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Designing small music practice rooms for sound quality

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ABSTRACT

Small music practice rooms for non-amplified musical instruments are essential requirements in the teaching of music in music education facilities. The requirements for wall partitions and doors sound insulation performance for music practice rooms are usually the primary consideration and generally well understood. In this paper, the focus is on the sound quality within the music practice room as perceived by the music student and teacher. The size, shape and finishes of the small music practice rooms decided at the design phase would determine the final cost, floor areas utilised and resulting acoustic quality of the built music practice rooms. This paper reviews the various options for the design of music practice rooms for specific musical instruments and for multi-purpose use. The determination of music practice room sizes, proportions, shapes and finishes and their potential impact on the sound quality of the rooms are discussed. Issues regarding standing waves, room modes and the even distribution of the modes in small music practice rooms are also addressed. The various methods of varying the reverberation times and diffusivity in the music practice rooms with the use of alternative room elements and finishes are reviewed and discussed in the paper.

USER REQUIREMENTS FOR SMALL MUSIC ROOMS

The small music room probably receives the greatest level of usage of all the specially built music spaces. Small music rooms vary in size, and accommodate diverse groups ranging from a solo instrumentalist to small music ensembles. In the past noise control and isolation have been the main concerns in their design. As music students can spend up to 40 hours per week in music practice and rehearsal rooms, these rooms are very important in the daily activity of a music school or department [Lamberty, 1980].

Good room acoustics in a small music room enable a music teacher to more effectively teach subtle concepts such as intonation, articulation, balance, dynamics and tone production while a poor acoustical environment can adversely affect the development of basic musical skills of a music student [McCue, 1990].

Although many acousticians may have a musical background, they may not be acquainted with the problems of teaching music, which requires a different acoustical situation from that of the auditorium or concert hall. Another issue confronting the acoustician and architect in the design of small music rooms is the lack of understanding of the problems of teaching young musicians. The job of solving the acoustical problems has been complicated, in part, by the lack of communication between the musician-teacher and those involved in building construction. This has been complicated further by the failure of music teachers to separate acoustical problems from the general problems created by the inexperience of young performers. For example, in teaching situations involving balance, intonation, articulation, dynamic control, and tone-colour control, the teacher may it difficult to determine whether the disappointing result is due to inexperience or a poor acoustical environment [Patrick & Boner, 1967].

SMALL MUSIC ROOMS DESIGN ISSUES

As recently as 2002, the British Government guide [DfES, 2002] for the design of rooms for music in schools only specified the desired room reverberation times and general mention of room modes and diffusivity to reduce flutter echoes and improve sound diffusion in the music rooms. Most of the focus of the acoustical issues is still the background noise from external (e.g. vehicular traffic) and internal (e.g. building services) sources and sound isolation between the adjacent music rooms. This indicates that not much has transferred from research work in small room acoustics to the design and construction of them since the days of Sabine (1922) and Knudsen (1930).

In this paper the acoustical issues in the design of small music rooms addressed are:

Room Modes and Standing Waves

Room Reverberation Times

Room Diffusivity and Flutter Echoes

Room Noise Isolation and Background Noise are mentioned but not covered in any detail.

Room Modes and Standing Waves

As early as 1896, Rayleigh had recognised and shown that the air enclosed in a rectangular room has an infinite number of normal modes of vibration. The frequencies ‘f’ at which these modes occur are given by the following equation: [Beranek, 1986] [Everest, 1991].

$f = 0.5c\,((p/L)^2+(q/W)^2+(r/H)^2)^{0.5}$

Where c is the speed of sound (344m/s),
L is the length of the room in metres,
W is the width of the room in metres,
H is the height of the room in metres,
p, q, and r are the integers 0, 1, 2, 3 etc.

With the rapid growth of radio broadcast industry in the first half of the twentieth century, interest in small room acoustics, particularly small rectangular announcers' studios and music studios, revealed the negative impact of room modes. As a consequence of this, Gurin & Nixon (1945) proposed a height, width and length ratio of 2:3:5 for radio broadcast studios so as to minimize the objectionable grouping of resonant frequencies in the space.

