CLASSROOM ACOUSTICS
The Impact of Classroom Acoustics on Scholastic Achievement

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What are the relationships between scholastic achievement and acoustics in learning spaces? Answers to this difficult question are needed to support setting objective limits for noise and reverberation. Good acoustics is necessary in classrooms and learning spaces whenever speech communication is important to the learning process. It is clear that excessive noise and reverberation interfere with speech communication and thus present acoustical barriers to learning. Acoustical allowances are needed to accommodate differences in student abilities, health, and scholastic preparation. This paper reviews speech communication criteria and studies that have linked scholastic performance with acoustical noise or reverberation. Some studies link aircraft noise with delayed language acquisition, reading deficiencies, reduced motivation, and long-term recall of learned material. Others link ground transportation noise with reduced academic achievement. Aside from reduced speech intelligibility, little data were found to gauge the impact on learning achievement from heating, ventilating, and air conditioning noise; from the noises of students interacting in cooperative learning environments; or from reverberation. Despite their incomplete nature, some useful inferences can be drawn from these studies. For example, evidence for cumulative impact of poor acoustics on scholastic achievement suggests that good acoustics be made a high priority for children in lower grades.

INTRODUCTION

Good classroom speech communication is essential for the acquisition of academic, social, and cultural skills. Noise and reverberation are barriers to speech communication. All knowledge-based societies should strive to eliminate acoustical barriers to learning.

Speech discrimination in noise and reverberation has been studied in laboratory settings. But the link between laboratory tests of speech perception and student achievement in acoustically unsatisfactory classrooms is more tenuous. It is important to document the links between good acoustics and learning because it provides needed justification for decision makers to improve classroom acoustics.

Noise as An Acoustical Barrier to Learning

Noise level and teacher vocal strain

Excessive noise is partially ameliorated when teachers elevate their voice levels - but at the cost of voice fatigue. A study by Pearson, et al, showed that average A-weighted sound level, \(L_A\) at 1 meter from teachers increased from 60 dB in quiet (average for normal and raised voice effort) to about 62 dB in A-weighted background noise levels of 35 dB; to 67 dB in backgrounds of 45 dB; then increased about \(dB\) for \(dB\) as the background noise rises above 45 dB. Thus, in their attempt to maintain the same signal to noise ratio in noisy rooms, teacher vocal strain increases, leading to vocal fatigue and teacher absenteeism. Also, there are fewer verbal exchanges between teachers and students. The impact on achievement is unknown.

Tests in 56 classrooms in 5 different studies in the U.S. show the A-weighted noise level has a mean of 45 \(dB\) and a standard deviation of 8 \(dB\). This suggests that 28% of US schools have noise levels exceeding 50 \(dB\), which is 15 \(dB\) above the limit proposed in a US standard for classroom acoustics now approaching a final draft. It also suggests that teacher voice levels are 10 \(dB\) above speaking levels in quiet. This may explain the prevalence of teacher voice fatigue.

A US Government Accounting Office (GAO) survey found that 28% of US schools reported “acoustics for noise control” as their top environmental problem.

Teachers cannot effectively compensate for excessive classroom reverberation by raising their voice levels.

Scholastic Achievement and The Acoustical Environment

Educational research shows that learning depends on the ability to employ spoken language and that perception of spoken language is the foundation for the ability to read and write. About 60% of classroom learning involves spoken exchanges between teachers and students. Interference with communication can only be adverse to student achievement.

Acoustical barriers are raised for students burdened with hearing impairments, learning disabilities and non-native students. These compound the negative impacts of acoustical barriers on achievement. Concern for students with communication disabilities inspired current efforts to improve classroom acoustics.
A non-classroom study of noise and reading in home settings by Cohen, et al, measured reading and auditory processing skills of children living on different floors of an apartment building located over a busy highway in New York City. They found that children living on higher residence floors and were exposed to lower background noise levels had higher reading scores.

Another study was carried out on a school located 67 m (220 ft.) of an elevated train track (Figure 1). Bronzaft and McCarthy found that reading scores of 2nd-to 6th-grade children in classrooms facing the noisy tracks were lower than those in classrooms. They found that lower grade children on the noisy side were 3 or 4 months behind in reading scores relative to those on the quieter side. The quiet side advantage grew to an impressive 11 months for the higher grades. After track noise was reduced by 3 to 8 dB on both sides of the school, further tests showed that substantial differences remained in reading scores. Fig. 1 shows that children in the “noisy” rooms were about one year behind those in the “quiet” rooms. The data suggests a compounding effect of noise degradation on scholastic achievement with many years of noise exposure.

A study by Lukas, et al, at 14 schools in Los Angeles, California, located at various distances from freeways, found that background noise differed by up to 19 dB between the noisiest and quietest schools. Fig. 2 shows grade equivalent reading scores vs. C-weighted background noise level. Although Lukas, et al, found that C-weighting correlated best with the reading scores, the average difference between the C-

and A-weighted noise levels was about the same, (14 to 15 dB) for the “noisy” and “quiet” locations. The data in Fig. 2 show greater decrease in reading scores for the 6th grade than for the 3rd-grade classes. This appears to be a more prominent effect of grade differences than is shown by the Bronzaft data. It is important to know if noise effects on learning are cumulative and compounded. Careful prospective studies are needed.

Other research links aircraft noise with delayed language acquisition and reading, reduced motivation and reduced recall of learned material. Aside from reduced speech intelligibility, little data were found to gauge the achievement impact of ventilation noise or the noise of students interacting in cooperative learning. These seem fruitful areas for future study.

A study at Heriot-Watt University evaluated 60 classrooms in 13 schools in the United Kingdom before and after adding acoustical treatment. A-weighted background noise levels in unoccupied classrooms averaged 45 dB, identical to that cited earlier for US schools. After ceiling acoustical treatment, unoccupied noise levels dropped to 40 dB, reflecting reduction in reverberation. The average RT60 (reverberation times) in unoccupied rooms dropped after treatment from 0.7 to 0.4 sec. As stated by the researchers: “subjectively, classrooms with acoustic treatment were favored by the teachers and pupils, who reported a greater ease of communication and increased performance.”

**SUMMARY**

Limited data confirms that poor classroom acoustics – noise and reverberation - are indeed barriers to learning as indicated by reduced scholastic achievement. They also show strong correlation between good acoustics and improved scholastic achievement. This should inspire decision makers to improve the acoustics of schools. The vital necessity of providing good acoustics while students are acquiring language skills seems especially important. References and details are provided in an extended version of this paper.
Estimated Cost for Improving Acoustical Comfort Conditions of an Existing Classroom

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Acoustical needs to improve hearing-teaching activities in educational buildings have been transformed into international-national guidelines and recommendations and in some countries into national regulations. However, different studies have shown and continue to prove that for many countries, for a high percentage of schoolrooms acoustical quality is clearly below the required level. Realisation of acoustical improvements depends basically on cost. Therefore knowledge on the realistic costs may help the authorities to decide for the improvements. The aim of this study is to investigate the additional cost to improve acoustical comfort conditions for existing classrooms. In order to exemplify the situation one of the most common classroom types has been selected. Acoustics project has been prepared and the cost analyses to realise the improvement has been determined for the selected classroom. Cost efficiency was the most important factor on the selection of the materials and details to be used. Thus, the additional cost to improve room acoustical conditions of an existing classroom has been illustrated.

INTRODUCTION

Descriptors of good acoustics for the learning environment and the conditions to realise the appropriate acoustics in these spaces have been outlined on an abundance of research and other published data [1, 2, 3 and others]. However, different studies have shown and continue to prove that for many countries, for a high percentage of schoolrooms, acoustical quality is clearly below the required level. The situation is worst for the developing countries where the classroom acoustics is far away to be one of the persistent design and implementation criteria [4].

The realisation of acoustical improvements depends basically on cost. Measures are less costly and more effective when applied in the early design of the buildings. On the other hand, it is also necessary to improve the comfort conditions in the existing learning environments and especially in the classrooms. Knowledge on the realistic costs may help the authorities to decide for the improvements. The aim of this study is to investigate the additional cost to improve room acoustical comfort conditions for existing classrooms.

ACOUSTICAL ENVIRONMENT OF THE CLASSROOMS

In order to exemplify the situation a common classroom type of elementary schools (at Turkey) is chosen to work on [5]. Figure 1 shows the plan of the classroom with source (S) and receiver (R) positions. Table 1 gives the architectural properties of the space. The reverberation time (RT) and other relevant room acoustical parameters are measured according to ISO 3382 for the occupied and unoccupied room.

![Figure 1. Classroom plan and source (S), receiver (R) positions.](image)

| Dimensions of the classroom: l: 7.0 m, w: 6.95 m, h: 2.85m |
|-------------------|-------------------|---|
| S= 176.8 m² | V= 138.6 m³  | N= 50 students and 1 teacher |

<table>
<thead>
<tr>
<th>Surface</th>
<th>S (m²)</th>
<th>Material</th>
<th>IIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>48.7</td>
<td>Plastered concrete</td>
<td>25</td>
</tr>
<tr>
<td>Floor</td>
<td>48.7</td>
<td>Stone tiles on heavy floor</td>
<td>52</td>
</tr>
<tr>
<td>Wall</td>
<td>60.9</td>
<td>Plastered brick</td>
<td>50</td>
</tr>
<tr>
<td>Window</td>
<td>7.1</td>
<td>Single pane of 4 mm glass</td>
<td>26</td>
</tr>
<tr>
<td>Door</td>
<td>2.2</td>
<td>Solid core wood</td>
<td>22</td>
</tr>
<tr>
<td>Chalkboard</td>
<td>3.1</td>
<td>Hard plastic panel</td>
<td></td>
</tr>
<tr>
<td>Curtain</td>
<td>14.0</td>
<td>Two layers; light cloth and tulle</td>
<td></td>
</tr>
<tr>
<td>Board</td>
<td>6.0</td>
<td>Wood panel, cloth surface</td>
<td></td>
</tr>
</tbody>
</table>

Besides the measurements, calculations to describe the acoustical environment of the classroom are made. The differences between calculated and measured RT’s are relatively high at low frequencies. Measured and calculated RT’s are given at Figure 2.
The optimum RT at mid-frequencies (mean of the 500 Hz and 1000 Hz octave bands) for unoccupied classrooms of this volume, is given as 0.40 to 0.75 s at various literatures [6, 7]. Measured mid-frequencies RT is 1.0 s and estimated RT is 1.11 s for the unoccupied room, showing clearly that RT should be decreased. There are of course several ways of decreasing RT, however, in this study the materials and the details which could be implemented easily and cheaply have been preferred as the cost is the most important factor to persuade the decision makers on the improvements.

