ACOUSTICS

OF

OPEN PLAN CLASSROOMS

IN PRIMARY SCHOOLS

Thesis submitted in partial fulfilment of the requirements of

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By

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Glossary and abbreviations

Term	Abbreviation and units	Definition
A-weighted sound pressure level	**L_{pA} (dB)**	A single figure value of the sound pressure level using the A-weighting network that modifies the response of a sound level meter with frequency in approximately the same way as the human ear, in order to assess subjective loudness.
Absorption coefficient	**α**	Frequency dependent ratio of sound energy absorbed by a material to the total sound energy randomly incident on its surface, with 0 indicating a totally reflective material and 1 indicating totally absorptive.
Acoustic absorption	**A (Sabines)**	Loss of sound energy when striking a surface material, or due to its transmission outside a room. Measured in Sabines, the acoustic absorption is the product of the material's absorption coefficient and its surface area
Ambient noise level	**$L_{Aeq,30min}$(dB)**	See indoor ambient noise level
Annular design		Open plan classroom layout of ring or donut shape, where classbases are arranged around a courtyard or other central enclosed space.
Articulation index	**AI**	Method for the calculation of speech intelligibility or privacy defined in ANSI 3.5 (1969) that accounts for the influence of background noise on the relevant speech signal at the receiver position (but not distortions in the time domain)
Carpet area		Area within the classbase with a carpeted floor which is clear of desks and other furniture. Used for children to gather together on the floor around the teacher for whole class instruction ('mat work'). Also used as a quiet area for reading/storytelling, etc.
Child centred learning		Aspect of progressive teaching philosophy where teaching is focused on the needs and choices of the child rather than the teacher
Chi square test	**χ^2**	Statistical test which tests a null hypothesis that the frequency distribution of certain events observed in a sample is consistent with a particular theoretical distribution. The chi-square statistic is then used to calculate a p-value by comparing the value of the statistic to a chi-square distribution.
Clarity	**C_{50} (dB)**	Ratio of early arriving sound energy (within 50 ms of direct sound), to late arriving sound energy (after 50 ms of direct sound)
Class A absorber		Sound absorbent material with sound absorption performance rated as Category A in accordance with ISO 354
Classbase		Main teaching space in an open plan classroom where whole class gather together for instruction. Also referred to as a homebase in the literature
Classroom noise		Any sound audible in a classroom which is not the relevant speech signal, e.g. external noise, irrelevant speech, non-verbal activity noise, classroom equipment etc.
Cluster design		Type of semi-open plan classroom design where classbases are arranged around a central resource area, with classbase openings facing onto each other
Decay curve		Decay of sound pressure level as a function of time at one point in the room after the source of sound has ceased
Definition	**D_{50}**	Ratio of early arriving sound energy (within 50 ms of direct sound) to total arriving sound energy (after 50 ms of direct sound)
Department for Children,	**DCSF**	United Kingdom government department formed in 2007

Schools and Families		following the disbanding of the Department for Education and Skills, responsible for the education system and children's services (up to age 19)
Direct communication		Person-to-person communication with both persons in the same environment without making use of electro-acoustic equipment
Dirac delta function		Idealised signal function approximating a tall narrow spike function, or unit impulse of infinitely narrow width
Department for Education and Skills	**DfES**	United Kingdom government department between 2001 and 2007 responsible for the education system and children's services in England
Early decay time	**EDT (s)**	The reverberation time (T) in a room calculated from the first 10 dB of the decay curve
English as an additional language	**EAL**	Children with EAL in the UK are defined as children who speak a language other than English at home
Equivalent continuous sound pressure level	$L_{eq,T}$ **(dB)**	Value of the notional steady continuous sound pressure level that would, over a given period of time, deliver the same sound energy as the actual fluctuating sound over the same period
F-test	***F***	Ratio of variance between groups to variance within groups (used in ANOVA). F-statistic used to calculate a significance value, p, by comparing to a F-distribution
Factor analysis		Method of identifying underlying variables, or factors, that explain the pattern of correlations within a larger set of observed variables
Flexible open plan classroom		Type of classroom design where learning areas can be opened out or closed off easily by means of sliding partitions
Fully open plan classroom		Type of classroom design without interior walls. Divisions between different learning areas provided only by means of loose furniture
(Fast) Hadamard Transform		Type of Fast Fourier Transform used on MLS signals to obtain the impulse response of a room
Impulse response		Plot as a function of time of the sound pressure level in a room as a result of excitation of the room by a Dirac delta function
Individual instruction		One-to-one teaching
Individual learning		Teaching method where pupils learn independently from the teacher using a variety of different resources
Indoor ambient noise level	$L_{Aeq,30min}$ **(dB)**	Equivalent continuous A-weighted sound pressure level measured in an unoccupied classroom during normal teaching hours. This includes noise from external sources and building services noise, but excludes noise from other teaching activities/equipment within the school premises, rain noise and noise from equipment within the classroom
Intrusive noise level	$L_{Aeq,\ 2min}$ **(dB)**	$L_{Aeq,\ 2min}$ measured in an unoccupied classbase during normal teaching hours. Includes noise from adjacent teaching activities within the school open plan unit.
Just Noticeable Difference	**JND**	Minimum change in acoustic parameter that is subjectively perceivable by the human ear
Kurtosis		Measure of the 'peakedness ' of a statistical distribution
Linear design		Open plan layout with classbases arranged in a line. Classbase openings face onto shared resource area, not each other
Lombard effect		Spontaneous increase of the vocal effort induced by the increase of the noise level at the speaker's ear
Mann-Whitney U test		Non-parametric significance test to assess whether two independent samples of observations come from the same

		distribution by comparing rank order of data
Mat work		Whole class instruction taking place in carpet area
Maximum length sequence	**MLS**	Deterministic periodic pseudo-random binary sequence with similar properties as a true random white noise signal. Correlation function is a Dirac impulse
Mid-frequency early decay time	**EDT_{mf} (s)**	Arithmetic average of the early decay times (EDT) in the 500 Hz, 1kHz and 2 kHz octave bands
Mid-frequency reverberation time	**T_{mf} (s)**	The arithmetic average of the reverberation times (T) in the 500 Hz, 1 kHz and 2 kHz octave bands
Modulation transfer function	**m(F)**	Function describing the reduction in modulation index between the input and the output of a communication system
Newly qualified teacher	**NQT**	Label attached to teachers in the United Kingdom who have been qualified for less than 12 months
Not significant	**NS**	Probability of statistical test exceeds 5% level ($p > 0.05$)
One way analysis of variance	**ANOVA**	Used to test for statistically significant differences between two or more independent groups using F-test statistic
Open plan unit		Collection of (semi) open plan classbases, resource areas, enclosed quiet or group rooms and ancillary spaces, usually separated from the rest of the school building by a set of closed doors
Otologically normal listener		Person with normal hearing capacity
Percentile level	**L_{AN} (dB)**	A-weighted sound pressure level exceeded for N % of the measurement period, T. For example, L_{A90} is the level exceeded for 90% of the time and is commonly referred to as the background or residual noise level. L_{A10} is the level exceeded for 10% of the time and may be considered to be an ‘peak average’ level
Personalised learning		Type of teaching method where the student is placed at the centre of the learning process and teaching is tailored to the student’s individual needs
Plowden classroom		An open plan classroom design favoured during the 1970s which attempted to facilitate individualised instruction methods promoted in the Plowden Report (1968)
Post-Plowden classroom		A semi-open plan classroom design favoured during the 1990s which attempted to facilitate a hybrid of whole class instruction methods promoted in the Alexander Report (1992), with individual learning
Project based learning		Inquiry-based or experiential learning focused around project work
Quiet room		Room with four walls and a door located within teaching unit, used for quiet or noisy activities, or small group instruction (including Special Educational Needs teaching).
Relevant speech signal		Speech signal which conveys the instructional message (often the teacher’s voice, but could also be pupil’s speech, or audio/visual learning aid)
Resource area		Shared area linking together main classbases in an open plan unit. Used for practical activities and to store shared classroom materials and equipment eg library and I.T.
Reverberation time	**T or T_{60} (s)**	Time that would be required for the sound pressure level in a room to decay by 60 dB
Room Acoustics Speech Transmission Index	**RASTI**	Index obtained by a condensed version of the STI method (using only 500 Hz and 2 kHz octave frequency bands), focused on direct natural communication between persons without using amplification
Semi-open plan classroom		Type of classroom design where learning areas are generally open but teaching spaces are defined by walls which have openings within them.