In 1965, Sepmeyer (1965) suggested that to minimise the room modal effect (an improvement on Gurin & Nixon, 1945), the following room proportions as the best starting point:

	Height	Width	Length
A	1.00	1.14	1.39
B	1.00	1.28	1.54
C	1.00	1.60	2.33

(The room proportions A, B, and C are ratios relative to the room height. If in the case of room Type B, the height of the room is 3.0 metres, the width should be 3.42 metres and the length should be 4.17 metres.) A summary of studies relating to room modes done by other researches in this field is summarised below in Table 1.1.

Bonello (1981) noted that at low frequencies, in small rectangular rooms, the room modes (eigentones) spacing can be very large and usually greater than half octave apart and he asserted that this caused 'peaks and valleys' in the room response which is undesirable. To minimise the effects of the 'peak and valleys' Bonello proposed the criteria for the acceptability of room modes distribution pattern based on his prescribed spread of the room modes (eigentones). Bonello's first criterion for room acceptability is to plot the eigentones over each one-third octave band and examine the resulting plot to check that each one-third octave has at least the same number or more modes than the preceding one-third octave. This provides an even spread and gradual increase in room modes as the frequency increases. Bonello's second criterion is to examine the modal frequencies to make sure that there are no coincident modes [Everest, 1991]. A check of the above combinations in Table 1 using the 'Bonello Criteria' shows that the Knudsen, European, Volkmann, Golden Section and Sabine marginally failed the first criterion, but all the combinations passed the second criterion. The second criterion is probably the more significant of the two.

Small Music Room Reverberation Times

The Reverberation time (RT) is probably the most widely used parameter in room acoustics, and is usually measured using the Schroeder integrated impulse response technique [Schroeder, 1965], and linear regression between -5 and -35 dB (or -25 dB when the dynamic range is insufficient) [Pelorson et al, 1992]. Studies by Lamberty (1980) on room reverberation noted that 59% of music students preferred a 'live' room while 11% preferred a 'dead' room and 30% preferred something midway. By the process of elimination, it was found that when the students were thinking of a 'dead' room they were thinking of a room with a reverberation time of 0.4 to 0.5 second and a live room having a reverberation time of 0.8 to 0.9 seconds. Over 85% of the students found domestic bedrooms far too dead to practise in and the majority felt that a bathroom would be impossible to practice in. The overall preferred reverberation time was in the region of 0.7 seconds. Most students agree that the ideal room would have variable acoustics, which would enable them to practice in different conditions, including difficult ones: e.g., in dead conditions (which the students believed to be better to practice in) for a certain period, and then live conditions which are far more pleasurable and more rewarding for them. Most students agreed that a room of 15m^2 would be acceptable.

Table 1.1 Recommended Room Dimension Ratios for Small Rooms

Name of Ratio	Ratio of Room Dimensions	Normalised for Equal Volume	Relative Floor Area	Normalised Equal Height	Relative Floor Area
Harmonic	1:2:3	1:2:3	6.00	1:2:3	6.00
V.O.Knudsen	1.6:3:4	1.09:2.04:2.71	5.53	1:1.88:2.5	4.69
European	3:5:8	1.11:1.84:2.95	5.43	1:1.67:2.67	4.44
J.E.Volkmann	1:1.6:2.5	1.14:1.83:2.86	5.24	1:1.6:2.5	4.00
Golden Ratio	1:1.25:1.6	1.44:1.80:2.31	4.16	1:1.25:1.6	2.00
Golden Section	$(5^{\frac{1}{2}}-1):2: (5^{\frac{1}{2}}+1)$	1.12:1.82:2.94	5.35	1:1.63:2.63	4.25
P.E.Sabine	2:3:5	1.17:1.75:2.92	5.13	1:1.5:2.5	3.75
Sepmeyer 1	1:1.14:1.39	1.56:1.78:2.17	3.85	1:1.14:1.39	1.58
Sepmeyer 2	1:1.28:1.54	1.45:1.86:2.23	4.14	1:1.28:1.54	1.97
Sepmeyer 3	1:1.6:2.33	1.17:1.88:2.73	5.12	1:1.6:2.33	3.73
Louden	1:1.4:1.9	1.31:1.83:2.49	4.55	1:1.4:1.9	2.66
BBC Prototype	3.25:4.9:6.7	1.25:1.88:2.57	4.82	1:1.51:2.06	3.11

Adapted from: Sepmeyer (1965), Louden (1971), Rettinger (1988), Walker (1995), DfES (2002).

