Education Acoustics:
An Overview of Issues and Recommendations

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Education Acoustics: An Overview of Issues and Recommendations

1. PURPOSE

This report was written to respond to questions around acceptable acoustical performance for schools, in particular for newly constructed school gymnasiums, music rooms and cafeterias. We have included general information for classrooms as well, however this is not intended to be an exhaustive report on all aspects of educational acoustics.

Questions arose when, during a pre-occupation walk through with Halifax Regional School Board staff, a simple clap test in the gymnasium at the new Sir John A Macdonald High School revealed reverberation of more than 2 seconds, and possibly more than 2.5 seconds. Upon examination of *The Final Report, Pre-Occupation Indoor Air Quality Testing, Western HRM High School, September, 22, 2006* we found that the ambient noise had been tested and passed requirements, but that reverberation had not been assessed. Enviro-Health Consulting was asked to look into the issues around gymnasium acoustics and make recommendations for consideration for possible further examination and correction of acoustics at Sir John A Macdonald High school, and for consideration for future new school design and construction.

2. GENERAL SUMMARY

In general, poor acoustics have the potential to permanently harm hearing and voices of teachers in particular, because they tend to spend their days in the same rooms. Further, research shows that behavioural problems improve, stress and fatigue reduce, and learning is improved when students can hear the teacher clearly.

3. EDUCATIONAL ACOUSTICS

The issues related to ambient noise levels and reverberation in the educational setting can be viewed from two perspectives; the effects on the educator and the effects on the students. The negative effects are different for each and can be reduced through proper management of the educational environment. In some situations, by teaching in poor acoustical environments, educators are risking their health, such as suffering hearing loss, voice damage and non-auditory effects of noise. Children risk lower academic achievement and the non-auditory effects of noise.

3.1 Impact of noise on educators

For the educators, noise levels above acceptable levels increases the risk of vocal abuse. Research has clearly demonstrated that teachers suffer from significantly higher rates of voice disorders, up to 30% greater, than the general public. (*Roy N et. al 1997 and Smith, E. et. al 2004*). A survey of speech language pathologists in New Brunswick that treat voice disorders revealed that as much as 50% of their caseload can be teachers. And these are the severe cases that have had several incidents of vocal strain and for progressively longer periods of time. Generally treatment recommendations by the speech language pathologist would include education on vocal hygiene techniques, periods of vocal rest and voice therapy. The final two recommendations increase the time away from work by the teacher. Due to long wait lists most teachers never actually see a speech language pathologist for an assessment or treatment. One study found that teachers comprise more than 20% of the voice-clinic load which is about five times what would be expected given their prevalence in the workforce (*Titze, IR, Lemke, J and Montequin, D, 1997*). The risk for voice disorders is greater for females than males due to the natural intensity that most women speak. Women speak 3 to 5 dB softer than men. Research has demonstrated the following: (Table 1)

	Female Intensity dBA	Male Intensity dBA
Normal Speech	60-65	65-68
Raised Speech	68-70	70-75
Loud Speech	70-75	75-80

Table 1 *Spengler, JD, et. at 2001 report*

A difference of 3 to 5dB may seem insignificant but with every 3dB increase in intensity sound has doubled. Therefore to increase speech by 3 to 5dB and maintain that level above the background noise can take considerable effort.

Depending on the specialization of the teacher the risk for a work related noise induced hearing loss is present. A noise induced hearing loss is a permanent loss of hearing in the higher frequencies. These frequencies of sound are important for the comprehension of speech and hearing in noisy situations. Research studies have demonstrated this risk is higher for music and physical education teachers. (*Whitehead and Sharpe; Jaing T; and Worksafe BC*)

The task of speaking above a normal level for an extended period of time, as well as being in a noisy situation for and extended period of time has also been linked to excessive fatigue and increased stress levels. These are the non-auditory effects of noise. A more detailed list of the effects can be seen in Table 2. When the acoustics of an environment exceed the recommended levels for the usual activity ascribed for that facility then the risk for the non-auditory effects increases.

