REVERBERATION TIME, STRENGTH & CLARITY IN SCHOOL HALLS: MEASUREMENTS AND MODELLING

J Harvie-Clark Apex Acoustics Ltd, Gateshead UK
D Wallace Apex Acoustics Ltd, Gateshead UK
N Dobinson Apex Acoustics Ltd, Gateshead UK
F Larrieu Apex Acoustics Ltd, Gateshead UK

1 INTRODUCTION

Reverberation time is such a significant problem in school halls that the revision to BB 93 intends to allow a scheme of absorption to be considered as a “deemed to satisfy” route to compliance with regulatory criteria. The problem is that the measured reverberation time often has very little resemblance to any calculation method, and the inclusion of relatively small amounts of diffusion can have a significant effect on the reverberation time measured. This means that meeting the reverberation time criterion is risky for contractors, and unsatisfactory for acoustic designers who either have to deliberately “over-design”, bear the risk of a test failure, or test with different arrangements of diffusion and wave their arms to explain themselves. However, the unreliability of reverberation time predictions and sensitivity of measurements to small changes in room conditions (that cannot be predicted) indicate that reverberation time may be a fickle parameter that is not the best indicator of the acoustic conditions that are required for the users.

The users of sports halls require spaces that do not become too noisy in use, and in which speech communication is possible over reasonable distances. In a space that responds roughly in accordance with the assumptions behind the Sabine relation – in which there is a diffuse sound field – the reverberation time may be used as a reliable indicator of these properties, as it can be used to determine the relation between sound power and sound pressure level, and the Clarity of speech. This paper investigates the potential to predict these qualities directly from the room geometry and surface finishes, rather than by means of the reverberation time which is very unreliable.

2 BACKGROUND

The parameter which describes the relation between sound power and sound pressure is Strength, G, as defined in ISO 3382-1 [1]; that Standard also defines speech Clarity, C_{50}. These parameters are not defined as area-averaged, but between a single source and receiver position. This paper investigates the potential to predict the spatial variation of Strength, G and Clarity, C_{50}, and considers the spatial definition of, and values for these parameters that may be appropriate for sports halls.

Many researchers have proposed modifications to the Sabine or Eyring relations to try and predict reverberation time in spaces where there is an uneven distribution of absorption, such as Fitzroy [2], Arau-Puchades [3], and Nilsson in Annexe D of BS EN 12354-6 [4]. However, in these circumstances, it is less likely that the reverberation time will relate to other acoustic parameters which may be better correlated with the users requirements, such as limiting the build-up of reverberant sound or speech intelligibility.

It is well known that in rooms where acoustic absorption is concentrated on the ceiling that reverberation time calculations invoking the diffuse field assumption often underestimate the actual reverberation time. In sports halls, the requirement for flat, impact resistant wall surfaces restricts the types of absorption and sound scattering materials that can be used. As a result, measured reverberation times frequently bear no resemblance to any simple formulaic expression; geometric acoustic modelling in software has also been shown by Wallace et al [5] to have limited potential to predict reverberation time with any useful level of accuracy.

The potential to use acoustic parameters that directly relate to users requirements has gained more recognition in recent years. Luykx [6] has proposed the use of Strength, G measured at a distance of the mean free path in sports halls to characterise the gain of a hall; he has previously suggested measurements at 10 from the source, but does not offer design information to achieve the proposed limit. Zander, Schnelle and Kurz [7] have carried out acoustic modelling to demonstrate that the average absorption coefficient, α_m, correlates better than reverberation time with the spatial decay of sound, DL_2, and Definition D (simply related to Clarity, C_{50}); while the spatial decay of sound may be important for sports hall users, it is unlikely to be as important as the absolute level. The Definition or Clarity, however, is well correlated with speech intelligibility, and therefore likely to be important.

The German Standard DIN 18041 [8] describes the requirement for rooms of different sizes with reverberation time as a function of room volume, and depending on whether or not the hall is used by one group at a time or more than one group. The requirements are written around a mean absorption coefficient of 0.19 where there is one group using the hall, or 0.23 if there is more than one group using the hall. The represents an interesting method of allowing reverberation time to increase in larger volume spaces, as the build up of noise will be controlled by the combination of the larger volume and increased quantity of absorption.

A goal for the definition of sports hall performance requirements is to determine which parameters correlate with users' acoustic needs, and to determine how these can be achieved simply and most cost effectively in the construction of sports halls. If a relationship between average absorption coefficient and another relevant acoustic measure can be determined, adequate sports hall designs can be generated without the need for geometric modelling. The current investigation looks at the potential to use Strength, G, and Clarity, C_{50} in this way. The spatial variation of these parameters has recently been investigated in very sound absorbent classrooms by Harvie-Clark et al [9] as a function of the measured reverberation time, and good correlations have been found. It has also been demonstrated that geometric acoustic modelling of spaces such as sports halls

3 THEORY

3.1 Spatial variation of Strength

According to Barron's revised theory [10], the diffuse (ie non-direct component) sound level is a function of distance *d* and may be given by:

$$Diff_{bar} = \frac{4(1-\alpha)^{d/mfp}}{A} \quad (1)$$

Where α is the average absorption coefficient, *A* is the equivalent sound absorption area, and *mfp* is the mean free path. The direct sound level is a function of distance as:

$$Dir = \frac{Q}{4\pi d^2} \quad (2)$$

Where *Q* is the directivity of the source (Q = 1 hereafter), and *d* is the distance between the source and the receiver . The total sound level at a distance d is given by Eqn. (3).

