The A-weighted (equivalent continuous) sound pressure level, L_{pAeq} is to be determined over a typical 8-hours workshift, which is then called the rating level L_r; this level may include, or may be supplemented with corrections to account for the impulsive or tonal character of the rated noise.

5   Noise emission

5.1   General

The term "Noise Emission" is used to describe the characteristics of the acoustical output of equipment. It refers always to one functional unit and requires standardized test conditions for the acoustical measurements as well as the installation and operation of the equipment under test; this is illustrated in figure 1.

Noise emission is preferably expressed in terms of sound power, which, for practical purposes, is one real invariant, independent of the environment. It may also be expressed in terms of sound pressure which however is dependent on the measurement location, the distance from the equipment and the test environment.
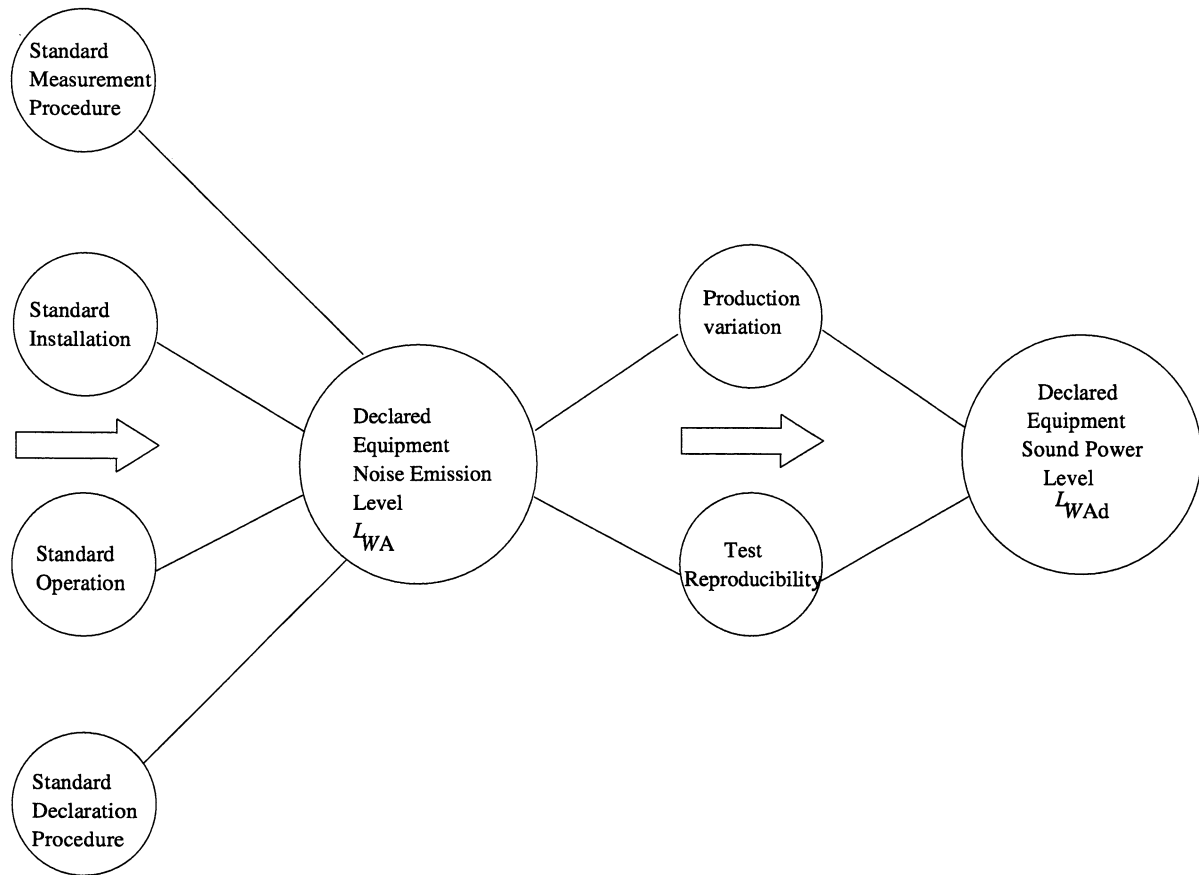
ECMA-94-0219-A

Figure 1 - Noise emission

5.2 Measurement of noise emission

The basic noise emission quantity is the A-weighted sound power level, L_{WA} in decibels re 1 pW.

For computer and business equipment it is determined according to Standard ECMA-74 (or ISO 7779) and/or ECMA-160 (ISO 9614-2) and declared in accordance with ECMA-109 (ISO 9296), as the declared A-weighted sound power level L_{WAd}. Generally, for mass-produced equipment, the declared noise emission value takes into account production variations and measurement uncertainties (ISO 4871, ISO 7574). The declared value may therefore be 3 dB to 5 dB higher than the value for the average production unit. These factors must be taken into consideration, when using declared values for the determination of the installation noise level; further details are given in 5.3.

The measurements are performed in either of the two acoustical environments, a semi-anechoic room (providing a free field over a reflecting plane), or a reverberation room (providing diffuse field conditions).

Other noise emission quantities of interest are the sound pressure level, L_{pA} in dB re 20 μPa (decibels with reference to 20 micropascals), measured at the specified equipment operator position(s) or at an otherwise defined position(s), the bystander's position(s). Furthermore the noise spectrum and the directivity of the noise radiation may be useful information when planning an installation.

It should however be clearly understood, that these noise emission quantities are not personal exposure values (rating levels). Generally there exists no simple relationship between the (equipment) emission levels and the (personal) rating level. However, the rating level can be determined if all relevant parameters, as indicated in figure 2, are known.

5.3 Use of noise emission values

Product noise emission data may be used in a number of ways:

- to assist in making product development design changes,

- to control product quality in production,
- to provide a declared product noise emission value in accordance with standards and regulations,
- to characterize the state of noise control for that class of product,
- to compare competing products.

Most important for the task described in this Technical Report are the product noise emission levels, which are used for the prediction of the installation noise level.

6. Noise immission

6.1 General

The term "Noise Immission" is used to describe the influence of noise on man. Rating of immission may be performed with respect to hearing impairment, annoyance or interference with speech or work. For rating the noise immission at a workplace with respect to its influence on an individual person, the rating level is to be determined, which is always valid for a typical 8-hour workshift.

Immission in general depends on the noise level of the installed equipment, the actual operation of each unit, the acoustical properties of the room and the background noise (due to air conditioning systems, road, rail and air traffic, etc.). Furthermore, a person's location(s) in the room as well as the actual exposure durations during the workshift, are of importance. In some countries criteria are applied for the presence of discrete tones and/or impulsive noise. The installation noise level predicted by the procedures of this Technical Report is not necessarily identical to the (personal) rating level, because there may be differences in the equipment operation and in the exposure time of an individual person; figure 2 shows this relationship.
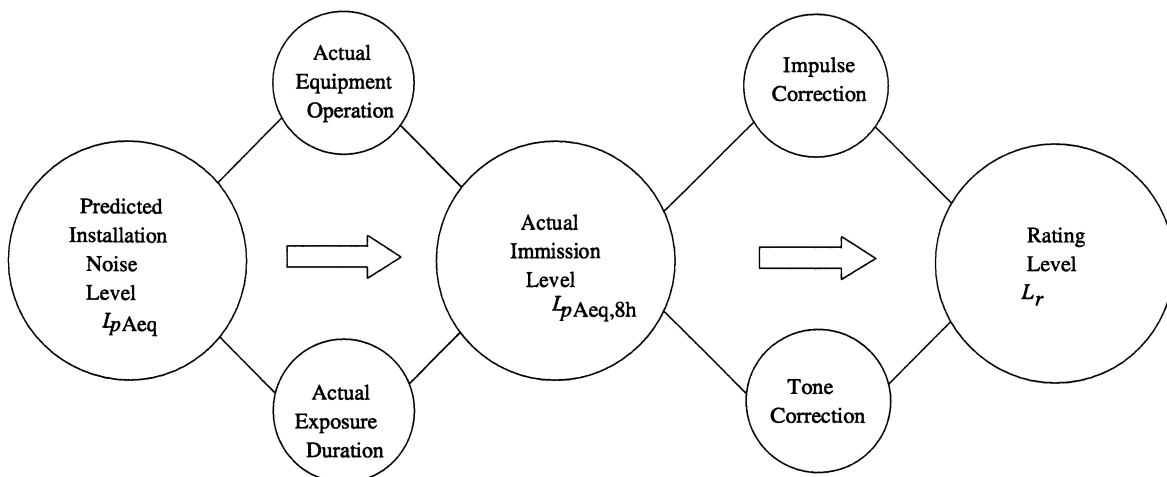
ECMA-94-0220-A

Figure 2 - Relationship between Installation Noise Level and the Rating Level at a specific location.

6.2 Determination of noise immission

Noise immission can be measured according to standardized procedures. The basic quantity for noise immission is the rating level L_r. This is an A-weighted sound pressure level L_{pA} in dB, averaged over a typical 8-hour workshift (other averaging periods may be used for interpretations other than the daily work). This average level is also known as the equivalent continuous sound pressure level, $L_{pAeq,8h}$. Finally, the rating level is basically an $L_{pAeq,8h}$ with corrections (if any) for prominent tones and impulsive noise.

If national regulations prescribe corrections for the annoyance due to impulsive noise and/or discrete tone(s), these corrections are to be added to the equivalent continuous sound pressure level, to obtain the rating level (DIN 45645). Due to the 8-hour averaging, equipment that is not in continuous operation during the day contributes less to the rating level than might be expected from the equipment noise emission level.

A daily exposure time of less than 8 hours (or less than 40 hours per week) has the same influence. Typical cases are the part-time operation of just one or only a few units during the day or if the person concerned has different work-places at which the noise immission is different. In both cases a number of decibels are to be subtracted from the equivalent continuous sound pressure level.

The correction for actual exposure duration, ΔL, is determined from equation 1 or read from figure 3. Alternatively, the equivalent continuous sound pressure level can be calculated using equation 2.

$$\Delta L = 10 \log \frac{t_i}{t_0} \tag{1}$$

$$L_{pAeq,8h} = 10 \log \left[\frac{1}{t_o} \sum_{i=1}^{n} t_i \, 10^{0,1 L_i} \right] \tag{2}$$

where:

$L_{pAeq,8h}$	is the total equivalent continuous A-weighted sound pressure level in decibels re 20 μPa, averaged for an 8-hour workshift,
L	is the value to be subtracted from equivalent continuous sound level due to an exposure time of less than 8 hours,
L_i	is the measured sound pressure level or calculated installation noise level in decibels re 20 μPa,
t_i	is the individual exposure time in hours during a typical 8-hour workshift, t_0 is equal to 8 hours.
t_o	is equal to 8 hours
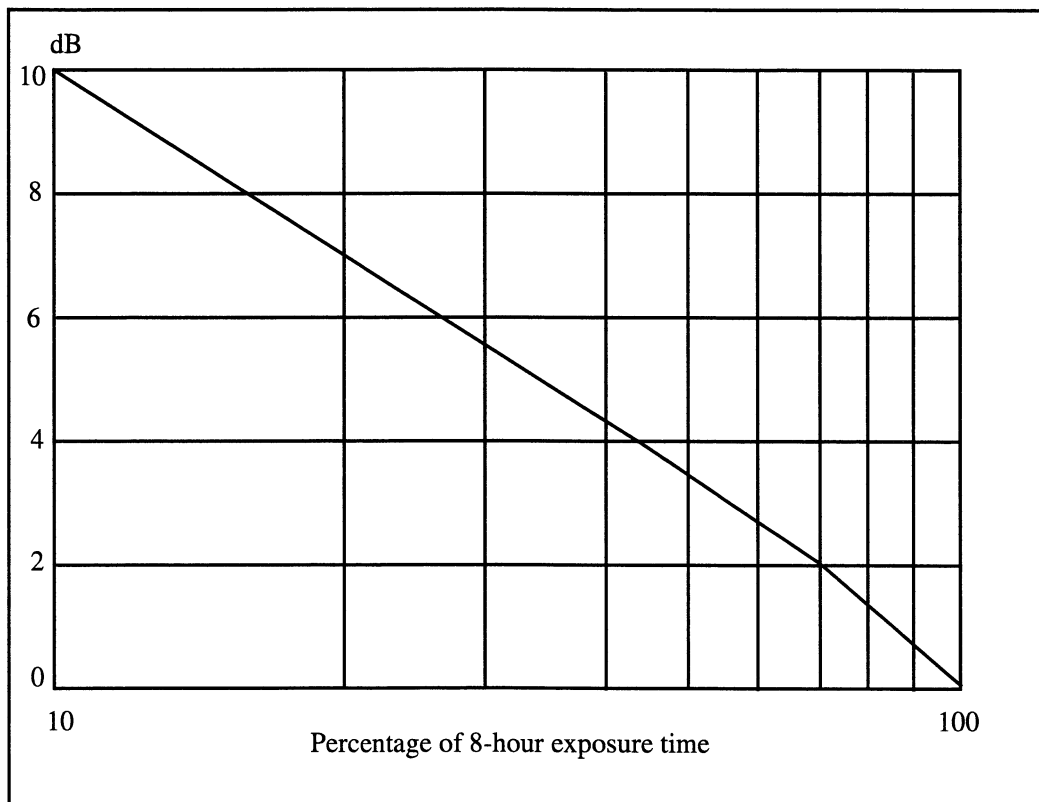
ECMA-94-0221-A

Figure 3 - Number of decibels to be subtracted from the equivalent sound level if the daily noise exposure is less than 8 hours.

