Classroom Acoustics - A New Zealand Perspective

Principal Authors: Joanne Valentine – Marshall Day Acoustics
Oriole Wilson – National Audiology Centre

Other Authors: Miklin Halstead[1], George Dodd[1], Ken McGunnigle[2], AnneHellier[3], John Wood[3]

Acoustics Research Centre, University of Auckland[1], Prendos NZ Ltd[2], Specialist Education Services, Ministry of Education[3].

Abstract:

This paper presents the findings of a research project into the acoustic characteristics of New Zealand primary school classrooms. The study was sparked by a surge of complaints relating to the acoustic properties of relocatable classrooms.

The project is currently being carried out by a multidisciplinary team of professionals who have a strong belief that good acoustics should be one of the prime design considerations for new classrooms.

Classroom listening environments in primary schools have been investigated using teacher survey questionnaires, speech perception tests in live and simulated background noise, day-long recordings of classroom noise levels, and measurements of clarity and reverberation time.

The survey identified classrooms that were rated by teachers as either good or poor acoustically. Twelve of these rooms have been investigated in detail. The rooms that were identified by teachers as being poor acoustically have been modified with the addition of acoustic ceiling tiles and the measurements repeated. A follow-up survey reveals that teachers and pupils are enthusiastic about the improvements. Comments include: less noise, reduced frustration, better hearing, more on-task behaviour and the ability to successfully work at different tasks in small groups.

The preliminary results of the research are presented together with practical and affordable building design recommendations for making classrooms acoustically suitable for their purpose.

Introduction

This paper presents the preliminary findings of a research project into the acoustics of New Zealand primary school classrooms. The study was sparked by a surge of complaints in the media about the acoustics of relocatable classrooms. This has also coincided with overseas concerns and activity (especially in U.K. and U.S.A.) particularly with respect to “Access” for mainstreamed hearing impaired pupils.

Many new classrooms in New Zealand are constructed as “relocatables” or “pre-fabs”. These rooms are of lightweight (timber frame) construction, and can be moved when the demographics of an area change and the number of rooms required on a school site changes. They are built to Ministry of Education specifications and the design has varied over the years. A recent widely used design has given rise to a number of complaints from educators about the design’s acoustic characteristics. Complaints had been received by the teacher advisors in our team, particularly with respect to the ability of hearing impaired children to function in these rooms.

The Ministry of Education’s Health and Safety Code of Practice for State Schools(1993) outlines requirements for egress, lighting, heating and ventilation but does not include acoustic standards for classrooms.

The project team (listed above) share a strong belief that good acoustics should be a prime design consideration for all new classrooms.

The Oticon Foundation has funded the project. The Oticon Foundation is a charitable trust that provides grants to projects that increase awareness and knowledge about hearing loss.

The aims of the project were:

- to identify classrooms with good and poor acoustics
- to investigate these in detail
- to come up with practical and affordable building design recommendations to optimise the acoustics of primary school classrooms
- to make the results of the study widely available to the Ministry of Education, architects, designers, educators and the general public.
- to raise the awareness of the importance of good acoustics in NZ classrooms for both normal hearing and hearing impaired children.

Project Approach

1. Survey Questionnaire.

A survey questionnaire was administered to 120 teachers in seven schools throughout wider Auckland region. The survey was developed with the help of three architectural acoustics masters students from the University of Auckland. The survey was given an initial test at an Auckland primary school, and then reworked to better serve the aims of the project. Six schools were initially selected for the study, but an additional school was surveyed when one of the schools had no rooms that were subjectively rated as acoustically “poor”. The schools selected covered the full socio-economic range from Decile 0 to Decile 10, and each school had a small number of hearing impaired students. The overall response rate to the survey was 93%.

2. Building Survey.

A plan of each school was obtained. The siting, dimensions, surface finishes and construction materials were recorded on standard forms for each room, in addition to photographic records of the interior and exterior, for correlation with the survey questionnaires.

3. Selection of Test Rooms for Detailed Study.

The questionnaires in conjunction with the building surveys were used to identify “test” rooms for further detailed investigation. The selection of the test rooms was made on the basis of:

- The teachers’ answer to question 3 of the questionnaire: “How do you rate your classroom listening environment?”
- Whether rooms of the same design in that school had a similar rating for question 3
- The age of the children in the room. For speech testing purposes the children had to be between 8 and 11 years old

Twelve rooms were selected, two from each school, one of which was identified by teachers as acoustically good (or v. good) and the other as acoustically poor (or v. poor).

4. Detailed Investigations/Objective Measurements

Detailed investigations included speech perception tests in live and simulated background noise for both normal hearing and hearing impaired children, measurements of acoustic parameters e.g. reverberation time and clarity, and recordings of classrooms noise levels over an entire day.

Speech Perception Tests

Four normal-hearing children were selected in each classroom and 1-3 hearing impaired students in each school, for the speech testing. The speech testing was carried out under two conditions:

- Using recorded classroom babble as background noise, set at a signal to noise ratio of 0 dB
- In live background noise with the remainder of the class working on an activity sheet in pairs.

The speech material used was the BKB sentence test. The test material consists of 21 lists of 16 sentences, containing 50 key words in each list. Each child was presented with one sentence list.

A more detailed description of the test method is included in Appendix One – Speech Testing Experimental Method, Page 15.

Reverberation Time and Clarity Measurements

Reverberation time and clarity measurements were carried out in the twelve test rooms in both occupied and unoccupied conditions, using the University of Auckland room acoustics measurement equipment. The results were analysed with the MIDAS room acoustics software developed by the University of Auckland and the University of Le Mans.

Day Long Recordings

In 10 of the 12 classrooms a "day in the life" of the classroom was recorded. Two microphones were used; one near the front of the room close to the teachers desk and one towards the rear of the room. These were suspended from the roof trusses where possible (at a height of approximately 2m from the floor), and mounted on microphone stands (1.5m from the floor) when this was not possible. The exact position varied between classrooms depending on the furniture layout and the need to position the equipment in secure and convenient locations. In most cases the microphones were connected to a DAT recorder but in a few of the rooms an analogue system was used. A calibration tone was recorded at the start of the day for each microphone. Teachers and children were instructed to ignore the equipment and to carry on "as usual".

5. Room Modifications

Based on the analysis of the detailed measurements for the good versus poor rooms, the six rooms that were rated as acoustically poor were modified by the installation of selected acoustic ceiling tiles.

