CIRA(EXT) 009
April 1996

AN INVESTIGATION INTO THE MEASUREMENT OF THE ENVIRONMENTAL CORRECTION FACTOR USED IN THE DETERMINATION OF THE SOUND POWER LEVEL AND EMISSION SOUND PRESSURE LEVEL OF MACHINES

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ABSTRACT

The introduction of a number of EC Directives has made it necessary for machinery manufacturers to provide information on the airborne noise emitted by machinery under defined operating conditions and in defined acoustical environments. Machinery noise emission is evaluated using the procedures described in several ISO standards. The most commonly used methods involve measurements of sound pressure level over a measurement surface (hemispherical or parallelepiped) enveloping the source. The acoustics of the test site are taken into account by means of an environmental correction factor, K_2, which is a correction term to account for the influence of reflected or absorbed sound on the measured sound pressure level.

The ISO 3740 and ISO 11200 series of standards describe a number of methods for determining K_2 which range from measurements using a reference sound source to subjective assessments of the sound absorption properties of the surroundings. In this investigation, measurements of the environmental correction factor (A-weighted) K_{2A} have been made by different methods in five test rooms with different acoustical properties, and the results compared.

It is concluded that the absolute method using a reference sound source is the only method that will consistently provide an accurate assessment of K_{2A}. The method involving measurement of reverberation time generally over-estimates K_{2A} and will result in values of sound power level that are too low. It performs best in rooms where the reverberation time (for A-weighted broad-band noise) is high (> 1 s). The two surface method generally under-estimates K_{2A} and will result in values of sound power level which are too high. It should not be used where the larger enveloping surface is affected by reflections from nearby objects. The estimated room absorption method provides only a range of possible values of K_{2A} when the descriptors in the ISO standards do not match well the room characteristics, and performs badly in rooms where the reverberation time (for A-weighted broad-band noise) is high (> 1 s).

ISSN 1361-4053

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CONTENTS

1 INTRODUCTION

The introduction of a number of EC Directives has made it necessary for machinery manufacturers to provide information on the airborne noise emitted by machinery under defined operating conditions and in defined acoustical environments. One of the most wide-ranging Directives affecting industrial products is 89/392/EEC[1] and its two amendments 91/368/EEC[2] and 93/44/EEC[3] on "the approximation of the laws of the Member States relating to machinery" - the so-called EC Machinery Directive. This Directive applies to all machinery and is principally concerned with the safety of machines, one aspect of which involves controlling excessive noise emission.

The Machinery Directive contains detailed instructions regarding the nature of the information to be provided by the manufacturer. This includes the emission sound pressure level at the work station (the position of the operator) and the overall sound power level. The decision on which of these two acoustic parameters is to be provided is made by comparing the values of the A-weighted time-averaged emission sound pressure level, L_{pA}, at the work station to thresholds specified in the Directive, as follows:

- If L_{pA} is less than 70 dB then only this fact need be stated.
- If L_{pA} is between 70 dB and 85 dB then only L_{pA} need be provided.
- If L_{pA} is greater than 85 dB, then the A-weighted sound power level, L_{WA} as well as L_{pA} must be provided.

Sound power is evaluated using the procedures described in several ISO standards. The most commonly used methods involve measurements of sound pressure level over a measurement surface (hemispherical or parallelepiped) enveloping the source. The acoustics of the test site are taken into account by means of an environmental correction factor, K_2, which is a correction term to account for the influence of reflected or absorbed sound on the measured sound pressure level. ISO 3744[4] requires that the environmental correction factor is less than 2 dB (and in some cases it can be ignored). ISO 3746[5] can be used with higher value factors that must be accounted for.

For emission sound pressure level the ISO 11200 series of standards is used. These standards offer a number of different methods for measuring the emission sound pressure level at work stations. ISO 11201[6] gives an engineering grade measurement method in a closely controlled acoustical environment, so no K_2-factor is required. ISO 11202[7] offers a lower grade measurement method in a more loosely prescribed environment in which K_2 must not exceed 2.5 dB. ISO 11204[8] may be used in a wide range of acoustical environments for which a local K_2-factor must be determined from a series of sound pressure measurements around the machine.

Taken together, these standards permit K_2 to range from 0 dB to 7 dB. Since K_2 is added to measured noise levels, it is clear that it must be determined accurately. Recent experimental work at NPL[9] has shown the discrepancies which may otherwise arise. The various ISO standards describe a number of methods for determining K_2-factors which range from measurements using a reference sound source to subjective assessments of the sound absorption properties of the surroundings. Depending on which method is used, and how it is used, the determination of K_2-factors may vary between manufacturers or test houses carrying out measurements in the same acoustical conditions. It is possible, therefore, that the reported sound power and emission sound pressure levels of a machine will be affected by the choice of the method of determination of the K_2-factor. It is important that this possibility is investigated and, if necessary, the International and national Standards amended accordingly.

Here, we report a series of measurements of K_2 made using all of the methods permitted by the ISO standards, and we inter-compare the results. Measurements were carried out in five acoustical environments ranging from hemi-anechoic to semi-reverberant.

2 METHODS OF DETERMINING K_2

2.1 NOISE SOURCE

For those methods of determining K_2 which require a reference sound source, a Brüel & Kjær type 4204 was used. The type 4204 is an aerodynamic broad band noise source that complies with the requirements of ISO 6926[10]. It is cylindrical in shape and we have assumed a "reference box" of 0.4 m square by 0.3 m high. The reference box is defined as a hypothetical surface which is the smallest rectangular parallelepiped that just encloses the source and terminates on the reflecting plane or planes. The reference sound source type 4204 used in this study has been calibrated regularly over several years in accordance with ISO 6926, yielding a stable A-weighted sound power level of 90.9 dB ± 0.2 dB re 1 pW.

2.2 ABSOLUTE COMPARISON METHOD

This is a substitution method in which a reference sound source is placed in the same location as the machine under test. The sound power level is determined as described in Clauses 7 & 8 of ISO 3744. Here, the sound power level, L_W, is derived from the spatially and temporally averaged sound pressure level, L_p, over an enveloping measurement surface and is given by:

$$L_W = L_p + 10.\log(S/S_0) \qquad \ldots\ldots\ldots (1)$$

where S is the area of the enveloping measurement surface and S_0 is the reference area (1 m^2).