In their study in determining the optimum reverberation times and minimum acceptable size for music teaching studios and practice rooms, Lane et al (1955) concluded that for small practice rooms a reasonable design for the reverberation time would be between 0.4 to 0.5 seconds. A slight rise to 0.6 or 0.7 sec at 100 Hz is acceptable. For the teaching studios with a volume of approximately 60 m^3, a reverberation time of 0.5 to 0.6 seconds with a rise to approximately 0.8 seconds at 100 Hz is satisfactory. As a relative comparison with larger spaces, Kuttruff (1989) considers an RT of 1.8 to 2.1 sec. a sensible target for concert halls and an RT of 1.4 to 1.6 sec as appropriate for recital halls (for solo and chamber music performances).

In their White Paper on Acoustic Criteria and specification, the British Broadcasting Corporation [Walker, 2002] stated that "the reverberation time is the only objective measure of the internal acoustic conditions within a small studio or room that is reasonably well understood, but it is, at best, a poor guide to the subjective acoustic environment. Many proposals for alternative or additional measurements have been made over the years but none can, at present, be interpreted subjectively, at least in small rooms. There is some good evidence that these alternatives are meaningful in concert halls and other large spaces."

Table 1.2 Recommended Reverberation Times for Small Music Rooms

Music Activity Space	Area m^2	Height m	Volume m^3	AS2107,2000	DfES,2002	BB93,2003	OCPS,2003	ANSI S12.60
Music theory classroom	50-70	2.4-3.0	120-210	0.5-0.6	0.4-0.8	<1.0	N/A	<0.6
Ensemble /music studio	16-50	2.4-3.0	38-150	0.7-0.9	0.5-1.0	0.6-1.2	0.5-0.7	<0.6
Recital rooms	50-100	3.0-4.0	150-400	1.1-1.3	1.0-1.5	1.0-1.5	N/A	N/A
Teaching/practice room	6-10	2.4-3.0	14-30	0.7-0.9	0.3-0.6	<0.8	<0.5	<0.6
Studio Control room	8-20	2.4-3.0	19-60	0.3-0.7	0.3-0.5	<0.5	<0.6	N/A

RT is the reverberation time in seconds. For ANSI S12.60, DfES,2002 and BB93,2003 the RT is the mid-frequency value of Reverberation Time of the mean of the values in the octaves centred on 500Hz, 1000Hz and 2000Hz. (N/A means Not Available)
(from AS2107,2000, ANSI S12.60, 2002, DfES,2002, DfES(BB93),2003 and OCPS,2003)

Table 1.2 above shows the typical dimensions and the recommended mid-frequency (T_{mf}) reverberation times for the various music rooms normally found in educational facilities.

Table 1.3 below shows actual reverberation time measurements (sec) made in unoccupied rooms by the acoustic consultants of some completed Music Building Projects [McCue & Talaske, 1990] [Blankenship, Fitzgerald & Lane, 1955].