Wall surfaces upper parts have been used for the application of the required sound absorption. Ceiling and chalkboard wall are left reflective to permit the first reflections. The board, which is used for the exposition of the students work, have been modified to a modular element (6mm plywood with 50mm air space), basically used for the absorption of the low frequencies. The total area of the acoustical boards has been increased from 6 m² to 13m²; they have been arranged as to constitute a band starting at 1.2 m above the floor. Walls upper parts have been covered by sprayed on acoustical material (55mm). Table 2 shows the estimated RT’s after the treatment. The new reverberation time at mid-frequencies, has been calculated as 0.52 s for unoccupied classrooms, which is within the limits of the optimum level.

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Table 2. Calculated RT’s of the classroom after treatment.

<table>
<thead>
<tr>
<th>RT (s)/f (Hz)</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unoccupied</td>
<td>0.77</td>
<td>0.63</td>
<td>0.52</td>
<td>0.53</td>
<td>0.48</td>
<td>0.45</td>
</tr>
<tr>
<td>Occupied</td>
<td>0.65</td>
<td>0.51</td>
<td>0.41</td>
<td>0.40</td>
<td>0.39</td>
<td>0.39</td>
</tr>
</tbody>
</table>

COSTS

Cost analysis of the acoustical treatments have been done taking into consideration that each classroom of a school will be evaluated completely. The cost of the acoustical boards, is 280 $ and the application of the sprayed on acoustical material is 220S, giving a total of 500 $ per classroom approximately.

This study does not cover the measures related with noise control which is the inseparable part of the acoustical comfort. Improvement of sound insulation in schools is much more difficult and costly than the improvement of room acoustics. Moreover it depends on the construction technology, architecture and the environment of the building. That’s why it is not available to give a general prediction on the cost of noise control at existing classes. Still, a brief research showed that in case of the improvement of only the windows sound insulation, an additional cost of 7000$ is required for a school having 12 classrooms.

CONCLUSION

The basic problem regarding the implementation of the measures for good acoustics in classrooms seems to inform/educate and persuade the decision makers on the necessity for improving acoustics in classrooms. Cost, which is one of the persistent factors, has been investigated in this study. For a typical classroom of 49m² and 138m³, the additional cost to realise the improvements of room acoustics of a school of 12 classrooms has been found as 6000 $, which is a suitable amount. On the other hand, it is obvious that this cost will diminish, if the precautions are taken in the early design and construction phase of the schools.

Detailed studies illustrating the realistic costs of the acoustical treatments for classrooms, besides its benefits on the education, may be utilised as a good means for motivation of the authorities related with the education.

REFERENCES

Good classroom acoustics can be achieved on a national scale only when technical, economic, and regulatory issues are addressed. This paper reviews the collaboration between the Acoustical Society of America (ASA) and the U.S. Access Board (USAB) to improve acoustics in classrooms in the United States. This effort began in 1997 when the USAB, which develops accessibility standards under the Americans with Disabilities Act (ADA), received a petition from a parent of a child with a hearing loss, requesting that the ADA Accessibility Guidelines include new provisions for acoustical accessibility in schools for children who are hard of hearing. The USAB approached the ASA, as the Society was already working on this issue which encompasses many technical fields in acoustics (architectural acoustics, noise, speech, psychological and physiological acoustics), and has the responsibility to develop standards for the American National Standards Institute (ANSI). A draft standard is now in the approval process.

INTRODUCTION

The basic theme of this paper has been reiterated by scientists and engineers in scores of articles in research and education journals over the past three decades; simply stated, good classroom acoustics are needed to improve learning, especially for those who are hearing disadvantaged. Increasing awareness of the problem and developing a standard are first steps to achieve this goal.

THE ACOUSTIC PROBLEM

In order to learn by listening, people require a sufficient signal-to-noise (S/N) ratio. The signal in the classroom is usually the voice of the teacher. But today's teaching methods also feature the students themselves and audio/visual/computer equipment as important sources of signals in the learning process. These signals can be distorted by reverberation and amplification, which reduces speech intelligibility. Also signal levels change with distance between source and listener. Increasing background noise lowers the S/N and hence speech intelligibility. Noise is generated both internally and externally to the classroom. Internal noise is created by the students as well as by audio/visual/computer devices. Loud ventilation equipment, especially window air conditioners, is raising noise levels in renovated schools. Obvious noise sources outside the classroom are automobile traffic, airplanes, and activities in neighboring classrooms, hall corridors, gymnasiums and the playground. We can all reference our own experience from school days, as well as a multitude of articles and books on the above acoustical subjects.

THE AUDIOLOGY PROBLEM

Researchers in the field of education point out that techniques have changed, and teaching at the primary grade levels now emphasizes engaging children to be interactive and experiential, which usually increases noise levels. It has been shown that young children (under 13) need higher S/N levels than adults for understanding speech. In addition, those in the U.S. who require excess S/N ratios for learning include children: 1) with permanent or temporary hearing losses (e.g. from otitis media), 2) with learning or auditory processing disabilities, and 3) who are non-native English speakers [1]. All told, it is estimated that these special categories cover 20% of all school age children. An inadequate S/N ratio not only impedes learning, it also affects teachers who must raise the amplitude of their voice to increase the S/N ratio. One study showed teachers with vocal injuries take an average of two days of sick leave per year, and are filing a growing number of complaints for workers’ compensation. Also voice strain decreases a teacher’s effectiveness [2].

THE ARCHITECTURE PROBLEM

Jerry Lilly, an acoustical consultant, summarized the problem of poor classroom acoustics in an editorial Establishing Acoustical Standards for Classrooms: “It is tragic that our young people have to face this type of learning impediment. This is especially true when there are simple, well-established, cost effective means of solving or avoiding these problems altogether”[3]. The solution requires bringing school administrators,
architects, contractors and purchasing agents together with an acoustical consultant early in the design of new schools or the renovation of old ones. An introductory booklet Classroom Acoustics [4] has recently been published by the ASA to foster communication between such design teams and acoustical consultants.

INCREASING AWARENESS

Several European countries have already adopted standards for reverberation times, noise levels and minimum signal-to-noise ratios [5]. The American Speech-Language-Hearing Association (ASHA) has produced a position statement and guidelines for acoustics in educational settings [6], and recently published a set of seven articles on classroom acoustics [7]. The ASA sponsored two workshops in 1997 and 1998; however not many attendees came from architectural or education fields. Many members of ASA, ASHA, and other organizations, dedicated to providing help for the hearing disadvantaged, have written articles for their organization’s publications, as well as for education journals and the popular press. Unfortunately almost no mention of classroom acoustics is included in U.S. government documents regarding the design of our schools to improve learning. The primary exceptions are the June 1998 USAB request [5] and the 1995 General Accounting Office (GAO) report to the U.S. Congress [6] which listed “acoustics for noise control” as the number one environmental issue in the U.S. school system. Although there are performance standards for illumination and design codes for buildings, including for the physically disabled, no national standards exist for classroom construction for proper acoustics.

ACTION TAKEN BY ACCESS BOARD

On April 6, 1997 the U.S. Access Board received a petition for rulemaking from a parent of a child with a hearing loss, requesting that the ADA Accessibility Guidelines be amended to include new provisions for acoustical accessibility in schools for children who are hard of hearing. Several acoustics professionals, parents of children with hearing impairments, individuals who are hard of hearing, and a consortium of organizations representing them also urged the Access Board to consider research and rulemaking on the acoustical performance of school classrooms and related student facilities. On June 1, 1998, the Board published a Request for Information to gather public input on this issue [5]. Approximately 100 comments were received from parents of children with hearing impairments and from professionals in acoustics and audiology. Few comments were received from school systems. The ASA responded with a proposal, and on March 10, 1999 the Board voted to collaborate with an existing ANSI approved ASA working group on Classroom Acoustics which had been established previously in September 1997 to develop a technical standard for classroom acoustics for children with disabilities.

STANDARDS WORKING GROUP (WG)

The Working Group 42 under ANSI Committee S12 (Noise) first met in June 1998. At the Access Board’s request, it was expanded to 49 members to include acousticians, audiologists, architects, and representatives from disability organizations, school systems and the Access Board. This was followed by many meetings of the WG, and extensive e-mailing of drafts. A basic issue which had to be addressed was whether the standard should adopt acoustic performance criteria or specify design requirements. Background noise levels and reverberation times are used for performance criteria, along with Sound Transmission Classes (STC). WG 42 has voted to approve the standard, but there are a number of steps which must be undertaken before it becomes an official standard, followed by methods to enforce it. An update on the progress on the availability of the standard will be presented at the meeting.

ACKNOWLEDGMENTS

The authors acknowledge their respective institutions for providing the support for this important endeavor. Many people have volunteered their time to develop the standard on classroom acoustics, and we only have space here to recognize the co-chairs of Working Group 42, David Lubman and Louis Sutherland.

REFERENCES

3. Lilly, J.L., Sound and Vibration, 5-6 (Dec. 1997)
6. ASHA 37 (suppl. 14), 15-19 (March 1995)
8. GAO Report HEHS-95-61
A Survey of Noise Levels in and around Primary Schools in London

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External and internal noise surveys of primary schools in London have been carried out as part of a larger study examining the effects of noise on primary school children in London. Noise levels have been measured outside 142 schools and inside 16 schools. A technique for measuring classroom noise has been established. Results of the external and internal surveys show that internal classroom noise is determined by the classroom activity rather than by external environmental noise.

INTRODUCTION

In recent years there have been many studies of classroom acoustics and the noise environment around schools [1-6]. However, although there are many guidelines recommending background noise levels and reverberation times for classrooms such as those in the UK [7] or of the World Health Organisation [8], there is no standard method for the measurement and assessment of noise in schools.

A study is currently being carried out to examine the effects of noise on the academic achievement and cognitive development of primary school children (that is children aged 5 to 11) in London. The study involves internal and external noise surveys of schools and classrooms, questionnaire surveys of children and teachers and experimental testing of children in controlled noise environments. External noise levels have been measured at 142 schools and internal surveys of 16 of those schools have been carried out. This paper presents the results of these surveys and discusses factors that determine the noise levels inside classrooms.

EXTERNAL NOISE SURVEY

Five minute samples of noise were measured outside schools using a Bruel and Kjaer sound level meter, Type 2236. Where possible measurements were made outside the noisiest façade, at the kerbside of the nearest road. Most measurement positions were at approximately 4m from the school façade; levels recorded at other distances were corrected to a distance of 4m. The measurement periods were chosen to be typical of the school day, avoiding for example rush hours times.