6. Repeat Measurements/Follow-up Questionnaire.

The speech testing, measurements of acoustic parameters, and day-long recordings were repeated in the modified rooms. A follow-up teacher survey was carried out.

Survey Questionnaire Findings

Teaching Style

One of the key findings highlighted by the Survey Questionnaire is the dramatic change in teaching style that has occurred in recent years. The traditional lecture-style teaching that today's adults experienced as children has been replaced with mat work and group work.

Figure 1 shows that the main teaching style of the teachers surveyed is group work (38% of teaching time on average) followed by mat work (31%). Lecture-style communication accounts for only 12% of teaching time.

The teaching style is a dynamic one with teachers spending a large part of their day walking around. 71% of the teachers surveyed described "walking around" as their usual position in the classroom. See Figure 2 below.

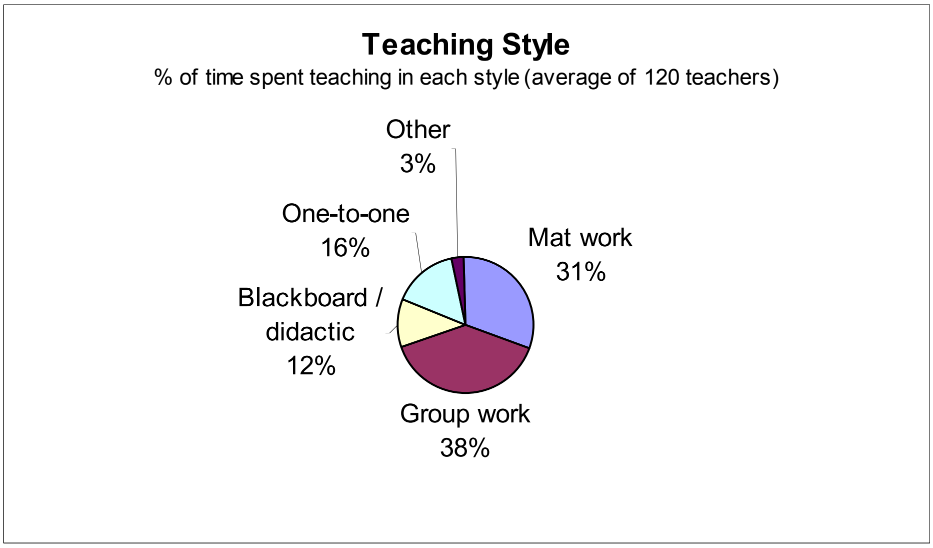


Figure 1: The proportion of time teachers spend teaching in each style

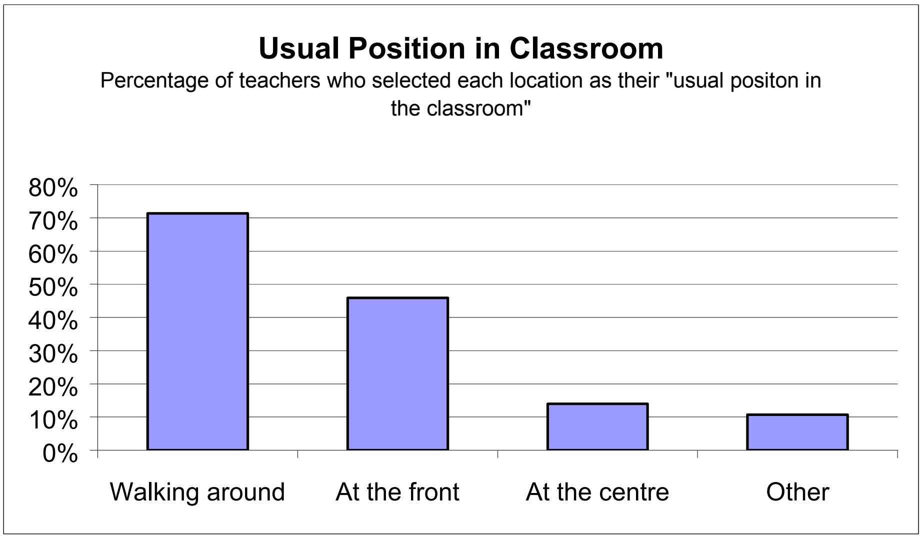


Figure 2: Location selected by teachers as their "usual position in the classroom" (in response to the question "Where is your usual location in the classroom?")

NZ primary school teachers are recognised internationally for their innovative teaching methods. A high emphasis is put on "incidental learning" i.e. children learning from each other. Children are encouraged to communicate with each other, and because of this noise levels in classrooms are undoubtedly higher than in the past.

Noise

Classrooms are noisy places. 71% of the teachers surveyed reported that noise generated within the classroom is a problem.

Many teachers commented that noise is at a level that significantly increases stress and irritability for teachers. 35% of the teachers complained that the level that they needed to speak at strained their voice.

61 % of teachers reported that most or all of the noise created inside the classroom is student generated. Computers were the most commonly identified other source of noise generated within the classroom.

86% of the teachers surveyed have problems with noise generated outside the classroom eg. from nearby classrooms, corridors, decks, sports fields, lawnmowers, and road traffic noise. Figure 3 shows the percentage of concerned teachers who identified the above noise sources as being a problem. Rain noise, and toilets and hand dryers from cloakrooms, were commonly noted in the "other" noise source category.