6.3 Use of noise immission values

The rating level is used to quantify the noise exposure of a person or persons in a given environment and to check compliance with prescribed limits.
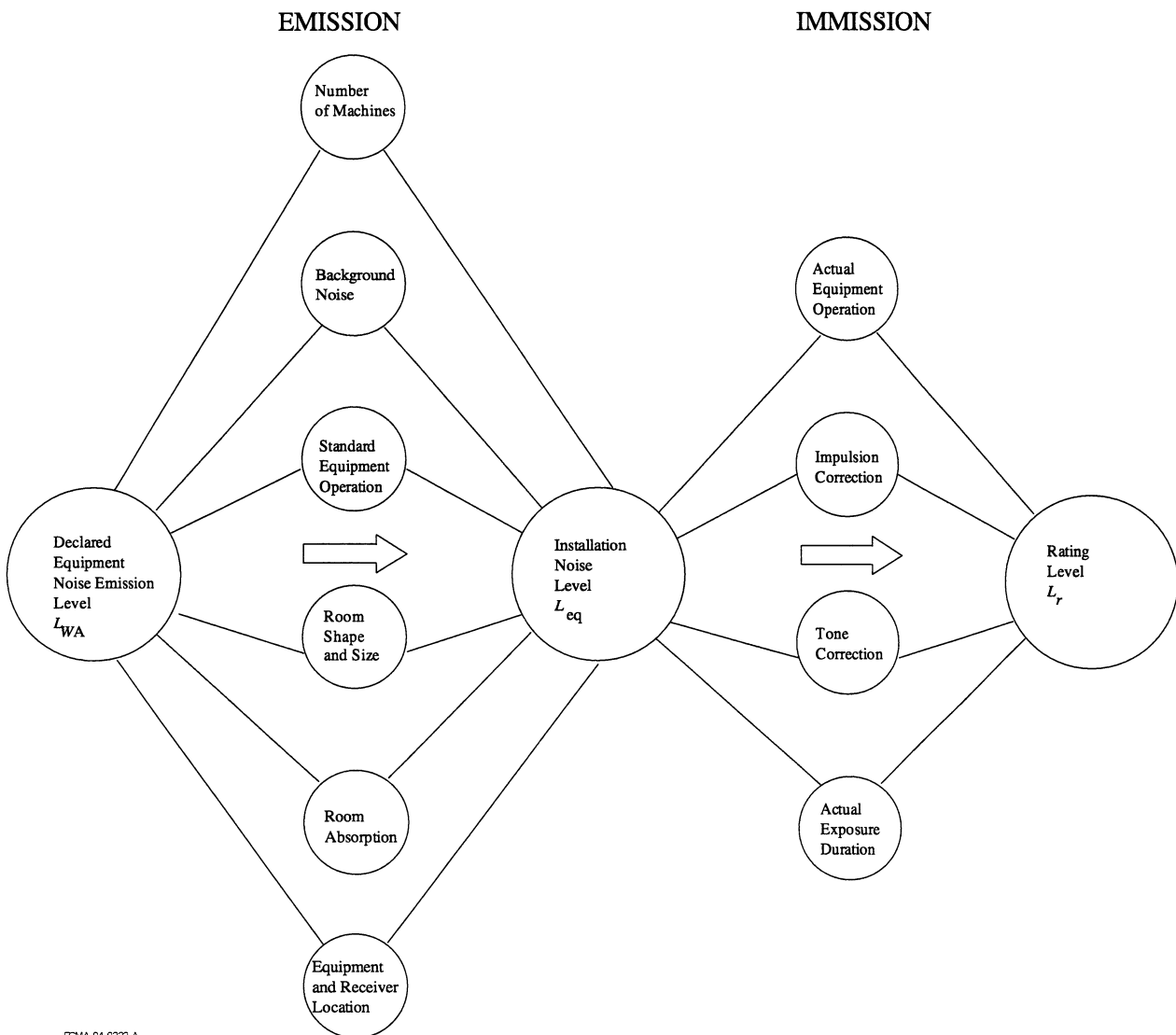
7. Installation noise

7.1 General

The term "Installation Noise" is used in this Technical Report to mean the noise at a specific location in a given environment due to all sources. This quantity is derived from the equipment noise, but allows a direct estimation of noise immission.

The installation noise level is basically an immission level; it differs from the personal rating level, since it does not consider individual personal exposure durations and annoyance criteria for discrete tones and/or impulse noise. Furthermore, it is based on standardized equipment operating conditions, which may differ from the operation under actual use.

The relationship of installation noise to the equipment noise emission level on the one side, and to the rating level on the other side, is shown in figure 4.

EMISSION   IMMISSION

Number of Machines

Background Noise

Actual Equipment Operation

Standard Equipment Operation

Impulsion Correction

Declared Equipment Noise Emission Level L_{WA}

Installation Noise Level L_{eq}

Rating Level L_r

Room Shape and Size

Tone Correction

Room Absorption

Actual Exposure Duration

Equipment and Receiver Location

ECMA-94-0222-A

Figure 4 - Relationship of installation noise level to emission and immission

The installation noise level can either be measured at specific locations within the actual environment, or it can be predicted from known equipment noise emission levels and room acoustical information. The interest in predicting such installation noise levels has increased, since some countries have established maximum allowable rating levels for certain types of work. Therefore, a prediction method is of greatest advantage in early installation planning.

7.2 Measurement of the installation noise level

The installation noise level at a specific location, L_{pAeq}, is usually the A-weighted sound pressure level in dB; it can be measured with an integrating sound level meter that meets the requirements of IEC 651 or IEC 804.

The measured level, at any specified location in the environment, may be compared with the predicted installation noise level, for the same location, determined in accordance with the procedures defined in this Technical Report. For the predicted level it is assumed that all the equipment of interest is operated continuously, simultaneously, and in a manner that yields the same noise output as the standardized operating condition specified for the equipment noise emission measurement.

7.3 Prediction of the installation noise level

7.3.1 Overview and assumptions of the method

The installation noise level is determined from:
- the total noise emitted by the equipment:
- the noise received on the direct path,
- the noise received due to reflections,
- the background noise.

The predicted installation noise level is an equivalent noise level, L_{pAeq}, in dB, and is determined for a specific location of interest in the environment. For the purposes of this Technical Report, only the A-weighted level will be considered, which greatly reduced the amount of calculations but will suffice for most practical applications. Furthermore, the prediction method described in this Technical Report is based on a number of assumptions which should be kept in mind when applying it. These assumptions are:

- the equipment-radiated noise emission is given in terms of sound power level valid for a single unit,
- the radiated noise does not show a strong directivity,
- the radiated noise does not vary greatly during the period of consideration,
- the room length and width are large compared to the wavelength of the radiated noise, usually larger than 5 m,
- the equipment noise does not contain strong discrete tone(s).

Most of these conditions are met by computer and business equipment and are satisfied in rooms where this equipment is installed, In rooms with hard reflecting boundaries the sound field may greatly vary from location to location within the room because of local interferences. In such cases, mainly when low frequencies are involved, this method yields only a spatial average value.

Because of unpredicatable variations in the individual equipment noise emission and in the room response, the measured installation noise level may deviate from the calculated level. The range of uncertainty is expected to be within 3 dB.

One should be cautious when using declared noise emission values for the prediction of the installation noise level, instead of data which are valid for the individual equipment. Declared values are generally valid as maxima for the whole production series and may include allowances for production variations and for measurement uncertainties. These allowances shall be removed from the declared emission value before determining the predicted installation noise level. If the measured value for L_{WA} (the A-weighted sound power level in dB re 1pW) is not known then the value of $(((\text{the declared noise emission value}, L_{WAd}, (\text{in Bels re 1pW})) \times 10) - 3)$ dB shall be substituted.

7.3.2 Guidance through the method

The prediction method described in this Technical Report may be considered as a sequence of steps, outlined briefly in this clause and specified in detail in the referenced clauses.

Step 1: The first step is to decide which of three categories of room shape and size (ordinary, flat or long) best fits to the room under consideration. Guidance on room categories is given in 5.3.3.

Step 2: Next, the sound pressure level at a single location of interest in the room due to a single equipment is calculated. The calculation procedure for ordinary, flat, and long rooms are given

in 5.3.4.1, 5.3.4.2 and 5.3.4.3, respectively.

Step 3: Adjustments to the calculated value must be made for added attenuation due to screens, if any, being close to either the equipment or the location of interest. These adjustments are specified in 7.3.5.

Step 4: When more than one equipment is present in the room, Steps 2 and 3 are to be repeated for each source. This is described in 7.3.6. Guidance is also given on mathematically combining several sources to minimize these repetitive calculations.

Step 5: Further adjustments to the calculated value may be required for the influence of background noise, such as noise from air conditioning equipment. These correction are determined according to 7.3.7, and are to be added to the total noise due to the equipment.

Step 6: If there is more than one location of interest in the room, Steps 2 to 5 are to be repeated for each of these locations, as stated in 7.3.8.

As offices and DP installations are equipped and furnished, the sound distribution within the environment may be considerably influenced by such "obstacles", which are usually called "scatterers" in acoustical terminology. This term applies also to pillars within the room and to other elements attached to walls or the ceiling and which cause additional sound scattering.

Scatterers reflect and/or absorb sound energy which results in lower levels at remote locations. This influence is considered in flat and in long rooms by the density factor, q, (equation 9), and the average absorption coefficient α_s of the scatterers.

7.3.3 Room categories

The noise level in the installation is greatly influenced by the room size and shape as well as its acoustical properties. Furthermore the density and orientation of the installed equipment or furniture influence the installation noise level.

Because of the numerous possibilities of room sizes on the one hand, and the requirement to determine the installation noise level with a high degree of confidence on the other hand, it is necessary to categorize the rooms in three broad classes. If a certain room does not fit exactly into one category, the category which is closest may be applied.

– Ordinary rooms
  Ordinary rooms are rooms having similar dimensions in all three directions, but having a length L and a width W smaller than three times the height H.

$$L < 3\,H$$
$$\text{and} \quad W < 3\,H$$

The prediction procedure for ordinary rooms is described in 7.3.4.1; equation 5 shall be used to calculate the installation noise level.

– Flat rooms
  Flat rooms are rooms having a length L and a width W of at least three times the height H.

$$L > 3\,H$$
$$\text{and} \quad W > 3\,H$$

The prediction procedure for flat rooms is described in 7.3.4.2; equation 7 or 8 shall be used to calculate the installation noise level.

– Long rooms
  Long rooms are rooms having a length L of at least three times the height H, and at least two times the width W.

$$L > 3\,H$$
$$\text{and} \quad W < L/2$$

The prediction procedure for long rooms is described in 7.3.4.3; equation 11 shall be used to calculate the installation noise level.

7.3.4   Prediction methods

Note 4

If the measured value for L_{WA} (the A-weighted sound power level in dB re 1pW) is not known then the value of ((((the declared noise emission value, L_{WAd}, (in Bels re 1pW)) x 10) - 3) dB shall be substituted.

Note 5

If the equipment or receiver is located close to a reflecting wall, i.e. within 1 metre, 3 dB should be added to the installation noise level. If the equipment or the receiver location is in a corner, the addition to the installation noise level is 6 dB.

7.3.4.1   Ordinary rooms

In ordinary rooms with a volume of less than 2000 m^3 the sound pressure level in the room decreases when the distance from the noise emitting equipment increases. In the vicinity of the equipment the sound pressure level decay closely follows the decay which exists in an ideal free space over a reflecting plane following equation (3):

$$L_{pA}(\text{free field}) = L_{WA} + 10\log\frac{Q}{2\pi\, d^{\,2}} \tag{3}$$

where:

L_{pA} (free field)   is the noise level in decibels re 20 μPa at distance d from the equipment due to direct sound transmission (free-field propagation).

L_{WA} is the equipment A-weighted Sound Power Level in decibels re 1 pW,

d is the distance of the receiver location from the equipment centre in m.

