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THE SOUND ABSORPTION OF UPHOLSTERED CHURCH PEWS

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INTRODUCTION

A few years ago the author was called in to advise on the acoustics of St. Luke's Church, Willerby. This is an Anglican church built in 1967. It is of fairly traditional form and construction, and holds about 150 people. It soon became apparent that the poor acoustics were due to the relatively long reverberation time. Surfaces were generally hard and there was little in the way of soft furnishings. Various recommendations were made to improve the situation, these included the use of a speech reinforcement system, added absorption on rear and side walls of the church, and upholstery in the pews. The first possibility was never seriously considered. The second possibility was investigated, and a scheme drawn up and costed using a proprietary absorbent panelling. Finally the Church Committee decided to adopt the third suggestion. Velour covered cushions made of plastic foam were fitted to congregation and choir pews. Reverberation time measurements had been made originally and these were repeated when cushions had been fitted to the congregation pews. The cushions had a surface area of 23 m^2.

MEASUREMENTS

Reverberation time measurements were made in the empty church at one-third octave frequencies from 125 Hz to 8000 Hz using a starting pistol as the source. Values are given in Table 1. In each case they are the average of two measurements with pistol and microphone in different positions.

Table 1. Reverberation time measurements

Frequency	Reverberation Times		Frequency	Reverberation Times	
	Originally	Finally		Originally	Finally
125 Hz	2.75 s	2.17 s	1250 Hz	2.70 s	1.97 s
160	3.00	2.35	1600	2.55	1.92
200	2.65	2.00	2000	2.50	2.00
250	2.80	1.95	2500	2.40	1.87
315	2.90	1.90	3150	2.35	1.75
400	2.65	1.95	4000	2.05	1.57
500	2.65	1.97	5000	1.90	1.42
630	2.70	1.90	6300	1.55	1.12
800	2.80	2.02	8000	1.25	0.95
1000	2.75	1.92			

CALCULATION OF ABSORPTION

It is usual to apply Sabine's formula for reverberation time,

$$T = \frac{0.16V}{A} \quad (1),$$

where the volume V and absorption A are in metric units. The formula may be re-arranged to give the absorption. On the basis of this formula extra absorptions were calculated at different frequencies. These are given in Table 2. The volume of the church was estimated as 1010 m^3

Table 2. Calculated extra absorptions - Sabine's formula

Frequency	Extra Absorption	Frequency	Extra Absorption
125 Hz	16 m^2	1250 Hz	22 m^2
160	15	1600	21
200	20	2000	16
250	25	2500	19
315	29	3150	24
400	22	4000	24
500	21	5000	29
630	25	6300	40
800	22	8000	41
1000	25		

These results are reasonable at the lower frequencies, but values would seem to be too large at the higher frequencies, giving absorption coefficients considerably greater than 1.0. The Sabine formula is only approximate, breaking down when the absorption is high and the reverberation time low. Moreover, at high frequencies air absorption plays a major part, and this can vary considerably depending upon the conditions.

Regrettably temperature and humidity readings were not taken at the time of the measurements. However, some estimate can be made of the conditions inside the church from weather observations taken at the Pearson Park Observatory by Kingston upon Hull City Council Leisure Services. Estimated temperatures and relative humidities are given in Table 3.

Table 3. Estimated conditions

Originally Afternoon of 26th November, 1979	Finally Afternoon of 23rd March, 1983
Temperature 15°C Relative humidity 70%	Temperature 10°C Relative humidity 70%

Further calculations were then made on the basis of the Eyring formula. This may be written as

$$T = \frac{KV}{CV - S\log_e(1 - OA/S)} \quad (2),$$

where V is the volume, C the volume absorption coefficient for air, S the total surface area, OA the surface absorption and K a constant given by

$$K = \frac{60}{1.086c} \quad (3),$$

c being the velocity of sound. This formula may be re-written to give

$$OA = S\left(1 - \frac{1}{\exp(KV/ST - CV/S)}\right) \quad (4).$$

A program was written in Basic which enabled values of OA to be calculated.

