Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Green Rating Systems and Classroom Acoustic Design

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ABSTRACT

With our increasing sensitivity to the impact of school buildings on the environment worldwide, we have moved towards goals of sustainability and green design. Early implications of 'green design' strategies indicated that design decisions should not be made solely on the basis of sustainability and energy conservation. But rather, these goals need to be pursued in conjunction with building Indoor Environmental Quality (IEQ) issues to ensure that users of these spaces will have a healthy and productive environment. Survey results from occupant satisfaction surveys such as by the Center for the Built Environment (CBE) from the University of California at Berkeley initially showed that 'green ' buildings (LEED® rated) generally did not fare as well as traditional buildings relative to occupant satisfaction with acoustics performance. More recently, the various green rating systems used around the world address acoustics within the frame work of the ratings either as prerequisites, or for enhanced credit points. School buildings are designed and built specifically for the purpose of educating students, where teachers teach and students learn primarily on the basis of verbal and visual teaching cues – obviously a primary goal must be acoustic performance. The acoustic design objective for classrooms must involve designing for speech clarity with architecture, and protecting the speech clarity by ensuring good mechanical system design to limit the background noise. Case studies of classrooms from around the world are presented showing the impact on both the teachers and students based on the acoustic performance of their classrooms.

CLASSROOMS – HEARING & UNDERSTANDING

It should be understood that teaching and learning in the lower grade classrooms is accomplish primarily through a combination of verbal (oral) and visual cues. In some subjects such as with languages, a primary emphasis must be on the pronunciation of words, whereas with other subjects such as mathematics, much of the learning is accomplished from the written words, or numbers in this case. So just hearing a verbal message is not adequate unless it can be heard with sufficient clarity to convey understanding of the message.

Unfortunately, adults are very poor judges of whether the acoustic performance of a classroom for young children will be adequate, yet they are the ones who usually pass judgement on the serviceability of the classrooms.

We need to remind ourselves that young children are in the process of learning the language, and that the local language may not even be the primary language spoken at home, making the understanding of speech even more difficult. And of course, even if the speech would be understandable to normal listeners, many children may have temporary (middle ear congestion) or permanent hearing loss or disabilities, rendering them with a loss in hearing acuity. For these and other reasons it is expected that children will have a more difficult time being able to understand speech even when an adult would have no difficulty doing so.

ACOUSTICS AND UNDERSTANDING

Assuming that the teacher's voice can be heard above the background noise within the classroom, how well can a child understand speech compared to an adult? Figure 1 shows the relationship for the audibility of the voice above the background noise as represented by the Articulation Index [1].

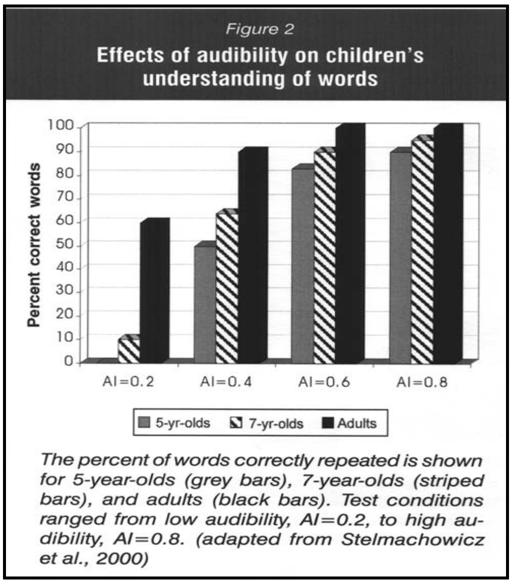


Figure 2

Effects of audibility on children's understanding of words

The percent of words correctly repeated is shown for 5-year-olds (grey bars), 7-year-olds (striped bars), and adults (black bars). Test conditions ranged from low audibility, AI=0.2, to high audibility, AI=0.8. (adapted from Stelmachowicz et al., 2000)

Figure 1. Understanding of speech in noise [2].