$$L_{p,bar} = L_w + 10\log(Dir + Diff_{bar}) \quad (3)$$

From this we can calculate the Strength, G from its definition in ISO 3382-1 as:

$$G = L_p - L_{p,10m} \quad (4)$$

Where $L_{p,10m}$ is the level in free field at 10 m. It can also be expressed as:

$$G = L_p - L_w + 31 \quad (5)$$

Substituting Eqn (5) into Eqn (3) gives the value of G as a function of distance:

$$G = 31 + 10\log(Dir + Diff_{bar}) \quad (6)$$

3.2 Spatial variation of Clarity

Clarity is defined as the ratio of early to late arriving sound, with the distinction for speech made at 50 ms between early and late. From ISO 3382-1:

$$C_{50} = L_{p,early} - L_{p,late} \quad (7)$$

Using Barron's revised theory from Eqn (3) and integrating to 50 ms, on the assumption of an exponential decay of sound:

$$L_{p,early} = L_w + 10\log\left(Dir + Diff_{bar}.\left(1 - e^{\frac{-0.69}{RT}}\right)\right) \quad (8)$$

$$L_{p,late} = L_w + 10\log\left(Diff_{bar}.e^{\frac{-0.69}{RT}}\right) \quad (9)$$

Where L_w is the sound power level of the source. It is noted that the key assumption necessary to describe C_{50} in this way is that the decay of sound is linear with a single slope, as described by the reverberation time; as such it is anticipated that the simple description of Clarity may be limited in accuracy.

4 CORRELATING STRENGTH AND CLARITY WITH SPEECH INTELLIGIBILITY AND AMBIENT NOISE

4.1 Voice level, SNR and intelligibility

In re-evaluating the requirements for classrooms, Bradley [11] has determined Signal to Noise ratios (SNR) that are required for different types of students. He concludes that a value of 15 dB is sufficient for secondary school pupils for most pupils to understand most words most of the time. Teacher voice levels may vary considerably in sports halls, and the requirement for teachers to raise their voices causes them problems.

Where the background noise level is 40 dB(A), the upper limit for external noise ingress in sports halls, a signal level of 55 dB(A) is required to achieve 15 dB SNR. For a raised voice level of 66.5 dB(A) at 1 m according to ANSI 3.5 (which is only partially raised according to ISO 60268), the value at 10 m in the freefield is 20 dB lower, ie 46.5 dB(A), by the definition of G. Hence the required value of Strength, G is 8.5 dB to achieve a signal level of 55 dB(A) at 10 m from the talker. This arbitrary distance is taken to illustrate the design considerations; lower levels of SNR may also be acceptable at greater distances in sports halls. If a teacher is addressing a group of students it would be reasonable for them to gather closer than 10 m from the teacher, so that the teacher would not need to raise their voce at all. Thus lower levels of G may also be acceptable for achieving sufficient SNR at closer proximities with good intelligibility.

4.2 Limiting the build-up of reverberant sound

As Strength, G describes the relationship between source sound power and sound pressure level directly, the only other consideration is the spatial definition of source and receiver positions. It would seem appropriate to define these over the distances typically encountered for a single group within a sports hall, rather than trying to determine the impact of one group on another. In addition, an absolute distance rather than an acoustic dimension of the space (such as mfp) is proposed, given that people using the hall will tend to operate over finite distances between them – when playing on particular courts, for example – rather than over acoustic dimensions of the hall. Hence a level at 10 m, as has been proposed by others, is considered suitable. In a typical 4 court, 600 m^2 sports hall, the mfp is close to 10 m in any case.

As well as a minimum value for speech reinforcement, the main consideration in sports halls is more likely to be the upper limit of Strength that is tolerable to users, as the lowest possible level is likely to be preferable to control the build-up of reverberant sound.

4.3 Clarity and STI

The correlation between Speech Transmission Index, STI, and Clarity, C_{50}, is discussed by many researchers, notably Marshall [12]. Marshall has indicated the weighting factors in Table 1 for the relevant octave band measurements to best correlate C_{50} with STI.

Octave band	500 Hz	1 kHz	2 kHz	4 kHz
Weighting factor	0.15	0.25	0.35	0.25

Table 1: Intelligibility weighting factors to correlate C_{50} with STI, from Marshall

Marshall has also indicated the C_{50} weighted values that correlate with different levels of STI as shown in Table 2.

Weighted C_{50}, dB	**-6**	**-3**	**0**	**3**	**6**	**9**
STI	0.3	0.4	0.5	0.6	0.7	0.8
Category	Poor	Fair		Good		Excellent

Table 2: Marshall's correlation for C_{50} and STI

From this it is suggested that a minimum value of 0 dB for C_{50} may be acceptable for sports halls, although higher values would be preferred, at the biggest typical communication distances. It is also notable that the value at 4 kHz is more significant than the value at 500 Hz, although under BB 93 the mid-frequency reverberation time assesses the mean of the 500 Hz, 1 kHz and 2 kHz octave bands only. It may be advantageous to include the 500 Hz octave band rather than the 4 kHz band to include some control of lower frequencies, as if the conditions are suitable at 2 kHz then in practice they are likely to be so at 4 kHz also. In the following measurements, the Marshall-weighted values of C_{50} are plotted against the measured ambient STI values as a function of distance, with the relative scale for each aligned, so that the values may be compared directly.

5 MEASUREMENTS IN THREE SAMPLE HALLS

The spatial variation of G and C_{50} was measured in three halls. The measured results are compared with both simple calculations based on average absorption coefficient and Barron's revised theory, and with an acoustic model made in CATT. Impulse response and sound level measurements with a calibrated omnidirectional sound source were taken for each measurement position on a line along the space diagonals of the hall, in the same manner as described by Zander et al. This allows the greatest possible range of source-receiver distances to be evaluated. The graphs depict the decay of each parameter with distance from the source, in metres. The source was located towards the corners at a distance of 4 metres from each wall. The characteristics of the halls are shown in Table 3.