3.2 Impact of teacher audibility

The impact of high ambient noise and excessive reverberation has been clearly identified and demonstrated to have a negative impact on the abilities of children in an educational setting. The majority of research has centered on the children's ability in math and literacy as these are easily measured and improvements related to improved acoustics can be re-measured. The following figures illustrate the significant benefits for the students in being able to hear the teacher clearly. The difference is not in the audibility of the speech but in the clarity of the speech. Poor acoustics will mask or cover the high frequency consonants required for speech comprehension. The improved acoustics which should be multi faceted: reduce background noise and reverberation and enhance the teachers' voice through amplification.

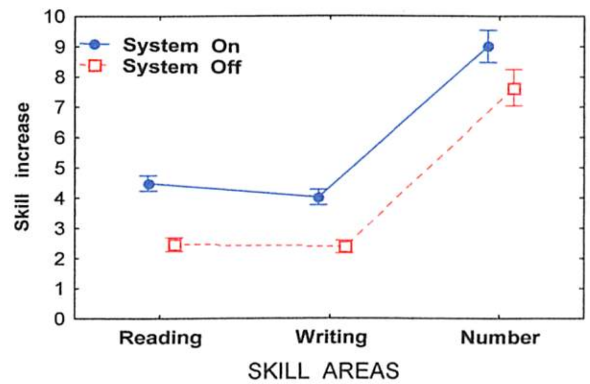


Figure 1 The upper line indicates the level achieved by the classes with amplification in each of the skill areas compared to the un-amplified classes, the lower line. (*Massie, R and Dillon, H*).

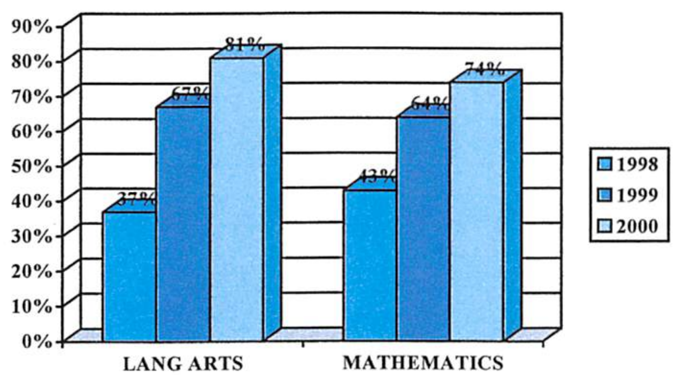
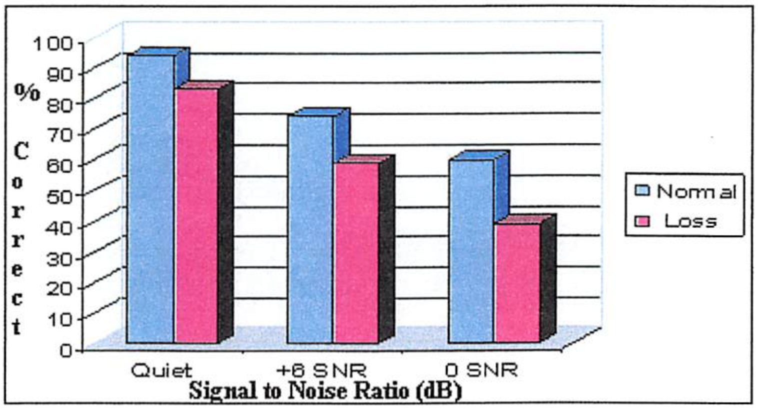


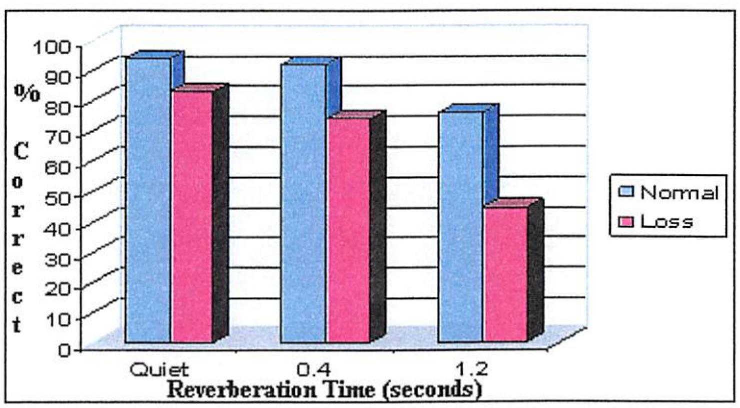
Figure 2 Grade 3 standardised tests in Language Arts and Mathematics in Alberta. Note the significant improvement from 1998 when no sound field amplification was used to the year 2000 where all children were in an amplified class and half of the children had 2 years with classroom amplification. (*Ayukawa, H*)

