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CLASSROOM ACOUSTICS
A RESEARCH PROJECT

SUMMARY REPORT
1999

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Summary

This report was compiled by David J. MacKenzie and Sharon Airey of The Department of Building Engineering and Surveying, Heriot-Watt University, Edinburgh, Scotland. It provides an account of research work undertaken into the acoustics of classrooms carried out between April 1998 and May 1999.

The report is a result of research funded by the Engineering and Physical Science Research Council (1996-1998) and by Ecophon (1998-1999) into the effect of poor acoustics in classrooms. Over seventy teaching spaces were investigated, all in primary schools. Schools were tested in Scotland, England and Northern Ireland.

A range of objective and subjective tests were carried out in classrooms which were both occupied and unoccupied. Various test cases were carried out in a series of classrooms before and after installation of Ecophon acoustic tiles. Children and teachers were an important part of this research project. During tests they were fully involved with the measurements and their comments were noted.

This work has highlighted the problem of poor acoustics in classrooms and this point has been raised many times in the national press and other media. Speech intelligibility was found to be poor in many classrooms as a result of excessively high background noise levels and long reverberation times. Results have clearly shown that the problem can be solved with the introduction of the appropriate material into the classroom concerned.

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1 Introduction

1.1 General Introduction

The majority of people, whether they are in the United Kingdom, Europe or anywhere else in the world, will have attended school at some time of their life. Whether this was a happy period or otherwise is open to debate. Education is part of our daily lives irrespective of the country in which we live.

Each school can be split into various areas, and this report will emphasise on probably the most important area within a school - the classroom. The classroom is the room in which the majority of children will spend most of their time whilst at school. Collins English Dictionary defines a classroom as: '*a room in which classes are conducted especially in a school or college*'[1]. A class is a group of people who are brought together to be taught.

To young children, in particular, a classroom is an important room - a room that most will remember for the rest of their lives. In primary schools, pupils tend to remain in the same room for the year whereas in secondary schools, rooms are used for teaching a particular subject hence pupils will stay in a room for one or two hours at a time. The work described in this report concentrates on classrooms within primary schools. The majority of the schools visited are around the Edinburgh area, with others being in Ireland and England. The environment within a classroom must be acceptable for teaching and learning purposes. Although this internal environment covers a number of different aspects, this report will concentrate on research into the acoustics of classrooms.

1.2 Aims of Research Project

The aims of the research project were as follows:

a. Aim 1 - Investigate the effect of reverberation time on the acoustics of classrooms;

b. Aim 2 - Investigate the psychological effect of excessive classroom noise on primary school children;

c. Aim 3 - Investigate the psychological effect of excessive classroom noise on primary school teachers, and

d. Aim 4 - Education package.

1.3 Children With a Hearing Impairment

During a child's development, information about the world around them is taken in through their senses and processed by the brain. This is learning. One of the most important senses, hearing, provides the child with new concepts and new vocabulary. Hearing and speaking enable the child to interact with others, form a language with which to reason and question, and to learn.

However, as Fiellau-Kikolajsen discovered in 1983, *"up to 95% of primary school children suffer middle ear disease in the first 10 years"*[2]. The majority of hearing losses clear up, but this problem often goes undetected. A teacher may not realise which children in his/her class are hearing properly and which children may not be hearing well, or perhaps hearing but not understanding, due to some form of temporary hearing problem. Coughs and colds, the main causes of temporary hearing loss, are prevalent in school age children, and hearing problems tend to occur at an age critical for normal development, i.e. during the primary school years.

As well as a number of hearing children with temporary hearing loss, a class may contain children with a wide range of more serious hearing impairment. The 1981 Education Act[3] states that special needs children must not be excluded from mainstream schools. Consequently, more and more hearing impaired children, some with hearing aids, are being integrated into mainstream schools and being taught in mainstream classrooms. Many of these classrooms were not designed with good acoustics as a main priority. Subsequently, noise and poor speech intelligibility could be putting up barriers to learning for certain children.

1.4 Definition of Speech Intelligibility

These words have appeared a number of times. Within any classroom, or in fact any room whereby people need to listen to what is being said, speech intelligibility is an extremely important parameter of that space. So what does it mean? Speech intelligibility is the process whereby a person can clearly hear what is being said and fully understand the context of the spoken word. This will be discussed in more depth within a later section. In a classroom situation, children should not only clearly hear what the teacher is saying but also the teacher must hear what the pupil is saying, perhaps in the reply to a question he/she may have been asked.

In a recent article[26], definitions were put forward with respect to the following terms:

a. Clarity;
b. Audibility, and
c. Intelligibility.

Clarity: the property of sound, which allows its information bearing components to be distinguished by the listener;

Audibility: the property of sound which allows it to be heard among other sounds, and

Intelligibility: this is a measure of the proportion of the content of a speech message that can be correctly understood.

Clarity + Audibility = Intelligibility

1.5 Factors Which Affect Speech Intelligibility

There are many factors within a classroom which can affect speech intelligibility. Some are more important than others, and these are shown in Figure 1.1 below:

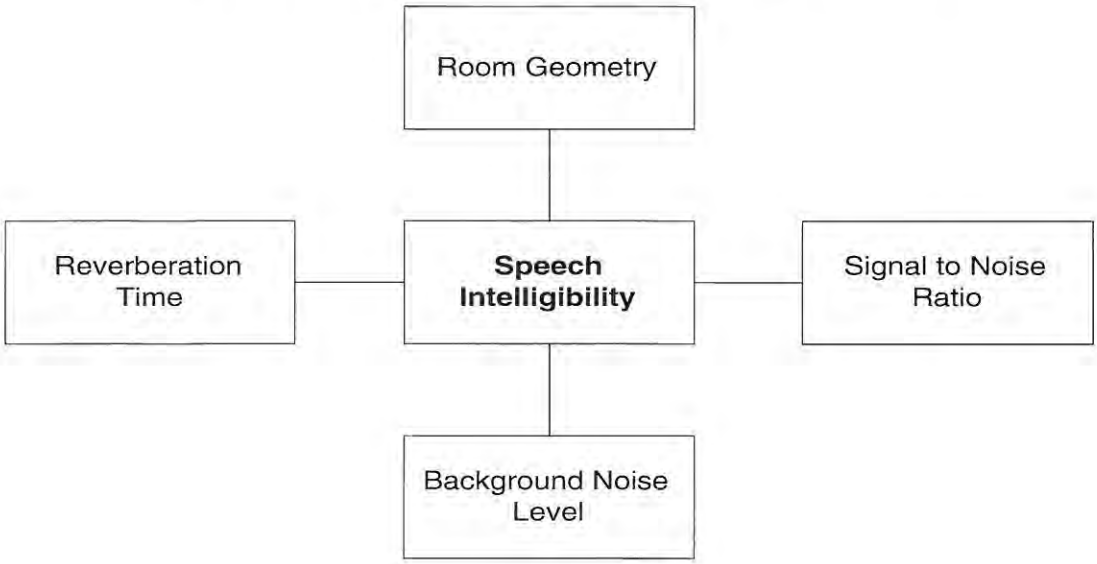

Figure 1.1: Factors Which Can Affect Speech Intelligibility

Reverberation Time: this is the time it takes for sound to decay by 60dB. The value of the reverberation time is given in seconds, and is dependent upon the surface finishes within the room. Increased absorption lowers the reverberation time;

Room Geometry: many of the older classrooms are of a rectangular shape with the teacher located at one of the shortest wall dimensions. However, modern schools have classrooms that have many different shapes, both on plan and cross-section. For example, instead of having a flat ceiling, many have sloping ceilings. The location of where the teacher is the majority of the time whilst delivering lessons is important with respect to the shape of the room;

Signal to Noise Ratio: this is the relationship between the signal level (teacher's voice) to the noise level (background noise), within the classroom. The smaller the difference between these two levels the more difficult it will be for pupils to discriminate what is being said. The recommended signal to noise ratio is +15dB. That is, the teachers voice should be 15dB above background noise level, and

Background Noise Level: this is the noise level that exists in the classroom as result of normal everyday operations.

The quality of the speech intelligibility in a classroom is therefore dependent upon a number of factors. Changing one of these factors may improve the speech intelligibility or it may not.

1.6 Impact of Poor Acoustics Upon The Room's Occupants

The effect of reverberation and noise upon word identification was investigated by Yacullo and Hawkins[4]. These researchers presented thirty-two normally hearing 8-9 year olds with words in rooms with reverberation times of 0.0 seconds and 0.8 seconds, plus signal to noise ratios of +2 and +6dB. Reverberation was found to decrease the mean speech recognition by 41.1%, whilst the scores decreased by 27.4% as the signal to noise ratio dropped. This paper also presents reverberation time as having the most detrimental effect on the intelligibility of speech in classrooms.

A comprehensive study carried out in 1997[5] discussed previous research and presented findings from a new investigation. This report discusses the detrimental effect of speaker to listener distance and the masking of speech sounds by high and low frequencies; it also reviews previous work on the combined effect of reverberation time and background noise levels. Findings from the Finitzo-Heiber[6] paper were discussed and the combined effects of reverberation and background noise on normally hearing and hearing impaired children were presented as shown in Table 1.1 below:

	RT = 0.0 seconds		**RT = 0.4 seconds**		**RT = 1.2 seconds**	
Signal/ Noise Ratio	**Normal Hearing**	**Hearing Impaired**	**Normal Hearing**	**Hearing Impaired**	**Normal Hearing**	**Hearing Impaired**
quiet	94.5	83.0	92.5	74.0	76.5	45.0
+12 dB	89.2	70.0	82.8	60.2	68.8	41.2
+6 dB	79.7	59.5	71.3	47.7	54.2	27.0
0 dB	60.2	39.0	47.7	27.8	29.7	11.2

Table 1.1: Percentage of Words Correctly Identified in Various Conditions by Normal Hearing and Hearing Impaired Children

Much work has been conducted on the effect of noise upon humans, and various research papers have identified the large amount of classrooms with poor acoustics around the world. Some researchers have discussed what the effects upon children and teachers may be. The main causes of poor speech intelligibility have been found to be high levels of background noise and long reverberation times. Very little work has been conducted on the difference between occupied and unoccupied classrooms.

1.7 The School Premises Regulations

The following statement from The School Premises Regulations[7] appears in the Department For Education and Employment, *'Guidelines For Environmental Design in Schools'* (Building Bulletin 87)[8] - *'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'*. This is a particularly interesting statement and one that needs to be carefully considered during the design or refurbishment of classrooms.

1.8 Guidelines For Environmental Design in Schools

This report published by the Department For Education and Employment (DfEE) in 1997, which is also known as Building Bulletin 87, supersedes Building Bulletin 17 *'Guidelines For Environmental Design and Fuel Conservation in Educational Buildings'* the second edition of which was published in 1981[9]. Table 1.2 presents an extract of the acceptable background noise levels within certain rooms:

Room Activity	**Activity Noise Level**	**Background Noise Level**	
	General Category	**Tolerance Level: General Category**	**Maximum BNL $L_{Aeq,1hr}$, (decibels)**
General Teaching Classrooms	Average	Medium	40 (30)
Lecture Rooms	Average	Low	35 (25)
Indoor Sports	High	High	50 (40)

Note: the background noise levels in brackets are for rooms used for teaching hearing impaired children. It is recommended that the $L_{Aeq,1hr}$ level be at least 10dB lower.

Table 1.2: Recommended Acoustic Standards For Specific Rooms[8]

Table 1.3 below shows the minimum sound insulation values between adjacent rooms for different situations. The table is used by checking whether the spaces adjacent to each other are of a high or low tolerance level. For example, a space with a high noise level next to a space with a low tolerance level would need to provide a wall with high sound insulation properties.

Minimum Sound Insulation, D_w, (decibels)				
Tolerance Level in Receiving Room	High	38 (48)	28 (38)	28 (38)
	Medium	48 (55)	38 (48)	28 (38)
	Low	52 (58)	48 (55)	38 (48)
		High	Medium	Low
	Activity Level in Adjacent Space			

Note: the sound insulation levels in brackets are for rooms used for teaching hearing impaired children. It is recommended that the D_w level be at least 10dB lower.

Table 1.3: Recommended Minimum Sound Insulation[8]

In the above table, the lower the value the poorer the sound insulation of the wall or floor. A higher value provides a better sound insulation.

1.8.1 Noise Control

Noise intrusion into a classroom from various sources should not, during school hours, exceed those recommended in Table 1.2. The background noise level in a teaching classroom should not exceed a $L_{Aeq,1hr}$ of 40dB.

There is a mention in this section that if a classroom or space is mechanically ventilated, the background noise from the ventilation system can be used to "mask noise from neighbouring activities". It is also beneficial for the background noise level in a teaching classroom not to fall below a $L_{Aeq,1hr}$ of 30dB. In the event of impact noise, this may be controlled through the use of carpets or resilient vinyl.

1.8.2 Reverberation Time

Recommended reverberation times for different unoccupied spaces within primary schools are shown in Table 1.4 below:

Room Activity	**Approximate Size**		**Recommended Unoccupied Mid-frequency RT (seconds)**
	Area (m^2)	**Height (m)**	
Classrooms	30 - 65	2.4 - 3.0	0.5 - 0.8 (0.3 - 0.6)
Hall (assembly/physical education)	80 - 200	3.7 - 6.0	0.8 - 1.2
Hall (music/drama)	80 - 200	3.7 - 6.0	0.8 - 1.4
Library	12 - 70	2.4 - 3.0	0.5 - 0.8

Note: the reverberation time in brackets are for rooms used for teaching hearing impaired children. It is recommended that the RT be at least 0.2 seconds lower than standard values.

Table 1.4: Recommended Reverberation Times (Primary Schools)[8]

1.9 Other Criteria

Some of the other criteria that is used for the design of schools and classrooms is shown in Appendix A. Appendix B highlights room design from the BRE publication "The Acoustics of Rooms For Speech".

2 Project Outline

2.1 Introduction

Prior to the commencement of the Ecophon project, initial research work in this area was undertaken in a project funded by the EPSRC, which commenced on January 1 1996 and ended on March 31 1998[10]. The project leader was David J. MacKenzie with Professor Bob Craik as co-researcher and Sharon Airey as the researcher for the project.

2.2 Research Project Decisions

2.2.1 Which Classrooms Have Been Included and Why?

With these points in mind, a number of decisions were taken concerning the research project which commenced in 1996. These are:

a. Only primary schools would be included in the project.

The reasoning behind this was that if the acoustics of primary school classrooms were as bad as reported, this would have a detrimental effect on young children who are just beginning to embark on their education;

b. Classrooms, which included children with a hearing impairment, would be included in the research.

The selection of schools for testing was undertaken by St. Giles Centre for Hearing Impaired Children in Edinburgh. This centre oversees the education of hearing impaired children in the Lothian Region of Scotland. The criteria for a school to be selected was that one or more hearing impaired children were placed in a mainstream classroom within the school. Generally none of these classrooms had undergone any specific treatment, primarily due to lack of advice and funds, and what treatment there was tended to be limited to various degrees of carpeting.

Several additional schools were selected across the UK as test cases, to investigate the standard of acoustics before and after the installation of acoustical suspended ceilings and/or ceiling and wall tiles. One school in particular (Aberdeen School For The Deaf) was selected as an 'ideal' school with which to compare other schools. This school was specifically designed for deaf children receiving an aural education. The pupils all wear bodily worn hearing aids and good acoustics are essential for listening in this situation. The school was designed and built 12 years ago and achieving excellent acoustics was a priority for the architect and designers.

c. The classrooms tested would be from a diverse range of schools.

The schools were all primary schools, apart from two special needs schools where pupils consisted of both primary and secondary school age. The schools covered a diverse range including:

- urban and rural;
- old and modern;
- single storey and multi-storey, and
- several temporary (Portacabin style) classrooms were also tested in this survey

d. The project would concentrate on mainstream classrooms.

Over sixty teaching spaces were tested in a total of 13 schools around the United Kingdom. The rooms tested were primarily classrooms, but also included halls, gyms, libraries and general work areas. The following is a breakdown of rooms tested:

- 83% are mainstream and 17% are special needs classrooms;
- 80% are cellular and 20% are open-plan classrooms, and
- 83% have no acoustical treatment and 17% have some acoustical treatment, primarily acoustical ceilings (classified absorption Class A according to EFISO 11654).

e. The classrooms would be tested both empty and occupied.

This was a major decision and one which had a radical effect on the measurement techniques used throughout the research project. Most primary school classrooms are occupied by up to 30 pupils. This is the maximum recommended within a classroom - of course, there can be less. Although a fair amount of research has been conducted in empty classrooms, few researchers have ventured into occupied classrooms. This is understandable, as taking accurate acoustical measurements in a room full of 30 young children, asking them all to sit still and be quiet at times, and to talk normally at others, is daunting. However, as classrooms function as learning environments during school hours and when occupied by the full complement of pupils, teachers and often non-teaching assistants, it is essential to find out exactly how the room functions during its normal use.

Apart from the cases of the special schools where pupils were of a much wider age range, all children were primary school age, from five to eleven years old. There was a fairly equal distribution of sexes and ages. Room occupants also included the typical teaching and non-teaching staff, usually no more than two. These staff tended to be female and were of a variety of ages.

