Proceedings of the Institute of Acoustics

AUDIENCE NOISE - HOW LOW CAN YOU GET?

J. P. Newton & A. W. James
BDP Acoustics Ltd, 16 Gresse Street, London W1A 4WD

ABSTRACT

The trend towards designing auditoria to extremely low noise levels can add substantially to the costs of structures to isolate noise from outside and of services to provide virtually inaudible background noise. It has been postulated that even in the quietest moments of a performance, there is inherent audience noise. If this is so, there is presumably a threshold level below which there is no point in further reducing noise from other sources. This threshold level would be a function of the size of audience present and of the reverberant and direct field in the auditorium. To our knowledge there has not so far been a systematic programme of measurements to quantify this. Measurements of minimum noise levels in concert halls with and without audience have been taken. This paper presents the results of the research, attempts to establish a means of predicting audience noise and considers the possible design and cost implications of a threshold minimum level of audience noise.

INTRODUCTION

The acoustics consultant designing a concert hall has at his disposal numerous accounts of the criteria used for great concert halls around the world. Reverberation times, ideal shapes, volumes, energy parameters and reflection patterns are all relatively well documented, whether by the hall's designers or by present-day acousticians seeking the recipe for the 'perfect' auditorium, but little seems to have been said about the derivation of the ambient noise levels to which the hall was designed. The noise specification is probably derived from a mixture of past experience, noise levels quoted for similar projects and research carried out thirty years ago for an entirely different purpose.

Commonly used criteria for ambient noise levels in auditoria tend to be based upon any of a number of noise rating curves such as NR, NC, PNC or N. None of these were specifically derived for use in performance spaces and with the increase in Hi-Fi signal-to-noise ratios and the corresponding trend towards lower ambient levels in live performance and recording venues, their use at the low levels striven for is debatable [1].

The references show a wide range of noise levels specified for auditoria built over the last forty years [2, 3, 4, 5]. For a typical 2,000 seat concert hall, a level of NR15 seems to be the norm, perhaps with some reduction at low frequencies. Some recent well-publicised halls have, however, been designed to levels close to the threshold of hearing. The extra 10-15dB of attenuation needed to achieve this can have serious cost implications. Typically, in terms of the structure-borne noise, this might require an extra "skin" in the building envelope, a very heavy roof construction and perhaps resilient layers at the foundations to reduce ground-borne noise. For ventilation and plant noise, a third or fourth level of duct attenuation will be needed, with consequent increases in the sizes of plant and plantrooms, and there will be very stringent requirements for the plant isolation using both floating floors and discontinuities in the structure between plantrooms and auditoria. All of these measures add considerably both to the capital cost of a building and to its running costs.

A question is thus raised as to whether the contribution of the audience to the ambient noise levels in an auditorium should be taken into account and used in the choice of the design criterion. Indeed, we first need to determine whether or not there is an inherent noise level that we can associate with an audience and, if so, how can this aid the choice of a specification.

THEORY

Kleiner [6] has developed an equation to determine the sound power level, L_w, of a person breathing normally and describes tests to verify this. Using simple theory for the direct/early reflected and reverberant fields around a listener or microphone in an audience, and assuming the directivity of noise from audience breathing to be similar to that of speech at the same frequencies, it transpires that the reverberant field is likely to be in the range 1 to 3 dB higher than the sum of the direct/early reflected contributions from what is effectively an area source, relatively evenly distributed in the stalls of an auditorium with a reverberation time, Tr, of more than 1 second (occupied) at the frequencies of interest. This is borne out by experience; unless there is a particularly noisy person (e.g one with respiratory problems or a cold etc) seated nearby, the listener will not notice breathing noise from any particular source or direction.

Additionally, the direct contributions from individuals more than 2 metres away are generally negligible compared with the reverberant field, so that the listener at the edge of a block of seats will receive almost the same level of audience noise as one surrounded by people.

