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IN-SITU MEASUREMENT OF THE ACOUSTIC REFLECTION COEFFICIENT

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1. INTRODUCTION

This paper is a continuation of the new method presentation of in-situ determination of the complex acoustic reflection coefficient (see [1]). The method bases on the measurement of the complex sound intensity by two-microphone technique. The article includes measurement algorithm developed during experiments. The proposed procedure makes possible to determine the expected errors and to verificate the measurement reliability. The results of the reflection coefficient measurements for two kinds of materials are presented (plastered oil colour painted wall and two-pane window)

2. METHOD

Complex sound intensity at the given point of the stationary acoustic field, measured in direction d, can be expressed [1] as:

$$Id = \frac{1}{2} P^{*} Ud \qquad (1)$$

where: P – "complex amplitude" of the acoustic pressure;

Ud – "complex amplitude" of the acoustic particle velocity in direction d.

Let's consider the plane wave incident on the reflecting surface. Sound intesity measured twice in the same point, in the direction of the incident wave and in the direction of the reflected wave may be writen as:

$$Ii = \frac{1}{2} P^{*} (Ui - Ur \cos 2\theta) \qquad (2)$$

$$Ir = \frac{1}{2} P^{*} (Ur - Ui \cos 2\theta) \qquad (3)$$

where: P – "complex amplitude" of the acoustic pressure;

Ui - "complex amplitude" of the acoustic particle velocity of the incident wave;
Ur - "complex amplitude" of the acoustic particle velocity of the reflected wave;
θ - incident angle.

If $\theta=45^\circ$ and point is situated on the surface then the ratio of intensities is equal to the ratio of velocities wich defines the complex reflection coeficient. The distance depending on the dimension of the microphone probe causes the phase correction:

$$\frac{Ir}{Ii} = R\ \exp(j\varphi_R)\ \exp(j\varphi x) \qquad (4)$$

where: x - distance between the measurement point and the reflecting surface;
$\varphi x = -kx\sqrt{2}$.
R, φ_R - amplitude and phase of the reflection coefficient.

So we can calculate reflection coefficient in the following way:

$$R = \left|\frac{Ir}{Ii}\right| \qquad (5)$$

$$\varphi_R = \arg\left(\frac{Ir}{Ii}\right) - kx\sqrt{2} \qquad (6)$$

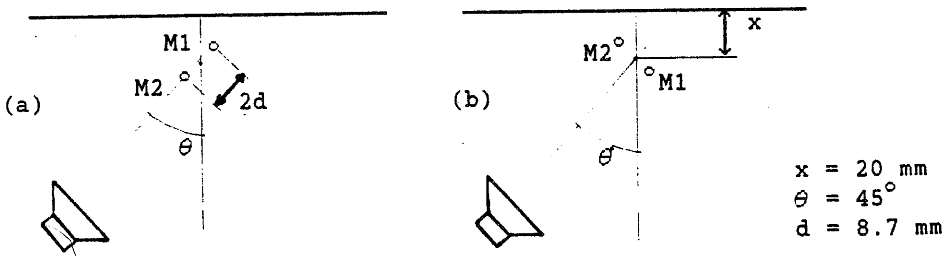

Fig.1 Measurement of the complex sound intensity.
(a) incident wave - Ii (b) reflected wave - Ir

The method used for the intensity measurement bases on the two-channel FFT technique and calculation of the cross-spectrum and auto spectra [2] [3]. In order to the gradient of velocities is approximated by diference of presures (divided by distance

between microphones) equations (5) and (6) include a systematic error. Since it's necessary to determine its value or to propose a method of the error correction the exact dependence between complex sound intensity and complex refflection coefficient has been derivated.

For plane wave and stationary, harmonic signal the active and reactive sound intensity are equal:

a) in the direction of the incident wave:

$$I_{Ri} = -\frac{P_o^2}{\omega\rho 2d}\left(\sin 2\varphi d + 2R\sin\varphi d\cos\varphi z\right) \qquad (7)$$

$$I_{Ui} = -\frac{P_o^2}{\omega\rho d}\ R\sin\varphi d\sin\varphi z \qquad (8)$$

b) in the direction of the reflected wave:

$$I_{Rr} = -\frac{P_o^2}{\omega\rho 2d}\left(R^2\sin 2\varphi d + 2R\sin\varphi d\cos\varphi z\right) \qquad (9)$$

$$I_{Ur} = \frac{P_o^2}{\omega\rho d}\ R\sin\varphi d\sin\varphi z \qquad (10)$$

where: $I_{Ri} + jI_{Ui} = Ii$;
$I_{Rr} + jI_{Ur} = Ir$;
P_o - amplitude of the incident wave;
2d - distance between microphones;
k - wave number
$\varphi d = -kd$ $\qquad \varphi z = \varphi r + \varphi x$.