Table 1.3 Measured Reverberation Times in Music Practice Rooms

Space Type	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	Building
Choral Rehearsal Rm	1.6	1.1	0.9	0.8	0.8	0.7	0.7	n.a.	Davis Middle School, Dublin,Ohio - CA
Choral Rehearsal Rm	1.2	0.9	0.7	0.8	0.7	1.1	1.0	0.6	Tachikawa School Bldg 3, Tokyo - NHK
Choral Rehearsal Rm	n.a.	1.1	1.0	1.0	1.1	1.2	1.2	0.8	Doshisha Women's College, Kyoto - MNA
Ensemble Room	0.7	0.6	0.4	0.3	0.2	0.2	0.2	0.1	Berklee College of Music, Boston - CTKM
Ensemble Room	0.9	1.1	1.1	0.9	1.0	1.1	1.0	0.8	University of Texas Music Building - BFL
Percussion Rm	0.4	0.3	0.1	0.1	0.2	0.2	0.2	0.1	Tachikawa School Bldg 3, Tokyo - NHK
Practice Room	n.a.	0.6	0.4	0.3	0.3	0.3	0.3	0.2	Doshisha Women's College, Kyoto - MNA
Practice Room	0.8	0.7	0.4	0.3	0.3	0.2	0.2	n.a.	Olin Arts Centre, Maine - CTA
Practice Room	n.a.	0.7	0.3	0.3	0.3	0.3	0.3	0.3	Suka Tomasa Hall, Tochigi - NHK
Practice Room	n.a.	0.6	0.4	0.5	0.6	0.7	0.8	0.6	University of Texas Music Building - BFL
Teaching Studio	n.a.	0.7	0.6	0.6	0.6	0.7	0.6	0.5	Doshisha Women's College, Kyoto - MNA
Teaching Studio	1.0	0.7	0.6	0.8	0.9	1.0	0.9	0.8	University of Texas Music Building - BFL

CA- Campanella Associates CTKM - Cavanaugh Tocci/Klepper Marshall
CTA - Cavanaugh Tocci Associates MNA - Minoru Nagata Acoustic
NHK - NHK Engineering Services BFL – Blankenship, Fitzgerald & Lane (1955)
(from McCue & Talaske, 1990 and Blankenship, Fitzgerald & Lane, 1955)

Table 1.4 Summaries of Recommended Maximum Background Noise Levels

Music Activity Space	Cav.(1990)	AS2107,2000	ANSI,2002	DfES,2002	BB93,2003	OCPS,2003
Recording Studio	20dBA	25dBA	N/A	S/A	30dBA	NC 15-25
Recital Hall	25dBA	S/A	N/A	25dBA	30dBA	N/A
Rehearsal Room	35dBA	35dBA	35dBA	30dBA	35dBA	35dBA
Music Classroom	35dBA	40dBA	35dBA	30dBA	35dBA	N/A
Ensemble Practice	38dBA	45dBA	35dBA	30dBA	30dBA	35dBA
Individual Practice	42dBA	45dBA	35dBA	30dBA	35dBA	35dBA
Music Listening	42dBA	35dBA	35dBA	30dBA	35dBA	N/A

S/A = Special Advice N/A = Not Available NC = Noise Criteria

(from AS2107-2000, Cavanaugh,1990, ANSI S12.60-2002, DfES,2002, DfES(BB93),2003 & OCPS,2003).

Room Noise Isolation and Background Noise

Lamberty (1980) noted that when asked about the background noise levels, 86% of the music students found the noise from other students practicing most disturbing, followed by 9% that found traffic noise most disturbing and 4% found other noises disturbing. This emphasizes the importance of the isolation between music rooms and the need for proper zoning of music rooms and facilities.

As musical instruments can produce as much sound power in small rooms as in large auditoriums, they can be uncomfortably loud in small spaces. This is a common problem in small music rooms with insufficient acoustic absorption, and can give rise to sound levels which could, in the long term, lead to hearing damage. Many professional orchestra musicians have noise-induced hearing loss due to extended exposure to high noise levels both from their own instruments and, to a lesser extent, from others instruments nearby. For reduced sound intensity, sound absorbing materials or membrane absorbers are normally used extensively in music buildings [DfES, 2002] [Zha, Fuchs & Drotleff, 2002]. Small music rooms also require a good deal of installed sound-absorbing material for the sake of reverberation control, and in particular instances, elimination of flutter echo paths between parallel walls (Marshall & Klepper, 1999).