The environmental correction, K_2, is given by:

$$K_2 = L_{Wr} - L_W \qquad \ldots (2)$$

where L_{Wr} is the calibrated sound power level of the reference sound source. In the case of the reference sound source used in this study, L_{wr} was taken to be 90.9 dB re 1 pW.

2.3 ROOM ABSORPTION METHOD

Here K_2 is calculated from estimates of the equivalent sound absorption area, A, of the measurement room from:

$$K_2 = 10.\log(1 + 4(S/A)) \qquad \ldots (3)$$

The Standards define two ways of establishing the equivalent absorption area, an approximate method and a reverberation time method. Both are examined in this

Report and are described in the following two sub-sections.

2.3.1 Approximate method

In this approximate method the value of the equivalent sound absorption area of the room is obtained from:

$$A = \alpha \, . \, S_V \qquad \ldots\ldots\ (4)$$

where S_V is the total area of the surface of the test room (walls, ceiling and floor) and α is the mean sound absorption coefficient. Values of α are obtained from those listed in Table A.1 of Annex A in ISO 3744 and ISO 3746. This Table, reproduced below as Table 1, gives values of α corresponding to a variety of room descriptions.

Table 1 Approximate values of the mean sound absorption coefficient, α.

Mean sound absorption coefficient α	Description of room
0.05	Nearly empty room with smooth hard walls made of concrete, brick, plaster or tile
0.1	Partly empty room, with smooth walls
0.15	Room with furniture, rectangular machinery room, rectangular industrial room
0.2	Irregularly shaped room with furniture, irregularly shaped machinery room or industrial room
0.25	Room with upholstered furniture, machinery or industrial room with a small amount of sound absorbing material (for example, partially absorptive ceiling) on ceiling or walls.
0.35	Room with sound absorbing materials on both ceiling and walls.
0.5	Room with large amounts of sound absorbing materials on ceiling and walls

2.3.2 Reverberation method

The equivalent sound absorption area of the room is estimated from a measurement of the reverberation time of the test room from:

$$A = 0.16\,(V/T) \qquad \ldots\ldots\ (5)$$

where V is volume of the room in cubic metres and T is the reverberation time in seconds. The environmental correction, K_2 is calculated from equation 3. It should be noted that this method is not applicable to hemi-anechoic environments.

2.4 TWO SURFACE METHOD

This method is only applicable to rooms whose length and width are each less than three times the ceiling height. Here the sound power level determined from measurements using a surface of area S is compared with the sound power level determined from measurements using a geometrically similar surface, symmetrical with respect to the machine under test, with a larger surface area, S_2. The microphone locations on the larger surface must correspond to those on the smaller surface and the ratio S_2/S should be at least 2, and preferably greater than 4.

The ratio S/A used in equation (3) to determine K_2, is calculated from:

$$S/A = (1 - M.S/S_2) / (4 (M - 1)) \qquad (6)$$

The parameter, M, is calculated from:

$$M = 10^{0.1(Lp1 - Lp2)} \qquad (7)$$

where L_{p1} is the average sound pressure level on S, and L_{p2} is the average sound pressure level on S_2. Normally, this method makes use of the machine under test, but in this investigation the reference sound source was used.

3 THEORETICAL APPROACH

If it is assumed that the noise source is omnidirectional and is located at the centre of a spherical enclosure, then K_2 may be obtained from[11]:

$$K_2 = 10.\log [1 + 4(r/R)^2 - ((1/\alpha) - 1)] \quad \ldots\ldots\ (8)$$

where r is the radius of a spherical measurement surface and R is the radius of the enclosing spherical boundary with absorption coefficient α. The values of K_2 as a function of normalised distance, r/R, for two values of α, representative of high and low absorption, have been calculated and are shown in Figure 1.

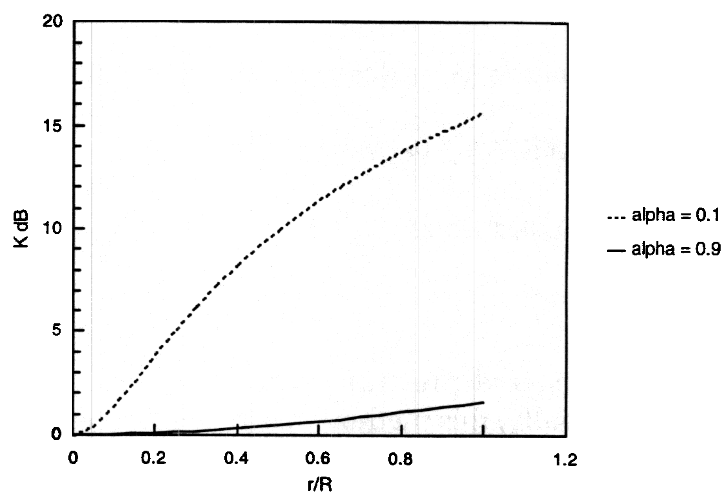

Figure 1. Theoretical K_2-factor for ideal conditions

It can be seen that the magnitude of K_2 increases with measurement distance (r/R), and the rate of change of K_2 with measurement distance is dependent on the value of α and on the absolute value of the ratio r/R. For a room with highly absorbent walls ($\alpha = 0.9$), the increase in K_2-factor with increasing measurement distance (r/R) is small. For a room with reflective walls ($\alpha = 0.1$) the K_2-factor depends critically on the measurement distance. For instance, for approximately hemi-anechoic conditions ($\alpha = 0.1$) a doubling of measurement distance from r/R of 0.2 to r/R of 0.4 results in a change in K_2 of 0.3 dB; the corresponding change for semi-reverberant conditions ($\alpha = 0.9$) is approximately 5 dB. Although this treatment is highly idealised by comparison with practical measurement conditions, it provides a revealing indication of the dependence of K_2 on measurement distance in different environments.