Within the rather demonstrative scope of our project, it therefore seems to be a reasonable approximation to use simple Sabine based theory to link the sound power level L_w per person and the reverberant part of the audience sound pressure level, L_{pr}:

$$L_{pr} = L_w + 10 \log_{10} N + 10 \mathrm{Log}_{10} T_r - 10 \mathrm{Log}_{10} V + 13.9 \text{ dB}$$

where:

L_{pr} is the reverberant part of the audience noise level,
L_w is the sound level per person (dB),
N is the number of audience present,
T_r is the reverberation time of the hall (seconds)
and V is the volume of the hall (m^3)

AUDIENCE NOISE

The direct/early reflected contribution will generally be 1 to 3 dB below L_{pr}, resulting in a combined level, L_p, of between 1.7 and 2.5 dB higher than L_{pr} in most concert halls.

Consequently L_{pr} increases by approximately 3dB for each doubling of N or T_r for a given volume, and decreases by 3dB for each doubling of volume if N and T_r remain constant. In practise, these parameters are inter-related and their traditional relationships in different types and sizes of auditoria are such as to limit the range of corrections to L_W to between 2 and 10 dB. The direct/early reflected contributions are not generally affected by changes in T_r or V, and are only affected by N if the listener has little or no audience nearby.

Since changes in the reverberation time due to occupancy changes are generally small and the volume of a given hall is constant, the greatest variation in L_p will be with the number of people present in a given hall; the listener in a hall with a capacity audience will thus theoretically hear some 2-3 dB more audience noise that if the hall is half-empty. This presupposes that noise from the audience is essentially constant and that individuals emit similar sound power levels

METHODOLOGY

The aim of the measurements was to obtain the lowest level of noise in each octave band at a typical seat during a performance at several well-known concert venues.

Noise levels were measured in London at the Royal Festival Hall, Barbican Hall, Wigmore Hall and St Johns, Smith Square, at the Fairfield Halls, Croydon and at Symphony Hall, Birmingham using a Bruel & Kjaer Type 2143 Real Time Frequency Analyser fitted with a half-inch microphone type 4165. The analyser enables minimum sound pressure level in each octave band to be measured over a specific period and it is this parameter that was measured both during a performance and once the concert hall had cleared of people. Where reliable data for the reverberation time of the hall did not exist, this was measured using the same instrument, with a gun shot as the noise source.

In the mode used, the real-time analyser samples the noise level every 15 micro seconds and stores the minimum level obtained in each octave band using an exponential averaging time of 0.25 seconds ("fast"). The resulting spectrum will not necessarily have existed at any one instant, but contains the minimum level attained in each octave band over the measurement period.

The microphone was held at comfortable arms length in front of the measuring person (the elbow generally rested upon the arm of the seat) so as to be approximately 0.4m from the nearest body. The measuring person was located in the mid to rear stalls in each hall.

AUDIENCE NOISE

The equipment was calibrated in accordance with manufacturer's instructions before each measurement using a microphone calibrator type 4230, and a further more detailed check was subsequently made at Bruel and Kjaer's laboratory in London. No abnormalities or variations of more than 0.1 dB were noted at any stage. The noise floor of the analyser and microphone was also measured at Bruel and Kjaer's laboratory and the results are shown in Figure 7.

RESULTS AND DISCUSSIONS

The pieces of music played at the concerts were mainly large orchestral works (symphonies and piano concerti) with the exception of those in the Wigmore Hall and St Johns, Smith Square which were song recitals (piano and voice) and choral works respectively. It was noted that there were "silent" moments in each of the concerts and that the minimum mid-frequency noise levels often occurred in the piano concerti, a reflection perhaps on the composers' affinity for the dynamics of the piano-forte.

The results of the measurements are shown in graphical form, along with three NR curves for reference purposes, in Figures 1-6. The measurements have been corrected where necessary to take account of the noise floor of the equipment used (see Figure 7).