The AI is calculated from the relative signal-to-noise ratio, S/N, and is the summation over the frequency bands representative of the range of speech, with appropriate weighting for the frequency contributions to intelligibility of speech. Assuming that the speech sounds have adequate clarity, then high background noise is indicative of a low AI, whereas low background noise will result in a high AI level. Accordingly, as we see in Figure 1, the background noise is a factor that can have a significant effect on the speech intelligibility, and especially so for young listeners. Even with high (AI = 0.8) audibility, a 5 year old will at best understand only 90% of words. And, with low (AI = 0.2) audibility a 5 year old will understand essentially no words, and even an adult will only understand 60% of words for this listening condition.

Now in Figure 2, we can also see that the reverberation time, which is related to the sound clarity within the space, is also a significant factor, especially for children with a non-typical hearing response [3].

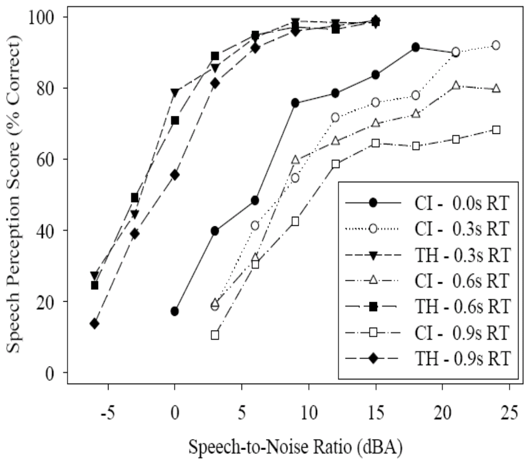


Figure 2: Mean scores plotted as performance/intensity curves for each reverberant time (RT) condition across speech-to-noise ratios for participants with cochlear implants (CI) and those with typical hearing (TH).

The heavy curves on the left side of Figure 2 are for 'typical' listeners, children with no special hearing issues. The light curves on the right side of Figure 2 represent listeners with significant hearing impairment, and the area between would encompass those with lesser degrees of hearing impairment.

It will be noted that for 'typical' listeners, that moderate (0.9 sec) to low (0.3 sec) reverberation time will result in good speech intelligibility if the S/N ratio (audibility) is at least 10 to 15 dBA. However, if the listener has some degree of hearing impairment, the level of reverberation will be the limiting factor irrespective of the S/N even for 20 to 25 dBA. In Figure 2 we see that a hearing impaired student will at best understand less than 70% of words for a room reverberation time of 0.9 seconds, whereas the level of understanding goes up to close to 90% for a reverberation time of 0.3 seconds.

The consequence of these studies is that the characterization of classrooms for speech intelligibility with children in grades K-12 needs to consider two acoustic design factors – both the reverberation time and the background noise.

CLASSROOM ACOUSTIC DESIGN FACTORS

For the reasons previously stated, the normal descriptors used for acoustical design and performance of architectural spaces when addressing speech sounds, such as AI, STI [4], etc. are not directly applicable for all K-12 students, since these were developed on the basis of normal hearing young adults. Accordingly, we will need to address acoustics in K-12 classrooms using reverberation time and background noise levels. The reverberation time is indicative of the speech clarity, and the clarity is determined by the architecture - including classroom size, shape and surface treatments. Unless the architecture is physically changed, the sound clarity will not change – for good or for bad. The background noise on the other hand, is based primarily on the factors of exterior (environmental) noise intrusion, and interior HVAC noise. Noise changes all the time, so listening harder or longer may actually enable some degree of understanding.

BUILDING IEQ & SUSTAINABILITY

When the concept of green buildings and sustainability was first introduced in the United States, the goal was to design/build/operate buildings that were energy efficient and sustainable, which of course was an important goal. Less obvious was the unintended consequence that design decisions based on these 2 factors would have on the acoustic environment within these buildings. Although acoustics is an integral part of the architectural performance, and a significant factor in the building IEQ, the early sustainability rating systems in the USA did not include acoustics in any of the design credits.

Accordingly, the IEQ acoustics tended to suffer in these buildings since design decisions based on factors such as 'natural ventilation' had an unintended consequence of allowing 'outside noise' to become 'inside noise' by simply opening windows facing a busy street, highway, airport, etc.

Post occupancy satisfaction surveys of the type administered by the University of California at Berkeley's Center for the Built Environment indicated that 'green building' at that time did not do particularly well in comparison to standard building – which themselves did not do very well either in terms of occupant satisfaction with acoustics. Typical survey results from 2005 [5] and 2007 [6] are presented in Figures 3, 4, and 5 respectively.