AS2107 (2000) recommends an ambient sound level of 30dBLA$_{eq}$ for music studios, 35dBLA$_{eq}$ for drama studios and 40dBLA$_{eq}$ for music practice rooms. DfES (2002) recommends the indoor ambient noise level by for all school music facilities is 30dBLA$_{eq,30mins}$, and for some uses noise limits below 30 dB LAeq may be required. Table 1.4 above shows a summary of recommended maximum levels.

Room Diffusivity and Flutter Echoes

Brown (1964) stated that although diffusion is an issue, but for practical reasons it is not always possible to alternate types of treatment evenly over all surfaces. In such cases the following prescriptions should be observed for broadcast studios.

a. Some of each type of absorption should be applied normal to each of the three planes (longitudinal, transverse and vertical of each room).

b. Untreated areas should not face each other.

Brown (1964) did not specifically comment on potential problems with parallel walls and flutter echoes but this was addressed in later work by others. [Wenger, 2001] [DfES, 2003]. There have been various ways ‘traditionally accepted’ ways of dealing with problems of parallel walls and flutter echoes such ‘item b’ above described by Brown (1964) and treating the walls with absorptive fabric wrapped panels, or absorptive materials directly applied on the walls. Flutter echoes can also be reduced and room diffusivity increased with the use of the quadratic residue diffusers proposed by Schroeder (1975), and later commercially developed by D’Antonio [D’Antonio & Konnert, 1984]. Unlike absorptive wall panels or finishes, the quadratic residue diffusers can minimise flutter echoes and improve room diffusivity without significantly reducing the room reverberation times.

Other factors that can affect sound quality

A further issue confronting the search of the ideal music room is the variations in acoustic radiation properties of the various musical instruments. For the trumpet or cornet (bell-mouthed instruments), the low frequency components are radiated relatively omni-directionally, while the higher frequencies show progressively more and more directivity in the forward direction. For the oboe or clarinet-like woodwind, the radiation pattern is considerably more elaborate than the brass instrument [Benade, 1985]. The cello has an even more complex radiation pattern due to the asymmetric seated cellist position and the shadowing by the cellist body. This issue is currently being researched on and beyond the scope of this paper.

Music room requirements for various musical instruments

Various types of musical instruments have differing requirements from a small music practice room. Issues to be taken into consideration are the potential sound power that can be generated by the instrument, the frequency range of the instrument and the type of instrument itself (wind, string, percussion etc.). This would determine the sound insulation requirements between music rooms and the type of internal acoustic treatment.

Research conducted on subjective listener assessments of the sounds of various instruments in practice rooms indicates the following are the preferred mid-frequency reverberation times for the various types of instruments for rooms between 20 and 100 cubic metres. [Osman & Fricke, 2003] [Osman et al, 2003].

Instrument Type	Preferred RT
Percussion Instruments	0.3 - 0.5 secs
Bowed String Instruments (violin, cello)	0.6 – 0.9 secs
Wind Instruments (trumpet, flute)	0.4 – 0.7 secs

The lower range of the reverberation time is recommended for room volume of about 10m^3 and the higher range for room volumes of about 100m^3.

Other factors such a loudness, signal to noise ratio, clarity, balance (interaural level difference) and music genre has a slight influence the ideal reverberation times [Osman, 2005] but this is beyond the scope of this paper.

Start with the Room Shape and Size

Although rooms with non-parallel walls, floors and ceilings are preferred for music rooms, to maximize the utilisation of the available space the rooms in music teaching facilities are normally rectangular in size with floors and ceilings perpendicular to the walls. Where rectangular rooms with parallel walls, floors and ceilings are adopted, care should be taken to determine the ratios of the room length, width and height. Computer modelling by the author shows that based on a 3 metre room height and the musical instruments tuned to the noted in a tempered scale, the BBC prototype ratios provided the room dimensions for the optimum predicted performance, taking into consideration the Bonello criteria and Room Mode frequencies (at standard speed of sound of 344m/s).

For rooms with non-parallel straight walls and ceilings, it is recommended that the optimised dimensions be applied to the room dimensions in the middle of the room (i.e. averaged room length, width and height). Curved walls are not recommended for small rooms to avoid focussing and other undesirable effects.