4 EXPERIMENTAL INVESTIGATION

4.1 MEASUREMENT ENVIRONMENTS

Sound power determinations and reverberation time measurements were carried out in five rooms on the NPL site. The rooms were chosen to cover a wide range of K_2-factors and room volume. In all the cases the measured background noise level was negligible. A brief description of each room is given in the following sub-sections.

4.1.1 Test room A

Test room A is a hemi-anechoic room that satisfies the requirements of ISO 6926, for hemispherical measurement surfaces with radii up to 1.5 m. It is an acoustically isolated asymmetrical chamber consisting of acoustically absorbent wedges on the walls and ceiling and a hard painted concrete reflecting floor. Figure 2 depicts a plan view of the room with the location of the reference sound source annotated with "X", approximately in the centre of the room on the floor. Relevant room size data are listed in Table 2.

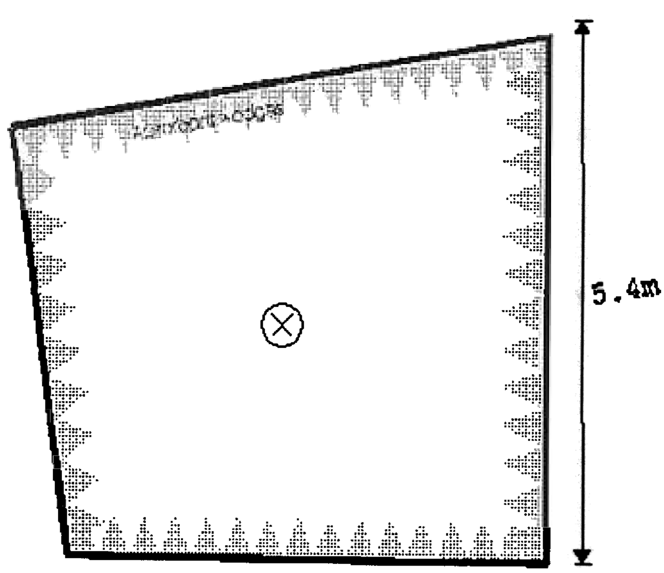

Figure 2. Schematic plan view of room A

Table 2 Size of room A

Area S_v (m^2)	Volume V (m^3)	mean height (m)
134	91.5	3.8

4.1.2 Test room B

This room is a general-purpose laboratory with workbenches and cupboards along two sides. There is a mezzanine floor constructed at half the room height of 4.6 m with access stairs at one end of the room (see Figure 3). The underside of the mezzanine floor (ie the ceiling of the test area) is covered with fibre board acoustic tiles. The walls are of painted brick and the floor is covered with linoleum. The reference sound source was positioned in the centre of the room as indicated by the "X" in Figure 3. Relevant room size data are listed in Table 3

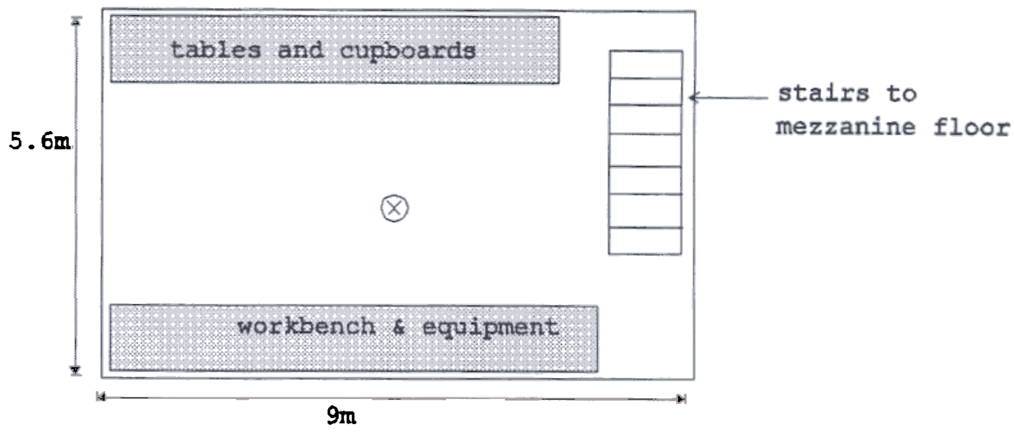

Figure 3. Schematic plan view of room B

Table 3 Size of room B

Area S_v (m^2)	Volume V (m^3)	room height (m)
168	116	2.3

4.1.3 Test room C

This room was originally part of a three-room transmission suite and is constructed with non-parallel walls on its long side and a sloping ceiling. It now houses a free-standing anechoic chamber and an environmental cabin with associated workbenches and control equipment and a large walk-in storage cupboard. The walls are of painted brick, the ceiling plastered and the floor painted concrete. The schematic diagram in Figure 4 shows the approximate location of these items together with the two locations used for the reference sound source. Relevant room sizes are listed in Table 4.