The ratio of those complex intensities is equal:

$$\frac{Ir}{Ii} = \frac{(R^2\sin 2\varphi d + 2R\sin\varphi d\cos\varphi z) + j(R\sin\varphi d\sin\varphi z)}{(\sin 2\varphi d + 2R\sin\varphi d\cos\varphi z) - j(R\sin\varphi d\sin\varphi z)} \qquad (11)$$

For $\varphi d \to 0$: $\left|\frac{Ir}{Ii}\right| \to R$ and $\arg\left(\frac{Ir}{Ii}\right) \to \varphi z$

The difference between R, φr calculated from (5), (6) and R, φr calculated from (11) is rather small increasing with frequency and dependent on the distance between microphones.

To determine correct values we should find R and φ_R from equ.(12)

$$R_m \exp(j\varphi_{Rm}) = \frac{(R^2 \sin 2\varphi d + 2R \sin\varphi d \cos\varphi z) + j(R \sin\varphi d \sin\varphi z)}{(\sin 2\varphi d + 2 R \sin\varphi d \cos\varphi z) - j(R \sin\varphi d \sin\varphi z)} \qquad (12)$$

where: Rm, φ_R - amplitude and phase of reflection coefficient calculated from measured intensities (eqs(5)(6))

But this is not the only one source of the measurement errors. The method assumes that incident wave is plane. In practical use it seems sufficient to have "localy plane wave" in the proximity of the measurement point. The good test of the local structure of the field are symmetrical values of reactives intensities. The verification is done by comparing Iui and Iur obtained from eqs (8), (10), where R, φ_R are corrected values calculated from equ.(12). The problem to obtain the local plane wave is grater when the ratio oh the wavelenght and sound intensity probe dimensions increases.

The error sources wich are characteristic of in-situ conditions are distortions caused by refflections from the other surfaces or generated by noise sources. The disturbing waves parallel to the incident or reflection direrection are of the greatest importance. It's a effect of the directional characteristic of the sound intensity probe.

In-situ conditions are the specific ones and therefore it's essential to determine the results confidence. Searching the expected error area is based on the complex intensities (active and reactive parts) measured and calculated from eqs (7),(8), (9) and (10).

We define functions: MaxR, MinR, Maxφ_R, Minφ_R

$$\mathrm{MaxR}=\mathrm{Max}\left(\left|\frac{I_{Rr} + jI_{ur}}{I_{Ri} + jI_{ui}}\right|\right) \qquad \mathrm{MinR}=\mathrm{Min}\left(\left|\frac{I_{Rr} + jI_{ur}}{I_{Ri} + jI_{ui}}\right|\right) \qquad (13)\ (14)$$

$$\mathrm{Max}\varphi_R=\mathrm{Max}\left[\arg\left(\frac{I_{Rr} + jI_{ur}}{I_{Ri} + jI_{ui}}\right)\right] \qquad \mathrm{Min}\varphi_R=\mathrm{Min}\left[\arg\left(\frac{I_{Rr} + jI_{ur}}{I_{Ri} + jI_{ui}}\right)\right] \qquad (15)(16)$$

where: I_{Ri}, I_{ui}, I_{Rr}, I_{ur} are elements of the set of values I_R and I_u obtained from measurement and from

calculations (eqs (7) - (10)).

The expexcted error area is expressed as:

$$\delta R = \mathrm{MaxR} - \mathrm{MinR} \qquad (17)$$

$$\delta\varphi_R = \mathrm{Max}\varphi_R - \mathrm{Min}\varphi_R \qquad (18)$$

The relative error area is defined as:

$$\Delta R = \frac{\delta R}{R}\, 100\% \qquad (19)$$

$$\Delta\varphi_R R = \frac{\delta\varphi_R}{\varphi_R}\, 100\% \qquad (20)$$

3.EXPERIMENTS

The paper includes in-situ investigations of two kinds of materials:

- plastered oil colour painted wall of a staircase;
- two-pane window (50cm x 40cm, distance between sheets 3cm).

