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METHODS OF MEASURING THE ACOUSTIC ABSORPTION OF AUDITORIUM SEATING

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1. INTRODUCTION

In measuring seating absorption, one hopes to predict the behaviour of a large array of seats in an auditorium. The traditional method, as recommended by BS3638: 1987, is to place a rectangular array of the seats in the centre of a reverberation chamber and measure the random incidence sound absorption of the array. Because this over-emphasises the absorption of the front row and side aisles, it leads to results higher than those obtained from in-situ measurements in theatres.

Kath and Kuhl [1,2] have proposed an alternative method, in which the seating array is placed in the corner of the reverberation chamber, and the exposed edges obscured with barriers. An initial study [3] of Kath and Kuhl's method at Salford produced encouraging results. The present study seeks to optimise the method to give the best agreement with auditorium results. Five pairs of measurements have been made so far in which the absorption of seats tested in the laboratory are compared with results from the auditorium.

2. REVERBERATION CHAMBER PARAMETERS

Parameters investigated in the optimisation process include: array position in chamber, row spacing, barrier height, number of edges obscured by barriers and array configuration. These have been investigated for six seat types, both lightly and heavily upholstered, and covered with a variety of materials. Figures 1 to 3 demonstrate the effects of some important parameters on four rows of six typical cloth-covered well-upholstered seats, from Bolton Town Hall. In each case, the solid line is obtained from Kath and Kuhl's 'standard' test: placing the seating array in the corner of the chamber, at the theatre row spacing, surrounded by 0.9 m high barriers, with no corrections for pressure doubling or edge absorption.

2.1 Row Spacing

As shown in figure 1, increasing the row spacing definitely reduces absorption coefficient (the graphs are distinct at a 95% confidence level). The high correlation coefficient (at worst, $r = 0.9938$) between all three, however, indicates that any two might be accurately derived from the other.

2.2 Barrier Height and Position in Room

In figure 2, moving the seating array, surrounded by barriers, from the corner to the centre of the reverberation chamber, has an effect below 250 Hz only. The evident increase in absorption is thought to be due to standing waves inside the array: standing waves would be inhibited in the non-orthogonal corner of the room. Increasing the height of the barrier from 0.9 to 1.2 metres increases the measured absorption coefficient significantly, above 2 kHz. This is perhaps attributable to the barriers limiting the angles of incidence onto the seating - normal incidence absorption coefficients for seating foams are higher at high frequencies than are random incidence ones. Both of these frequency-dependent effects are confirmed by Student's t test for significantly different means.

2.3 Pressure Doubling and Finite Area Corrections

Kath and Kuhl have advocated [2] a correction to be added to the plan area of the seating array to take account of the pressure doubling effect when the seats are in the corner of the test chamber. This increase of the area takes the form of a strip of width $\lambda/8$ along sides adjacent to the walls of the chamber, and a further term of $(\lambda/8)^2$ for the increased effect in the corner. As shown in figure 3, this has little effect above 250 Hz. For smaller test arrays, however, the correction will become more important.

A further correction may be applied to take account of the absorption of front rows and side aisles of the finite seating arrays in the auditorium. Because the test array is considered to be mirrored in the walls of the chamber, the absorption coefficient obtained from the 'standard' Kath and Kuhl method is for an infinite plan area. Estimates of front row and side aisle absorption may be obtained by testing the seats with barriers on the front or side only. Hence the absorption of particular large finite seating areas in the auditorium may be found. An example appears in figure 3. Unfortunately, the errors incurred in estimating edge absorption in this way are large, so that this correction has no definite effect.

3. COMPARISON WITH AUDITORIUM MEASUREMENTS

In five cases it has been possible to make reverberation time measurements in an auditorium with and without the seating present, and to test a sample of 24 of the unoccupied seats in a reverberation chamber. Each set of absorption coefficients produced by varying the above parameters is tested against the in-situ measurement, and ranked in order of agreement. The criterion is the sum (over frequency) of the squares of the differences between the two error envelopes, at a 95% confidence limit.

The five auditoria are: West Yorkshire Playhouse, Leeds, a new 700-seat theatre; Bolton Town Hall, a 700-seat concert hall; Queen Elizabeth Hall, Oldham, a 670-seat multipurpose hall; Middleton Civic Hall, a 385-seat multipurpose hall; King George's Hall, Blackburn, an 1800-seat concert hall.