The means and standard deviations of the measured parameters measured are shown in Table 1. Noise sources heard outside each school during the 5 minute sampling period were noted. The percentages of schools outside which each noise source was heard are illustrated in Figure 1.

The most commonly occurring source of noise was road traffic, principally cars. Sirens were heard at surprisingly few schools, although they are commonly regarded as a regular feature of the London noise environment, and reported as being frequently heard by teachers and children [9].

INTERNAL NOISE SURVEY

An additional aim of the study was to develop a suitable protocol for the measurement of noise levels in classrooms, particularly those of young children. Pilot noise surveys were carried out, together with classroom observation, to establish a measurement protocol for the main survey [10]. Several different techniques were used in order to identify the most appropriate and practical method for accurate measurement of classroom noise. As a result of the pilot study it was decided to use a hand held sound level meter and monitor noise over a series of 2 minute samples for the main study. Dose badges worn by children did not provide any reliable data on general classroom noise as the levels recorded merely reflected the level of the wearer’s voice.

Classroom observation in several schools identified 6 distinct classroom activities: 1) silent reading or tests; 2) 1 person (child or teacher) speaking; 3) individual work at tables; 4) individual work with movement around classroom; 5) group work at tables; 6) group work with movement. Representative levels of these activities were recorded in each school, and
Table 2. Internal noise levels

<table>
<thead>
<tr>
<th>Activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>OC</th>
<th>UC</th>
<th>COR</th>
<th>OAH</th>
<th>UAH</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{Aeq}$</td>
<td>57.9</td>
<td>65.1</td>
<td>65.5</td>
<td>73.8</td>
<td>70.1</td>
<td>76.9</td>
<td>70.3</td>
<td>48.9</td>
<td>55.9</td>
<td>66.1</td>
<td>50.8</td>
</tr>
</tbody>
</table>

also in various spaces around the schools such as foyers, empty classrooms, and corridors. The average internal $L_{Aeq,2\text{min}}$ levels for the various classroom activities are shown in Table 2, together with the mean $L_{Aeq}$ levels for occupied (OC) and unoccupied (UC) classrooms, corridor (COR) spaces, and occupied (OAH) and unoccupied (UAH) assembly halls.

It can be seen that for activities 2 and 3 which may be regarded as typical of teaching situations the levels are very similar. The quietest areas measured around the schools were unoccupied classrooms.

In all schools, there were large fluctuations in the parameters measured across the school day in each classroom. The only periods during which the noise level was relatively stable was when the children were engaged in activities 2 and 3.

RELATION BETWEEN INTERNAL AND EXTERNAL LEVELS

The relationship between internal and external levels has been examined for the sixteen schools for which both sets of measurements have been obtained. There is no significant correlation between any of the external levels and the internal levels. This corresponds with the subjective impressions gained during the internal surveys that the noise in classrooms is dominated by the noise of the children, and depends upon the particular activity they are engaged in. During the internal surveys the researchers were not aware of any external noise, although the children report hearing many external noise sources while in the classroom [12]. It should be noted that all except one of the schools surveyed have double or secondary glazing and the windows were closed at the time of the surveys.

CONCLUSIONS

A survey of noise levels outside primary schools in London has shown that most schools are subject to noise from road traffic. It has been established that use of short (2 minute) measurement samples provide reliable data on typical noise levels inside schools. Measurements in classrooms demonstrated that the internal levels were determined by classroom activities, and not by external noise.

ACKNOWLEDGEMENTS

This research has been funded by the UK Department of Health/DETR. We would like to thank the staff and pupils of the schools which have taken part in the project.

REFERENCES

Classroom acoustics - Do existing reverberation time formulae provide reliable values?

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The acoustical conditions in classrooms are important in the educational task. It is well recognized that different types of absorber treatments in classrooms influence speech intelligibility. In the stage of planning such classrooms it is therefore important to predict the reverberation time sufficiently correctly. The aim of this paper is to investigate the accuracy of existing reverberation time formulae and computer simulated reverberation times. Some measured reverberation times in real classrooms are also compared with predicted reverberation times. The results of this paper suggest that Eyring’s formula may provide reasonable RT values if calibrated absorption coefficients obtained from measurements are applied. Using absorption coefficients from standard tables does in general yield, however, too high RT values compared to measured values.

INTRODUCTION

In classrooms usually the main absorption is on the ceiling and also on the floor due to the high audience absorption area where the pupil sits over. Using classical reverberation time formulae may therefore lead to incorrect predicted reverberation time values due to non-regular distributed sound absorption in the room. In calculating respective reverberation times (RT) it has been also well-recognised in the past that using classical RT formulae leads to differences in predicted RT values obtained using standard absorption data. Comparison of well-known classical reverberation time formulae as well as computer simulated reverberation times are presented in this paper. Measured reverberation times in eleven classrooms are reported for comparison. Also, some regulations recommend a mid reverberation time well below 1 s [1,2] in real classrooms often quite different reverberation times are perceived; especially at low frequencies.

REVERBERATION TIME FORMULAE

The reverberation time formulae that are usually given in Standards are either the Sabine or Eyring formula. Although it is well know that these reverberation time formulae are based on diffuse field theory and real rooms are likely not to fulfil these requirements, Sabine’s formula is still used by acousticians. Other reverberation time formulae are that of Millington-Sette [3,4], Arau [5], Fitzroy [6], Tohyama [7], the model of Annex D of CEN prEN 12354-6 [8] and the Fitzroy-Küttruff equation as proposed by Neubauer [9,10].

THE CLASSROOMS

Acoustical measurements of reverberation times were carried out at multiple source and receiver positions in 11 classrooms in 5 different schools. The measured RTs are shown in Figure 1. The rooms were in general rectangular having room volume of 50 m³ to 230 m³. All measurements were carried out in unoccupied rooms. Some classrooms contained absorbing ceilings some were without absorbing treatments on the ceiling. The floors were hard covered and one of the sidewalls was a window-facade.

Measured Reverberation Times

![Figure 1](image-url)  
*Figure 1. Measured reverberation time in 11 classrooms at frequencies across 50 Hz to 5 kHz.*
CALCULATED RT VALUES

The calculated RT values reported are the mean values at 500 Hz and 1 kHz. The values obtained by computer simulation are performed by the CATT-Acoustic program [11], using frequency dependent diffusion factors 0.2 and 0.4 for the frequency 500 Hz and 1 kHz, respectively. The calculation results are compared with measured RT as reported in Table 1. The used absorption coefficient where taken from standard tables or from product information’s and calibrated using Sabine’s theory.

Table 1. Measured and calculated reverberation time at mid frequency of 500 Hz - 1 kHz using calibrated sound absorption coefficients.

<table>
<thead>
<tr>
<th>No</th>
<th>RT [s] at Mid Frequency (500 Hz - 1 kHz)</th>
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Table 2. Mean and standard deviation of the calculated RT at mid frequency of 500 Hz - 1 kHz using calibrated absorption coefficients. Reported is: (Calc.-Meas.)/Meas.*100%

<table>
<thead>
<tr>
<th></th>
<th>Relative Difference at Mid Frequency</th>
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The Eyring, Millington-Sette and the Fitzroy-Krutruf formula provide smaller and the Fitzroy, Tohyama, Arau and prEN 12354-6 provide longer RT values than measured. The mean of the relative difference of calculated reverberation times compared to the measured RT are shown in Table 2. Indicated is the average mean and standard deviation for the mid frequency of 500 Hz and 1 kHz. The Eyring formula underestimates the RT in average less than 10% of the measured RT. The Tohyama’s formula, although at mid frequencies similar to the mean of the Fitzroy-Kruttruf formula, does not seem to be consistent over the six octave band frequencies. The Fitzroy formula and the model of Annex D of prEN 12354-6 yield highest differences compared to the measured RT. It is noted that the values using the CATT-Acoustic program are systematically higher than using the Eyring formula. It has also calculated the RT using all formulae with standard absorption coefficients. The average mean of the relative difference at mid frequency of all calculations as reported in Table 3 was found to be about 40%.

Table 3. Mean and standard deviation of calculated RT at mid frequency of 500 Hz - 1 kHz using standard absorption coefficients. No calibration was applied.

<table>
<thead>
<tr>
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<th>Relative Difference at Mid Frequency</th>
<th>Mean and Standard Deviation in %</th>
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</tr>
<tr>
<td>Stdv</td>
<td>21.7</td>
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</tr>
</tbody>
</table>

Sab: Sabine

Using standard absorption coefficient yield in general too short RT values typically more than 35% except of Fitzroy and prEN 12354-6 which yield in most cases too high RT values. No consistency in predicting respective RT compared with measured values was observed in any RT formula as well as for computer simulated results across all frequencies. In average of all formulae the relative difference of calculated RTs at mid frequencies using calibrated and standard absorption coefficient was of about 37%.

CONCLUSIONS

The results in this paper suggest that when predicting reverberation time in cases of unevenly distributed absorption, no one of the classical formula may predict RT reliable within a accuracy in average of 10%. Using standard absorption data yield for classical formulae in most cases too short RTs. The Fitzroy formula and the model of Annex D of prEN 12354-6 yield too high RT values.

REFERENCES
1. DIN 18041, Deutsches Institut für Normung (1968).
8. European Committee for Standardisation, final draft of Annex D of prEN 12354-6 (May 2001).
New Zealand primary school classroom types have been investigated for how well their acoustics support NZ teaching styles which use little teacher-at-the-board type of instruction. When rooms were modified to lower their reverberation time (RT) this raised teacher-ratings of the rooms from poor to good. Pupil speech perception scores did not show a marked change but activity noise levels were reduced significantly. Current research is addressing the measurement of S/N ratio in in-use rooms, the rating of floors for contact-generated noise, and a novel speech reception test.

INTRODUCTION

120 teachers in 7 Auckland schools were surveyed for their judgements of the success of the various classrooms they use, and their judgements were correlated with major design features of the rooms. In addition the teachers provided information about sources of noise and how they impacted on them and their teaching.

Based on the survey results 6 highly-rated rooms and 6 rooms with poor ratings were identified for detailed study. Data collected included MLS-measured impulse responses (from which standard acoustical parameters were derived), recordings of classroom sound during a full-day of use, and speech reception tests.

TEACHING STYLES AND CLASSROOM TYPES

Figure 1 gives a breakdown of the teaching styles found in the survey. Notable is the fact that conventional teacher-at-the-blackboard instruction accounts for only a small percentage of the time.