The measurements conditions were strongly reverberant and the high level of the disturbing reflected waves was observed.

The sound intensity probe consisted of two 1/2" microphones in side-by-side configuration. The loudspeaker was used as a harmonic signal source. The presented figures contain results of two measurement series. During investigations a special algorithm of the measurement procedure has been developed. The algorithm is presented in fig.2.

The one of the problems was how to find the areas (the measurement points) of localy plane wave. The proposed method bases on the pressure level measurement in the points situated in the same distance from the surface. The pressure level measured by each microphone of the probe located parallel with reflecting surface should be the same. Such finding places were different for each measurement frequency.

The first session made sure only of equal signal levels during measurements of Ii and Ir. During second series the signal levels were controled, the points of the localy plane wave were searched and a field structure was modified (if necessary and possible). E.g. the position of the loudspeaker could be changed symmetricaly to the measurement point.

4. REFERENCES

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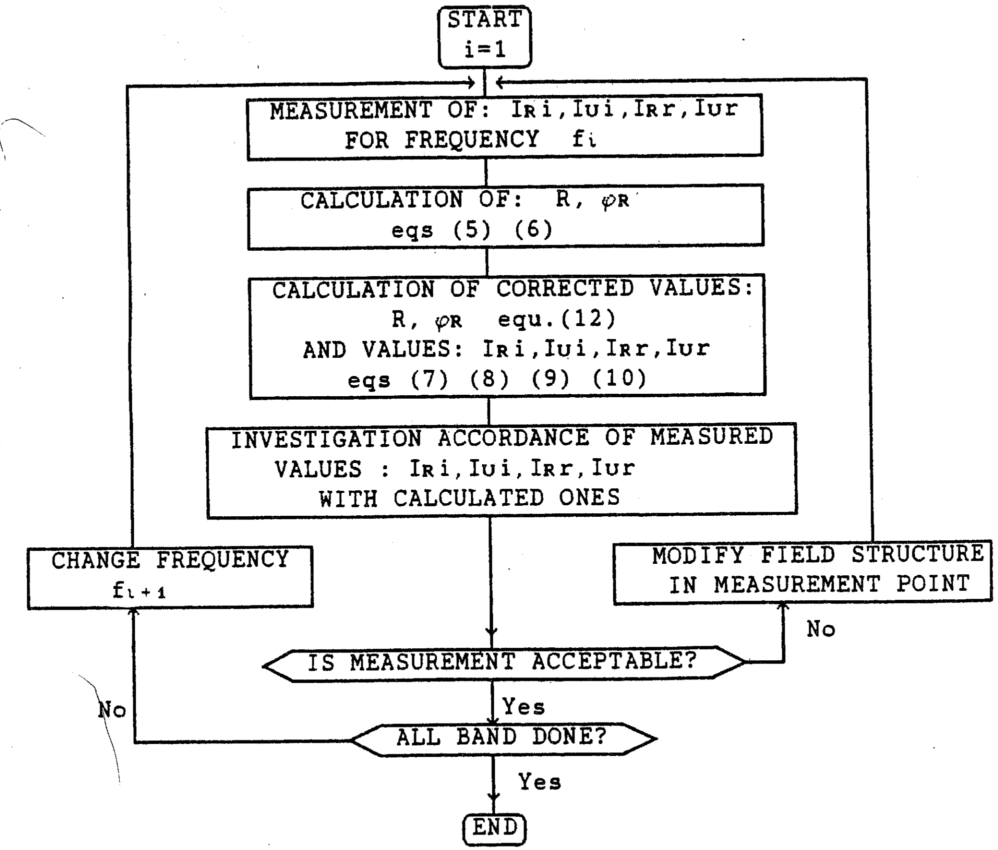
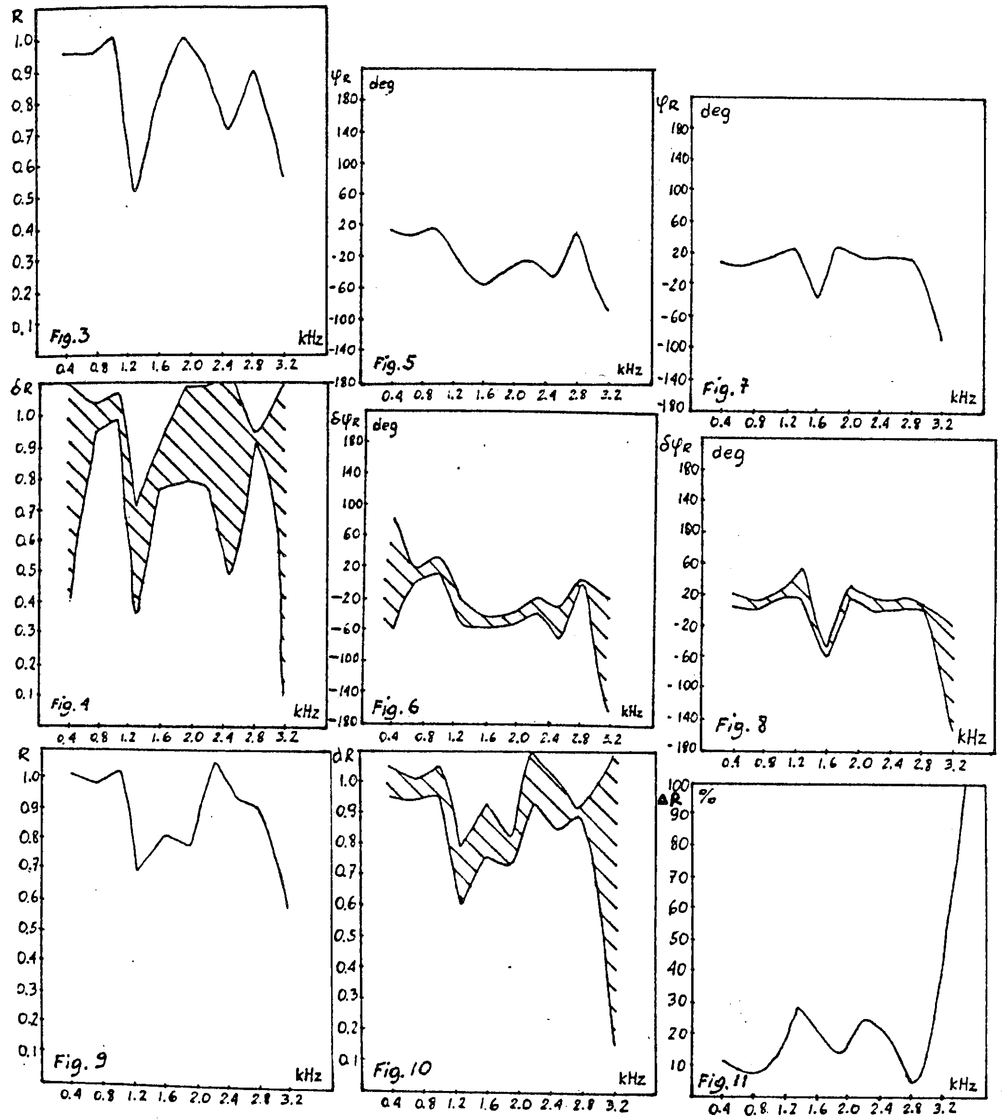


Fig.2. Calculation of the corrected values R, φ_R and verification of the validity of measurement.

COMPLEX REFLECTION COEFFICIENT - WINDOW
R-amplitude, φ_R-phase δ-error area, Δ-relative error
1st series: figs 3,4,5,6. 2nd series: figs 7,8,9,10,11