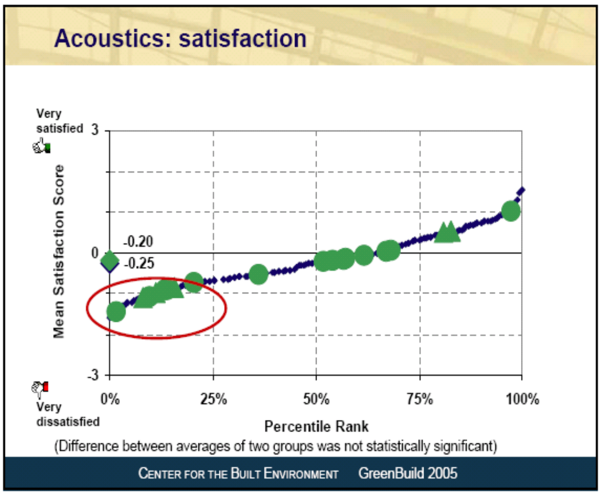


Figure 3. Occupant satisfaction with acoustics in green buildings, relative to other buildings, before LEED credits for acoustic design. [5]

The small blue triangles in Figure 3 are the satisfaction ratings for other buildings whereas the large green circles and triangles are for LEED$^{®}$ and other green (not certified) buildings. You will note that many of the green rated buildings are at or below the 50 percentile in satisfaction level, and that the average satisfaction level for the green buildings is – 0.25 compared to other (normal) buildings that are also negative, but only - 0.20. Obviously, acoustic performance is generally overlooked in most buildings, and in 2005 even more so in green buildings.

Prior to the acknowledgement within the green rating systems that acoustics are an important factor in the occupants perception of the acceptability of the building IEQ, no credits were given for acoustic design, and thus the satisfaction ratings suffered accordingly.

However, green buildings generally delivered on the targeted indoor environmental factors as shown in Figure 4.

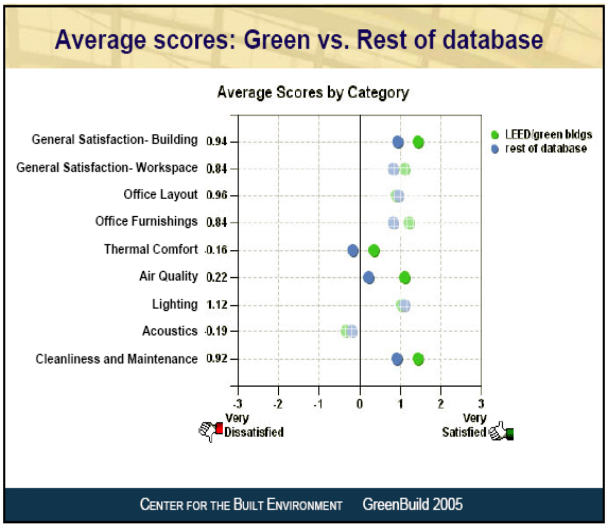


Figure 4. Occupant satisfaction with building IEQ in green buildings relative to other buildings before LEED credits for acoustic design. [5]

Summary results presented in Figure 4 for building IEQ indicate that for those factors typically addressed in green building, e.g. thermal comfort and air quality, the LEED/green buildings did significantly better than the rest. However, for acoustic satisfaction the LEED/green buildings tended to be less satisfactory then the rest, although all buildings did poorly in acoustic satisfaction.

In Figure 5 are presented the scatter of the acoustic satisfaction by building type (other, LEED/green, naturally ventilated) from a 2007 survey. Again the LEED/green buildings tended to be at or below the 50 % level, with a negative average rating of – 0.44 in occupant satisfaction.