Q = 1, 2 or 4 as appropriate

Note 6

The value 1 in the numerator of the equation is a reference area in m^2. It must be replaced by the value 2 when the equipment is placed within 1 m of a reflecting wall, and by the value 4 when the equipment is placed in a corner.

larger distances the sound pressure level in the room is mainly due to reflections and approaches a constant value which would exist under ideal diffuse field conditions according to the following equation:

$$L_{pA}(\text{diffuse field}) = L_{WA} + 10\log\frac{4}{S\alpha_{sab}} \tag{4}$$

$$S.\alpha_{sab} = \sum_{i=1}^{n} S_i . \alpha_{sab,i} \tag{5}$$

where:

L_{pA}(diffuse field) is the noise level in decibels re 20 μPa at distance, d, from the equipment due to reflections (diffuse field portion),

L_{WA} is the equipment A-weighted sound power level in decibels re 1 pW,

S is the total surface area of room boundaries and furniture in square metres,

S_i is the area of individual room surface in square metres,

α_{sab} is the Sabine Absorption Coefficient of room and furniture surfaces,

$\alpha_{\text{sab},i}$ is the Sabine Absorption Coefficient of individual room surfaces.

Note 7

The index "sab" refers to Sabine absorption that, in this Technical Report, has been obtained by averaging the absorption coefficients at 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. This value is also known as Noise Reduction Coefficient (NRC). See annex B for values for some typical materials.

Note 8

The constant value 4 in the numerator of the equation is a reference area in square metres.

The predicted installation noise level in ordinary rooms therefore depends on the distance from the equipment and the room absorption, and is calculated as follows:

$$L_{p\text{Aeq}} = L_{W\text{A}} + 10\log\left(\frac{Q}{2\pi d^2} + \frac{4}{S.\alpha_{\text{sab}}}\right) \tag{6}$$

where:

$L_{p\text{Aeq}}$ is the predicted installation noise level in decibels re 20 µPa, due to the equipment, and at distance, d, from the equipment.

Q = 1,2 or 4 as appropriate

7.3.4.2   **Flat rooms**

The propagation of sound in flat rooms may deviate significantly from the conditions described for ordinary rooms, since no diffuse sound field exists. This means that the sound pressure level continuously decreases with distance from the equipment. This is mainly due to the low height of such rooms compared to the other room dimensions. On the other hand a free sound propagation does not exist either. The sound pressure level at remote distances is largely dependent on the room height and scatterers in the room such as furniture and other equipment. These influences have been combined in equations (7) and (8):

$$L_{p\text{Aeq}} = L_{W\text{A}} - 10\log(Hd) + \Delta L_{\text{F}} \quad \text{(Empty rooms)} \tag{7}$$

$$L_{p\text{Aeq}} = L_{W\text{A}} - 20\log H + \Delta L_{\text{F}} \quad \text{(Furnished rooms)} \tag{8}$$

where:

$L_{p\text{Aeq}}$ is the predicted installation noise level in decibels re 20 µPa at distance d from the equipment (Note 6),

$L_{W\text{A}}$ is the equipment A-weighted sound power level in decibels re 1 pW (Note 5),

ΔL_F is the correction term for flat rooms in decibels (see annex A)

H is the height of the room in metres,

d is the distance of the receiver location from the equipment centre in metres.

Note 9

In close vicinity of an equipment (normally within 5 m) the sound pressure level cannot be lower than the level which would exist under free field conditions (equation (3)). This should be considered when using equations (7) and (8).

The correction term L_F includes several influences on the sound pressure level, such as the distance from the equipment relative to the room height, the average absorption coefficient of the room, the surface area of the scatterers in the room, if any, and their absorption properties. The correction term L_F is obtained from A.1, diagram 1 shall be used for the empty room, and diagrams 2 to 6 for rooms with various q factors for the density of the scatterers, see also table 1.

Table 1 - Flat rooms - Reference list to figures in A.1

	Empty Room $q = 0$	$q = 0,05$	$q = 0,1$	$q = 0,2$	$q = 0,3$	$q = 0,4$
Figure Number	A.1	A.2	A.3	A.4	A.5	A.6

Absorption of scatterers is assumed to be $\alpha_s = 0,1$.

Calculation of the density factor q of reflecting objects;

$$q = \frac{1}{4S_F} S_E \qquad (9)$$

where:

S_E is the total surface of scatterers in square metres,

S_F is the surface area of room floor in square metres.

In the above calculations of the surface area of the scatterers only those surfaces which are exposed to incident sound, and which have dimensions greater than 0,2 m need be considered. An estimate of such surfaces is sufficient. For A-weighted levels, to which this Technical Report is restricted, and for most cases of offices and in low-density DP installations a density factor of $q = 0,2$ is appropriate. For larger DP installations with closely spaced equipment a density factor of $q = 0,4$ may be used.

Absorption Coefficient of Scatterers

In many cases of DP installations and office rooms the absorption of the installed equipment and furniture is low. A value of $\alpha_s = 0,1$ is appropriate in these cases; a value of $\alpha_s = 0,3$ is appropriate if absorbing screens are installed in the room (e.g. landscape office).

Figures 2 to 6 in Annex A.1 are based on $\alpha_s = 0,1$. If $0,1 < \alpha_s < 0,3$ the additional error that may appear at larger distances will be smaller than 1,5 for d/H < 20.

Average Room Absorption Coefficient

$$\overline{\alpha} = \frac{\alpha_{sabC} + \alpha_{sabF}}{2} \qquad (10)$$

where:

α_{sabC} is the absorption coefficient of the ceiling,

α_{sabF} is the absorption coefficient of the floor.

Note 10

The average room absorption coefficient should not be determined from reverberation time measurements made in the installation. Instead, measured values for typical materials (annex B) should be used.

7.3.4.3 **Long rooms**

In long rooms the calculation of the installation noise level is similar to that described for the flat room.

Accordingly we obtain:

$$L_{pAeq} = L_{WA} - 10\log(\text{HW }) + \Delta L_L \qquad (11)$$

where:

$L_{p\text{Aeq}}$ is the predicted installation noise level in decibels re 20 µPa at a given location from the equipment (Note 5),

L_{WA} is the equipment A-weighted sound power level in dB re 1 pW (Note 12),

ΔL_L is the correction term for long rooms in dB (a function of the distance, d, from the equipment), see annex A,

H is the height of the room in metres,

W is the width of the room in metres,

d is the distance of receiver location from the equipment in metres.

Note 11

Close to en equipment (within 5 m) the sound pressure level cannot be lower than the level which would exist under free-field conditions over a reflecting plane (equation 3). This should be considered when using equation 11.

The correction term ΔL_L considers the same influences as described in 7.3.4.2 for the flat room, and assuming again an absorption coefficient of $\alpha_s = 0{,}1$ for the scatterers. The correction term ΔL_L is obtained from annex A, diagrams A.7 to A.24 for different q factors and for different ratios of room height to width, H/W, see table 2.

Because of the smaller width of such rooms compared to the room length reflections from the side walls may contribute to the noise level at the location of interest. This influence is considered by the ratio H/W.

Table 2 - Long rooms - Reference list to figures in annex A

H/W	Empty room $q = 0$	Furnished Room with Density, q, of Scatterers				
		$q = 0{,}05$	$q = 0{,}1$	$q = 0{,}2$	$q = 0{,}3$	$q = 0{,}4$
		Diagram Numbers				
1/1	A.7	A.8	A.9	A.10	A.11	A.12
1/2	A.13	A.14	A.15	A.16	A.17	A.18
1/3	A.19	A.20	A.21	A.22	A.23	A.24

Absorption of scatterers assumed to be $\alpha_s = 0{,}1$

The average room absorption coefficient $\overline{\alpha}_{\text{sab}}$ is determined from:

$$\overline{\alpha}_{\text{sab}} = \frac{H\ (\alpha_{\text{SW1}} + \alpha_{\text{SW2}}) + W\ (\alpha_F + \alpha_C)}{2(H + W)} \tag{12}$$

where:

$\overline{\alpha}_{sab}$ is the average room absorption coefficient,

α_F is the absorption coefficient of the floor,

α_C is the absorption coefficient of the ceiling,

α_{SW1} is the absorption coefficient of one side wall,

α_{SW2} is the absorption coefficient of the other side wall,

H is the height of the room in metres,

W is the width of the room in metres.

Note 12

The average absorption coefficient should not be determined from reverberation time measurements made in the installation. Instead, measured values for typical materials (annex B) should be used.

7.3.5   Adjustments for screens

In offices and DP installations large equipment may shield certain locations against the noise emitted by other equipment. This may result in a significantly lower installation noise level than calculated from the equations in the previous clauses. The same effect is intentionally wanted when acoustical screens are installed between a workplace and noisy equipment.

The noise attenuation of screens (and large equipment) becomes more effective, the closer the equipment or the receiving location (or both) are to the screen, i.e. the greater the difference is between the direct path (without screen), and the indirect path around the screen, see figure 5.

This attenuation can be calculated; however a number of parameters must be known which are beyond the scope of this Technical Report.
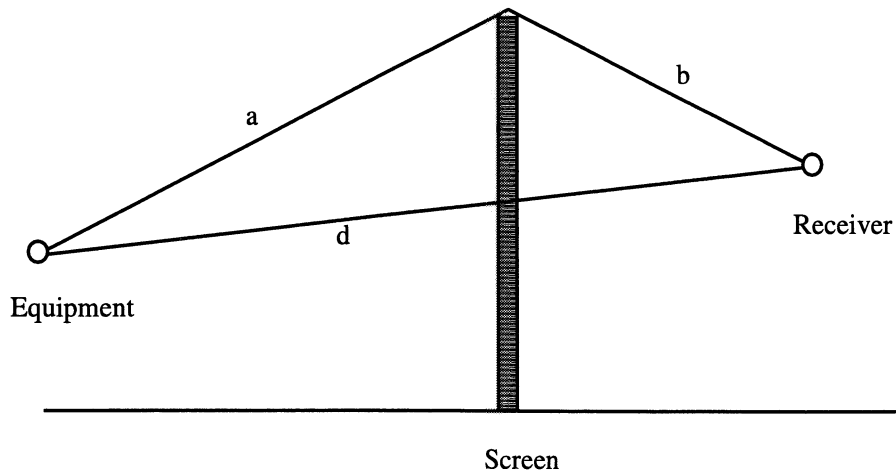
ECMA-94-0223-A

Figure 5 - Direct path (d) and indirect path (a+b) around a screen

Detailed information on screens has been published by the Association of German Engineers, VDI. Experimental data for indoor spaces is shown in table 3 that may be used to estimate the attenuation due to the screen.

The attenuation ΔL_c is to be subtracted from the calculated installation noise level in equations 8 and 11 respectively.

$$L_{pAeq,c} = L_{pAeq} - \Delta L_c \tag{13}$$

where:

$L_{pAeq,c}$ is the predicted installation noise level in decibels re 20 μPa, corrected for the additional attenuation by the screen,

L_{pAeq} is the predicted installation noise level in decibels re 20 μPa, determined according to equations 8 and 11,

ΔL_c is the attenuation in decibels from table 3.

Table 3 - Attenuation ΔL_c in decibels, due to a screen installed between source and receiver (Reference: VDI 2720, Blatt 2).

$\dfrac{\text{Screen Height}}{\text{Room Height}} = \dfrac{h}{H}$	$\dfrac{\text{Distance between Source and Receiver}}{\text{Room Height}} = \dfrac{d}{H}$		
	$< 0{,}3$	$0{,}3$ to 1	1 to 3
$< 0{,}3$	7 dB	4 dB	no data
$0{,}3 - 0{,}5$	10 dB	7 dB	4 dB
$> 0{,}5$	no data	9 dB	6 dB

7.3.6   **Multiple equipment in a room**

If several units are installed in a room and are operated simultaneously, the total installation noise level at the point of interest is the sum of the influences of all the noise emitting equipment in the room. Therefore, the calculation procedures defined in 7.3.4.1, 7.3.4.2 and 7.3.4.3 respectively, are to be applied to each equipment and its corresponding distance to the location of interest. These individually calculated levels are then added by using equation 14 to obtain the total installation noise level.

Alternatively figure 6 may be used to determine the number of decibels by which the installation noise level increases if two levels are being combined.

$$L_{pAeq} = 10\log \sum_{i=1}^{n} 10^{0,1L_{LpAeq,i}} \tag{14}$$

where:

$L_{p\text{Aeq}}$ is the predicted total installation noise level in dB re 20 µPa at a specific receiver location in the environment,

$L_{p\text{Aeq},i}$ is the predicted individual installation noise level determined for a single machine, or a single group of machines,

n is the number of individual installation noise levels to be added.