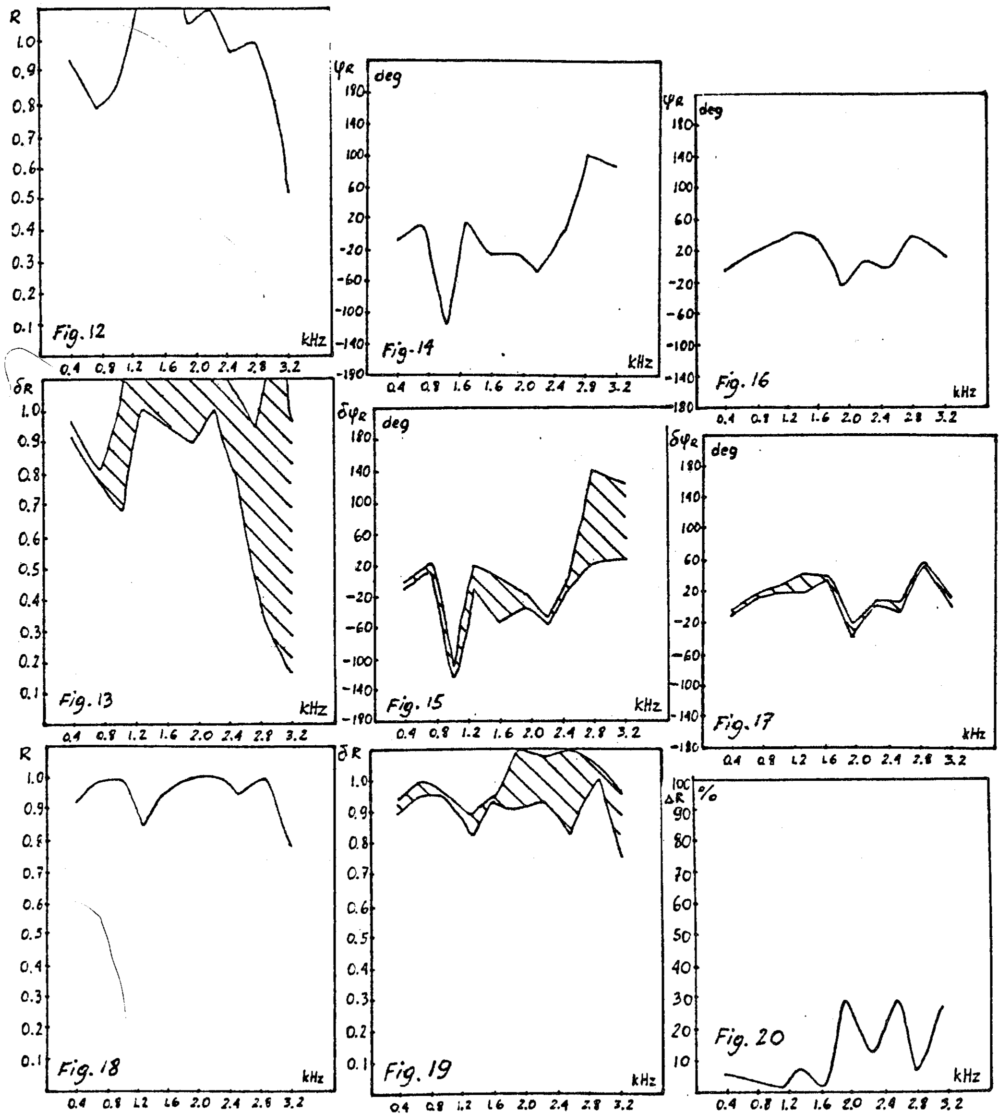


IN-SITU MEASUREMENT

COMPLEX REFLECTION COEFFICIENT - WALL

R-amplitude, φ_R-phase δ-error area, Δ-relative error

1st series: figs 12,13,14,15   2nd series: figs 16,17,18,19,20



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COMPARISON OF THE NEW TEST PROCEDURE PROPOSED BY HEVAC FOR ACOUSTIC LOUVRES WITH IN-DUCT SILENCER STATIC INSERTION LOSS MEASUREMENTS

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ABSTRACT

The British Standard for testing in-duct silencers, BS4718, specifically excludes acoustic louvres and states that they should be considered as a partition which should be tested between two reverberant rooms using BS2750. It is considered more appropriate by some manufacturers to test louvres as though they were in-duct silencers, pending publication of any new standards. The Heating, Ventilating and Air Conditioning Manufacturers Association, HEVAC, Acoustic Group 1990, have proposed a method of testing which attempts to simulate industrial installations by comparing the noise emission from an aperture in the external wall of a reverberant chamber with and without the acoustic louvre installed. This method also produces additional information on directivity. This paper compares these test methods and also the results obtained from sound pressure and intensity measurements.