All subjects wore ear defenders when the noise levels were considered to be uncomfortable, for example during the measurement of reverberation times.

2.3 Acoustic Measurements

Measurements of a range of acoustic parameters were measured in the classrooms both when empty and occupied. The following have been measured:

Objective Measurements

a. Background noise level (BNL);
b. Reverberation time (RT), and
c. Speech Intelligibility:
   Speech Transmission Index (STI), and
   Percentage Articulation Loss of Consonants (%ALcons).

Subjective Measurements

a. Word Intelligibility by Picture Identification (WIPI).

2.4 Background Noise Level (BNL)

One of the most detrimental factors on speech intelligibility in any room is the background noise level: this is the sound pressure level that exists within a room. The level of pressure can consist of permanent and fluctuating levels of noise. There are three main sources of noise which are present within a typical classroom:

a. Classroom noise - noise generated from within the classroom itself

b. Internal noise - noise which is generated from within the school building, but outside of the classroom itself, and

c. External noise - noise which enters the room from outside of the school building.

A classroom usually has many more sources of noise than other environments used for speaking and listening. It is a rare teacher that never complains about his/her workplace suffering from excessive levels of noise. The louder the background noise in a classroom, the worse the signal to noise ratio will be. As previously mentioned, it is recommended that for a listening environment to perform well, the signal to noise ratio should be at least 10-15dB(A), i.e. if the background noise level in a classroom were 60dB(A), a teacher would have to speak at 70-75dB(A), not considering the detrimental effect of distance. As the signal to noise ratio decreases, so does the intelligibility of speech.

Typical Noise Sources in a Classroom

Table 2.1 highlights the major noise sources which can be found within classrooms:

Typical Noise Sources Found In Classrooms		
Internal (Classroom)	**Internal (School)**	**External (School)**
Heating systems (e.g. warm air systems); Ventilation fans; Computers; Printers; Impact on floor; Impact on desk tops; Rain noise on rooflights; Rain noise on metal roofs; Roof cracking (thermal expansion); Mechanical opening devices for windows; Overhead projectors; Birds (on rooflights); Fluorescent fittings;	Voices (from corridors); Impact noise (doors closing); Impact noise from floors; Airborne noise (through demountable partitions); Singing; Gymnastics; Music; Period bells; Trolleys.	Traffic noise: vehicles, aircraft, trains, helicopters; Grass cutting equipment; Trees; Wind noise; Empty HGV's on speed reducing devices; Rain impact noise on building components.

Table 2.1: Typical Noise Sources Found Within Classrooms.

Measurement Techniques

There are many ways of measuring background noise levels; the methods selected for this study are:

a. Continuous Background Noise Levels ($L_{Aeq,15min}$)

$L_{Aeq,15min}$ measurements were conducted using a B & K Precision Integrating SLM, Type 2222. Readings were taken over a 15 minute time period throughout the school day, with the sound level meter placed at seated head height in a random listening position in the classroom, to represent the typical noise levels experienced at a child's seated position. All noise produced during the school day were included in the measurements, including the teacher's and pupils' voices. These measurements were undertaken prior to the publication of Building Bulletin 87 which requires the measurement of the L_{Aeq} over a 1 hour period. The results should be quite similar.

b. Instantaneous Background Noise Levels (dB(A))

These measurements were conducted wherever possible when the classrooms were occupied and empty. Six measurements were taken at random locations round the room when unoccupied, and the average of these measurements was calculated. When the room was occupied six random locations were measured and the mean calculated for three different conditions:

1. all pupils and teachers silent;
2. only pupils talking, and
3. only teacher talking.

Condition 1 was measured to obtain some idea of the background noise level with the teacher and pupils present but quiet. Condition 2 was intended to simulate normal working conditions during the school day. Pupils were instructed to talk in their normal "classroom" voices at levels they perceived to be typical and would be acceptable to the class teacher. The teacher also verified that the noise levels produced were typical for group working conditions where children were permitted to talk in reasonable voices. Condition 3 was intended to simulate the signal level of the teacher's voice which could then be compared to the background noise level (condition 2).

Equipment used was a B & K 2231 Modular Precision SLM, which fed the measured noise levels into a computer which analysed the levels using the Maximum Length Sequence System Analyser (MLSSA) software programme. The sound level meter was set to linear and the computer programme analysed the information with an A weighting, which has been shown to be representative of the human ear's listening capabilities. However, this A weighting does not take into account either a child's listening spectrum or that of a child with hearing aids or hearing impairment. All equipment was calibrated before and after tests.

2.5 Reverberation Time (RT)

Reverberation is the persistence of sound in an enclosed space or room after the source of sound has ceased. It is quantified as the time taken for the sound pressure level to decay by 60dB after the sound source has stopped. As previously discussed, as the reverberation time increases, the intelligibility of speech in a room usually decreases.

Reverberation time tends to be directly related to i) the room volume and, ii) the amount of absorptive material in a room. School classrooms tend to be reverberant enclosures because they often have a relatively high volume. Older schools, especially those built in the Victorian era, usually have high ceilings as seating was often raised or tiered. It was also thought that high ceilings would reduce the risk of infections such as tuberculosis spreading amongst pupils and staff as germs would rise up to the high ceilings.

Consequently, classrooms were often built with very high plastered ceilings, often with sloping angles incorporated into the design. But it is not just older style classrooms that have high volumes. More modern classrooms tend to be large with the aim of creating a spacious, airy environment. The size of teaching spaces studied in this research project ranged from $118m^3$ to $831m^3$, and this included classrooms, small computer rooms and a large sports hall. However, the results reported are purely from classrooms.

All ages and styles of classrooms tend to have many reflective surfaces. Ceilings are often painted plaster or plasterboard, and walls are similar. Windows are often large and rarely covered by curtains. These large rooms with many reflective surfaces tend

to have much longer reverberation times than is desirable for speech. Teachers often cover walls with bright displays of children's work, but these have very little effect on the room's reverberation time and the displays only tend to go up to children's eye height. Occasionally rooms will be carpeted throughout, but carpet is not very practical particularly in primary school classrooms where much of the work involves messy substances, such as paint and plastercine.

One of the main aims of this research project was to investigate the differences between occupied and unoccupied classrooms. When classrooms are designed, reverberation is often not a main priority. However when the predicted reverberation time is calculated using such formula as Sabine, it is usually the qualities of the empty room which are considered. Little work has been conducted on the absorbent effect of the human body on reverberation times. Wherever possible the reverberation times in the rooms studied were measured both empty and with the full complement of pupils and staff.

Reverberation times were measured using a B & K Building Acoustics Analyser, Type 4418. The noise source was a B & K Sound Source, Type 4224 and input was via a ½" B & K Condenser Microphone, Type 4134. Reverberation times were measured at 1/3 octave bands, between 100 and 4000Hz. The frequencies at either end of this spectrum tend to be outside the normal speech frequencies, but it was intended to discover if there were any abnormal reverberation times in these frequencies that may be detrimental to both children and hearing aid wearers, whose hearing covers a much more diverse range of frequencies than most normally hearing adults.

Reverberation times were tested at 5 or 6 random locations around each room, and an average time for each frequency was obtained. The results at all frequencies were noted; the DfEE recommend that the mean of the 500 and 1000Hz results be calculated and used to represent each room's reverberation time, as this tends to be the mid-frequency of speech. Other text books tend to use the result at 500Hz only. During measurements of reverberation times, all room occupants wore over the head ear defenders as a safety precaution.

2.6 Speech Intelligibility

2.6.1 Speech Transmission Index (STI)

The speech transmission index (STI) has been used by various researchers as a guide to speech intelligibility in classrooms. It measures the reduction of a signal which undergoes fluctuations when travelling from source to receiver. It takes into account such detrimental factors as reverberation of the space and background noise. The measurement is carried out in seven octave bands, commencing at 125Hz up to and including 8KHz and at 14 modulation frequencies. The modulated transfer function, measured in each octave band, is converted into a figure between 0 and 1, where 0 indicates that no speech would be understood and 1 indicates that 100% of the syllables in speech are understood. Speech intelligibility is determined on the scale shown in Table 2.2 below:

Speech Transmission Index Response Scale	
Numerical Value	**Rating**
0.000 - 0.300	bad
0.301 - 0.450	poor
0.451 - 0.599	fair
0.600 - 0.749	good
0.750 - 1.000	excellent

Table 2.2: Comparison of Speech Transmission Index Numerical Value and Rating

It can be argued that a score of 0.451-0.599 (fair) or below is not adequate because as much as 40% of speech may still be lost or misunderstood. So, for the purposes of this research project, it will be considered that only rooms with a score of 0.600 or above will be adequate for speech. Other scales are available[10], however the values given in the table above have been used for analysis purposes in this study.

2.6.2 Percentage Articulation Loss of Consonants (%ALcons)

Percentage articulation loss of consonants (%ALcons) is an indication of the quality of speech arriving at a particular point in a room. It is an objective measure of the percent of consonants that will be lost or misunderstood and is an excellent indication of speech intelligibility. Table 2.3 shows some recommended %ALcon values for different listening conditions.

Recommended %ALcon Scale	
%age Articulation Loss of Consonants	**Listening Condition**
>15%	Not acceptable except for very simple or well known messages
15 - 10%	Acceptable for general messages of low complexity
5 - 10%	Good
<5%	Excellent

Table 2.3: Recommended %ALcon Scale[10]

The recommended %ALcons, for excellent intelligibility in room where children are listening to speech is no more than 5%. **It is very important to note that there are no DfEE guidelines for either %ALcons or STI.**

Speech is made up from a mixture of vowels and consonants, with vowels being the power sounds whilst consonants making up the bulk of speech. If children in a

classroom are not able to understand what is being said due to poor room acoustics, this can have a profound effect on their learning ability. The following examples show 100% loss of vowels in a sentence and then 100% loss of consonants.

100% Loss of Vowels

_ll ch_ldr_n h_v_ t_ _tt_nd pr_m_ry sch__l

which, when the vowels are added in becomes: All children have to attend primary school.

Most people might be able to guess the meaning of the above sentence with the vowels missing. On hearing this in a classroom, young children might just be able to understand what is being said. They will probably be able to make out what the sentence means since most of the content of the sentence will be heard.

100% Loss of Consonants

On the other hand,

_o_e __a___oo__ _a_e _oo_ a_ou__i__

which, when the consonants are added in becomes: Some classrooms have poor acoustics.

Here, it is extremely difficult even to guess what the sentence means. Therefore for young children hearing a sentence read out in a classroom, and there is a 100% loss of consonants, the speech is quite unintelligible.

2.7 Maximum Length Sequence System Analyser (MLSSA)

In this study, objective measurements of the STI and the %ALcons were generated using the Maximum Length Sequence System Analyser (MLSSA) method. MLSSA is a computer software programme which uses the modulated transfer function principle to calculate STI and %ALcons. It is also capable of calculating the rapid speech transmission index (RASTI) scores, plus scores for male and female voices.

It was decided that for the purposes of this study that all measurements would be gathered, but only STI and %ALcons would be considered in detail as these are generally accepted as being the most reliable and representative of a room's actual performance. The availability of this additional data will be useful for further studies concerning the relationship of the various types of STI measurements.

The MLSSA software was run on a DAN personal computer, which was connected to a Sony loudspeaker, from which the MLSSA programme regulated the measurements by generating impulses representative of the frequencies found in human speech embedded in white noise. The noise was received by a Bruel and Kjaer 2231 sound level meter, which acted as a microphone and amplifier, feeding the received noise levels back to the computer for analysis. The loudspeaker was placed at teacher head height and set in a position the class teacher deemed most typical of his/her usual

speaking location. This point is extremely important and was checked for every classroom tested.

The loudspeaker was set to a level of 67.5dB(A) at 1 metre from the face of the speaker, which, after a thorough investigation, was selected as the level most representative level of a teacher's voice when addressing the whole class. The microphone was placed at ear level of a seated child at every location around the room, when the room was both empty and occupied. Care was taken to ensure that the person holding the microphone did not influence the sound arriving at the child's ear.

It is acknowledged that during class teaching, the teacher, and often the pupils, move around the room. However, it would have been impossible to measure every possible listener and speaker combination. Also, due to time restraints, only one measurement in one location was taken, occasionally additional readings were taken if a particular location appeared to render an abnormal score. Each individual location STI and %ALcons score was recorded; the average STI and %ALcons score was calculated for each room.

2.8 Word Intelligibility by Picture Identification (WIPI)

Although the STI function is considered to be a reliable and accurate measurement of speech intelligibility, for the purposes of this research project, it was deemed necessary to find a way of assessing the subjective view of the quality of speech. As far as it is known, the objective speech intelligibility tests only take into account an adults' view and do not consider that children may be affected differently by various acoustical factors. It is known that children's hearing spans a more diverse range of frequencies than adults, and that they are more easily distracted by noise.

There are several subjective tests of speech intelligibility and probably the most well known of these is the Fairbanks' Rhyme test[11]. However, such tests are fairly complex and too difficult for primary school children to use. A test was required that needed no reading or writing skills, as many of the subjects were only just beginning to learn these skills. It was also necessary for the test to involve an immediate response to the stimulus to avoid the result being dependant on any memory skills.

Several tests were considered in terms of suitability and the one that was decided upon was the Word Intelligibility by Picture Identification test (WIPI). The original test was designed as a method of assessing the extent of individual children's hearing loss. However, it was easily modified to assess how much speech groups of children could hear in any given room. Because the test originated in America, several words and pictures were not suitable for use with British schoolchildren. Prior to the testing, the original WIPI word and picture lists were presented to groups of children and adults: any words or pictures that were regularly mistaken were omitted from the actual test.

The modified WIPI test consists of 20 groups of six pictures, each one representing phonetically balanced words, as shown in Appendix C. For each group of six words a carrier sentence is presented containing one target word relating to one of the pictures. The child then has to identify the heard word by marking the corresponding picture. Because this study aimed to determine how much speech a child can hear in a classroom with varying amounts of background noise, the modified WIPI test was

carried out under 3 different test conditions in random order to eliminate any effects of learning, and these were:

1. Control condition: the test sentences were presented to the subjects through a set of headphones, thus eliminating the effects of background noise. The sentences were presented at a level of 67.5dB(A), measured at the headphone earpiece;

2. Effects of room condition: the test sentences were presented free in the occupied classroom, but with all the other pupils in the classroom in total silence. The sentences were presented at 67.5dB(A) at one metre from the loudspeaker, in anechoic conditions, and

3. Effects of background noise: the sentences were presented under identical conditions as 2), but with background noise created by other pupils in the room talking at normal speaking level. This was a fairly consistent volume across rooms, ranging from 61dB(A) to 65dB(A), usually depending on the age of the pupils in the room with the older pupils tending to be louder.

Children were tested at random locations in the room, eight pupils at a time. They were instructed to only look at their own answer sheet and not to copy anyone else's answers or they would be asked to leave the experiment. Throughout the test they were carefully monitored to ensure that this was the case. The subjects were also instructed that in the case of not hearing a word at all they were to leave that page blank and move on to the next set of words. This was so it could later be determined which words had not been heard, those that had been misheard and those that had been correctly identified.

The sentences were presented as a pre-recorded female voice on compact disc and relayed from teacher head height from a Phillips stereo unit, at the location selected by the class teacher as being the location where he/she was most likely to stand. For the control condition, the children listened through junior headphones linked by a splitter box to the stereo. Each test was marked as a %age of correct answers and a mean improvement figure, between test conditions was calculated for each room.

3 Results

3.1 The Two Classroom Conditions

The majority of the classrooms measured during the course of the project had no acoustic treatment. However, an opportunity arose to apply acoustic treatment to a number of existing classrooms. Measurements were carried out before and after the application of this treatment.

3.1.1 Untreated Classrooms

The majority of primary school classrooms in the United Kingdom generally have no acoustic treatment. This will depend on the use of the classroom, the age of the school and whether any refurbishment work has recently been carried out.

Typical surface materials found in an untreated classroom are:

Walls:	hard plaster, plasterboard, pin boards, hard door surfaces, glass;
Floors:	vinyl, varnished timber flooring, maybe some carpeting but this tends to be hard,
Ceilings:	hard plaster, plasterboard and
Furniture:	hard timber or laminated surfaces.

3.1.2 Treated Classrooms

In some of the schools, classrooms have some form of acoustic treatment. These include:

Walls:	plasterboard, acoustic absorption panels, acoustic tiles to the upper levels; fabric covered doors; curtaining to windows;
Floors:	carpeting - this depends on the age group concerned;
Ceilings:	plasterboard, acoustic absorption panels, acoustic tiles in the form of a suspended ceiling, and
Furniture:	there may be some form of acoustic treatment to the tops of desks.

As far as this report is concerned, acoustic treatment to classrooms that formed part of the exercise was in the form of acoustic ceiling or wall tiles, which were either fitted into a suspended ceiling system or fixed directly to the existing ceiling surface.