Increment in dB to be added to higher level

Difference in decibels between two levels being added
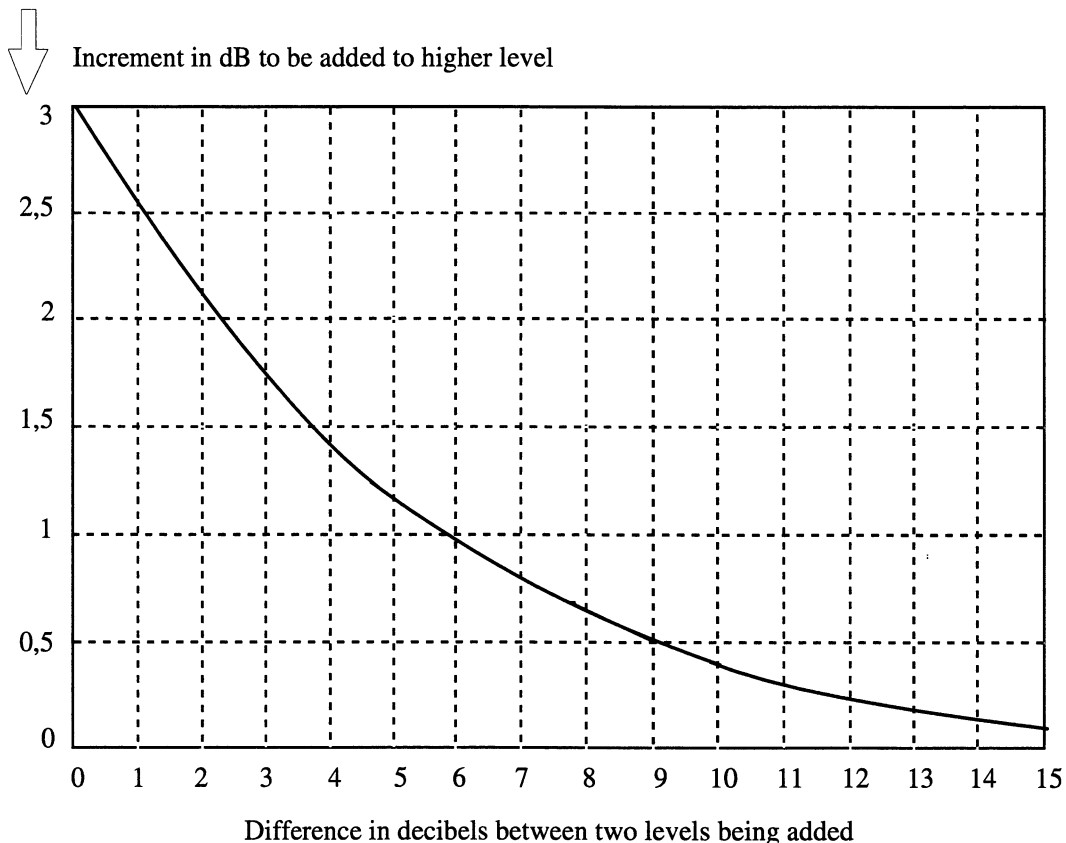
ECMA-94-0224-A

Figure 6 - Number of decibels to be added to the larger value if two sound levels are being combined.

To reduce the number of calculations for multiple equipments, several machines may be combined in one group, if either of the following conditions is met:

− the room is an "ordinary room" and has hard, acoustically reflecting surfaces and a room volume of less than 2000 m³, or

− several machines are closely arranged and the receiver location is at least 1,5 times the largest dimension of the group away from the centre of the group.

In all other cases individual calculations are necessary.

The noise emission level of the whole group is obtained by adding the individual equivalent noise emission levels. Equation 14 may be used, where the term installation noise level is to be substituted by A-weighted sound power level and n is the number of machines.

7.3.7   Adjustments for background noise

The noise in a room which remains after the installed equipment has been turned off completely, is the background noise. It may be due to air conditioning , or may originate outside the room (e.g. traffic). Background noise must be treated separately, because in most cases it cannot be described in terms of sound power level. Instead, its sound pressure level, L_b, can often be measured or estimated.

The total installation noise level, including steady background noise, may be calculated in either of two equivalent ways.

$$L_{p\text{Aeq,corrected}} = 10\log 10^{(0,1L_{p\text{Aeq,calculated}} + 0,1L_b)} \tag{15}$$

or

$$L_{p\text{Aeq, corrected}} = \max\{L_{p\text{Aeq,calculated}}; L_b\} B \tag{16}$$

where:

$L_{p\text{Aeq,calculated}}$	is the predicted total installation noise level at a specific location, in dB re 20 µPa, due to all computer and business equipment, as calculated according to the preceding clauses,
L_b	is the steady A-weighted background noise level at the same location in dB re 20 µPa,
$L_{p\text{Aeq,corrected}}$	is the predicted total installation noise level in dB at a specific location due to all equipment and steady background noise,
max $\{a;b\}$	is equal to a or b, whichever is the larger,
B	is the background correction in dB obtained from table 4 or figure 6.

Table 4 - Corrections for steady background noise

Absolute value of the difference between the calculated installation noise level, $L_{p\text{Aeq}}$ calculated and the background noise level L_b	Increment B in dB to be added to the higher level
0; 1	3
2; 3	2
4; 5; 6; 7; 8; 9	1
10 or greater	0

7.3.8   Calculations for several locations of interest

If there is an interest in the installation noise level for several locations within a room, the calculations of 7.3.4 to 7.3.7 must be repeated for each location of interest.

7.4   Actual installation noise level

The actual value of the installation noise, $L_{p\text{Aeq}}$, level may differ from the predicted installation noise level if the installed machines operate differently from the standard operating conditions used to determine the machine's noise emission levels and if the operator's exposure is different.

7.5   Rating level

The rating sound level, L_r, in decibels is used for rating the noise immission of a person at a work station. The A-weighted equivalent continuous sound pressure level, $L_{p\text{Aeq}}$, is determined over a typical 8-hours workshift is called the rating level, L_r; this level may include, or be supplemented with corrections to account for the impulsive or tonal character of the rated noise.

Annex A
(normative)
Corrections for the determination
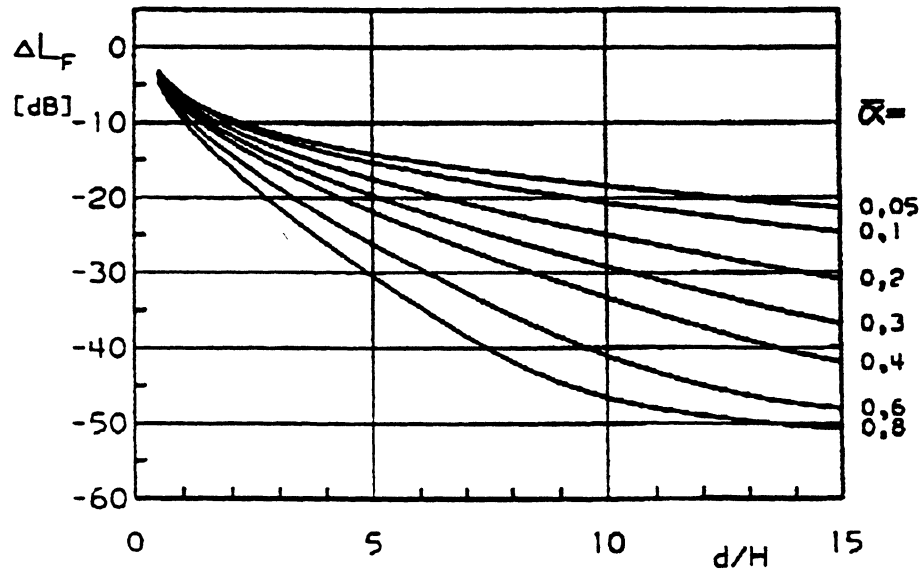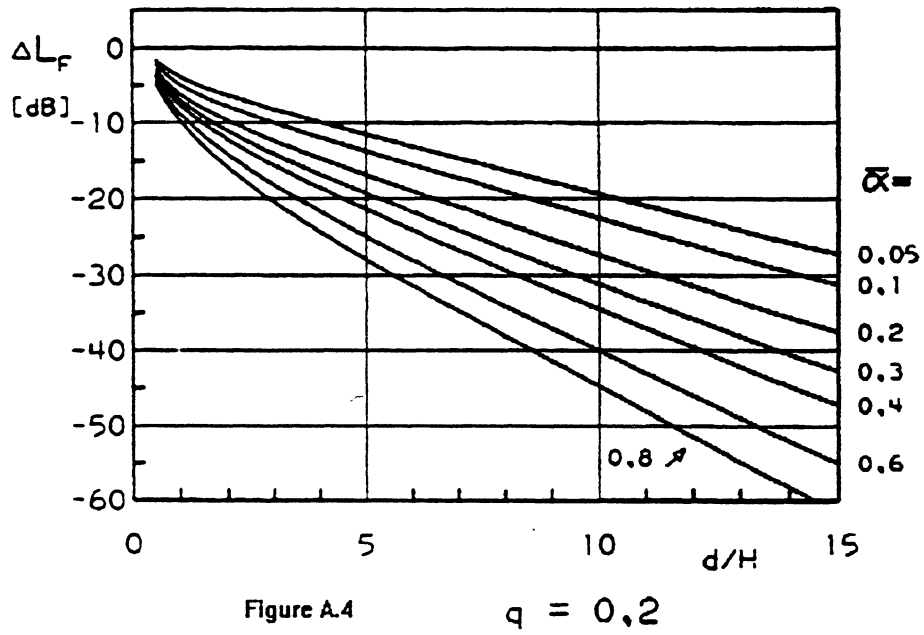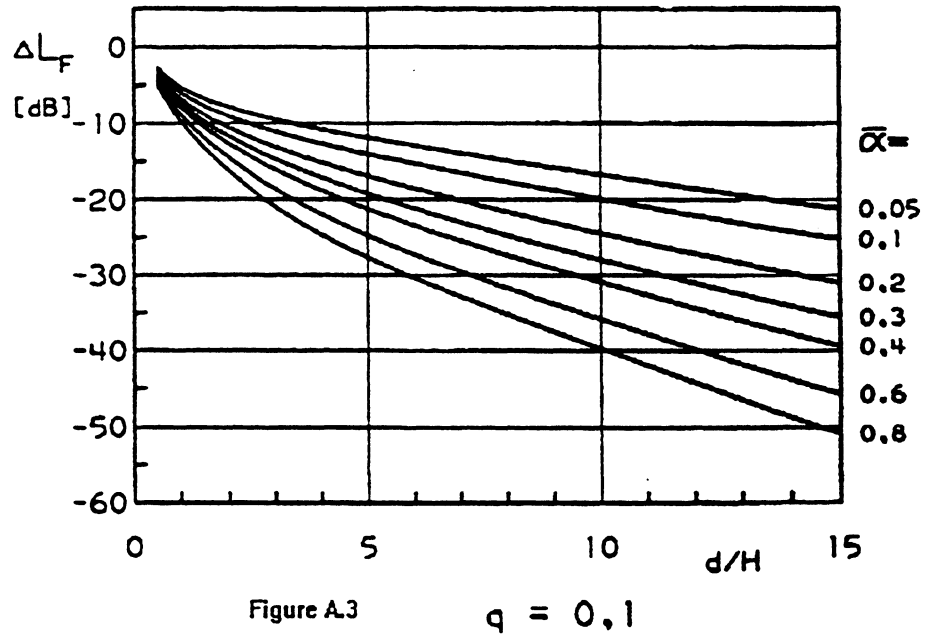**of the installation noise level**
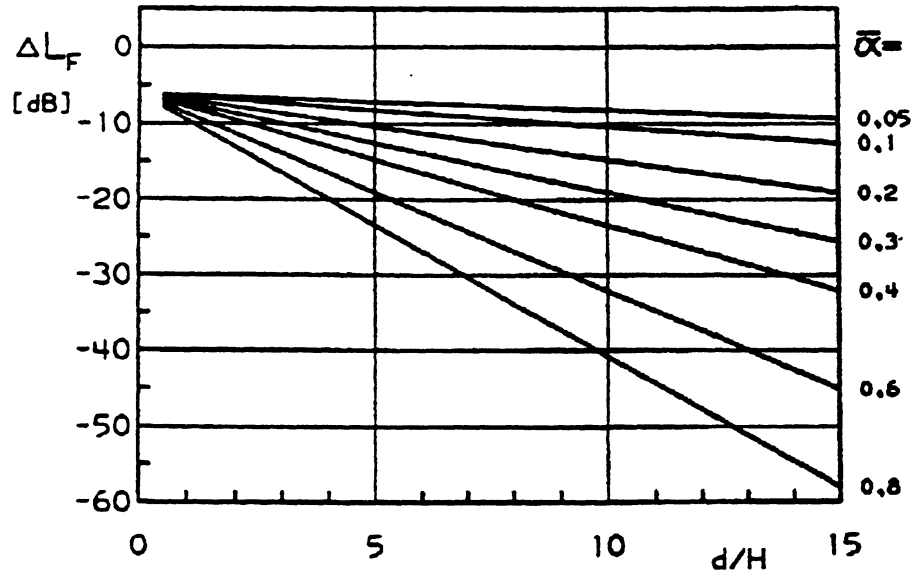
Figure A.1

