CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Having stated the importance of the study and the objectives clearly, it is necessary to learn the innumerable contributions made in this field which has led to the present study. Numerous investigators have demonstrated that the acoustical environment in a classroom is an important variable contributing to the academic achievement of children. The acoustical environment of a classroom has been identified as a critical factor in the psycho educational and psychosocial achievement of children. Specifically inappropriate levels of classroom noise and /or reverberation have been shown to deleteriously affect not only speech perception, but also reading/spelling ability, behaviour, attention, concentration, and academic achievement in children. A large amount of work has been done towards this and also in identifying the various sources of noise that cause these. In this chapter a brief review of the literature pertaining to the scope of the work mentioned in Chapter 1 is presented.

2.1.1 Noise Descriptors

Noise from different sources can be measured or described in different ways. Scientists have conducted surveys and laboratory studies to develop descriptors to best correlate the community response to various environmental noise sources. Sound pressure is not equally sensed by human
ear at different frequencies. Human ear is more sensitive to the sound frequency range 1 kHz to 4 kHz than sound at very low or high frequencies. Higher sound pressures are therefore acceptable at lower and higher frequencies than in the mid range. Hence to express sound pressure levels certain frequencies are weighted more. The most acceptable noise measurement is based on A-weighting. The A-weighted sound level represents the human hearing in the best possible way. This is expressed as adding ‘A’ to the decibel. Other weightings adopted are B-weighting and C-weighting. Sound level meters are normally fitted with filters adapting the measured sound response to the human sense of sound, such as ‘A’ filter. B-weighting and C-weighting do not have much practical applications. The decibel filter A is represented with Octave band mid frequencies (Hz) and A-weighting decibels dB as shown below (NBC 2005):

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>A-weighting dB</th>
</tr>
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<tbody>
<tr>
<td>125</td>
<td>-16.1</td>
</tr>
<tr>
<td>250</td>
<td>-8.6</td>
</tr>
<tr>
<td>500</td>
<td>-3.2</td>
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<td>1000</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>1.2</td>
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<tr>
<td>4000</td>
<td>1</td>
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<tr>
<td>8000</td>
<td>-1.1</td>
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Where human hearing is involved and practically in all noise problems in classrooms, auditoria etc, the sound measured would be expressed in dB A and sometimes denoted as dB (A). Some authors also specify dB according to the context. In the fluctuating sound pressure levels $L_n$ indicates that the sound pressure level exceeded for ‘n’ percent of the time. For example $L_{10}$ indicates that for 10 % of the time the sound has a sound pressure level above the dB A given as $L_{10}$. In the literature $L_{10}$, $L_{50}$ and $L_{90}$ are commonly used to represent the background-noise or ambient noise. $L_n$ can be obtained by analyzing a given noise by statistical means. If the noise is measured in A weighted scale, $L_n$ is often written as $L_{An}$. The descriptor $L_{10(50min)}$ indicates that during noise survey of 50 minutes, in 10 % of time the noise has exceeded the value L. If the time within brackets is not shown it may be for a continuous long time. Another noise descriptor commonly used is $L_{eq}$. It is the
constant noise level which, under a given situation and time period, contains the same acoustic energy as the actual time varying noise level. When noise or sound is measured in dB A, it is customary to denote the equivalent continuous sound pressure level as $L_{A_{eq}}$ dB. Similarly $L_{A_{max}}$ and $L_{A_{min}}$ give the maximum or minimum sound pressure levels during the measured time. In the literature the researchers use dB A or dB (A) or dB, $L_{A_{eq}}$ dB, $L_{A10}$ dB etc according to the context.

2.2 IMPORTANCE OF ACOUSTICS IN LEARNING

Education of its citizens is of prime importance to any country and almost all countries are giving top priority to school education which primarily starts at a young age of children and that too inside school classrooms. The chief function of a school classroom is instruction, and instruction comes and likely will continue to come, by word-of-mouth and listening. The school classrooms are established to promote learning, which is by speaking and listening (Nelson 2003). In elementary school classrooms, most learning involves listening to the teacher and to each other (Goodland 1983). Therefore, acoustics is one of the most important physical properties that determine how well the school classroom building can serve its primary function. Thus the exclusion of noise and reverberation are indispensable in adapting classroom to the function of oral instruction (Knudsen et al 1950).

Speaking to a class of young children, in a room with poor acoustics is similar to making the children read in dim light (Issue Track 1999). Good acoustical quality is critical for a classroom to function well for its intended purpose. The acoustical properties of classrooms are often ‘forgotten variables’ in ensuring students’ academic success, particularly for students with unique communication or educational needs (Crum and Matkin 1976, ASHA 2005). In spite of the care taken for the construction of school
buildings, the conditions in the classrooms for a congenial environment for learning by young children are not fully achieved, especially regarding the acoustical performance. Elementary-school children are the most vulnerable section of the student population, needing good learning environments. The effectiveness of this communication, and hence the effectiveness of the learning environment, can be evaluated by way of the acoustical conditions in the classrooms. Though defects in lighting and ventilation are discernible to the administrators and planners, the requirement of acoustics suitable for children in the classroom cannot be fully experienced by the grownups. Unfortunately a student’s difficulty in understanding speech in a noisy situation may not be recognized by adults, because adults are better able to discriminate speech in noise (Bradley 2007).

It is observed that the classrooms have usually been designed to adult speech criteria so as to provide an environment in which adults experience adequate Speech Intelligibility. An assumption that children can be regarded as ‘scaled-down adults’ is not appropriate as primary school children do not have the developed language skills, or the lexicon of the adults and their hearing systems are not fully mature. If children try to understand speech in an environment in which there is excessive reverberation or a poor Signal-to-Noise Ratio, they are less able to interpolate the ‘masked’ speech information and understand what is being said, whereas adults, through experience, have learnt to ‘fill in the blanks’ and anticipate an intended meaning because of the context and rules of syntax and grammar. Furthermore the physical auditory system does not reach maturity until the early teenage years so the way in which children process as well as interpret auditory information is likely to be different from adults. Decades of research by audiologists, speech language pathologists, acousticians and others have documented the educational value of good acoustics and the detrimental effect
of poor acoustics on students’ auditory comprehension, learning and behavior, and on teachers’ vocal health (ASHA 2005).

### 2.3 EFFECT OF NOISE ON CHILDREN

There has been a great deal of research in the past 30 years into the relationship between noise exposure of school children and their performance in various cognitive tasks at school. This has been mainly concerned with the primary school age range (5 to 11 years), and has included studies on the effects of chronic exposure to different kinds of environmental noise and other kinds of classroom noise. Many of these studies have examined the effects of noise on children’s cognitive processing in a range of tasks and on their academic performance at school.

A major effect of noise in the classroom is the reduction of speech intelligibility, and the hearing and understanding of speech by children of different ages in various noise and acoustic conditions is a related important research field. In parallel with studies of the effects of noise at school, there have been several surveys of classroom noise and acoustics, and investigations into the way in which the acoustics of classrooms may be improved. It is generally accepted that noise has a detrimental effect upon learning and the earlier studies were concerned mainly with the external environmental noise exposure of schools, but the effects of the internal classroom noise on attainments of primary school children have been investigated (Berglund et al 1995, Institute 1997). At the beginning of the 1990s there were two major reviews of previous works to date in this area (Hetu et al 1990, Evans and Lepore 1993), both of which concluded that chronic noise exposure of young children has a particularly detrimental effect upon their reading ability. Picard and Bradley (2001) have published a major review of issues related to Speech Intelligibility in classrooms, which covers many aspects of noise and acoustics in the classroom.

The types of noise that have been considered in these studies include aircraft noise (Cohen et al 1980, Cohen et al 1981, Stansfeld et al 2000, Evans 1995, Evans and Maxwell 1997, Evans et al 1998); train noise (Hambrick 1986, Hambrick 1988, Bronzaft and McCarthy 1975); traffic and street noise (Meiss et al 2000, Evans et al 2001). Despite these, there have been few studies in which the effects of irrelevant noise in the classroom have been considered. One such study is the large scale investigation by Shield and Dockrell (2002) which examined, separately and in combination, the effects of environmental and classroom noise on children’s perceptions of noise and performance.

Elliot (1979) studied recognition of sentences in noise by children of 9 to 17 years old. The performance of 9 year old children was significantly poorer than that of 11 year old children, who performed significantly worse than 15-17 year old children. Hygge (2003), with his classroom experiments, established that excessive noise can interfere with children’s learning, by
affecting memory. The acoustic conditions in the classroom are known to influence children’s academic achievements (Finitzo and Tillman 1978, Nabelek and Nabelek 1994). Numerous researchers have thoroughly documented the deleterious effect of excessive classroom noise and reverberation levels on speech recognition ability and educational/social development (Crandell and Smaldino 2000, Johnson 2000).