3.2 Background Noise Levels

3.2.1 Continuous Background Noise Levels ($L_{Aeq,15min}$)

The $L_{Aeq,15min}$ background noise levels throughout a typical working day were measured in the majority of the classrooms. An example of these measurements in a local primary school is shown in Figure 3.1. Noise levels range from 49dB(A) up to 85dB(A), however on the whole the background noise levels within the various spaces

are fairly constant over the measurement time period. When a classroom is vacated, the background noise level drops by about 15/20dB(A) depending on the use of the room. At 15:15 hours, the children had singing lessons, hence the high level.

Note that the Guide For The Environmental Design in Schools recommends that the maximum background noise level, i.e. the $L_{Aeq,1hr}$ value, should not exceed 40dB in a classroom and also recommends a maximum $L_{Aeq,1hr}$ of 30dB where hearing impaired children are present in the classroom. Although the measurements here are for $L_{Aeq,15min}$ it can easily be seen that these levels are well exceeded for both of these schools.

3.2.2 Instantaneous Background Noise Levels (dB(A))

The average results of the instantaneous background noise level within a range of classrooms is shown in Table 3.1 below.

BACKGROUND NOISE LEVELS (dB(A))		
	Untreated	**Treated**
Room Unoccupied	44.7	40.1
Pupils Silent	55.5	46.5
Pupils Working	77.3	70.1

Table 3.1: Measured Average Background Noise Levels.

The background noise levels measured using this technique confirms the results measured continuously throughout the working day. The values for the treated classrooms are between 7 to 9dB(A) lower than untreated classrooms.

The background noise level within the classrooms was found to vary depending on a number of factors, such as:

1. The general design and layout of the school. Some classrooms were accessed directly off a central hall that was used for periods of the school day for choral practice, gym lessons etc.;

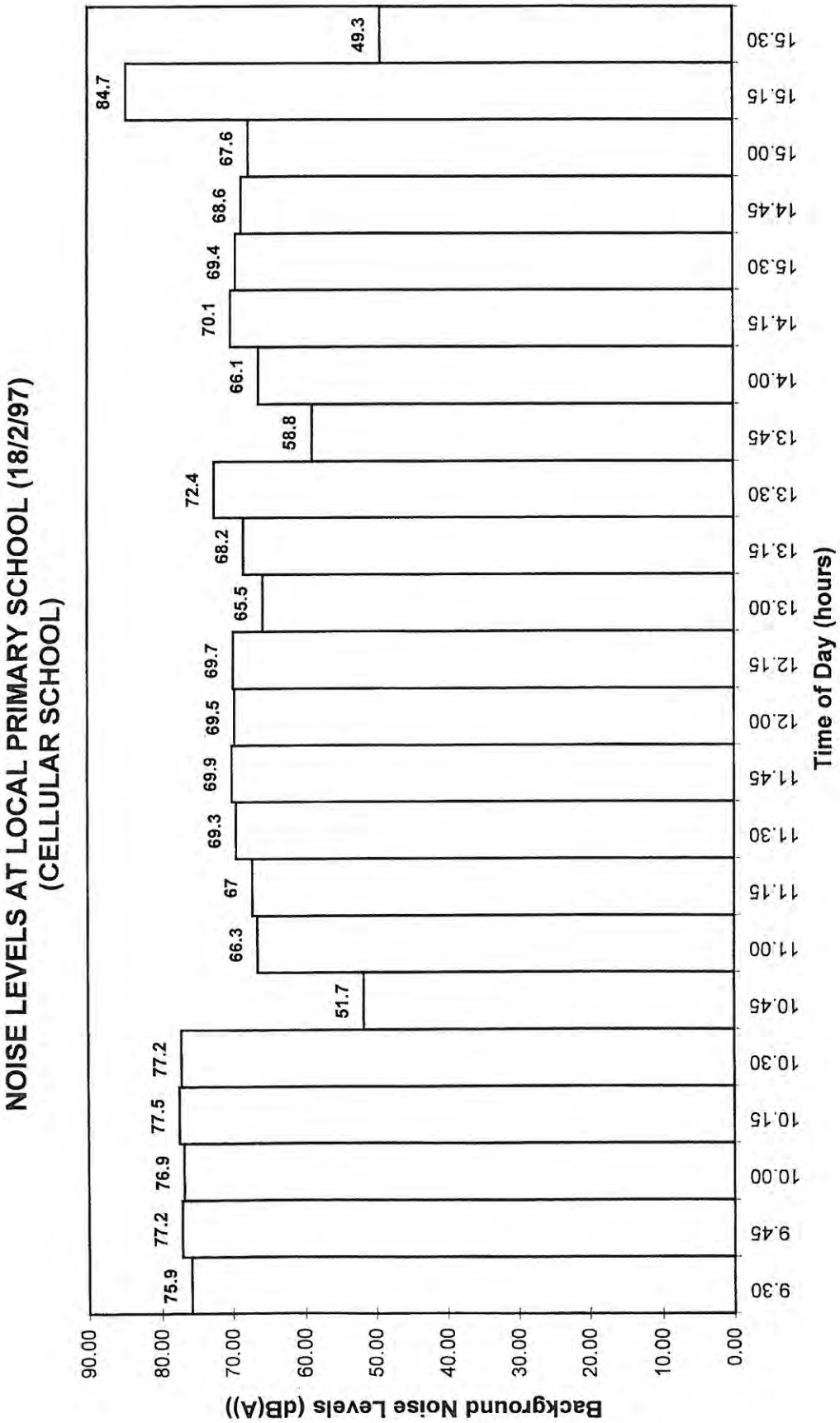

Figure 3.1: $L_{Aeq,15min}$ Background Noise Levels in Local Primary School

2. The occupation capacity of the room and the age of the occupants. Younger children produced more noise for longer periods of the day, but older children tended to be louder when they were speaking;

3. The location of the school and its various classrooms with respect to traffic noise and other external noise sources such as grass cutters, air traffic etc.;

4. Various construction methods such as lightweight roofs with metal cladding, or traditional stone built buildings;

5. Varying sound insulation qualities of separating walls and floors, and

6. Noise sources within the room, such as fan heaters, computers etc.

Some background noise levels were affected by inadequate maintenance. Many classrooms had lightweight access doors without working door closers which, if changed to a heavier door system, with appropriate door closers, may reduce intrusion noise to an acceptable level. Many other distracting noise sources included buzzing light fittings and noisy heaters.

3.3 Frequency Analysis of The Measured Background Noise Levels

The background noise measurements within the various classrooms have been further analysed and the frequency spectrum of the different situations have been developed.

3.3.1 Cellular Classrooms: Untreated and Treated

Figures 3.2 and 3.3 respectively show the average sound pressure level spectra, measured in various primary school classrooms, for two different room conditions. Figure 3.2 shows conventional cellular designed schools where the classrooms tested have no acoustic treatment (i.e. untreated), and Figure 3.3 shows conventional cellular designed schools where the classrooms tested have acoustic treatment in the form of added absorption (i.e. treated).

Both figures show four different measurement situations, which are:

1. Pupils talking;
2. Teacher talking;
3. Pupils quiet, and
4. Room unoccupied.

As would be expected, pupils talking within the classroom displays the highest noise level across the frequency spectrum. It is interesting to notice the speech frequencies, from 125 hertz up to 2000 hertz, can clearly be identified. This is also shown for the spectrum of the teacher's voice, which is not quite so loud as the pupils in the classroom. Of course, when the pupils are quiet the resulting noise level reduces in value, and this is shown in Figure 3.2. This time the noise level drops rapidly with

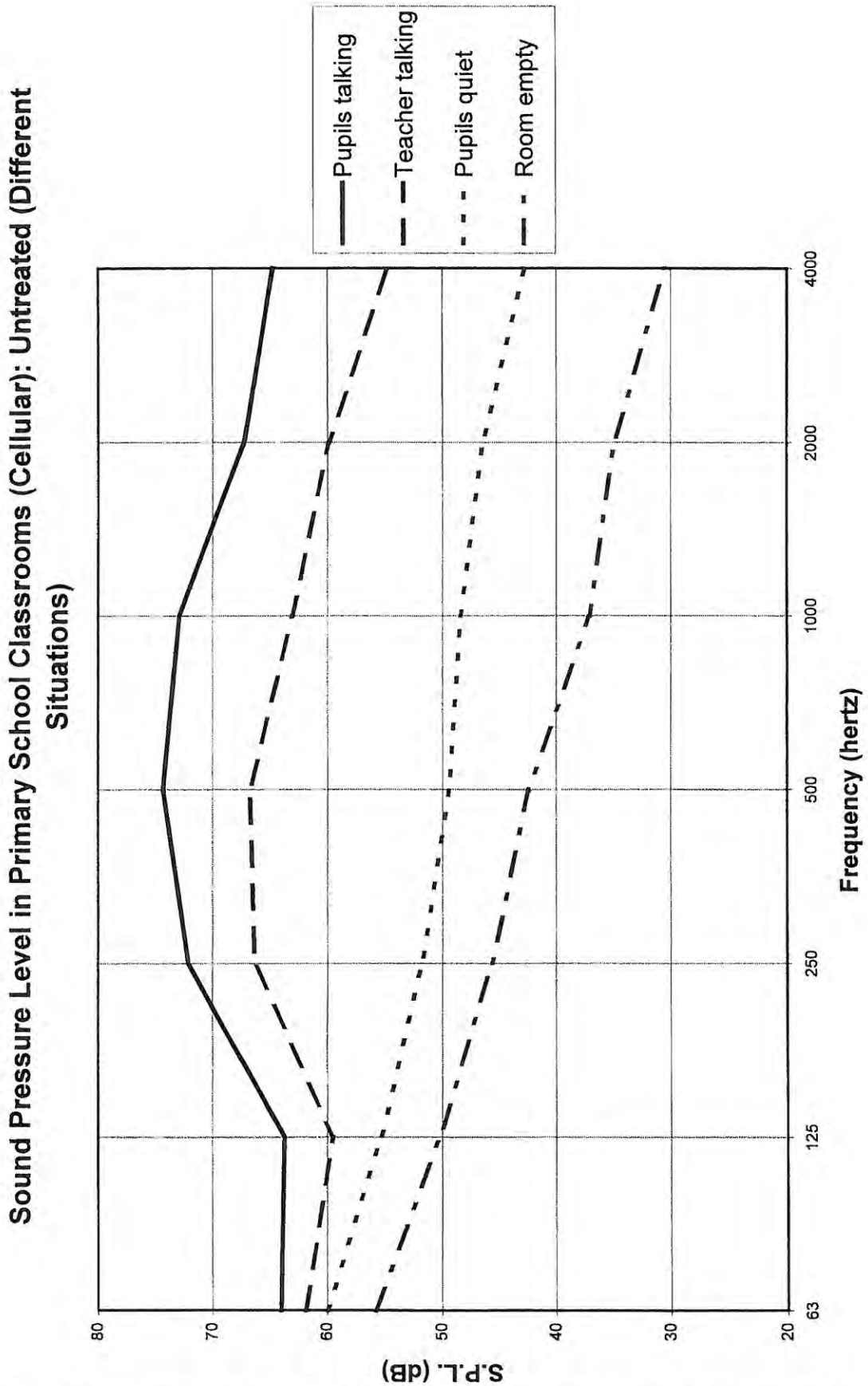

Figure 3.2: S.P.L. in Primary School Classrooms (Cellular): Untreated Different Situations

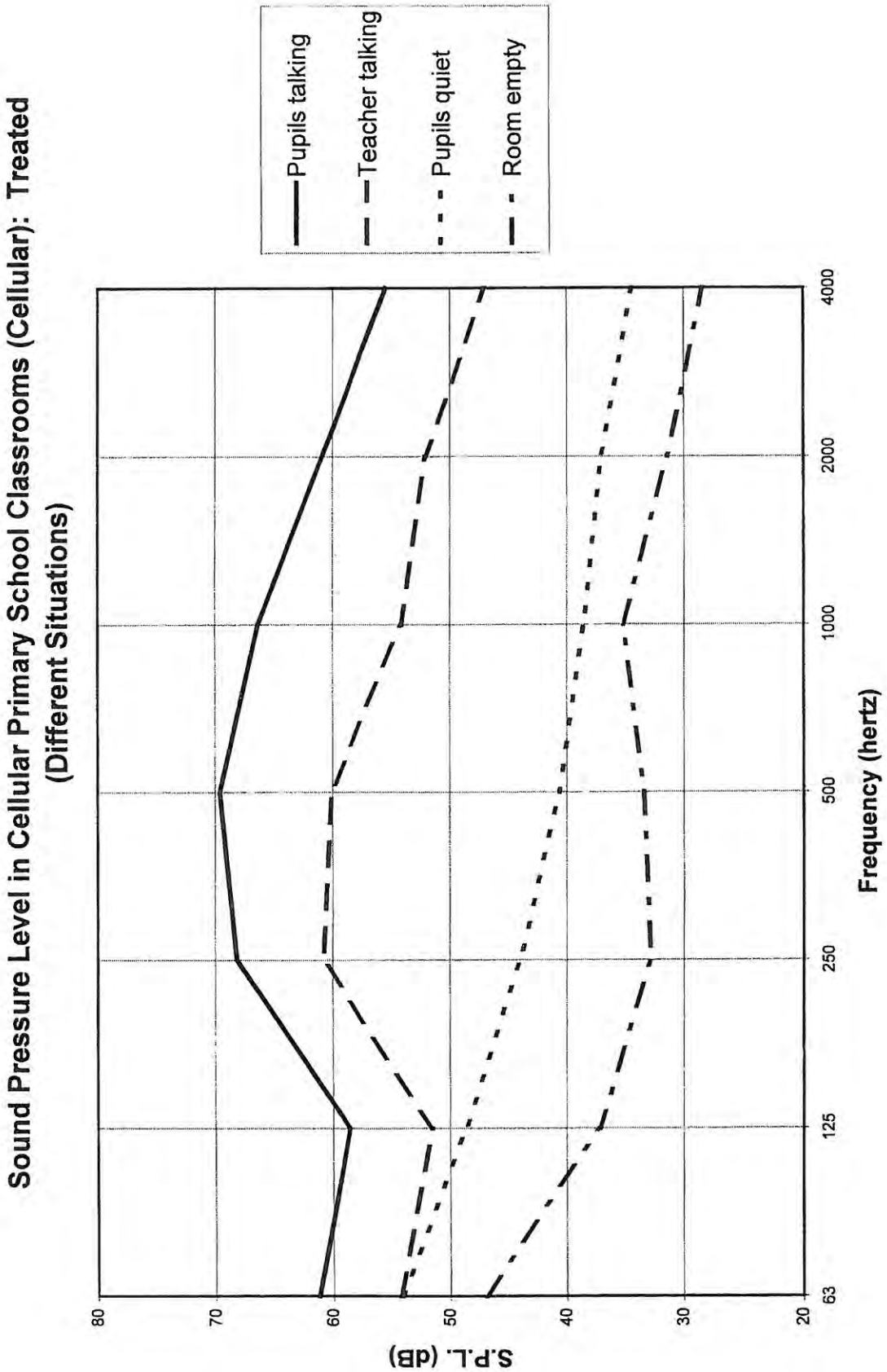

Figure 3.3: S.P.L. in Primary School Classrooms (Cellular): Treated Different Situations

increasing frequency, which is normal for background noise. The quietest of the four spectra is that for the unoccupied classroom.

Figure 3.3 shows the same four situations, but for treated classrooms. This graph is purely to show that although the sound pressure levels are lower, the shape of the curves are quite similar, except for that of the empty classroom which has a greater dip at lower frequencies. Figures 3.4 to 3.7 respectively show a comparison between the untreated and treated rooms for the four different measurement situations.

3.4 Reverberation Times

3.4.1 Average Reverberation Times

The average reverberation times for various classrooms are shown below:

REVERBERATION TIMES (seconds)		
	Untreated	**Treated**
Room Unoccupied	0.7	0.4
Room Occupied	0.6	0.4

Table 3.2: Measured Average Reverberation Times (at 500 hertz)

As expected, the RT was dependant not only on the room volume, but also the layout and design of the classroom. Some rooms had fully carpeted floors, some had small areas of carpet where children sat for story time and other activities, some rooms had areas of vinyl and some had bare timber flooring.

Curtaining ranged from no curtaining at all, which was the majority of classrooms, to net curtains and occasionally heavier curtains or blinds. Very few classrooms, except those with specific acoustical treatment, had any form of ceiling treatment. Classroom furniture ranged from traditional wooden chairs and tables, to modern plastic furniture. All of these factors can have an effect on the RT of a room. The measured values for acoustically treated classrooms fall within the reverberation time range of 0.3 to 0.6 seconds as recommended by the DfEE Guidelines, and in particular, spaces where children with a hearing impairment will be taught.

3.4.2 Frequency Analysis of Measured Reverberation Times

Figure 3.8 shows the frequency spectrum for four different reverberation time measurements:

1. Classrooms untreated and unoccupied (empty);
2. Classrooms untreated and occupied;
3. Classrooms treated and unoccupied (empty), and
4. Classrooms treated and occupied.

