ACOUSTICAL PERFORMANCE CRITERIA, TREATMENT AND GUIDELINES FOR MULTIFUNCTIONAL SCHOOL GYMNASIA

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ABSTRACT

This paper identifies the acoustical requirements for multifunctional urban school gymnasia and discusses the lack of acoustic guidelines in achieving this objective. The requirement of compromise in determining such a criterion is also discussed in the light of recent ANSI standards. An alternative practical criterion for acceptable reverberation levels is established. The supporting case studies, measurements, analysis and discussions are presented.

SOMMAIRE

Cet article identifie les exigences acoustiques pour les gymnases d'écoles urbaines multifonctionnelles, et discute l'absence présente de critères acoustiques qui seraient requis pour atteindre ces objectifs. Compte tenu de l'avènement récent de nouveaux standards ANSI, il est aussi discuté de la nécessité d'un compromis au cours de la détermination de tels critères. Un critère pratique pour la détermination d'un temps de réverbération acceptable est établi. Les études de cas, prises de données, analyses et discussions pertinentes sont présentées.

1. Introduction

Growing programme demands and space requirements in urban schools require contemporary gymnasia to be multifunctional. Their diverse uses include sporting events, student assemblies, drama production, band concerts, and after school education/daycare to name a few. These uses fall into two broad categories namely, gymnasium use and auditorium use. Acoustical quality requirements for these two categories are unfortunately not quite the same. Gymnasium use suggests a level of acoustical liveliness while auditorium use requires speech intelligibility, which is defined as the percentage of speech material correctly identified by an average, normal-hearing listener working in their first language [1]. Satisfying one purpose degrades the acoustical quality requirement of the other and hence a compromise is vital.

Excessive background noise or reverberation in learning spaces interferes with speech communication and speech intelligibility and hence, presents an acoustical barrier to learning [1, 2]. ANSI standard S12.60-2002 was released in 2002 to address this issue. It focuses on three main acoustical characteristics to improve speech intelligibility in classrooms. These characteristics are background noise, noise isolation, and reverberation.

As stated in the standard itself, it can be effectively used in new school development or major renovation of existing classrooms. In those situations, the acoustical designer has good control over the influencing parameters. Background noise can be controlled effectively by considering the HVAC system, in-class equipment, and outside student activities, etc. at the design stage. Noise isolation is achieved by properly incorporating rated sound transmission class (STC) and impact insulation class (IIC) walls and ceiling assemblies to effectively control air-borne and structure-borne noise. The other parameter that influences the speech intelligibly is the reverberation, which determines the characteristic of sound within the space considered. The reverberation depends on the physical dimensions of the space as well as the acoustical characteristic of materials that form the interior special envelope [6].

In established schools, a complete overhaul of the gymnasia may not be possible because of the economic and time considerations, and hence control over all the influencing acoustical parameters may not be possible. In these circumstances, acoustical treatments are generally considered as a viable alternative. The introduction of varying amounts of acoustically absorptive materials on the interior surfaces of the walls and ceiling is the basic method of acoustical treatment [3]. The placement of the absorptive materials is also important. Absorptive materials are specified by the area of coverage, the acoustical absorption coefficients in octave bands (α) and the Noise Reduction Coefficient (NRC).

The reverberation time (RT60) has traditionally been the key factor in quantifying the acoustic environment [3]. In most teaching spaces, the optimum reverberation should be fairly low (approximately 0.6 s, [2]), so that reflected sound decays rapidly, which allows for better speech conditions. In spaces for sporting or music events, longer reverberation times have been found to be preferred (up to 2.4 s [7]) in-order to provide some excitement and liveliness.

This paper establishes a criterion for acceptable reverberation time limit for multifunctional gymnasia and provides treatment guidelines to achieve this criterion. A few case studies of Greater Toronto Area (GTA) school gymnasia are included.

2 ASSESSMENT CRITERIA

As noted in the literature [3,7] an RT60 at the low end of the range may provide acceptable speech intelligibility in a classroom or lecture room-like setting with students at a relatively close distance, but is likely to detract from the excitement of an athletic competition or the enjoyment of a music recital. Thus, setting an assessment criterion for a gym, which must accommodate varied activities, is not straightforward. Published literature suggests that the optimum range for good speech intelligibility is 0.6 to 2.0 s, (for classroom, lecture hall, small theatre-like settings and 0.6 s being ideal for core learning spaces) while the optimum range for a 'live' space such as auditorium, concert hall, symphonic, etc. is from 1.4 to 2.6 s [2, 3, 6, 7]. Thus a compromise is required for multi-functional gymnasia in order to serve both purposes.