It is well known that in general air absorption decreases as the relative humidity increases and many of the standard books on architectural acoustics give air absorptions for different relative humidities at 20°C. Values at other temperatures are not so readily available. Very comprehensive data are given by C.M. Harris [1,2]. The most up-to-date information would appear to be that in B.S.5727:1979 [3]. In the third reference values are given for attenuations in decibels per 100 m. These figures need to be divided by 108.6 to give volume absorption coefficients. Using these values for absorption coefficients, calculated extra absorptions on the basis of Eyring's formula are given in Table 4.

Table 4. Calculated extra absorptions - Eyring's formula

Frequency	Extra Absorption	Frequency	Extra Absorption
125 Hz	15 m^2	1250 Hz	21 m^2
160	14	1600	20
200	19	2000	16
250	24	2500	16
315	28	3150	21
400	21	4000	18
500	20	5000	22
630	24	6300	29
800	21	8000	25
1000	25		

These figures are seen to be much more reasonable. The large values at high frequencies found previously being presumably due to the increased air absorption for the final measurements.

RANDOM AND SYSTEMATIC ERRORS

The most serious source of error is probably in the measurement of reverberation time. It is estimated that reverberation times are known to within about $\pm$0.1 s at the lower frequencies, and $\pm$0.05 s at the higher frequencies. The overall effect is to produce an error of about $\pm$5 m^2 in calculated values of the upholstery absorption.

The volume of the church was estimated as 1010 m^3. This is known to within about 5%. Using the Sabine formula, calculated values of absorption are proportional to volume. This is not strictly true if the Eyring formula is used. Differences, however, are small and it may be assumed that any uncertainty in the value for the volume of the church introduces a similar uncertainty in values for the absorption of the upholstery. This error is of course systematic and affects all results in the same way.

In the Eyring formula the surface area S of the room or building appears. This was estimated as 695 m^2. Substitution of different values in the formula shows that this can vary considerably with little effect on the final result. For instance a 10% change in the value of S produces only a 0.5% variation in the value of the absorption.

It has already been seen that air absorption plays an important part in room acoustics, particularly at the higher frequencies. It is estimated that values of air absorption coefficients are known to within about $\pm$10%. These uncertainties have a negligible effect at frequencies of 2000 Hz and less, but could introduce an error of $\pm$5 m^2 in the absorption at 8000 Hz.

The important errors then are in the values for the reverberation times and in values for air absorptions, and the latter only at frequencies above 2000 Hz. At 2000 Hz and below it is estimated that the added absorption is known to within about $\pm 5\ m^2$, and at 8000 Hz the standard error has increased to $\pm 7\ m^2$.

DISCUSSION

It would appear that adding upholstery to the church pews has increased the sound absorption considerably at all frequencies from 125 Hz to 8000 Hz. Assuming the total area of the cushions is 23 m^2 then absorption coefficients are between 0.61 and 1.26, with an average value of 0.91. The absorption does not appear to increase steadily with frequency, as might be expected for soft furnishings, but varies periodically, with maxima at 315 Hz, 630 Hz and 1000 Hz. Whether this is a real effect or not is unknown. The harmonic variation could be associated with some pew dimension, such as the height of the pew back, 400 mm, or the pew separation, about 1.0 m.

In general comments from the clergy, choir and congregation have been favourable. The reduction in reverberation time has resulted in greater clarity of speech. The reduction is not as great as that originally suggested. Following the initial measurements it was estimated that the absorption needed to be increased by about 30 m^2 at the mid-frequencies to reduce the reverberation time to a reasonable value of 1.3 s for a half-full church. Adding another 3.5 m^2 of cushions to the choir pews should result in a further slight reduction in reverberation time.

The upholstery has of course raised the level of the seating by 50 mm from 430 mm to 480 mm. Only one person complained that this made the pews more uncomfortable.

In conclusion it should be noted that the overall cost of adding cushions was about £1200. This is somewhat less than the cost estimated for purchasing and fixing the proprietary acoustic panelling.

REFERENCES

[1] C.M. Harris, 'Attenuation of sound in air versus humidity and temperature', National Aeronautics and Space Administration Contractor Report CR-647, (1965).

[2] C.M. Harris 'Absorption of sound in air versus humidity and temperature', J.A.S.A., Vol. 40, 148-159, (1966).

[3] 'Method for describing aircraft noise heard on the ground', British Standard 5727, (1979).

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