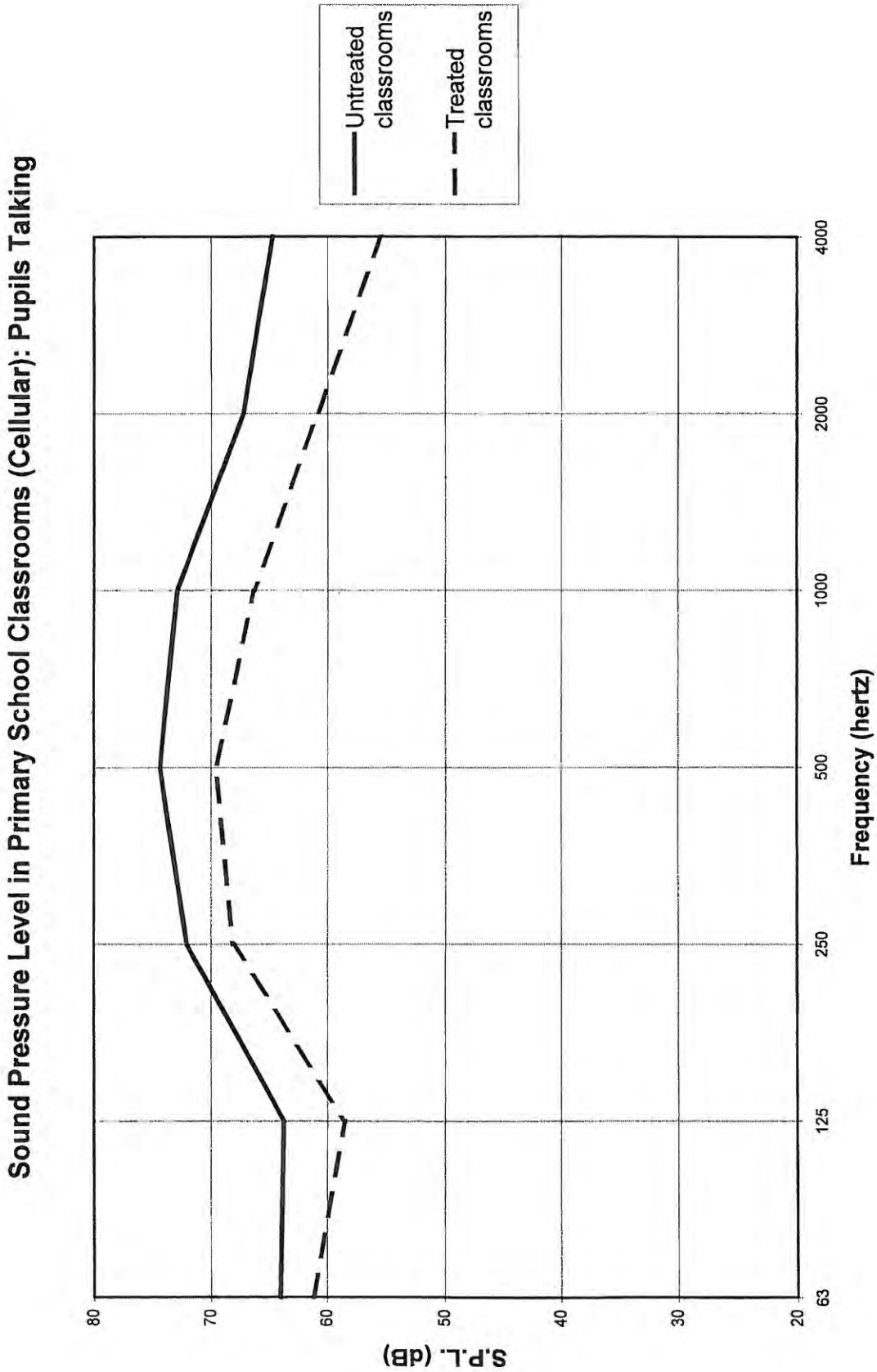

Figure 3.4: S.P.L. in Primary School Classrooms (Cellular): Pupils Talking

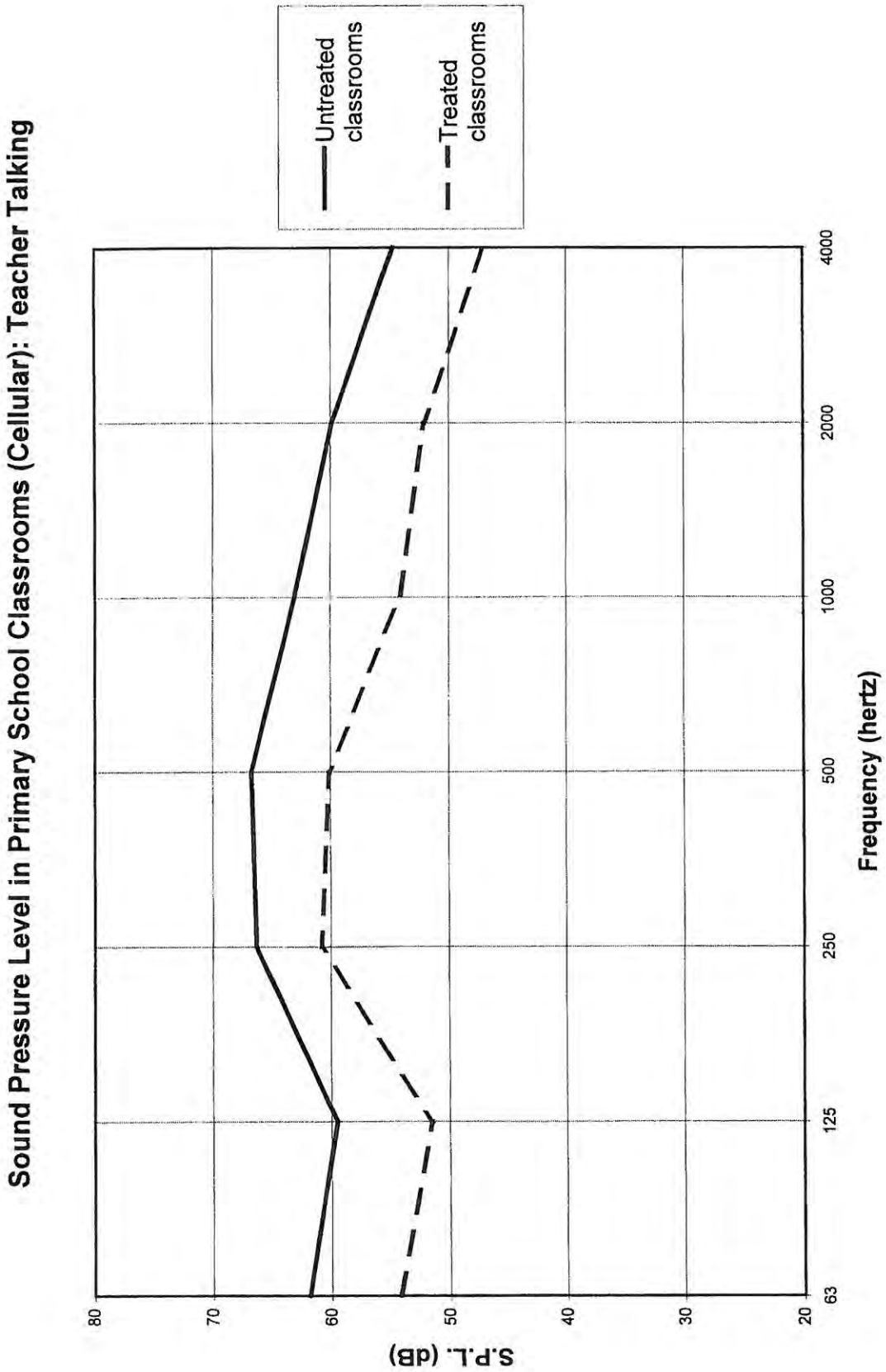

Figure 3.5: S.P.L. in Primary School Classrooms (Cellular): Teacher Talking

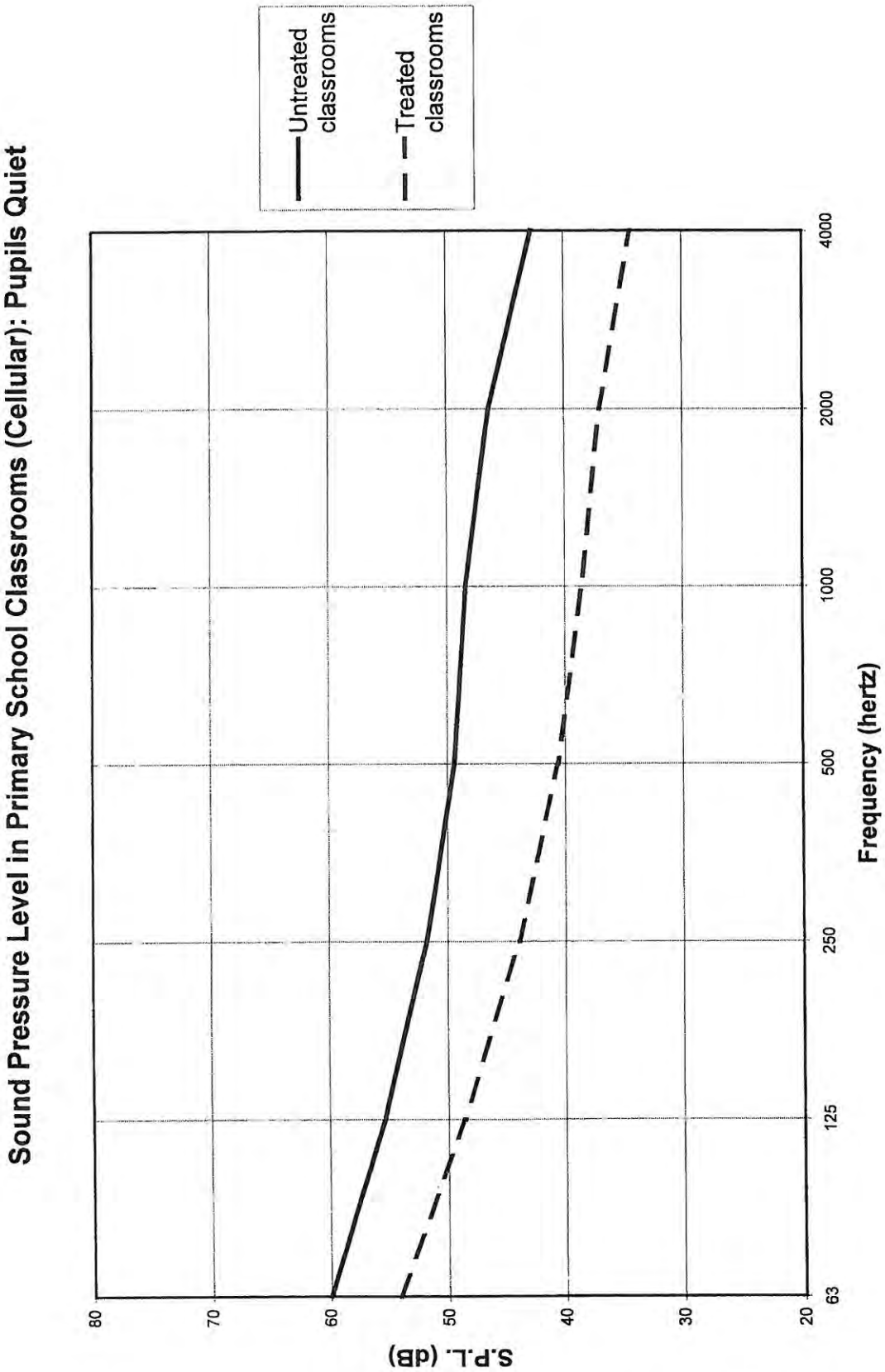

Figure 3.6: S.P.L. in Primary School Classrooms (Cellular): Pupils Quiet

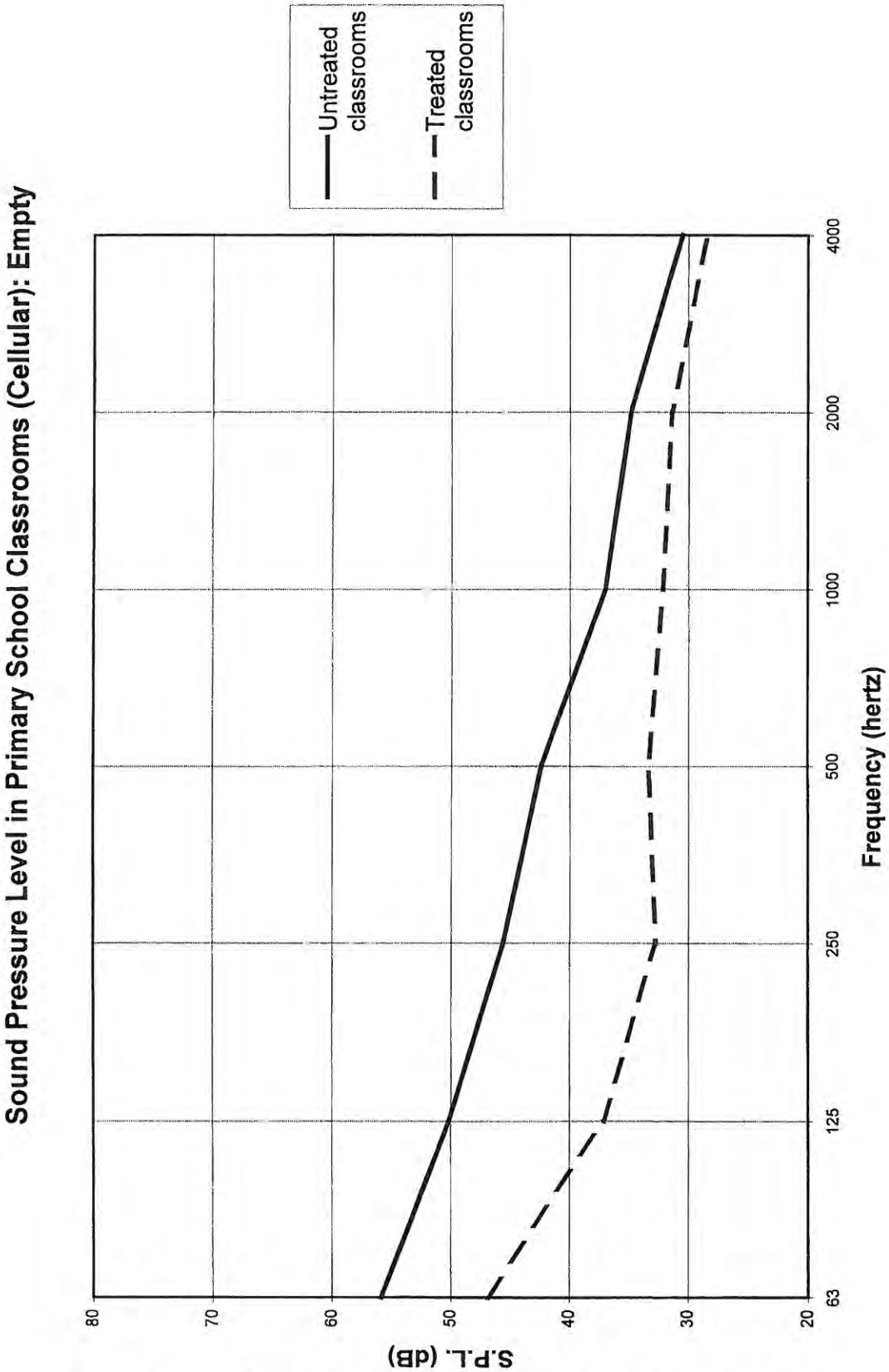

Figure 3.7: S.P.L. in Primary School Classrooms (Cellular): Empty

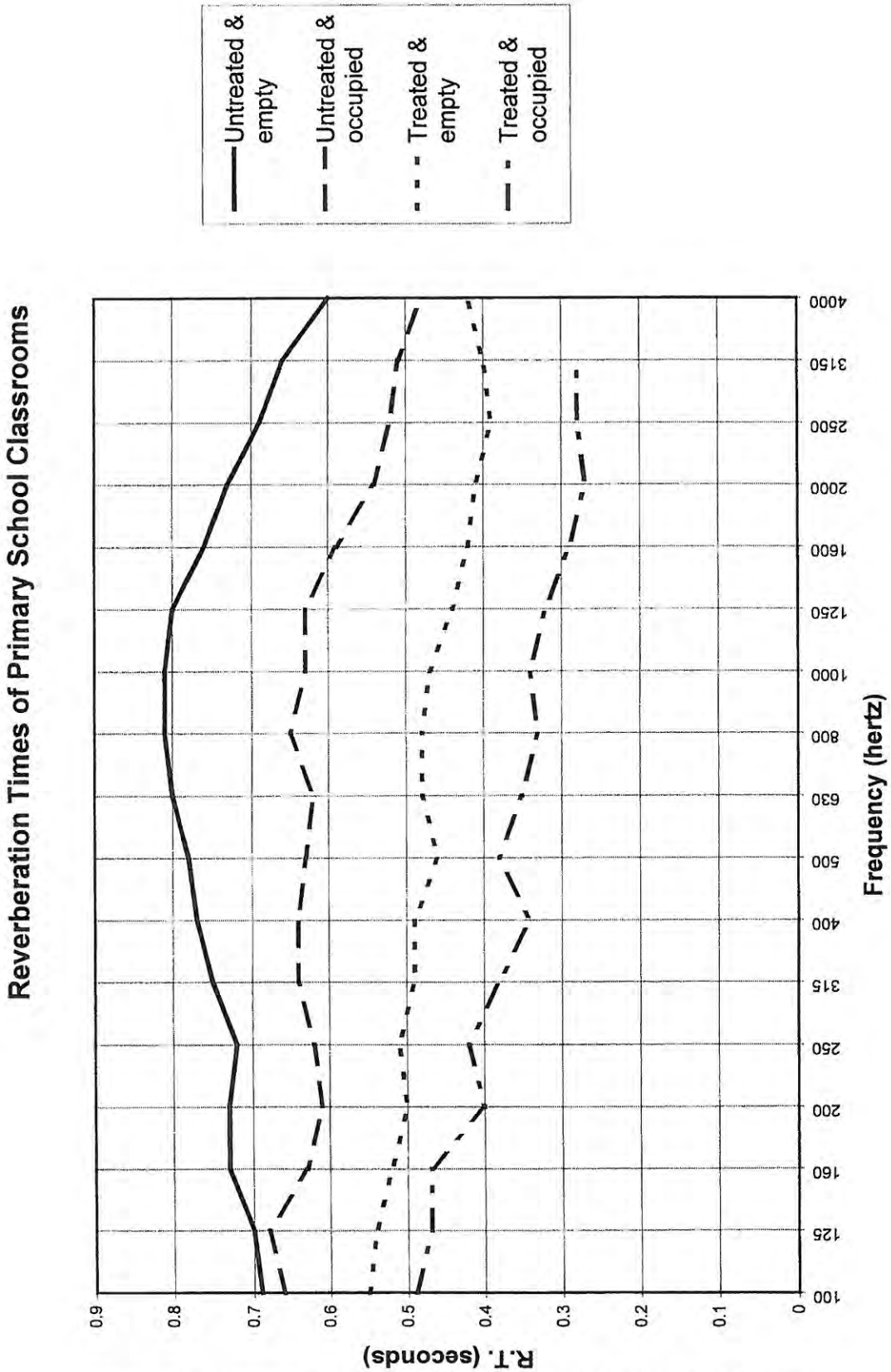

Figure 3.8: Reverberation Times In Primary School Classrooms

As a reminder, untreated classrooms have no acoustic treatment within the room, whilst treated classrooms have Ecophon Class A absorber ceiling tiles or Ecophon wall tiles incorporated into the design of the room. this may be in the form of a suspended ceiling or surface mounted tiles depending on the situation. Situation 1 above has the longest reverberation time whilst treated classrooms, which are occupied by up to thirty children, have the lowest values.

Figure 3.9 compares the reverberation time values for treated classrooms that are empty and occupied with the recommended values given by Building Bulletin 87, which states that for classrooms used for the teaching of hearing impaired children the reverberation time should be between 0.3 and 0.6 seconds respectively. The bulletin, in fact, states that the reverberation time values are for the mid-frequencies which it goes on to define as the average of 500 and 1000 hertz. Figure 3.10 shows the reverberation times of various other spaces.

3.5 Speech Intelligibility

3.5.1 Speech Transmission Index

The STI was calculated for every pupil location in the classroom, both occupied and unoccupied. Each location was allocated a score between 0 and 1 and a rating between bad and excellent. As of yet, only the occupied STI and %ALcons have been examined and are ready for presentation. However, as each STI test was conducted it was observed that the scores for occupied rooms were generally lower, i.e. poorer. This is in contrast to a study by Diaz [12] who found that RASTI scores improved when rooms were occupied, due to reduction in the RT.

The average STI scores measured within the occupied classrooms are as follows:

SPEECH TRANSMISSION INDEX (STI)		
	Untreated	**Treated**
Room Unoccupied	0.601	0.700
Room Occupied	0.501	0.700

Note: a lower numerical value indicates poorer speech intelligibility

Table 3.3: Average STI Values for Cellular Classrooms.

Only classrooms with an average score of 0.600 (good) or above will be classed as acceptable for children's listening environments. Most of the classrooms tested do not provide an appropriate acoustic measurement, and only acoustically treated classrooms meet this criteria. By adding absorption to a classroom (in the form of acoustic tiles) not only lowers the background noise level and decreases the reverberation time, but also improves the overall speech intelligibility of the classroom.

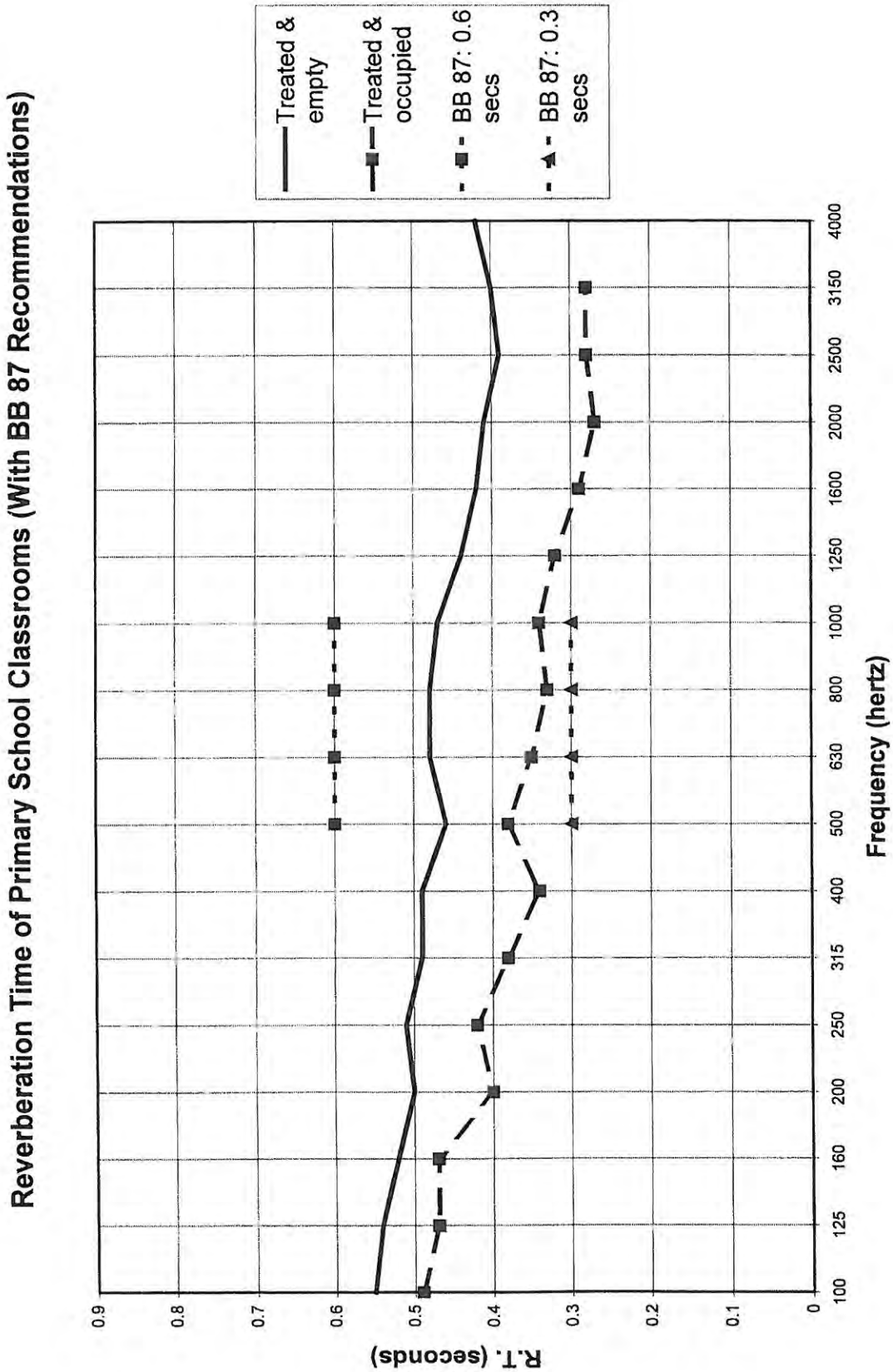

Figure 3.9: Reverberation Times in Primary School Classrooms: With BB87 Recommendations

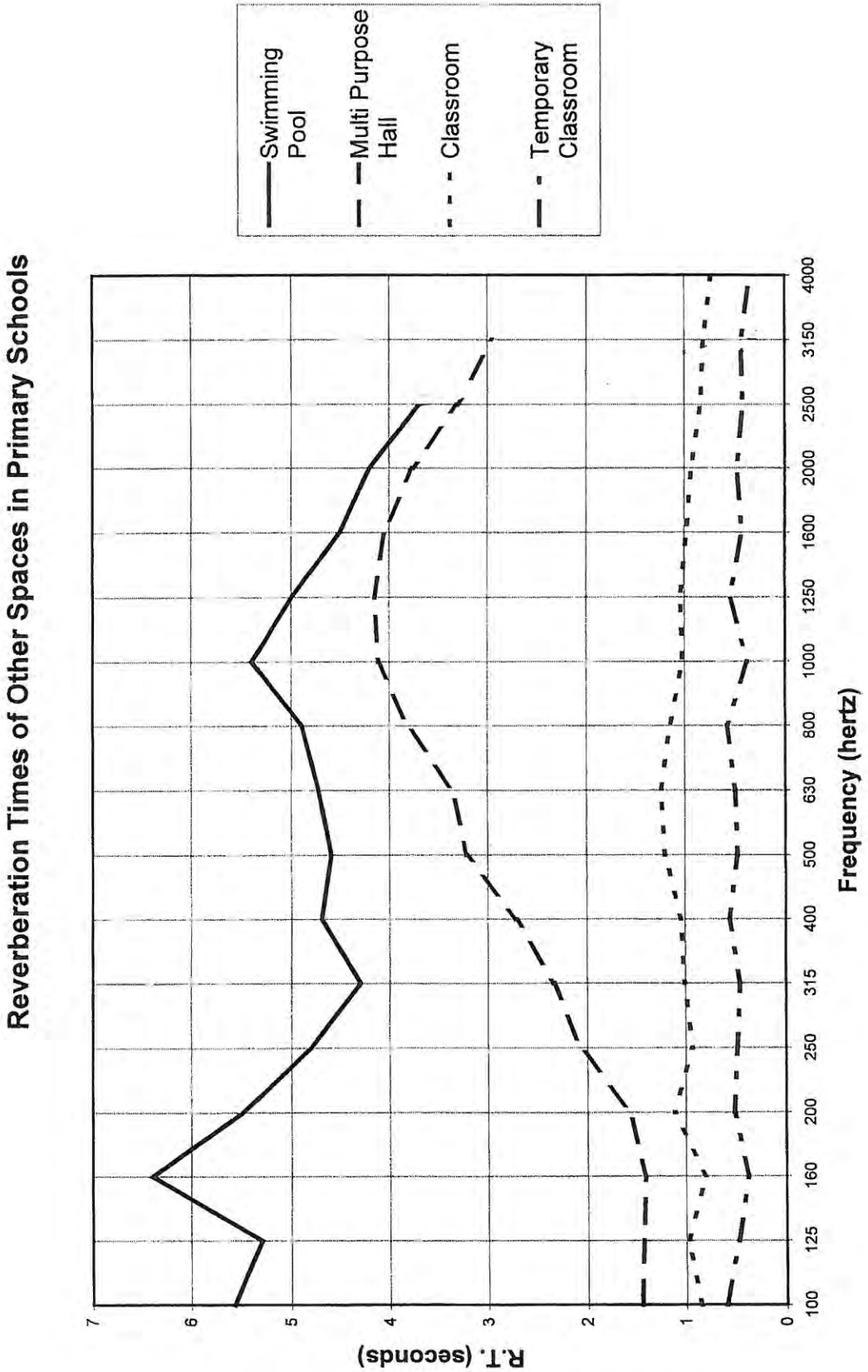

Figure 3.10: Reverberation Times of Other Teaching Spaces in Primary Schools

3.5.2 Percentage Articulation Loss of Consonants

The table below shows the average percentage articulation loss of consonants for all of the classrooms tested in the project:

PERCENTAGE ARTICULATION LOSS OF CONSONANTS (%ALcons)		
	Untreated	**Treated**
Room Unoccupied	10.8	4.6
Room Occupied	13.7	4.6

Table 3.4: Average %ALcons Scores for Cellular Classrooms

A %ALcons value of no greater than 5% is recommended for classrooms, especially where hearing impaired children will be taught. It can be seen that both the cellular classrooms and the open plan classrooms fail to meet this criteria; however the acoustically treated classrooms are satisfactory with a rating of 4.6%. This is excellent for teaching purposes.

3.6 Dead Spots Within Classrooms

By measuring the %ALcons at each and every seat location in a classroom, it is possible to gain some idea of the distribution of sound within that room. Most are satisfactory, however it has come to light that depending on the shape of the cross-section of the classroom, dead spots may be created unknowingly within the classroom. Measurements have shown that it is possible to have an %ALcons score of 100 at these locations. This is described in Appendix D

3.7 Word Intelligibility by Picture Identification