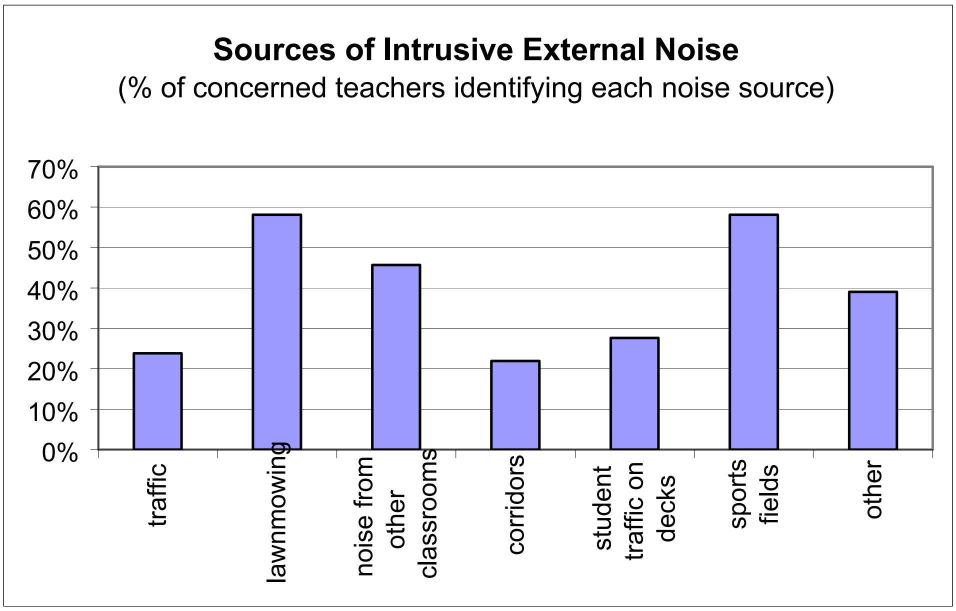


Figure 3: External noise sources identified as a problem

The combined effects of New Zealand's interactive teaching style and our reliance on opening windows for ventilation, result in high noise levels in the classroom. This results in difficult listening conditions for all children but especially disadvantages hearing impaired children. One teacher commented that a hearing impaired child in her class was unable to hear other children speaking and sharing their work, and that the child had to be taken out onto the deck to be given instructions.

Vision Hearing Screening Services screens the hearing of all new entrant children. The national average failure rate in 1998/99 was 7.7% overall, 13.9% for Maori children and 13.8% for Pacific Island children. A "fail" means children have failed two hearing tests carried out 16 weeks apart.

Correlation with Building Survey

Four main classroom types were identified in the building survey. These were:

- Relocatable classrooms constructed from lightweight materials (timber framing, raised particle board floor) with an acoustically-hard, pitched ceiling following the line of the roof (central ridge and 15 degree pitch)
- Relocatable classrooms (lightweight construction) with softboard acoustic ceiling tiles fixed to the underside of the trusses, forming a horizontal ceiling plane
- The older style permanent classrooms with a concrete on grade floor construction and softboard acoustic ceiling tiles (perforated softboard) forming a horizontal ceiling.
- The older style permanent classrooms with a concrete on grade floor construction and an acoustically hard, flat ceiling (plasterboard or fibrecement)

Table 1 below presents the range of building types in the survey, and the teachers' subjective ratings of the classroom listening environment for each classroom type.

Definition of categories of classroom in the study							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Type	Relocatable	Relocatable	Permanent	Permanent	Permanent	Permanent	Open Plan
Ceiling	hard	acoustic	acoustic	hard	acoustic	hard	acoustic
Floor Construction	timber	timber	concrete	concrete	timber	timber	concrete
Floor covering	carpet	carpet	carpet	carpet	carpet	carpet	carpet
Walls-overlay	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard
Number of Responses (subjective rating of classroom listening environment) in each category							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Subjective Rating							
Good or Very Good	2	23	19	3	5	0	0
Acceptable	7	9	15	8	0	0	1
Poor or Very Poor	12	2	3	4	1	3	2
Total number rooms of this type	21	34	37*	15	6	3	3

* includes 8 partially open plan classrooms (6 rated as "acceptable", 2 rated as "very good")

Table 1: Teachers subjective ratings for different building types

Classrooms that were identified as having good acoustics were generally permanent older style classrooms with masonry floors and softboard acoustic ceiling tiles (Type 3), permanent classrooms with timber floors and softboard acoustic ceiling tiles (Type 5), or relocatable classrooms with a suspended softboard acoustic tile ceiling (Type 2). The classrooms identified as having poor acoustics were generally relocatable type classrooms with acoustically hard pitched ceilings, or permanent classrooms of a similar design. Permanent classrooms with hard ceilings and concrete floors were mainly regarded as acceptable. Figures 4-7 below show the teachers' subjective ratings for each of the main classroom types.

We speculate that the poor subjective ratings for relocatables with hard ceilings result from a combination of a hard pitched ceiling that is slightly sound-focussing and floor noise associated with the timber floors and attached timber decks. Floor noise and student traffic on decks were identified as problems in the extra comments section of many of the questionnaires relating to relocatable classrooms.

Overall, there is a strong correlation across all cellular classroom types between acoustic ceiling tiles and good subjective ratings of the classroom listening environment. 66% of classrooms with acoustic tile ceilings were rated as good or very good. See Figure 8 below.

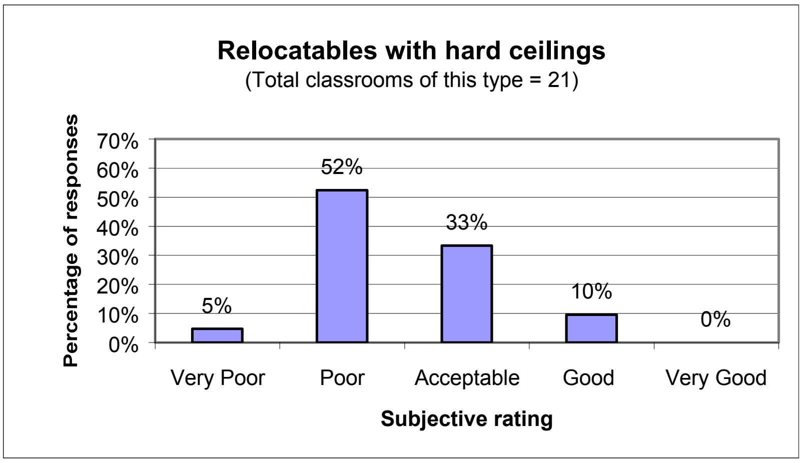


Figure 4: Subjective ratings for relocatables with hard ceilings

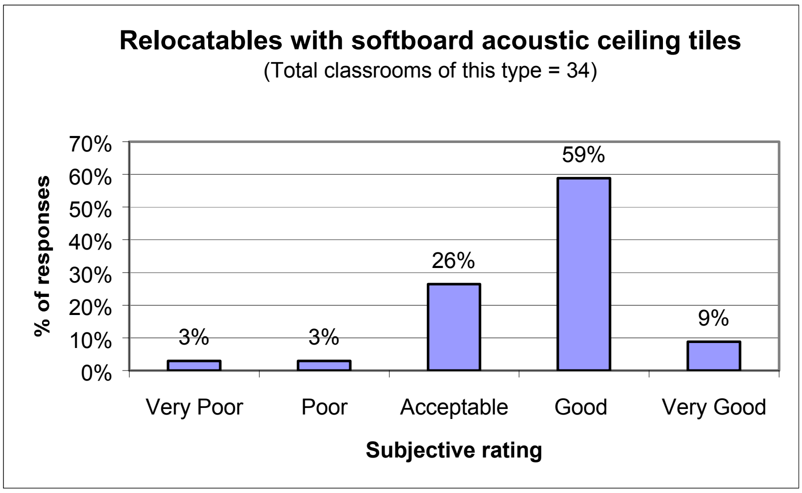


Figure 5: Subjective ratings for relocatables with softboard acoustic ceiling tiles