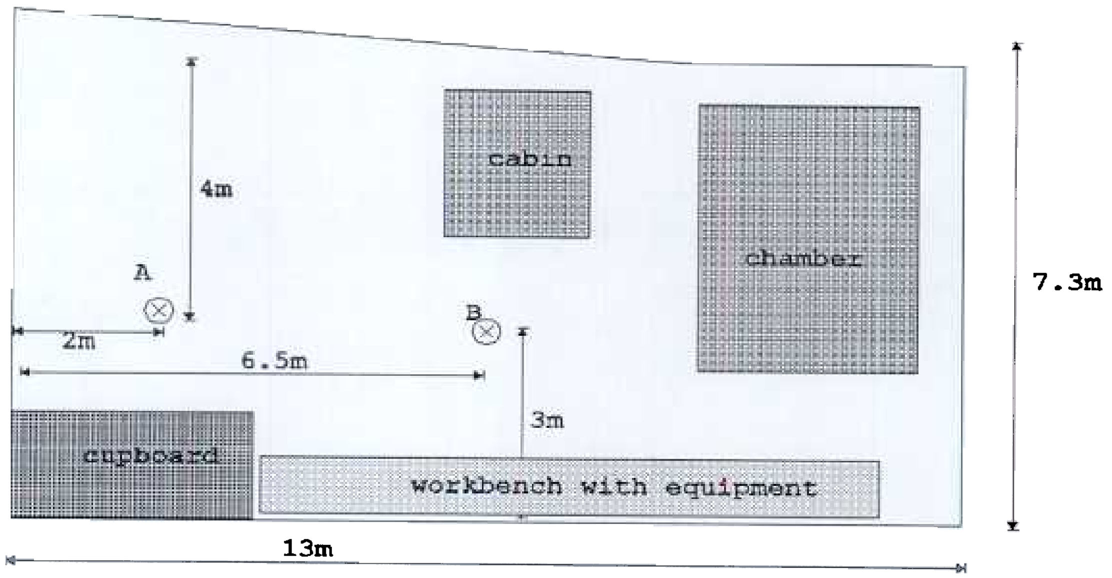

Figure 4 Schematic plan view of room C

Table 4 Size of room C

Area S_v (m^2)	Volume V (m^3)	mean room height (m)
373	428	4.5

4.1.4 Test room D

This room is a medium size exhibition hall located on the NPL site. Relevant room sizes are listed in Table 5. It has a false acoustic tile panelled ceiling suspended from the original building roof at some 10 m in height. The floor is covered with a short pile carpet and the walls are of painted brick. There are a number of chairs and tables located around the room perimeter which are indicated in the schematic of Figure 3 together with the approximate positions ("X") of the two reference sound source locations.

Table 5 Sizes of room D

Area S_v (m^2)	Volume V, m^3	mean room height (m)
834	1188	4.5

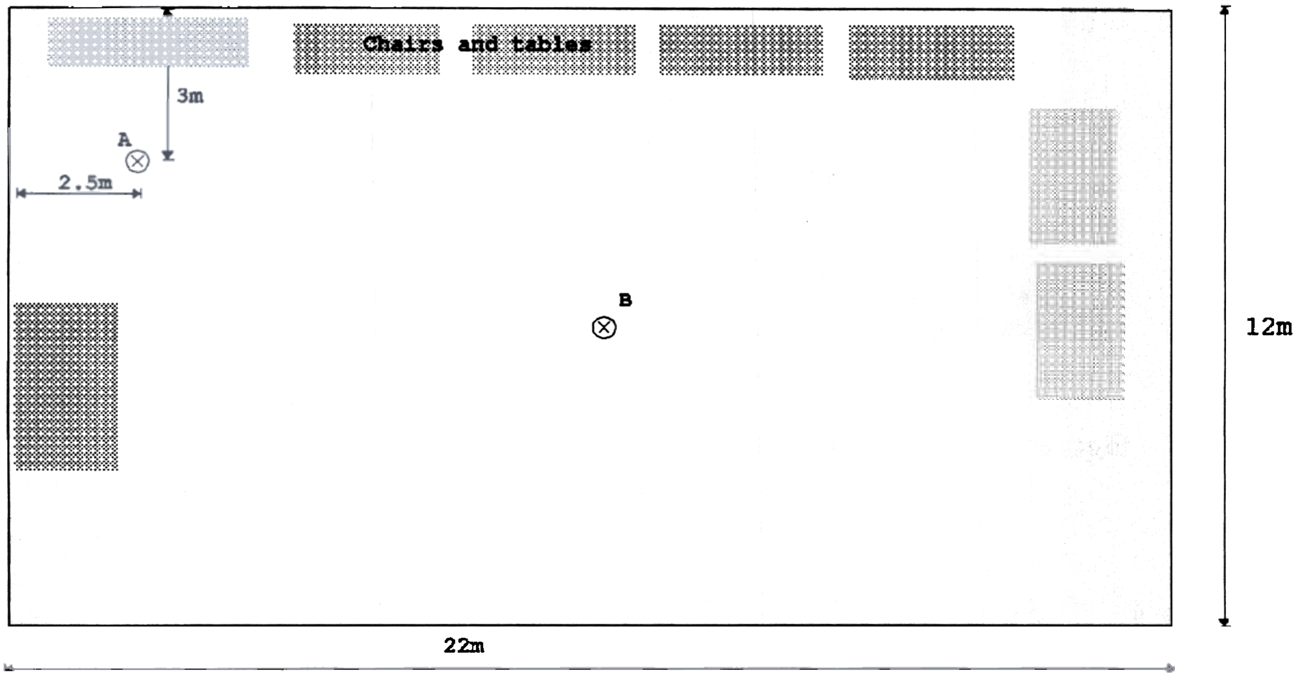

Figure 5 Schematic plan view of room D

4.1.5 Test room E

This room was designed for use as a reverberation chamber. Relevant room sizes are listed in Table 6. It has asymmetric walls and a sloping ceiling all of painted plaster and a painted concrete floor. As can be seen from the schematic diagram of Figure 6, the room now contains an audiometric cabin and a number of work benches and cupboards and an electronic equipment storage area. When empty, the room has a very long reverberation time and consequently a K_2-factor out of the range permitted by the standards. However, in its current condition it is ideal as it is representative of an environment with a K_2-factor near the ISO standards upper limit. The approximate location of the reference sound source is at position "X" in Figure 6.