Hall ID	Volume / m^3	Mean Mid-Frequency Absorption Coefficient	Measured T_{mf} / s	T_{mf} based on Sabine calculation / s
1	5500	0.20	2.6	1.9
2	7000	0.30	2.0	1.5
3	2300	0.26	3.2	1.3

Table 3: Hall characteristics

Halls 1 and 2, illustrated in Figure 1 and 2, are typical 4 court sports halls with perforated roof liners and absorbent panels on the walls. They exhibit the typical variation between the simply-calculated reverberation time and measured values. Hall 3, illustrated in Figure 3, is a partially fitted out theatre, with absorbent rafts suspended beneath the concrete soffit and some absorbent wall panels at high level. It is due to be fitted out with bleacher seating that was not present at the time of the measurements. This space exhibits a particularly high difference between measured reverberation time and that calculated with the Sabine formula.

Figure 1: Hall 1, with the band of grey absorbent panels visible at high level

Figure 2: Hall 2, with perforated panels visible above 3 m height around all sides

Figure 3: Panorama in Hall 3, with suspended rafts and some wall panels

5.1 Results for Hall 1

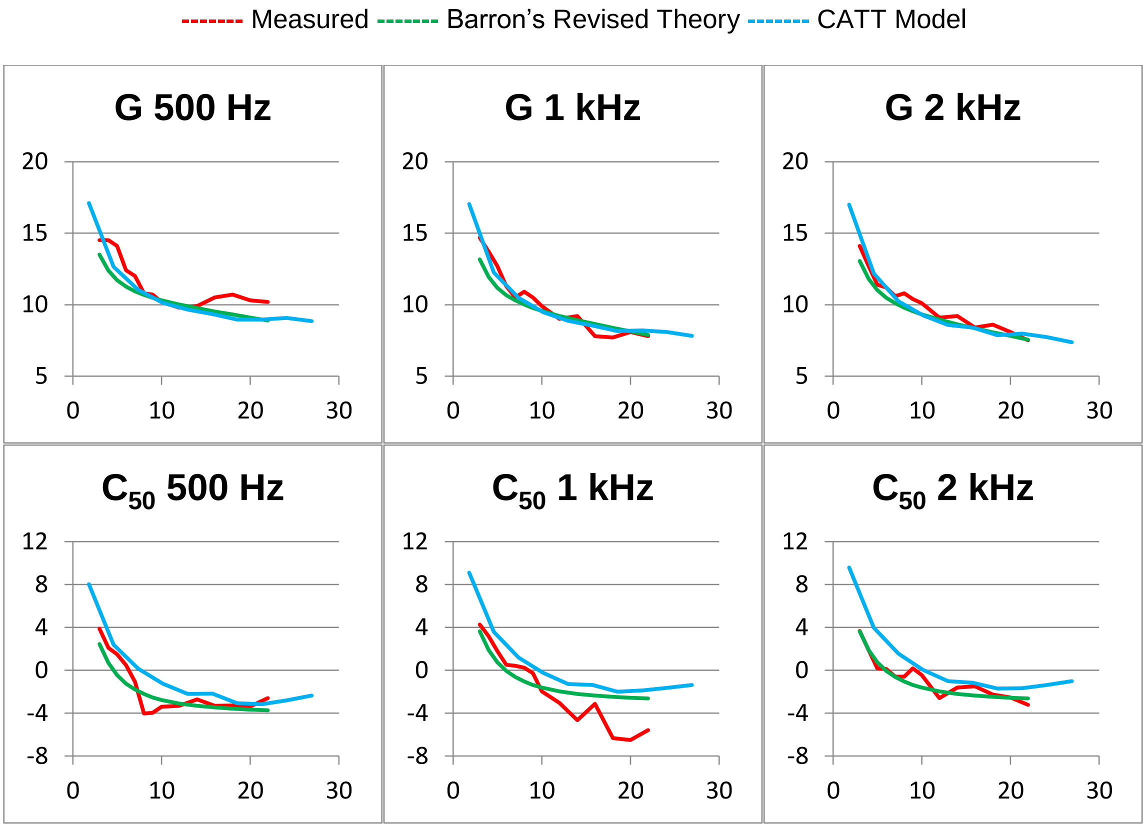

Figure 4: Results for Hall 1

The different calculation methods for G and C_{50} both correlate well with the measurements for Strength; the measurements for Clarity are more variable, but appear to be slightly better represented by the simple formula than by the CATT model. The measured Clarity in the 1 kHz band drops below that calculated at distances greater than 10 m. The correlation between the measured and calculated Marshall-weighted values of C_{50} and the measured STI is shown in Figure 5.

Figure 5 illustrates that the values calculated based on the average absorption coefficient tend to under-predict that measured by up to 2 dB at some distances, while at some distances the prediction is accurate.