FIGURE 1. The proportion of time teachers spend teaching in different teaching styles

Table 1 shows the range of room types encountered. The main distinguishing features are the type of material used for the floor structure (all rooms are carpeted) and whether or not the ceiling has an additional absorptive treatment.

RESULTS

The main difference between "good" and "poor" rooms is the presence of an absorbing treatment on the ceiling. This is substantiated by the fact that in the rooms subjected to detailed study the 6 "good" rooms have significantly lower RT’s (0.4s cf 0.6s). Clarity measurements (i.e. C50 values) appear to correlate with the RT values but have not helped interpret the results from the speech perception tests.

Modified Rooms

Three different ceiling treatments were used to modify the 6 "poor" rooms with the goal of achieving a flat RT characteristic at 0.4s (see Fig. 2). The changes were unanimously welcomed by the teachers - for reasons of less noise, more on-task behaviour, reduced frustration, and removal of voice strain - and they also prompted appreciative comments from children.

FIGURE 2. Reverberation Times in the rooms before and after adding absorptive ceilings
Table 1. Categories of classroom in the study and their ratings by teachers

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<td>hessian on softboard</td>
</tr>
</tbody>
</table>

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 of rooms 21 34 37 15 6 3 3

Speech Reception Tests

Small groups of both normally-hearing and hearing impaired (HI) children were used for BKB speech tests which were carried out (1) with recorded classroom babble adjusted to give a speech-signal to babble-noise ratio of 0 dB at the test group, and (2) with live background noise from the rest of the class working in pairs on activity sheets.

The results for the speech perception tests (Fig. 3) did not differ significantly between the good and poor rooms (p=0.38 for live noise, and p=0.32 for recorded noise) but class activity noise levels differed very significantly (P<0.0001). HI children fitted with normal hearing aids performed very poorly (scores<50%) whereas those fitted with FM radio hearing aids in addition to their normal aids typically had scores in the range 50-90%.

We conclude that this test procedure has not satisfactorily quantified the acoustic performance of classrooms. Either the sensitivity and resolution of the tests are inadequate for showing up differences between the intelligibility in the rooms or the intelligibility was equally good in both types of room and differences perceived between the rooms are caused by features which we are not measuring.

CONTINUING RESEARCH

In separate projects we are investigating (1) the correlation between room rating and S/N using percentile level measures of the normal room activities, (2) a modified tapping machine to rank floors and coverings for suppression of scuff noise and other contact generated noise, and (3) the potential of chopped, segment-reversed speech as source material for speech reception tests.

CONCLUSIONS

A survey of 119 classrooms has indicated that ceiling absorption - and a resulting low RT - is an essential part of the room design if teachers are to feel satisfied with the acoustical performance. This was confirmed by making ceiling modifications to a group of rooms which reduced mid-frequency RT from 0.6s to 0.4s and raised the rating of the rooms from "poor" to "good". Speech perception tests using the BKB sentence test did not distinguish between the room types.

Further research is needed to determine if a more sensitive speech test is necessary and to establish measures for features relating to the noisiness of rooms.
Good Classroom Acoustics is a Good Investment

David Lubman \textsuperscript{a} and Louis C. Sutherland \textsuperscript{b}

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\textsuperscript{b}Acoustical Consultant, 27803 Longhill Drive, Rancho Palos Verdes, CA 90725 USA, lou-sutherland@juno.com

The incremental costs for achieving good classroom acoustics is a small fraction of total costs of new school construction. But since school construction funding is limited, good acoustics must compete with other programs intended to improve the education and lives of citizens. Good acoustics can survive this competition if decision makers are convinced that its costs are justified by their economic benefits. A proper economic study of this question has never been attempted. However, informal engineering estimates made by acousticians, audiologists, and material vendors suggest that the case for good classroom acoustics is strong. This paper identifies and estimates some of the costs for good acoustics in new construction. It also identifies and estimates some previously unrecognized economic benefits of good acoustics, as well as some of the hidden costs of marginal or poor acoustics. Costs and benefits are compared using recent economic data from the USA. Results suggest that the economic benefits of good acoustics far outweigh its costs. Therefore, a case can be made that good classroom acoustics is a good economic investment. The authors intend this paper to inspire others to more fully study the economic, social, and educational benefits of good acoustics.

\section*{DO BENEFITS OF GOOD CLASSROOM ACOUSTICS JUSTIFY COSTS?}

The education of its citizens is essential to all modern societies. Most formal education takes place in classrooms. Classroom learning typically involves intensive speech communication between teachers and students, and among students. The effectiveness of this communication, and hence, the effectiveness of the learning environment is mediated by acoustical conditions in the classroom. Good classroom acoustics greatly facilitates learning. With good classroom acoustics, learning is easier, deeper, more sustained and less stressful. Excessive noise and reverberation in classrooms are barriers to learning to the extent that they degrade or inhibit speech communication.

Poor classroom acoustics degrades the educational process for all students and teachers. It is also true that noise and reverberation are selective barriers to learning. Young children, adult learners, and persons with hearing, language, speech, attention deficit or other learning disabilities are especially vulnerable to marginal or poor acoustics.

The educational benefits of good classroom acoustic environments have not been quantified. This creates a problem. Absent clear statements of their benefits to learning, the features necessary to ensure good classroom acoustics are often omitted from classroom design specifications. Even when acoustical features are initially included in design, they are often removed in value engineering design exercises because they are perceived as costs without quantifiable benefits. It is important therefore to quantify the cost benefits of good classroom acoustics. This paper offers exercises intended to quantify cost benefits of good acoustics.

\section*{Costs for New School Construction}

Figure 1 shows recent costs for K-12 (Kindergarten through 12\textsuperscript{th} grade) US classrooms for the year 2000.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{costs.png}
\caption{Costs per square foot for new schools in US}
\end{figure}

\section*{Costs for Acoustical Ceilings}

Some classrooms suffer from excessive reverberation due to insufficient sound absorption. If the ceilings are not too high, a cost-effective way of introducing sound absorption is with an acoustical ceiling. Table 1 shows that the cost difference between a mediocre acoustical ceiling of NRC (Noise Reduction Coefficient) 0.55 and a good ceiling with NRC 0.75 is less than $1 USD per student, when amortized over a 20-year lifetime. It also
Ceiling Costs

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Cost per year (20 year life)

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<th>$53</th>
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<tr>
<td>$53</td>
<td>$61</td>
<td>$72</td>
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</tbody>
</table>

Cost per student per year

| $2.64 - $3.05 | $3.60 - $4.03 | $.97 |

| $700 - $800 | $700 - $800 | $.97 |

Table 1. Cost and performance of two ceiling acoustical treatments for a small classroom (30 students, 1110 sq. ft.)

shows that unoccupied classroom $T_{60}$ for the mediocre ceiling is 0.75 sec., somewhat too high for a learning space. The better ceiling reduces $T_{60}$ by almost 0.2 sec, which can make a noticeable improvement.

Educational Benefit of Upgraded Classroom Acoustical Ceiling

The maximum $T_{60}$ recommended for unoccupied classrooms of about 10,000 ft$^2$ is 0.6 sec. Table 1 shows a $T_{60}$ of 0.75 sec with the NRC 0.55 ceiling, which exceeds this recommendation. If the classroom has a fairly high ceiling of about 11 or 12 ft (not recommended), $T_{60}$ may even exceed 0.8 sec. Even if the SNR (speech-to-noise ratio) is an excellent 15 dB, the RASTI (Rapid Speech Transmission Index) score will be only about 0.6, which is marginal for learning. Upgrading the acoustical ceiling reduces $T_{60}$ by nearly 0.2 sec., which increases RASTI scores by about 0.05. The lower $T_{60}$ improves recognition of unfamiliar sentences by about 3% to 4% for normal listeners, and even more for listeners with communication disabilities. The benefit is even greater at low SNR.

Cost Benefit Ratio for an Upgraded Classroom Acoustical Ceiling

The cost for educating a child in a mainstream classroom is about $7000 USD per year per student. With the better ceiling, about 3% more unfamiliar sentences are understood correctly by normal students. A measure of the economic value of this improvement is $(0.03)*$7000 or $210. The additional $1 cost for the better acoustical ceiling is relatively insignificant. By this measure, the economic value of the better ceiling exceeds its cost by a factor of 200. That is surely a good investment! But unless value-engineering reviewers are told the economic benefits, they are likely to reject the better ceiling on costs alone.

Acoustical Access to Education

A metric is proposed by which the annual economic value of quiet can be estimated. Assume that AAE (Acoustical Access to Education) is nil when classroom ambient noise levels are 65 dBA and over. Also assume that AAE is 100% when classroom ambient noise is 35 dBA or less. Assume a linear relationship between AAE and noise level over the 30 dB range. Then every 3 dB of noise reduction in this range improves AAE by 10%. If the annual cost of education is $7000 per student, the value of a 3 dB classroom noise reduction is $700 per student. The value for a class of 20 students is thus $140,000 USD per year. This argument can be used to justify paying more for quiet HVAC or other noise-making products. It can also guide purchasing decisions when quieter but more expensive products are available alternatives.

Benefits of Reduced Teacher Absenteeism due to Vocal Strain

There were 2.9 million public school teachers in the US in the Year 2000 (National Center for Education Statistics) Teachers lose an average of 2 days/year for vocal fatigue caused by raising their voices to talk over noise. Recently, the cost for substitute teachers was about $220 per day. The national cost for teacher vocal fatigue is estimated at $638M USD. A large fraction of that cost could be saved each year if schools were quieter. Teacher satisfaction and the amount of verbal interaction between teachers and students would also improve. Dividing $638M among the 85000 US public schools would provide an annual budget of $7500 per school for educational purposes.

CONCLUSION

Current methodologies for estimating the costs and benefits of good acoustics are inadequate. Studies are needed to determine the full impact of acoustics on learning, the full social costs of poor acoustics, and the cost benefits of good acoustics. In the absence of methodical economic studies, crude estimates were made here. (Other examples will be given in the oral presentation). By standardizing and proliferating such measures, good classroom acoustics can be given the economic foundation it now lacks.

REFERENCE

1An earlier version of this paper was presented at the 138th Meeting of the Acoustical Society of America, J. Acoust. Soc. Am, Vol 106, No 4, Pt. 2, October 1999.
A Procedure to Improve Speech Intelligibility in University Classrooms

A. Astolfi, M. Perino, A. Piccaluga

INTRODUCTION

Speech intelligibility depends both on room acoustic effects, generally assessed in terms of reverberation time (T), and on background noise. To obtain optimal conditions for speech in a classroom a reverberation time of 0.4 - 0.5 s and an A-weighted background noise level of 35-40 dB(A) are required [1].