Skewness		Measure of the asymmetry of a probability distribution
Speech communicability		Rating of ease with which speech communication is performed according to ISO 9921
Speech communication		Conveying or exchanging information using speech, speaking, hearing modalities, and understanding
Speech intelligibility		Rating of the proportion of speech cues understood
Speech Intelligibility Index	**SII**	Objective method for prediction of intelligibility (or privacy) based on the Articulation Index and defined in ANSI 3.5 (1997) representing the proportion of speech cues available to the listener. Accounts for the influence of background noise on the relevant speech signal at the receiver position but not distortions in the time domain
Speech Interference Level	**SIL (dB)**	Difference between A-weighted speech level and the arithmetic average of sound pressure levels of ambient noise in four octave bands with centre frequencies of 500 Hz, 1kHz, 2kHz and 4 kHz
Speech privacy		Rating of the proportion of speech that is not understood
Speech-to-noise ratio	**S/N(A) (dB)**	Difference between the A-weighted sound pressure level of the relevant speech signal and the A-weighted level of the background noise at a particular listening location
Speech Transmission Index	**STI**	Objective method for prediction and measurement of speech intelligibility. Unitless quantity representing the transmission quality of speech with respect to intelligibility. Accounts for noise interference and distortions in the time domain (reverberation)
Speech Transmission Index for public address systems	**STIPa**	Index obtained by a condensed version of the STI method but still responsive to the distortions found in room acoustics including public address systems
Standard deviation	**σ**	Measure of dispersion of a set of values. Square root of the variance of a set of values
T_{30}	**T_{30} (s)**	The reverberation time calculated from the 30 dB decay range from 5 dB to 35 dB below the initial level
T_{20}	**T_{20} (s)**	The reverberation time calculated from the 20 dB decay range from 5 dB to 25 dB below the initial level
t-test	*t*	Statistical test used to determine whether the means of two parametric distributions are equal
Variance		Measure of dispersion. Average of the squared distance of possible values from the expected value (mean)
Vocal effort	**$L_{S,A,\ 1m}$ (dB)**	Exertion of the human speaker, quantified objectively by the A-weighted speech level at 1 m distance in front of the mouth and qualified subjectively by a description (eg Normal, Raised, Loud etc)
Vulnerable listener		Person for whom the relevant speech signal is less intelligible than for a typical adult, due to a hearing impairment or other circumstances (EAL, SEN etc)
Weighted level difference	**D_w (dB)**	Single figure rating of the field measurement of frequency dependent airborne sound insulation between rooms, determined by reference to ISO 717-1
Weighted sound reduction index	**R_w (dB)**	Single figure rating of laboratory measured frequency dependent airborne sound insulation of a building element or material determined in accordance with ISO 717-1
Weighted speech-to-noise ratio	**S/N_w (dB)**	Single figure value which takes account of the speech-to-noise ratio in each octave frequency band using a weighting factor which corresponds to the importance of the band's contribution to speech intelligibility
Whole-class instruction/teaching		Teaching method where the teacher gives all or part of a lesson by addressing all of the pupils in the class at once (usually from the front of the classroom). Pupils either sit at their desks or gather closely around the teacher

Abstract

Open plan classrooms are becoming increasingly popular in new build schools, despite having faced a major backlash in the past due to being associated with acoustic problems. In order to investigate whether these designs are acoustically fit for purpose with respect to current and future learning trends in the UK primary school sector, acoustic conditions were surveyed in 42 open plan primary classrooms over a two year period using both objective techniques (acoustic measurements) and subjective techniques (questionnaire surveys of children and teachers). Measurement methodologies were developed in accordance with relevant standards, to assess compliance against the acoustic performance standards of Building Bulletin 93 (minimum speech transmission index, STI, 0.6; maximum $T_{mf(unfurnished)}$ 0.6 - 0.8 seconds; maximum internal ambient noise level 40 dB $L_{Aeq,30min}$). The suitability of these performance standards for a primary school audience was also explored.

Speech intelligibility was investigated through measurement of STI within classbases, with a focus on teacher-to-student communication. The effect of reverberation time and speech-to-noise ratio on STI was explored. Practical design recommendations to provide optimum control of intrusive noise and reverberation, and hence achieve STI criteria were developed. These include achieving a reverberation time of less than $T_{mf(furnished)}$ 0.4 s, limiting open plan units to three shared classbases or fewer, and providing access to an enclosed quiet room. Specific management strategies, such as co-ordination of certain teaching activities, and gathering children closely around the teacher for whole class instruction, were shown to have a direct effect on the STI criterion achieved. These recommendations were supported by the results of both the children and teacher surveys. Given the likely listening audience, an alternative enhanced minimum criterion of STI 0.68 to 0.75 is proposed for vulnerable listeners.

Distraction of teachers and students was investigated through measurements of the fluctuation and distribution of intrusive noise. The analysis showed that open plan unit size, ceiling finish and activity type all affected the noise distribution and hence likely distraction level. Speech privacy (SII) between classbases was also measured, since this has been shown to be related to distraction/annoyance for open plan office situations. Analysis established that a criterion of SII_{raised} < 0.1 – 0.2 is required to achieve appropriate speech privacy between classbases. Practical recommendations to achieve the necessary attenuation between classbases (unit layout, sound attenuation between openings and minimum masking noise level) are proposed, together with classroom management strategies, including consideration of teachers' vocal effort.

Chapter 1: Introduction

1.1 Background

The current building stock of open plan classrooms in UK primary schools consists largely of a mixture of the original ‘Plowden’ classrooms (built between 1967 and 1977), and Post-Plowden classrooms built during the early 1990s. Plowden classrooms were intended to accommodate both progressive education philosophies and area/cost per place limits, but faced a major backlash in the late 1970s due to the clash between changing pedagogy and classroom design. However, since 2003, Britain has witnessed a major new school building programme, with plans announced in 2006 to rebuild or refurbish 50% of all primary schools by 2021. Open plan designs are becoming increasingly popular in many new build schools in both primary and secondary sectors to achieve flexibility for personalised learning, a key part of the UK Government’s current initiatives for education.

Since 2003, acoustic performance standards for open plan classrooms have been mandatory under Approved Document E of The Building Regulations in England and Wales. The normal means of achieving compliance with the Regulations is to achieve the performance criteria set out in Building Bulletin 93: Acoustic design of schools (BB93)[1], which includes criteria for speech intelligibility within classbases, maximum reverberation times and maximum ambient noise levels for open plan teaching areas.

Due to the widely recognised problems with acoustics in open plan classrooms in the past, particularly regarding control of intrusive noise levels from adjacent classbases, the need for a detailed acoustic assessment of the current stock of open plan classrooms was identified. This was deemed necessary to ensure that new-build open plan learning environments are acoustically fit for purpose.

1.2 Aims and objectives

The aim of this thesis is to assess compliance of existing open plan learning spaces against BB93 performance standards, with respect to current and future learning trends in the primary school sector. Results of objective and subjective surveys are used to identify optimum design strategies to achieve compliance, and to investigate the suitability of these performance standards for a typical primary school audience, against a background of realistic classroom management and organisation strategies.

The findings will aid and improve the design of future school buildings, and will be useful to clients and stakeholders involved in the early design stage of new school buildings. The findings will also be key for teachers (and pupils) operating in open plan primary classrooms, to enable them to achieve effective classroom organisation and management for this type of design.

1.3 Overview

The thesis is split into eleven chapters. Chapters 2-6 comprise reviews of the literature, from emerging classroom design and pedagogy, to previous studies into classroom acoustics, speech intelligibility of classroom audiences, speech communication theory, and current acoustic design standards and guidance. The findings in these chapters inform the design and development of the objective acoustics survey (Chapter 7), teachers' questionnaire survey (Chapter 9) and children's questionnaire survey (Chapter 10). Results and analysis of each survey are presented in Chapters 8-10. The findings of all three surveys are summarised and triangulated in the concluding chapter (Chapter 11).