Figure 3
These figures illustrate the effect of noise, reverberation and noise plus reverberation on speech perception. A group of normal hearing students and students with a hearing loss were assessed in both conditions. In all cases as the acoustics deteriorated the ability to understand speech was negatively affected. The effect was greater on the students with the hearing loss. (*Adapted from Crandell, C.C. and Smaldino, J.J*)

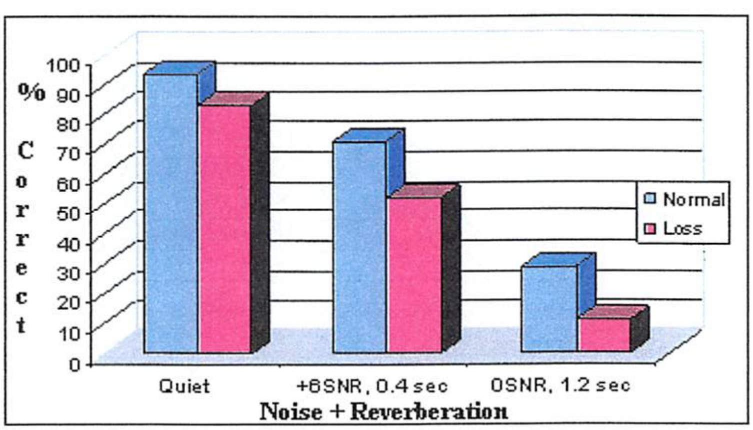
Speech perception in noise.



Speech perception with reverberation



Speech perception in noise plus reverberation



3.3 Classroom Acoustics and Learning Performance

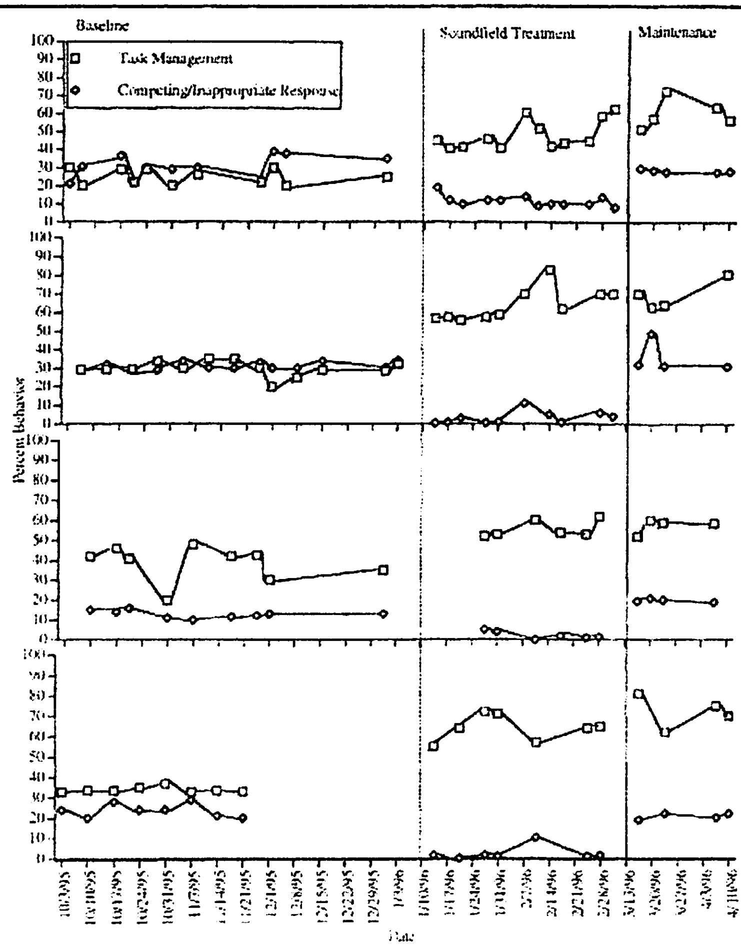
The research has also examined the speech comprehension in a variety of classroom settings and discovered significant differences in ability depending on the acoustics of the classroom. These differences are not limited to just one group of children, such as the hearing impaired, but all children. The negative effect of poor acoustics has it greatest impact on younger children for two reasons. They lack a fully developed auditory system. The auditory system develops gradually after birth and reaches maximum efficiency around age 13-15 in noise and reverberation. The second issue for young children is language level. Young children do not have the ability to make the predictions to fill in the blanks of a message that has been distorted by poor acoustics. The redundancy in language, e.g. the topic, the sentence structure, allows people with well developed language to accurately predict and piece together a message that is not complete. Without the experience of language, children are unable to do this with the same level of accuracy as an adult until approximately 8-10 years old in quiet. The number of children being referred for extra support in the area of literacy should decline given improved acoustics. One very significant note in this summary is the 1990 study looking at 60 classrooms over 5 years, there was close to a 40% reduction in students being placed in programs for the learning disabled with the use of the sound field system. (*The MARRS Project*)