Schools and day-care centres should be located in areas that are as noise-free as possible (Berglund et al 1995). That loud sounds may be harmful to hearing has been accepted for many years but it is not realized by people that the number of people suffering actual hearing loss from noise is huge (Bronzaft 2002). Cohen et al (1973) found that children who lived on the lower floors of an apartment complex, which exposed them to nearby traffic noise, had poorer reading scores than children living in the same complex but on higher floors. In another study, Wachs and Gruen (1982) it was found that noise in the home, impaired a child's cognitive and language development. When something is done to lessen the noise in classrooms, students do better. Bronzaft (2000) provides a more extensive review of the studies that have found that noise interferes with learning.

There have been many studies of children’s understanding of speech in different noise and reverberant conditions, some of which have paid particular attention to the acoustic conditions of classrooms. These studies have shown that young children are far more susceptible to poor acoustic conditions than adults. Nelson (2003), in describing the development of the 2002 ANSI standard on classroom acoustics (ANSI 2002), gives a brief review of recent work in this area. It has been shown through research with children of differing ages that a child’s understanding of speech in noise and reverberation does not reach an adult level until the late teenage years. Before this time, younger the child the greater the detrimental effect of noise and

2.3.1 **Sources of Noise in the Classroom**

The noise in a classroom is made up of external noise which is transmitted through the building envelope and open windows and doors, plus internally generated noise, as a result of which children in school may be exposed to noise from a wide variety of sources. An additional source of noise which is reputed to cause significant disturbance to teaching is the noise of rain falling on lightweight school roofs (Department 2003, O’Neil 2002).

The predominant external noise source, particularly in urban areas, is likely to be road traffic (BRE 2002, Shield and Dockrell 2002) although aircraft noise may also affect many schools, with fewer schools exposed to railway noise. A survey in 2000 by Shield and Dockrell (2003) of noise sources outside schools in London found that the predominant sources were cars (outside 86% of schools), aircraft (54%), lorries (35%) and buses (24%), with 11% of schools exposed to railway noise. This distribution of sources agrees closely with the occurrence of sources recorded outside dwellings around the UK during the 2000/2001 National Noise Incidence Survey (BRE 2002) (for example the survey found 87% of dwellings were exposed to road traffic noise, and 12% of dwellings exposed to railway noise). It can therefore be assumed that these figures are likely to reflect the typical noise exposure of schools in industrial societies. Studies of annoyance caused by noise heard in schools by Dockrell et al (2001), Dockrell and Shield (2002, 2003) suggest that certain occasional noise events such as over-flying aircraft, trains or sirens may affect children and teachers disproportionately to their contribution to the overall noise environment of a school.
In addition to external noise transmitted through the building facade, open windows and doors to a classroom, noise inside a classroom may include noise from teaching equipment (computers, projectors and so on), noise from building services (fan) in the classroom and noise transmitted through the walls, floor and ceiling from other parts of the school. Shield and Dockrell (2002, 2003), however, in a survey of 140 primary school classrooms, found that the dominant source of noise in a primary school classroom was the noise generated by the pupils themselves as they took part in a range of classroom activities. The class activity noise pertains to classes where the teaching method involves activities by the children also. Class activity noise is the noise created by the occupants of the room whilst working. The sole of the foot wear worn by the students if made of hard synthetic/natural material would add to the background noise. It is a background noise issue which has not been adequately addressed in classroom acoustics studies. Although this is a separate issue from ambient noise, the two may well be linked, in that, if there is a high level of ambient noise the activity noise will rise to compensate. This can be explained by the Lombard effect, (or Café effect or cocktail effect). In a social environment where there are a number people engaged in separate conversations, i.e. in a café, cocktail party, or indeed a classroom during a group work activity period, the speech noise from numerous conversations generates a background noise level. If that resulting level is sufficiently high to cause Lombard effect in the speakers of each group, the noise level of each group will rise, causing the other groups to raise their level also. This competition causes the noise level in the room to rise – this is called the “café effect” (Pick et al 1989).

2.3.2 Effects of Environmental Noise on Classroom

The majority of the researches into the effects of noise on children’s performance in the classroom have examined the issue in one of
two ways; either the performance of children exposed long term to significant
levels of environmental noise has been compared with that of children with
low noise exposure, or the effects of a reduction in environmental noise on
children’s performance in the classroom

In the UK road traffic noise has been found to cause dissatisfaction
with the classroom environment among teachers, Sargent et al (1980) found
that there was a greater incidence of complaints about noise at levels above 60
dB A. Lukas et al (1981) found that exposure to traffic noise had a detrimental
effect upon children’s reading ability. More recently tests in both primary and
secondary schools exposed to noise from road traffic found that noise had a
detrimental effect on children’s attention (Sanz et al 1993, Romero and Lliso
1995). The levels of road traffic noise in these studies were around 70 dB A
on average. Hygge (1993) investigated the effects of noise from various
transportation sources on children aged between 12 and 14.

Other studies have examined the effects of school exposure to train
and road traffic noise, Bronzaft and McCarthy (1975) found that children on
the quieter side of a school next to an elevated railway had reading scores
higher than children on the side exposed to the train noise, at levels of up to
89 dB A. A noise abatement programme reduced the train noise inside the
school by 6 to 8 dB A, after which no difference was found between the
reading scores on the two sides of the school (Bronzaft 1981).

Shield and Dockrell (2002) compared external noise levels at over
50 London schools with the schools scores of children aged 7 and 11. There
were significant relationships between external noise levels and scores, the
relationships being stronger for the older children. The noise parameter that
had the highest correlation with the score results was $L_{A\text{max}}$, suggesting that it
is the noise of individual events, or acute exposure, which may have the most
significant effect. In contrast to other studies, the subjects most affected were
Mathematics and Science. The significant relationships were maintained when the data was corrected for school socio-economic factors such as percentages of children for whom English was not the first language and percentages of children receiving free school meals. Similarly, Haines et al (2002) found that chronic exposure to aircraft noise was significantly negatively related to performance in the standardized mathematics tests of 11 years olds, although the relationship was not statistically significant when the data was corrected for socio-economic status.

From all these studies it is found that both chronic and acute exposure to environmental noise may adversely affect children’s academic performance. There are many other factors, often unreported, that may influence performance, and interact with the effects of noise. These include child-based factors such as ability, language or social deprivation. In their study of London schools, Shield and Dockrell (2002) found that there was a high correlation between a school’s external noise level and the percentage of children having free school meals at the school, the latter being a recognized indicator of social deprivation in an area (Williamson and Byrne 1977, Higgs et al 1997). This suggests that deprived children already living in noisy areas attend schools where their exposure to environmental noise may additionally negatively affect their academic performance.

2.3.3 Effects of Classroom Noise

There has been less research in the past into the effects on children of noise in the classroom than of environmental noise. However, research in these areas is increasing, several recent studies having investigated the effects of internal noise on children’s reading, numeracy and overall academic performance (Shield et al 2002, Mackenzie 2000, Maxwell and Evans 2000, Lundquist et al 2000).
Hetu et al (1990) found a significant drop in children’s performance, particularly in learning to read, when the background noise level interfered with speech. Mackenzie (2000) compared the performance of children in primary school classrooms that had been acoustically treated thereby reducing background noise levels and reverberation times, with children in untreated classrooms. Children performed better in word intelligibility tests in the acoustically treated rooms the improvement being particularly marked when other pupils were talking in the classrooms. Similar results were obtained by Maxwell and Evans (2000) in a study of pre-school children who had been exposed to levels in the classroom of 75 dB A. Following acoustic treatment to reduce the noise the children’s performance improved in letter, number and word recognition. In contrast, in a study of older children, aged 13 and 15, working in levels of 58 to 69 dB A during Mathematics classes (Lundquist et al 2000) there was poor correlation between sound level and standard of work; however, there was a significant relationship between annoyance and the effect of noise on schoolwork.

Shield and Dockrell (2003) in comparing standardized assessment test scores with internal noise levels in 16 schools found significant relationships between background (L_{A90}) levels in classrooms and test scores for several subjects. The test which showed the strongest association with noise was the English test of the older (age 11) children, the relationship still holding when the data was corrected for socio-economic factors. A possible explanation of this result is that background speech in the classroom interferes with general processing of languages.

2.3.4 Children’s Perception of Noise at School

The most widespread and well documented subjective response to noise is annoyance. However, while there have been many studies concerned with annoyance caused to adults by different types of noise, including ones
which have established close response relationships between noise and annoyance, children’s annoyance due to noise is a relatively under researched area. Yet children’s annoyance may be an important factor in determining the effects of noise. Indeed, Lundquist et al (2000) found that there was a stronger relationship between school performance and annoyance than between sound level and performance.