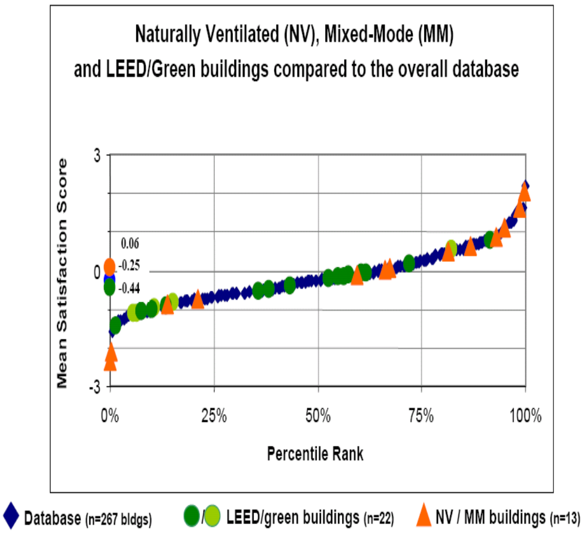


Figure 5. Acoustic satisfaction scores for LEED/Green buildings vs. other building types. [6]

ACOUSTIC DESIGN IN SCHOOLS - ANSI

In 2002 the Acoustical Society of America developed a new American National Standards Institute (ANSI) standard S12.60 Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, which addressed the need for proper acoustic design of classrooms and other learning spaces within K-12 school buildings [7].

These requirements were based on the need for both 1) good architectural design to provide for sound clarity within the classroom, and 2) good mechanical equipment (HVAC) design to ensure that the background noise level will be sufficiently low making it possible to hear the signal above the background.

This standard has since been revised to the current 2 parts, ANSI/ASA S12.60-2010/Part 1 Permanent Schools, and Part 2 Relocatable Classroom Factors. The acoustic requirements for reverberation time and background noise are expressed as shown in Table 1 [8].

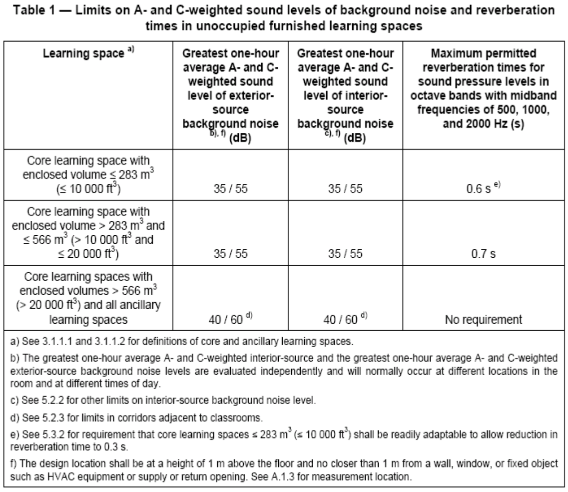


Table 1 — Limits on A- and C-weighted sound levels of background noise and reverberation times in unoccupied furnished learning spaces

Learning space [a)]	Greatest one-hour average A- and C-weighted sound level of exterior-source background noise [b), f)] (dB)	Greatest one-hour average A- and C-weighted sound level of interior-source background noise [c), f)] (dB)	Maximum permitted reverberation times for sound pressure levels in octave bands with midband frequencies of 500, 1000, and 2000 Hz (s)
Core learning space with enclosed volume ≤ 283 m^3 (≤ 10 000 ft^3)	35 / 55	35 / 55	0.6 s [e)]
Core learning space with enclosed volume > 283 m^3 and ≤ 566 m^3 (> 10 000 ft^3 and ≤ 20 000 ft^3)	35 / 55	35 / 55	0.7 s
Core learning spaces with enclosed volumes > 566 m^3 (> 20 000 ft^3) and all ancillary learning spaces	40 / 60 [d)]	40 / 60 [d)]	No requirement

a) See 3.1.1.1 and 3.1.1.2 for definitions of core and ancillary learning spaces.

b) The greatest one-hour average A- and C-weighted interior-source and the greatest one-hour average A- and C-weighted exterior-source background noise levels are evaluated independently and will normally occur at different locations in the room and at different times of day.

c) See 5.2.2 for other limits on interior-source background noise level.

d) See 5.2.3 for limits in corridors adjacent to classrooms.

e) See 5.3.2 for requirement that core learning spaces ≤ 283 m^3 (≤ 10 000 ft^3) shall be readily adaptable to allow reduction in reverberation time to 0.3 s.

f) The design location shall be at a height of 1 m above the floor and no closer than 1 m from a wall, window, or fixed object such as HVAC equipment or supply or return opening. See A.1.3 for measurement location.