$q = 0$

Figure A.2

$q = 0.05$

Figures A.1 and A.2 - Corrections for flat rooms

Figure A.3   q = 0.1

Figure A.4   q = 0.2

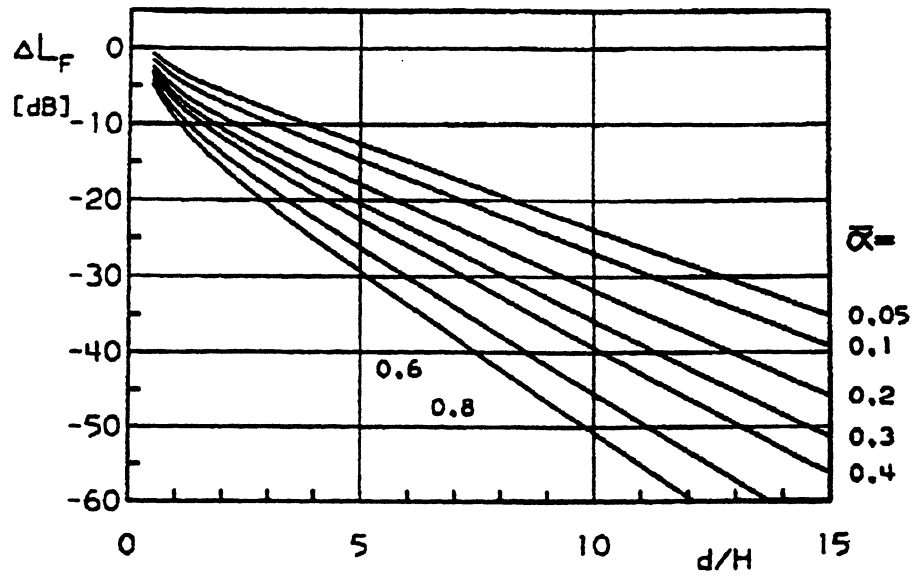Figures A.3 and A.4 - Corrections for flat rooms
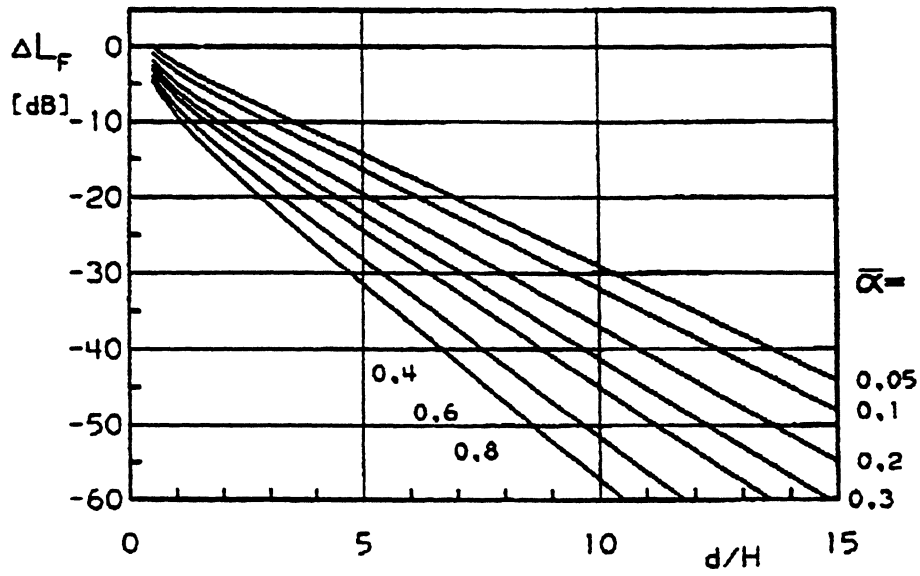
Figure A.5   q = 0.3

Figure A.6   q = 0.4
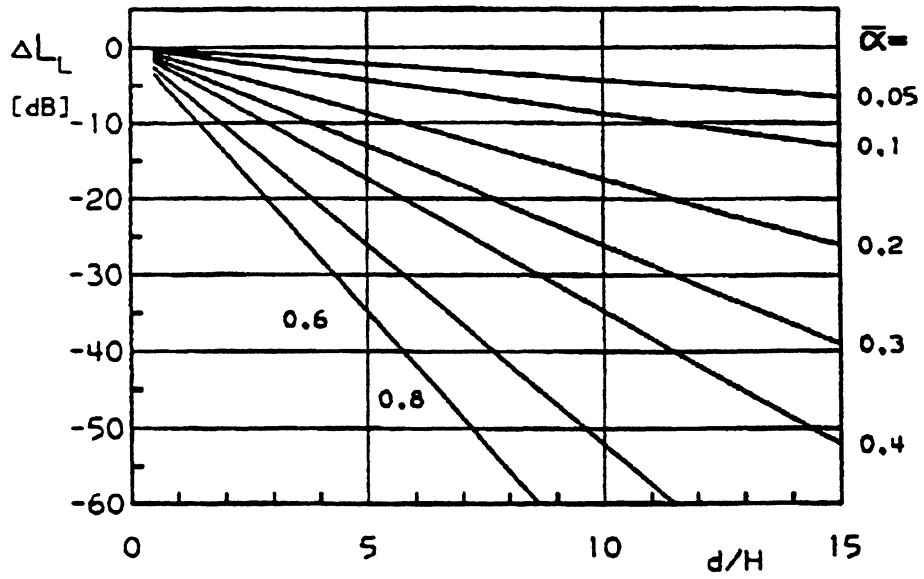
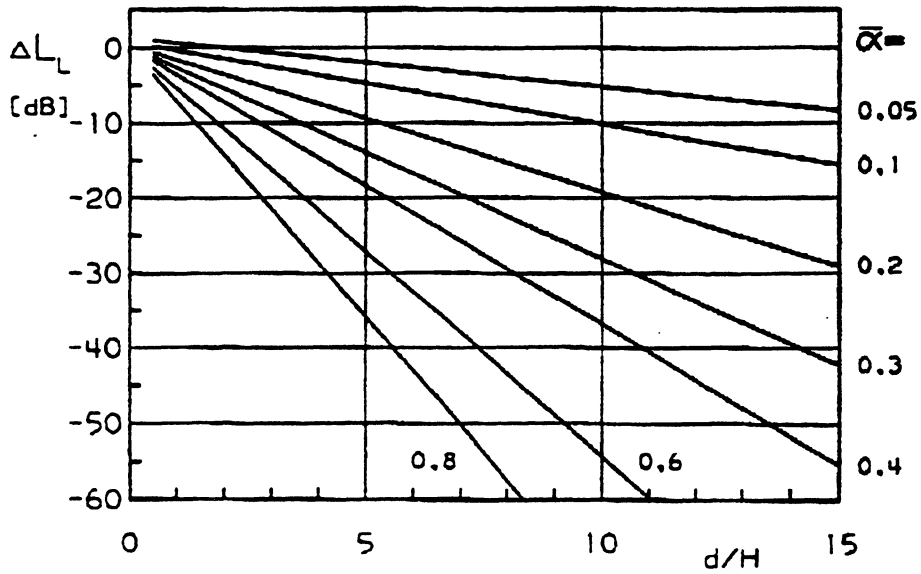Figures A.5 and A.6 - Corrections for long rooms

Figure A.7   q = 0   H/W = 1

Figure A.8   q = 0.05   H/W = 1

Figures A.7 and A.8 - Corrections for long rooms
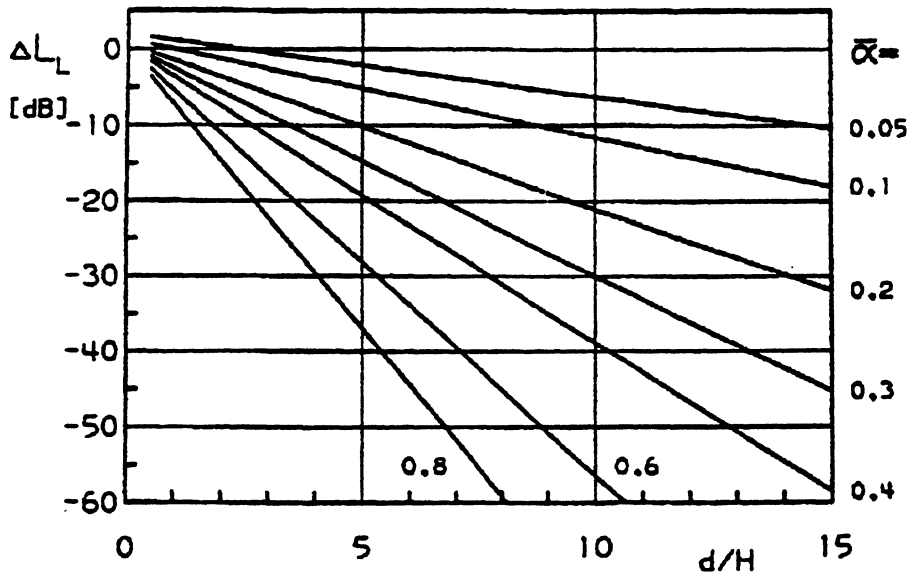
Figure A.9   q = 0.1   H/W = 1
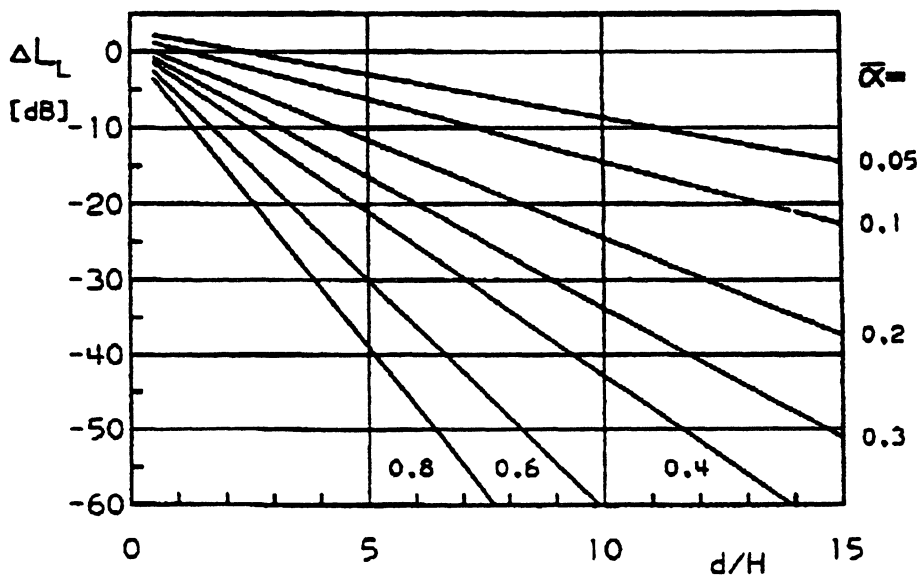
Figure A.10   q = 0.2   H/W = 1
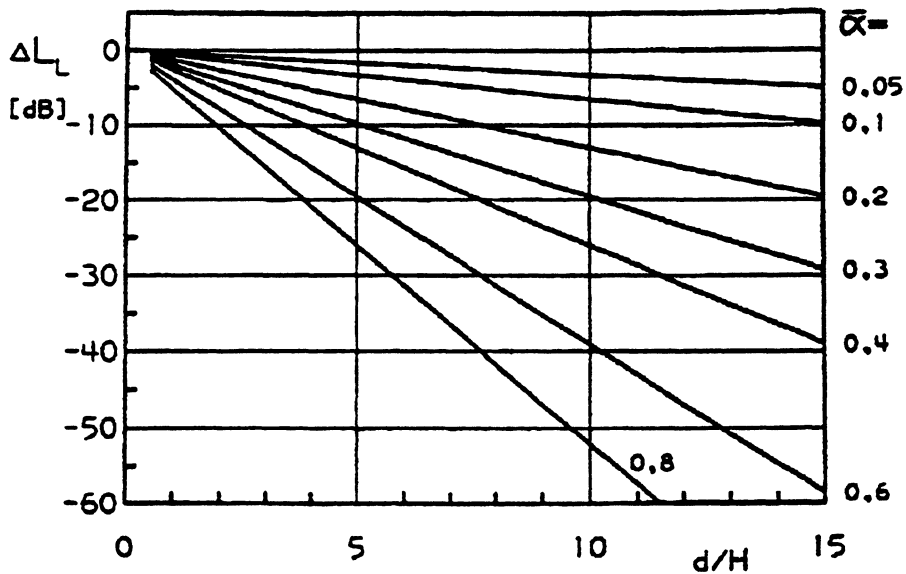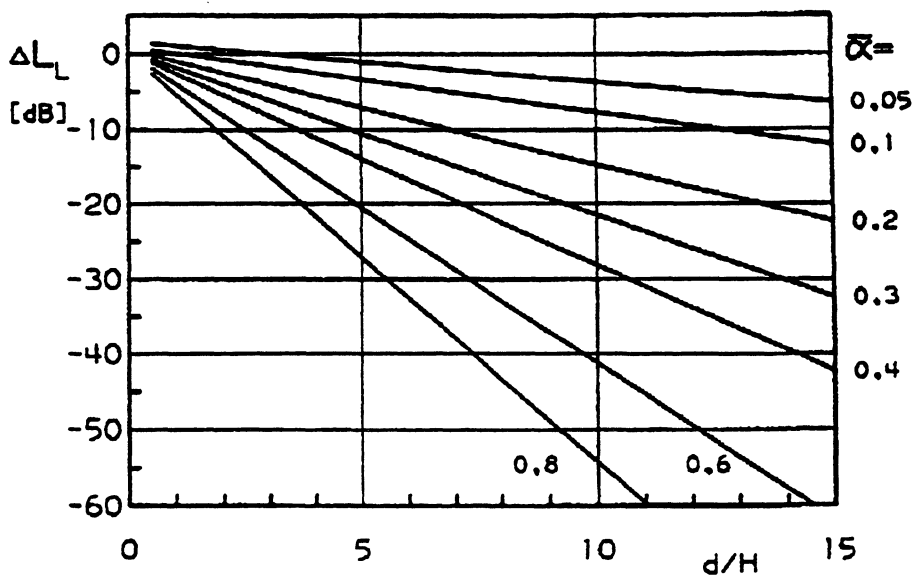
Figures A.9 and A.10 - Corrections for long rooms
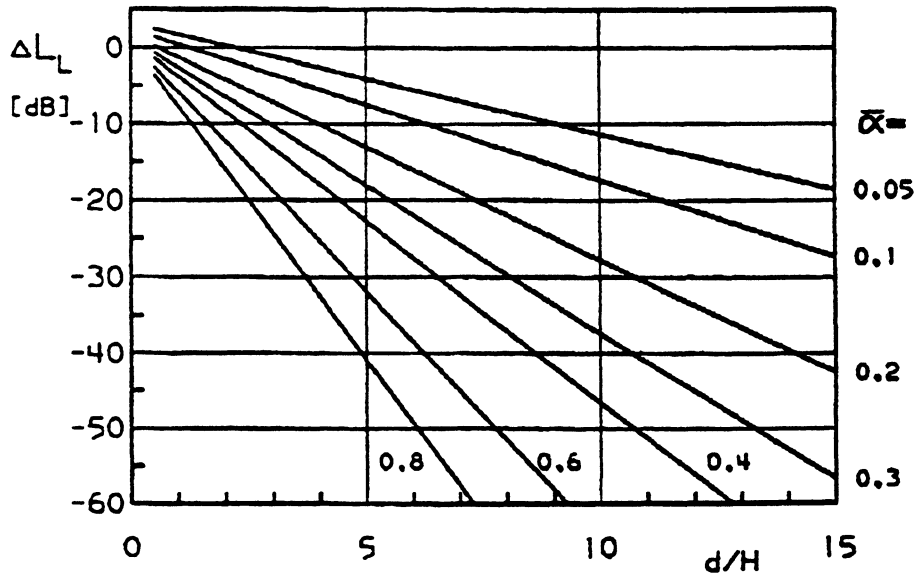
Figure A.11   q = 0.3   H/W = 1
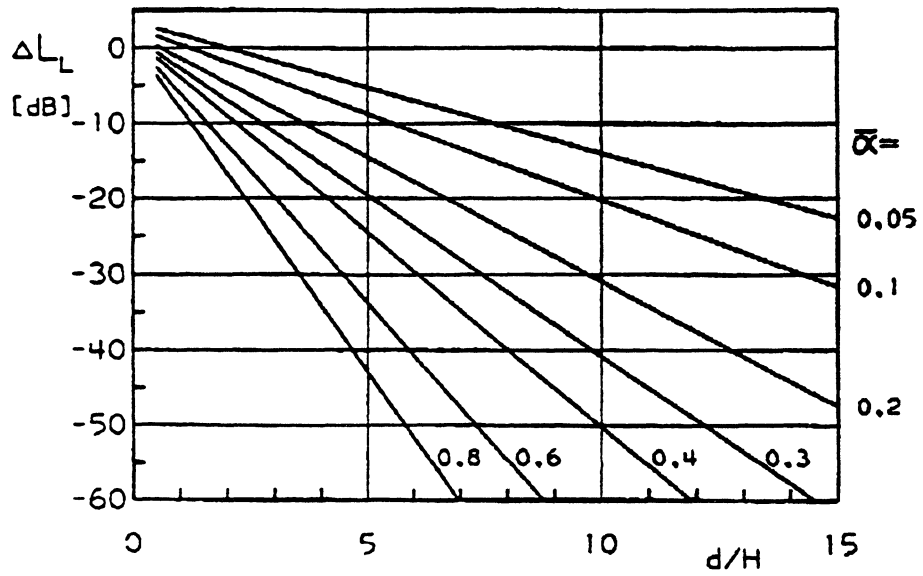
Figure A.12   q = 0.4   H/W = 1