An acoustical parameter that bears a direct relation to speech intelligibility and combines both these information into a single index is the Speech Transmission Index (STI) [2]. It is based on the determination of the modulation transfer function that, in the case of purely exponential reverberation, can be derived applying the statistical room acoustics [3].

The early-to-late arriving sound ratio, clarity C50, is another parameter that is related to intelligibility and it, usually, represents a better indicator than reverberation time to characterise the effects of room acoustics.

This work presents the results of an investigation concerning determination of optimal acoustical conditions, assessed in terms of both STI and C50, in classrooms. Analyses were performed for two parallelepipedal shaped classrooms of the Politecnico di Torino, named R 5 and R 7, with volumes respectively around 700 and 1000 m³. The objective of the study was to assess the optimum reverberation time and location of added sound absorbing material for the occupied classrooms. The main characteristics of the classrooms and the 3D view of the geometrical models are reported in [4].

OPTIMUM REVERBERATION TIME

Figure 1 shows the calculated STI values, in the far field, versus the reverberation time (at 1 kHz), with the overall A-weighted noise level at the listener’s location (Lₐ) as a parameter, for R 5 classroom. Calculations (see [3] for the adopted procedure) have been performed assuming an A-weighted overall speech pressure level at 1 m in front of the talker (Lₚ₁ₘ) of 63 dB(A) (typical value for voice level produced by teachers in classrooms [1]). From this procedure the optimum reverberation times for which the STI is maximised for given Lₐ values were obtained.

Figure 1 gives the STI values that refer to: the present state of classroom R 5 (case R 5(0) - characterised by T = 1.3 s and Lₐ = 51.8 dBA) and two retrofit cases. The latter have been obtained by reducing reverberation time only (case R 5(1) - T = 0.6 s and Lₐ = 51.8 dBA), and by reducing both reverberation time and noise level (case R 5(2) - T = 0.5 s and Lₐ = 40 dBA). In case R 5(2) the reverberation time was reduced according to comfort limits reported in literature since further improvement of T would not have changed the subjective scale judgement from “good” to “excellent”.

The same analysis (not shown here for the sake of brevity) was performed for R 7, comparing the present state R 7(0) (T = 1.3 s and Lₐ = 50 dBA) with a retrofit case R 7(1), similar to R 5(1), (results are T = 1.3 s and Lₐ = 50 dBA) [5].

The rectangle shown in Figure 1 represents the parameter value range where the best compromise between comfort condition and intervention costs is reached.

LOCATION OF SOUND ABSORBING MATERIAL

Starting from the knowledge of the optimum reverberation time, the effects of the location of the added sound absorbing material on STI and C50 values were analysed with the ray-based calculation code RAMSETE 1.6 [6]. Analyses were carried out in octave bands, obtaining the optimal reverberation time profile versus frequency according to [7] (only 1 kHz results are here presented). For each case, R 5(1)-(2) and R 7(1), the optimum total sound absorption was kept constant and one type of material was added and it substituted part of existing coverings in the classrooms. Five different positions of the added sound absorbing materials were tested [5]. Only three of them (the most relevant) are shown in this paper (configurations A, B and C - Figure 2).

The sound source was simulated as omni-directional, producing an overall level of 65 dB at 1 m in front of the talker. This is equivalent to an A-weighted level of 63 dB(A), according to IEC 60268-16 [2]. It was located at the typical teacher position. Results are related to about sixty typical student positions, evenly spaced over the classroom.
RESULTS

$C_{50}$ values were averaged over the various receiver positions for the present states R 5(0) and R 7(0), and for the configurations A, B and C of the R 5(1), R 5(2) and R 7(1) cases. Results are plotted in Figure 3. An improvement of clarity can be seen, compared to the present states, by adopting configuration B. For classroom R 5 the clarity is maximum in case R 5(2).

Mean STI values and STI uniformity coefficient ($STI_{mean}/STI_{max}$) for each case are shown in the same figure. It can be seen that for R 5(1) and R 7(1) cases there are no sensible differences between the present state and all the absorption material configurations, either in terms of average value or in terms of uniformity values. For case R 5(2), on the other hand, a good improvement is found, in particular adopting a B or C configurations. A good spatial uniformity of STI is shown in Figure 2 for the former configuration.

In conclusion, the results show that when there are high background noise levels the speech intelligibility is not sensitive to relatively small changes around the optimum reverberation time and to the absorption material location. On the opposite the influence of the ambient noise levels is quite strong [1] [8]. When the noise is low (less than 40 dBA), the combined effects of optimum reverberation time and absorbing material location become a key factor. In this respect configurations B and C seem to be the best, with small differences between uniformity values.

REFERENCES

Noise, Classroom Behavior and Third and Sixth Grade Reading Achievement

J. S. Lukas

Consultants in Engineering Acoustics, 225 Bush Street, Suite 370, San Francisco, California 94104, USA

In 1977-79 noise levels were measured in 81 third and sixth grade classrooms in Los Angeles, California with and without children present. Schools adjacent to freeways were categorized as being noisy, while the nearest schools not adjacent to freeways were considered to be quiet. The socioeconomic compositions of the two groups of schools were similar. Student and teacher behaviors in response to noise were measured for several days in each classroom. Teachers’ voice levels were used to calculate the Articulation Index. Intrusive noise in classrooms was found to be from freeways, local streets and HVAC systems in the classrooms of both “noisy” and “quiet” schools.

A multiple-correlation technique was used to demonstrate the relationship between achievement in reading and mathematics and classroom and community noise levels, the Articulation Index and socioeconomic variables. The data show that English-fluent students had higher test scores in reading and mathematics than non-English-fluent students. Noise had a greater effect on reading than on mathematical achievement. Results suggest that higher noise levels are tolerable inside a classroom if community noise levels are low. However, these results may be deceiving because noisy schools tended to be located in noisy communities.

INTRODUCTION

Some studies suggest that intrusive noise in classrooms affects student achievement and behavior [1,2] and others that chronic exposures affect reading [3,4]. The study described below attempted to address these issues. Noise levels were measured in 3 to 5 locations in each community supplying children to each school and in the classrooms of 15 schools in Los Angeles.

Table 1 shows the mean sound levels in the areas providing children to each school. Note that some quiet schools are in noisy communities. Mean sound levels and their ranges inside the classrooms of the noisy and quiet schools are shown in Table 2. Sound levels in the classrooms of noisy schools are, on average, higher than in the classrooms of quiet schools. However, levels in some classrooms in quiet schools are higher than in classrooms in noisy schools due to heavy traffic on streets adjacent to the quiet schools.

Table 2. Classroom noise levels (Leq in dBC) in noisy and quiet schools - no children

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<td>41.7</td>
</tr>
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<td>45.5</td>
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<tr>
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<td>51.1</td>
</tr>
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<td>50.3</td>
</tr>
<tr>
<td>62.7</td>
<td>58.4</td>
<td></td>
</tr>
</tbody>
</table>

Behavioral results

Some relationships between noisy and quiet classrooms are shown in Table 3. Noisy and quiet classrooms are classified by whether classroom sound levels from external sources (traffic) or HVAC systems are greater or less than 58 dBC (about 45 dBA). As might be expected, the Articulation Index was higher in quiet classrooms than in noisier ones. Table 3 also shows that reading achievement among English-fluent students was higher in quiet class-rooms than in noisy ones.

Table 3. Mean classroom noise levels (in dBC) with and without children, can’t hear level changes, articulation index and teacher voice levels in classrooms categorized by noise levels without children (English-speaking)
Figures 1 and 2 show the calculated relationship between reading achievement in English-fluent students and desirable classroom and community noise levels given the racial composition of the Los Angeles school district and the actual noise levels and racial composition of the specific schools in this study. Figure 1 is relevant to students in 3rd grades, whereas Figure 2 is relevant to 6th grade students. These results suggest that, given some noise level in the area providing students to the school, increasing noise levels in the classroom result in lower reading achievement. And at a given noise level inside classrooms, increasing the community noise level is expected to decrease reading achievement.

REFERENCES


**FIGURE 1.** Relationship between reading achievement of English-fluent third graders and classroom noise levels given different noise levels in communities. The population is assumed to be 23 percent Black and 24 percent White.

**FIGURE 2.** Relationship between reading achievement of English-fluent sixth graders and classroom noise levels given different noise levels in communities. The population is assumed to be 23 percent Black and 24 percent White.
This document is part of a current study into the discomforting acoustics, perceived in some primary school canteens of the town of Bolzano. Over the last few years the use of canteens has become more important, due to the necessity in some schools to serve several successive sittings at mealtimes. The school canteens must guarantee hygiene. This demands aseptic materials, which are easy to keep clean. The canteens mentioned here are often found in premises set in basements. The proportion and characteristics of these spaces are those of cellars: reflective ceiling, as well as windows built close towards the ceiling. Therefore one can immediately notice a remarkable discrepancy between the necessity of cleanliness, sterility, washability and the strong acoustic pollution caused by children’s chatter. The problem of high reverberation time could be solved by intervening with heavy works of sound absorption in the traditional way. But that would mean to transfer the problem on to other times and premises. An articulate methodology to confront a problem and its complex nature is proposed. The school canteens must not neglect the sensitivity of the children and their need for an appropriate acoustics to allow dialogue and learning. Thus acoustics is to be integrated into the architecture as well as into the pedagogical programme of the school.

**Problem-field**

The meal represents an important moment in an infant’s school life. Apart from the satisfaction of a primary physiological need, during the meal the child gets drawn into a complex involvement of all senses. Beside this important sensitive experience, the child lives through an intense experience of socialisation and of contact with other people. Such experiences and strong sensations demand an environment for the child that contributes to its recreation and well-being. It should not become a source of stress or even lead to a refusal of the meal [1].

In order to create peace and encourage communication in school canteens, we have to improve their acoustics and transform the moment of the meal into an occasion of learning and of fulfilment of the senses.

**Acoustical environment and annoyance**

The room acoustics of canteens is often very aggressive. Sound-hard surfaces, like stone, ceramics and tiles, guarantee cleanliness and correspond to the hygienic demand, but they cause an acoustically unstable sound behaviour with reverberation time peaks up to 4 seconds. Even normal speaking, stimulated by this strong resonance, becomes an unbearable source of disturbance. This happens because persons tend to speak louder or even scream when they cannot hear each other clearly.