1. INTRODUCTION

The method of test for silencers (attenuators) for air distribution systems is specificed in the British Standard BS4718:1971(1) and the section defining the scope of this standard contains the following:

"the results obtained from tests carried out using the standard should not be used to determine the performance of: .... silencers designed to be installed to increase the sound insulation of a partition having a ventilation opening. The sound insulation provided by such silencers can be assessed by tests carried out in accordance with BS2750". Thus the appropriate current standard for testing acoustic louvres is BS2750. Recommendations for field and laboratory measurement of airborne and impact sound transmissions in buildings (2) which states that the acoustic louvres shall be tested as a partition between two reverberant rooms. This procedure is not generally considered an appropriate measurement for predicting the performance of many installed acoustic louvres, and the Heating, Ventilating and Air Conditioning Manufacturers Association, HEVAC, are currently preparing their own test standard. This investigation compares the static insertion loss of two examples of acoustic louvres using the following methods:

Method (i)

A diffuse sound field is generated in a reverberant room, Figure 1, which has a 1m square aperture in one wall. The external sound pressure level at nine stations 3m from the centre of the aperture, figure 2, is measured with an open aperture and with the acoustic louvre fitted. The static insertion loss is given by the difference between the sound pressure level averaged over the nine positions with and without the louvre.

Method (ii)

As above, but measuring acoustic intensity.

Method (iii)

This method (3) closely follows BS4718 in that the acoustic louvre is placed between the long inlet and outlet duct, the outlet duct protruding into the reverberant chamber. The deviations from the full procedure are as follows:

(a) no substitution duct is used, for the "silencer out" test the inlet and outlet duct being directly coupled.

(b) a rotary microphone method as specified in BS4196 (4) is used as this is quick and is in close agreement with the six position method (5).

Method (iv)

This is a modified BS4718 in that the acoustic louvre is mounted in the wall of the reverberant chamber, the bird screen being flush with the inner face of the chamber wall, and the inlet duct connected to the louvre, the outlet duct is discarded. For the "silencer out" test the end of the inlet duct is positioned to be flush with the inner face of the chamber wall.

Instrumentation: Sound pressure levels were measured using Nortronic 823 system and intensity using Bruel & Kjaer 4433 system.

The proposed HEVAC procedure, method (i) and the intensity method was used for two louvres:

1m wide, 1m high, 270mm deep 30% open area
1m wide, 1m high, 540mm deep 30% open area

The BS4718 based procedure, method (iii) and (iv) was used on the same type of louvres but reduced to 500mm x 800mm cross section. These reduced area louvres were also fitted with a birdscreen.

Results for Insertion Loss

Comparison of the various methods, normalising to the HEVAC method (i)

270mm deep louvre

OCTAVE BAND CENTRE FREQUENCY, Hz

	63	125	250	500	1K	2K	4K	8K	16K
Method (ii) dB	--	-0.7	-0.7	-0.2	-1.0	-1.6	-0.4	-0.8	--
Method (iii) dB	-2.6*	+0.9	+1.5	+1.0	+0.1	+1.4	+2.8	+2.1	+2.8
Method (iv) dB	-1.0*	+1.4	-0.9	-0.5	-0.7	-1.8	-1.3	-2.3	--

540mm deep louvre

OCTAVE BAND CENTRE FREQUENCY, Hz

	63	125	250	500	1K	2K	4K	8K	16K
Method (iii) dB	-3.3*	+0.4	0	+0.7	+2.0	+3.9	+1.8	-0.9	+0.5
Method (iv) dB	-0.8*	+0.3	-1.8	-0.3	+0.4	+1.2	-0.6	-2.4	-1.6

*Reverberant room too small for 63Hz band

Results for Directivity

Open Aperture

Octave Band Centre Frequency Hz

		63	125	250	500	1K	2K	4K	8K	16K
Sound Pressure level (dB)	Max-Min	3.4	1.5	2.2	4.0	4.4	6.0	5.1	6.5	7.4
	Max-Mean Position	1.3 60°	0.5 90°	1.4 105°	0.9 105°	1.7 120°	3.3 45°	2.2 90°	2.6 90°	2.8 120°
Sound Intensity (dB)	Max-Min	-	1.8	3.4	3.6	5.0	5.0	3.2	2.1	-
	Max-Mean Position	- -	0.8 90°	1.3 105°	1.4 90°	1.8 105°	1.5 75°	0.9 105°	1.6 75°	- -