Figures A.11 and A.12 - Corrections for long rooms

Figure A.13   q = 0   H/W = 1/2

Figure A.14   q = 0.05   H/W =1/2
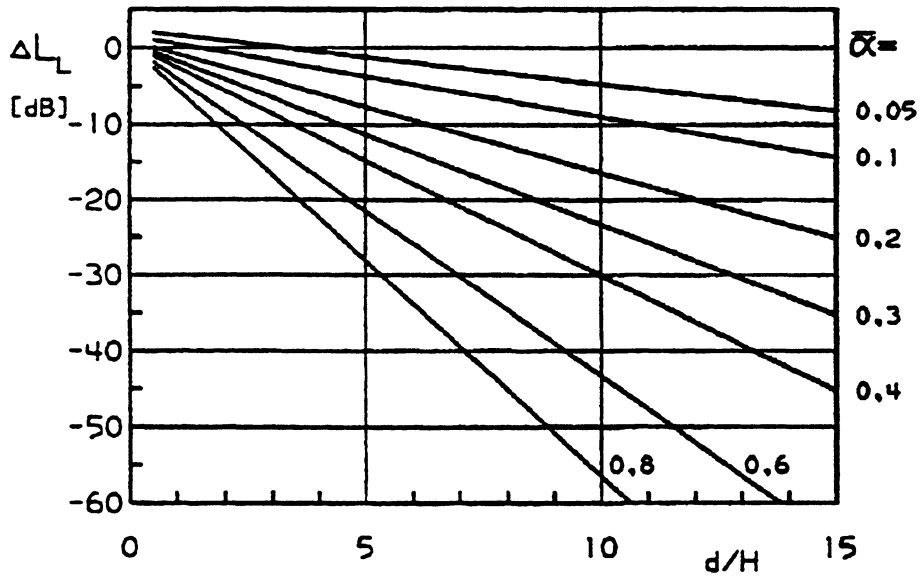
Figures A.13 and A.14 - Corrections for long rooms

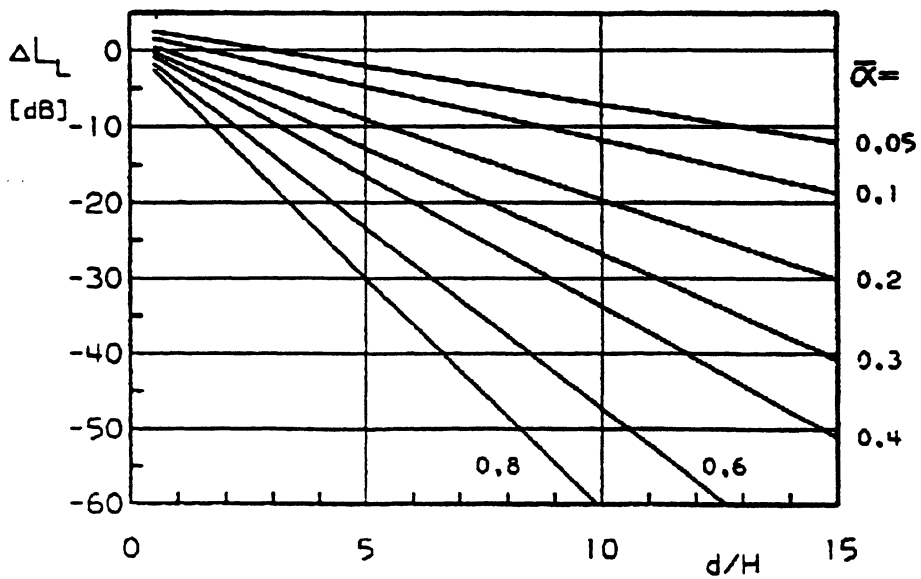Figure A.15   q = 0.1   H/W = 1/2

Figure A.16   q = 0.2   H/W = 1/2
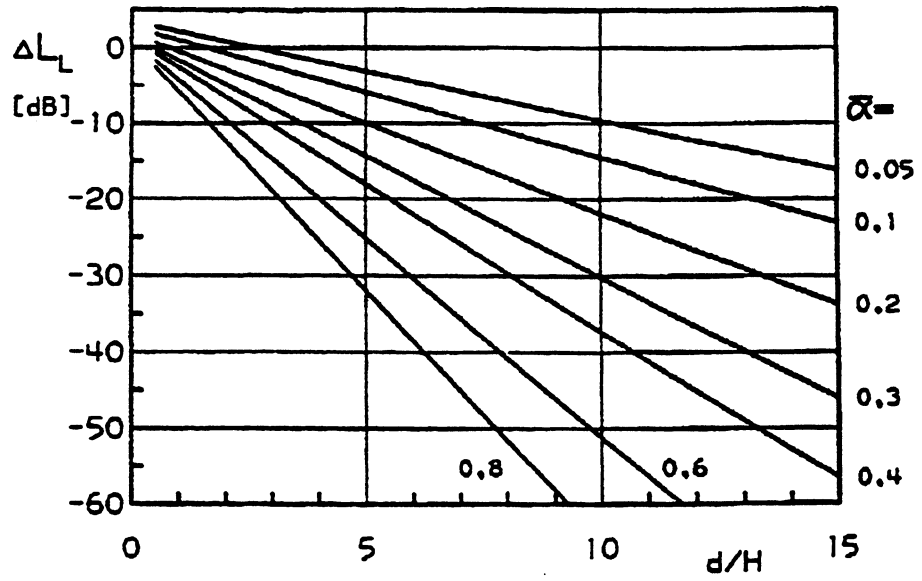
Figures A.15 and A.16 - Corrections for long rooms
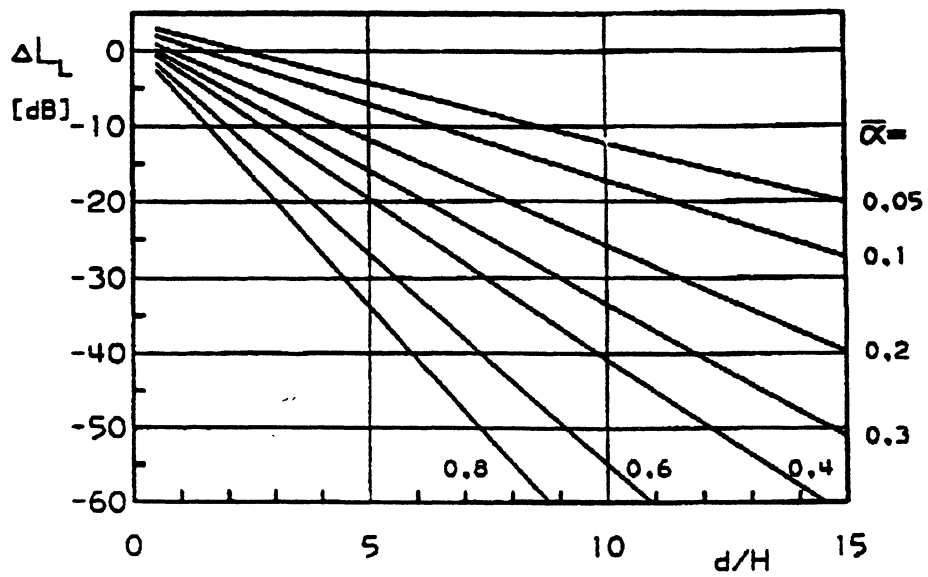
Figure A.17   q = 0,3   H/W = 1/2