The results of this test will give some idea of whether the acoustics of a classroom really does affect the people working within the room. This is a subjective test and involves the children within the room carrying out set tasks. Again it is important to point out here that none of the tests carried out in the project were set up purely for the research exercise: these were everyday schools going about their normal business and the pupils were those within the classrooms selected for testing. Results from the application of the modified word intelligibility by picture identification (WIPI) test have yet to be thoroughly analysed. However, the average room scores for classrooms with and without acoustical treatment have been summarised. These are shown in the table given below.

WORD INTELLIGIBILITY BY PICTURE IDENTIFICATION (WIPI)		
	Untreated	**Treated**
Control	96.7%	97.5%
Quiet Classroom	94.2%	97.5%
Pupils Working	57.2%	67.0%

Table 3.5: Average Room WIPI Scores.

It can be seen that when pupils around those being tested are talking, there is a significant reduction in the percentage of words being understood, with treated classrooms being better than untreated classrooms. Therefore reducing the background noise level within a classroom can improve the working conditions within that space.

It appears that there is a trend for the WIPI test scores to follow the STI results, in that a room that has a high objective speech intelligibility score also has a high subjective response rating as well. Reducing noise in a classroom, whether it by the installation of a suspended ceiling or other means, will certainly create a better working environment and one that hopefully increases the percentage of correct answers. This is an exciting test and one that proves without a doubt that noise can affect a young person's concentration in a normal working environment, i.e. a school classroom.

3.8 Case Studies

The results of two case studies are shown in Appendix E. Case study one is for The Priory School, Tadley, Hampshire, England and Case study two is for Balgreen Primary School, Saughton, Edinburgh, Scotland.

4 Classroom Environment Survey

4.1 Introduction

A detailed questionnaire concerning teachers' subjective opinions of the effect the classroom environment has upon themselves and their pupils was drawn up. This questionnaire served several purposes:

4.2 Aim of Questionnaire

a. As a subjective tool to place the objective measurements in context;

b. To obtain a 'picture' of a larger number of schools to ensure those used in the objective tests were typical;

c. To gain an idea of teachers' satisfaction with their teaching environments;

d. To obtain an idea of the type of teachers using the classrooms that were objectively measured;

e. To obtain the users' perspective on the effects of classroom acoustics on themselves and their students;

f. To ask questions that could later be related to other questions and findings to observe the effect of acoustics on e.g. teacher absences, and

g. To discover problem areas outside of the acoustical measurements.

4.3 Distribution and Collection

In total 424 questionnaires were distributed. These were hand delivered to the headteachers or deputy headteachers with a request to dispense to staff. This was intended to inspire and motivate completion by the teachers. A date was then set for collection. A week before this date, a telephone call was made to each school to remind them of the collection date, in order to give time for the allocated person to gather any remaining forms. Completed questionnaires were then collected, again in person. All forms were gathered together and the individual teachers and their schools remained anonymous.

4.4 Analysis of Results

The questionnaires were counted and totalled 126, a return rate of 29.7%. This was a much higher number than the 10% expected. Primary schools amounted to two thirds of the sample (10/15) and primary school teachers amounted to 58% of the sample. Percentages and averages were calculated and the results were then analysed using various statistical methods, in particular the Mann Whitney test and the Kruskal Wallis test. A level of significance was set at <0.05.

The largest percentage of teachers were in the 41-50 or 51-60 age groups, with 38.4% and 23.3% respectively. No teachers in this survey were over the age of sixty. The teachers' ages had no effect on their responses.

The majority of subjects described themselves as 'classteachers' (71.2%) or 'senior teachers' (13.7%). The other respondents were a mixture of headteachers, deputy headteachers and learning support staff. With regard to sensory impairments, only a few teachers suffered hearing impairments (2.7%) and none of these wore hearing aids. However, a large number of subjects reported using visual correction, with 50.7% wearing glasses, 9.6% wearing contact lenses and 5.5% wearing both, totalling 65.8% of the total subject pool. No subjects answered "Yes" to the question "Are you physically disabled?". There were not enough hearing impaired teachers for it to have had an effect on the results. Whether a teacher wore contact lenses or glasses, or neither, had no effect on their response.