For some of the halls in which measurements were taken it would appear that the unoccupied minimum noise level at low frequencies was higher than that when occupied. This can be accounted for by the fact that the unoccupied noise levels were measured over a much shorter time period than those measured during the performances and are thus likely to include low frequency noise that was not present throughout the performance, typically from traffic or other external sources. The occupied noise levels were typically measured throughout a two hour concert whereas the unoccupied data were obtained over one or two minutes when the noise from post-concert activities had died down.

This difference in measurement period does however highlight the difference between noise levels in the occupied and unoccupied halls. As can be seen from Figures 1-6 there is typically a notable difference of some 3-5 dB between the two sets of measurements at mid and high frequencies.

As it was not possible to take meaningful unoccupied measurements after the performance at the Fairfield Hall these were completed at a later date. The reliance of the Hall's ventilation supply on several environmental factors meant that, in order to approximate the minimum noise level likely from the ventilation system during the concert, measurements were taken with the system turned off. Although it is likely that there were times during the performance when the ventilation was running on minimum, it cannot be stated with certainty whether or not these coincided with the quiet moments in the music. The results thus exhibit the maximum possible differences for this Hall.

The noise levels measured at the Royal Festival Hall appear to show less than average differences, namely 2.5 dB in the 500 Hz octave band and less in others. This is possibly accounted for by the size of the audience which was just over half capacity.

AUDIENCE NOISE

The approximate audience sizes and the calculated minimum sound power level per person are given in Table 1. The contribution from each person to the minimum noise level in each auditorium can be seen to vary quite considerably and is plotted against frequency in Figure 8. The results differ significantly from those presented by Kleiner [6], who's research concentrated on the sound power level generated during the exhale part of the breathing cycle. It is hypothesized, therefore, that there must be times during a concert when a large proportion of the audience are at a quieter part of the breathing cycle and this may account for the differences in results.

Auditorium	Octave Band Centre Frequency (Hz)						No. of Audience
	250	500	1000	2000	4000	8000	
Symphony Hall	9.0	9.8	6.9	4.9	2.9	*	2000
St Johns, Smith Square	*	10.6	6.8	8.9	6.3	5.2	500
Royal Festival Hall	*	14.4	*	5.5	4.5	2.4	1600
Barbican Hall	*	18.5	14.7	10.6	8.2	7.6	1391
Wigmore Hall	12.5	10.8	11.4	11.1	8.1	5.9	500
Fairfield Hall	21.0	17.3	14.6	11.9	7.7	2.3	1428

Table 1: Calculated Minimum Sound Power Level per Person re 10^{-12}W.

Notes:

(1) * Denotes values where the occupied and unoccupied noise levels differed by less than 1 dB

(2) All values calculated using unoccupied reverberation time - maximum increase in L_w due to reduction of T_r by 0.5 seconds in any frequency band is 1.5 dB in any of the above halls.

There appears to be some correlation between the minimum sound power emitted per person and the general noise levels in each hall, i.e. the quieter the hall, the lower the sound power level emitted per person during the quiet passages of music. This suggests that the audience may perceive low noise levels in an auditorium and react by reducing their own sound power output during quiet passages of music. Typically there were only two or three instances in each concert when levels close to the minima presented in this paper were achieved, however, it remains a matter of further discussion as to whether the measuring person's awareness of these instances was increased by his ulterior nadir-seeking motives, and whether a constant broad band noise of 5-10 dB above the lowest levels measured would be deemed unacceptable noisy by the concert going public. The latter would almost certainly reduce the costs involved in structural isolation by providing noise to mask intrusive sounds.

CONCLUSIONS

Measurements of minimum noise levels in six concert halls with and without audience have been taken. There is typically a notable increase due to the audience of 3-5 dB in each octave band from 500-4 kHz.