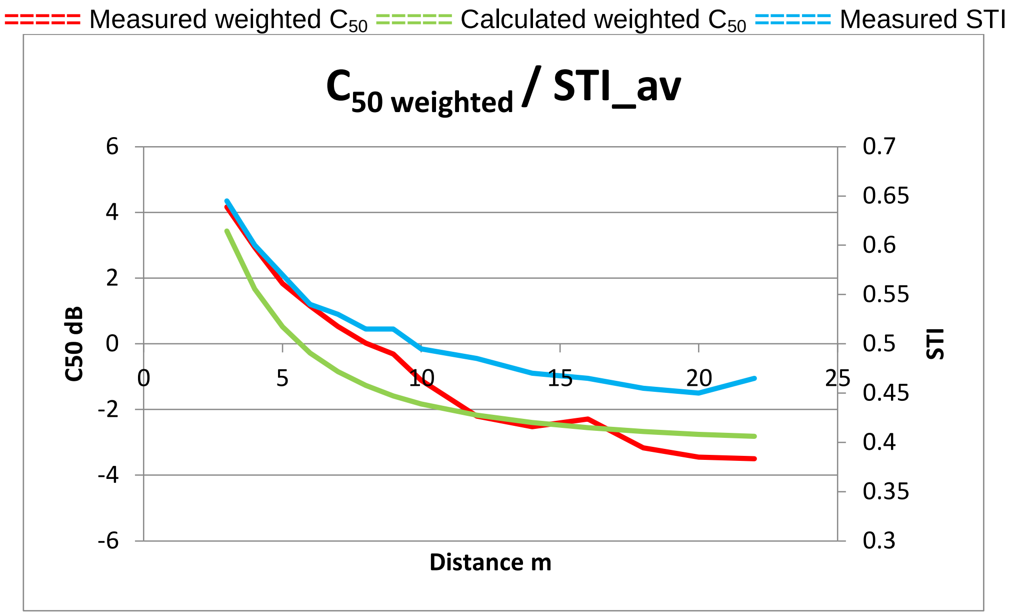

Figure 5: Correlation between measured Marshall-weighted C_{50}, that calculated using Equations 7, 8, and 9, and measured STI against distance in Hall 1. The average of the two measurement lines is presented.

5.2 Results for Hall 2

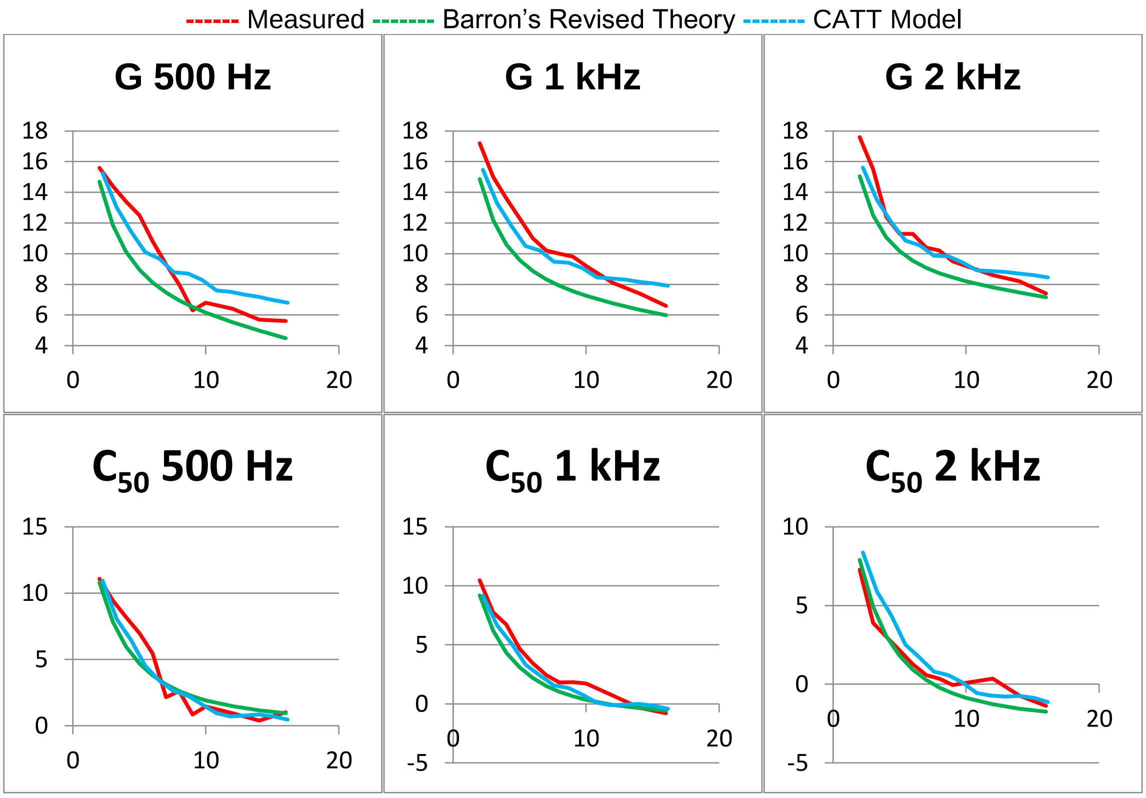

Figure 6: Results for Hall 2

The simple model appears to under-predict the value of Strength, typically by between 1 and 2 dB, although the CATT model seems to make better predictions of this parameter. Measurements of Clarity appear reasonably predicted by both the simple theory and CATT modelling. The correlation between the Marshall-weighted values of C_{50} and the measured STI is shown in Figure 7.

===== Measured weighted C_{50} ===== Calculated weighted C_{50} ===== Measured STI

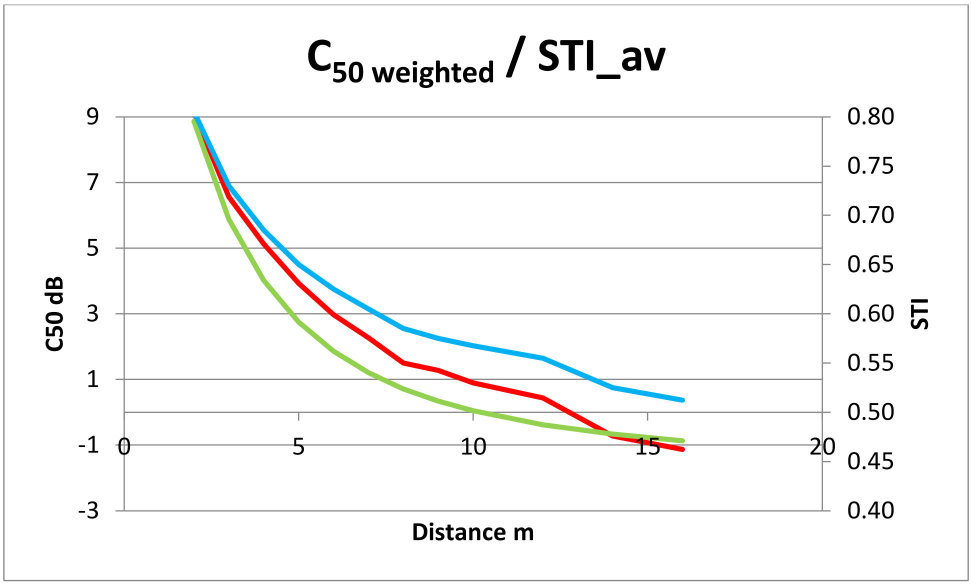

Figure 7: Correlation between measured Marshall-weighted C_{50}, that calculated using Equations 7, 8, and 9, and measured STI against distance in Hall 2. The average of the two measurement lines is presented.