Firstly, in order to substantiate the relevance of the open plan classroom to current and future school building, it is necessary to explore the past. Chapter 2 explores the history of the original open plan classroom movement of the 1960s and 1970s, the educational ideologies and other factors which influenced the designs, and how the designs evolved against a background of largely unchanging teaching methods in practice, ultimately leading to strong negative reaction against open plan design due to problems with noise and distraction, amongst other issues.

Chapter 3 covers the more recent history of open plan classroom design (1990s to present day) and current/future educational practice, demonstrating that open plan classrooms are becoming increasingly desirable in new build schools and that this trend is likely to continue as the Building Schools for the Future programme expands, together with the Government's vision for flexibility in design and personalised learning.

Seminal designs discussed in both Chapters 2 and 3 reveal that new build open plan designs are experiencing problems with poor acoustics similar to those suffered by the original designs, and that expensive remedial works have taken place in both new build and older types of open plan design.

The issue of noise in open plan classrooms is discussed in Chapter 4, beginning with a review of the more general deleterious effects of noise on the learning process (in both enclosed and open plan classrooms), followed by a review of the noise climate measured in open plan classrooms as compared to enclosed classrooms. Appropriate criteria in order to avoid distraction and annoyance, and practical noise control methods are also discussed.

Chapter 5 explores speech communication in open plan classrooms, with a focus on speech intelligibility within classbases and speech privacy between classbases. The effects of both noise and reverberation on speech communication are explained, particularly concerning the child (and other more vulnerable groups) as the listener, and the teacher as the talker (effects on vocal effort). Objective acoustic parameters generally used to describe speech intelligibility (particularly speech transmission index, STI) and speech privacy are reviewed. Their relationships to noise and reverberation, and recommended criteria for suitable listening conditions, are discussed.

Chapter 6 provides a review of recommended acoustic criteria, international design guidance, and details of the UK required acoustic performance standards for open plan classrooms, against which the results of the objective survey are to be assessed.

The findings of the literature review are used to inform the design and procedure for the objective acoustic survey, including measurement methodology, preliminary laboratory work and pilot studies, as detailed in Chapter 7. The results and analysis of the objective survey are presented in Chapter 8. The analysis identifies optimum acoustic parameters and physical design factors in order to achieve current acoustic standards. Combinations of simultaneous teaching activities are also identified to demonstrate how the acoustic standards may be achieved in practice, and suitable activity management plans are developed as a result of the findings. Alternative acoustic criteria and management strategies for vulnerable listeners in open plan classrooms are also proposed.

Chapter 9 details the design and implementation of the children's questionnaire, the results and analysis of the survey, and compares the findings with those of the objective survey, in order to provide support for the proposed acoustic criteria, physical design and management strategies identified in Chapter 8. Similarly, Chapter 10 describes the teacher's survey, results and analysis, including comparison with both the objective survey and children's survey.

The findings of all three surveys are summarised and triangulated in the concluding chapter, and current acoustic standards for open plan classrooms are reviewed in light of the results. The findings are used to make 17 acoustic design recommendations and 9 classroom management strategies for open plan classrooms. From these, 7 key acoustic design criteria are derived. Areas requiring further work are also discussed.

Chapter 2: History of open plan classrooms

2.1 Introduction

In order to investigate the relevance of the open plan classroom in current and future classroom design, it is firstly necessary to explore and understand the history of the educational philosophies and methods which inspired the original open plan movement.

The open plan school has been described as one which 'recognises the link between progressive educational needs and the need to break down the class or form into several working groups'[2], by providing flexibility of design. This refers to the progressive post-war educational reform movements occurring in the UK after 1950, linked with the open plan 'Plowden' classrooms of the late 1960s and 1970s (so called after the 1967 publication of the Plowden Report by the Department for Education and Science[3]). Before this time, pedagogy largely consisted of didactic teaching, with the teacher speaking in a fixed position at the front of the class and the pupils listening from formal rows of desks. The post-war years witnessed a breakdown of this formality, as education began to focus on the individual needs of the pupils rather than the 'convenience'[4] of teachers.

In this chapter, a selection of the most influential open plan school designs of this era are discussed in detail in the following sections. The underlying reasons behind the decline of the original open plan movement are also discussed.

2.2 Progressive educational methods

The 1967 Plowden Report[3] summarised the development of post-war primary schools and presented a set of progressive ideologies and methods, in which importance was placed on 'learning by experience and discovery'[5]. Reflecting the changing political times, the new generation of educationalists were seen to reject anything considered authoritarian[6]. These progressive philosophical changes were apparent in the organisation and arrangement of the classroom;

didactic teaching was replaced with experiential learning centred on individual assignments and group work.

As learning came to be regarded as a personal and individual matter, more choice was given to pupils, and the rigid timetabling structure was replaced with 'the integrated day'[7], where a number of different learning activities would take place simultaneously in the classroom. The curriculum content became interdisciplinary, with a range of subjects encompassed in a single assignment. More importance was placed on practical subjects in primary settings which required specialist dedicated facilities. These educational methods placed an emphasis and focus on the child rather than the teacher, and were embodied by a 'child-centred' pedagogic approach.

Arrangement of furniture within the classroom also became more informal to accommodate the child-centred approach, with desks placed together for group work. School furniture and fittings were redesigned with the ergonomics of the child in mind[8], to create a home-like atmosphere, and provide children with a greater sense of security'[5]. Schools also began to experiment with vertical (mixed age range) grouping of students.

Specialist facilities were required within a single classroom to accommodate the new variety of classroom activities. Educators called for a change of thinking in classroom design that would not place limitations on the learning environment. The educationalist George Baines summarised the emerging changes in curriculum and teaching organisation in his lecture notes (*c.* 1962-1967) as shown in Table 2.1[9].

Although the architectural design of the school did not necessarily dictate educational practice, it is fair to say that child-centred learning methods were 'exemplified' by early open plan school designs[6].

Table 2.1: Developments in educational philosophies (*c.* 1962-1967)[8]

Change	From	To
Curriculum content	Mono-disciplinary	Interdisciplinary
Pedagogy	Didactic teaching	Discovery learning
Organisation	Rigid timetabling	Flexible timetabling
Pupil grouping	Homogeneous	Heterogeneous
Pupil choice	Limited	Extensive
Assessment	Single mode	Multiple modes
Basis of pupil control	Positional	Personal
Teacher roles	Independent	Interdependent
Architecture	'Closed plan'	'Open plan'

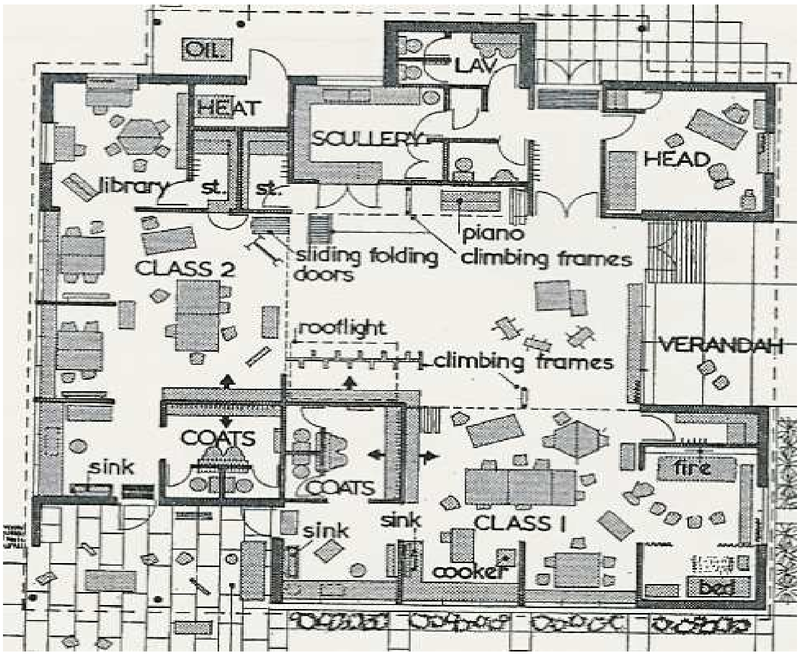
2.3 Area and cost limits

The emergence of child-centred teaching methods coincided with the introduction of government cost and area per place limits on primary school building in 1950. Presented with such limits, Ministry of Education architects sought to reduce the amount of non-teaching space provided, while protecting the available teaching space[5]. Redundant circulation space was already being creatively utilised by teachers in Primary schools, where there were reports of children 'spilling out of the classroom' into corridors as a result of the multiple activities taking place[10]. The absorption of circulation space and cloakrooms into the main classroom space in new school building appeared to be a natural progression. In general the literature agrees that the open plan school emerged as a *combined* result of responding to the new needs of the 'progressive' educationalists, and of the cost and area limits placed on new schools[4, 5, 11-13].