Some of the studies of the effects of noise on children already discussed have also considered children’s perceptions of sound. Children at school have consistently been found to be annoyed by chromic aircraft noise exposure (Evans et al 1995, Haines et al 2001). In their study of the effect of high levels of aircraft noise Haines et al (2001) demonstrated that annoyance levels due to aircraft noise were significantly higher among children in schools exposed to high levels of aircraft noise compared with schools with lower exposure levels. In contrast, levels of annoyance due to road traffic noise both at school and at home did not differ significantly across the high and low aircraft noise schools.

Children may be aware of noise without necessarily being annoyed by it. A recent survey by Dockrell et al, of over 2000 London primary school children aged 7 and 11 years, in schools exposed to a range of environmental noise sources, found that children were more aware of the noise, while the younger children found noise more annoying. The most annoying noise sources were trains, motorbikes, lorries and sirens, suggesting that it is intermittent loud noise events which cause most annoyance to children while at school.

2.4 ACOUSTICAL CONSIDERATIONS FOR CLASSROOMS

In a good learning space the main acoustical concern is the quality of verbal communication (Picard and Bradley 2001). The quality of verbal
communication can be quantified by the Speech Intelligibility (SI) (Bradley 1986). For good Speech Intelligibility the learning space should have low noise levels and minimum reverberation (Goodland 1983). Unfortunately many learning spaces have excessive background-noise (BN). Students of all ages and abilities, and their teachers, need appropriate classroom acoustics to communicate effectively in the classrooms and other school learning environments. Good environmental conditions in classrooms would lead to an increase in the school performance of the students and in the productivity of teachers (Astolfi and Pellerey 2008). Bad acoustic conditions in classrooms decrease the quality of verbal communication, reducing the school performance of students and causing the teachers to suffer from fatigue. According to the ISO 9921:2003 standard (Ergonomics 2003), the quality of verbal communication can be expressed in terms of Speech Intelligibility, which is quantified as the percentage of a message that is understood correctly. Reverberation (quantified by the Reverberation Time (RT) (ASHA 2005)) and background noise control the Speech Intelligibility in a room (Sylvio et al 2000). The Speech Intelligibility at a listener’s position in a classroom is known to be directly related to the speech Signal-to-Noise Level Difference (commonly referred to as the Signal-to-Noise Ratio) which is the difference between the teacher’s-voice and the background-noise levels and inversely related to the amount of reverberation (Bradley 1986 a) and can be predicted by the Speech Transmission Index (STI) which combines the above two factors (Houtgast et al 1980). As a longer RT tends to mask the teacher’s voice, it is found that smaller RT would be beneficial so that the acoustical environment in primary school classrooms can be improved by harnessing the early reflections. Early (arriving up to 35 ms after the direct sound) sound waves reaching the children from the teacher enhance the hearing quality for children (Whittlock and Dodd 2008).
The subject of acoustical comfort (background-noise (BN), sound insulation, Reverberation Time, Speech Intelligibility, Speech Transmission Index) in classrooms of primary schools, secondary schools, as well as university classrooms has been the focus of several studies around the world (Hodgson 2002b). Classroom noise level which is nothing but the background noise refers to any auditory stimuli that interfere with what a child wants or needs to hear and understand (EN 2003); external noise is the noise outside the classroom.

2.4.1 Classroom Noise Levels

Despite the body of research into the effects of poor Speech Intelligibility and noise on children in the classroom, there is relatively little published data on typical noise levels in classrooms and outside schools (Shield and Dockrell 2004). Furthermore, owing to changes in instrumentation, measurement techniques and parameters over the past 30 years, the data that is available is limited in scope and often difficult to interpret in terms of current noise parameters and methodologies. The reported levels have on the whole been presented as single figure ratings, either in dB A with no explanation of which acoustic parameter was measured, or in terms of $L_{Aeq}$ without reference to time or classroom activity. The impacts of excessive noise vary according to the age of the students, because the ability to focus on speech is a developmental skill that evolves and does not mature until ages 13 to 15 years. As children mature they tend to develop strategies to cope with noise levels. Accordingly, young children require better acoustical environments than do adult listeners to achieve equivalent word recognition scores (Elliott 1979). Classrooms of younger children are also found to be noisier (Picard and Bradley 2001).

A student’s difficulty in understanding speech in noisy situations may not be recognized by teachers, building designers, or other adults. That
is, adults cannot rely on their own perception of speech under adverse listening conditions to recognize a child’s difficulty under the same conditions. (Elliott 1979) found that the ability to recognize sentences in noisy environments improves systematically with age for children who are 5 to 10 years old. Similar effects of children’s age on speech perception in noisy environments were reported by Finitzo Hieber and Tillman (1978) and Marshall (1987).

In a review of classroom noise data published between 1977 and 1991, Hodgson et al (1999) reported that in most cases it was difficult to determine precisely how the measurements were obtained and in what classroom conditions. Picard and Bradley (2000), in a large scale review of classroom noise levels also note the lack of detailed data on noise in classrooms. However, with increasing interest world wide in school and classroom acoustics, the rate of publication of classroom and school noise data is increasing. For example, the UK government has funded several large scale studies of classroom noise and the effects of noise on children (Stansfeld et al 2000, Shield et al 2002, MacKenzie and Airey1999) and similar work was undertaken on a European wide basis (Matheson et al 2002).

Published data include measurements of teachers’ speech levels, background levels in empty classrooms and levels due to student activities in the classroom. However, previous surveys have shown a wide range in noise levels in classrooms, as discussed below.

2.4.1.1 Teacher’s Speech Levels

The review by Hodgson et al (1999) found that data on teachers’ speech levels ranged from 40 to 80 dB A. Picard and Bradley (2001) also noted the wide range in reported speech levels, the variation being due to different measurement methods and microphone positions. From the
published data they estimate that the average speech level in a classroom 2 meters from the teacher is 60.1 dB A.

2.4.1.2 Background-noise levels in empty classrooms

In empty classrooms the noise is likely to be due to sources within the classroom such as ventilation system noise (fan), plus noise transmitted from other areas in the school and from external sources. The review by Hodgson et al (1999) found measured levels of ventilation noise in classrooms ranged from 23 to 55 dB A. Other surveys have included data on noise levels in empty classrooms, without the noise sources being specified. A survey of empty classrooms in elementary schools in Istanbul (Celik and Karabibber 2000) shows a range of measurements from 35.7 to 60.6 dB A; from the data presented the average can be calculated as 47.8 dB A. Empty classrooms have been measured in several of the surveys of classroom noise in the UK. A survey of seven primary school classrooms by Hay (1995) found that the background noise levels in empty classrooms was 44.8 dB A. Airey and Mackenzie (1999) in a comparison of acoustically treated and untreated classrooms found average background noise levels in the treated classrooms of 40 dB A compared with 44.7 dB A in untreated rooms. The survey of primary schools in London by Shield and Dockrell (2003), found an average of 47 dB A $L_{Aeq}$ in empty classrooms. Considering that these surveys include schools in urban (in both the UK and Turkey), suburban and rural areas, the results are surprisingly consistent, the larger surveys showing average noise levels in empty classrooms of 45 to 48 dB A (assuming no acoustic treatment).

2.4.1.3 Noise levels in occupied classrooms

Several studies (Shield and Dockrell 2003, Mackenzie 2000, Hodgson 1994) have found that, even when students are silent in a classroom,
their presence significantly increases the noise level above that of the unoccupied condition. As with empty classrooms, the noise levels measured in occupied classrooms with students or pupils engaged in quiet activities are remarkably consistent between studies, regardless of the age of the students. In a survey of university classrooms Hodgson (1994) found that a typical background noise level of 35dB A in an empty classroom increased to 56 dB A when students were present. Mackenzie (2000) in a survey of primary school classrooms found that the average level was 56 dB A when pupils were silent in acoustically untreated classrooms, although this dropped to 46.5 dB A in treated rooms. The average $L_{Aeq}$ level measured by Shield and Dockrell (2003) when pupils were quiet was 56.3dB A. It would appear from these studies that, regardless of the noise levels when the room is empty, or of the age of the students, the presence of students, even when quiet, increases the noise level in a room to around 56 dB A. The published data on noise in occupied classrooms, with students engaged in teaching and learning activities, display a wide range. The review by Hodgson et al (1999) found that reported levels ranged from 40 to 70 dB A and in the review by Picard and Bradley (2001) occupied levels in a full range of classrooms from kindergarten to university varied from 42 to 94 dB A. However, it is possible to observe some patterns among the published data. Shield and Dockrell (2003) found that the ambient noise level in an occupied primary school classroom was closely related to the pupil activity. The measured activity levels ranged from 56 dB A (silent activity) to 77 dB A $L_{Aeq}$ when the pupils were engaged in noisier activities involving group work and movement around the classroom. The level for the most common activity, children sitting working at their tables with some interaction between them, was 65 dB A $L_{Aeq}$ while the average overall level of all occupied classrooms in this study was 72 dB A.
An average occupied level of 65 dB A was measured in both primary and secondary school classrooms by Moodley (1989). In this study it was found that in primary schools, a mean level of 47 dB $L_{A_{eq}}$ for empty classrooms, with a range from 35.0 to 64.2 dB $L_{A_{eq}}$, and for occupied classrooms, a mean of 65 dB $L_{A_{eq}}$ and a range from 47.5 to 81.3 dB $L_{A_{eq}}$. Another survey of seven UK primary school classrooms by Hay (1995) measured background-noise levels in empty classrooms from 35 to 45 dB $L_{A_{eq}}$, and in occupied classrooms with the children talking and working, from 58 to 72 dB $L_{A_{eq}}$. These surveys suggest that a representative value for typical classroom activity in UK primary schools is 65 dB A $L_{A_{eq}}$. Maxwell and Evans (2000), in a study found preschool children exposed to levels of 75 dB $L_{A_{eq}}$ in the classroom. Lundquist, Holmsberg and Landstrom (2000), found that older children working in levels of 58 to 69 dB $L_{A_{eq}}$ during Mathematics classes.