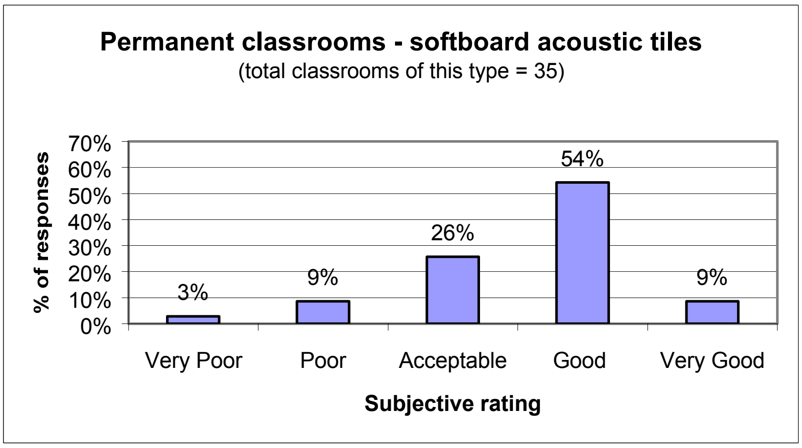


Figure 6: Subjective ratings for permanent classrooms with softboard acoustic ceiling tiles
(includes concrete and timber floor constructions but excludes partially open plan rooms)

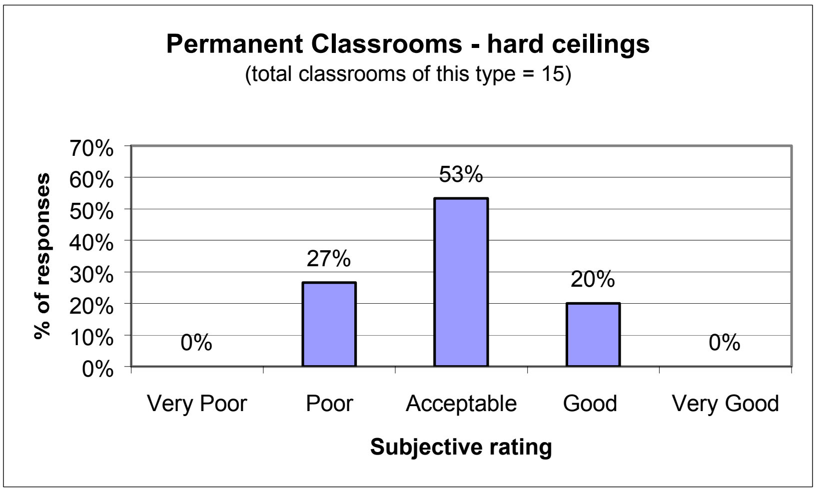


Figure 7: Subjective ratings for permanent classrooms with hard ceilings and concrete floors

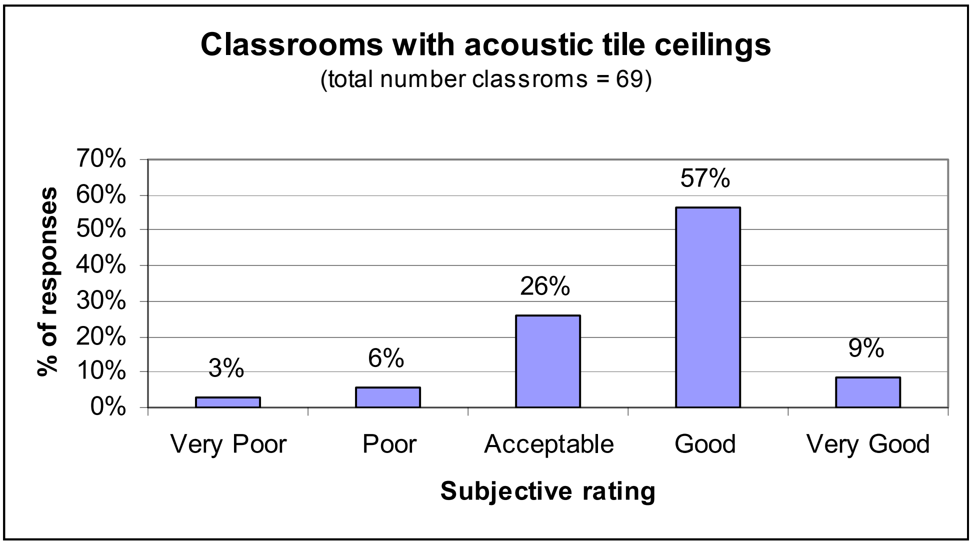


Figure 8: Subjective ratings of cellular classrooms with softboard acoustic ceiling tiles

Measurements

Reverberation

The average measured reverberation times for the six good and six poor classrooms are graphed below in Figure 9.

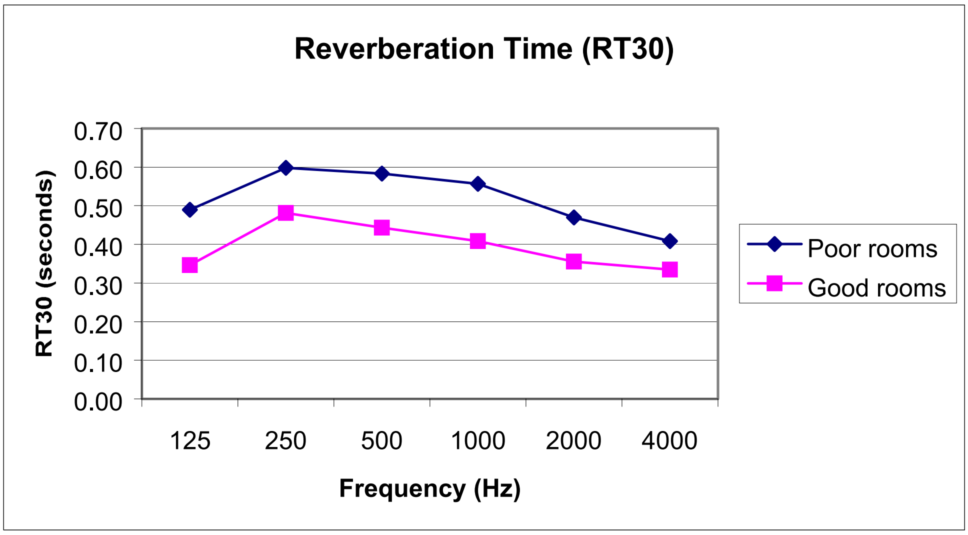


Figure 9: Average occupied reverberation time measurements for good and poor classrooms

The ‘good’ classrooms typically had a mid-frequency (average of 500 Hz & 1kHz) reverberation time (RT) of 0.4 seconds, with the exception of one room, which was a permanent classroom with a concrete floor and a sprayed plaster finish (acoustically hard) ceiling. This classroom had a mid-frequency RT of 0.56 seconds.