2.4 Post-war classrooms

The first open plan school recognised in the literature was the small two class Finmere Primary School in rural Oxfordshire (1959), see Figure 2.1. The design of the school was detailed in Building Bulletin 3[14] as part of the series of guidance documents published by the various governmental education departments over the years in order to disseminate best practice in school building. Vertical grouping was already commonplace in village schools due to small pupil and teacher numbers, and the school naturally lent itself to the open plan concept.

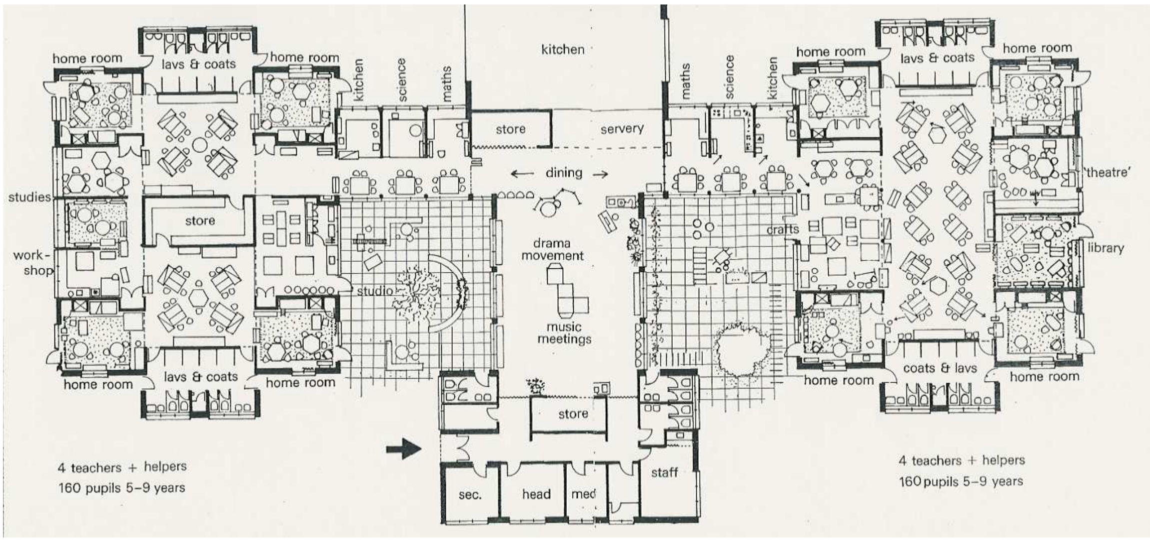
Figure 2.1: Finmere School, Oxfordshire (1959)[14]



Teaching space was broken up into a number of linked bays to provide a dedicated zone for different practical activities[14] within an informal home-like environment. Folding screens were used to separate each class when necessary so that classes could work individually without distraction. This small but pioneering school has been credited with 'setting the course of primary school design for at least a decade'[4].

Following the success of Finmere, Oxfordshire Education Authority was prompted to scale up the design for 320 children. The result was Eynsham First School (1966), see Figure 2.2. The challenge here was to maintain the same intimate and co-operative environment experienced in the successful small rural open plan schools. This was achieved by planning for 'small communities within a large one'[15]. The school consisted of two separate units each containing four semi-open plan classbases opening onto a shared central teaching area. Separate entrances were planned for each classbase to maintain the feeling of intimacy and security. This also reduced the risk of potential distraction problems associated with shared circulation space in teaching areas. Bays were provided for various specialist practical activities plus a large library area separated off by a heavy curtain[14]. Small and intimate study areas were created by use of mobile book trolleys and display units.

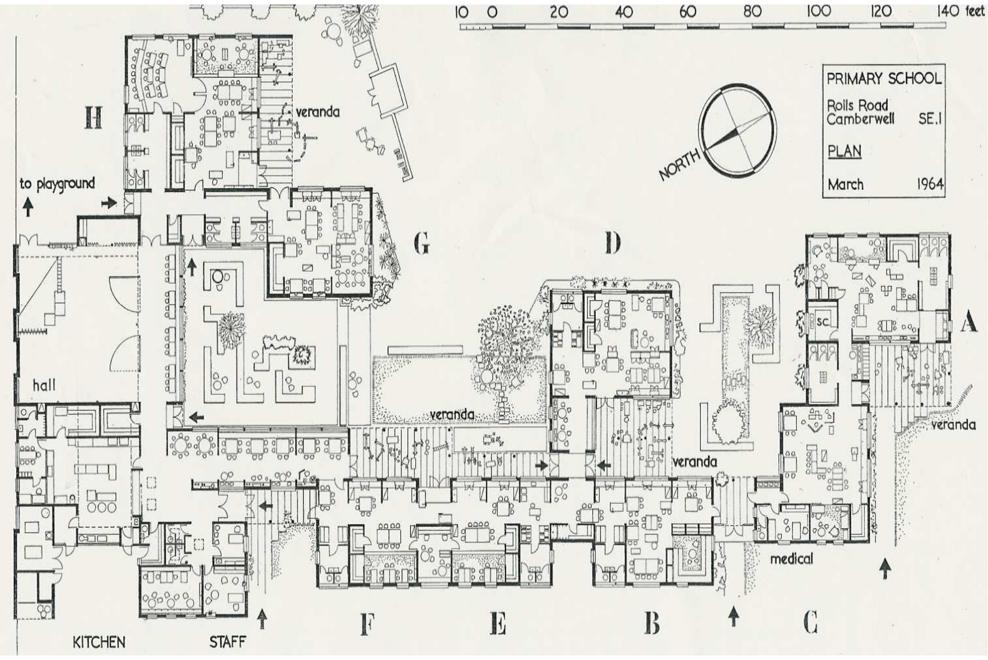
Figure 2.2: Eynsham First School, Oxfordshire (1966)[4]



The success of the design was largely due to the close working collaboration between teachers and designers in planning the school[15]. The Oxfordshire Schools experiment illustrated an attempt to provide for as many activities as possible, in order for each child to develop physically, emotionally, and intellectually as far as possible and to have experiences which would develop the whole child'[15].

Attention soon turned to planning new schools to accommodate a large number of pupils in urban areas. A research and development group was formed by the Architects and Buildings Branch of the Department for Education and Science to 'look into the objectives and practice of those teachers who were advancing the frontiers of primary education'[4]. The output of their findings was the design of Eveline Lowe Primary School - a large urban open plan primary school built in 1966 in Southwark, London (see Figure 2.3)[16]. This school was described as 'probably the most influential school based on the open plan model during the 1960s'[10].

Figure 2.3: Eveline Lowe Primary School, Southwark (1966)[17]



Eveline Lowe shared many common design elements with Eynsham (8 classbases each with own entrance, range of dedicated activity spaces for practical work and various group sizes, home-like furniture/fittings and vertical class grouping). Most areas followed the semi-open plan format, with classbases opening onto a shared central resource and work area. Two of the areas (D & G) have a more fully open plan format, with space subdivided through use of moveable cupboards rather than fixed divisions/partitions. However most areas have access to enclosed or carpeted ‘quiet’ areas, for withdrawal.

The purposeful arrangement of fittings and furniture within a ‘pedagogic scheme’ is apparent on the plans of both Eynsham and Eveline Lowe. This was regarded as an essential part of the architect’s work in order to create a successful working environment[5].

Following post occupancy appraisals[16, 18], Eveline Lowe was generally regarded as successful and was developed and modified throughout the 1960s and 1970s. As part of this research, the school was visited in 2003 and was still found to operate successfully in a semi-open plan environment (although minor alterations had been made and the area per pupil had been increased).