Figure A.18   q = 0,4   H/W = 1/2
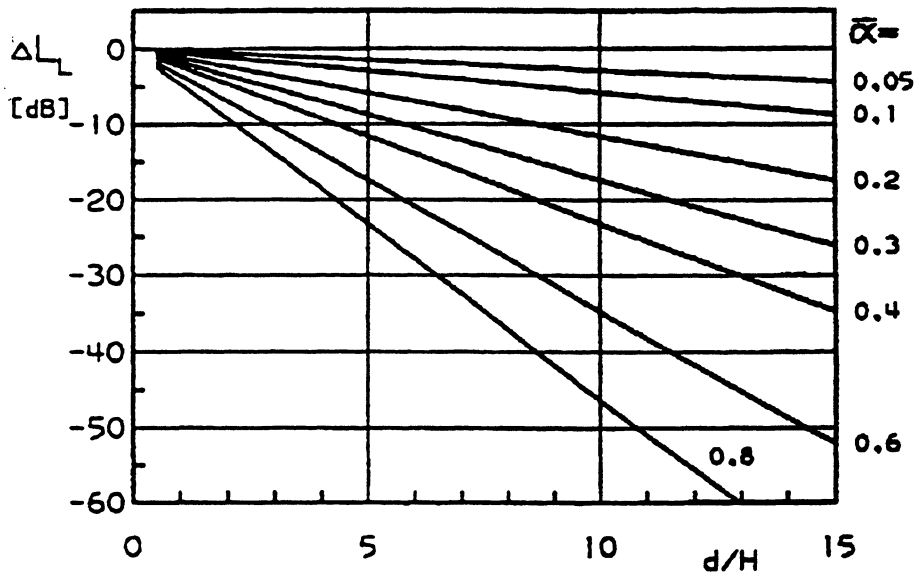
Figures A.17 and A.18 - Corrections for long rooms

Figure A.19   q = 0   H/W = 1/3
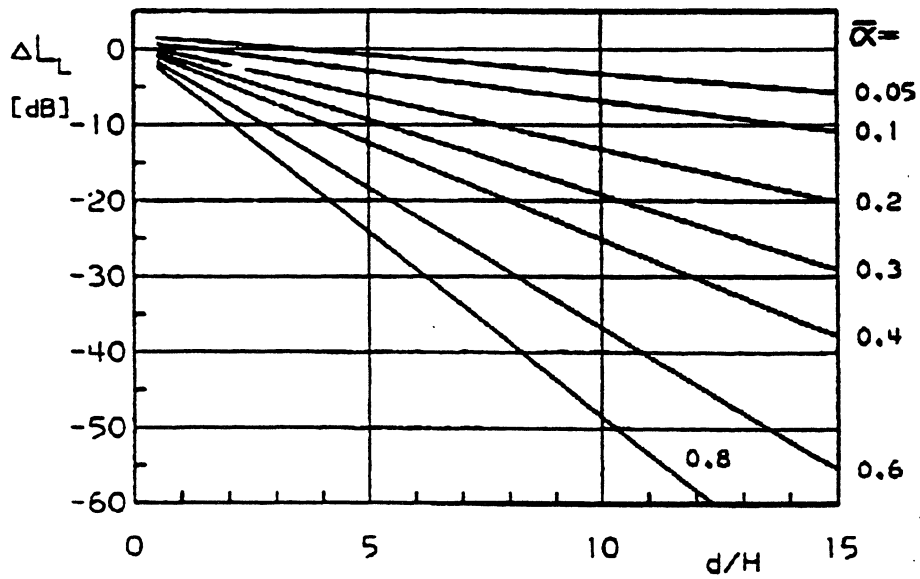

Figure A.20   q = 0.05   H/W = 1/3

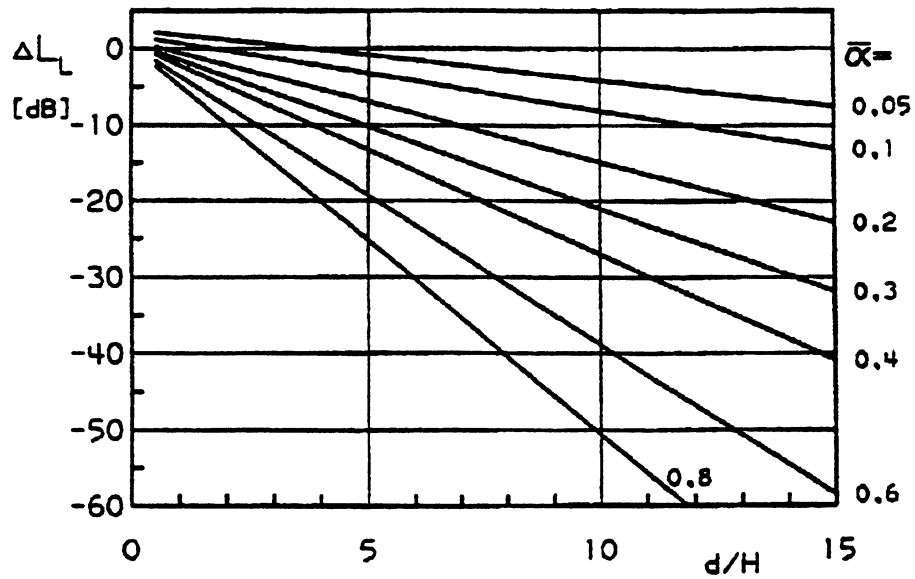Figures A.19 and A.20 - Corrections for long rooms

Figure A.21   q = 0.1   H/W = 1/3
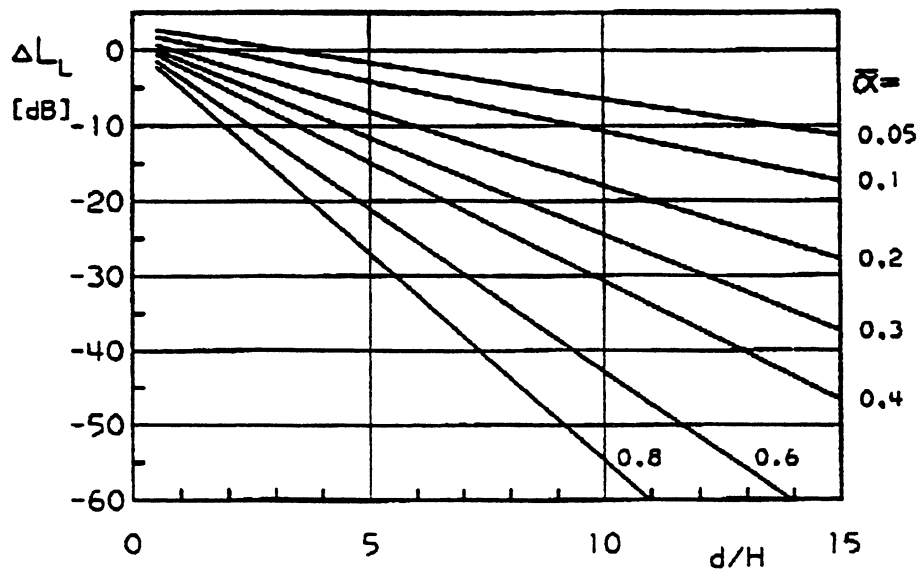

Figure A.22   q = 0.2   H/W = 1/3

Figures A.21 and A.22 - Corrections for long rooms
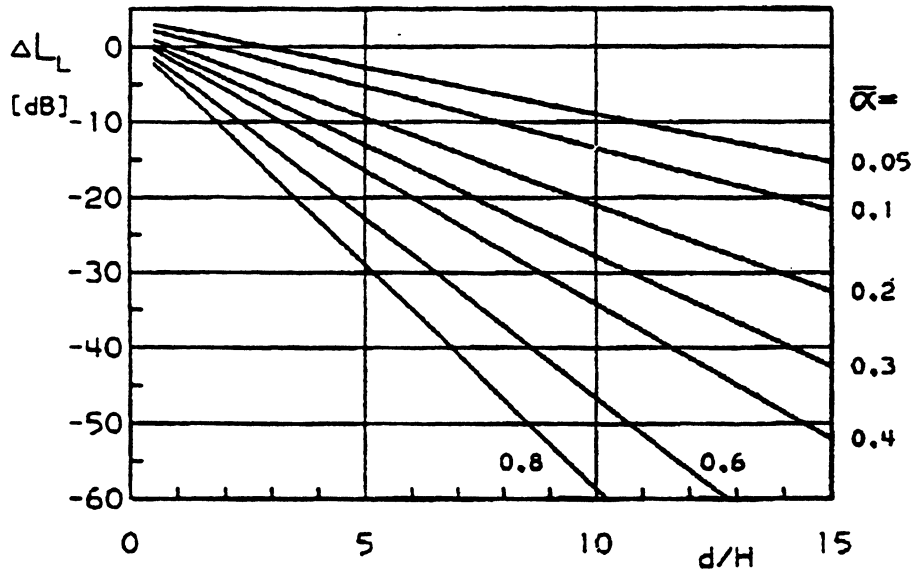
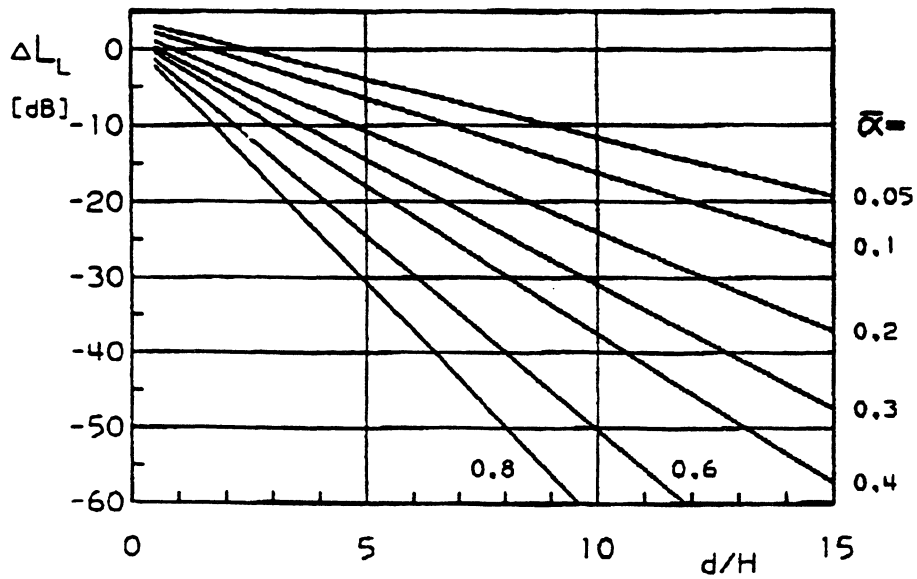Figure A.23 $q = 0.3$ $H/W = 1/3$

Figure A.24 $q = 0.4$ $H/W = 1/3$

Figures A.23 and A.24 - Corrections for long rooms

Annex B
(informative)
Absorption coefficients of some typical building materials

Table B.1 - Absorption coefficient for building materials

Building material	Thickness mm	Average Sabine Absorption Coefficient (NRC)
Floor:		
Wood or asphalt		0,05
Linoleum	5	0,05
Carpets		
on hard floor	5	0,10
on 8mm felt	13	0,50
wool pile on pad	16	0,40
Walls:		
Concrete and plaster, gypsum		0,05
Bricks, untreated	100	0,15
Bricks, open slots		0,35
Wooden panels with air space		0,20
Glass window		0,20
Draperies Velour 500g/m² straight		0,20
draped to half area		0,55
Satin, draped 200 mm from hard surface		0,80
Ceiling:		
Perforated panels 500 x 500 mm with mineral wool	200	0,60
Laminated metal with 20 mm thick mineral wool 150 mm air space	180	0,95

Table B.2 - Typical absorption coefficients from VDI 3760

No.		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
1	walls and ceilings with untreated surfaces	0,06	0,07	0,08	0,08	0,09	0,1
2	acoustical ceiling with flat and closed surface	0,3	0,55	0,69	0,83	0,87	0,88
3	acoustical ceiling with openabsorbingelements	0,28	0,34	0,65	0,87	0,88	0,99
4	metals cattering elements (machines)	0,03	0,04	0,04	0,045	0,05	0,06
5	wooden scattering elements (furniture etc)	0,08	0,08	0,09	0,09	0,1	0,12

Table B.1: Frequency dependent sound absorption coefficients determined in accordance with DIN 52212

Note to No.2 The sound absorption coefficients are average values of 10 commercially available highly absorbing products used in industrial halls.

Note to No.3 The sound absorption coefficients for open elements depend greatly on the density of the arrangement pattern.

Note to Nos.2/3 An acoustical ceiling is assumed to be qualified as "absorbing" in accordance with VDI 3755.

Other sources of absorption coefficient data are:

DIN EN 20354 Akoustik; Messung der Schallabsorption im Halllraum (ISO 354:1985); Deutsche Fassung EN 20354:1993)

Acoustics: measurement of sound absorption in a reverberation room (ISO 354:1985), German version of EN 20354:1993.

Sound Absorbing Materials - Evans and Bazley - Her Majesty's Stationery Office, London

Annex C
(informative)
Supplementary information on the prediction theory

C.1 General

The mathematical basis used for the development of the simplified procedure described in the main body of this report was taken from work published by KRAAK and JOVICIC (see annex D). Some of this background materials is summarized in this annex. As the original work also distinguishes between small rooms and long and flat halls, these three room categories are also used in this annex. Instead of "Small Room", the term "Ordinary Room" is used in this report, to make the reader aware, that this room category may be applicable to a wide range of offices and business rooms.