Table 6 Sizes of room E

Area S_v (m^2)	Volume V (m^3)	mean room height (m)
258	274	5.5

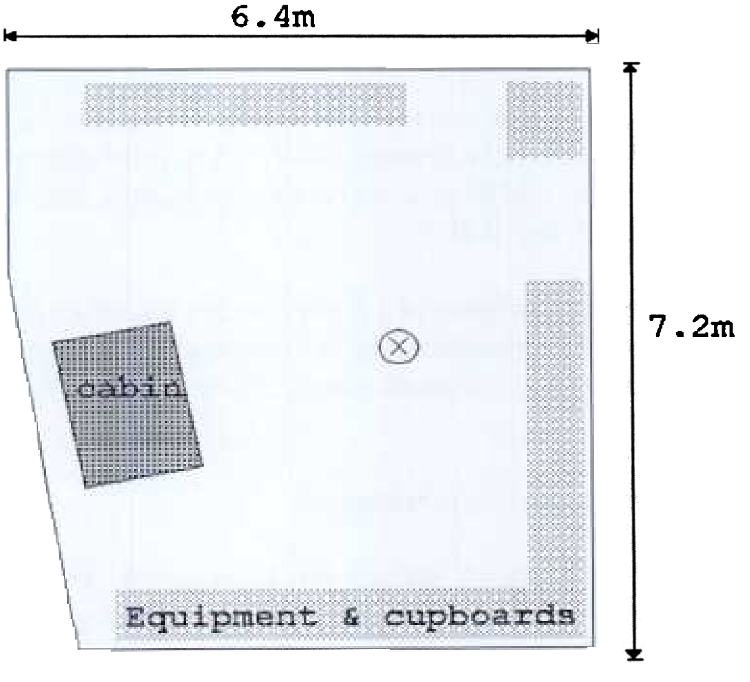

Figure 6 Schematic plan view of room E

4.2 MEASUREMENT SURFACES

Sound power determinations were made in all rooms using a 1.5 m radius hemisphere, called surface 1 in Table 7. The reference sound source is calibrated at NPL (in test room A) with this enveloping surface. The reference sound source used in this study is calibrated at regular intervals and so we can have a great deal of confidence in the measured data. The results presented in reference 9, show that there is not a significant systematic difference between sound power levels measured using parallelepiped surfaces compared with those obtained using hemispherical surfaces. The measurement procedure involved in using parallelepiped surfaces can provide results more rapidly than using hemispherical surfaces. We have, therefore, used parallelepiped surfaces for the majority of measurements in this study. Three parallelepiped surfaces (called surfaces 2 to 4) were used with the associated measurement distances shown in Table 7. Measurement distance is defined in the standards as, the distance from the reference box to a box-shaped measurement surface.

Table 7 Measurement surfaces

surface 1	surface 2	surface 3	surface 4
hemisphere radius (m)	parallelepiped measurement distance (m)		
1.5	0.85	1.3	1.8

Surface 2 with a measurement distance of 0.85 m was used because the resulting hypothetical parallelepiped measurement surface has the same surface area as the 1.5 m hemisphere and so will permit a comparison between two apparently similar methods.

Surface 3, with a measurement distance of 1.3 m was used because the distance from the centre of the box on the floor-plane is approximately 1.5 m (the hemisphere radius) from the centre of a vertical face. In addition, it is also approximately double the surface area of surfaces 1 & 2 (see sub-section 2.4).

Surface 4 with a measurement distance of 1.8 m provides a further doubling of surface area (over surface 3). However, measurements over this surface were only possible in rooms A and D due to limitations of room size and immovable obstacles.

4.2.1 Microphone positions for the hemisphere

The schematic diagram of Figure 7 shows the location of microphones used for measurements according to ISO 3744. The exact locations of the microphones are listed in Table B1 in ISO 3744 and are referred to as the 10 key positions. Each microphone is positioned to cover one tenth of the enveloping measurement surface. Measurements were also conducted according to ISO 3746: here only four microphone positions are required, a sub-set of the 10 key positions, and these are shown in Figure 8. The sound power level of the reference sound source was determined using both these methods. Because the reference sound source is a broad band, omnidirectional noise source, the difference between sound power levels obtained using these two methods was negligible (see sub-section 5.1).

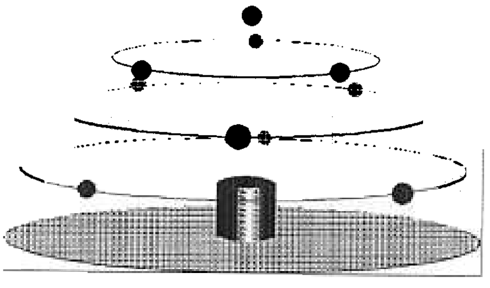

Figure 7 Microphone positions for ISO 3744

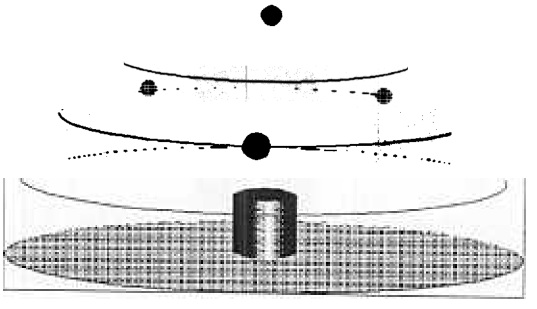

Figure 8 Microphone positions for ISO 3746

4.2.2 Microphone positions for a parallelepiped

The number of microphone positions required by the ISO standards when using parallelepiped enveloping surfaces is dependent on the size of the parallelepiped, or more correctly, upon the ratio of the partial area corresponding to each microphone position, to the measurement distance. For ISO 3744 the minimum number of microphone positions is 9, and was appropriate for all the measurements reported here. These positions are shown in Figure 9. The number of microphone positions required for measurements according to ISO 3746 is determined in a similar way to ISO 3744, but here the minimum number is 5 which was again appropriate for all the measurements reported here. The five positions are shown in Figure 10. Sound power determinations have been carried out using both methods and differences of approximately 1 dB observed. Both sets of results are reported in sub-section 5.1.