The mid-frequency reverberation time in the “poor rooms” ranged from 0.53 to 0.63 seconds, with an average value of 0.57 seconds.

Discussion

Compared to overseas studies, where reverberation times in untreated rooms often exceed 1 second, the level of reverberation in the poor rooms does not seem excessive. In New Zealand it is Ministry standard to have a carpeted floor (albeit thin), which provides a moderate degree of acoustic absorption at mid and high frequencies. In many other countries of the world hygiene regulations do not permit the use of carpet. Many overseas classrooms therefore have acoustically hard floors and acoustically hard ceilings, which result in a high reverberation time.

Overseas research has shown that speech perception falls off steeply for hearing impaired listeners when the reverberation time exceeds 0.4 seconds.[1] It is also generally agreed that hearing impaired listeners require a higher signal-to-noise ratio (SNR) than normal hearing listeners and that children require a higher SNR than adult listeners:[2]

Normal-hearing listeners –	Adults –	SNR at least 6 dB
	Children –	greater SNR than for adults
Hard of hearing listeners –	Adults –	SNR 15 dB
	Children –	greater SNR than for adults

Audiologists have noted that children, because they are neurologically immature and lack the experience necessary to predict from context, are inefficient listeners who require optimal conditions in order to hear and understand. Those who miss key words, phrases and concepts because of poor listening conditions must struggle to keep up, may do poorly academically and suffer from behaviour problems. At particular risk are children experiencing temporary hearing loss from otitis media (ear infections), children with a permanent hearing impairment, children with speech impediments, children who have learning disabilities, children for whom English is a second language, and very young children.[3]

Overseas studies have indicated that 20% of children fall in the “at risk” category. In New Zealand it is estimated that 15-20% of primary school children fall in the “at risk” category.

Until further research has determined optimum reverberation times for children in the classroom setting, several overseas authors have suggested that reverberation times in classrooms should follow the same acoustical recommendations utilized for hearing impaired listeners.

American Speech-Language-Hearing-Association (ASHA) Acoustical Guidelines[3] recommend that:

- Unoccupied classroom noise levels should not exceed 30 dBA,
- Reverberation times should not exceed 0.4 seconds, and
- The signal-to-noise ratio at a student’s ear should exceed a minimum of +15dB.

Our research indicates that due to the high levels of noise experienced in our classrooms, all children are effectively “hard of hearing”. In these conditions an appropriate reverberation time is 0.4 seconds or less, in line with the guidelines for hearing impaired listeners. Teachers in our survey have clearly indicated that a reduction in reverberation time from 0.6 seconds to 0.4 seconds is significant, and that acoustic absorption at ceiling level is desirable.

Clarity

No significant differences were found between C50 values for good versus poor classrooms. It is hypothesised that strong reflections from a hard ceiling balance the effects of the higher level of reverberation in the poor rooms, thus keeping the C50 early-to-late sound energy ratio relatively constant.

An explanation of technical terms (Clarity and Reverberation Time) is included in Appendix Two.

Day Long Recordings

The results of the day long recordings are not available at the time of writing, but will be discussed during the conference presentation.

Preliminary analysis indicates average noise levels of 50–70 dBA in the classrooms measured. These are in line with noise levels measured in classrooms in the United Kingdom by researchers from Heriot-Watt University in Edinburgh[4]. Average noise levels of 55 dBA were measured in "quiet" classrooms and 77dBA with pupils working.

Comparison with Overseas Studies, and Previous NZ Research

There have been several studies carried out of acoustics in NZ classrooms (Coddington 1984[5], Blake & Busby 1994[6], and Harper 1995[7]). These have shown high noise levels and poor signal-to-noise (S/N) ratios, similar to acoustic conditions found in other international studies. S/N ratios in NZ classrooms in a variety of listening conditions have ranged from –5 to +10 dB. Blake & Busby (1984) reported median S/N ratios of +1dB in multifunction activities (group) and +10 dB in single function teaching activities. American research by Crandell (1992)[1] found that commonly reported S/N ratios in classrooms ranged from between –7 to +5 dB.

Unoccupied background noise level is a measure that is often used in overseas research. This is important for rooms that have a constant background noise from heating, ventilation or A/C. In NZ classrooms that are naturally ventilated via open windows, unoccupied classroom noise levels fluctuate with intermittent external noise. Previous NZ research has shown unoccupied noise levels range from 28-60 dBA. In occupied classrooms the signal-noise-ratios are constantly fluctuating throughout the day and single figures do not give an indication of the range a child encounters.

New Zealand classrooms differ from North American and European schools. In overseas schools excessive reverberation (from predominantly hard surfaces), and high background noise levels from heating/air-conditioning/mechanical ventilation are the main problems. New Zealand classrooms, being carpeted, typically have lower levels of reverberation than many overseas classrooms, but have high levels of student generated noise, and high levels of intrusive external noise due to open windows.

Speech Testing

A plot of noise levels and speech scores for normal hearing subjects in both poor and good rooms are shown in Figure 10 below.

The results of the speech perception tests for normal hearing children did not differ significantly between the good and poor rooms.