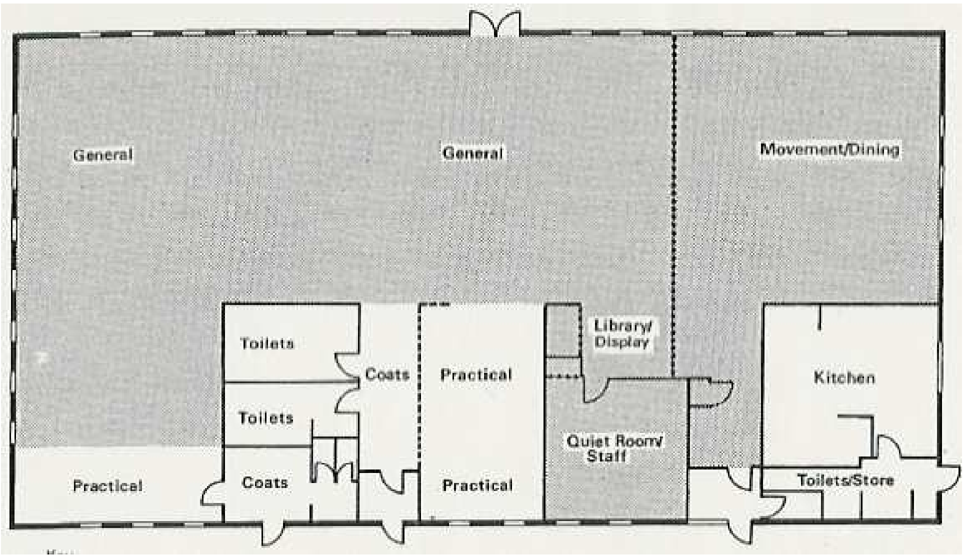
2.5 The Plowden era

2.5.1 Plowden classrooms

Following the publication of the Plowden Report[3] in 1967, the experimental school designs in Oxfordshire and at Southwark received much attention and interest from visitors on a national and international scale who began to adopt the open plan concept.

Designs developed from the semi-open plan arrangement of the original post-war designs, to the more radical fully open plan 'school without walls' such as Eastergate Primary School, West Sussex (1970) – see Figure 2.4. These vacuous designs lacked any specific pedagogical scheme (definition of classroom boundaries, classroom fittings and furniture layout, and spaces with unique characteristics). Extreme experiments were carried out in some fully open plan schools, such as providing less than one chair per child 'to encourage movement and fluid behaviour'[6]. A lack of sufficient private withdrawal areas made it 'difficult to work in either a formal or informal way' and this type of design soon lost its popularity in Britain[19]. Eastergate was investigated as part of this project and it was found that the school had since carried out remedial treatment to provide enclosed classrooms.

Figure 2.4: Eastergate Primary School, West Sussex (1970)[20]



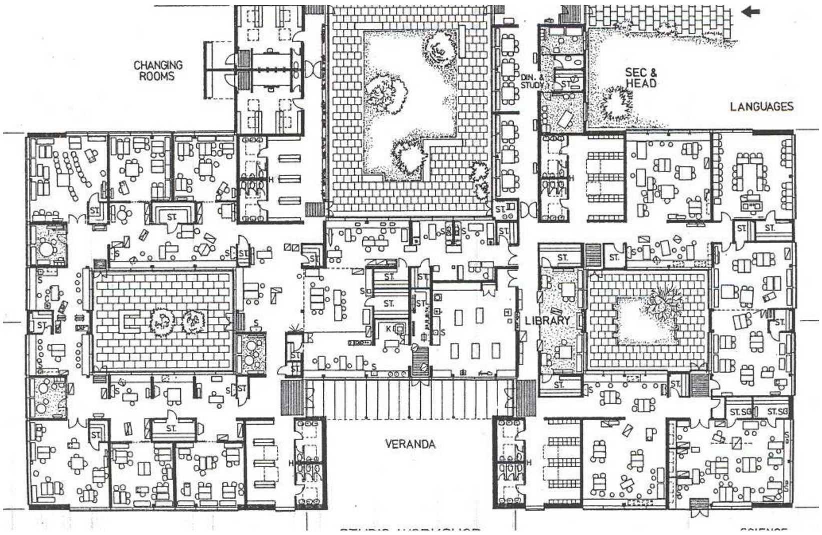
A prolific increase in the number of new and converted open plan primary schools followed from 1969 throughout the 1970s, with a peak in 1974[21]. By 1976, 10% of all primary schools in England and Wales were open plan[20, 21]. In the U.S at this time, over 50% of new build schools were either fully or semi-open plan[22].

The term 'open plan' became synonymous with the non-pedagogically planned school without walls, and hence became a disparaging term in Britain[5, 19, 23]. The term 'open planning' became preferable amongst designers to describe the type of designs with a degree of openness and a dedicated pedagogic layout[24]. As David Medd, of the original Architects and Buildings Branch explains, the original design intention of open planning 'had never been extended to the removal of all walls or the concentration of large numbers of children in a single [fully] open space'[24].

Whilst there was a surge of open planning in the building of new primary schools, the design concept was far less common in secondary schools. However, transfer arrangements from primary to secondary school were altered during the 1960s with the introduction of middle schools for pupils aged 8-13 years. There was a desire to 'open up the secondary schools to the liveliness and innovation which characterised the best primary schools'[5].

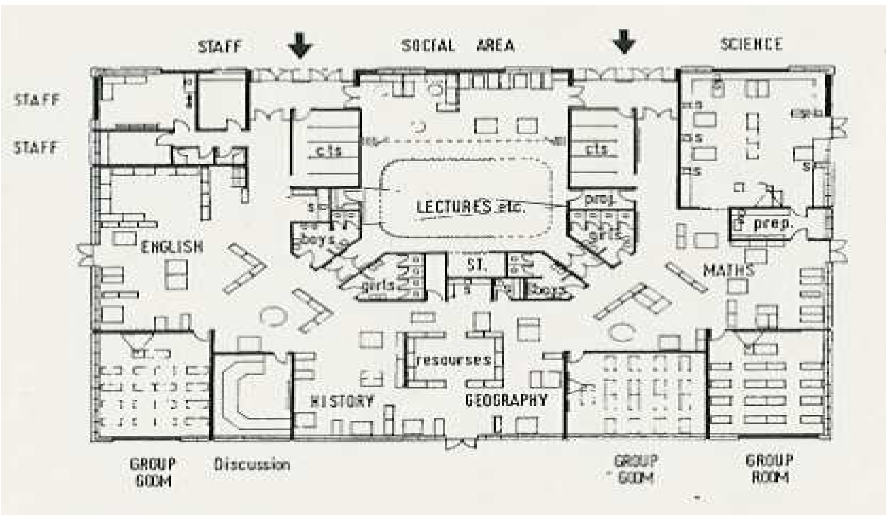
Delf Hill Middle School in Bradford (Figure 2.5) was one of the first purpose built middle schools. The design was a typical semi-open plan design, creating the usual variety of activity spaces within 'centres' for each year group. Some rooms were fully enclosed and 'sound-proofed' for quiet activities and language work[25-27].

Figure 2.5: Delf Hill Middle School, Bradford (1969)[26]



In secondary schools the teacher's role was also changing, albeit more slowly than in the primary school, and overall 'there was a change in method towards project work and discovery methods[5]. Open planning in secondary schools took the form of a 'centres of interest' approach. The extension of Maiden Erlegh Secondary School (Figure 2.6), was broken down into 'centres for related studies', which took the form of semi-open plan linked areas, to allow for flexibility in working group size, and to allow areas and resources to be shared between subjects[28]. As part of this research the school was visited in 2004 and some parts of the school still operate in a semi-open plan environment.

Figure 2.6: Maiden Erlegh Secondary School, Reading (1974)[29]



2.5.2 Research

The prolific increase in open plan school building occurred before a thorough appraisal of the first phase of the new schools could be carried out. Research into open plan schools was conducted and published within a short time, with the majority of available texts and reports dating from 1970-1975[30]. Various aspects of open plan schools were investigated, including pupil and teacher attitudes[10,31-34] performance standards[35], teaching methods and organisation[10, 11, 19, 21, 36 37, 38], and acoustic assessments[22, 36, 39-42].

One of the largest studies into open plan schools in England and Wales was carried out by Bennett[20] between 1975 and 1978. Bennett[20] identified three main types of open plan design as shown in Table 2.2.