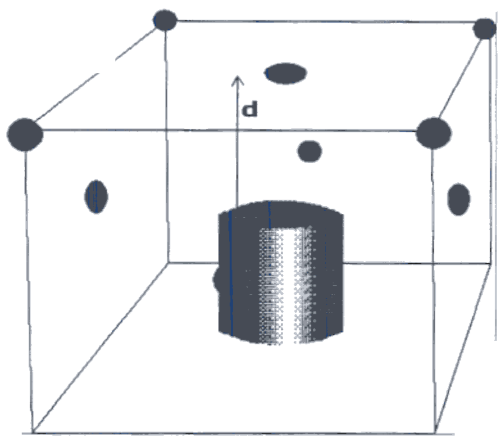

Figure 9 Microphone positions for ISO 3744 parallelepiped

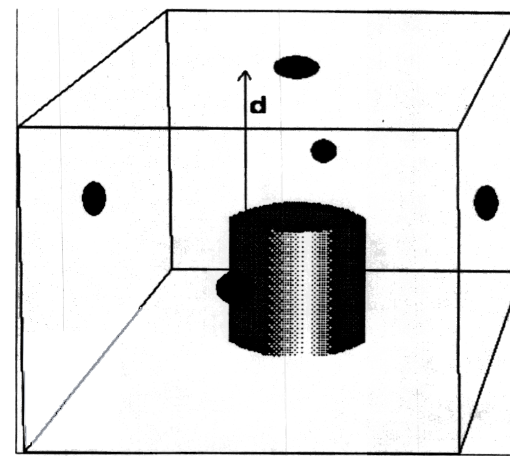

Figure 10 Microphone positions for ISO 3746 parallelepiped

4.3 INSTRUMENTATION

There is an inherent requirement for all instrumentation to adhere to the specifications described in the various standards which includes calibration traceability to national standards. The equipment used in this study satisfies the requirements and is listed below:

Real time frequency analyser	Brüel & Kjær type 2144,
½ inch condenser microphone	Brüel & Kjær type 4165,
Windscreen (used outdoors)	Brüel & Kjær type UA 0237,
½ inch microphone preamplifier	Brüel & Kjær type 2639,
Microphone power supply	Vinculum type M591,
Sound level calibrator	Brüel & Kjær type 4228,
Reference sound source	Brüel & Kjær type 4204.

5 RESULTS

The various EC Directives concerned with machinery noise emission require the A-weighted sound power level or A-weighted emission sound pressure level to be provided. All the results in this study are therefore presented as A-weighted levels. Thus the values of K_2-factors also correspond to A-weighted data and strictly should be termed, K_{2A}-factors.

5.1 SOUND POWER MEASUREMENTS

The sound power level of the reference sound source was determined in the five rooms described in sub-section 4.1 using the measurement configurations described in sub-section 4.2. Linear averaging was selected with a sampling period of 15 s. A recent experimental investigation (reference 9) provides evidence that the repeatability standard deviations of such measurements are less than 0.2 dB. So, for the majority of sound power determinations only one measurement was conducted for each configuration. Results are listed in Table 8 together with the measurement surface area and measurement method ("*" indicates ISO 3744 and "+" indicates ISO 3746). Shaded areas indicate that no measurements were performed.

Table 8 Measured A-weighted sound power levels (dB re 1 pW)

		room and reference sound source position						
surface	area	A	B	C		D		E
number	(m²)	centre	centre	centre	side	centre	corner	centre
1*	14.1	90.9	94.2	94.3	95.5	91.2		96.1
1+	14.1	90.8	93.9	94.3	95.1	91.3		96
2*	14.1	91.5	94.3	94.4	95.5	91.8	92.1	96.4
2+	14.1	92.9	95.4	95.1	96.2	93.4	93.2	96.9
3*	28.2	91.9	95.2	96	97	92.2	93.3	98.6
3+	28.2	93.2	96.2	98.1	97.6	93	94.3	98.4
4*	49.6	92				92.8		
4+	49.6	93.3				93.8		

It can be seen that measured sound power levels range from 90.8 dB to 98.4 dB, a potential range of K_{2A}-factors of 7.6 dB indicating that the required range of environmental conditions has been achieved. This wide range of measured sound power levels is the result of carrying out measurements in differing acoustic environments (the sound power of a noise source is a constant and is independent of acoustic environment) and emphasises the importance of the application of an environmental correction factor and of course the importance of its accurate assessment.

The reference sound source is routinely calibrated in room A using surface 1 (based on ISO 6926) so it is unsurprising that the results for this configuration are identical to the calibrated level of the source (90.9 dB re 1 pW). However, the variation of sound power level with measurement surface for room A indicates that the room cannot be regarded as hemi-anechoic at the larger measurement distances (the room only satisfies ISO 6926 up to a maximum 1.5 m radius). The measurements were repeated on a large outdoor hemi-anechoic site where the sound power level measured using surface 4 was found to be only 0.2 dB greater than that measured using surface 2. This confirms the inadequate behaviour of room A at the larger measurement distances and is in accord with the theoretical prediction discussed in Section 3.

The data in Table 8 are used in the absolute method (of sub-section 2.2) to calculate K_{2A}-factors which are discussed in sub-section 5.3.

5.2 MEASUREMENT OF REVERBERATION TIME

The reverberation time was measured at three locations in all five rooms. The noise source used for these measurements was a Brüel & Kjær type 4205 reference sound source. This is an electronic loudspeaker-driven noise source that can be operated to generate a broad-band or band-limited noise signal. The operation of the source was electronically synchronised to the Brüel & Kjær type 2144 real time frequency analyser to provide automated reverberation time measurement. The reverberation time was measured using a 1 kHz band-limited signal and also using a broad-band signal that was analysed through an A-weighting filter. Both these approaches are considered in the ISO standards. Results are listed in Table 9 together with the corresponding mean

Table 9 Measured reverberation time and associated room absorption

Room	Area S_v (m^2)	Volume V (m^3)	Reverberation time T (s)		α			
					calculated		estimated	
			1 kHz	A-wt	1 kHz	A-wt	from	to
A	134	91.5	0.04	0.2	2.7	.55	0.5	0.5
B	168	116	0.6	0.5	.19	.22	0.1	0.25
C	373	428	1.3	1.3	.14	.14	0.1	0.25
D	834	1188	0.9	1.0	.25	.22	0.2	0.5
E	358	274	2.4	2.3	.05	.07	0.05	0.05

sound absorption coefficient, α, calculated using equations 4 and 5 and a range estimated from Table 1 (A-weighted only). The room surface area and volume are shown for completeness. When estimating values of α, a range of values is shown in Table 9, because the descriptions given in the ISO standards (reproduced in Table 1) are not sufficiently precise to allow any confidence in matching the test room with one of the seven descriptions in the Table. This problem becomes more acute when acoustical conditions are removed from anechoic (ie decreasing values of α). The method is described in the ISO standards as an "approximate method"; it certainly is and should be used with caution, especially for ISO 3746 where a correction is applied and the conditions may be semi-reverberant (low α).