Achieving an RT60 of 2.0 s or less across the speech frequency range would be a reasonable target without significantly compromising speech intelligibility [3]. Whereas, achieving an RT 60 of 1.5 s or more would be considered as a reasonable target without significantly compromising the excitement required for regular gym activities. Slightly longer reverberation times at lower frequencies are acceptable, as this will have little effect on either overall levels or intelligibility. Similarly shorter reverberation at high frequencies are typical due to the large physical volumes and air absorption without degrading speech intelligibility or the quality required for excitement.

In this assessment a reverberation scaling curve generally used for audio engineering [9] was applied to a 1.5 s (at 500Hz) lower limit for speech intelligibility, and a 2.0 s (at 500Hz) upper limit for other regular gym activities. These were used to set a recommended lower and upper limit of the reverberation criteria between frequencies of 125 Hz and 4000 Hz. These limits are shown in Figure 1.

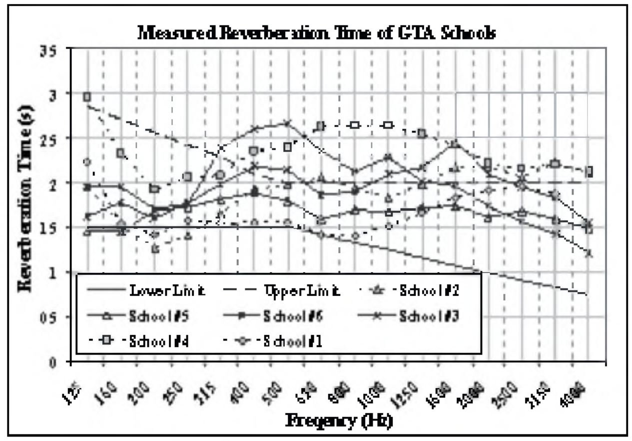

Figure 1: Assessment criteria and Measured Reverberation Time of six GTA Schools

3 SELECTED GYMNASIA AND REVERBERATION TIME MEASUREMENTS

Six GTA school gymnasia were selected based primarily on availability and tested using standard testing procedures. The gymnasia and test methods are described below.

3.1 DESCRIPTION OF THE GYMNASIA AND REVERBERATION MEASUREMENTS

The schools are referred in this paper as School #1, School #2, School #3, School #4, School #5, and School #6. The surface materials on the walls, floors and ceilings of those gymnasia are given in Table 1. School #1 and School #6 have acoustic steel roof decks, School #2 and School #4 have regular (non-acoustic) steel roof decks and School #3 and School #5 have Brand Name Commercial Product (BNCP) roof decks. All schools have acoustically similar floors. School #1, School #3 and School #4 have BNCP wall panels of varying coverage. School #2 and School #6 incorporate sound absorbing masonry units in the walls.

Discussion with school personnel indicated that School #1 and School #5 have recently been improved to a satisfac-

Table 1: Summary of Test Gymnasia – Major Surface Materials

School	Roof	Wall	Floor
School #1	Acoustic steel deck	Painted masonry, acoustic wall panels	Resilient tile on concrete
School #2	Steel deck	Standard painted block, acoustic masonry units (AMU type1), Solid Vinyl	Varnished Hardwood Floor
School #3	"BNCP" deck	Hard brick, painted block, acoustic wall panels.	Varnished Hardwood Floor
School #4	Steel deck	Acoustic wall panels and hardwood panels	Varnished Hardwood Floor
School #5	"BNCP" deck	Standard gypsum drywall	Varnished Hardwood Floor
School #6	Acoustic steel deck	Painted masonry and (AMU type2)	Varnished Hardwood Floor

Note: in addition, other wall materials such as masonry, brick, glass, wood, drywall, etc. were appropriately accounted for along with the area they cover in each wall.

tory level from their original state after acoustical treatment. Other schools' staff indicated that the gymnasia were either recently constructed or have had some remedial treatment but there is still room for improvement. HGC Engineering did not have an opportunity to test those gymnasia before treatment which might have taken place years ago. It was noted that, in most cases, only portions of walls have been acoustically treated. The lack of treatment in the vertical direction (floor and ceiling) can similarly cause poor performance, which will be discussed in detail in the subsequent sections.