Table 2.2: Open plan design types (after Bennet[12])

Design type	Description
Open plan	Design provides a large degree of openness with divisions provided only by means of loose furniture.
Semi-open plan	Building is generally open but teaching spaces are defined by walls which have openings within them.
Flexible open plan	Areas can be opened out or closed off easily by means of sliding screens.

The most prevalent type of design observed in Bennett's[20] study was the semi-open plan unit, with separate classbases for main teaching, and a shared resource space and quiet room. Units were designed for up to 5 or more teachers, the most common being for two or three teachers (80% of surveyed schools). The following factors were identified as crucial to create a successful open plan environment and avoid interference from noise:[13, 16, 18, 31, 43, 44]

- Careful planning and organisation of teaching activities
- Co-operational teaching methods
- Lower pupil-teacher ratios (around 20:1)
- Provision of quiet carpeted withdrawal/retreat areas
- Provision of sound insulated quiet rooms
- Structuring of open plan space to a detailed pedagogical plan

Whilst research studies found no appreciable difference between academic achievements of children in open plan schools and traditional enclosed schools[31, [45-47] advantages of open plan classroom designs were identified as follows:[11-13, 31 33 45, 47]

- Greater visibility of groups for better pupil supervision
- More stimulating and greater variety of work
- Better support from other teachers
- Better social development, mixing and co-operation between children
- Greater feeling of involvement, and increased interest in work
- Children are more independent, self-disciplined and responsible
- Children are allowed to develop at their own rate

Disadvantages were identified as follows:[10, 11, 13, 31, 32]

- Higher noise levels from adjacent classbase activities
- Circulation in shared areas causing noise and distraction
- Greater visual and auditory distraction (particularly in fully open designs)
- Lack of display space
- Lack of storage space
- Greater mental strain placed on teachers
- Teachers feel exposed and lack confidence teaching in front of others

Generally, higher noise levels were reported in open plan environments, however opinions were divided on whether this would cause distraction and affect performance[13, 36, 39-42]. Often the *type* of noise (for example interfering speech or environmental sources, continuous or intermittent, and spectral characteristics) rather than overall noise level was considered to be more important in determining levels of distraction[22, 41, 42]. A detailed review of the literature relating to acoustics in open plan schools will be discussed later in Chapters 4 and 5.

As a combined result of issues such as lack of consultation between architects and teachers[31, 34, 48] and lack of training and preparation[33], a degree of dissent arose among teachers who felt that educational methods (and the associated architectural designs to accommodate them) were being imposed on them. In reality, fully progressive, co-operational team teaching was found to occur in only one third of open plan schools, with the majority of teachers operating 'independently but co-operating a little with one another'[13], resulting in potential conflicts between the actual and intended use of the space. There was also a suspicion that open planning was adopted purely as a method of meeting the cost and area per place limits, by providing a cheaper alternative to the traditional classroom model[5, 31]. However, in reality, the need to provide a greater floor area to provide a successful acoustic environment for learning negates any cost advantage to be gained from removing partitions in open plan designs[40]. This opposition was exacerbated by the time-lag between the planning and opening of the school building (up to 6 years), by which time 'educational change had marched on'[5].

2.6 Conclusions

Educational practices are among the first to reflect current social and political trends[49], and as such, classrooms designed to accommodate a specific learning method can result in strong negative reaction. Plowden-style pedagogy and classrooms faced strong criticism during the social and political climate of the late 1970s and early 1980s, as politicians and educators called for a 'return to basics'[46, 49]. As a result, the proliferation of open plan classrooms (which were synonymous with progressive teaching styles) declined rapidly in favour of a return to more traditional education, and very little research on Plowden-style classrooms was published after 1979[30].

However, in recent years, open plan designs have been regaining recognition in new school building once again. The status of open plan classrooms in current and future school building is discussed in the next chapter.

Chapter 3: Open plan – today and the future

3.1 Introduction

This chapter maps the rise in popularity of open plan classroom designs in the UK from the 1980s to today, and discusses the changes in pedagogy and governmental policy which brought these changes about. Specific landmark school buildings and designs are discussed to exemplify how these changes occurred, and how the status of open planning may be seen in the future.

Changes in education methods during the 1980s and 1990s resulted in a change in classroom organisation, with a return to whole class teaching. Plowden classrooms were generally not compatible with this learning approach, and as a result, many existing schools of this design sought remedial treatment to enclose classrooms. However a minority of 'neo-progressives' formed 'hybrid' practices during this time, combining student-centred and topic-based integrated methods with more traditional techniques. The open plan classroom survived in a revised semi-open 'Post-Plowden' form to accommodate these hybrid techniques. This practice is still seen in UK primary school classrooms today. The cyclical nature of policy change is being reflected in current educational practice, with aspects of progressive education once more being encouraged by recent government plans and initiatives, in a 'neo-progressive' format.

Today, Britain is undergoing the largest nationwide new school building effort since the Victorian era. As educators and designers look to the future, new schools are required to be flexible enough to provide facilities to support a variety of different learning methods and working group sizes, in order to respond to changing trends in classroom practice and maximise the lifetime of the building. Open planning is being used increasingly in high profile and 'exemplar' classroom designs in order to respond to this change. However it is unlikely that open planning in UK schools will be seen again on an equivalent scale to that during the 1970s.

3.2 Changes in educational methods

The 1988 Education Reform Act[50], implemented by the UK Conservative government, prescribed a common National Curriculum for pupils of compulsory age in maintained schools which regulated the time spent on core subjects (for example numeracy and literacy), and set out specific attainment targets for each subject at each 'Key Stage' level[51]. As a result, children and teachers had reduced freedom of choice over activity. The new curriculum also included practical subjects such as art, music, information and design technology which required specialist facilities.

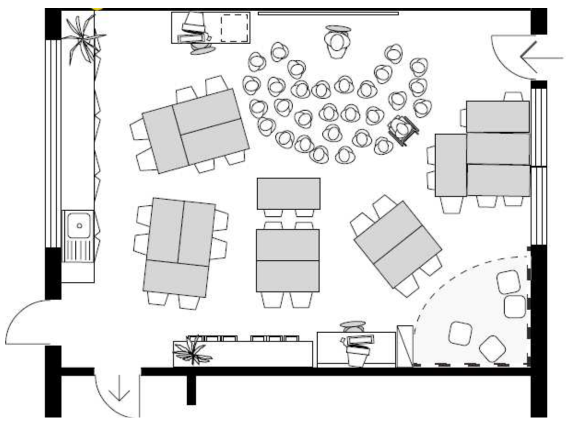
The 1992 Alexander Report[52] concluded that too much time was being spent on individual teaching, and promoted whole class teaching to improve pupil-teacher contact time, (including a balanced degree of individual learning). In adition, the National Literacy and Numeracy Strategies (implemented 1998/1999[53]) specified class organisation and teaching methods[54], placing an emphasis on direct, 'interactive whole class learning'[55]. The strategies set out a precisely defined daily 'literacy hour' to include a whole class work session (advised for 75% of the lesson time[56]), both at the beginning and end of each lesson, with individual work occurring between. However the need for new and refurbished schools to facilitate this new educational strategy was 'largely ignored'[57] during this time, and ushered in a 'period of neglect' in new school building[58]. Investment in school building reached a low point in 1996/1997[58].

Recent reviews which compared classroom organisation practices between the 1970s and 1990s (matched classroom subjects)[54, 57, 59, 60] indicated a decline in individual work and a corresponding increase in whole class activities. However individual work still remained the most prevalent form of teaching practice. Classroom layouts, with children sat together in small groups, remained similar between these decades[54], however it is important to consider the level of interaction when considering pupil groupings and organisation, since it is common for pupils to be seated in groups but actually be working individually. Although the most common physical grouping was the small group, recent studies[57, 61, 62] have found that the most common form of interaction was individual work, with a much smaller proportion involved in interactive/collaborative group work.

A more recent 2006 study[54] also compared recent classroom practice (2003-2006) to previous decades (1970s and 1990s) This study identified changes in curriculum organisation, from integrated subject-based to objectively target-based, with a strong focus on single subjects. Classroom and organisational strategies were found to remain fairly constant between 1976 and 1996, but have undergone major changes in the last decade. The study found a significant increase in 'whole class lessons' (defined to include lessons such as the literacy hour which include individual work periods).