Regarding the calculated values of α, it can be seen that inter-comparing results from the two methods of measuring reverberation time shows good agreement, with the exception of room A. Here the reverberation time measured using the broad-band noise source is heavily influenced by low frequency energy owing to the relatively rapid decay of high frequency energy and will therefore be artificially high. Room A presents hemi-anechoic conditions and so reverberation measurements are not strictly valid (see ISO 3744 clause A.4.2).

The data in Table 9 are used in the room absorption method (described in sub-section 2.3) to evaluate K_{2A}-factors which are discussed below in Section 5.3.

5.3 ESTIMATED ENVIRONMENTAL CORRECTION FACTORS

Values of K_{2A}-factors have been estimated using the four methods described in Section 2. Tables 10 to 14 show the values of these estimates for rooms A to E respectively. Results for the "absolute method" and "two surface method" are derived from those measurements made with the reference sound source located in the centre of each room. The estimates using the "reverberation time method" are listed for those made using broad-band noise and band-limited noise signals in the measurement of reverberation time. For the "two surface method", results appear in the tables under "surface 2" and were derived from measurements using surfaces 2 and 3, or from measurements using surfaces 2 and 4 as indicated in the tables.

The data in parenthesis in Tables 10 to 14 are the differences between the K_{2A}-factors obtained using the absolute method and those obtained using the other methods. We have assumed that results obtained using the absolute method represent the true value of K_{2A}.

It can be seen from the four tables that the K_{2A}-factors generally increase with increasing measurement distance, the rate of increase being larger for the rooms with the higher K_{2A}-factor. For example the K_{2A}-factor in room E increases by 2.5 dB from 5.2 dB to 7.7 dB, while the corresponding increase in room B is 1.0 dB from 3.3 dB to 4.3 dB. This is in accord with the theoretical calculations of Section 3. More specific observations for each room are given below with each table.

Room A

It can be seen from Table 10 that estimates of K_{2A} obtained from the "A-weighted" reverberation measurements over-predict the true value, although the "1 kHz" data show good agreement, and this generally confirms that, as discussed in sub-section 5.2, reverberation time measurements should not be used in hemi-anechoic conditions. The K_{2A}-factors obtained using estimated room absorption are generally too high by, on average, 0.7 dB. The reason for this is that the room descriptions given in the ISO standards do not include rooms that approach hemi-anechoic conditions (the largest mean room absorption coefficient is 0.5). The two surface method provides results that slightly under-estimate K_{2A}. It is concluded that for rooms with a low K_{2A}-factor only the absolute method should be used.

Table 10 Values of K_{2A}-factor for room A

method	surface 1	surface 2	surface 3	surface 4
absolute	0	0.6	1	1.1
reverberation (A-wt)	2.5 (2.5)	2.5 (1.9)	4.0 (3.0)	5.7 (4.6)
reverberation (1 kHz)	0.4 (0.4)	0.4 (-0.2)	1.2 (0.2)	1.9 (0.8)
estimated room absorption	0.8 (0.8)	0.8 (0.2)	1.5 (0.5)	2.4 (1.3)
two surface (2 & 3)		0.2 (-0.4)		
two surface (2 & 4)		0.1 (-0.5)		

Room B

It can be seen from Table 11 that the reverberation method over-predicts with a mean excess of 1.3 dB. This room had a number of obstacles (see Figure 3) and hence the sound field would not be diffuse and this is probably the cause of the discrepancy. K_{2A}-factors obtained from estimated room absorption are less than true values with differences that range from -2.1 dB to zero with a mean of -1.3 dB. The two surface method used a second surface close to various room obstacles and this is probably a contributing factor in the -2.2 dB under prediction. For this room the reverberation method produces K_{2A}-factors that are closer to true values than for room A when considering "A-wt" data, but not when considering "1 kHz" data. It is concluded that this method should be used carefully in rooms that are not empty.

Table 11 Values of K_{2A}-factor for room B

method	surface 1	surface 2	surface 3
absolute	3.3	3.4	4.3
reverberation (A-wt)	4.0 (0.7)	4.0 (0.6)	6.0 (1.7)
reverberation (1 kHz)	4.5 (1.2)	4.5 (1.1)	6.7 (2.4)
estimated room absorption	1.3 to 2.6 (-2.0 to -0.7)	1.3 to 2.6 (-2.1 to -0.8)	2.2 to 4.3 (-2.1 to 0)
two surface (2 & 3)		1.2 (-2.2)	

5.3.3 Room C

It can be seen from Table 12 that K_{2A}-factors obtained using the reverberation time method are in good agreement with true values, with a mean difference of -0.2 dB. This room is larger than room B and although there are obstacles they are, volume-wise, relatively small and the sound field will, therefore, be more diffuse. This is confirmed by the results of Table 9 where the reverberation time is 0.5 s for room B and 1.3 s for room C. The estimated room absorption method under-predicts by between -2.1 dB and -4.0 dB with a mean of -2.8 dB. The performance of the two surface method is between these two with an under-prediction of -0.9 dB. Again, for this room the use of the table of estimated room absorptions should be avoided.

Table 12 Values of K_{2A}-factor for room C

method	surface 1	surface 2	surface 3
absolute	3.4	3.5	5.1
reverberation (A-wt)	3.2 (-0.2)	3.2 (-0.3)	5.0 (-0.1)
reverberation (1 kHz)	3.2 (-0.2)	3.2 (-0.3)	5.0 (-0.1)
estimated room absorption	0.6 to 1.3 (-2.8 to -2.1)	0.6 to 1.3 (-2.9 to -2.2)	1.1 to 2.3 (-4.0 to -2.8)
two surface (2 & 3)		2.6 (-0.9)	

5.3.4 Room D

The K_{2A}-factors determined for room D are shown in Table 13. It can be seen that the reverberation method provides K_{2A}-factors that, on average, over-predict true values by 0.7 dB, with a range from 0.1 dB to 1.2 dB. The K_{2A}-factors obtained using the table of estimates generally under-predicts K_{2A} with differences ranging from -1.8 dB to 0.1 dB and a mean value of -0.7 dB. The two surface method was carried out with the ratio S_2/S approximately 2 and approximately 4, resulting in K_{2A}-factors of - 0.4 dB and 0.0 dB relative to true values.