The impact of poor acoustics has a greater impact on children who have reduced hearing ability. The range of 'normal' hearing in adults is between 0 decibels (dB) and 25dB. On the dB scale the larger the number the louder or more intense the sound is. When testing hearing, the audiologist determines the least intense sound an individual can hear at a variety of frequencies or pitches of sound, this is their threshold of hearing. The larger the number for an individual's threshold the louder the sound required for the individual to just barely hear the sound. For children the range of normal hearing has been reduced to 0dB to 15dB. Bess (1998) in researching the educational outcomes of children with minimal sensorineural hearing loss discovered that two thirds of this group had thresholds no worse than 25dB, considered 'normal' for an adult. These children had significantly greater academic difficulty than children with 'normal' hearing. In fact they discovered that on average 37% of the grade 3, 6, and 9 children in the study repeated a grade compared to the rate of less than 10% for the school district. These studies underline the importance of ensuring the teachers' voice is audible to all children.

The measures of being able to hear clearly are not limited to academics, in 1998 Palmer reported on the changes in time on task and inappropriate behaviours. This study found significant improvements in all behaviours measured for all children. Figure 4 is an example of the data presented in this report. The teacher was unaware of which student was being monitored and the teacher's classroom behaviour did not vary significantly throughout the course of the study. The only manipulation performed was the introduction of a soundfield system. These systems boost the teacher's voice throughout the classroom by approximately 6-8dB. This is loud enough for the children to hear the teacher clearly wherever the teacher is standing in the room and not loud enough to be heard by an adjoining classroom. In the Palmer study in the 'Baseline' section of the figure the teacher is wearing the microphone for the sound field system without the system being turned on. In the 'Soundfield Treatment' section the soundfield system was turned on. In the 'Maintenance' section the soundfield system was turned off again. It is easy to see in Figure 4 that significant changes in behaviour occurred immediately with the increased audibility of the teacher.

Figure 4

Percent competing/inappropriate response and task management for four first-grade students. Each graph contains the complete data for one student



Similar research from Alberta revealed the number of call outs (being sent to the office), daydreaming, playing, wandering, talking to other students revealed a significant reduction in these behaviours once the children were able to hear the teacher clearly. The four class average decreased from 147 incidents before amplification to 54.5 incidents after amplification. (*Ayukawa, H*)

Table 1

NON-HEARING LOSS EFFECTS OF NOISE
Excessive noise, whether or not it is intense enough to cause damage to hearing, may still have the potential to cause some other undesirable auditory and non-auditory effects, including physiological and psychological complications. These may include:
• Constriction of blood vessels • Respiration rate increase • Shallow breathing • Muscle tensions increase • Visual focus ability decrease • Increased gastric acidity • Hormonal production increase • Increased coronary disease • Headache • Tension • Anxiety • Irritability • Frustration • Decrease in quantity of work production • Decrease in quality of work production • Decrement in effective emergency response ability
Guidelines for Community Noise, Chapter 3; World Health Organization 1999, edited by Birgitta Berglund , Thomas Lindvall, Dietrich H Schwela
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3.4 Cost Effectiveness

A cost benefit analysis of improving the acoustics, that is, reducing background noise and reducing reverberation, will demonstrate that improving the acoustics will over the long term cost less than providing less expensive but poor acoustically designed rooms.