In all cases, a variant of Kath and Kuhl's method gives a better agreement with the auditorium results than does the traditional method. The corrections for pressure doubling at chamber walls and for large finite areas do not improve the match. In figure 4, the new method is identical with the in-situ measurement from West Yorkshire Playhouse, at a 95% confidence limit. (The standard error in the latter is large at low frequencies.) As expected, the traditional reverberation chamber method has significantly overestimated the absorption at high frequencies. Similarly, for Bolton Town Hall, the new method is significantly better than the old one, as shown in figure 5.

In figure 6, the comparison for Queen Elizabeth Hall is complicated by the pronounced dip in the auditorium absorption coefficients around 2 kHz. A similar result was obtained from Middleton Civic Hall. Though this was not predicted by any reverberation chamber measurements, Kath and Kuhl's method is still in better agreement overall than the traditional one. Because there are large standard errors in these auditorium measurements, a lack of diffusion is suspected. In particular, a non-uniform directional distribution of reflections may have led to two or more distinct decay rates.

For the lightly-upholstered seats from King George's Hall, in figure 7, the choice of test chamber technique makes little difference to the results.

3.1 Comparison with Beranek

In 1969, Beranek [4] published average absorption data for occupied and unoccupied seats calculated from a large number of halls. Because these figures are still widely used, it is instructive to compare them with ones obtained by the present method. In figure 8, the present figures for typical occupied well-upholstered seats measured in a reverberation chamber agree well with Beranek's. The new unoccupied seat absorption data is substantially greater than Beranek's, however. This result can be explained by the observations that occupied seat absorption is principally due to the auditor, while Beranek's seats were probably less well-upholstered than those used in today's concert halls.

4. CONCLUSION

A form of Kath and Kuhl's method for measuring seating absorption has produced a better agreement with auditorium absorption coefficients than has the traditional reverberation chamber method, for four halls of various sizes. The improvement is greatest for well-upholstered seats in diffuse halls. In general, the best procedure is to place the seating array in the corner of the test chamber, surrounded by barriers 0.9 metres high for unoccupied seats and 1.2 metres high for occupied ones. Corrections for pressure doubling and large finite areas of seating do not significantly improve the match.

Whilst this validation procedure is continued with another five halls, the effects of differences between sound fields in auditoria and test chambers are being investigated. In particular, incorporating a model of the directional distribution of reflections in auditoria might improve prediction accuracy. The possibility of predicting the variation of seating absorption coefficient with sample area will be investigated with scale models.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] U KATH & W KUHL, 'Messungen zur Schallabsorption von Personen auf Ungepolsterten Stühlen', *Acustica* 14, 50-55, (1964).
[2] U KATH & W KUHL, 'Messungen zur Schallabsorption von Polsterstühlen mit und ohne Personen', *Acustica* 15, 127-131, (1965).
[3] R J ORLOWSKI & W SUBAGIO, 'More measurements on Audience and Seat Absorption', *Proc IOA* 7, 23-31, (1985).
[4] L L BERANEK, 'Audience and Chair Absorption in Large Halls. II', *JASA* 45, 13-19, (1969).

Figure 1: Effect of Seat Absorption Parameter: Row Spacing

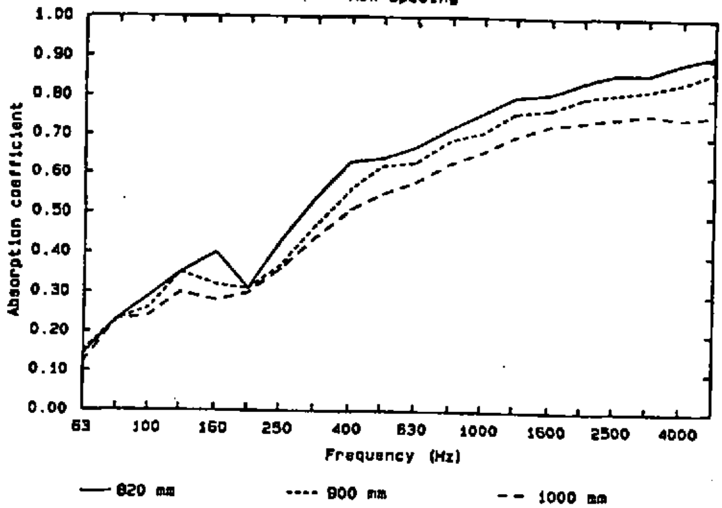

Figure 2: Effect of Seat Absorption Parameter: Barrier Height and Position in Room