2.4.1.4 Factors affecting classroom noise levels

It is assumed that noise levels inside classrooms are affected by external noise. However, while external noise might act as a ‘distracter’ to pupils there is little evidence on the relationship between internal and external noise levels. The only study to address this issue in detail is that of Shield and Dockrell (2003). They found that external noise had an effect on the internal noise level only when pupils were engaged in quiet activities. Furthermore, it appeared to be external background noise levels that were related to internal ambient $L_{A_{eq}}$ levels.

There is conflicting evidence as to whether or not noise levels are affected by the age of the children. The data examined by Picard and Bradley (2001) suggest that classroom noise levels decrease as the age of the children increases; however, this trend was not evident in the data collected by Shield and Dockrell in primary schools (2003). The levels measured by Moodley
(1989) in nursery schools are considerably higher (75 dB A on average) than those measured in primary and secondary schools, although the average levels for the last two categories are the same (65 dB A). Shield and Dockrell (2003) did however find that the noise levels in primary school classes were related to the number of children in the class; this could possibly account for some of the effects of age observed in other studies. Hay (1995), in her survey of 7 schools, related measured noise level to the experience of the teachers and found that the lower levels were measured in classes with an experienced teacher, and the higher levels when a trainee teacher was taking the class.

2.4.2 External Background Noise

An additional source of noise which is reputed to cause significant disturbance to teaching is the noise of rain falling on lightweight school roofs (O’Neil 2002). The predominant external noise source, particularly in urban areas, is likely to be road traffic (Shield and Dockrell 2002) although aircraft noise may also affect many schools, with fewer schools exposed to railway noise.

In the Metropolitan area of Brazil at two locations of public schools, the quality of school classrooms has been analysed (Zannin and Zwirtes 2009), based on the measurement of BN, external noise and RT. The measured external noise levels show that measurements made were 62 dB $L_{Aeq}$ and 59.5 dB $L_{Aeq}$. Results reveal the poor acoustical quality in the classrooms. Examples of external noise levels outside schools in a densely populated urban environment in central Istanbul were provided by surveys carried out in the late 1990s (Shield and Dockrell 2003) (Celik and Karabiber 2000), which found levels ranging from 54 to 79 dB $L_{Aeq, 5 min}$, from 72 to 97 dB $L_{Amax}$ in the most densely populated areas, from 55 to 73 dB $L_{A10}$, and from 49 to 61 dB $L_{A90}$, all schools being subject to road traffic noise.
2.5 REVERBERATION TIME

Reverberation time (RT) is the time required for reflections of a direct sound to decay by 60 decibels after the source has been turned off. As the sound waves consist of various frequencies, the decay time of each wave frequency is denoted as the RT for that particular frequency. Hence RT is measured or calculated for each of octave band mid frequencies from 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, to 8000 Hz. In ANSI S 12.60(2002) and Building Bulletin 93(2003), the required RT for classroom is stipulated as the mean of RT’s corresponding to frequencies 500 Hz, 1000 Hz and 2000 Hz. In NBC (2005) the RT is stated for 500 Hz only. However RT in seconds is frequently stated by researchers as a single value without mentioning the frequencies. This would correspond either to a frequency of 1000 Hz, or the mean of RTs for 500 Hz, 1000 Hz and 2000 Hz.

Sato and Bradley (2008) reported that measurements of classroom Reverberation Times were mostly in the range between 0.4 and 1.2 s. Bradley (1986 a) reported that the mean measured Reverberation Time in 10 classrooms was 0.7 s at 1 kHz. Measurements made in Brazilian classrooms by Losso et al (2004) reported that Reverberation Times ranged from 1.1 to 1.7 s. Reverberation Time measured in 32 classrooms by Knecht et al (2002) ranged from 0.2 s to 1.27 s. Only four of these classrooms had RTs less than the desired value of 0.6 s. In a recent study (Zannin and Zwirtes 2009) the mean RT values at 1000 Hz varied from 0.89 s to 2.2 s in schools measured in Brazil.

Long RTs also affect the clarity of speech. This is due to the reflected signal over-lapping with the new direct signal, causing what is known as temporal masking or smearing. In rooms with very short RTs the noise decays quickly and cannot interfere with the direct signal (Nabelek and Pickett 1982). Hearing-impaired subjects are more greatly affected by long
reverberation times. Carr (1996) reviewed the literature where empirical research had led to recommendations that classrooms for children should have RTs of < 0.4 s for the young hearing-impaired listener. In Carr's own research (1995) she found longer RTs had a much greater effect on the hearing-impaired than normally hearing listeners.

2.6 SPEECH INTELLIGIBILITY PREDICTORS

Research has been carried out to indicate Speech Intelligibility indicators which include experimental and analytical work, with emphasis on developing objective criteria for Speech Intelligibility.

2.6.1 Signal-to-Noise Ratio

Kindergarten, first and second grades are the main years in which children learn to break written words into their phonetic components and acquire the ability to read. Careful listening is needed to develop the ability to discriminate among minor differences in words such as pet, pit, pot, put, and pat (Anderson, 2004). Such differences can be lost in a noisy environment, so young children require the higher Signal-to-Noise ratios provided by quieter conditions. Signal-to-Noise ratio (S/N ratio) is of pre-eminent importance for communication in any space since in the absence of an adequate S/N ratio all other design efforts become irrelevant. Signal-to-Noise ratio is a ratio of the $L_{eq}$ of a desired sound to the background noise, expressed in dB A and it is also expressed as the difference between the speech signal and the background noise.

In a classroom the ‘signal’ is generally the teacher’s voice (in a group work situation it is the other students communicating in the group) and the ‘noise’ is the sound from all other sources. S/N ratio will vary depending on a student’s position in the room and the activity taking place but there is a
minimum value which should be maintained in order to ensure optimum Speech Intelligibility. This, ideally, is equal to the dynamic range occupied by the speech material, however as people become familiar with the syntax and lexicon of a language they can tolerate a reduction of this ideal.

In order to improve the Signal-to-Noise ratio in a classroom, either the signal must be increased or the noise decreased in level. An increased signal suggests a louder speaking voice of the teacher, but as the voice strain amongst teachers is a common work-related illness, they cannot be required to ensure an adequate S/N ratio in conditions of high background-noise.

For young children of normal hearing S/N ratio should be about +15dBA (Bradley 2007) for more than 90% recognition of words. S/N Ratio, RT and percentage of words recognised by the students are interconnected; if RT is low (less than 0.6 s) the S/N ratio of +15 dB A would result in more than 90% word recognition for elementary school children (Shield and Dockrell 2003). The S/N ratio and reverberation seriously affect (Weatherill 2002) the normal hearing of children as detailed below:

<table>
<thead>
<tr>
<th>S/N Ratio</th>
<th>Reverberation time</th>
<th>% recognition of monosyllabic words</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 12 decibels</td>
<td>0 s</td>
<td>89.2%</td>
</tr>
<tr>
<td>+12 decibels</td>
<td>1.2 s</td>
<td>68.8%</td>
</tr>
<tr>
<td>0 decibels</td>
<td>0 s</td>
<td>60.2%</td>
</tr>
<tr>
<td>0 decibels</td>
<td>1.2 s</td>
<td>29.7%</td>
</tr>
</tbody>
</table>

With an S/N ratio of +12 decibels and RT 0.0 s the speech recognition of mono syllabic words is as high as 89.2%, whereas the speech recognition is reduced to 29.7% with S/N ratio of 0 decibels and RT of 1.2 s.
Innace et al (2002) published results for schools exposed to high outdoor noise levels with indoor background levels of 51-61 dB A and early decay times of 1.2-1.5 s. Another study of Italian schools (Astolfi and Corrado 2002) found similar quite reverberant conditions. More adverse conditions were reported by Losso et al (2004) in Brazilian classrooms. The reported ambient noise levels varied from 51 to 70 dB and Reverberation Times ranged from 1.1 to 1.7 s. Research from Japanese schools indicated shorter Reverberation Times of 0.2-1.0 s (Tachibana et al 2002) (Nishizawa et al 2004) and ambient noise levels between 22 and 59 dB A. Ueno et al (2002) reported 30 s $L_{eq}$ values for various activities in Japanese schools varying from 45 dB A for “moral education” to over 80 dB A for musical activities; a recent United States study (Bowden 2004) also reported less extreme results with ambient noise levels varying between 38 and 55 dB A (unoccupied) and Reverberation Times from 0.3 to 1.1 s (occupied). Almost all reported ambient noise levels exceed current recommendations such as those in the ANSI S12.60 (2004) classroom acoustics standard.