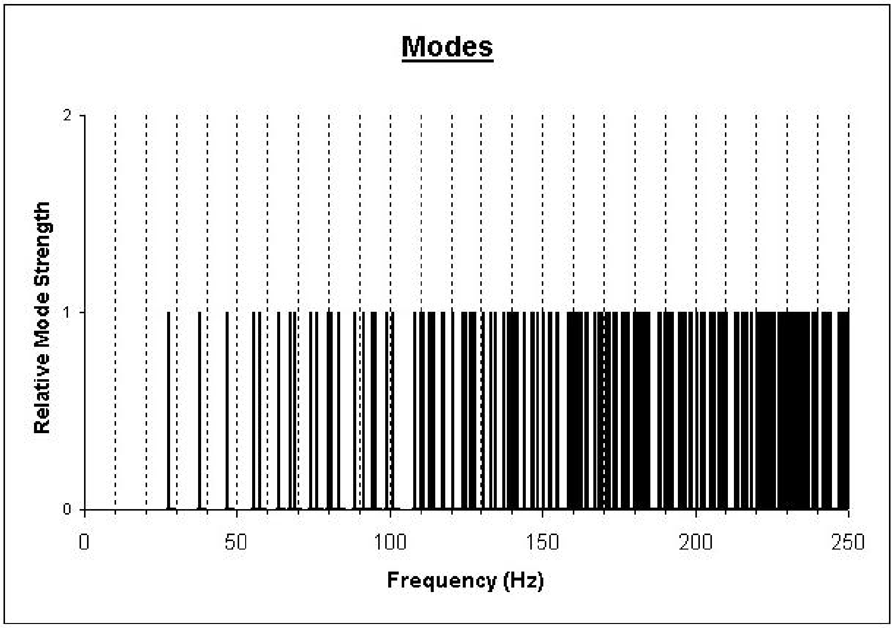

Figure 1 Room Modes for a 6.58m X 4.52m X 3.0 high (BBC Prototype ratios) room.

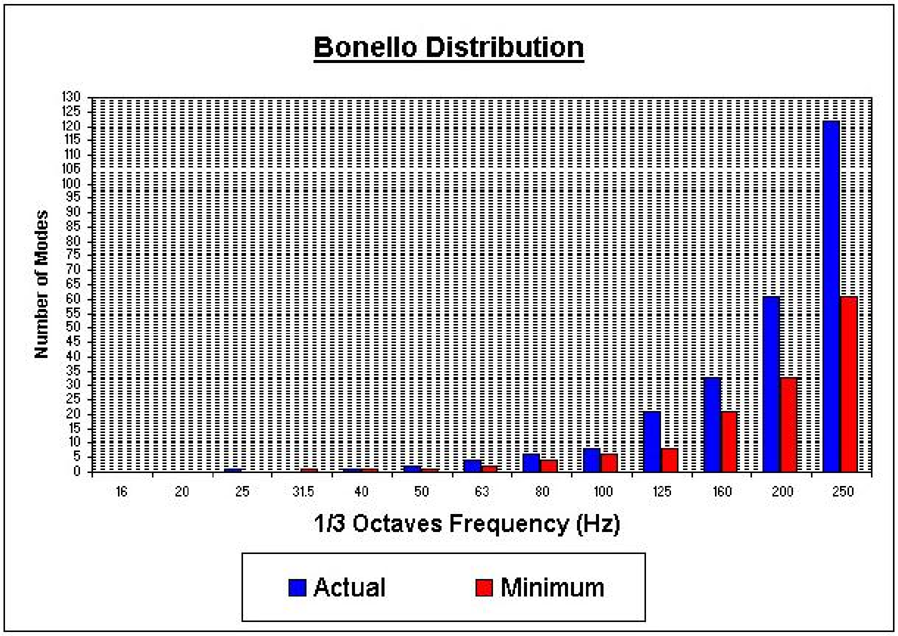

Figure 2 Room Mode Distribution for a 6.58m X 4.52m X 3.0 high (BBC Prototype ratios) room based on the Bonello Criteria.