3.2 MEASUREMENT METHODOLOGY

Standardized reverberation measurements were conducted in the six school gymnasia pursuant to the methodologies described by ISO 3382-1997, "Acoustics - Measurement of the reverberation time of rooms with reference to other acoustical parameters". The measurements were made using a Brüel & Kjær condenser microphone (Type 4188, S/N 2140820) interfaced to a Hewlett-Packard Dual Channel Real Time Frequency Analyzer (Model 3569A, S/N 3442A00141). The measurement channel was correctly calibrated before and after the measurements using a Brüel & Kjær sound level calibrator (Model 4231, S/N 2170332). Reverberation measurements were performed using the decay rate method based on ASTM C423, as prescribed in E1007.

As discussed by Bradley [8], acoustic measurements are generally done, a) to compare with design criteria and to evaluate whether the design target has been achieved, b) to better understand acoustical phenomena of the space, or c) to diagnose the cause of identified acoustical problems. Accordingly the measurements and data processing will depend on the purpose of the measurements. As the objective here was to compare various gymnasia with a performance criterion and to evaluate/compare their acoustical qualities, hall-average values of the acoustical measurements were used.

Our reverberation measurements at the school gymnasia are also given in Figure 1 along with the criteria.

4 ANALYSIS AND DISCUSSION

Our measurements and subsequent theoretical modeling based on the observed materials and their published absorption properties are shown in Figures 2 to 8. The modeling used Sabine theory, modified to consider three dimensional effects using Fitzroy analysis, appropriate for larger rectangular spaces. It should be noted that in addition to major absorptive materials (Table 1), the analysis also includes general construction materials as noted during the visits, for which data are well established.

RT at 500 Hz has traditionally been used to compare acoustical performance mainly for simplicity. Figure 2 compares RT (at 500 Hz) of each school with criteria. It indicates that schools #1 and # 5 satisfy the criteria while school #2 also marginally satisfies. Schools #3, #4, and #6 exhibits excessive RT, making it only suitable for sporting events.

As indicated in Table 1, School #2 has no significant sound absorptive material except acoustically absorptive slotted masonry units (AMU-type1) on portions of walls. Although this gym has acoustical qualities that are acceptable for sporting activities, speech intelligibility is compromised especially at high frequencies (See Figure 4). As indicated in Table 2, the AMUs do not have significant high frequency absorption, and the area of coverage is insufficient.

School #3 and School #4 exhibited excessive RT in the mid frequency bands, School #3 has absorptive roof deck (BNCP roof deck) covering the whole ceiling area, but it has no significant absorptive material on any of the walls. Although this BNCP roof deck has good high frequency absorption, their absorption coefficients in the mid bands are less than 0.5. Due to these reasons School #3 exhibits some excess in the mid frequency band reverberation. School #4 has a few clustered BNCP wall panels as the only absorptive materials covering approximately 45 % of the wall area. The absorption of these panels is good, but the lack of absorption in the vertical direction and insufficient area of coverage in other directions, results in the excessive reverberation.

School #1 has acoustic roof deck and scattered BNCP acoustic wall panels, covering 11% of the wall area. School #5 has BNCP acoustic roof deck and standard drywall on the walls. Both of these gymnasia exhibit good performance and satisfy the criteria.

School #6 has 31 % of the wall covered by AMUs (type 2) and an acoustic roof deck. Both the AMUs (type 2) and

Table 2: Absorption Coefficients of Selected Materials used in the Analysis

Material	125	250	500	1k	2k	4k	NRC
Steel Roof Deck	0.07	0.30	0.15	0.18	0.15	0.13	0.20
BNCP Roof Deck 3" (School #5- 100% of ceiling)	0.21	0.41	1.00	0.75	1.00	0.97	0.80
BNCP Ceiling 1" x 24" x 24" (School #3 - 100% ceiling)	0.40	0.42	0.35	0.48	0.60	0.93	0.45
BNCP Wall 1" C-20 (School #4 - 45% wall, School #1 - 11% wall)	0.16	0.43	1.00	1.05	0.79	0.98	0.80
30" wide 1.5" flute acoustic deck (School #6 - 100% roof deck)	0.52	0.96	1.05	0.91	0.61	0.30	0.90
Acoustic deck (School #1 - 100% roof deck)	0.33	0.75	1.01	0.92	0.55	0.33	0.80
(AMU type2) (School #6 - 31% wall)	0.57	0.76	0.99	0.94	0.54	0.59	0.80
(AMU type1) (School #2 -25 % wall)	0.20	0.88	0.63	0.65	0.52	0.43	0.65
Revised Coefficients Correlated to Measurements							
Revised Coefficient School #1 Roof Deck	0.25	0.60	0.30	0.30	0.20	0.01	0.35
Revised Coefficient School #6 Roof Deck	0.40	0.30	0.20	0.20	0.14	0.06	0.20

acoustic roof deck have good low frequency absorption but have less high frequency absorption. In addition AMUs (type 2) cover only 31% of the wall area. Due to these reasons, there are relatively high levels of reverberation.