4.5 Schools Included in The Sample

The schools, as described by the subjects, covered a range of styles, ages and locations. Whilst most schools were primary schools, teaching the full range of primary school children (ages 4-11), many were smaller sections of the primary age range. For example, some schools were infant schools (ages 4-7), others were junior schools (ages 7-11)

There is a wide spread of school age, with the buildings spanning over a hundred years. Such a large time span covers a range of different theories of pedagogy and architecture and this is reflected in the variety of school design. Schools varied in the amount of storeys they consisted of with 38% of schools comprising of one storey, 37% having two storeys, 22% having three storeys and 3% of schools having four or more. The internal design of schools varied also: whilst most classrooms were fully closed (cellular), separate rooms from each other, i.e. linked only by a corridor, several classrooms were of the open-plan design.

4.6 School Age

The age of the school had a significant effect on several other factors. The older schools were less likely to have carpets ($p = 0.0003$ where a significance rating is set at > 0.05)[1] and the ceilings were more likely to be high ($p = 0.0186$). Newer schools were more likely to be built in rural or residential areas rather than urban ($p = 0.0003$) and these newer schools were much more likely to be of an open-plan or semi open-plan design ($p = 0.0012$). Newer schools also have more pupils per classroom ($p = 0.0175$)

1 The lowest level of confidence acceptable to scientists is 5%, or 0.05. This means that only one in twenty, or 5% could be due to chance. Anything below p=0.05 will be accepted as significant and the lower the figure, the more significant the result will be up to a maximum significance of 0.001. The tests used can be found and explained in more depth in any popular statistic books.

4.7 School Interior Design

The style of the interior design of the school building had a significant effect on several other factors. The ceilings in more modern, open-plan schools were lower ($p = 0.0106$) and were more likely to be suspended ceilings than those in traditional schools ($p = 0.0032$). The open-plan classrooms had more pupils ($p = 0.0025$). Open-plan schools were also newer than traditional schools and more likely to be built in residential or rural areas. Teachers in these open-plan schools were more likely to feel that acoustics played an important role with respect to themselves; they thought acoustics contributed to any headaches they may suffer ($p = 0.0427$) and their pupils, they thought acoustics had an effect on the pupils' performance ($p = 0.0165$).

4.8 School Surroundings

The area in which the school is built has an effect on several factors. Schools built in urban areas are more likely to be older and built in the traditional cellular style. They are less likely to have carpets ($p = 0.0029$), suspended ceilings ($p = 0.0101$), ceiling tiles ($p = 0.0035$) and are more likely to have higher ceilings ($p = 0.0448$). In these schools, teachers are more likely to have days off work sick ($p = 0.0463$).

4.9 Classroom Features

The amount of carpeting a classroom has is related to other factors. Classrooms with carpeting are more likely to also have a suspended ceiling ($p = 0.0151$) and have a tendency towards having double-glazing ($p = 0.0540$). Teachers in rooms with more carpeting are less likely to think their job contributes to throat problems ($p = 0.0318$), have less throat problems ($p = 0.0675$) and have a tendency to rate the acoustics in their classrooms highly ($p = 0.0568$).

4.10 Ceiling Height

The height of a classroom's ceiling is significantly linked to other factors as well as school age and design. Classrooms with high ceilings are much less likely to have ceiling tiles ($p = 0.0001$) or suspended ceilings ($p = 0.0021$). Teachers in such classrooms feel their job contributes to throat problems ($p = 0.0074$) and are more likely to suffer voice and throat problems ($p = 0.0261$)

4.11 Acoustics

Overall Rating

Teachers were asked to rate their classrooms for quality of acoustics. The largest number of subjects decided their classrooms were "fair". However, those teachers who rate their acoustics as "bad" or "poor" were more likely to say that the acoustics affect their performance ($p = 0.0002$), their pupils' performance ($p = 0.0008$) and their pupils' behaviour ($p = 0.0468$) than those teachers who rated their classrooms more favourably. Teachers in the classrooms with better acoustics were more likely to

respond that their classroom was less noisy (p = 0.0001) and less reverberant (p = 0.0206) than those teachers who rated the acoustics "poor" or "bad". In the concluding question, teachers who rated their classrooms as poor acoustically were more likely to ask to improve the acoustics above any other aspect of their classroom (p = 0.0230).

Noise

Teachers were also asked how noisy they thought their classroom was. No teachers thought that their classroom was "too quiet", 11.0% thought that their classroom was "quiet", 54.8% thought it was "fair", 26.0% thought their classroom was noisy and 5.5% thought it was "too noisy". Teachers in classrooms without carpet were more likely to think their classroom was noisy (p = 0.0144). Teachers in noisy classrooms were more likely to suffer headaches (p = 0.0325) and to think their job contributes to throat problems (p = 0.0141). A teacher working in a noisy classroom is more likely to take a day off sick when they have throat problems than a teacher in a quiet room (p = 0.0144). A teacher with a noisy classroom is also more likely to rate the classroom as reverberant (p = 0.0005).

Reverberation

Similar results were gathered for the teachers who rate their classrooms as reverberant. Classrooms rated as less reverberant had more carpet (p = 0.0168), are less noisy (p = 0.0001) and the teachers are less likely to suffer throat problems (p = 0.0312). Teachers in reverberant rooms are more likely to think acoustics have an effect on their own performance (p = 0.0046), their pupils' performance (p = 0.0062) and behaviour (p = 0.0034). Teachers in classrooms which are more reverberant take more days off sick each year than teachers in classrooms that are not reverberant (p = 0.0134).

A large number of teachers suffer voice and throat problems. Only 5.5% of teachers say they have never suffered voice and throat problems, whilst a total of 68.5% say they suffer occasionally or frequently. Teachers tend to believe their job contributes towards these problems. Speaking is blamed as the most significant factor contributing to voice and throat problems. As mentioned earlier, teachers working in reverberant classrooms are more likely to have a higher number of days off sick than other teachers. Teachers in classrooms with suspended ceilings are also less likely to suffer from voice and throat problems (p = 0.0187), than their colleagues working in classrooms without suspended ceilings. A teacher who suffers more frequent throat problems is more likely to take a day's absence when they have these problems than a teacher who only occasionally suffers (p = 0.0016).

4.12 Pupil and Teacher Performance

As mentioned earlier, teachers working in noisy, reverberant rooms are more likely to think acoustics have an effect on their own performance and the behaviour and performance of their pupils. Teachers of pupils in the older age range of the primary spectrum are more likely to think their pupils are affected by acoustics than those teaching younger pupils (p=0.0170). Those teachers who think acoustics affect their own and their pupils' performance are more likely to choose to improve the acoustics than any other factor (p = 0.0005 and 0.0001).

4.13 Discussion

As a result of the teacher questionnaires, a much broader picture of schools, classrooms and individual teachers has been obtained. Experiences of schools and teachers during the whole research project have been strongly supported by this survey. Many teachers have been encountered during acoustical measurements in schools and the teachers who responded to this survey closely match those met with regard to age, gender and other details. This is also true of the schools visited. The age, style and design of those schools visited are reflected in the survey results. It is encouraging to confirm that the schools, classrooms and teachers included in the objective measurements are 'typical' and representative of the overall sample.

It has been extremely valuable to have the 'user's' opinion of acoustics in classrooms to compare to the previous objective findings. The subjective opinion of classroom acoustics is nowhere near as poor as the objective findings. However, one major problem in this survey is that a huge number of subjects responded "don't know" or rated a room "fair". This is typical of subjective responses in social science surveys and usually unavoidable. There could be many reasons for subjects not committing themselves to other answers, such as lack of knowledge of the question area, lack of time to fully consider answers, or fear of expressing opinions.

Of course, the teachers could indeed think that their classrooms are "fair", when it comes to acoustics, but in the experience of the researchers, most teachers encountered during the research have been unhappy with the quality of acoustics in their classrooms, but have felt little could be done to improve this. Teachers involved in the case studies where Ecophon ceilings have been installed have always declared a vast improvement. Whilst teachers in the survey may respond they have a suspended ceiling in their classroom, due to the anonymity of the procedure, it was not possible to know the type and quality.

One of the most interesting findings from this survey is that in classrooms with less carpet, high ceilings and no suspended ceiling, teachers are more likely to have days off work sick. There are several factors which could contribute towards this, but it does suggest that the poor acoustics invariably found in these types of classrooms could be at least partly to blame. Therefore improving the acoustics could well help to reduce staff absenteeism. Subjective reports in schools involved in the earlier case studies support this theory. This view is also supported by the findings in this survey that in classrooms where a suspended ceiling is installed, teachers are less likely to suffer voice and throat problems. Indeed, a large proportion of teachers believe their job, in particular speaking and shouting, contributes to any voice and throat problems they experience.

It must be observed that statistical results proving a significant link between two factors cannot rule out the effects of many other factors. For example, whilst it may be significant that teachers in classrooms with carpets suffer less sore throats than teachers without carpets, other factors such as school age, classroom design, suspended ceilings and number of pupils on roll (i.e. multivariate influences) are inextricably linked and may all play a part in the result. Therefore, whilst a result may be significant and it is highly likely that the two factors are linked, it cannot be proven that one certain factor alone is responsible for any one result.

5 Discussion and Conclusion

5.1 Discussion of Results

From the work conducted so far, it can be assumed that the majority of classrooms in the UK do have poor acoustics.

Reverberation times (RT) in the rooms studied were long, with an average of 0.7 seconds in the cellular classrooms. Although this appears to be a reasonable RT, this average score is not representative of the diverse range of measured RTs. A few exceptionally low scores in certain cellular classrooms meant that the average score was lower than expected. There were many rooms in the 0.9 - 1.0 second range, and several even longer than this. These RTs are simply not acceptable for good classroom listening environments. It can be seen that once the RT drops below approximately 0.5 seconds, the Speech Transmission Index (STI) score becomes acceptable.

The measured noise levels in classrooms spanned a huge range. The lowest **Background Noise Levels (BNL)** were obviously when the classrooms were empty. However, even when the room was occupied, and the children were silent, the background noise level generally increased. When children begin talking in a classroom the noise level rises dramatically. The quietest class produced an average of 51.9dB(A) of noise and the noisiest produced 101.1dB(A). These noise levels are incredibly high and anyone exposed to these would soon become fatigued and stressed. Trying to hear a teacher talk would be difficult and understanding would be impossible unless the teacher shouted.

Treated classrooms did fare better than untreated classrooms. The RTs were lower than most untreated rooms and this can be observed in the average score. The background noise level in treated classrooms is between 9/10dB lower than the noise level measured in untreated classrooms. There was a less diverse range of background noise levels within treated classrooms (58.9 - 79.0dB(A)).

The improvement in acoustically treated rooms is much better represented in the **Percentage Articulation Loss of Consonants (%ALcons)** and **Speech Transmission Index (STI)** scores. As far as the %ALcons is concerned, in untreated classrooms (cellular and open-plan combined) children are only hearing an average 84.9% of all consonants, however, children in treated rooms hear 96.4% of consonants. As consonants contain the most information in speech, this is an important difference.

The STI scores also support this finding, with untreated rooms being rated as 'Fair', which we have deemed unacceptable, and treated achieving a rating of 'Good'. Whilst results may be indicating that treated classrooms perform better than untreated, it has not yet been concluded what type of treatment is best, the most appropriate placement of treatment and the frequency area of different improvements.

These findings support the conclusions of previous research in that the main causes of poor **speech intelligibility** in classrooms are high levels of background noise and long reverberation times. It is not yet clear which one of these factors has the most detrimental effect upon speech intelligibility, but it is thought to be a combination of the two.

It can be seen from this research that a reasonable number of classrooms appear to meet the UK Department for Education and Employment recommendations **(Guidelines For Environmental Design in Schools, 1997)** for background noise levels. However, this is only when the classrooms are empty, as we have seen, and once the rooms are occupied they become extremely noisy. A very small minority of untreated classrooms meet the criteria for RT, only 10.7%. It is disappointing to see how few classrooms are designed with hearing impaired children in mind, as very few rooms meet this criteria. However, it can be seen that 100% of treated classrooms meet the stricter recommendations for hearing impaired children.

It can be questioned whether these guidelines are adequate. An RT of 0.3 - 0.8 seconds is a very diverse range and would produce a wide range of speech intelligibility scores. Only the lower end of the RT range (0.3 - 0.5 seconds) would produce acceptable STI scores. The background noise levels appear to be achievable but measured in classrooms that are unoccupied; classrooms that meet the criteria still have very high levels of background noise once occupied which could be due to the RT and noise entering the classroom, both of which are controllable.

Several other areas for discussion have arisen during this survey of schools. One of these is the appearance of acoustical **"dead spots"** in certain rooms with abnormal ceiling shapes. 'Abnormal' refers to any ceiling shape that is not flat, and may incorporate sloping angles or beams. Several "dead spots" have been discovered in classrooms that have relatively good RTs and background noise levels and is only identified by a particularly low STI score, with %ALcons occasionally being as high as 100%. This irregularity could be due to a number of reasons, such as sound being reflected away from a location, and is an area which needs much more research. Certainly, the detrimental effect on a child's education is something that should be further investigated.

The findings from the **subjective tests**, such as the Word Intelligibility by Picture Identification (WIPI) test and the teacher questionnaires, reinforces the theory that people perform better if the classroom acoustics are good. The WIPI test showed children achieving higher scores once an acoustical ceiling was installed in their classroom. Although the children performed better in the tests conducted in silence, it was during the tests conducted in background noise that showed the most dramatic results. As this test simulates 'real' classroom conditions, such as typical noise levels, it can be assumed that if children perform better in treated rooms during this test, then they would perform better in their day to day schooling. The teachers who participated in the survey also responded they felt that children would perform better in improved acoustical environments. It was also shown that teachers in rooms with poor acoustics have more days' absence than those in better classrooms. They were at less risk of suffering voice and throat problems and headaches, the two main areas of illness for teachers after the common cold.

5.2 Conclusions

A large number of classrooms were measured, and it is thought that the sample is a fair representation of classrooms in use today. Also, a random sample of teachers were questioned and it is thought that their opinions and answers are typical of most teachers teaching today.

In most classrooms, reverberation times were found to be above the recommended values, and in some classrooms were found to be excessive. Very few untreated classrooms were suitable for the teaching of hearing impaired children, although most classes will contain at least one or more such children, including those with common colds and ear infections. Background noise levels were also found to be well in excess of recommended levels for classrooms. These long reverberation times and high background noise levels create poor speech intelligibility in most classrooms and this has been verified by objective and subjective measurements. These facts confirm that poor acoustics can be harmful to a good learning environment. If pupils cannot hear and understand the teacher with ease, it makes learning much more difficult. A noisy classroom will not cause behavioural and learning difficulties, but it may well accentuate existing problems. Another result of poor acoustics, particularly noisy classrooms, is that staff are more likely to take days off sick, and suffer voice and throat problems. This could well lead to increased costs and disruption to the children's education as supply teachers are brought in.

Tests conducted in classrooms with acoustic treatment, usually in the form of a Class A absorbent ceiling system, fared much better in all tests. All reverberation times were within the guidelines, and most were even acceptable for children with hearing impairments. Background noise levels were also reduced in treated classrooms. Subsequently, the speech intelligibility was acceptable in all treated classrooms. Subjectively, classrooms with acoustical treatment were favoured by teachers and pupils, who reported a greater ease of communication and increased performance.

Acoustically treating a classroom improves the acoustics and creates a better working and learning environment for all. Every classroom is different so no one solution can be given for every case. Each situation must be tackled differently, with consideration given to the age of pupils, use of room, volume and design of room, amongst other things. Generally speaking, the more absorption introduced to a classroom, the better the acoustics are. There have been very few cases, if any, where too much absorption was added to a room, making the reverberation time too low. It is recommended that the DfEE guidelines for classrooms containing hearing impaired children (RT : 0.3 - 0.5 seconds and BNL of 30dB(A)) should be adhered to in ALL classrooms. The extensive tests carried out in this research proves that this is the only way to ensure good speech intelligibility and comfort.

The years a child spends at school are amongst the most valuable in their life, if not the most important years. Schools were built in order to facilitate learning, so surely the rooms where this learning takes place, should be designed to facilitate listening. Teachers are some of the most important people in the education of children and they should be given the tools necessary to ensure they do their job well, and one of the tools should be a classroom where their pupils can hear well and understand what is being said, and where they can teach without undue stress and strain. Before now, few people were aware of the detrimental effect that poor classroom acoustics could have upon pupils and teachers, least of all the teachers and pupils themselves.

Hopefully, now this area has been highlighted, solutions can be offered and improvements made. If pupils and teachers are to perform to the best of their abilities, then they should have the optimum environment in which to do so.