Table 1. Acoustic design requirements for Classrooms ANSI/ASA S12.60/Part 1: Permanent Schools.

The maximum acceptable room reverberation time is set in Table 1 at 0.6 seconds for classrooms up to 10,000 cubic foot volume, and 0.7 seconds for those between 10,000 and 20,000 cubic foot volume. The background noise requirement is set for maximum 35 dBA in classrooms up to 20,000 cubic foot volume, with 40 dBA for those that are larger in volume.

It is also required that rooms intended for students with significant levels of impairment or disability be readily adaptable to achieve a reverberation time of 0.3 seconds.

ACOUSTICS & GREEN DESIGN IN SCHOOLS – USA BASED RATINGS

The United States Green Building Council (USGBC) [9] took the requirements of this ANSI/ASA standard as the basis of their development of LEED® for Schools, which was introduced in 2007 with specific acoustic requirements for both prerequisites and enhanced credit points in recognition that acoustics were certainly important in schools. This rating system has since been revised (2009) to include the acoustic requirements stated in Table 2. These requirements are given as a part of the building Indoor Environmental Quality factors ((IEQ), and include a combination of prerequisites and credit points for enhanced acoustic performance.

The Collaborative for High Performance Schools (CHPS) [10] also used the ANSI/ASA standard as a basis for the development of its green rating system, and this is also presented in Table 2. The CHPS criteria do not include requirements for the wall sound transmission loss as provided by ANSI or LEED for Schools.

K–12, Standard Classroom	RT$^{\#}$	Noise, dBA	Wall Insulation
ANSI S12.60	0.6s	35	STC 50
LEED for Schools	0.6s	45/40*	STC 50*
CHPS	0.6s	45/40*/35*	--------
GBI	0.6s*	Mech Design	STC 50*

Table 2. Acoustic design requirements for Classrooms, USA based rating systems.

In Table 2, the * indicates that this requirement is only for enhanced acoustic performance credit points, and not a prerequisite. The 'Mech Design' indicates that this is addressed through prescriptive design approaches for the HVAC equipment.

More recently a new ANSI standard, ANSI/GBI 01-2010 Green Building Assessment Protocol for Commercial Buildings [11] was approved, which addresses schools in a section on Acoustical Comfort, giving enhanced acoustic performance credit points. This standard was developed from the Green Globes environmental design and assessment rating system for new construction. It has features similar to those found in a number of sources including the ANSI/ASA S12.60, and the FGI (Facilities Guideline Institute) Guidelines for the Design and Construction of Healthcare Facilities [12]. In this case, the interior background noise from HVAC equipment is handled by prescriptive design approaches as opposed to stating a resultant noise level in dBA.

ACOUSTICS & GREEN DESIGN IN SCHOOLS – INTERNATIONALLY BASED RATINGS

The BREEAM (BRE Environmental Assessment Method) [13] developed in the United Kingdom (UK) was the first to address acoustics in schools. The acoustic performance requirements were based on Building Bulletin 93, Acoustic Design of Schools - A Design Guide, which provides extensive guidance into the design of schools.

The CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) [14] developed in Japan addresses the acoustic performance in schools with 5 Levels of performance from a standard level (1) up to a high performance level (5). The requirements are both in terms of performance levels such as dBA for background noise, to prescriptive in nature based on design approaches such as countermeasures to take in reducing noise effects.

The Green Star system developed by the GBC Australia (Green Building Council) [15] addresses acoustics in schools with the Green Star – Education rating tool. These requirements are similar to the LEED for Schools requirements.

These are some of the primary internationally based green building rating systems that include acoustic requirements for the design and performance of school facilities, in recognition that good acoustics are necessary for the education of those children in grades K-12.

The acoustic performance requirements for room reverberation time are tabulated in Table 3 as a comparison to those in Table 2 for the USA based rating systems. Values specified in the 'green columns are prerequisites, and * indicates 0.4 s is for students with disabilities, otherwise 0.5 s is acceptable.

	< 10,000 ft^3	< 20,000 ft^3	>20,000 ft^3
ANSI/GBI	0.6 s	0.7 s	< 1.5 s
LEED2009	0.6 s	0.7 s	
CHPS	0.6 s	0.7 s	
	Teaching Spaces - Primary schools		
Green Star	0.4 s to 0.5 s*		
CASBEE	-		
BREEAM	< 0.6 s		

Table 3. Acoustic design requirements for Classroom Reverberation Time (seconds) by room volume, internationally based rating systems.