Generally it is noted that four of the theoretical models (School #2, School #3, School #4 and School #5) are in very good agreement with the measurements, while two of the theoretical models (School #1 and School #6) do not correlate well with the measurements. These models predict much lower levels of reverberation than actually measured. This imply that one or more of the materials forming the special envelop absorb less energy than theoretically expected. A sensitive parameter analysis on material coefficients indicates that the roof decks of School #1 and School #6 do not provide as much absorption in situ as would be indicated by published absorption data. Good agreement with measurements is only achieved if significantly lower absorption coefficients are used as shown in Figures 9 and 10.

The discrepancy in material performance is a common phenomenon that can be expected in old/existing schools, mainly due to lack of acoustical consideration in the past, poor maintenance. This indicates improvement to these gymnasia based on the observed and published manufacturers' absorption coefficients will not result in the expected performance. It is possible that the holes in the flutes of the deck

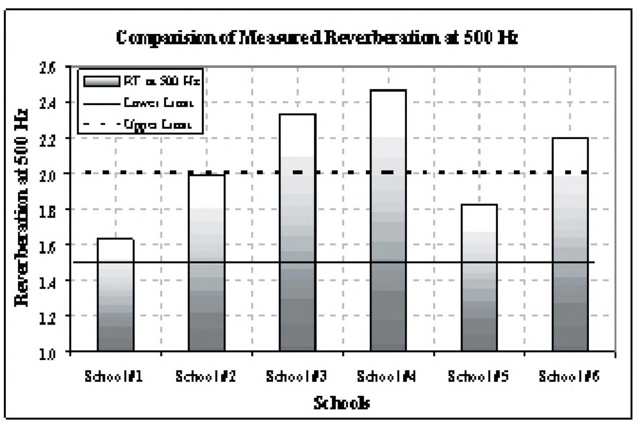

Figure 2: Measured Reverberation Time of six GTA Schools

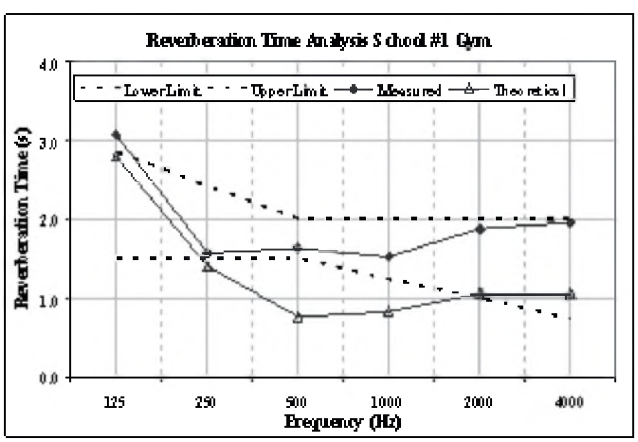

Figure 3: Measured and Theoretical Reverberation Time for School #1 Gym.

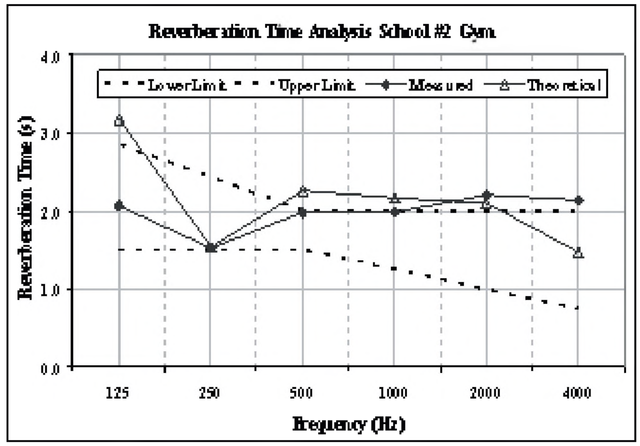

Figure 4: Measured and Theoretical Reverberation Time for School #2 Gym.