It is clear that whole class teaching is still prevalent in the UK in the primary sector, although this occurs in a more informal setting, with children gathered around the teacher on the 'mat', or carpet area[6, 57, 62], see Figure 3.1[63] as a typical example. The importance of the carpet area in primary classrooms is also identified in the current UK area guidelines for schools[64].

Figure 3.1: Example of typical arrangement for whole class teaching activity[63]



A 2002 study of primary schools in New Zealand'[38] identified a similar change in whole class teaching style, with 'traditional lecture-style teaching' (didactic teaching at the blackboard to children at desks) being replaced with 'mat and group work'[38].

The New Zealand study[38] also investigated teachers' reported usual position in the classroom. Teachers reported spending a significant portion of their day walking around the classroom in addition to standing in just one position[38]. In the UK, teachers were observed to move around the classroom to give individual/small group instruction[57]. This dynamic approach, in order to facilitate more informal teaching styles, results in shorter communication distances for individual/group instruction and hence improves teacher-student speech communication. Whilst this may be beneficial to improve signal to noise ratio, it should be noted that using this technique during whole class teaching may mean that the teacher has to communicate with their back to some students, which can be detrimental, especially to vulnerable listener groups who may rely more strongly on visual cues to understand speech.

3.3 Post-Plowden classrooms

Plowden classrooms were generally not compatible with the new brand of whole class teaching methods, especially those where classbases were too small to accommodate a whole class of 25-30 children. As a result, many schools with Plowden classroom designs sought remedial treatment in the form of larger enclosed classrooms.

One study highlighted the ’virtual eradication’[54] of practices such as the integrated day and open plan classrooms, as all seven of the schools with open plan classrooms at the time of the 1992-94 study had been modified to enclose the classrooms when revisited in 2003-05[54]. Teachers indicated that open plan classrooms were ‘incompatible’ with whole class teaching strategies[54]. However this sample size used for this study[54] was relatively small.

In order to provide a rough overview of the present situation in UK schools, 154 Local Authorities were contacted by the author in 2004 to determine whether any schools within the Local Education Authority had open plan or flexible space designs. Of the 41 authorities that responded, 32 (78%) stated that they did have some open plan schools and were able to provide details of between 1 and 5 schools as examples (although the brief and informal nature of the survey meant that the precise number of existing open plan schools was not confirmed). The remaining authorities (22%) stated that there were no such spaces in any of the schools within their jurisdiction.

41% of the respondents further stated that many existing open plan classrooms had undergone remedial treatment to achieve either a semi-open plan or fully enclosed design. Furthermore, 32% of respondents voluntarily identified problems with noise in open plan schools.

However, some educationalists maintained that open classrooms that were carefully organised and prepared, and did not neglect basic skills had 'much to offer students'[47], and advocated that open classrooms should be reconsidered 'in revised form and implemented far more carefully and thoughtfully'[47], acknowledging that classroom organisation needed to be highly structured to create an effective open classroom[47]. This minority of 'neo-progressives' was committed to integrated curricula and performance based assessments, and formed 'hybrid' practices during the late 1980s and early 1990s, combining student-centred methods with more traditional techniques[49]. The open plan classroom survived in a revised 'Post-Plowden' form to accommodate these hybrid techniques.

During the 1990s, several Post-Plowden semi-open plan schools were built, notably St John's School, Sefton[65], completed in 1991 (Figure 3.3). Semi-open plan classbases are arranged around a courtyard (annular layout) and curtained off from the main space. Each classbase (39.5 m^2) is designed to accommodate 30 children at tables for whole class work (Figure 3.2A), although table space is limited. A large carpeted bay is located in a 'niched' recess off most of the classbases to provide a quiet retreat area for the entire class to gather (Figure 3.2B). Dedicated enclosed rooms are also provided for music, practical and small group activities.

Figure 3.2: St John's School Sefton (1991): Classbase arrangements

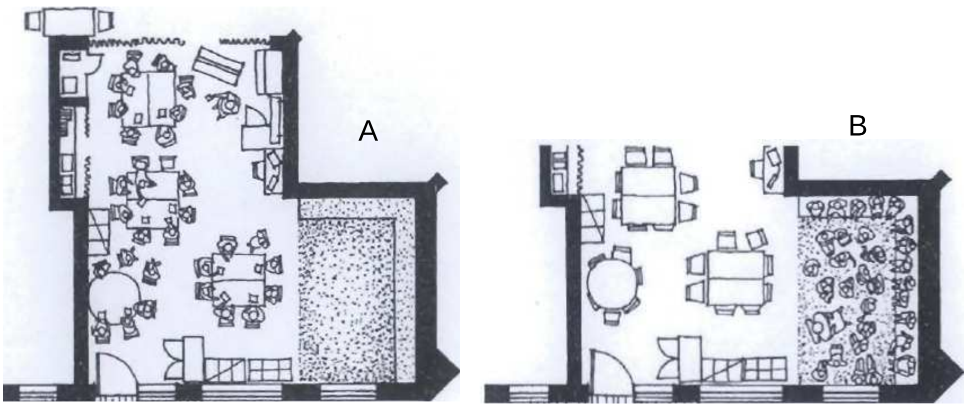
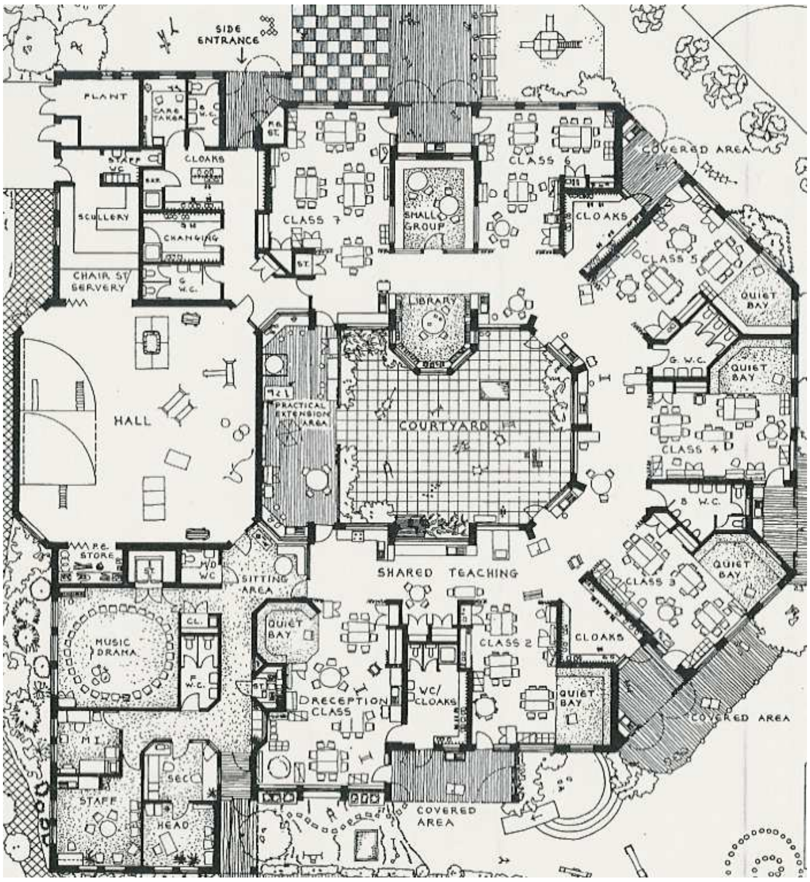
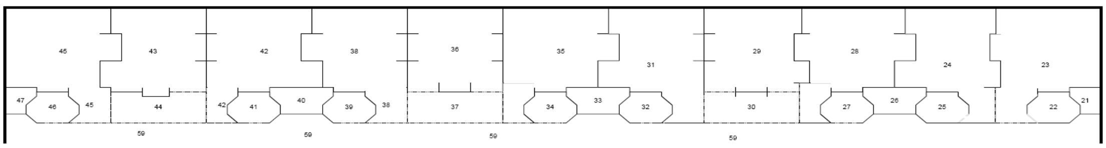


Figure 3.3: St. John's School, Sefton (1991)[66]



The hybrid approach is also exemplified by the design of Queen's Inclosure First School in Hampshire (Figure 3.4). Large semi-open plan classbases (49-54 m^2) with focused views towards a whiteboard facilitate whole class teaching with a considerably lower pupil density than St John's School[65]. The classbases open onto a central 'mall' to enable mixed activities and group work[6]. Small enclosed quiet rooms are used for withdrawal and larger semi-open pods are used for practical work.