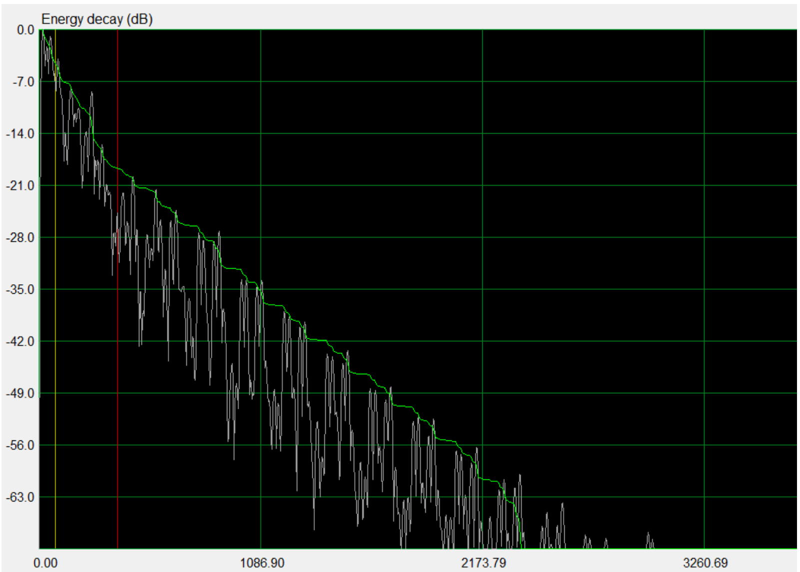

Figure 8: Flutter echo at 250 Hz in Hall 2

5.3 Results for Hall 3

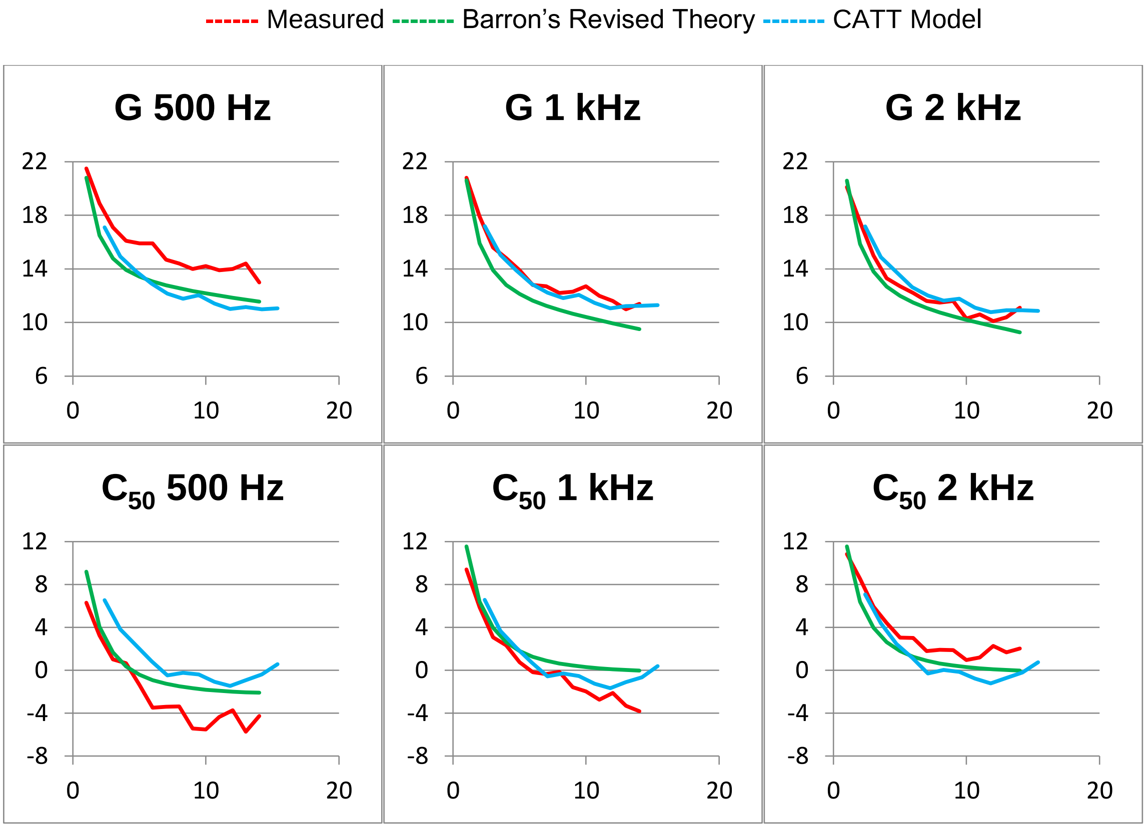

Figure 9: Results for Hall 3

The results in this hall differ significantly between the three octave bands presented. The reverberation times in each octave band, as measured and as calculated according to Sabine, are shown in Table 4.