Speech Intelligibility in a noisy environment with low reverberation, as in the case of a small occupied secondary school classroom (eg. 300m$^3$) can also be approximately investigated with the Reverberation Time and Signal-to-Noise level difference (SNA). According to Picard and Bradley the optimal values of the mid-frequency reverberation time and the minimum value of the SNR$_A$ for 12+ years old students, in occupied classrooms, are estimated to be 0.5s and 15dB, respectively. As far as the noise level is concerned, an upper level of 33dBA is indicated as the ideal condition, restricted to more vulnerable groups, which can rise to 40 dB A for an acceptable condition, to be used for more general purposes. Research on the effects of noise and poor acoustics in schools (Crandell and Smaldino 2000) has recently led many countries to write or revise a series of guidelines on classroom acoustics. For example the ANSI S12.60 standard (2004) and
the UK Building Bulletin 93 (2003) in unoccupied classrooms, require a maximum ambient noise level of 35 dBA, $L_{Aeq}$ 1h and $L_{Aeq}$ 30 min, respectively, plus a maximum reverberation time, quoted in terms of the average in the 500Hz, 1 kHz, and 2 kHz octave bands, of 0.6 and 0.8 s respectively.

2.6.2 Early Reflections

For a listener in a reverberant space, there is a point in time after the arrival of direct sound where reflections begin to become less than 100% useful for Speech Intelligibility. This time delay is termed ‘The Integration Time of Speech’ (Whitlock and Dodd 2008). It is the threshold which divides fully useful and partially detrimental sound energy. For adults, this point has variously been found to be between 40 and 70 milliseconds (ms) depending on the type of experiment to measure it (Henry 1951, Miller 1948, Haas 1972, Whitlock 2001). But for design purposes it is generally taken as being 50 milliseconds. It is recommended that this value should be smaller for children as their limited understanding of language and immature hearing system.

The acoustic parameters of room design which impacts directly on integration time are early reflections. The number and strength of reflections which are received by a listener within the integration time are maximized using reflectors and absorbers, thereby enhancing speech intelligibility. The combined effect of early arriving sound reflections and the direct sound increases the intelligibility of speech making the direct sound seem louder and sharper while the later arriving reflections degrade the intelligibility causing the speech sound to blur into next one.

To further identify why the needs of children and adults for speech perception are so different the ‘integration time’ of speech for adults and children was measured using a novel technique to obviate the complicating
effects of differing language. The results for children are significantly different than for adults (35 ms compared to 50 ms for adults) and recommendations for classroom design based on the children’s requirements have been made. It is established by Sato and Bradley (2008) that early arriving reflections of speech sounds reaching the listener within 50 ms after the arrival of direct sound are useful because they can help to increase the effective signal to noise ratio and hence the intelligibility of the speech. Whitlock et al (2004, 2008) studied the effect of early reflection and established, by calculating the integration time of speech, that early reflections reaching the young students within 35 ms would enhance the speech intelligibility, whereas it would be 50 ms for adults.

### 2.6.3 Articulation Index (AI)

The concept of Speech Intelligibility was introduced with the evolution of telecommunication technology systems. Contributions made (French and Steinberg 1947) in developing a subjective measure of speech intelligibility is known as Articulation Index (AI). AI is calculated from the score of a group of experienced listeners with normal hearing who write sentences, words or syllables read to them from selected lists (Eagen 1988). A ratio of clearly read words represents the percentage of intelligibility scored from 0 to 1. The subjective rating heavily depends on the type of speech information being imparted. The curves suggest a low intelligibility rating when the subject understands fewer words and as the AI score is higher, the intelligibility rating also increases.

The percentage of words understood relates to the AI value, and also to the percentage of sentences understood (Whitlock and Dodd 2008). When words are in the context of a sentence one has a better chance of understanding the word and AI would be higher. Take for example an AI
rating of 0.7, for single words the score is at about 90% understanding; and for words in a sentence, it is up at something close to 98% understanding.

2.6.4 % $\text{AL}_{\text{cons}}$

Peutz (1971) further emphasized the validity of AI by detailing the procedure to calculate the articulation loss of consonants ($\%\text{AL}_{\text{cons}}$), thus separating the subjective analysis of vowels and consonants. He conducted tests under varying conditions of reverberation, distance to the source and background-noise and proposed the formula where $\%\text{AL}_{\text{cons}}$ is the articulation loss of consonants as a percentage.

Experiments (Peutz 1971) showed a decrease in intelligibility rating with the distance from the sound source until a critical distance $D_c$ is reached beyond which the intelligibility is independent of the distance between the source and the listener. Since consonants are more vulnerable to reverberation than vowels, $\%\text{AL}_{\text{cons}}$ is a better SI indicator than AI. The logarithm of $\%\text{AL}_{\text{cons}}$ was found to be linearly related to the background noise, expressed as a signal to noise ratio and having the reverberation time as a parameter.

2.6.5 Ratio of Useful to Detrimental Sound Energy

A survey of the available speech intelligibility metrics that take into account the room sound reflections and background noise reveals that they can be classified into three different categories (Bistafa and Bradley 2000). The first category includes Speech Intelligibility metrics that make use of the acoustical energy ratio concept. This concept classifies the available acoustical energy (direct+reflected+noise) into a useful part (direct+earlier arriving reflected) and a detrimental part (later arriving reflected noise). The ratio of these has proved to be correlated to speech intelligibility by different authors (Lochner and Burger 1961, Latham 1979, Bradley 1986 a). The
second category is used by just one type of metric known as the Speech Transmission Index STI, and makes use of the concept of the modulation transfer function m(F) (Houtgast and Steeneken 1973). The third category is an experimental based procedure that gives an expected articulation score as a function of the reverberation time and the signal-to-noise ratio. The articulation score is that of a syllable articulation type of test in which the result is given as the articulation loss of consonants (Peutz 1971). Although the form of these types of measures is quite different, a recent experimental study showed their values to be strongly correlated (Bradley 1998).

The ratio of the early arriving to later arriving sound has been used as an indicator of the Speech Intelligibility and is referred to as the clarity index C_{50}. This is the logarithmic ratio of direct sound and reflected sound arriving within 50 ms to the reflected sound reaching beyond 50 ms. This value ranges from -6.4 to 1.0 dB as the ideal situation. Another indicator is, Deutlichkeit (D_{50}), (which is a German word meaning Definition-50 ) which is the ratio of early arriving sound energy up to 50 ms to the total energy arriving at the location. The acceptable values for D_{50} are from 0.4 to 0.6. Another index is U_{50} which is defined as the logarithm of the ratio of useful sound energy (Direct sound and early arriving reflected sound) reaching within 50 ms to detrimental sound energy ( sum of the late arriving speech energy and the background noise ). U_{50} ranges from -5.6 to 1.0. Analytical formulae were obtained by Bistafa and Bradley (1999) for each speech intelligibility matrix namely, U_{50}, \%AL_{cons} and STI and concluded that a unique linear relationship exists between U_{50} and STI.

2.7 SPEECH INTELLIGIBILITY (SI)

A major effect of noise and poor acoustics in the classroom is the reduction of Speech Intelligibility. SI is the percentage of speech material
presented to an average listener which is correctly transmitted from a speaker to a listener (Hodgson 2001). Non-optimal classroom design, acoustical conditions and SI can result in impaired verbal communication between a teacher and a student. If children are unable to understand the teacher then the major function of a classroom in providing an environment that enables the transfer of information from teacher to pupil is impaired. In addition it is important, both for learning and for social interaction, that children are able to hear and understand their peers in the classroom.