The minimum sound power level per person has been calculated for each hall and values show large variation between concert halls. Generally it would appear that the quieter the concert hall, the lower the average sound power level per person suggesting that audiences react sympathetically to the ambient noise level in the auditorium. This reaction by the audience is likely to be influenced by the conductor's control of the musicians and use of the hall's dynamics. Noise levels generally reached a minimum at two or three instances during a concert and it is hypothesised that these coincide with a large part of the audience being in a quiet part of their respiratory cycle, and rely on the conductor's ability to enthrall the audience.

ACKNOWLEDGEMENTS

The author s would like to thank: the management and staff at all of the halls involved in our project for their patience and assistance; Stuart Robinson and the Hallé Concerts Society for helping to get the measurements underway; Andrew Small and the B&K technical staff for their technical assistance; Michael Barron for his permission to use data from his unpublished work and Peter Lord and the rest of our colleagues at BDP Acoustics for their continuing support and encouragement.

REFERENCES

[1] James A. W. "*Background noise levels in Studios and Auditoria*" Colloque de Physique, Vol 51, February 1990.

[2] Beranek L.L., "*Music, Acoustics and Architecture*" John Wiley, New York/London 1962.

[3] Barron M, "*Survey of British Concert Halls*" Unpublished data.

[4] Lord P, Templeton D W, "*The Architecture of Sound*", Architectural Press, 1986

[5] Talaske R H, Wetherill E A, Cavanaugh W J, "*Halls for Music Performance - 1962-1982*", American Institute of Physics

[6] Kleiner M, "*On the Audience Induced Background Noise Level in Auditoria*", Acoustica Vol 46 (1980)