Frequency band/ Hz	Mean Mid-Frequency Absorption Coefficient	Measured T / s	T based on Sabine calculation / s	10*Log ($T_{measured}$ / T_{Sabine}) / dB
500	0.21	3.8	1.6	3.8
1 k	0.29	3.3	1.1	4.6
2 k	0.30	2.6	1.1	3.8

Table 4: Characteristics in Hall 3

In the 500 Hz octave band, simple theory appears to under-predict Strength by around 2 dB; the results in Table 4 suggest that if the measured reverberation time was used in the simple prediction rather than that calculated based on Sabine, the difference would be about 4 dB. The modelled values follow those predicted with the simple theory in this octave band, and hence the model does not appear to be capturing the room characteristics that are causing measured values of Strength to be higher. Similarly for the Clarity, beyond 5 m distance the simple theory and CATT model over-predict the values by more than 2 dB compared with the measurements in this frequency band.

In the 1 kHz octave band the predicted values of Strength are generally less than 2 dB below the measured values, despite a greater relative discrepancy between measured and Sabine-calculated reverberation times. In this band the CATT model appears to better predict the room characteristic for Strength and Clarity, although the simple theory makes reasonable predictions up to about 10 m from the source.

In the 2 kHz band, the relative difference between measured and calculated reverberation times is the same as at 500 Hz, equivalent to just under 4 dB in Strength terms. However, the simple theory appears to make good predictions for both Strength and Clarity across the range of measured distance, with differences generally less than 1 dB.

The correlation between the Marshall-weighted values of C_{50} and the measured STI is shown in Figure 10.

===== Measured weighted C_{50} ===== Calculated weighted C_{50} ===== Measured STI

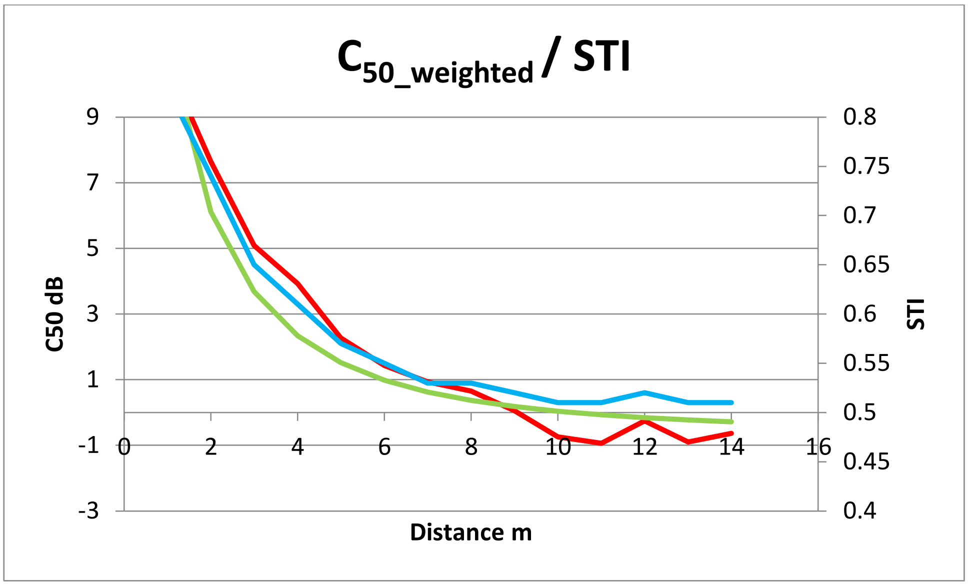

Figure 10: Correlation between measured Marshall-weighted C_{50}, that calculated using Equations 7, 8, and 9, and measured STI against distance in Hall 3

On the basis of the three separate octave band measurements in this hall, there does not appear to be consistency in the deviation between measured values and those calculated using simple theory for Strength and Clarity. The higher values of Strength at 500 Hz are not replicated at 1 and 2 kHz, despite equal or greater differences between absorption and Sabine-calculated parameters.

When considered in aggregate, Figure 10 indicates surprisingly good correlation between measured Clarity and that calculated based on the room finishes; the measured STI is also very well approximated by the Marshall-weighted values of Clarity. Up to 9 metres from the source, the simple calculation is again prudent in estimating the Clarity compared with the measured values.

6 DISCUSSION: STRENGTH

The measurements presented here demonstrate that Strength may be reasonably predicted with simple methods based on the mean absorption coefficient alone; where the absorption is relatively evenly distributed, deviations of up to 2 dB are noted in Halls 1 and 2 for some octave bands, but average deviations are lower. Where the absorption is very unevenly distributed in Hall 3, slightly higher deviations are noted.

The simple predictions and acoustic modelling with CATT appear to yield similar results, so that there is no particular benefit achieved from the additional work required to model the spaces.

Further measurements not presented above in two similar-sized 4 court halls on one school site found values of for G at 10 m of 12 dB (with 2.2 s T_{mf}) and 13 dB (3.4 s T_{mf}). The hall with the marginally higher value of Strength but significantly higher reverberation time was considered to be acoustically defective by the users. In another case, additional absorption to reduce the value of G at 10 m from 17 dB to 12 dB in a smaller hall of 260 m^2 floor area was considered effective; in this hall, the mean mid-frequency absorption coefficient on completion was 0.19.

Given the problems with reverberation time, it may be more appropriate to design or regulate to limit the build-up of reverberant sound rather than reverberation time, ie to a value of Strength. Although at first it may seem intuitive that a single value for Strength would be desirable in different sized halls or rooms, the implications of different sized rooms with a single value of Strength lead to very high level of sound absorption in smaller rooms and increasingly low levels of absorption in larger rooms. It would appear that the approach of DIN 18041, to adopt a constant average absorption coefficient, does in fact lead to the type of conditions that would be desirable in terms of the more familiar reverberation times, as demonstrated in Table 5, with the value of Strength at a given distance calculated according to Equation 6.