The acoustical landscape is defined at first by the children’s screams, accompanied by strong background rumours that are not perceived consciously. These rumours particularly stress the child’s ear which is especially delicate in the sound field of mid and high frequencies.

This kind of acoustic disturbance is caused by the impact of plates and glasses, by colliding pots, by metallic noise of knives and forks, by shaky loaded trolleys and by moving chairs and tables. Other noises are originated in the kitchen, like putting the plates into the dishwasher, the gush of water in the washing tubs, rumours of machinery, the dishwasher itself, refrigerators and the noise of the heating and air-conditioning system. Neighbouring and so called coupled rooms (stairscases, courtyards, streets, etc.) do also generate or amplify noises, the resonance in this case is delayed and thus very irritating.

**Organisation of the staff and intervention on the furnishings in the rooms and their disposition**

A good organisation of the movements and the sequence of the staff (service of meals, passing of the course, etc.) can avoid situations of conflicts. Furniture like chairs, tables and trolleys for the service should not become a source of noise (wheels and shelves should be “silenced”, etc.).

While big groups of children make conversation difficult, tables for groups of maximal 6 children seem to be more interesting [2]. A small group of children around one table can easier be helped by the staff and the teachers. To avoid
crowding of the children, the disposition of the tables needs to be studied with accuracy (relationship table/wall).

**Acoustic materials and applications**

Room acoustics has to privilege the hearing of the voices in an acoustically transparent and relaxing atmosphere. Linearity of sound frequency in space respects the naturalness of voices, and is fundamental for good acoustics and perception. Considering that the child’s auditory sensibility lies mainly in high frequencies, sound absorption should avoid too much absorption in that important region of the frequency spectrum. Linearity of sound frequency can be reached only by a special treatment of the low frequencies and of the sound absorption in areas of major noise. Absorbing and reflecting surfaces should in any case be distributed equally in the room, as to guarantee a homogenous sound behaviour in the room.

Materials like carpets, curtains and tapestry often present problems of cleaning. Still, a variety of materials are suitable to the purpose, for instance accurately covered and protected mineral wool panels, panels of synthetic fibres, such as polyester [3], and other porous sound absorbing panels. Special elements, like for instance wooden boxes with slits filled with mineral wool, for the absorption of the low/mid frequencies, can be partially fitted into the furniture, put on the ceiling or hung on the walls as decorative elements. By application of acoustically transparent perforated metal panels on the ceiling, the required quantities of sound absorbing materials and/or resonators can be placed in the “in between” spaces at disposition.

Acoustical materials however should not diffuse harmful microfibres into the air and/or contain formaldehyde, considering the hygienic and sanitary point of view.

**Aesthetic and architectural factors indirectly tied to the acoustical environment**

The ear must be allayed and not molested by sounds and voices, whose task it is to appeal to the senses. Natural and regular sounds, such as the running water of a little fountain could therefore positively accompany the meal, just as the nice sound of the burning wood, the chirping of canaries, and the ticking of the clock in grandmother’s kitchen.

As the acoustical environment of the canteens contributes to the sociability of the children, the architectural environment should be hospitable and introduce the image of nature (plants, window into nature, etc.). All the furnishings should be essential and rich at the same time, open niches for instance to create intimacy should guarantee transparency and visual contact to the rest of the room in an atmosphere of tranquillity and of respect. The sensibility of the child (maybe more than the one of the adult) perceives these characteristics and reacts consequently.

Sound absorbing objects settled in the space could be made by the children themselves, eventually in collaboration with the more creative teachers.

The canteens should be studied also regarding their colour, and be illuminated with natural light as much as possible. Artificial light should be as close as possible to the solar one, in respect to the natural colour of the food, which increases the appetite and encourages the conversation [4].

**ACKNOWLEDGEMENTS**

Many thanks to the Private Lecturer Dr. Dorothea Baumann, Universität Zürich, and to Prof. Dr. Yoichi Ando, Graduate School of Science and Technology, Kobe University.

**REFERENCES**

Children’s Perceptions of Noise in Schools

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Over 2000 primary school children in London have completed a questionnaire designed to examine their perception of noise in the classroom. The questionnaire also examined the ease with which they hear their teacher in different classroom situations. The children reported hearing many different noise sources, of which cars were the most frequent. Cars, lorries, motorbikes and sirens caused most annoyance, and trains the least. Older children were more aware of external noise than the younger age group, but were on the whole less annoyed by the noise. There were also variations in ease of hearing the teacher between the different age groups.

INTRODUCTION

Over the past 25 years there have been many studies into the effects on children and teachers of noise in schools [1-7]. However there is a lack of information on the attitudes to the noise of children themselves. This paper reports the findings of a questionnaire survey of over 2000 school children aged between 7 and 11, designed to investigate their perception of noise and of classroom listening conditions. This survey is part of a wider study into the effects of noise on primary school children in London [8,9].

QUESTIONNAIRE DESIGN AND SURVEY

Before designing the questionnaire interviews were held with pupils and teachers in a school outside London. To establish the children’s perceptions they were encouraged to discuss their opinions of noise and sound, and to say what noises they heard at school and at home. Based upon the results of these interviews a questionnaire was constructed in which a number of noise sources are listed and children asked to indicate whether they can hear each noise when at school, and, if so, whether they are annoyed by it. They are also asked the same questions relating to their home environment. The children were also asked to indicate, on a 5 point picture scale, how easy they found it to hear the teacher under different classroom situations. Additional questions elicited personal information from the children including language spoken at home and whether they suffered from any ear-related medical problems.

The questionnaire was distributed to all 53 primary schools in the London Borough of Haringey, and completed by all children in Year 2 (6-7 year olds) and Year 6 (10 to 11 year olds). In total 2036 children completed the questionnaire, of which 51% were boys and 49% girls, 43% were in Year 2, and 57% in Year 6.

77% of the children spoke English at home. For 66% of the children English is the only language spoken. Seventeen other languages were cited as being spoken at home; of these Turkish had the highest frequency being spoken in 5.9% of homes.

RESULTS OF THE SURVEY

Classroom listening conditions

The average score for each listening condition gives the following rating, from best to worst: 1) under test conditions, 2) when there is no noise outside the classroom, 3) when the teacher is talking and moving around the classroom, 4) when the teacher’s face cannot be seen, 5) when one pupil is answering a question from the teacher, 6) when working in groups, 7) during PE in the playground and 8) when children are making noise outside the classroom.

There were some minor differences between the two age groups, the older children finding it more difficult than the younger ones to hear when they cannot see the teacher’s face (F (1,2034) = 93.451, P<.001) and when children are making noise outside the classroom (F (1,2034) = 13.451, P<.001). There could be due to the more complex nature of the information being transmitted by the teacher. However, the older age group found it easier than the younger one to hear in test conditions (F (1,2034) = 63.316, P<.001), when there is no noise outside the classroom (F (1,2034) = 22.257, P<.001) and when the teacher is talking and moving around (F (1,2034) = 67.371, P<.001).
Figure 1. Percentages of children hearing noise sources

Figure 1 shows the percentage of children reporting hearing the different noise sources at home and in the classroom. It can be seen that the most frequently heard source in the classroom is cars (heard by 71% of children) followed by sirens (61%) and lorries (58%). For the majority of sources the older children reported greater incidence of hearing than the younger children.

Figure 2 shows, for the environmental sources heard, the percentages of children annoyed in the classroom.

The sources causing most annoyance are cars, lorries, motorbikes and sirens, with around 34% of children on average reporting being annoyed by these sources. The younger children reported being annoyed by more sources than the older children.

CONCLUSIONS

A questionnaire survey of over 2000 primary children in London has shown that children are aware of, and annoyed by, environmental noise when at school, and that ease of hearing the teacher varies according to the classroom situation.

ACKNOWLEDGEMENTS

This research has been funded by the UK Department of Health and DETR. We would like to thank the staff and pupils of the schools which have taken part in the project.

REFERENCES

9 B Shield and R Jeffery. A survey of noise levels in and around London primary schools. 17th ICA, Rome (2001)
Experimental and Numerical Analysis of the Sound Field in University Classrooms

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In this paper the results of an experimental and numerical analysis for the characterisation of the sound field in university classrooms are presented. The goals of the work were the comparison of models for the prediction of sound field in small and medium sized rooms. The study has been devoted to the assessment of the calculation procedure performance. In particular attention has been focused on models suitable for design stage. To this aim acoustical measurements were performed in unoccupied small and medium sized university classrooms in order to determine the “reference” values of the most relevant acoustical comfort parameters. For all the cases analysed the room shape was parallelepipedal. At the same time, the sound field in classrooms was simulated adopting both the typical model based on statistical acoustics (diffuse-field theory) and a calculation code based on the beam tracing algorithm. Calculated and measured values were compared and critically analysed.

INTRODUCTION

The work goal was to evaluate what is the most suitable design tool for the prediction of the acoustical comfort parameters in classrooms. To that purpose experimental results were compared with analytical and computer predictions for unoccupied university classrooms. The sound field in classrooms was simulated adopting both the typical model based on statistical acoustics (diffuse-field theory) and a calculation code based on the beam tracing algorithm. The reverberation time \( T \), the Sound Propagation index \( SP \) and the early-to-late sound ratio \( C_{50} \) have been assessed.

Analyses were performed in parallelepipedal shaped classrooms, varying from small lecture rooms to medium sized classrooms (from about 50 to 1000 m\(^3\)- see Tab. 1).

ANALYSES

Samples were performed at different points (1 to 6 locations) coincident with typical student positions. Measurements were taken in octave bands from 125 Hz to 4 kHz, using a Larson & Davies real-time SLM 2900 analyser, positioned at 1.2 m above the floor. The reverberation time \( T \) (based on the –5 to –30 dB range of the sound decay) was measured adopting the interrupted noise method [1] (Brüel & Kjær sound power source type 4205 - pink noise test signal).

The results for two sources and microphone positions were combined in order to obtain a spatial average for each classroom. \( SP \) [2] was measured in each position (noise source located in a central position, 1.5–2.5 m from the front-end wall, height above floor = 1.5 m). It is a useful index that describes how the room affects the variation of sound pressure level independently from the source output level. Finally \( C_{50} \) was determined in each position using the impulse response technique (a blank pistol bang was released in the same place of the noise source).

The diffuse field approximation was assumed for the simplified analytical predictions. The Sabine theory was applied for the calculation of the reverberation time and the steady-state sound pressure level [2]. \( C_{50} \) was determined from the analysis of an impulse response [3].