In addition, research is indicating that enhancement of teacher audibility with sound field amplification brings further educational benefit. The Province of New Brunswick has made the priority to amplify all kindergarten to grade 3 classrooms. They have committed to this process with purchase of 165 sound field systems in 2006. The Miramachi School Board has outfitted all P-3 classrooms with soundfield systems. The benefits to the quality of education are well demonstrated, but improved acoustics and the systems can pay for them selves through reduced time off for teachers due to vocal and stress related illnesses.

4. WHAT NEEDS TO BE DONE

The recommended acoustics, background noise levels and reverberation, vary depending on the most common use of the room. The more instruction that takes place in the room, the lower the level of recommended background noise and reverberation required to ensure an adequate learning environment.

4.1 Reverberation:

A gymnasium needs to have reverberation control if it is used as a teaching space the lower reverberation time improves the noise level and improves comprehension for the students.

The ANSI S12.60-2002 American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools make the following recommendations for gymnasium reverberation

Reverberation control for ancillary and large core learning spaces.

For ancillary spaces, such as corridors, gymnasia, cafeterias and large core learning spaces [volume. 566 m3 (. 20 000 ft3)] sound-absorbing material should be installed to reduce noise caused by the activities of occupants, as well as to control reverberation.
The amount of acoustical treatment will vary widely, but corridors should generally have a total surface area of sound-absorbing material that is not less than 50% of the ceiling area and up to 75% if possible; 75% treatment area is recommended for corridors with high traffic or noisy lockers.
A measure of the sound absorption coefficient of acoustical materials is provided by a single number rating called the noise reduction coefficient (NRC), [C4, C5]. For cafeterias and for large core learning spaces with ceiling heights up to 3.7 m (12 ft), a suspended ceiling with an NRC of 0.70 or higher should be used for the full ceiling area exclusive of the area required for lights and ventilation grilles. Higher NRC ratings should be considered especially for ceiling heights less than 3.7 m. When the ceiling height is greater than 3.7 m (12 ft), especially if greater than 4.6 m (15 ft), a more detailed analysis by experienced personnel may be required to provide adequate control of reverberation. In any event, as suggested by table C.1, wall treatment should be included for such high ceiling rooms. Depending on the amount of wall treatment, the ceiling NRC or treated area might then be reduced when some of the wall area is covered by sound-absorbing material. When permitted within sanitation restrictions, similar acoustical treatment should be employed in food-serving and food-preparation areas.

NOTE: The Noise Reduction Coefficient is equal to the arithmetic mean of the sound absorption coefficients at 250, 500, 1000, and 2000 Hz, rounded to the nearest multiple of 0.05. The NRC of acoustical material should not be used for design or calculation of reverberation time for core learning spaces for purposes of this standard.

For rooms with high ceilings, such as gymnasia, the installation of acoustical treatment on the walls is important to minimize reverberant build-up of noise level. Absence of any acoustical treatment on the walls of high-ceiling rooms can make the material on the ceiling less effective than expected. Guidance is available in the references listed in the bibliography in C5 for many other architectural acoustics design objectives applicable to reverberation control in ancillary spaces and large core learning spaces. These objectives include but are not limited to:

- providing suitable reverberation times for large core learning spaces and dual-purpose ancillary spaces such as a cafeteria also used as an auditorium *(e.g. - Ref. C5, C6, or C7)*, and
- including additional sound-absorbing material on the walls in corridors connecting noisy rooms to quieter areas of the school and in corridors with busy foot traffic or noisy lockers.

[C5] W. Cavanaugh and J. Wiles, Architectural Acoustics Principles and Practice, Wiley, NY, (1999).
[C6] M.D. Egan, Architectural Acoustics, McGraw-Hill, NY (1988), San Francisco, CA (1998).
[C7] R. Coffeen, et al., ''Classroom Acoustics, a resource for creating learning environments with desirable listening conditions,'' Acoustical Society of America, Melville, NY, (August 2000).

The ideal reverberation time varies depending on the source consulted. "Acoustics.com" recommends the following reverberations times for gymnasiums.

"To properly absorb excessive noise in this naturally loud environment to protect the users and minimize distractions and help to ensure the audibility of the PA system."