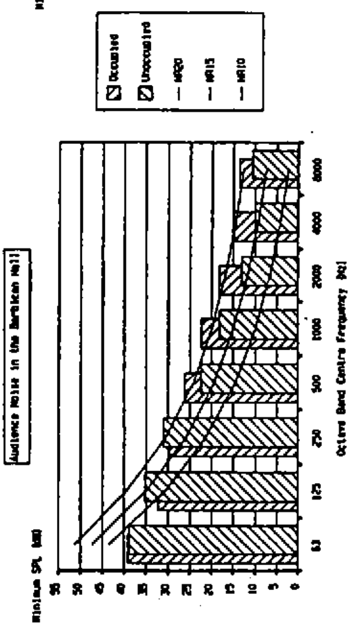

Figure 1

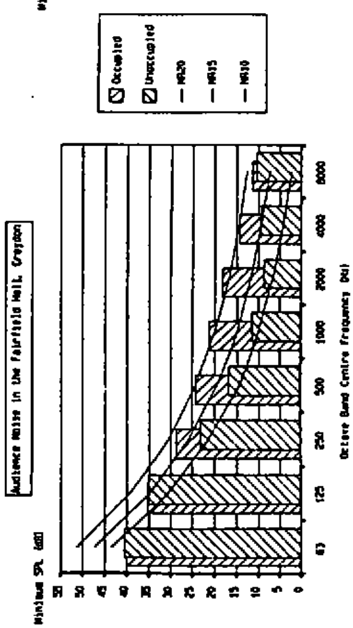

Figure 2

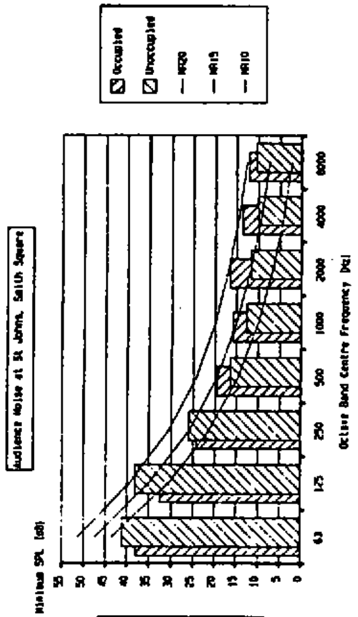

Figure 3

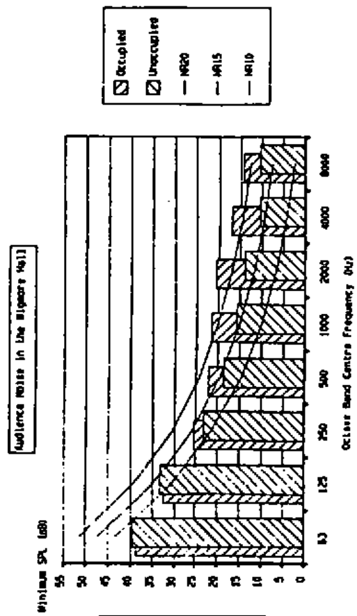

Figure 4

AUDIENCE NOISE

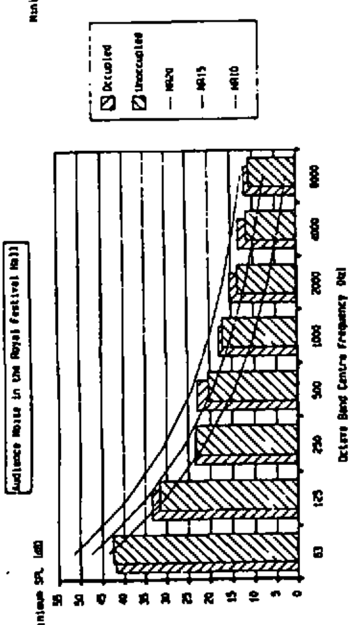

Figure 5

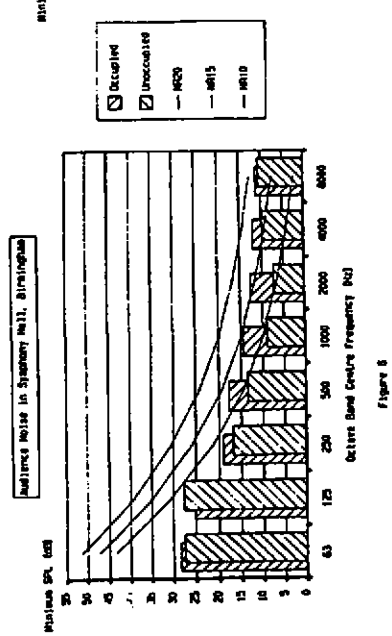

Figure 6

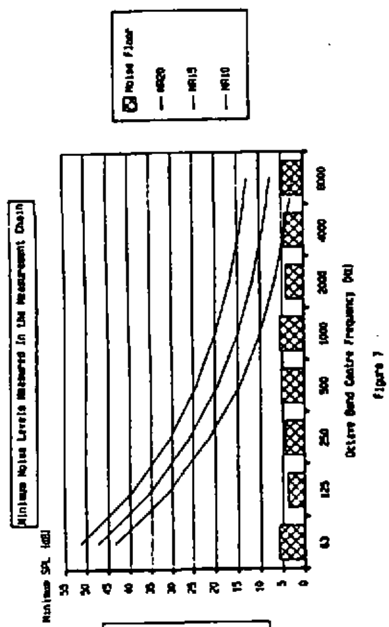

Figure 7

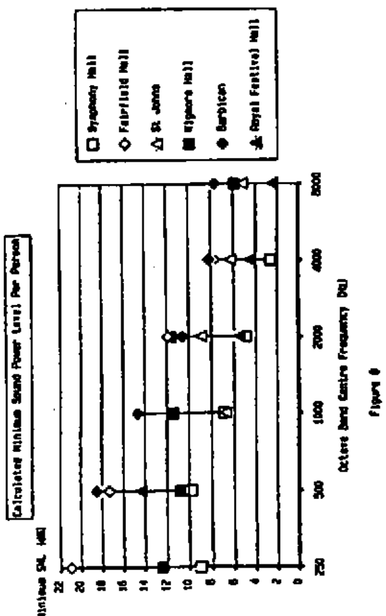

Figure 8