The acoustic performance requirements for room background noise are tabulated in Table 4 as a comparison to those in Table 2 for the USA based rating systems. Values specified in the 'green columns are prerequisites.

	Prerequisite (required)	Additional Optional Credits				
		1	**2**	**3**	**4**	**5**
ANSI/GBI	-	-	-	-	-	-
LEED2009	< 45 dBA	40 dBA	-	-	-	-
CHPS	< 45 dBA	40 dBA	-	35 dBA	-	-
Green Star	-	35 dBA	-	-	-	-
CASBEE	-	45 dBA	42 dBA	38 dBA	35 dBA	< 35 dBA
BREEAM	-	35 dBA	-	-	-	-

Table 4. Acoustic design requirements for Classroom Background Noise (dBA), internationally based rating systems.

The actual 'value' of the IEQ Acoustic factors within the overall design for green and sustainability are presented in Table 5. This table shows the actual credit points available for acoustic performance at the enhanced performance levels for each of the rating systems taking into consideration the total points available. Table 5 shows that acoustics accounts for between 1% and 8.3% of the available credits for good design/performance depending on the rating system used.

	Total Points	Acoustic Points	Acoustic Value
ANSI/GBI	1000	22	2.2%
LEED2009	100	1	1.0%
CHPS	85	3	3.5%
BREEAM	85	3*	2.5%
CASBEE	20	5*	8.3%
Green Star	146	2	1.4%

Table 5. Acoustic credits as a percent of the overall credits available for sustainable design.

It should, however, be noted that for some of these rating systems, that the acoustic requirements are prerequisites, which means that no 'certification' can be possible without meeting those requirements (see the green colored columns, Tables 3,4).

CLASSROOM ACOUSTICS – CASE STUDIES

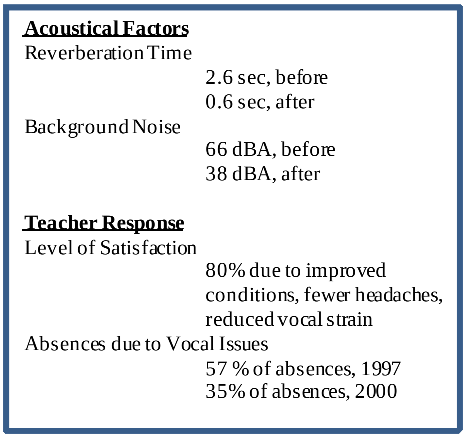
Two typical case studies for classroom architectural interventions that focused on both the reverberation time and the background noise in the classrooms are being presented. In each case the student grades were evaluated (over more than

1 year's time) to look for any academic effect of the acoustical remediations, these being for classrooms that originally suffered from unacceptable acoustics.

Case 1: Classrooms in Santiago, Chile [16]

The first case was for classrooms that were both very reverberant and very noisy. Acoustical treatments were added in the form of a suspended acoustical ceiling, with some wall acoustical treatment also being added to the upper back wall. These were provided to reduce the reverberation time to an acceptable level thus improving the speech clarity in the classroom.

The exterior windows were also improved by addition of a second sheet of glass, spaced out from the existing glass, to improve the window sound transmission loss. This was done to reduce the intrusion of traffic noise, which kept the teachers voice from being adequately heard above the background noise. The objective results of these architectural modifications are presented in Table 6, along with teacher issues.



Acoustical Factors

Reverberation Time	
	2.6 sec, before 0.6 sec, after
Background Noise	
	66 dBA, before 38 dBA, after

Teacher Response

Level of Satisfaction	
	80% due to improved conditions, fewer headaches, reduced vocal strain
Absences due to Vocal Issues	
	57 % of absences, 1997 35% of absences, 2000

Table 6. Acoustic and teacher performance for classrooms before and after architectural remediations.

Additionally, the student's grades were shown to have improved in the classrooms that had been architecturally renovated (blue), Figure 7, compared to those that had not been renovated (red).