RAMSETE 1.6 [4] was the ray-based calculation code used for the computer simulation. Its algorithm is based on the beam tracing model. The surface reflection was modelled as specular. All the furniture was modelled as faithfully as possible. To compare different modelling solutions (classrooms 15 S, 11 B and R 7), the chairs and the desks were simulated in three different ways: like a flat surface (1), like a block (2) and as real chairs and desks (3). The absorption coefficients of the seats (wooden chairs and desks) were obtained from field measurements in classroom 15 S (validation of experimental data has been performed comparing the results with values found in literature).

The source features were assumed analogous to those of the source used for the measurements and the same absorption coefficients were used in both simplified and detailed numerical analyses.

RESULTS

Figure 1 shows, for each classroom, experimental reverberation times in octave bands, together with the predictions using both the Sabine formula and RAMSETE. Comparisons are shown for different seat configurations. Moreover, the average relative errors across the six octave bands from 125 Hz to 4 kHz are shown in order to evaluate the overall quality of the predictions. It can be seen that the Sabine formula gives the best estimates for the larger classrooms and the average relative errors agree with those reported in [5]. RAMSETE generally underestimate the reverberation time. Better results are obtained modelling the seats by means of a flat surface (1).

In Figure 2 \( SP \) versus source/receiver distance in the classrooms is shown for R 5 and R 7 (measured and theoretical data). Results are shown for 250 Hz, 1 kHz and 4 kHz octave bands. In all the analysed cases levels decrease monotonically with increasing distance and the best predictions are far from the source [2]. In the range of medium and high frequency bands Sabine theory generally underestimates levels while RAMSETE give generally better results. At lower frequency bands Sabine theory is better than RAMSETE (which tends to overestimate the actual values).
Table 1. Main characteristics of the classrooms and 3D view of the geometrical models.

<table>
<thead>
<tr>
<th></th>
<th>Meeting</th>
<th>IS 5</th>
<th>SI B</th>
<th>R 5</th>
<th>R 7</th>
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</thead>
<tbody>
<tr>
<td>volume [m³]</td>
<td>32.2</td>
<td>124</td>
<td>216</td>
<td>681.3</td>
<td>984.1</td>
</tr>
<tr>
<td>number of seats</td>
<td>8</td>
<td>34</td>
<td>42</td>
<td>80</td>
<td>207</td>
</tr>
<tr>
<td>Cₚₚ at 1 kHz [-]</td>
<td>0.11</td>
<td>0.07</td>
<td>0.09</td>
<td>0.1</td>
<td>0.09</td>
</tr>
</tbody>
</table>

3D view of the geometrical model

Figure 1. (●) Experimental and numerical predictions of reverberation time: (−−−−) Sabine; (····) RAMSETE (3); (····) RAMSETE (1); (−−−−) RAMSETE (2). Average relative errors across the six octave bands from 125 Hz to 4 kHz: white blocks, Sabine; solid bl., RAMSETE (3); cross-hatched bl., RAMSETE (1) (for 15 S, 11 B and R 7); slashed bl., RAMSETE (2) (for 15 S, 11 B and R 7).

Figure 2. (●) Experimental and numerical predictions of SP: (−−−−) Sabine theory; (····) RAMSETE.

Figure 3 shows the measured and theoretical values of the early-to-late sound ratio, Cₑₐ, as a function of the source/receiver distance (1 and 4 kHz octave bands). It can be seen that both diffuse field theory and RAMSETE slightly overestimate the Cₑₐ values, whilst there is a fair good agreement between the calculated profiles.

In conclusion, the analysis of the results suggests that the use of complex ray-based calculation codes for predicting acoustical comfort parameters in medium sized classrooms, does not seem to be particularly suitable at the design stage. In fact, they do not show a greater accuracy compared to simple diffuse field theory and, moreover, they require great computational resources. However the use of complex codes becomes mandatory when spatial details of the sound field are required (for example for the choice of the optimal sound absorbing material distribution inside the rooms [6]).

REFERENCES

The effect of repeating the same word-lists in listening test of word intelligibility and listening difficulty

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The listening difficulty is superior to intelligibility for evaluating the quality of speech transmission. The characteristics of the listening difficulty should be studied more in detail for practical purposes. In this paper, the repeating effect on the listening difficulty, and word intelligibility were investigated. In the tests, the same words selected according to word familiarity were presented for the same subject. As the results, intelligibility increases as the number of presentation increases and it finally becomes almost 100%. On the other hand, the listening difficulty hardly changes even if the number of the presentation increases. This means that it is possible to repeat the same words for the same subject in the listening test on the listening difficulty.

INTRODUCTION

In the previous study [1], the results of listening tests on word intelligibility and listening difficulty using test words selected according to word familiarity [2] demonstrated that: (1) the listening difficulty is highly correlated with intelligibility, (2) the listening difficulty can evaluate the quality of speech transmission more exactly and sensitively than intelligibility. Furthermore, the results suggested some other advantages in using the listening difficulty as opposed to intelligibility.

However, the properties of the listening difficulty should be investigated more in detail to use the listening difficulty in practice. Then, a lot of listening tests must be performed in spite that the number of word is not infinite.

This paper investigates whether the listening difficulty is affected when the same word is repeated for the same subject, comparing intelligibility.

LISTENING TESTS

Sound Fields and Test Signals

Figure 1 shows the impulse response of the test sound fields. Sound fields were composed of a direct sound and a reverberation signal. First reflection came at 50ms after the direct sound.

![Figure 1. Impulse response of the test sound fields.]

Table 1. Sound fields used in listening tests

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sound Field</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
</tr>
<tr>
<td>Reverb. Time (s)</td>
<td>0.5</td>
</tr>
<tr>
<td>Sound Pressure Ratio (Pr/Pd)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Three test sound fields, H, M, and L were used in the listening tests. Reverberation time was set at 0.5s, 2.0s, and 6.0s for H, M, and L, respectively. In all of test sound fields, the sound pressure ratio of the on-set component of the reverberation to the direct sound, Pr/Pd was fixed at 0.5. Table 1 shows the sound fields used in the listening tests. H, M, and L indicated high, middle, and low intelligibility in the previous study [1].

Test signals were prepared by convolving words with impulse response of test sound fields. Four test signals were used in the listening tests as shown in Table 2. In the tests, two word-lists with the highest familiarity were used. Each list includes 50 words.

Test signals were presented to two subjects at a time in an anechoic room. Frequency response of the loudspeaker was flat within 1 dB from 100 to 10kHz at listening positions. The listening positions were located 3m from the loudspeaker and 30 degrees from the central axis. The averaged peak level of direct sound was set to 55.0 dB 3.0dBA at the listening positions.

Procedure

Two series of test were performed as below. In the first test, the test signals M1 and H1 were presented by turns, to focus on the change in the response to M1. In the second test, the test signals L2 and H2 were presented by turns, to focus on the change in the response to L2.
RESULTS AND DISCUSSION

Figure 3 shows the averaged values and standard deviations of scores of intelligibility and the listening difficulty for each presentation. The results of the first and second test were obtained for 10 and 12 subjects, respectively. Because the results of two subjects for the listening difficulty in the first test had not any tendency and were quite different from the others, it may be considered that they were inexperienced in rating listening difficulty.

In both tests, intelligibility increases as the number of presentation increases. It finally becomes almost 100% and there are no differences between the two sound fields. This can be regarded as a learning effect caused by repeating the same word-list. The listening difficulty hardly changes even if the number of presentation increases. The differences between the two sound fields were constant. This means that the listening difficulty is not affected by repeating the same word-list for the same subject.

T-tests were performed to determine whether or not the difference between averaged scores in each presentation of sound fields was significant. As for intelligibility, there are significant differences between the first presentation and all of the others in both M1 and L2 (p<0.05). And also, there are significant differences between the second and the fourth, as well as, the second and the fifth (p<0.05). There is no significant difference in any combination of the third, fourth and fifth. On the contrary, the listening difficulty shows a significant difference only between the first and fourth presentation in H1 (p<0.05).

CONCLUSIONS

Intelligibility is affected by repeating the same word-list for the same subject, but the listening difficulty is not. This means that it is possible to repeat the same word-list for the same subject in the listening test on the listening difficulty. It is not possible to repeat the same word-list for the same subject in intelligibility.

REFERENCES

Acoustic Performance of Rectangular Classrooms

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An acoustic analysis was carried out by experimental acoustic measurements of several rectangular classrooms of different dimension in order to obtain the room impulse responses. Several acoustic indices (EDT, $C_{50}$, $C_{30}$, STI) were considered related to the intelligibility of the speech. Numerical results were validated by some experimental measurements in real rooms of significant geometric similitude to calculated situations. The analysis carried out produced design rules for correct classroom acoustics.

INTRODUCTION

The acoustic design of classrooms should be achieving the highest possible degree of speech intelligibility for all listeners in the classroom. The room acoustic response influences significantly speech intelligibility. The enclosure enhances the perception of speech when the bigger amount of energy reaches the listener in the first 35-50 ms (integration period). Late arriving reflections and high reverberation interfere with the direct speech signal so too much late sound energy tends to reduce speech intelligibility.

In order to predict the speech intelligibility several acoustic parameters were proposed such as EDT, $RT_{20}$ and $RT_{30}$ reverberation times and early/late energy ratios as $C_{50}$, $C_{30}$, $D_{30}$.

All that parameters are derived by impulse response of the room. The impulse response is a complete characterization of a LTI (linear and time invariant) system and is intimately related to the system function. The excitation signal used is the pseudo-random sequence of pulses called MLS (Maximum Length Sequence) [1,2]. The MLS input signal enables to obtain an impulse response containing the entire audio frequency range over the measured time range. The impulse response of the system is obtained by computing the cross-correlation between input and output signal. The cross-correlation reduces the background noise uncorrelated with MLS increasing the S/N ratio.

ACOUSTIC PARAMETERS

The EDT parameter (Early Decay Time) is the reverberation time, measured over the first 10 dB of the decay. $T_{20}$ or $T_{30}$ is the reverberation time of the room evaluated over a 20 dB (or 30 dB) decay range, from -5 to -25 dB, on the integrated Schroeder curve. As reverberation parameters, the EDT, $T_{20}$ and $T_{30}$ are computed for every octave band. In addition, other parameters, also derived from impulse response, related to early/late sound energy were calculated.

The $D_{30}$ parameter (Definition) is the early to total sound energy ratio. The $C_{50}$ parameter (Clarity) is the early to late arriving sound energy ratio.