Table 13

method	surface 1	surface 2	surface 3	surface 4
absolute	0.3	0.9	1.3	1.9
reverberation (A-wt)	1.1 (0.8)	1.1 (0.2)	2.0 (0.7)	3.1 (1.2)
reverberation (1 kHz)	1.0 (0.7)	1.0 (0.1)	1.8 (0.5)	2.9 (1.0)
estimated room absorption	0.1 to 0.4 (-0.2 to 0.1)	0.1 to 0.4 (-0.8 to -0.5)	0.3 to 0.7 (-1.0 to -0.6)	0.1 to 1.1 (-1.8 to -0.8)
two surface (2 & 3)		0.5 (-0.4)		
two surface (2 & 4)		0.9 (0.0)		

5.3.5 Room E

It can be seen from Table 14 that the reverberation method over-predicts K_{2A}-factors by about 0.7 dB, and is fairly independent of distance. The difference between the two surface method result and the true value is numerically similar to the reverberation method result but of the opposite sign. The results from using the estimation table are very poor with a K_{2A}-factor of approximately 3 dB below true values.

Table 14 Values of K_{2A}-factor for room E

method	surface 1	surface 2	surface 3
absolute	5.2	5.5	7.7
reverberation (A-wt)	5.9 (0.7)	5.9 (0.4)	8.4 (0.7)
reverberation (1 kHz)	6.1 (0.9)	6.1 (0.6)	8.5 (0.8)
estimated room absorption	2.7 (-2.5)	2.7 (-2.8)	4.3 (-3.4)
two surface (2 & 3)		4.7 (-0.8)	

5.4 SUMMARY OF K_{2A}-FACTOR RESULTS

Examining the observations made above it may be concluded that the only consistently reliable method to determine K_{2A}-factors is the use of a reference sound source as described in the "absolute method". The reverberation method generally over-predicted K_{2A} but performed best in rooms where the reverberation time (for A-weighted broad-band noise) was high (>1 s). The two surface method consistently under-predicted K_{2A} and performed particularly badly where the second surface was close to room obstacles. The estimated room absorption method provided only a range of possible values of K_{2A} when the descriptors in Table 1 did not match well the room characteristics, and performed particularly badly in rooms where the reverberation time (for A-weighted broad-band noise) was high.

It should be noted that values of K_{2A} listed in Tables 10 to 14, that are described as under-predicted, are less than the true value and will result in the sound power level supplied by the manufacturer or test house being greater than the true level. Thus the estimated room absorption method, with the exception of rooms with very high values of α (eg room A), and the two surface method will result in sound power levels that are too high and the reverberation time method will generally provide sound power levels that are too low.

5.5 EFFECT OF SOURCE POSITION IN ROOM

To examine the effect of positioning the reference sound source near to a reflecting wall the two alternative locations, shown for room C in Figure 4 and for room D in Figure 5, were used. The resultant K_{2A}-factor determinations are shown in Figures 15 and 16 for rooms C and D respectively.

Table 15 Values of K_{2A}-factor for test room C (near side)

method	surface 1	surface 2	surface 3
absolute	4.6	4.6	6.1
reverberation (A-wt)	3.2 (-1.4)	3.2 (-1.4)	5.0 (-1.1)
reverberation (1 kHz)	3.2 (-1.4)	3.2 (-1.4)	5.0 (-1.1)
estimated room absorption	0.6 to 1.3 (-4.0 to -3.3)	0.6 to 1.3 (-4.0 to -3.3)	1.1 to 2.3 (-5.0 to -3.8)
two surface (2 & 3)		2.3 (-2.3)	

Table 16 Values of K_{2A}-factor for test room D (near corner)

method	surface 2	surface 3
absolute	1.2	2.4
reverberation (A-wt)	1.1 (-0.1)	2 (-0.4)
reverberation (1 kHz)	1 (-0.2)	1.8 (-0.6)
estimated room absorption	0.1 to 0.4 -1.1 to -0.8)	0.3 to 0.7 (-2.1 to -1.7)
two surface (2 & 3)	1.7 (0.5)	

It can be seen that the value of the K_{2A}-factors has increased (cf Tables 12 and 13), consistent with reflections from the nearby walls elevating the measured sound power level, as predicted in Section 3 (r/R approaching unity). The average increase in K_{2A} for room C is larger than that for room D. This is in accord with Section 3 where a larger increase in K_{2A} is predicted for the room with the lower value of α (see the absolute method data in Tables 12 and 13). The determination of K_{2A} from the reverberation method and the estimation method remain unchanged. It is concluded therefore that as K_{2A} is clearly dependent on the position of the noise source relative to the walls neither of these two methods of K_{2A} determination should be used in the above situations. K_{2A} determinations using the two surface method are dependent on source location and were under-predicted in one case and over-predicted in the other. It is concluded that in situations where the noise source is close to a wall the absolute method should be used.

6 CONCLUSIONS

The methods recommended by ISO 3744 and ISO 3746 for the determination of the environmental correction factor, K_{2A}, have been investigated experimentally by performing measurements in five rooms with different acoustical characteristics. It is concluded that the absolute method using a reference sound source is the only method that consistently provides an accurate assessment of K_{2A}. The method involving measurement of reverberation time generally over-estimates K_{2A} and will result in values of sound power level that are too low. It performs best in rooms where the reverberation time (for A-weighted broad-band noise) is high (> 1 s). The two surface method generally under-estimates K_{2A} and will result in values of sound power level which are too high. It should not be used where the larger enveloping surface is affected by reflections from nearby objects. The estimated room absorption method provides only a range of possible values of K_{2A} when the descriptors of Table 1 do not match well the room characteristics, and performs badly in rooms where the reverberation time (for A-weighted broad-band noise) is high (> 1 s).

7 ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the National Measurement System Policy Unit of the UK Department of Trade and industry.

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