2.7.1 Acoustic Factors Affecting Speech Intelligibility in Classrooms

The room acoustic factors that affect Speech Intelligibility are background-noise level and Reverberation Time. Bradley, Hodgson and their colleagues (Bradley et al 1999, Bradley 1986 a, Bistafa and Bradley 2000, Hodgson and Nosal 2002 a, Bradley 1986, Hodgson 2002) have carried out experimental and theoretical studies to investigate the relationship between these factors and Speech Intelligibility in the classroom. A general conclusion of these studies is that noise is the more critical factor and that criteria for acoustical conditions in the classroom should be based upon Speech Intelligibility. In their work with adults Bradley et al (1999) found that noise, rather than reverberation, was the most significant factor in understanding speech and that the most important parameter for Speech Intelligibility was the Signal- (that is, speech) to-noise ratio. As the levels of teacher’s voices vary, this means that it is particularly important to reduce the background noise level in a classroom. Bradley (1986 a), in an analysis of measurements of acoustical conditions and Speech Intelligibility in classrooms for 12 and 13 year old students, concluded that 30 dB A was an appropriate background-noise level, with optimum Reverberation Times of 0.4 to 0.5 s. There is however some disagreement about the ideal value of the signal-to-noise ratio for classrooms. Finitzo Hieber and Tillman (1978) recommended a signal-to
noise-ratio of 12 dB for both normal hearing and hearing impaired students although others (Ross 1986, Olsen and Bess 1988) argued that a higher S/N value of 20 to 30 dB is required for the teaching of hearing impaired children. More recently Bistafa and Bradley (2000), following a series of theoretical studies, recommended that the speech to noise ratio should be greater than 15 dB throughout a classroom, 25 dB being the ideal value and 20 dB an acceptable value 1m in front of speaker. These values assume a reverberation time of less than 0.4 to 0.5 seconds. Signal-to-Noise ratios of 15 or 20 dB are recommended for classrooms by the American Speech-Language-Hearing Association (1995) and the British Association of Teachers of the Deaf (2001).

It is usual to assume that Speech Intelligibility will increase as Reverberation Time decreases to zero (Nabelek and Pickett 1974). Although it is generally accepted that, to maximize Speech Intelligibility, it is necessary to have a relatively short Reverberation Time, Hodgson and Nosal (2002 a) argue that, when the noise inside a classroom is taken into account longer Reverberation Times are possible without compromising the Speech Intelligibility. When accounting theoretically for noise of equipment and occupants in a classroom they predicted that it was possible to achieve high Speech Intelligibility with Reverberation Times of up to 1 s, depending on the size of the room. However, the authors concede that their results may not be appropriate in the case of younger and hearing-impaired listeners.

Picard and Bradley (2001), in a major review of research on Speech Intelligibility in classrooms compared measured noise levels and teacher’s voice levels from a range of studies. They estimated that in reality the speech to noise ratio varies from 3 dB in a kindergarten to almost 7 dB in university classrooms. The issue of the differences between adult and child Speech Intelligibility criteria was first highlighted by Neuman and Hochberg (1983), and a research by the New Zealand Classroom Research Group or
NZCRG (Wilson et al. 2002) has supported this. It has been suggested by Latham (1979), Shield and Dockrell (2003) that in the case of normal hearing adults working in their first language, the Speech Intelligibility should exceed 97%.

When both noise and reverberation are present in a room, Crandell and Smaldino (2000) established that their combined effects (individual effects being 10% in each case) on speech perception might actually equate to a 40% to 50% reduction. In an earlier study, Houtgast (1981) determined from classroom measurements that a Signal-to-Noise Level difference of 15 dB was desirable for good communication in classrooms. This was confirmed by acoustical measurements and related Speech Intelligibility tests in 10 classrooms by Bradley (1986 a). The mean measured Reverberation Time in the 10 classrooms was 0.7 s (at 1 kHz), and ambient noise levels (in occupied classrooms without student activity) varied from 38 to 45 dB A. The Speech Intelligibility values in terms of $U_{50}$ have been presented (Bradley 1986, Yang and Hodgson 2006). Latham (1979) has given an expression for SI % in terms of Signal to Noise ratio (SNR). Similarly the Speech Intelligibility is calculated using STI and the quality descriptors for Speech Intelligibility are given by Hodgson (2002). The Table 2.1 gives the quality descriptors for Speech Intelligibility in classrooms (Hodgson 2002).

Table 2.1 Quality Descriptors

<table>
<thead>
<tr>
<th>Speech Intelligibility Range</th>
<th>Quality rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 98%</td>
<td>“Excellent”</td>
</tr>
<tr>
<td>&gt;96%</td>
<td>“Very Good”</td>
</tr>
<tr>
<td>&gt;93%</td>
<td>“Good”</td>
</tr>
<tr>
<td>&gt; 88%</td>
<td>“Fair”</td>
</tr>
<tr>
<td>&gt; 80%</td>
<td>“Poor”</td>
</tr>
<tr>
<td>&lt;80%</td>
<td>“Bad”</td>
</tr>
</tbody>
</table>
2.7.2 **Speech Transmission Index**

Description of Speech Intelligibility using the modulation transfer function method gives an index called Speech Transmission Index (STI). Speech intelligibility at a listener’s position in a classroom depends on the Signal-to-Noise level difference and the Reverberation Time; this can be predicted by the Speech Transmission Index (Steeneken and Houtgast 1980) which varies from 0 to 1. The higher value of STI means high Speech Intelligibility. The prediction of STI considers the Signal-to-Noise level difference of speech and the early part of the local reverberation time at the listener’s location. In the beginning of 1970 Steeneken and Houtgast (1980) introduced this totally different concept for the use in the field of room acoustics. STI is a good measure of the combined effort of the signal-to-noise level difference and the reverberation on verbal communication.

STI combines the two above mentioned factors in a single quantity and is related to a five – point intelligibility scale (Bradley 1986 a). ‘Bad’ for STI values lower than 0.30, ‘Poor’ between 0.30 and 0.45, ‘Fair’ between 0.45 and 0.60, ‘Good’ between 0.60 and 0.75, and ‘Excellent’ for STI values higher than 0.75. In situations of a relaxed type of communication, such as during lectures a ‘Good’ level of intelligibility is recommended, considering a ‘Normal’ vocal effort (Bradley 1986 a). Vocal effort refers to the exertion of the speaker. It is quantified by the A - weighted speech level at a distance of 1m in front of the speaker’s mouth and subjectively as Very Loud, Loud, Raised, Normal and Relaxed. Free – field normal vocal efforts are given by Pavlovic (1987) and Byrne (1994), and typical vocal efforts in classrooms are reported (Houtgast 1981, Picard and Bradley 2001, Sato and Bradley 2008). A study (Jacob 1989) described a comparison between intelligibility ratings by the Modular Transfer function method, which is basically the STI concept and found that STI had the least error. Similarly research by (Bradley 2007) concluded that STI is an accurate method for

2.7.3 Computer Simulation Studies

Several computer simulation models have been developed and software are being used to study the acoustics of auditoriums, school classrooms and other spaces. The comparison of Reverberation Times in classrooms measured by impulse response and interrupted noise methods with ODEON software is reported (Passero and Zannin 2010) and it is concluded that computer simulation procedure produced accurate data. STI in classrooms were predicted using ODEON by (Keranen et al 2004). It is stated that one important parameter for describing speech intelligibility is STI and concluded that the differences between STI results using acoustic modelling using ODEON or simple prediction method are quite small. Hodgson and Daniel (2009) developed a software ClassTalk- 2.1 which is a prediction model to compute RT, Signal to Noise ratio at listener position, Speech intelligibility and Speech Transmission Index. (Astolfi and Pellerey 2008) compared ODEON 4.0, ClassTalk and measured values. The values of comparison show that Hodgson model fits the measured values better than the ODEON code. The reverberant speech levels decrease with increasing distance from the source and the Hodgson model fits the slope values quite well. In a study (Yang and Hodgson 2006) of optimum reverberation for Speech Intelligibility in classrooms CATT- ACOUSTIC v8.0 (2008) software was used to predict and auralize the sound fields.

calculate impulse responses in a lecture theatre. The measurement results and calculation results show the relative importance of early reflections.

2.8 CURRENT STANDARDS FOR CLASSROOM ACOUSTICS

In recent years there has been considerable debate about the acoustic design of classrooms, although research in this area has been limited mainly (Shield and Dockrell 2003a) to the work of Bradley, Hodgson, Crandell and their colleagues (Bradley et al 1999, Bradley 1986 a, Bistafa and Bradley (2000, 2001), Hodgson and Nosal 2002a, Bradley 1986, Hodgson et al 1999, Bradley and Reich 1998, Hodgson 1999a, Crandell and Smaldino 2000). There are several national and international guidelines relating to the background noise in classrooms when they are empty. Many countries have developed new or revised standards for classroom design and the World Health Organization includes recommendations for schools in its Guidelines for Community Noise (1999).