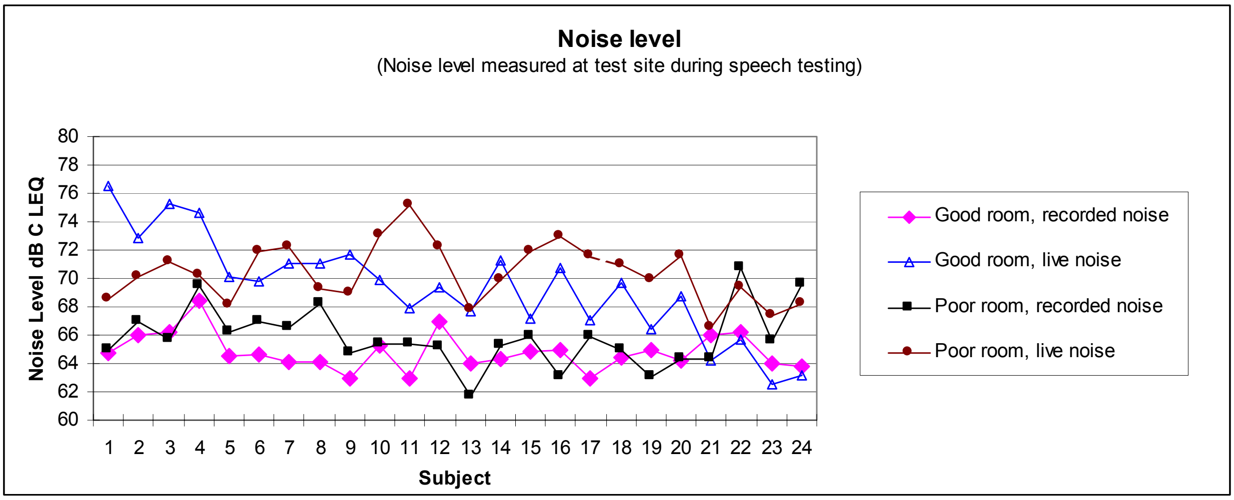
The live noise levels are consistently higher than the simulated noise levels in both types of rooms, hence in the live noise the signal-to-noise ratio is typically less than 0 dB. The live noise levels vary over a wide range between Leq 62-77 dBC. The live noise speech scores are highly negatively correlated (< 0.1% significance) with the live noise levels for both good rooms and poor rooms.

In the recorded background noise the speech score results are relatively consistent with the majority of scores falling in the range 80-100%. However, in the live noise the scores fluctuate widely ranging from 0 – 98%, with more than 40% of the scores falling below 50% correct. These results reflect the poor signal-to-noise ratio and show a clear difference between speech testing carried out in controlled conditions and speech testing carried out in a real room situation. Most speech testing has been carried out in laboratories or controlled conditions.

Hearing Impaired Subjects

The best performance by hearing-impaired children was obtained by those using FM systems, despite these being the children with the greatest degree of hearing loss. Children with degrees of hearing loss regarded as minor to moderate, fitted with normal hearing aids, performed very poorly in the speech testing, with the majority of scores ranging between 0-50%. Half of these children scored less than 20%.

Children with severe hearing loss who were fitted with FM radio hearing aids in addition to their normal hearing aids performed quite well, with the majority of scores ranging between 50-90%.



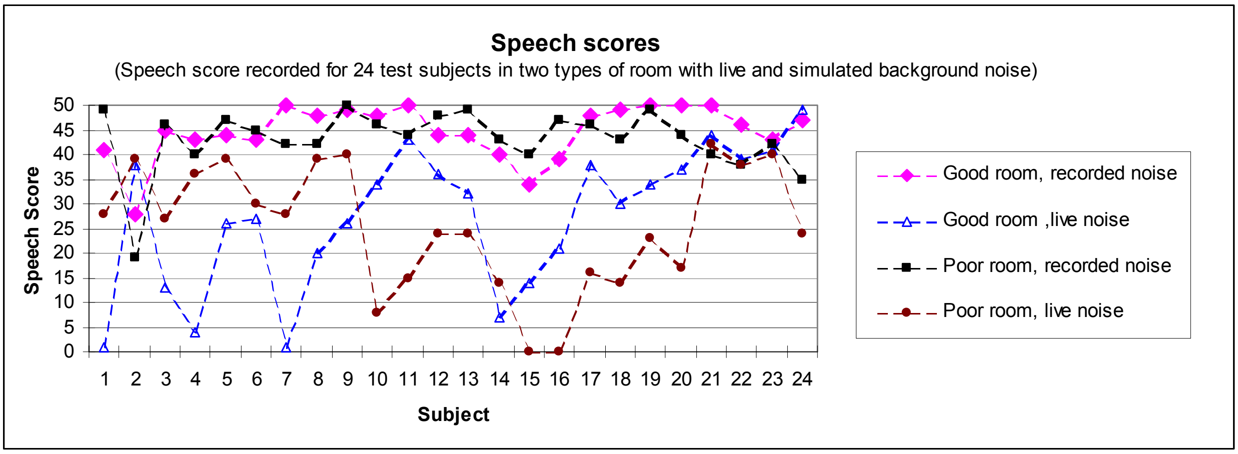


Figure 10: Plot of noise levels and speech scores for 24 normal-hearing subjects in both good and poor rooms

Classroom Modifications

Reverberation times were analysed for poor rooms to determine the room treatment required to achieve a 0.4 second RT with a flat response across the speech frequency range. Three solutions were proposed:

1. Echophon Master F- beta finish (40mm thick) ceiling tiles direct fixed to centre of the ceiling – approximately 35 m^2 of treatment in total
2. Rockfon Arktic mineral fibre ceiling tiles on a 200 mm airgap, to centre of the ceiling (approx half of the total ceiling area treated - 35 m^2)
3. Softboard acoustic ceiling tiles to the underside of the trusses (entire ceiling area) This solution came directly from RT measurements of relocatable classrooms treated in this way, that were rated as good in the Survey Questionnaire)

Two rooms were treated with each solution. All classrooms were of relocatable type.

Solution 1. This option has the least impact on the room visually. One teacher commented that you "hardly notice it is there". This is an ideal option for more complicated roof designs with clerestorey windows, raised skylights etc. where other options would not be possible. The tiles themselves have the highest cost per m^2 of the three solutions but as they can be direct-fixed, there was no requirement for a supporting grid system, and lighting fixtures did not require repositioning.

Solution 2. Visually this option has the effect of the trusses disappearing into a dropped ceiling. A suspension grid system was required, and lighting fixtures needed to be refitted to the new ceiling.

Solution 3. This option had the most impact on the room visually. We consider that this option is only suitable if the stud height is in the order of 3m or more, otherwise the ceiling feels oppressively low. When asked to identify any new problems created by the classroom modifications one teacher commented that she found the reduced ceiling height "slightly low".