5.3 Acknowledgements

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References

1. *Collins Dictionary of the English Language;* Editor Patrick Hanks; Collins; 1985

2. Fiellau-Kikolajensen; 1983

3. *Special educational needs*; Report of the Committee of Enquiry into the Education of Handicapped Children and Young People; (Chairperson: H.M. Warnock); HMSO; 1978; Leading to the Education Act 1981

4. Yacullo, WS & Hawkins, DB; *Speech recognition in noise and reverberation by school-age children;* Audiology 26; 235-246; 1987

5. Anderson, K. & Towne, R; *The changing sound of education;* Journal of Sound and Vibration; January 1997; pp 48-50

6. Finitzo-Heiber & Tillman, T; *Room acoustic effects on monosyllabic word discrimination ability for normal and hearing impaired children,* J. Speech and Hearing Research 21; 440-458; 1978

7. The School Premises Regulations (1996); SI 1996/360; HMSO Publications

8. Department of Education & Employment Building Bulletin 87; *Guidelines for Environmental Design in Schools*; HMSO; London; 1997

9. Building Bulletin 17 1981; *Guidelines For The Environmental Design and Fuel Conservation in Educational Buildings*; 1981; HMSO; London

10. *Speech Intelligibility in Classrooms;* EPSRC funded research project;GR/K*3632 EPSRC; Swindon; UK

11. Fairbanks G; *Test of phonemic differentiation: the rhyme test*, JASA 30; part 7; 596; 1958

12. Diaz C. & Velazquez C.; *A live evaluation of the RASTI method* ; Applied Acoustics; 1995; Vol. 46; page 363

13. Building Bulletin 25; *Lighting and acoustic criteria for the visually handicapped and hearing impaired in schools;* Department for Education and Science; 1981

14. *Design of Educational Facilities for Deaf Children;* British Journal of Audiology Supplement No. 3; 1980; pub. RNID

15. Barron, K.; *Building acoustics for the hearing disabled;* International Congress and Exposition on Disability; North Vancouver; 1992

16. Crandell, C. *Classroom acoustics;* Chapter 11 in 'Auditory Disorders in School Children'; 3rd ed.; Theime Medical publications; 1995

17. Berg, F. S.; *Classroom acoustics: the problem, impact and solution;* Language Speech and Hearing Services in Schools; Vol 27; pp 16; 1996

18. *The hearing impaired child and school;* Tucker and Powell; 1991; Souvenir Press

19. Finnish Ministry of the Environment Recommendations; 1991

20. American Speech Language Hearing Association; Position Statement; 1995

21. BS 8205: 1985; *Determining the design of learning spaces where audio-visual equipment will be used;* HMSO; London

22. BS 8233: 1987; *Sound insulation and noise reduction for buildings - Educational buildings*; HMSO; London

23. Smith, A. P.; *Noise and aspects of attention;* British Journal of Psychology 82; pp 313 - 324; 1991

24. *Noise Control in Building Services;* Editor A. Fry; 1988

25. *The acoustics of rooms for speech;* Building Research Establishment Digest; HMSO; 1976

26. BS 7827:1996; *Code of practise for designing, specifying, maintaining and operating emergency sound systems at sports venues*, Article in Acoustics Bulletin; May/June 1997; John M. Woodgate

Appendix A

Other Criteria

Table A1 highlights some of the other criteria that are available for the design of classrooms. It can be clearly seen that there is wide range of criteria available which makes selecting the correct one a very difficult task indeed.

Comparison of Different Criteria For Classroom Acoustics					
		Normal Hearing		**Hearing Impaired**	
Source	Room	R.T. (seconds)	B.N.L. (dB(A))	R.T. (seconds)	B.N.L (dB(A))
B. B. 87[7]	Classroom Hall Prac. Space	0.5 - 0.8 0.8 - 1.2 0.5 - 0.8	40 35 45	0.3 - 0.6 0.6 - 1.0* 0.3 - 0.6*	30 25 35
B. B. 25[13]	Classrooms	0.5 - 0.75	30 35		
RNID[14]	Classroom Artistic			0.5 (125 - 4000)	< 35 < 45
Barron, USA[15]				0.4	30 S/N: 20dB
Crandell, USA[16]				0.4	30 - 35
Berg, USA[17]				0.3	
H.I. Child & School, UK[18]				0.5	S/N: 30dB
Min. Of Env. Finland[19]		0.6 - 0.9	35		
Speech-Lang., USA[20]		0.4	30 S/N: 15dB NC: 20		
BS 8205, UK[21]	Classrooms Workshops	<100m^3: 0.5 <1000m^3: 1.0	40 45		
BS 8233, UK[22]	Classrooms Workshops		$L_{Aeq,T}$ 45 $L_{Aeq,T}$ 50		
Smith, UK[23]			NC: 25		
Fry, UK[24]			NR: 25/35		

S/N - Signal to Noise Ratio; NR - Noise Rating; NC - Noise Criteria

Table A1: Criteria Commonly Used For The Acoustic Design of Classrooms

Appendix B

Building Research Establishment Digest 'The Acoustics of Rooms For Speech'

In August 1976, the Building Research Establishment published a Digest called *"The Acoustics of Rooms For Speech"*[25].The first paragraph opens by posing a question:

Why are some rooms acoustically bad?

There are three main reasons why rooms may be acoustically bad for speech: they may be too reverberant for the speech sounds produced in them; they may be noisy because of the feeble resistance they offer to the penetration of noise from outside or from nearby rooms; or they may be shaped so that the speakers are more or less screened from their audience or part of it (this may be particularly serious in rooms used for discussions).

Reverberant sound: if there is too much reverberant sound, the listener is still receiving the reflected sounds of previous syllables when he/she is trying to cope with the direct sound of later syllables. The two then interfere, and speech is difficult to understand. This digest continues by stating that complaints have been made of poor hearing in rooms with low ceilings and deep transverse beams, a show in Figure B1. Here the beams can cut off the ceiling reflections to certain areas of the room, and often reflect the sound back to the speaker. Notice that dead spots can be created at certain locations within the room due to these adverse reflections.

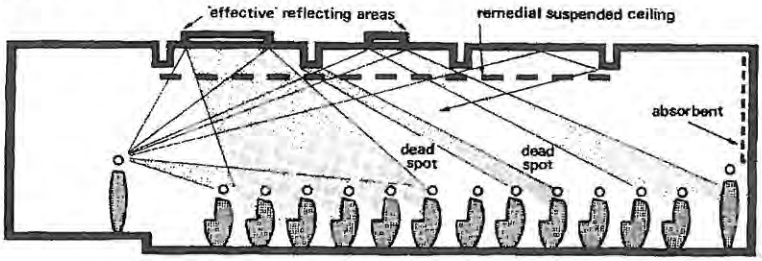


Figure B1: Room Design and Layout Can lead to Adverse Acoustic Conditions (Dead Spots)

The problem can be solved with the construction of a flat suspended ceiling under the beams. Another interesting comment is made: *"Every effort should be made in sparsely filled rooms to persuade audiences to sit near the platform. It is up to the speaker to ensure that his/her own delivery is acoustically beyond reproach. This means speaking slowly, and, if necessary, loudly, with syllables spaced out as evenly as possible".*

Appendix C

Word Intelligibility by Picture Identification

Figure C1 below shows an example of the pictures used for carrying out the word intelligibility by picture identification test.

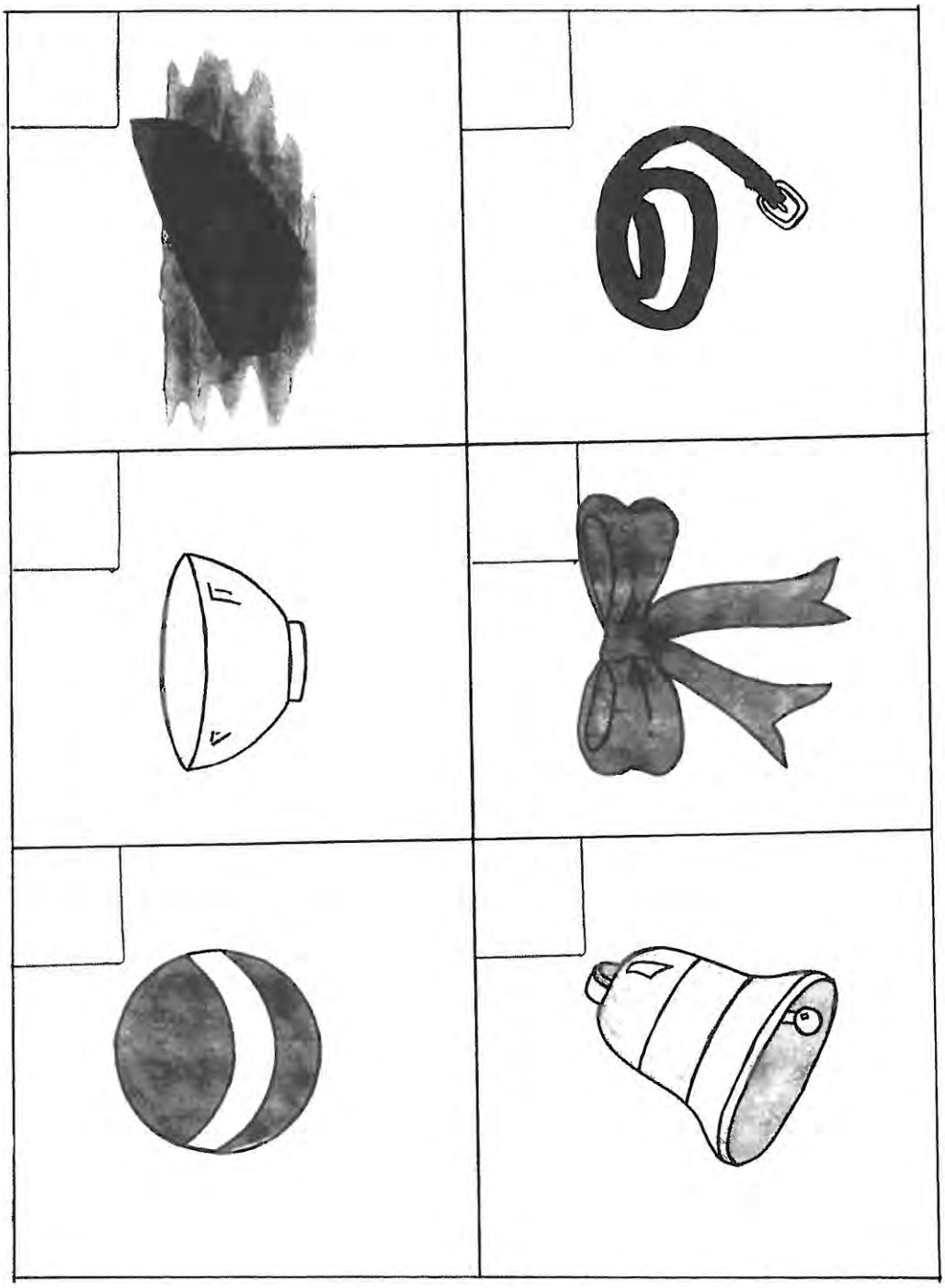


Figure C1: Group of pictures used for the WIPI test on primary school children

Appendix D

Dead Spots Within Classrooms

Table D1 shows the %ALcon results for a classroom where there is a wide range of values. There are a number of seats within the classroom which have exceedingly high %ALcons, thus indicating poor speech intelligibility. In fact 23 out of the 24 seats exceeds the maximum recommended %ALcons value of 5%, many being 100%.

On checking the classroom:

1. The ceiling line follows the roof line, to create a pitched roof to the classroom;

2. The majority of the seat locations with 100% ALcons can be pin-pointed to an area below the ridge line of the room;

3. Other poor locations are next to large sliding doors, which are continually left open, subdividing adjacent classrooms and a wet area, and

4. This classroom is barely a few years old, and yet the design is such that it is detrimental to a good teaching environment within the room.

From a pupil's point of view:

1. They will be completely disadvantaged if they are located at one of the seats with the 100% loss of consonants;

2. Since this is a measure of the quality of speech arriving at their ears, it is quite difficult to comprehend what they are actually understanding in class;

3. There is no doubt that the pupils will in fact hear sounds in the form of speech, but whether they are able to understand the spoken word is another matter altogether;

4. Since children usually sit in the same seat throughout the year, and so they may be completely disadvantaged through no fault of their own but rather due to the poor design of their classroom in which they find themselves, and

5. Pupils may be disadvantaged in their learning purely because of where they sit in class especially at a time when it is vitally important to grasp the basics of their future education.

From a teacher's point of view:

1. A number of teachers have mentioned that they thought something was wrong with their classroom; when the experiment was shown to them many different points they mentioned 'fell into place';

2. Many teachers were in fact relieved on finding this out to know it was 'not their teaching which was at fault', and

3. Teachers have particular quality standards to meet; if one is in charge of a class within a classroom where there is a major acoustical fault, and supposing there may be a number of students who are not progressing as well as they should be, then questions may be asked as to the teachers skills.

This same classroom was transformed after the installation of an Ecophon ceiling system. Table D1 also shows the %ALcon values before and after the installation of the ceiling. There is a massive change in the %ALcon values with all, bar one, showing a huge decrease to a much more acceptable value. Clearly, added absorption to a classroom can improve the speech intelligibility, as has been clearly shown in this example.

This phenomenon was noticed in other classrooms with a similar ceiling line to the one at Priory School. A much more detailed appraisal of this type of classroom is needed. Certainly installing the Ecophon ceiling system solved the problem. In fact, the room has become a much better teaching and working environment altogether.

Table 1: %ALcon Values For a Classroom (Before and After Ecophon Acoustic Treatment)

Location (within classroom)	%ALcons (before treatment)	%ALcons (after treatment)	Comment (acceptable value - 5%)
1	9.5	4.0	Improvement
2	9.4	3.0	Improvement
3	6.6	7.3	Slight Increase
4	4.7	2.3	Improvement
5	74.4	3.4	**Improvement**
6	11.2	3.4	Improvement
7	10.2	5.0	Improvement
8	14.6	4.0	Improvement
9	13.7	10.5	Improvement
10	99.0	4.4	**Improvement**
11	7.9	4.1	Improvement
12	12.6	2.8	Improvement
13	100.0	3.7	**Improvement**
14	6.7	3.9	Improvement
15	100.0	3.7	**Improvement**
16	7.1	6.4	Improvement
17	79.5	5.6	**Improvement**
18	87.0	5.3	**Improvement**
19	100.0	8.1	**Improvement**
20	92.0	13.2	**Improvement**
21	11.5	3.4	Improvement
22	12.7	5.3	Improvement
23	8.9	2.7	Improvement
24	5.9	3.9	Improvement

Appendix E: Case Studies

Previous research suggests that increasing the amount of absorption in a classroom effectively reduces the reverberation time, background noise level and improves the speech intelligibility. Similar effects have been observed during the course of this research. To investigate this further, tests were carried out on a series of classrooms whereby materials supplied by Ecophon were installed in the rooms. Acoustic measurements were carried out before and after the installation of these materials and the case studies are presented.

Case Study One:
The Priory Primary School, Tadley, Hampshire, England.

The Priory is a small village primary school set in the Hampshire countryside. The original school buildings were constructed in the 1850's and recently new classrooms and a school hall have been added, built in a similar style to the original buildings. The classrooms tend to have high sloped ceilings, large windows and are fully carpeted. The school is surrounded by farmland. Besides farm machinery, which is the main source of external noise, staff mentioned that Chinook helicopters fly directly overhead passing from one army camp to another.

Staff had complained about poor acoustics, 'echoey' rooms and high background noise levels. The school hall was also reported as having terrible speech intelligibility.