Most standards include guidance on some or all of the following, ambient noise levels in various types of school room (for example, classrooms, libraries, dining halls); Reverberation Times; sound insulation of the school-façade; sound insulation between rooms; and background- noise from building services. The two most recently published guidelines on classroom acoustics are the ANSI standard S12.60 (2002) in the USA and Building Bulletin 93 (2003) in the UK, both of which are summarized below along with a few national and international standards organisations.

2.8.1 ANSI S12.60-2002

The American National Standard Institute (ANSI) S12.60-2002 ‘Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools’ (ANSI 2002) was published in 2002 and provides design criteria and
guidelines for new and refurbished classrooms and other learning spaces. The standard specifies limit values for background-noise levels and Reverberation Times in ‘core learning spaces’ (that is teaching spaces including classrooms, conference rooms, libraries, music rooms and so on) which are classified according to their volume, as shown in Table 2.2. The spaces are assumed to be furnished but unoccupied. The RT values given are the mean values of RT corresponding to frequencies of 500 Hz, 1000 Hz and 2000 Hz for unoccupied condition of classrooms.

Table 2.2 ANSI S12.60-2002 Maximum Background Noise levels and Reverberation Times in learning spaces

<table>
<thead>
<tr>
<th>Volume of space</th>
<th>Background noise level, dB</th>
<th>Reverberation time, seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 283 m³</td>
<td>35</td>
<td>0.6</td>
</tr>
<tr>
<td>≥ 283 m³ and ≤ 566 m³</td>
<td>35</td>
<td>0.7</td>
</tr>
<tr>
<td>&gt; 566 m³</td>
<td>40</td>
<td>-</td>
</tr>
</tbody>
</table>

The standard includes annexes which give the rationale for the setting of the criteria: advice on noise control, control of reverberation and sound insulation, and recommendations for good practice to verify conformance to the standard.

2.8.2 Building Bulletin 93 (BB 93)

In the UK, although there has been guidance available on the acoustic design of schools since 1975, there have been no legal requirements for compliance with the standards till Building Bulletin 87 (DEE 1997). However from July 2003, the acoustic design of schools is to be regulated under amendments to the Building Regulations. The standards, which will have to be met by both new and refurbished schools, are contained in

Building Bulletin 93 replaces Building Bulletin 87 ‘Guidelines for Environmental Design in Schools’ (DEE 1997) which gave advice on heating, lighting, ventilation and acoustics in schools. James (ASHA 2002) discusses the background to the writing of Building Bulletin 93.

Building Bulletin 93 is a comprehensive document specifying indoor ambient noise levels, Reverberation Times and sound insulation requirements for over 30 types of teaching and learning spaces in schools. It also includes guidance on noise control, design of rooms for speech and music, the needs of and technology available for hearing-impaired children and case studies of good and bad examples of school and classroom design.

Examples of the performance standards for maximum indoor ambient noise levels, in terms of $L_{A_{eq,30min}}$ and Reverberation Times for BB 93 are shown in Table 2.3. Both noise levels and Reverberation Times are for unoccupied and unfurnished rooms. The Reverberation Time is the mean of the values at 500 Hz, 1000 Hz and 2000 Hz. Figures in brackets in Table 2.3 are the corresponding values from Building Bulletin 87, where a direct comparison is possible. (Note that the background-noise level in Building Bulletin 87 was expressed as a 1 hour $L_{Aeq}$ and the reverberation time was the mean of the 500 Hz and 1000 Hz values.)

Building Bulletin 93 specifies the required sound insulation between the various kinds of teaching spaces. Building Bulletin 93 also contains standards for open plan spaces, which are specified in terms of the speech transmission index, STI. The performance standard is that any open plan teaching or study areas should be designed so that the STI is greater than 0.6.
Table 2.3 Building Bulletin 93: upper limits for indoor ambient noise levels and reverberation times for a selection of school rooms

<table>
<thead>
<tr>
<th>Indoor ambient noise level, dB $L_{Aeq,30min}$</th>
<th>Reverberation time, seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary school classrooms</td>
<td>35 (40)</td>
</tr>
<tr>
<td>Secondary school classrooms</td>
<td>35 (40)</td>
</tr>
<tr>
<td>Large (&gt; 50 people) lecture room</td>
<td>30 (35)</td>
</tr>
<tr>
<td>Classrooms specifically for hearing impaired pupils</td>
<td>30</td>
</tr>
<tr>
<td>Library study area</td>
<td>35 (40)</td>
</tr>
<tr>
<td>Assembly halls</td>
<td>35 (35)</td>
</tr>
<tr>
<td>Science lab</td>
<td>40 (40)</td>
</tr>
<tr>
<td>Gymnasium</td>
<td>40</td>
</tr>
<tr>
<td>Dining rooms</td>
<td>45 (50)</td>
</tr>
</tbody>
</table>

Values in parentheses are corresponding values from Building Bulletin 87 (DEE 1997).

2.8.3 WHO Guidelines

The WHO guideline values for schools (1999) are summarized in Table 2.4.

Table 2.4 WHO guidelines for maximum noise levels and reverberation times in school

<table>
<thead>
<tr>
<th>Noise level, dB, $L_{Aeq}$</th>
<th>Reverberation time, seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classrooms</td>
<td>35</td>
</tr>
<tr>
<td>Halls and cafeterias</td>
<td>-</td>
</tr>
<tr>
<td>Outdoor playgrounds</td>
<td>55</td>
</tr>
</tbody>
</table>
The background-noise level of 35 dB A $L_{Aeq}$ in classrooms is based upon the assumption of 55 dB A for a typical teacher’s voice level at a distance of 1m, and of the need for a signal-to-noise ratio of 15 dB A. It is not clear whether the reverberation time requirements apply to occupied or unoccupied rooms. The guidelines state that both background noise level and reverberation time should be lower for hearing-impaired children. The maximum noise level of 55 dB A in outdoor playgrounds is chosen to be the same value as for outdoor residential areas in daytime, in order to prevent noise annoyance.

### 2.8.4 Standards for Hearing-impaired Pupils

Organisations concerned with the needs of deaf and hearing-impaired pupils also provide guidance on the acoustic requirements of classrooms. Examples include the position paper on acoustics in educational settings of the American Speech-Language-Hearing Association, ASHA, (1995), published in 1995, and the recommended standards for classroom acoustics published in 2001 by the British Association of Teachers of the Deaf (BATOD, 2001). The recommendations of both of these organizations include unoccupied ambient noise levels, reverberation times and signal to noise ratios, as shown in Table 2.5.

#### Table 2.5 Recommendations of ASHA and BATOD for classrooms

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Background noise levels</td>
<td>30 - 35 dB (A)</td>
<td>≤35 dB(A)</td>
</tr>
<tr>
<td>Reverberation time</td>
<td>≤0.4 s</td>
<td>≤0.4 s, 125 Hz to 4000 Hz</td>
</tr>
<tr>
<td>Signal to Noise ratio</td>
<td>≥15 dB</td>
<td>&gt;20 dB, 125 Hz to 750 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;15 dB, 750 Hz to 4000 Hz</td>
</tr>
</tbody>
</table>
In 2002 ASHA published a further report on appropriate facilities for students with speech-language-hearing disorders (ASHA 2002), the major part of which is concerned with the acoustics of classrooms.

2.8.5 DIN German Standards

DIN 18041 specifies three categories of noise limits, (Table 2.6). These are a function of distance between the talker and listeners, the makeup of the listeners and the type of instruction (for hearing impaired, difficult and foreign language texts). For classrooms noise limits of 35 dB (A) or 30 dB (A) are recommended for unoccupied class.

Table 2.6 Maximum allowable background noise levels in accordance with DIN 18041

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Maximum Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>40 dB(A)</td>
</tr>
<tr>
<td>Middle</td>
<td>35 dB(A)</td>
</tr>
<tr>
<td>High</td>
<td>30 dB(A)</td>
</tr>
</tbody>
</table>

For the unoccupied room the reverberation time should not exceed the recommended values by more than 0.2 seconds and proposes RT of 0.6s for occupied class.

The minimum requirements for lecture halls are given as a function of the room size and a testing method is described in (EN 2003)

Speech Transmission Index STI, 0.56
Definition, 0 dB
Articulation Loss of Consonants $AL_{cons} < 8\%$
This is the only standard which has prescribed norms STI and %AL$_{cons}$.