Property / Hall type	**Classroom**	**Small hall**	**Assembly hall**	**2 court sports**	**4 court sports**	**8 court sports**
Width / m	7.5	10	12	16	20	33
Length / m	7.5	14	18	18	30	37
Height / m	3.2	4.5	6	8.5	9	10
Volume / m^3	180	630	1296	2448	5400	12210
Mfp / m	3.5	5.1	6.5	8.5	10.3	12.7
Nominal Sabine T / s	**0.7**	**1.0**	**1.3**	**1.7**	**2.1**	**2.5**
Distance for G / m	7.5	10	10	10	10	10
G at distance above / dB	18.8	15.3	13.7	12.5	10.3	8.1

Table 5: Nominal reverberation time and calculated Strength at a given distance based on an average absorption coefficient, α = 0.20.

It is remarkable that the nominal reverberation time calculated in Table 5 is consistent with typical upper limits across the wide range of room sizes, although this is calculated from the average absorption coefficient and dimensions only. This table also demonstrates how Strength at 10 m distance reduces in larger rooms even with longer nominal reverberation times, and hence why a single value for Strength would not be appropriate.

If there is a design intent for Strength, such as the value calculated at 10 m from the average absorption coefficient, a higher limit for reverberation time may also be adopted. A value for T_{20} of 25 % greater than that calculated according to Sabine may be sufficient if Strength or mean absorption are also controlled. This could prevent poor acoustic conditions due to insufficient distribution of absorption or other features. The combination of specification of Strength and reverberation time in this way may be sufficient without the use of another parameter such as Clarity where the main purpose is to prevent the build-up of reverberant sound, such as in workshop areas or dining halls, where speech intelligibility for a talker addressing a large group is not a particular acoustic requirement. If there are also speech intelligibility requirements in the room, these can be addressed by the use of another parameter. This enables the design to be carried out very simply based on the total quantity of absorption in the room. The distribution of the absorption and any diffusion may assist in the control of acoustic defects and reverberation time. It is suggested that a minimum mean absorption coefficient of $\alpha = 0.20$ may be appropriate, or $\alpha = 0.25$ for reasonable control and $\alpha = 0.30$ for good control of reverberant sound.

The potential for defects such as flutter echoes to adversely impact the users' experience also needs to be taken into account. Strength is insensitive to the presence of flutter echoes, due to the fact that they do not usually appear until later in the decay (see Figure 6), and hence are not responsible for much of the energy transmission.

7 DISCUSSION: CLARITY

The correlation between the measured ambient STI (not affected by background noise) and the Marshall-weighted values for Clarity is striking. At higher values of Clarity or STI the correlation is so good that the two parameters are almost indistinguishable. Below a value of 0 dB in Halls 1 and 3, the values of Clarity predict lower speech intelligibility than the measured STI. In Hall 2, the divergence begins at a higher level, at around 3 dB, and again the values of Clarity tend to under-predict the speech intelligibility compared with the measured values of STI. The consistent under-prediction at lower values would tend to make the use of Clarity prudent, although the values are really only relevant when higher, where the correlation is demonstrated to be excellent in these halls.

Consideration of Clarity may be used to determine the room requirements for average absorption coefficient in the same way as for Strength. The same range of rooms is considered in Table 6 as in Table 5, although the relevant distance and target criteria vary. For the classroom, small hall and assembly hall, this distance is chosen as the length of the room, as this is likely to be the largest distance over which a talker and listener may be situated. In these rooms, the target criterion for Clarity is chosen as 3 dB to achieve “good” speech intelligibility, and the corresponding mean absorption coefficient is then calculated on that basis. The nominal Sabine-calculated reverberation time is shown for reference, and also the value of Strength that would result from those conditions at the same location.

For the sports halls, a reference distance of 10 metres is selected, with a target criterion of 0 dB for C_{50} at that distance. Similarly, the mean absorption coefficient is then calculated, and the nominal reverberation time and value for Strength at that distance.

As has been demonstrated previously by Harvie-Clark et al [9], when the value of Strength is not too small then at distances of the room extents between talker and listener the value of Clarity tends to a function of nominal reverberation time only, regardless of room size. Thus the three smaller rooms (classroom and halls) all have the same nominal reverberation time, and the mean absorption coefficient varies to achieve this. In the much larger sports halls consider a separation of 10 metres between talker and listener, the mean absorption coefficient remains approximately constant around a value of 0.3, independent of room size, and the nominal reverberation time increases with room volume.

Property / Hall type	**Classroom**	**Small hall**	**Assembly hall**	**2 court sports**	**4 court sports**	**8 court sports**
Width / m	7.5	10	12	16	20	33
Length / m	7.5	14	18	18	30	37
Height / m	3.2	4.5	6	8.5	9	10
Volume / m^3	180	630	1296	2448	5400	12210
Target value of C_{50} / dB...	3	3	3	0	0	0
… at distance, d / m	7.5	14	18	10	10	10
Mean absorption, α_m	**0.21**	**0.31**	**0.39**	**0.29**	**0.31**	**0.31**
Nominal Sabine T / s	0.6	0.7	0.7	1.2	1.3	1.6
G at distance above / dB	18.4	10.9	6.5	10.4	8.0	6.2

Table 6: Calculated mean absorption coefficients to achieve different criteria for C_{50} at a given distance; the value of G at that distance is also presented

8 COMPARISON OF REVERBERATION TIME AND MEAN ABSORPTION COEFFICIENT PREDICTIONS

The results in Hall 3 are particularly curious. It would be anticipated that with the excessive measured reverberation due to the very uneven distribution of absorption, there would be a significant divergence between the measured Strength and Clarity and that calculated based on the mean absorption coefficient alone. Consider that the predicted values of Strength and Clarity would not change if the absorption was evenly distributed, such that the reverberation time was reduced to a value close to that predicted by the Sabine relation. This would create a very different experience in this hall, and yet the predicted values of Strength and Clarity and associated speech intelligibility would not change.