- Because of the size and the materials typically used in this type of space, a gymnasium can become very reverberant, causing a tremendous build up of noise and difficultly understanding the PA system. Absorptive materials are needed to help control this reverberation. Ceiling and/or wall treatments are necessary. If the space is also used for assemblies, meetings or other activities, reducing the reverberation time is even more critical. The reverberation time needs to be below 2 seconds if you are just concerned with gymnasium noise, but in order to facilitate other activities, a reverberation time of 1-1.5 seconds is ideal. A reverberation time of above 2 seconds is unacceptable.

- Given the activities taking place in a gymnasium, and the equipment used for these activities, durability is a critical factor when choosing acoustic materials.

Natural Research Council Canada recommends reverberation time of 1.0 seconds for gymnasia. (*Warnock. A.C.C*) The closer the reverberation time is to the recommended level of 0.7 seconds for classrooms the better the comprehension of speech by the students. The slightly longer reverberation time is allowable in this situation as it aids in speech transmission over longer distances. The gymnasium is larger than the typical classroom therefore if too much of the speech signal is absorbed then the teacher would need to increase their speaking volume to project their voice that extra distance.

4.2 Ambient Noise:

The ideal ambient noise level for a gymnasium also varies depending which reference was used to assess the noise level. Some recommend using dBA and dBC measures. Others recommend using Noise Criteria (NC) or Room Criteria (RC) curves or a modified version of these curves Balanced Noise Criteria curves of RC Mark II. The final four use specific intensities measured at specific frequencies to determine whether the ambient noise level meets or exceeds the recommended value for the given space.

- NC (also known as NCB, or balanced noise curves): Noise value is based on ANSI standard S12.2-1995 (ASA 115-1995) Criteria for Evaluating Room Noise. It uses ANSI Class 1 octave-band filters to divide the sound spectrum into 9 octave bands, measuring the SPL level of each band. Then, the results are compared to a table of values defined in the specification. The table lists noise criteria numbers by row, with each row having values defined for each octave band. The NC band is defined as the lowest band number for which none of the octave-band SPL values for the row are exceeded.
- RC (Room Criteria): Noise based on the same ANSI standard, but with a different table of values primarily to rate noise in offices. This system was not intended for use in very quiet spaces below RC 25. Typically, RC is used in evaluating HVAC systems, while NC is used for more general purposes, including motion picture theatre spaces and offices. (*Sencore, Inc.*)

The NCB and RC Mark II have extended the frequency range from the older NC and RC curves. They also offer qualifiers to indicate the quality of the listening environment. In a personal communication from one of the top researchers in acoustics and education, Dr. Joseph Smaldino, he recommended

> "It would be best if you could construct an NCB curve for the room" and "You might also want to look at the Speech Interference Level which is an average of the sound level at .5, 1, 2, 4 KHz to get an idea of the effects of the sound on speech per se. Often the very low frequencies do not directly interfere with speech but do contribute to the annoyance of the sound (which in my mind is just as bad)...one fatigues more easily when listening to an annoying sound"

Acoustics.com recommends the following noise level.

> Even if everything else is controlled perfectly, the space might be negatively impacted if the background noise (e.g. HVAC system) is too loud. To help protect your design, the NC level should not exceed 35 to 45 (when used only as a gymnasium), 35 to 40 (when used only as a multipurpose room). When specifying NC, specify an actual rating, such as NC 20, rather than a range, such as NC 20-30. Although specifying a lower number will ensure minimal background noise, it might be cost prohibitive to achieve. Be realistic about the amount of acceptable noise and the project's budget when specifying an NC level.

The single dBA ambient noise level is consistent across many resources. For a multipurpose gymnasium 40dBA is the maximum intensity.

The ANSI S12.60-2002 standard recommends 40dBA or less for the ambient noise level. This is measured in an unoccupied gymnasium. The standard recommends performing dBA and dBC readings to determine if excessive low frequency noise is present. Low frequency noise will mask or interfere with speech to a greater degree than high frequency noise. Low frequency noise also is more prevalent due to mechanical ventilation systems, fluorescent lighting in buildings. Low frequencies due to their physical nature transmit easier through walls; therefore classroom to classroom noise transmission can be an issue. Other common sources that are external to the school are traffic noise and aircraft flyover noise.