270mm deep louvre

Octave Band Centre Frequency Hz

		63	125	250	500	1K	2K	4K	8K	16K
Sound Pressure level (dB)	Max-Min	5.1	2.0	1.6	4.2	5.6	7.0	9.5	6.4	4.5
	Max-Mean Position	1.8 45°	0.8 120°	0.7 105°	1.3 90°	1.2 90°	2.8 90°	3.1 90°	3.2 90°	2.1 90°
Sound Intensity (dB)	Max-Min	-	4.5	3.9	4.5	5.4	9.0	8.5	2.7	-
	Max-Mean Position	- -	1.8 60°	1.1 150°	1.6 90°	1.9 135°	2.8 90°	2.6 90°	1.4 135°	- -

540mm deep louvre

Octave Band Centre Frequency Hz

		63	125	250	500	1K	2K	4K	8K	16K
Sound Pressure level (dB)	Max-Min	4.4	2.6	4.5	2.7	4.1	4.5	2.1	4.4	4.0
	Max-Mean Position	1.7 75°	1.0 30°	1.5 90°	1.2 105°	1.8 90°	2.0 75°	1.4 90°	2.1 90°	1.6 90°

CONCLUSIONS

Insertion loss: BS4718 section 1.10. "Accuracy of measurement" states that the tolerances for insertion loss can be expected to be ± 3dB in the 125Hz band and ± 2dB in bands up to 8kHz. Only two readings in 35 results showed a variation greater than this tolerance so it is concluded that all the methods used were in reasonable agreement.

Directivity: An advantage of the HEVAC procedure is that information on directivity may be obtained. This is defined in the procedure as maximum minus mean level and ranged from 1 to 3dB. This was somewhat less than expected, possibly due to reflections from neighbouring buildings, however these values were confirmed by intensity measurements which should reduce this error.

Acknowledgement

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Figure 1

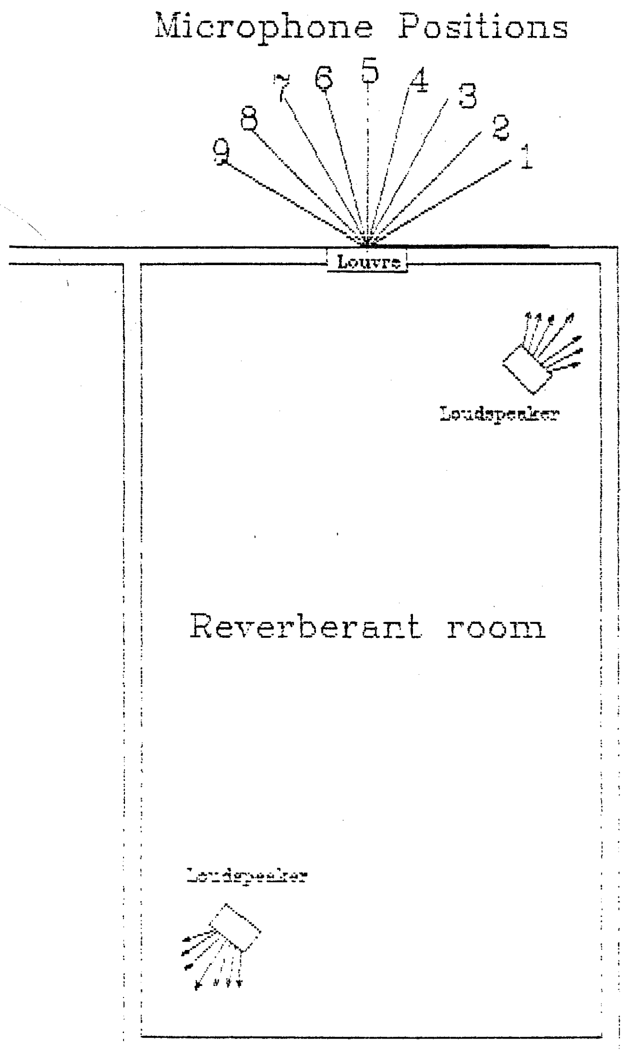

Figure 2