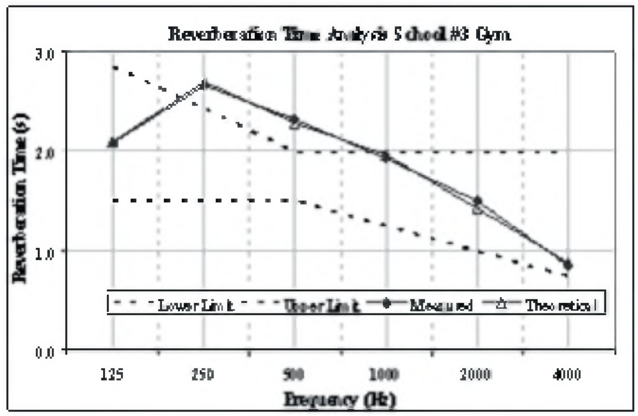

Figure 5: Measured and Theoretical Reverberation Time for School #3 Gym.

may be partially filled with paint or some other aspect of its installation has caused it to absorb less sound than expected, e.g. if the fibreglass insulation strips were not installed in the flutes of the deck, as specified by the manufacturer.

Improvements through renovation can be effective if the required absorption is estimated based on reliable reverberation measurements and suitable material is selected considering the performance in the frequency bands of interest. In addition, the optimal performance also depends on the area of coverage, absorption coefficients and distribution of the

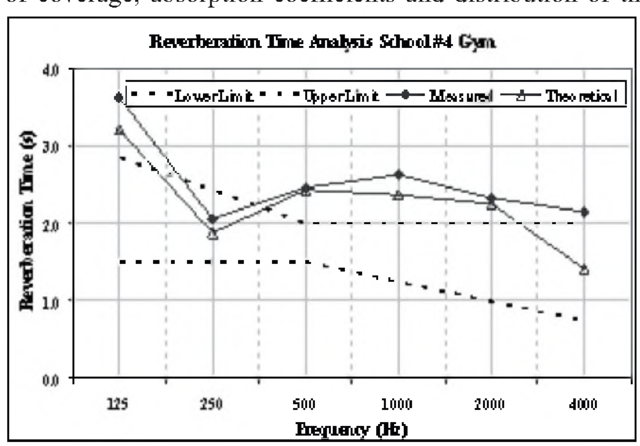

Figure 6: Measured and Theoretical Reverberation Time for School #4 Gym.

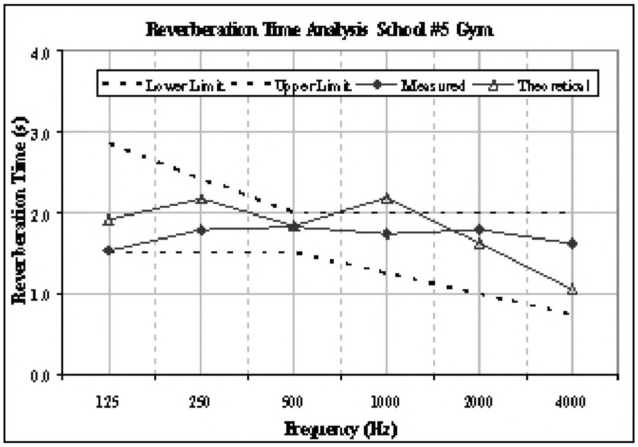

Figure 7: Measured and Theoretical Reverberation Time for School #5 Gym.

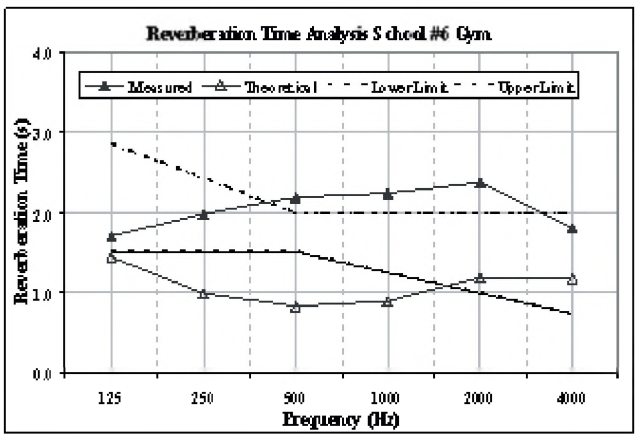

Figure 8: Measured and Theoretical Reverberation Time for School #6 Gym.