Repeat Measurements

For two of the classrooms the teacher questionnaire, measurements, classroom modifications, repeat measurements and follow-up measurements were carried out within the same school year. Four of the classrooms were not modified until the following school year. Unfortunately this introduced some additional variables. In one school the original teacher was replaced with a new teacher - new to the room, and to the school. She felt unqualified to respond to the follow-up questionnaire as she had only experienced the unmodified room for a few weeks. The children changed in four of the classrooms.

Figure 11 below shows the occupied reverberation time in the modified rooms compared with the original conditions. The results are the average of the six rooms treated.

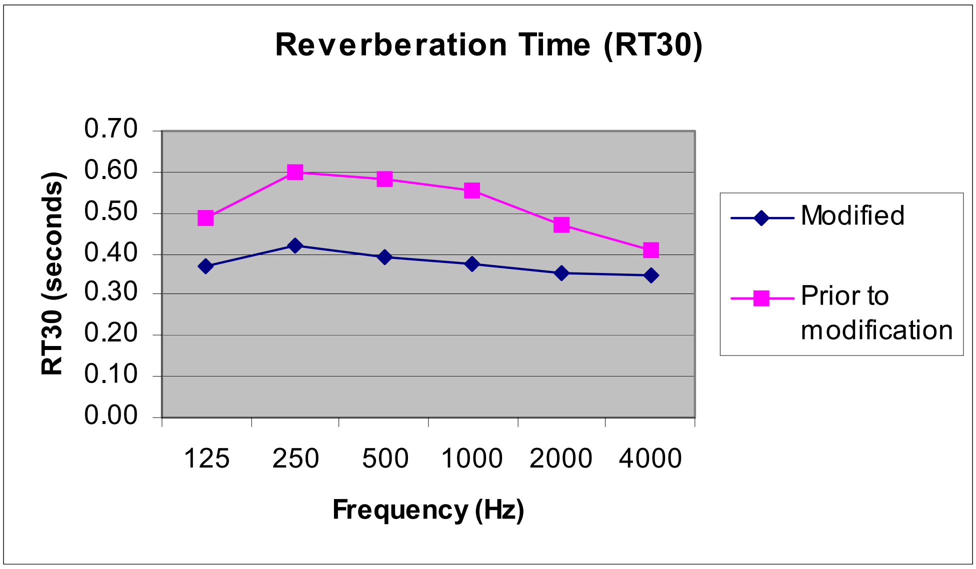


Figure 11: Average reverberation time in occupied classrooms before and after modification.

In five of the modified rooms the mid-frequency reverberation time in the occupied rooms ranged from 0.34 – 0.39 seconds. These values are consistent with the predicted reverberation times. In the remaining room the mid-frequency occupied RT was 0.52 seconds compared to a predicted value of 0.4 seconds. In 1999 there were 25 children aged 6 to7 years in this classroom. This year there are a smaller number of younger children (22 aged 5 to 6 years) in this room. This may account for the difference between the predicted and measured values.

In the unoccupied rooms the average mid-frequency reverberation time prior to modification was 0.69 seconds, and after modification is 0.43 seconds.

Follow-up Survey

Teachers in the modified rooms were re-administered the original survey and also asked to complete a follow-up questionnaire more specifically related to the classroom modifications. Teachers and pupils were enthusiastic about the improvements.

Four out of five teachers rated the acoustic environment in the modified rooms as significantly better, and one teacher as slightly–significantly better. The teachers' subjective ratings of the classroom listening environment before and after modification are tabled below.

Teacher	Teacher's Subjective Rating of Classroom Listening Environment	
	Prior to modification August-Oct. 1999	After modification May 2000
1	Very Poor	Acceptable
2	Very Poor	Good
3	Poor	Good
4	Poor	Good
5	Poor	Good
6	Poor	Poor*

* This teacher commented: "some sound has been absorbed but the room still has problems, mainly from floor noise"

The follow-up survey asked teachers to subjectively rate the modified classrooms for different teaching styles. All teachers rated inside noise levels and students' hearing ability as better for group work and mat work. Four out of five teachers rated inside noise levels and students' hearing ability as better for one-one and didactic/blackboard teaching styles. The remaining teacher rated the classroom as the same for one-one and didactic/blackboard teaching.

Additional comments from teachers include: less noise, more on-task behaviour, reduced frustration, better hearing, and the ability to successfully work in small groups on different tasks. One teacher commented that the children's' voices and movements were more muffled now and that she didn't feel that they were yelling, whereas previously she always felt as if the children were yelling. Similarly, another teacher commented on the ease of listening for the children now that the tiles had been installed. In the original survey prior to the modifications this teacher had described escalating noise levels due to the hard ceiling: "noise from children's voices seems to bounce back from the ceiling, then they raise their voices to hear each other, and so on." This effect is commonly known as "the cocktail party effect". One teacher commented that this is the first year in this classroom that she hasn't suffered from voice strain; another commented that she was more aware of off-task behaviour now, as before all the children had seemed off-task.

Unprompted comments from children included: better hearing, less noise and a more peaceful environment. Comments from other colleagues included: "can I have the same for my room", reduced rain noise compared to adjacent rooms and a noticeable improvement in the acoustics of the room during after school meetings. A relieving teacher with hearing aids in both ears found his days teaching much easier.

Some teachers commented that the floor needed to be treated now, and that floor noise and noise from adjacent classrooms was more noticeable now that the room was quieter.

Summary/Recommendations

- High levels of student generated noise and intrusive external noise are problems for the majority of teachers surveyed.
- The predominant teaching methods of primary school teachers are group work and mat work.
- For this style of teaching an absorptive ceiling (moderate broad-band absorption to central ceiling) is strongly preferred.

- A low reverberation time in occupied classrooms of 0.4 seconds or less is recommended.
- In the siting of classrooms/school design, consideration should be given to outside noise sources, both within and outside of the school eg. proximity to the bus stop, main roads, school hall, playing fields etc.
- Noisy activities such as lawnmowing should be rescheduled to occur outside of school hours.
- External decks need to be supported independently from classroom structure.
- Carpet over underlay is the recommended floor covering to reduce noise from footfall and furniture movement.
- A more solid floor construction is recommended to reduce the drumming associated with particleboard floors - perhaps two layers of particleboard instead of one.
- FM technology is recommended for hearing impaired children.

Further Study

Floor noise has been identified as worthy of further investigation.

We would also like to investigate the effects of installing high performance broad-band absorption to the entire classroom ceiling, and reducing RT to 0.1-0.2 seconds. This poses the question "Can the classroom be made too dead?" As group work is one of the main activities in the classroom it seems reasonable that primary school classroom acoustics are more akin to "open plan offices" than speech rooms, and perhaps should be treated as such.