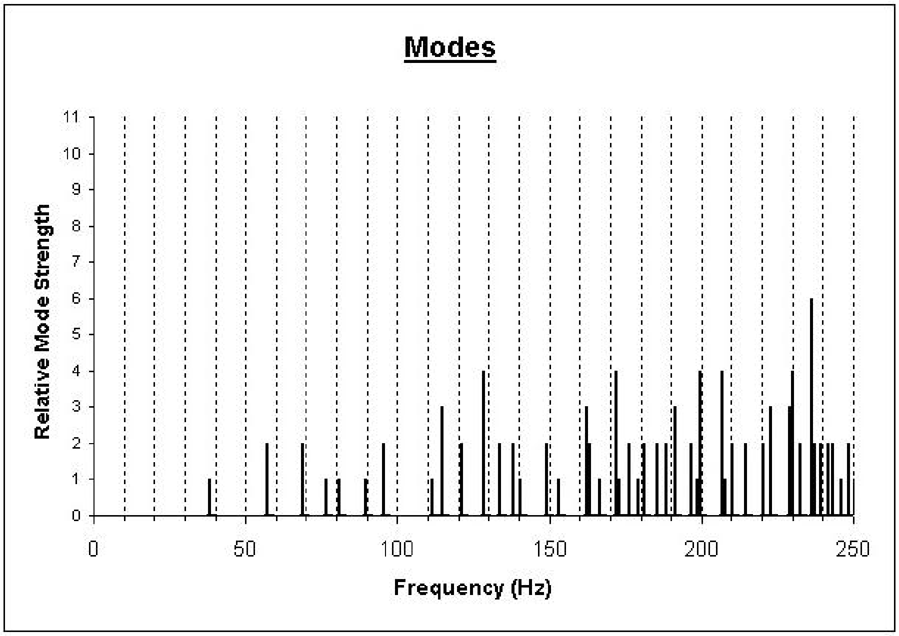

Figure 3 Room Modes for a 3.0m X 4.5m X 3.0 high room.

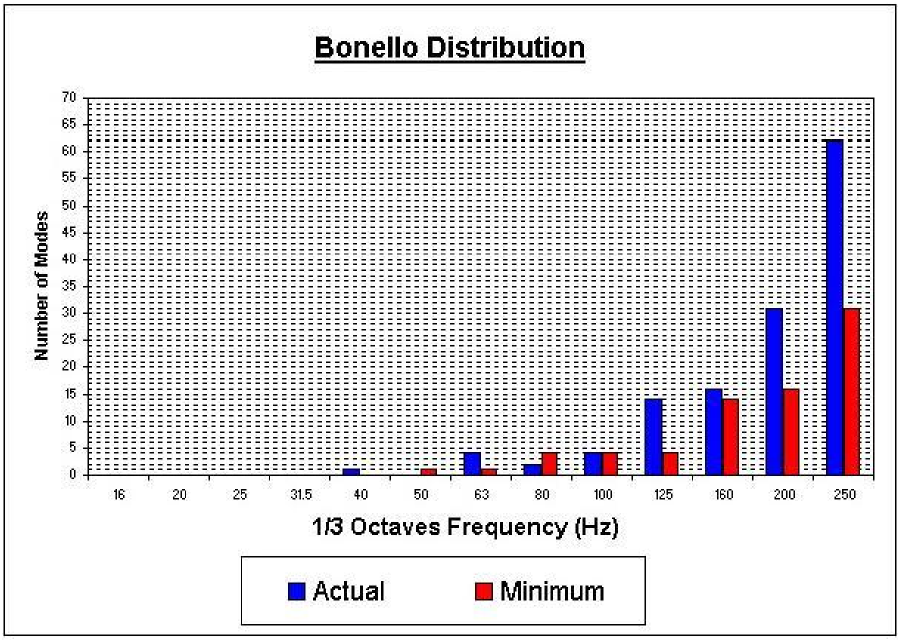

Figure 4 Room Mode Distribution for a 3.0m X 4.5m X 3.0 high room based on the Bonello Criteria.