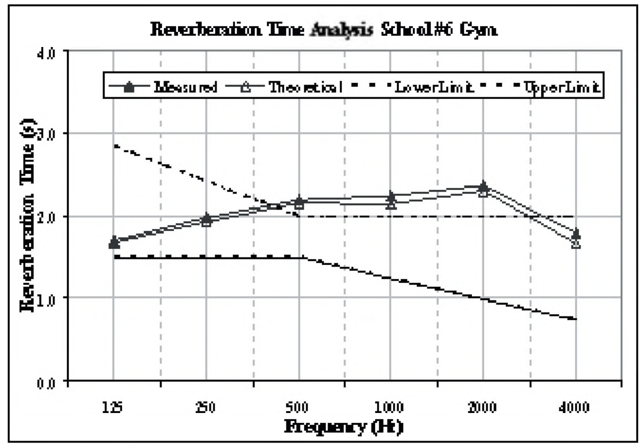

Figure 9: Measured and Theoretical Reverberation Time for School #6 Gym with modified roof absorption coefficients

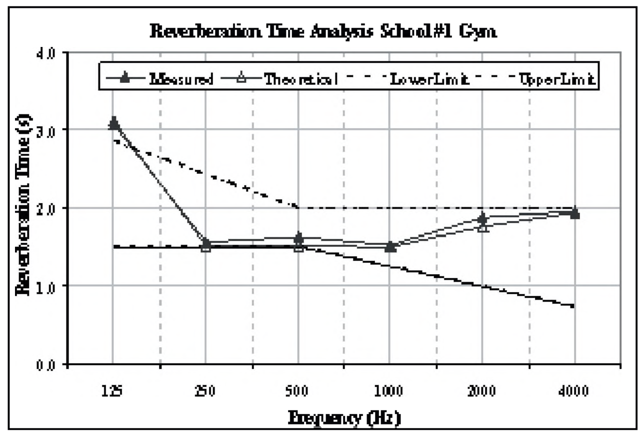

Figure 10: Measured and Theoretical Reverberation Time for School #1 Gym with modified roof absorption coefficients

absorptive materials.

5 ACOUSTIC TREATMENT GUIDELINES

The new ANSI standard does not specify performance criteria for larger enclosed learning spaces such as gymnasia in detail. As discussed previously, converting a gymnasium for multiple use (or multifunctional) is challenging but becoming an essential investment due to growing program and space requirements in most urban schools. Existing gymnasia were generally designed for sporting events, having less acoustical treatments than required for other activities.

In this paper, means of acoustically treating a gymnasium are investigated and discussed. It is assumed that the background sound level generated by HVAC and other sources has been properly controlled incorporating appropriate rated enclosures (wall, window, ceiling assemblies, etc., meeting or exceeding required minimum STC ratings), and silencers, etc. Under these circumstances, the significant issue for a gymnasium to be multi-functional is the reverberation.

Achieving acoustic control equal to the level of a regular classroom is challenging, practically and economically, and in most of the cases, not warranted.

Therefore, in order to achieve good acoustics in a multi-functional gymnasium a five step guideline is proposed:

1. Determine the existing acoustic treatments and measure the levels of reverberation to confirm their performance.
2. Determine the additional absorption required to achieve the criterion given in Section 2
3. Choose the absorptive treatments considering their low, mid and high frequency absorption coefficients and the level of reverberation already present in those frequency bands.
4. Determine an appropriate distribution of material based on acoustical modelling which considers all three directions (generally it is advisable to distribute the materials fairly evenly around the wall and ceiling considering the existing level of abortion in each direction), and confirm the resulting reverberation levels through testing after installation.
5. Ensure that the installation proceeds as per the manufacturer's recommendations or the materials may not achieve the desired level of absorption and excessive reverberation could result.

6 CONCLUSIONS

This paper identifies the acoustical requirements for multi-functional urban school gymnasia and discusses the lack of acoustic guidelines in achieving this objective. The requirement of compromise in determining such a criterion is also discussed in light of recent ANSI standards. Criteria for acceptable reverberation levels are suggested. Through an investigation of a number of gymnasia in the Toronto area, a five step guideline for the successful design of a new facility and the remedial treatment of an existing facility has been developed. The supporting case studies, measurements, analysis and discussions are presented.

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ACKNOWLEDGEMENTS

The authors would like to thank Sound Solutions Ltd, ON, Canada, for sponsoring part of this study. We also would like to extend our sincere gratitude to management staff, and custodians of the schools that have cooperated in the acoustic study. In addition, our sincere gratitude to our colleagues at HGC Engineering especially Alex Lorimer, Rob Stevens and Pierre Godbout for their direct and indirect support for this study.