Recent research by Bradley/Bistafa[8] on theoretical values for speech metrics for a 300 m^3 classroom, suggest that for very quiet classrooms (S/N ratio 20-30 dB) a RT of 0.1-0.3 s maximises speech intelligibility metrics, but 100% speech intelligibility is still possible with a RT of 0.4-0.5s, and this is the range recommended by them. For noisier classrooms with a S/N ratio of 10 dB, speech metrics drop off below reverberation times of 0.3-0.4 seconds.

Researchers from Heriot-Watt University recently carried out a study of the acoustics of primary school classrooms in the United Kingdom.[4] A reverberation time design guideline of 0.4 seconds was used for classrooms that were acoustically treated. It was considered that useful sound would not carry well enough in the classroom environment if the room was made "too dead".

The effects of a very low level of reverberation on noise levels, child behaviour and speech perception in classroom environments requires further study.

Acknowledgements

Many thanks to:

- Holden Architectural, Fletcherwood Panels and Link Distributors for donating the materials for the treatment of the classrooms,
- The Oticon Foundation for funding the project,
- The research team members for generously contributing to the project in their free time, and particularly Oriole Wilson for coordinating the project.

Appendix One – Speech Testing Experimental Method

Subjects

Four typical children aged between 8 and 11 years were selected from each classroom for the speech testing. The teacher was asked to select children where the reading age matched or exceeded the chronological age. It was also specified that no child should have: hearing loss, a learning disability or English as a second language.

A small number of hearing-impaired children were also tested in each of the schools. They were tested wearing their normal hearing aids and FM systems at normal settings. If an FM system was worn the transmitter microphone was placed at a distance of 20cm from the L/S, and slightly below to simulate the effect of a lapel microphone. A total of 10 hearing-impaired children were tested. They ranged in age from 7 – 11 years.

Speech Material

The speech material used was a University of Melbourne recording of BKB sentence lists. The BKB (Bamford-Kowal-Bench) sentence lists consist of 21 lists of 16 sentences with an open set response (sentences unrelated to each other). The sentences are based on the vocabulary and grammar of 8 to 16 yr old hearing impaired children. The University of Melbourne version is recorded by an Australian male speaker.

Equipment

A portable CD player connected via an amplifier to a directional loudspeaker approximating the directivity of the human voice was used to present the sentence material. The loudspeaker was set up where the teacher normally stands at the front of the classroom, at a hight of 1.5m from the floor. The sentence lists were calibrated using a 1kHz calibration tone so that at a distance of 1m at 0 degrees azimuth the level of the tone was 71 dBA (measured using a B&K 2260 SLM). This corresponded to the average peak level of the speech being 71 dBA. The test position was located at a distance of 4m from the L/S. The level of the signal at the test position ranged from 60-64 dBC.

Background Noise

The speech testing was carried out in both live and simulated classroom noise. For the simulated classroom noise, recorded classroom babble* via four loudspeakers distributed throughout the room, was used to achieve a signal to noise ratio of 0 dB at the test position. The A-weighted Leq sound level of one sentence was measured at the test position and the level of classroom babble was adjusted to be equal to the signal speech. The signal-to-noise ratio reflected a difficult but not atypical classroom listening environment. Reverberant classroom babble noise levels ranged from Leq 62-70 dBC. For the recorded background noise the remainder of the class was asked to read quietly.

For the speech testing carried out in live noise the remaining members of the class were given an activity sheet to work on in pairs. The same activity sheet was used in every class. The teacher told the children that normal working noise would be tolerated, and a 5 minute period was allowed to let the noise to settle to a “normal” level. During the presentation of the sentence lists the Leq background noise level was measured at the test site and noted on the individual score sheets. The live noise levels measured at the test position ranged from Leq 63-77 dBC.

Testing

The test subjects were asked to listen to a sentence list and repeat each sentence in turn to the tester seated alongside. The sentence list consisted of 16 sentences, with each sentence carrying 3-5 key words, to give a total of 50 key words in all. For each child the number of key words correctly relayed to the tester was recorded.

*The recorded classroom noise was developed by Harper, 1995. Real classroom noise was recorded in a classroom with 33 students aged 10-12 yrs. The noise recording includes voices, pens clicking, desk tops banging, movements around the classroom, doors shutting and chairs being moved. The levels fluctuate no more than 3-6 dB over the 46 minute period of the recording. The tape has a calibration tone.

Appendix Two – Technical Glossary

Reverberation Time

Reverberation time is defined as the time taken for an interrupted sound to decay by 60 decibels (or to one-millionth of its original intensity). In practice, this is approximated by measuring the time it takes for sound to decay from –5 to –35 dB, multiplied by a factor of 2 (RT30), or from –5 to –25 dB, multiplied by a factor of 3 (RT20).

Clarity

Clarity (C50) or the early-to-late sound energy ratio measured at a point in a room, is 10 log of the ratio of the the integrated squared pressure, arriving before 50 milliseconds, to that arriving after 50 milliseconds:

$$C50 = 10 \log \frac{E(0 - 50 \text{ ms})}{E(50 - \infty \text{ ms})} \text{ dB}$$

References

[1] Crandell, C. C. Gold, M.J. & Siebein, G.W. Principles of Classroom Acoustics: Reverberation. *Educational Audiology Tutuorial*

[2] Wetherill, E.A. Classroom Design for Good Hearing. *Better Schools for a New Century, American Institute of Architects San Francisco, April 1999*

[3] Kailes,J.I. Architectural and Transportation Barriers Compliance Board *The Federal Register, Nov.1999*

[4] MacKenzie, D.J. Speech Intelligibility in Classrooms. *Lecture presented to NZ Acoustical Society, March 1999*

[5] Coddington, K.(1980). Classroom acoustics and their relationship to children with hearing losses in normal schools. *Paper presented to NZ Acoustical Society, Auckland New Zealand.*

[6] Blake, P. & Busby, S. (1994). Noise levels in New Zealand Junior Classrooms: Their impact on Hearing and Teaching. *New Zealand Medical Journal*

[7] Harper M. (1995) Masters Thesis *Department of Audiology, University of Auckland*

[8] Bistafa S. R. & Bradley J. (1999) Reverberation time and maximum background-noise level for classrooms from a comparative study of speech intelligibility metrics. *Institute for Research in Construction–Acoustics National Research Council–Canada*