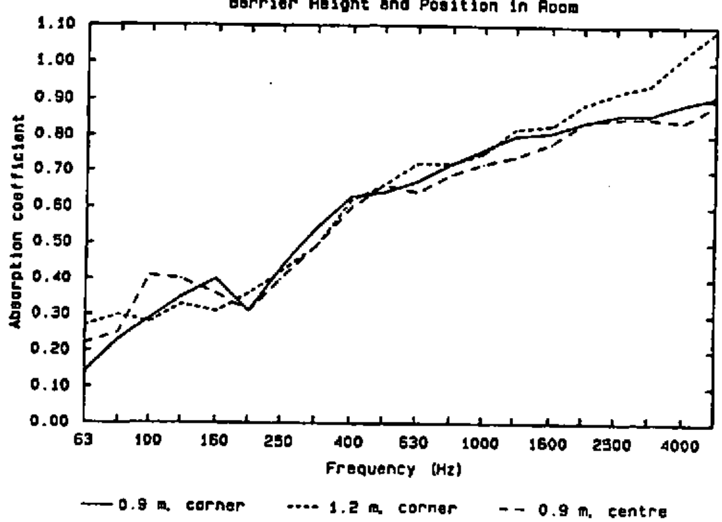

Figure 3: Effect of Seat Absorption Parameter: Pressure Doubling and Finite Area Corrections

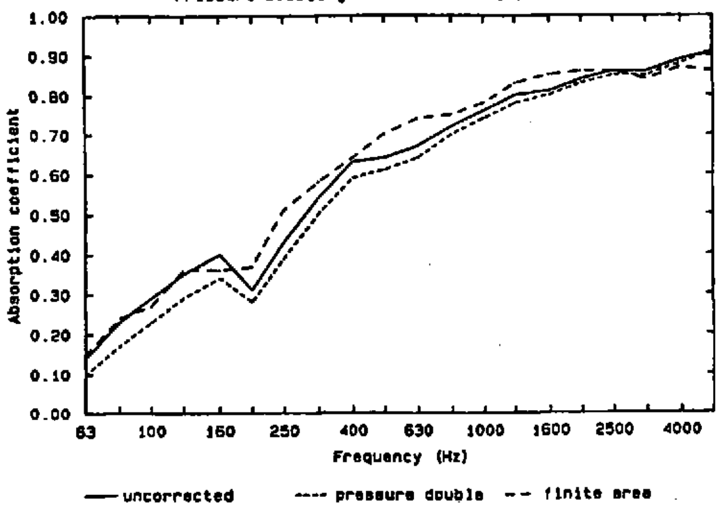

Figure 4: Unoccupied Seating in West Yorkshire Playhouse, Leeds: In-Situ Measurement and Old & New Reverberation Chamber Methods

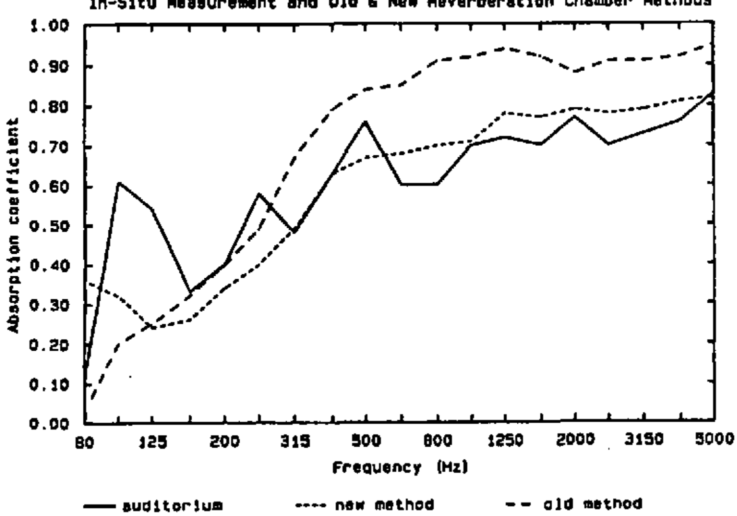

Figure 5: Unoccupied Seating in Bolton Town Hall:
In-Situ Measurement and Old & New Reverberation Chamber Methods