It is interesting to compare the measured values of Strength and Clarity with those predicted from the mean absorption coefficient, and those predicted from the same theory but based on the measured reverberation time and Sabine theory. As the 1 kHz octave band has the greatest relative divergence between predicted and measured reverberation time, this is used to illustrate the comparison with the measured room conditions in Figure 11.

------ Measured ------- Theory – mean absorption ------- Theory – measured reverberation time

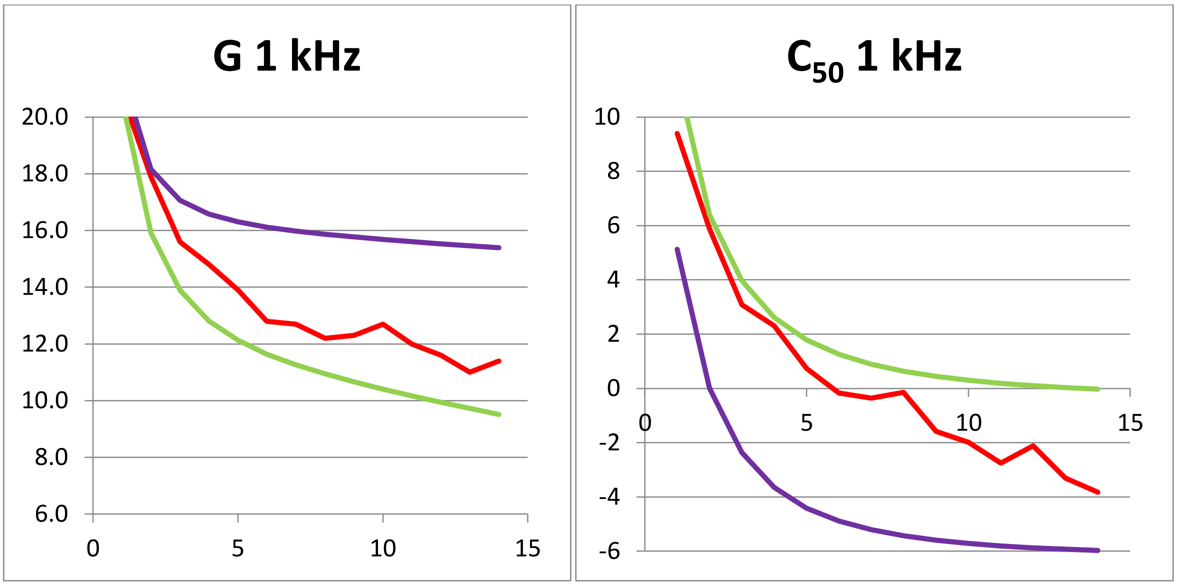

Figure 11: Comparison of measured and predicted values using the mean absorption coefficient and measured reverberation time

Figure 11 demonstrates that mean absorption coefficient appears to be a much better predictor for Strength and Clarity than measured reverberation time, especially at closer proximity to the source. There is an increasing divergence with distance, but as Figure 10 illustrated for Clarity, the weighted average values are well represented by the theory and average absorption coefficient.

It is also noted that the experience of being in this hall was of being in an echo chamber – it is difficult to conceive that the speech intelligibility is unaffected by the excessive reverberation, and yet Clarity and measured STI are both suggesting that speech intelligibility is not unreasonable up to distances approaching 10 metres. This may be the most significant result of all these measurements – that the values of the parameters used to represent the acoustic conditions appear to be reasonable, but experience in the hall in fact correlates better with the measured reverberation time, and the space is acoustically uncomfortable to inhabit.

9 CONCLUSIONS

It is remarkable that the measured Strength and Clarity may be predicted as a simple function of room geometry and mean absorption coefficient, regardless of the measured reverberation time.

The reverberation time is strongly dependent on the distribution of absorption in the room, and low reverberation times cannot be achieved through solely using absorption on the ceiling, for example. However, the measured results for Strength indicate that longer measured reverberation times do not mean that sound pressure levels increase for a particular source, as Strength remains reasonably correlated with the amount of absorption within the room and the room volume alone. Appropriate control of the build-up of reverberant sound can be achieved by determining the value of G at a suitable distance based on Equation 6, and hence the mean absorption coefficient. The acoustic design that follows is relatively straight forward, and only requires determination of the amount of absorption necessary to distribute around the space. Simple rules for the distribution of absorption, such as requiring a certain minimum percentage on the soffit and a certain minimum percentage on the walls in the same manner as proposed by Don Oeters [13], would enable the design to be carried out simply with similar results.

The measured results for Clarity also confirm that it does indeed correlate well, when Marshall-weighted, with STI, and also with the simply calculated levels based on equations 7, 8, and 9. Clarity also appears to correlate as a function of mean absorption coefficient rather than with the measured reverberation time. While the measured results in the sports halls appear to correlate with the experience of being in those spaces, the numerical values measured in hall 3 do not seem to correlate with the acoustic experience. It is suggested that an additional parameter may also be required to describe the acoustic defects such as those encountered in hall 3 that do not appear to affect the measurement of Clarity or STI; this could even be the reverberation time.

Further work is required to correlate users experience with the build-up of reverberant sound and Strength, and speech intelligibility with Clarity and another parameter. The effects of flutter echoes and other acoustic defects that do not appear to affect the values of Strength, Clarity or even reverberation time also require further investigation to determine their importance.

Creating room conditions that control the measured reverberation time to an appropriate value is a sufficient requirement to ensure suitable conditions, but it may not be a necessary requirement. The acoustic conditions that the users require may be better described by other parameters such as Strength and Clarity.

10 ACKNOWLEDGEMENTS

This work has been self-funded by Apex Acoustics. The contribution of all members of Apex Acoustics in operating the company is essential in enabling the work presented here to be developed; the authors therefore wish to express their gratitude to their colleagues. We are grateful for the use of the halls as test chambers.

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