It is common practice to calculate this parameter also over 80 ms ($C_{80}$). The TS parameter (Centre Time) is the time to reach half the response energy. [3,4]

Speech Transmission Index (STI) represents the mean apparent S/N ratio over the frequency range which is relevant to the modulation frequencies of the speech envelope.

![FIGURE 1. Simulation rendering of classroom #2](image)

The apparent signal-to-noise ratio, at frequency $f$, is:

$$ (S / N)_{app,f} = 10 \log \left( \frac{m(f)}{1 - m(f)} \right) $$

The function $m(f)$, called complex modulation transform functions is the complex Fourier Transform of the squared impulse response divided by its total energy.[5]

MEASUREMENTS

Measurements of impulse responses of three classrooms was carried out with a dodecahedron omnidirectional loudspeaker, a Bruel&Kjaer amplifier, $\frac{3}{4}$" microphone and signal conditioner. The acoustic signals were processed by AURORA-code for evaluating the impulse response and the acoustic parameters.

The STI values were evaluated handling the impulse response with self-made software. The reverberation times and the STI values were obtained by measurements carried out in the classrooms without occupants so obtaining values higher than actual ones. However the decreasing of intelligibility would have
the same trend with occupants.

The positions of loudspeaker and microphone in classroom #2 were shown in Fig. 2; in the others classrooms the same grid was used. The measurements were carried out on three classrooms of Facoltà di Ingegneria del Politecnico di Bari in Taranto with the same width and height and increasing length, obtaining volumes of 147, 294 and 607 m³. The classrooms have similar string windows and similar wall rendering; as a consequence the influence of acoustic absorption and of width-to-height ratio were considered negligible.

RESULTS

The processing of the experimental impulse response shows the deterioration of intelligibility from the first doubling of length, pointing out low values of STI with increasing of reverberation. All the acoustic parameters were related to early/late sound energy ratio.

### Table 1. Mean reverberation times and STI values

<table>
<thead>
<tr>
<th>Classroom</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length-to-height ratio</td>
<td>2.3</td>
<td>4.6</td>
<td>7.6</td>
</tr>
<tr>
<td>recommended RT [s]</td>
<td>.94</td>
<td>1.14</td>
<td>1.28</td>
</tr>
<tr>
<td>Sabine RT [s]</td>
<td>1.54</td>
<td>1.74</td>
<td>1.95</td>
</tr>
<tr>
<td>measured T₂₀ [s]</td>
<td>1.65</td>
<td>2.17</td>
<td>3.25</td>
</tr>
<tr>
<td>simulated T₂₀ [s]</td>
<td>1.68</td>
<td>2.21</td>
<td>3.29</td>
</tr>
<tr>
<td>measured STI</td>
<td>.44</td>
<td>.25</td>
<td>.22</td>
</tr>
</tbody>
</table>

In Tab. 1 we report the RT recommended by Italian Decreto Ministeriale (DM 18/12/75), the Sabine reverberation times, the T₂₀ evaluated through measured impulse responses and the T₂₀ values resulted by simulation with RAMSETE-code [6]. Reported values are averaged values versus frequency and space. The early/late sound energy ratios, reported in Tab. 2, show reduction of speech intelligibility with increasing volumes of the classrooms.

### Table 2. Mean acoustic parameters

<table>
<thead>
<tr>
<th>Classroom</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>D₅₀ [%]</td>
<td>35.6</td>
<td>14.9</td>
<td>12.1</td>
</tr>
<tr>
<td>EDT [s]</td>
<td>1.7</td>
<td>2.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Ts [ms]</td>
<td>121.8</td>
<td>182.8</td>
<td>237.2</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The measurements carried out and the evaluation of acoustic parameters show that doubling the length of a classroom involves a strong reduction of speech intelligibility, increasing the reverberation and the late arriving sound energy. In the smallest classroom the STI values have been between .32 and .77 from back to front of room; instead in the longest classroom the best STI value was .33 dropping to .21. STI values for classroom #1 are closely related to C₅₀ and C₈₀ values, STI values for classrooms #2 and #3 are poorly related. Trends for classroom #1 are shown in Fig.2 showing also all the measured points and for classrooms #2 and #3 in Fig. 3. A progressive loss of correlation is evident as the length-to-height ratio increases from 2.3 for classroom #1 to 7.6 for classroom #3; the value for classroom #2 is probably the threshold for the loss of significance of the correlation as the trend for C₈₀ has not yet lost a significant dependence versus STI.

### Figure 2. C₅₀ and C₈₀ energy ratios versus STI values.

<table>
<thead>
<tr>
<th>C₅₀ &amp; C₈₀ (% of STI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
</tr>
</tbody>
</table>

#### FIGURE 2
Trends for classroom #1

#### FIGURE 3
C₅₀ and C₈₀ energy ratios versus STI values and trends

A simple design rule can ensue from these considerations: when increasing length-to-width ratio the loss of significance for C₅₀ versus STI correlation is the pointer for overall deterioration of speech intelligibility.

REFERENCES

3. ISO3382, Acoustics – Measurements of reverberation time in auditoria, 1975
Guidance for Acoustics in Schools in the UK and the UK Building Regulations

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Until recently the Department for Education and Employment (DfEE) has been responsible for acoustics in schools in the United Kingdom, and has given advice in a number of documents containing the requirements and design guidance for acceptable acoustics. In April 2001, responsibility for schools passed from the DfEE to the Building Regulations section of the Department of Environment Transport and the Regions (DETR) which publishes the Building Regulations for England, Wales and Northern Ireland. The transfer of responsibility coincides with a revision of the building regulations for acoustics in Approved Document E and the updating of advice for acoustics in schools contained in Building Bulletin 87. This paper discusses some of the proposed changes and standards that are to be applied to new schools.

INTRODUCTION

In the United Kingdom there are approximately 22000 schools covering early years' education to 6th form colleges. Currently there about 50 new schools being built and a further 170 being refurbished in the state sector per year.

Three documents relevant to acoustics within schools are currently being revised in the UK. These are:

1. Approved Document E [1] (ADE) which sets out the requirements for acoustic conditions in and between residential dwellings and within schools

2. DfEE Building Bulletin 87 [2] (BB87) which includes guidelines for the acoustic design of schools


The proposed changes to ADE include three new requirements (Table 1) that directly relate to the acoustic requirements within schools and educational buildings. Proposed requirements E1 and E2 relate to residential accommodation (so called 'Rooms for residential purposes') within educational premises and are not considered in this paper. Requirement E5 is identical to that previously contained in the Education (School Premises) Regulations [6]. Guidance within ADE refers directly to BB87 and BB93.

| E1 - Protection against sound from adjoining dwellings or buildings etc. |
| "Dwellings and rooms for residential purposes, shall be designed and constructed in such a way that they provide reasonable resistance to sound from: adjoining dwellings; adjoining rooms for residential purposes; other parts of the same building; and adjoining buildings." |

| E2. Protection against sound within a dwelling etc. |
| "Dwellings and rooms for residential purposes' shall be designed and constructed in such a way that: (a) an internal wall between a room containing a WC and a living room, dining room, study or bedroom (except where the WC is en-suite) shall provide reasonable resistance to sound, and (b) an internal wall between bedrooms and between bedrooms and other rooms, and an internal floor between bedrooms and between bedrooms and other rooms, shall provide reasonable resistance to sound." |

| E5 - Acoustic conditions in schools |
| "Each room or other space in a school building shall have the acoustic conditions and the insulation against disturbance by noise appropriate to its normal use.” |

Table 1 Proposed building regulation requirements for schools

This paper discusses some of the reasons behind the changes and also introduces some of the proposed changes for the revised BB87.
BACKGROUND TO THE CHANGES

There are a number of reasons for the changes having been made. Firstly control over acoustics in schools transferred from DfEE to DETR Building Regulations following a review [7]. The benefits of this were perceived to be that (i) enforcement would be improved by transferring control, (ii) minimum design standards would now be applied to all new schools in both the state and private sector (iii) the status of available guidance would be improved by referral from within ADE.

INTENTION OF BB87

The intention of BB87 is to provide minimum and constructional standards for (i) ensuring appropriate background levels (ii) controlling reverberation and (iii) providing adequate sound insulation as a way of satisfying requirement E5. There are three parts to the guidance. Part A1 contains the guidelines for acoustic design in schools, Part A2 contains guidance on how to achieve the design targets in A1 and Part A3 gives glossary and definitions of commonly used terms.

MAIN FEATURES

The revised guide has introduced a number of changes. The principal ones are (i) the sound insulation criterion has been changed from $D_{w}$ to $D_{t_{w}}$, with $D_{t_{w}}$ values based upon maximum recommended room Reverberation Time (RT). (ii) Control of impact sound is included for the first time with a design value of $L'_{10,T_w} + C_i = 62$ dB. (iii) Control of RTs in corridors and stairwells is included. (iv) Control of external noise (façade insulation) is highlighted.

<table>
<thead>
<tr>
<th>Minimum $D_{t_{w}}$ (dB)</th>
<th>General teaching, seminar and tutorial class bases, science labs, administration offices, staff rooms, medical rooms</th>
<th>Individual study, withdrawal, remedial teaching, preparation, interview, counselling, offices (with need for privacy)</th>
<th>Libraries</th>
<th>Language laboratories, lecture rooms, audio-visual rooms</th>
<th>Indoor sports, changing rooms, dining rooms, kitchens, plant rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilets</td>
<td>40 (50)</td>
<td>50 (57)</td>
<td>50 (57)</td>
<td>50 (57)</td>
<td>43</td>
</tr>
<tr>
<td>General teaching, seminar and tutorial, class bases, science labs, commerce and typing, administration offices, staff rooms, medical rooms</td>
<td>40 (50)</td>
<td>50 (57)</td>
<td>50 (57)</td>
<td>50 (57)</td>
<td>50 (57)</td>
</tr>
<tr>
<td>Individual study, withdrawal, remedial teaching, preparation, interview, counselling, offices (with need for privacy)</td>
<td>40 (50)</td>
<td>50 (57)</td>
<td>50 (57)</td>
<td>50 (57)</td>
<td>54 (60)</td>
</tr>
<tr>
<td>Libraries</td>
<td>40 (50)</td>
<td>50 (57)</td>
<td>50 (57)</td>
<td>54 (60)</td>
<td></td>
</tr>
<tr>
<td>Language laboratories, lecture rooms, audio-visual rooms</td>
<td>50 (55)</td>
<td>54 (60)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Sound insulation values (values in brackets are values for hearing impaired)

REFERENCES