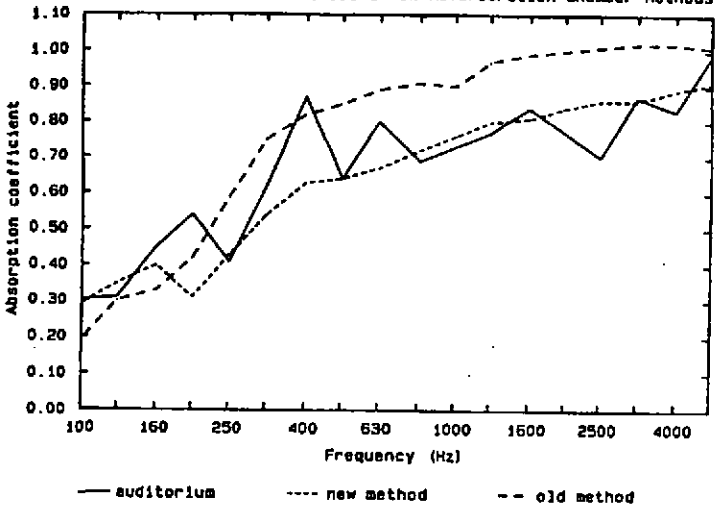

Figure 6: Unoccupied Seating in Queen Elizabeth Hall, Oldham:
In-Situ Measurement and Old & New Reverberation Chamber Methods

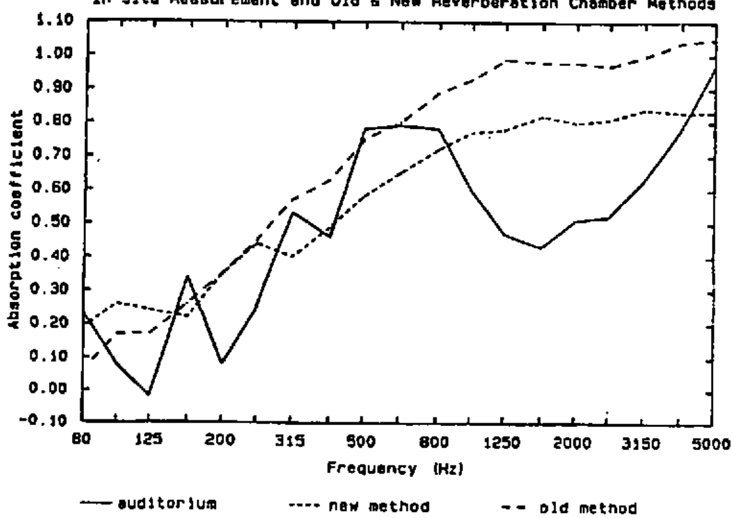

Figure 7: Unoccupied Seating in King George's Hall, Blackburn: In-Situ Measurement and Old & New Reverberation Chamber Methods

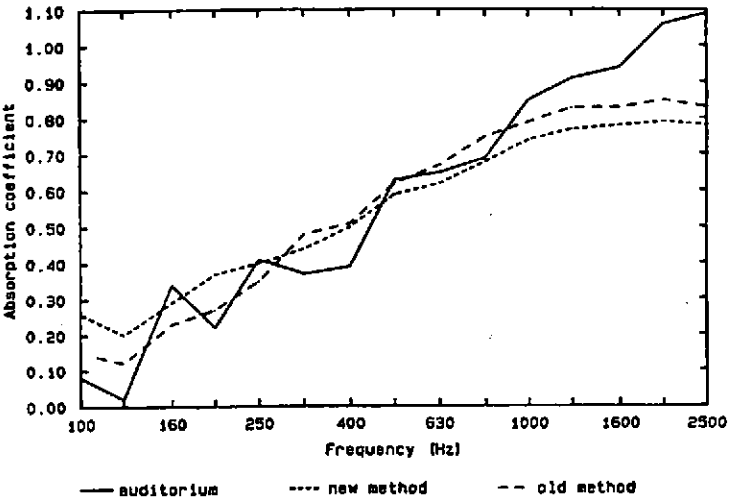

Figure 8: Comparison with Beranek: Occupied and Unoccupied Seating