NRC Canada recommends between 40 and 45dBA for gymnasiums.

The benefit of frequency specific analysis is that the low frequency noise, which would not be detected by the single value assessment i.e.dBA, can be assessed and proper remediation to reduce these sounds if necessary to the acceptable levels can be developed.

5. RECOMMENDATIONS FOR ASSESSING THE AMBIENT NOISE AND REVERBERATION IN SCHOOLS

These recommendations represent the methods for assessing acoustics for teaching spaces.

Ambient noise

Recommendation 1. The current method employed by the Department of Transportation and Public Works for determining the ambient or background noise in new schools is satisfactory as described in the Western HRM High School, September 22, 2006 post occupational testing report. However, the standard they use to assess whether the noise level exceeds acceptable levels should be changed to the NCB. The NCB method takes into consideration the tonal quality of the sound, low frequency rumble and high frequency hiss. The NCB method is also recognised by the ANSI standard S12.2-1995. The RC Mark II is reported to need more research to correlate this criterion to actual subjective perception. (*Wang, LM*)

Recommendation 2. The use of an octave band analyzer or digital recording and spectrum analysis of the frequency content of the ambient noise levels should be carried out prior to occupancy. This should be performed during the daytime and night time on a weekday, Monday to Friday, to determine the level of noise contribution from the HVAC versus external sounds entering the building.

Recommendation 3. A sample of classrooms shall be assessed for noise levels along with all music rooms, gymnasia, and cafeteria. Classrooms without acoustic ceiling tiles have the potential to have excessive noise due to the reduced quantity of sound absorbing material.

Recommendation 4. If cafeteria are to be used as multipurpose rooms then they shall be assessed the same as the music room and gymnasia.

Reverberation

Recommendation 5. When the facility is designed the architect predicts the reverberation time (RT) based on the dimensions of the space as well as the materials used to construct the space. Following the building of the facility the RT should be validated. Reverberation will affect the effort required for effective communication for all occupants of the room, and therefore the educational processes. The reverberation assessment should be carried out using a broad spectrum random noise such as a starter pistol or popping of a balloon. The noise created should be recorded and the RT60 determined. The RT60 is a measure of how long it takes a sound to be reduced from its peak value by 60dB. The RT60 should be determined at several locations and averaged together. The RT60 should be measured and calculated for 500Hz, 1000Hz and 2000Hz.

Dosimetry

Recommendation 6. Dosimetry will be carried out on all music and physical education teachers to determine if they are at risk for a work related noise induced hearing loss. Dosimetry is a special-purpose sound level meter that has the microphone affixed near ear level adjacent to the wearer's ear. When there are significant fluctuations in the noise levels the dosimeter is essential in measuring the risk for excessive noise exposure. The dosimeter computes two important values:

> **The "loudness equivalent or Leq"**, which is an average equivalent value, which can be interpreted as "the amount of sound intensity (loudness) experienced over

time. The average of which is the same as if the employee had been exposed to that one intensity value over the entire work day." This measurement relates to an 8-hour workday. The Leq values can easily be compared to the Nova Scotia Department of Labour threshold limit values for compliance.

The "dose", the Nova Scotia Department of Labour threshold limit values list the maximum period of time, in hours and minutes, for exposure to sounds of specific intensities. When an employee reaches that maximum exposure intensity for the given time, the dose is rated at 100%. In assessing a dose reading, it is the percentage of sound the employee has actually received; if that dose exceeds 100%, the employee has been exposed to more noise than the Occupational Health and Safety law allows.

6. SPECIFIC TARGETS

Due to conditions special to learning environments, we recommend using the following acoustic parameters.

	Gymnasium	Music Room	Classroom
Reverberation Time	1.0 seconds	0.5-1.0 seconds	0.6 - 0.7 seconds
Noise Criteria	NC 40	NC 30	NC 35

Note: The variability in reverberation time is accounted for by the size of the room. The larger the room the greater the reverberation time allowed. For the music rooms the volume of the room needs to be considered in construction with a minimum of 17 cubic meters allowed per student.

7. CONCLUSION

Due to the clear evidence of the importance of acoustics on educational outcomes and safe work environments in schools. It is critical to provide educators with facilities with acceptable acoustical performance to ensure a safe and healthy work environment that enables learning.

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