C.2 Ordinary Rooms

Ordinary rooms are considered to be relatively "small" with volumes not exceeding approximately 2000 m^3, and having similar room dimensions. Many offices designed for a few people as well as small DP system rooms will fall into this category. For such rooms ideal acoustical conditions may be used for calculating the installation noise level. At a location a distance d away from a single (point) source, the direct field is given by equation (3), and the reverberant field by equation (4). The combination of the two sound fields, equation (6), yields the sound pressure level at any location within the room (away from the source and from room boundaries). This assumes that the sound source is small and has an omnidirectionnal characteristic. Generally, not all technical sound sources fulfil these requirements. However, from practical experience, it is known that many computer and business equipment can be considered as being small, and as having no strong directivity in their noise radiation.

C.3 Flat Rooms

Rooms with dimensions in the horizontal plane, length and width, which are much greater than the room height, are considered as flat rooms. In a first approach the sound propagation within the room can be assumed to be infinite in the horizontal plane. Under this assumption the sound pressure level can be calculated for the empty room and for the equipped room.

C.3.1 Empty Flat Room

The sound pressure level in such rooms without any equipment and/or scatterers in the room or near the room boundaries is calculated according to KRAAK from the following equations:

$$L_p = L_W + 10\log\left(\frac{1}{4dH}e^{-\bar{a}\frac{d}{H}}\right) \quad (dB)$$

where

$$\bar{\alpha} = \frac{\alpha_C + \alpha_F}{2} + 2mH$$

α_C = Sabine absorption coefficient of the ceiling
α_F = Sabine absorption coefficient of the floor
m = air absorption coefficient in nepers per metre
H = height of the room in metres
d = distance to sound source in metres

Notes:

The absorption coefficients α_C and α_F are valid for statistical sound incidence, and are normally obtained through measurements made in the reverberation room. Results from direct reverberation time measurements in the flat room are generally not acceptable

The constant value 1 in the numerator of the equation is a reference area in square metres.

C.3.2 Equipped Flat Room

Equipment and/or scatterers, installed within the room or close to a room boundary, having dimensions greater than the wavelength of the propagating sound wave, may greatly influence the distribution of the sound energy density in the flat room. This will result in an increased sound pressure level in the vicinity of the source and in lower levels at remote locations.

The sound pressure level distribution in flat rooms, with randomly distributed equipment and/or scatterers throughout the room, is calculated as follows:

$$L_p = L_W + 10\log\left(\frac{1}{4dH}\,e^{-(\frac{\pi}{2}q+\bar{\alpha})\frac{d}{H}} + \frac{B'd}{H^3}K_1(\chi\,\frac{d}{H})\right) \quad \text{(dB)}$$

$$\chi = \sqrt{(\bar{\alpha}+\frac{1+\alpha_s}{4}\pi q)\,\frac{\pi q}{1-\alpha_s}}$$

$$B' = \frac{\chi^3}{2\pi\,(\bar{\alpha}+2\alpha_s q)(1+\frac{2\bar{\alpha}}{\pi q})}$$

where

$\bar{\alpha}$ = average absorption, see C.3.1

α_s = Sabine absorption coefficient of the scatterers

q = density factor, equation (9)

K_1 = modified first order Bessel function

$$K_1\left(\chi\,\frac{d}{H}\right) = K_1^*\left(\chi\,\frac{d}{H}\right)e^{-\chi\,\frac{d}{H}}$$

The function K_1^* ($\chi d/H$) may, in the frequency range of interest, be approximated by the following expression:

$$K_1^*\left(\chi\,\frac{d}{H}\right) \approx 0,25 + \frac{1,4H}{\chi^d}$$

C.3.3 Reflections from Side Walls

In many rooms, the walls of the four sides cannot be considered to be fully absorptive, but rather to have good reflection properties, i.e. $\alpha_{sw} < 0,2$. Considering these reflections, means that the whole installation has multiple images at each side. Thus one obtains an infinitely extended flat room with regularly distributed scatterers, and an infinite number of incoherent image sources.

The total sound pressure level at a certain location in the room, is determined as the sum of the influences from all the image sources at that location. To simplify the calculations, the absorption coefficien α_{sw} of all side walls is assumed to be the same.

$$L_{p,\text{is}}(d) = 10\log\sum_{i=1}^{\infty}\left[10^{0,1L_{pi}(d_{\text{is},i})}(1-\alpha_{sw})^{\mu}\right] \quad \text{for } \alpha_{sw} < 0,2$$

where

$L_{p,\text{is}}$ = sound pressure level contribution by image sources

μ = order of the image source ($\mu = 1, 2, ..., \infty$)

$d_{\text{is},i}$ = distance from i^{th} image source

According to GRUHL, the series calculations may be limited to $\mu = 1$; the remaining error will not exceed 1 dB; generally it will be almost removed in the calculations, because of an absorption coefficient of $\alpha_{sw} = 0$.

Under these assumptions the total sound pressure level in the room is obtained from

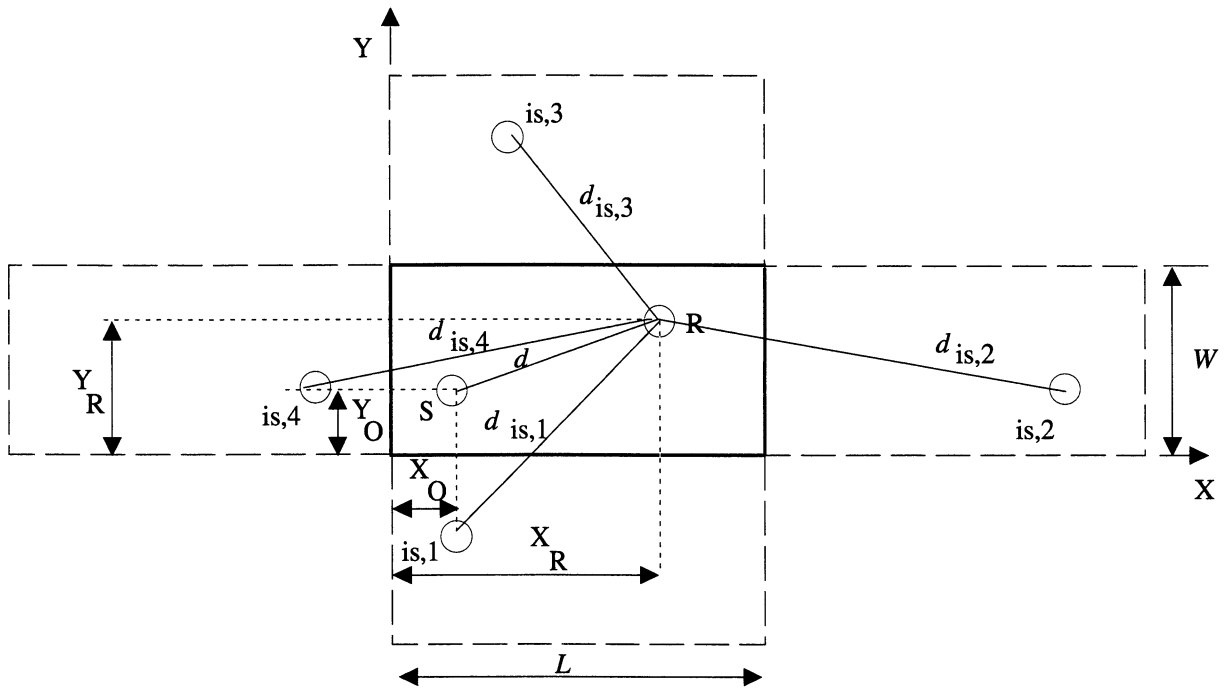$$L_{ptot}(d) = L_p(d_0) + 10\log\sum_{i=1}^{4} 10^{0,1L_{pi}(d_{is,i})} \quad (dB)$$

$L_p(d_{is,i})$ = sound pressure level as junction of the distance from the image source

When considering a corner of the room as the origin of a cartesian coordinate system, as shown in the figure below, the individual distances between the (image) sources and the receiver location are calculated as follows:

$$d_0 = d = \sqrt{(X_R - X_0)^2 + (Y_R - Y_0)^2}$$

$$d_{is,1} = \sqrt{(X_R - X_0)^2 + (Y_R + Y_0)^2}; \; d_{is,2} = \sqrt{(2L - X_R - X_0)^2 + (Y_R - Y_0)^2}$$

$$d_{is,3} = \sqrt{(X_R - X_0)^2 + (2W - Y_R - Y_0)^2}; \; d_{is,4} = \sqrt{(X_R + X_0)^2 + (Y_R - Y_0)^2}$$

ECMA-94-0226-A

S = source location

R = receiver location

is = image source

L = room length

W = room width

C.4 Long Rooms

In long rooms the room length is the dominating dimension, i.e. it is much greater than the other room dimensions; the room width is approximately of the same order as the room height.
Calculations of the sound pressure level can be performed on the basis of an infinite long room.

C.4.1 Empty Long Room

According to JESKE, the sound pressure level is calculated from the equation

$$L_P = L_W + 10\log\left(\frac{1}{WH}\ e^{-\left(\frac{H+W}{W}\right)\frac{\bar{\alpha}d}{H}}\right) \quad (\text{dB})$$

$$\bar{\alpha} = \frac{H\left(\alpha_{sw1} + \alpha_{sw2}\right) + W\left(\alpha_F + \alpha_C\right)}{2\left(W + H\right)} + \frac{2mWH}{W + H}$$

where

$\alpha_{sw1;2}$ = Sabine sound absorption coefficients of the side walls of the room.

C.4.2 Equipped Long Room

If equipment and scatterers are irregularly distributed throughout a long room, the sound pressure level distribution may be determined according to KRAAK and JESKE.

$$L_P = L_W + 10\log\left(\frac{1}{WH}\ \frac{\beta}{\bar{\alpha}\left(1+\frac{H}{W}\right)+2q\alpha_s}\ e^{-\beta\frac{d}{H}}\right) \quad (dB)$$

$$\beta = \sqrt{\left(\bar{\alpha}\left(1+\frac{H}{W}\right)+q\left(1+\alpha_s\right)\right)^2 - q^2\left(1-\alpha_s\right)^2}$$

where

L_p = sound pressure level at distance d

$\bar{\alpha}$ = average absorption coefficient according to C.4.1

q = density factor according to equation (9)

C.4.3 Reflections from Side Walls

The calculations are similar to those derived for the flat room, except that only the short sides on either end of the room are considered. The room including all equipment is reflected on these two sides; again only the first order reflections need be considered for the calculation of the total sound pressure level at the location of interest.

Annex D
(informative)
Bibliography

KRAAK, W.	Schallausbreitung in flachen grossen Raümen mit Quellenfeldern, Dissertation, TU Dresden 1976
JOVICIC, S.	Zur Schallausbreitung in flachen Raümen unter Berücksichtigung der Schallstreuung, Proceedings, Seventh International Congress on Acoustics, Budapest 1971, Vol. 2, pp 25-28
JOVICIC, S.	Anleitung zur Vorausberechnung des Schallpegels in Betriebsgebäuden, Ministerium für Arbeit und Soziales des Landes Nordrhein-Westfalen, 1979
JESKE, W.	Schallausbreitung in langen leeren Werkhallen, Hochfrequenztechnik und Elektroakustik, Leipzig, 1970
GRUHL, S.	Schallausbreitung in Räumen mit Quellenfedern, Dissertation, TU Dresden 1976
DIN 45645	Einheitliche Ermittlung des Beurteilungspegels für Geräuschimmissionen (Standardized determination of the rating level for occupational noise immissions).
BERANEK, L.	Acoustics, McGraw-Hill Book Company, New York 1954.
VDI 2720 (Blatt 2)	VDI Richtlinie: Schallschutz in Raumen durch Abschirmung.
VDI 3760	Berechnung und Messung der Schallausbreitung im Arbeitsräumen
DIN	Deutsches Institut für Normung, Schallabsorptionsgrad-Tabelle, Beuth-Vertrieb GmbH, Berlin 30, 1968.

Annex E
(informative)
Computer programs for installation noise prediction

Raynoise, System for Geometrical Acoustics.

Numerical Integration Technologies N.V.
Ambachtenlaan 11a
B - 3001 Leuven
Belgium

Tel: + 32 16 40 04 22
Fax: + 32 16 40 04 14

Indoor Noise (BL-dgmr)

DGMR
Raadgevende Ingenieurs BV
Eisenhowerlaan 112
2517 KM Den Haag
The Netherlands

Tel: + 31 70 350 39 39
Fax: + 31 70 358 47 52

Cadna/SAK

Datakustik Gmbh
Gräfelfinger Strasse, 133 A
D - 8000 Munich
Germany