Figures 1, 2, 3 & 4 above show the results of a room using the ‘BBC Prototype’ ratios and a room of the same height with poorly chosen room dimensions.

Placement of absorptive materials in the small music room

The ‘base building’ construction of a music room in a typical music teaching facility normally comprise of a concrete or timber floor, masonry or plasterboard walls and plasterboard ceiling or concrete soffit. With such a basic finish, one can expect the rooms to be relatively reverberant and sound reflections inside the room to be non-diffusive.

To reduce the reverberation times in a room, acoustically absorptive panels are fixed to the walls and ceilings, and carpets, when required, to the floor to achieve the desired reverberation times. The quantity of the absorptive materials can be calculated using the Sabine equations [Rossing, 1990]. It is recommended that the reverberation times for each octave band (125Hz to 4kHz) be determined using the Sabine equations. When selecting the absorptive materials, it is recommended that the reverberation times in the 250Hz, 500Hz, 1kHz and 2kHz octave bands be kept to within 10% of the target reverberation time. The reverberation time at 125Hz octave band may be higher but not lower than the target reverberation time. The reverberation time at 4kHz octave band may be lower but not higher than the target reverberation time.

The placement of the absorptive materials on the walls should be such that no untreated walls are directly opposite each other, where possible. The reverberation times of the room can be varied by having the absorptive panels mounted on hinges such that the absorptive panels can be swung on their hinges to expose or hide the absorptive finishes. The incorporation of the ability to vary the reverberation times in the room is highly recommended as it will allow the musician to experiment with room acoustics and also allow the room to be used for various musical instruments.

Diffusivity in the small music room

The placement of absorptive over the plasterboard or masonry walls would increase the sound diffusivity in the small music room while reducing the reverberation times. In cases where high diffusivity is required without the introduction of absorption into the space, it is recommended that Schroeder type QRD (quadratic residue diffusers) be introduced into the small room. The design and sizing of Schroeder QRD diffusers are extensively covered in readily available publications [Cox & D'Antonio, 2004].

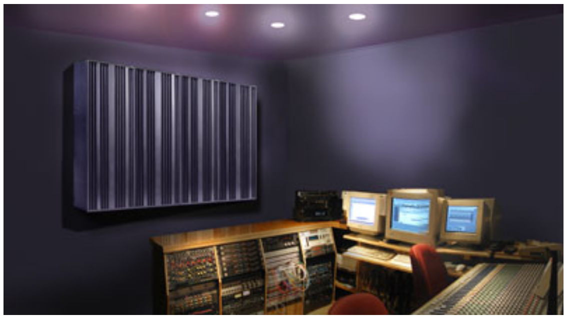

Figure 5 Example of a QRD panel installed in a sound control room. (The QRD panel shown is the 200mm deep commercially available PrimaAcoustic 'Razorblade Quadratic Diffuser' effective from 400Hz and upwards.)

Other commercially available flat panel low profile diffusers are available but their diffusion frequency range would generally be limited. The low profile diffusers can be used in conjunction with the absorptive panels mounted on hinges described above installed on the non- absorptive side of the panel. This will minimise specular reflections when the non-absorptive side of the hinged panel is exposed.

Figure 6 Example of a low profile milled QRD timber panelling suitable for small music rooms but has limited diffusion frequency range.

Summary

The type of musical instruments and the potential loudness of the instrument are to be considered first prior to the design of the small music room. The wall insulation properties (not covered in this paper) to be determined based on the instrument loudness and target background noise. The internal shape and dimensions of the small music room to be determined in conjunction with the project architect. Where rectangular rooms are proposed, it is recommended that the room be checked for room modes coincidence and room modes distribution as recommended by the Bonello criteria. Decide on the desired reverberation times of the music rooms and determine the type and quantity of the absorptive materials to be applied inside the room. It is highly recommended that the ability to vary the reverberation times in the room be incorporated as this will provide a versatile music room and can be used for various musical instruments. It is recommended that diffusive elements be introduced into the room, particularly on the walls to minimise specular reflections and flutter echoes.

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