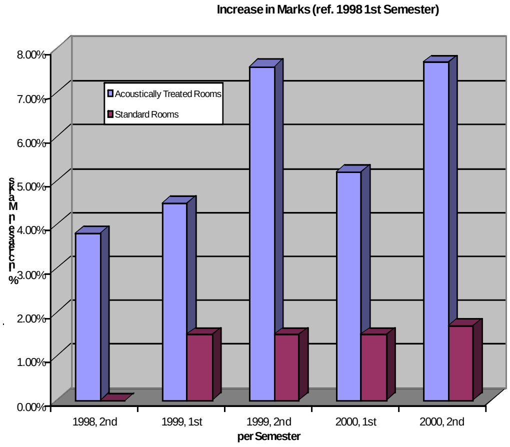


Table 7. Student's performance for classrooms with and without architectural remediations.

In total, there were 52 classrooms, 2 of which had been renovated, and a total of approximately 2000 students of ages 4 - 18 years. Those students in the renovated classrooms had an approximate improvement of 5% in their grades over the 2 years reviewed. This was a parochial school, and the parents funded the full treatment of the remaining rooms at the end of this study as they saw (actually heard) the value of good acoustic design and performance.

Case 2: Classroom in Shanghai, China [17]

The second case was for a classroom in China that was similar in architectural characteristics and acoustical issues to the classroom in Chile. In this case a suspended acoustical ceiling was added to control the reverberation time, and new windows were installed to control the exterior noise intrusion.

The reverberation time was reduced from 1.1 seconds, to 0.4 seconds with the addition of the suspended acoustical ceiling. This was a fourth grade class, and the same students where tracked in the renovated and in a non renovated (control) classroom. Results of student grades are presented in Table 8 showing both mathematics and English language class grades.

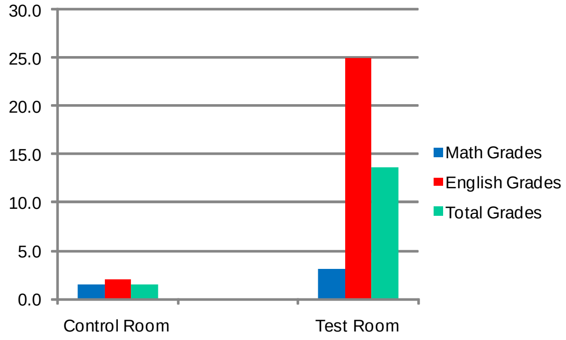


Table 8. Student's performance for classrooms with and without architectural remediations, for both mathematics and English language classes.

Since mathematics is very much a visual learning environment given that most examples are written on the board, it is not so surprising that the mathematics grades only showed a 3% improvement for the treated room. English language classes on the other hand, are a second language for the Chinese students such that good sound clarity is extremely important. Grades were seen to improve by 25% with the combination of clarity and low background noise provided by the treated room.

CONCLUSIONS

It is quite evident that acoustics must be a prime factor in the building IEQ assessment of the functionality of school facilities for grades K through 12. The purpose of a school is for teachers to teach and for students to learn, and much of these activities are centered on oral and visual cues. A combination of speech clarity and audibility above the background noise is essential for students and teachers to fully understand conversations.

The value of good acoustic design has been shown by case studies which indicate that student grades can be increased by as much as 5% to 10% with optimal acoustic design. Occupant satisfaction surveys for building IEQ have indicated that the least satisfactory environmental factor is poor acoustics as opposed to thermal comfort or poor lighting in all buildings.

Early building IEQ survey results indicated that green rated buildings suffered as much or more from poor acoustic comfort, compared to non green buildings most likely because the green rating systems in the USA did not take acoustics into account relative to the standard credits. More recently, many of the green rating systems have recognized that it is not enough to be energy efficient and sustainable, but that all buildings must also be healthy and productive spaces for the occupants as well.

Today most of the green rating systems include acoustic requirements either as prerequisites, and/or between 1% and 8.3% of the available credit points.

This bodes well for the schools of the future, as we are recognizing that IEQ – Acoustics is a major factor in school design and performance, and that both students and teachers can each do their best if they can hear and understand each other.

ACKNOWLEDGEMENTS

The author would like to acknowledge the valuable inputs provided by his colleague Amy Costello, LEED® AP, specifically as relates to the various green building rating systems internationally.

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