2.8.6 National Building Code, India

These mainly take the form of recommended values for background-noise levels in teaching spaces for schools. The Indian guidelines for acoustics (NBC 2005) recommend a value of 40 to 45 dB L$_{Aeq}$ for background noise, and 35 to 45 dB for libraries and the proposed RT value of 0.75 s for occupied class and a higher value of 1.25 s for the empty classroom. These RT values correspond to an octave band mid frequency of 500 Hz. It is stated that it is preferable to have same limit for other frequencies. The details are given in Appendix A 2.4.

2.8.7 New Zealand Standards

New Zealand standards (AS/NZ 2000) stipulate a value of 35 to 45 L$_{Aeq}$ dB as a maximum for classrooms and RT of 0.4 s to 0.5 s for primary school classrooms. In the NZCRG study (Wilson et al 2002) it was established that very low Reverberation Times are required for young children compared with accepted norms for adults. The surprise finding was that the difference in RT of 0.6 s and 0.4 s made the difference between “poor” classroom and a “good” classroom (Whitlock and Dodd 2004) a difference which for an adult would be insignificant.
• Discussion on Standards for Classroom Acoustics

A greater concern is that the ANSI standard mentioned above suggests that reverberation times of 0.6s are appropriate for classrooms. This may have simply been an effort to make the criteria more ‘practical’ as American schools have added acoustical complications as heavyweight construction and HVAC systems are common (and there was much opposition from HVAC manufacturers, claiming the criteria was too stringent).

Unoccupied background noise level is a measure that is often used in overseas research. This is important for rooms that have a constant background noise from heating, ventilation or air conditioning. In New Zealand classrooms that are naturally ventilated via open windows, unoccupied classroom noise levels fluctuate with intermittent external noise. Previous New Zealand research has shown unoccupied noise levels range from 28–60 dB A.

The values of BN and RT for school classrooms recommended by various countries and organizations are compared and given in Table 2.7. It is seen that many of the specifications stipulate a BN of 35 dB A and RT of 0.6 s for unoccupied classroom. However the specifications by NBC 2005 stipulates higher value 40-45 dB A for background-noise of unoccupied classroom and 1.25 s for RT of unoccupied class, which are at higher level than many others stipulations.
Table 2.7 Standards of countries/organisations for BN and RT

<table>
<thead>
<tr>
<th>Details of Specifications</th>
<th>Details of enclosures</th>
<th>Background noise $L_{eqA}\ dB$</th>
<th>Reverberation time in Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO Guide lines</td>
<td>Classrooms</td>
<td>35</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Halls and Cafeterias</td>
<td>-</td>
<td>&lt;1</td>
</tr>
<tr>
<td></td>
<td>Playgrounds</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td>ANSI 12.6 2002 USA</td>
<td>Class room vol.&lt;283 m3</td>
<td>35</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Class room vol.&gt;283&lt;566 m3</td>
<td>35</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Class room vol.&gt;566 m3</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Building Bulletin 93 U.K</td>
<td>Primary school</td>
<td>35</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td></td>
<td>Secondary school</td>
<td>35</td>
<td>&lt;0.8</td>
</tr>
<tr>
<td></td>
<td>Large &gt; 50 people</td>
<td>30</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td></td>
<td>Class room for hearing impaired</td>
<td>30</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td></td>
<td>Library study area</td>
<td>35</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td></td>
<td>Assembly halls</td>
<td>35</td>
<td>0.8 to 1.0</td>
</tr>
<tr>
<td></td>
<td>Science Lab</td>
<td>40</td>
<td>&lt;0.8</td>
</tr>
<tr>
<td></td>
<td>Gymnasium</td>
<td>40</td>
<td>&lt;1.5</td>
</tr>
<tr>
<td></td>
<td>Dining rooms</td>
<td>45</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>AS/NZ 2107:2000</td>
<td>Primary school teaching spaces</td>
<td>35-45</td>
<td>0.4 s to 0.5 s</td>
</tr>
<tr>
<td>Australian New Zealand standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASHA USA</td>
<td>30 to 35</td>
<td>&lt;0.4</td>
<td></td>
</tr>
<tr>
<td>BATOD U.K</td>
<td>&lt;=35</td>
<td>&lt;0.4</td>
<td></td>
</tr>
<tr>
<td>DIN 18041 Germany</td>
<td>30 to 35</td>
<td>0.6 Unoccupied class</td>
<td></td>
</tr>
<tr>
<td>INDIA NBC 2005</td>
<td>Classrooms</td>
<td>40-45</td>
<td>Empty 1.25</td>
</tr>
<tr>
<td></td>
<td>Libraries</td>
<td>35-40</td>
<td>Occupied 0.75</td>
</tr>
</tbody>
</table>


2.8.8 Standards Related to External Noise

NBC (2005) specifies that schools near public roads could be 30 m from the road; this would result in a sound level of about 50 dB \( L_{A_{eq}} \) at the façade, if the road noise level is about 70 dB \( L_{A_{eq}} \), and the BN within the classroom could be about 40 to 45 dB \( L_{A_{eq}} \), as stipulated by NBC (2005).

The WHO (2001) recommends that noise levels in school playgrounds should not exceed 55 \( L_{A_{eq}} \), dB whereas the UK Building Bulletin 93 (2003) specifies an upper limit of 60 \( L_{A_{30}} \) dB at the site boundary and 55 \( L_{A_{eq}} \) dB in outdoor areas such as playgrounds and playing fields.

According to the ISO 9921:2003 standard (Ergonomics 2003), the quality of verbal communication can be expressed in terms of Speech Intelligibility, which is quantified as the percentage of a message that is understood correctly. Signal to noise level difference of 15 or 20 dB A are recommended for classrooms by the American Speech-Language-Hearing Association (ASHA 1995) and the British Association of Teachers of the Deaf (BATOD 2001).

2.9 DISCUSSION

In the review of literature, it was noted that the ill effects of noise on children have been recognised since long time back. It was observed that in many countries (including an advanced country like USA) the acoustics in school classrooms were not up to the desired level and this had prompted many countries to stipulate the regulations regarding acoustics in school classrooms. The research to identify the parameters contributing to the speech intelligibility in school classrooms and to improve the acoustical environment has been pursued vigorously by many researchers. The real parameters are the background noise and, reverberation time which influence the voice signal of
the teachers to reach all the students in the classroom at a clarity level to understand and learn. The regulations for acoustic performance of the school classrooms formulated by the European countries and USA, are based on their real conditions namely noise created from HVAC, ventilating equipment etc in the classrooms existing in those countries. However, for a country like India, the regulations for acoustics based on the research abroad are not suitable. Publications based on research for Indian conditions appear to be very few. Many of the schools are situated in tropical areas with warm humid climate where natural ventilation in classrooms is a necessity and the windows and doors are kept open and not enclosed spaces with air-conditioning systems, and for additional ventilation, ceiling fans are also provided. The background noise in such situations is to be investigated and the speech intelligibility parameters in classrooms are to be assessed. It is seen that Speech Transmission Index is a better parameter for calculation of Speech intelligibility (Jacob 1989, Building Bulletin 2003). The descriptors of Speech Intelligibility and Speech Transmission Index give directly the quality of classrooms as Excellent, Very Good etc (Hodgson 2002). Hence in this study Speech Transmission Index and Speech Intelligibility were used as the main parameters to investigate the intelligibility in classrooms. Among the software used ClassTalk predicts Speech Intelligibility and Speech Transmission Index giving the quality descriptors, in addition to the distribution of Signal-to-Noise Ratio and Speech Levels of teacher at various listener positions etc. In this investigation software ClassTalk was used.

2.10 NEED FOR THE PRESENT RESEARCH

It has been observed that in India the value of classroom acoustics has not been adequately recognized or addressed. A school classroom fulfils its function only if the students sitting in the class are able to hear and understand what the teacher is speaking. To hear properly the lessons taught
by the teacher, the Speech Intelligibility in school classrooms should be sufficiently high. In classrooms in warm-humid climates where natural ventilation with open windows and doors is a necessity, the intrusion of external noise through windows and doors has been found to affect the background-noise (BN) in the empty and occupied classrooms. The background-noise and Reverberation Time in classrooms affect the Speech Intelligibility and they assume great importance in the evaluation of Speech Intelligibility in the classrooms.

A necessity to investigate arises from the fact that children need to hear and understand their teacher adequately and should have an environment where they can work without excessive noise. The schools were constructed where space was available and mostly near public roads and housing colonies. The classrooms with open windows and doors with fans can have more background-noise and the Reverberation Times than those stipulated in NBC (2005). All these have led to the necessity of investigating the following.

- To measure the background-noise inside the classrooms
- To measure the external noise and identify the influence of external noise on background-noise.
- To measure and calculate the Reverberation Time in the classrooms.
- To evaluate the Speech Intelligibility parameters to assess how far school classrooms are able to attain an environment for better learning
- To suggest some remedies which can improve the acoustic conditions where necessary.