Measurements carried out:

In classroom 3 -
Reverberation time (RT) ;
Background noise levels (BNL);
Speech intelligibility tests - Speech transmission index (STI) and %ALcons, and
Word intelligibility by picture identification (WIPI) - listening test

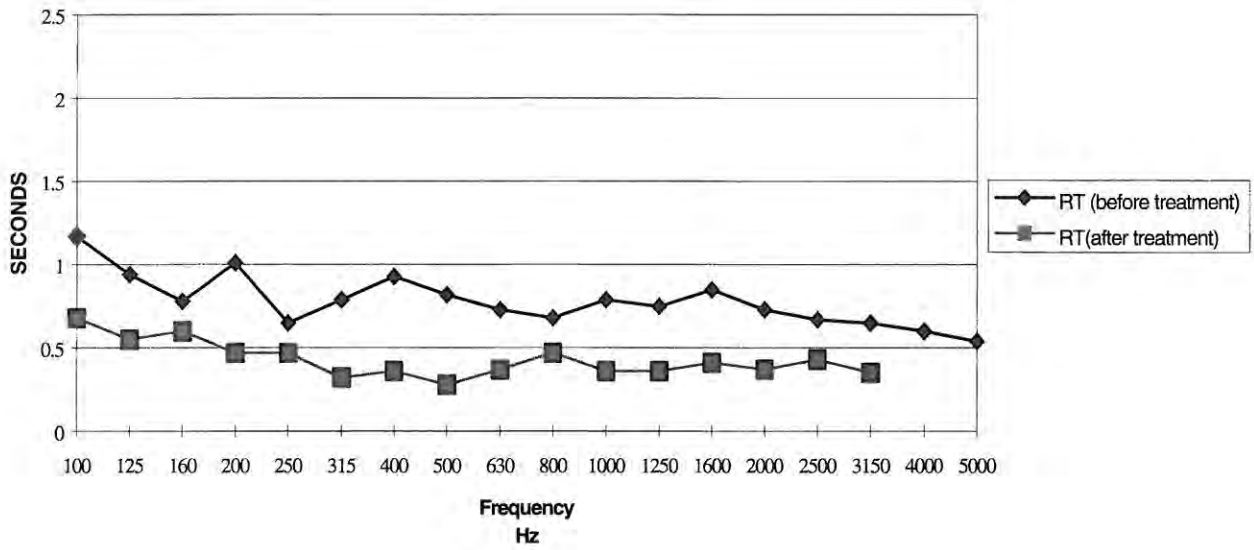
In general purpose hall -
Reverberation time

Results

Classroom 3

Reverberation time (occupied)

Figure 1. R.T. BEFORE & AFTER ACOUSTICAL TREATMENT - CLASSROOM 3

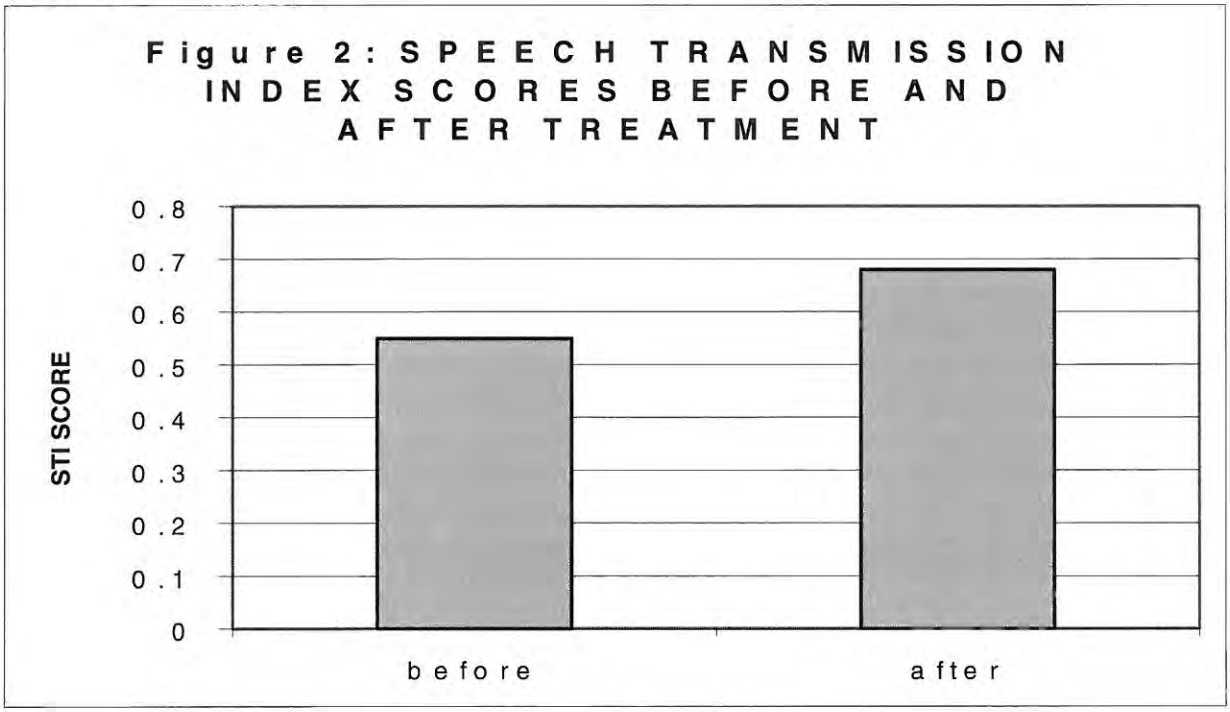


Background noise levels (occupied and empty)

	Room Unoccupied (dB(A))	Room Occupied (dB(A))	Class Talking (dB(A))
AVERAGE BACKGROUND NOISE LEVEL dB(A) BEFORE TREATMENT	35	60	70
AVERAGE BACKGROUND NOISE LEVEL dB(A) AFTER TREATMENT	-	45	65

Table 1: BACKGROUND NOISE LEVELS BEFORE AND AFTER TREATMENT – CLASSROOM 3

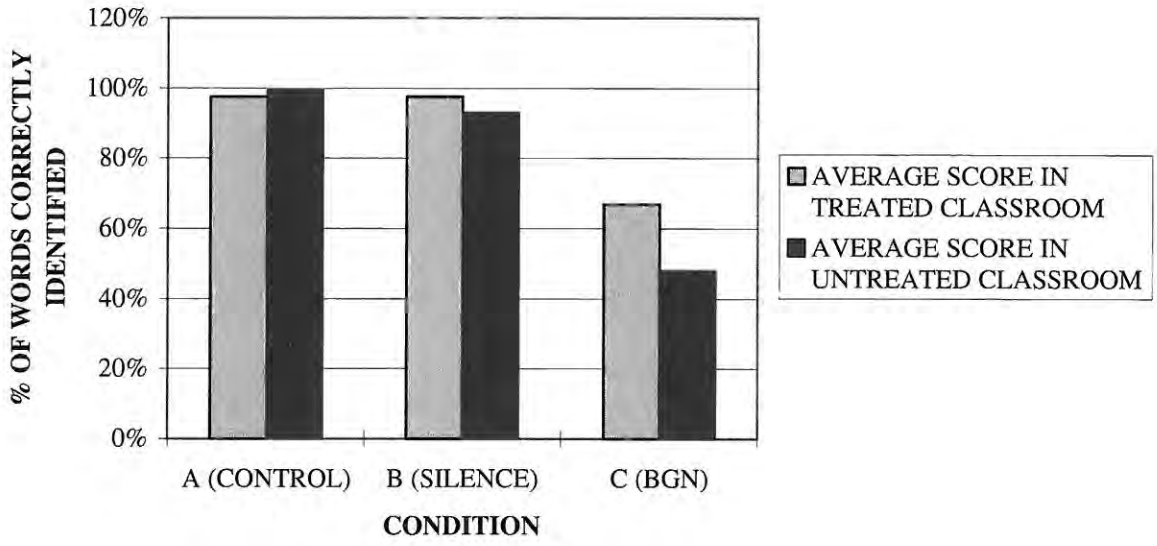
Speech transmission index



%ALcons

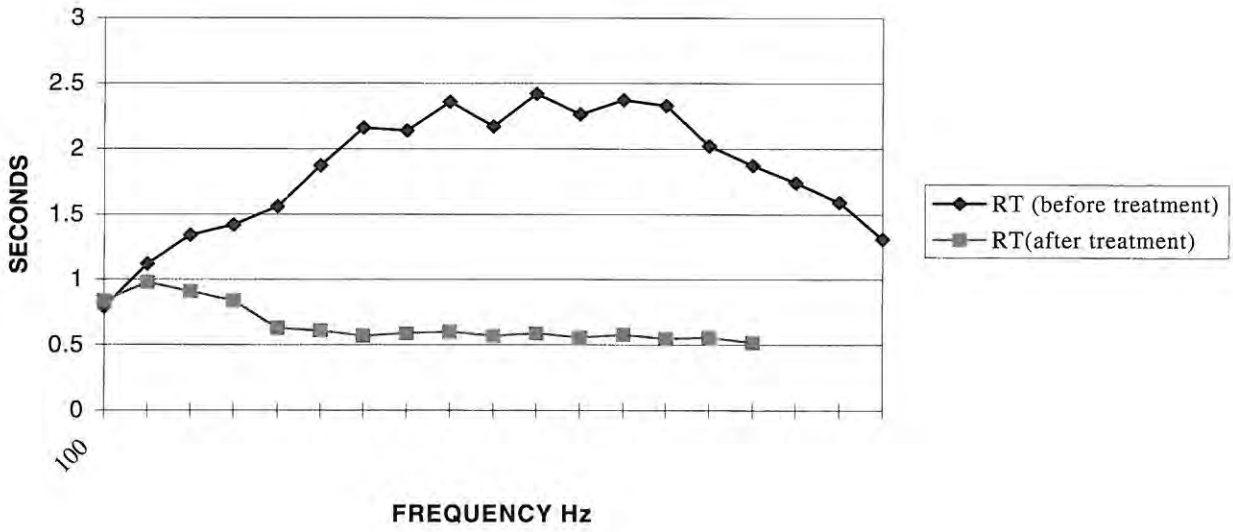
Word Intelligibility by Picture Identification tests

Figure 4. % OF WORDS CORRECTLY IDENTIFIED IN TREATED AND UNTREATED CLASSROOM



The Hall

Figure 5. PRIORY HALL REVERBERATION TIMES BEFORE & AFTER ACOUSTICAL TREATMENT



Conclusion

Classroom 3

Reverberation time

Before - As can be seen in Figure 1, the RT before treatment was 0.82 seconds at 500Hz. This is outside of the Department for Education and Employment guidelines for normally hearing pupils and well outside those for hearing impaired pupils, and there were both types of children in this classroom. The RT was fairly consistent across the frequencies, with a slightly loner RT at the very low frequencies.

After - After installation of a suspended ceiling, the RT drops considerably across all frequencies. The RT is no longer above the DfEE guidelines and it is a much more comfortable room. The effects of lowering the RT can be seen in the areas below.

Background noise level:

Before - The background noise levels were relatively high. When the class was empty, the BNL was acceptable. However, before treatment, even with the room occupied but silent, the noise levels were at 60dB(A). This increased to 70dB(A) when the children were talking and working. At this level, the teacher would have difficulty raising his voice to be heard over the background noise, and the room is subjectively uncomfortably noisy.

After - After installation of a suspended ceiling, the class when occupied becomes much quieter. When the children are silent, the BNL is 45dB(A), which is a noticeable difference. This results in the children not having to speak so loudly when working and the background noise level then is 65dB(A). This is a much more comfortable working environment, and this was confirmed by teacher and pupils alike.

Speech intelligibility:

Before - Before treatment the classroom was rated 'fair' on the STI scale with a score of 0.55. However, this meant that a %ALcons score of 9.7 was produced i.e. nearly 10% of consonants would be misheard. This may not seem much, but when you consider, in a classroom this totals a whole morning or afternoon of missed consonants. Due to the high BNL and RT, the male teacher found himself shouting which in turn distorted his speech even more.

After - With improved absorption, the classroom is now rated 'good' on the STI scale with a score of 0.68. This improvement is demonstrated in the %ALcons score of 4.8, which is less than half as many, mistakes as previously. The teacher now found he could talk at a comfortable level and still be heard, and more importantly, understood.

WIPI test:

Before - Scores during the control test were very high, showing that this class had the ability to perform well. The test conducted in the occupied room in silence still produced fairly good scores, but the children on average lost nearly 7% of speech. However, when the test was

conducted in a typical working background noise level, the scores dropped dramatically. The children were apparently mis-hearing more than half of all the words.

After - As expected, the children performed similarly well in the control test. Scores in the silent condition were slightly higher than before, equal in fact to the control condition. This suggests ideal listening conditions in this classroom when occupied but silent. When the background noise level increased to a typical working level, the scores still decreased, although nowhere near as dramatically as before treatment. Due to the reduced BNL and RT, the speech intelligibility improved to such an extent that the children could hear and understand much more easily.

The Hall

Reverberation time

Before - Before treatment the hall had an extremely long RT, particularly in the speech frequencies. This produced an extremely uncomfortable room, with terrible speech intelligibility and high levels of background noise. This RT is much higher than any accepted criteria.

After - The hall ceiling and some walls were lined with acoustical panels and the result is dramatic. The RT is now comfortably low, well within guidelines and is subjectively a much more pleasant room to talk in. Speech intelligibility is much improved and this room is now suitable for the purposes for which it was intended, such as drama, physical education and singing. Because the RT is so low, it can, to a certain extent, be controlled for various purposes by closing or opening of curtains on the large window lining one wall.

Case Study Two

Balgreen Primary School, Saughton, Edinburgh, Scotland

Balgreen is a typical city centre primary school, built at the turn of the century. The school suffers a number of major external noise sources including; traffic noise from a busy road directly outside, high speed trains and regular lawn mowers on the adjacent bowling green. The school is two storeys high and the classrooms are uncarpeted, have relatively high ceilings and large areas of windows.

Measurements carried out

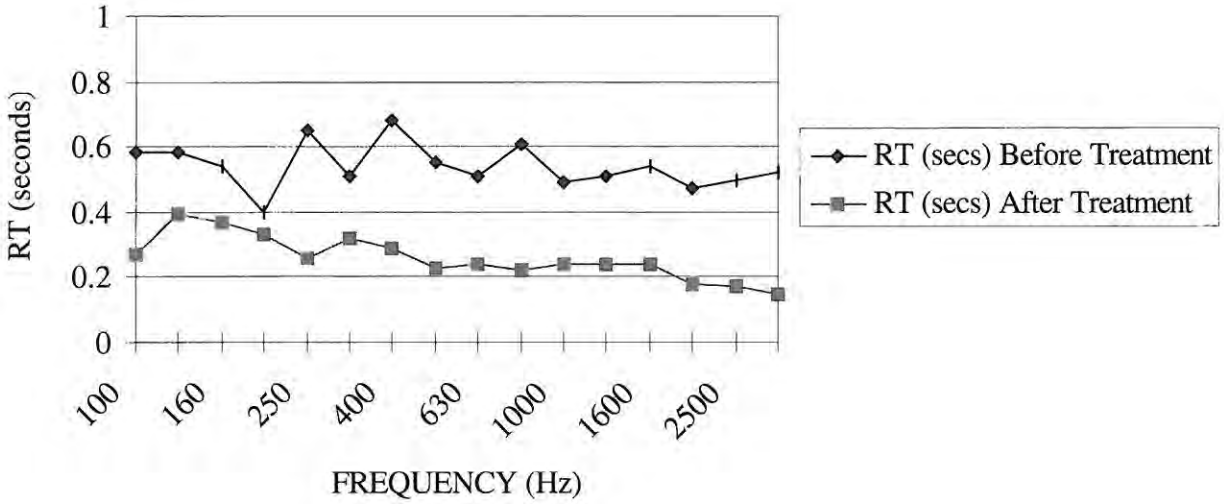
In classroom 1 and classroom 3:

Reverberation time (RT)

Results

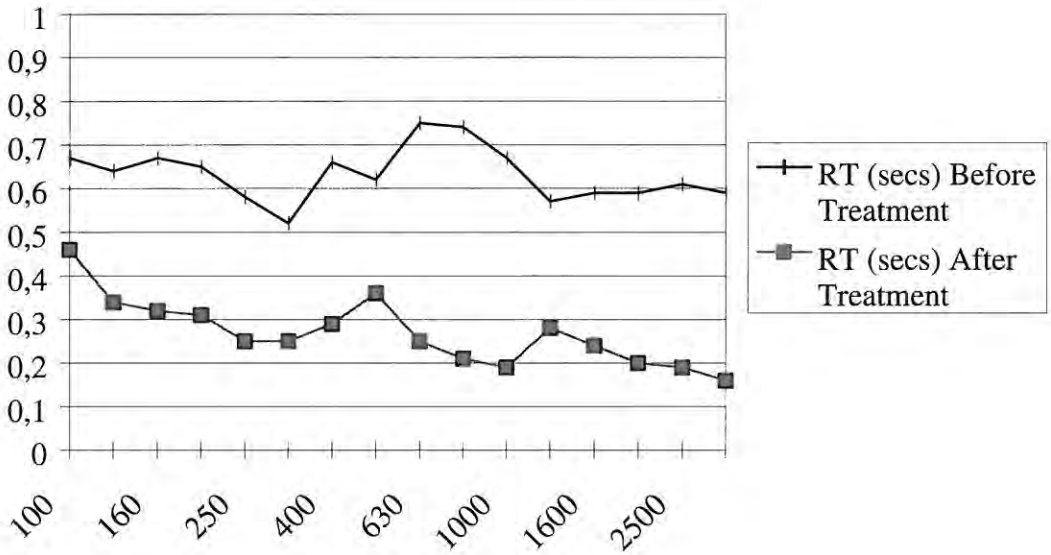
Classroom 1

Figure 7. R.T. IN CLASSROOM 1 BEFORE AND AFTER ACOUSTICAL TREATMENT



Classroom 3

Figure 8. R.T. IN CLASSROOM 3 BEFORE AND AFTER TREATMENT



Conclusion

Reverberation time - classrooms 1 and 3:

Before - Both classrooms have RTs which are well within the DFEE guidelines for normally hearing pupils. However, they are above those recommended for hearing impaired children. Research has shown the speech intelligibility only to be acceptable for everyone once the RT is below 0.5 seconds. Classroom 1 has a particularly uneven RT across the frequencies which would lead to distortion of speech. Classroom 3 suffers an increased RT in the mid-frequencies which will effect clarity of speech.

After - Although the RTs were not excessively long, the installation of a suspended ceiling in each classroom has effectively lowered the RT across the frequencies. In both classrooms, the RT is more consistent across frequencies so speech is less likely to be distorted. As a consequence of the lowered RT, BNLs will also be lowered and the speech intelligibility will be improved.

Mrs Read, classteacher in classroom 1 said: "The new ceiling definitely makes a quieter working environment. This leads to the children working more quietly and noise is less likely to build up. I don't need to raise my voice as much and the day is much calmer for the children and myself now."