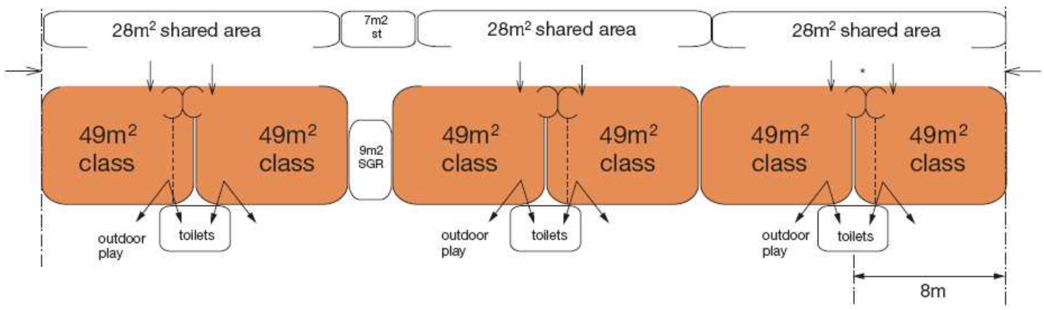
Figure 3.4: Queen's Inclosure First School, Hampshire (1990)



Generally, a hybrid approach to teaching can be seen in classrooms today[6], largely as a result of the demands of the National Curriculum[50] and National Literacy strategies[53]. The current area guideline for primary schools (Building Bulletin 99, or BB99)[64] sets out a specific requirement to provide a net 'basic teaching area' of 2.1 m^2 per child[64]. 'Basic teaching area' is defined as all types of learning areas other than halls, studios and learning resources areas[64]. This will include the classbase, group rooms, ICT bases, practical areas and shared teaching areas[64]. Ancillary areas are considered separately. The guidance states that every classbase should provide adequate free floor space, preferably carpeted (either to gather the whole class together sitting on the floor or for individual practical work), and sufficient table space with a chair for each pupil, generally arranged in groups, to facilitate individual and group work.

BB99[64] describes a semi-open plan option in order to provide sufficient net basic teaching area based on 30 pupils per class (equivalent to 63 m^2 per class), as indicated in Figure 3.5. This consists of small classbases of 49 m^2 'to accommodate activities crucial to numeracy and literacy'[61], opening onto shared practical resource areas (28 m^2 shared by two classbases). The guidance notes that this arrangement works best with multiple form entry schools where similar activities are being carried out by the classbases[64]. The guidelines note that although 'historically' this shared space has also been used as a circulation route, this is discouraged to enable the pupils to use the space 'freely without distraction'[64].

Figure 3.5: BB99 compliant semi-open plan layout example for primary schools[64]



BB99 also recommends at least one small enclosed group room for Special Educational Needs (SEN) learning and at least one further small group room for the nursery (if applicable) for quiet activities such as 'storytelling or withdrawal of individual children'[64]. Further small group rooms to serve every three to four classrooms are recommended as an optional extra. The intention of the group rooms is to provide an enclosed space ('preferably with a door') for small groups to use either as a quiet withdrawal space or with a peripatetic teacher. As a result of these demands, the large majority of Post-Plowden open plan classrooms existing today are of semi-open plan design with restricted openings to limit noise transfer.

3.4 The future of open plan classrooms

Today, Britain is investing in the largest building programme for schools since the Victorian era. There has been as much school building in the past five years (2002-2007) as in the previous twenty[67]. New school buildings were previously built to last for 25-50 years (or more in the case of Victorian schools), during which time significant changes in educational trends and practice were inevitable. There is a current focus on predicting how education will look in the future, in order to equip educational buildings for the 21st century and avoid being left with 'expensive white elephants'[68]. Whatever the visions of future classroom practice, it is clear that new schools must provide facilities to support a variety of different teaching and learning methods.

3.4.1 Teaching strategies of the future

The implementation of the Primary National Strategy[69] allowed some release from the National Curriculum, and experimentation with cross-curricular work. One study[54] identified commonalities between this and the topic-based integrated work of the progressive Plowden ideal. This study noted that some teachers described classroom practices as 'coming full circle' due to re-integration of separate subject teaching[54].

Advocates for educational reform in the US such as Nair[70, 71], Lackney[72] and Washnor[73] are lauding a neo-progressive educational model to provide knowledge and skills for a new global economy, coined as ‘New Paradigm’ schooling. The model embodies many original progressive ideas but is billed as being ‘only now a real alternative to traditional schools’[70]. ‘Personalised learning’, where the student is placed at the centre of the learning process, and ‘Project-based learning’, which uses inquiry-based or experiential learning, are seen as core principles of this approach.

The characteristics of project-based learning demand a wide variety of learning resources and a range of activity space in terms of size and style. Nair’s ’30 strategies for educational reform’[70] also cites vertical grouping, multidisciplinary curricula, co-operative learning, and team teaching as important strategies. Although open and shared space is encouraged, problems with noise and distraction in open plan settings are recognised by Lackney[72], who recommends allowing for as wide a variety of group learning sizes as possible by providing partially open space, with adjoining, smaller, enclosed spaces for more task specific activities. The notions of personalised learning and learner-centric education are also supported by UK educationalists and designers[74].

Personalised learning is one of the UK government’s current initiatives for schools. The Department for Children, Schools and Families (DCSF - formerly the DfES), revealed *The Children’s Plan* in December 2007[75]. This sets out a pedagogy and culture of personalised learning and teaching. The approach is actively learner-centred, but is more guided and structured than the Plowden ideologies, with a focus on knowledge and assessment. Personalised learning is also part of the Government’s vision for transformation of England’s education service between now and 2020[76]. In order to facilitate these changes, learning spaces need be designed to ‘be flexible enough to allow for a variety of learning and teaching approaches and greater diversity in the size and age mix of pupil groupings’ and ‘emphasise participation and collaboration’[76].

Key differences in future learning trends have been summarised by Clark[77] as shown in Table 3.1. This vision is largely in line with the Government’s current plan for educational transformation. Although different nomenclature is used, there are striking parallels between this and the predicted trends in Table 2.1

(written over 40 years previously). As Clark stresses, 'it seems inevitable that schools of the present and the future need elements from both lists'[77].

Table 3.1: Clark's key differences in future learning (2002)[77]

Traditional learning environments	New learning environments
Teacher centred instruction	Student centred instruction
Single sense stimulation	Multi-sensory stimulation
Single path progression	Multi-path progression
Single media	Multi media
Isolated work	Collaborative work
Information delivery	Information exchange
Passive learning	Active/exploratory/inquiry-based learning
Isolated, artificial context	Authentic, real world context

3.4.2 The future of school building

The UK Government's 'Building Schools for the Future' (BSF) programme was launched in 2003 with an aim to rebuild or renew every secondary school in England over a 10-15 year period. Although primary schools are not included in BSF, a separate programme was announced in 2006[78] to provide for the rebuilding, remodelling or refurbishment of 50% of primary schools over the next 15 years. To date, over 1,200 schools and 27,000 classrooms have been completed, and there are an estimated 675 primary schools and 1000 secondary schools in planning for modernisation[75].

Flexibility is seen as a key requirement in the Government's vision for new schools in order to 'embed'[79] sustainability and 'future-proof'[79] schools against change in pedagogy:

> *'All BSF projects must be approached with a view not just to providing environments compatible with the current state of educational thinking, but with an eye to future needs and developments'* [78]
>
> *'Classrooms need to be able to adapt quickly and easily to new requirements and ways of working, so they need to be designed with flexibility in mind'*[78, 80]
>
> *'Pedagogic trends come and go...we need to build for agility and flexibility to allow for changing trends. New school designs must show that they are capable of responding to changing pedagogy'*[80]

'If schools are to provide excellent educational facilities for the next 20 to 30 years, designs for new school buildings and major adaptations need to take account of current and likely future developments in education and technology. Design quality encompasses a number of issues but should include flexibility and adaptability'[63]

'We need to look at ways of designing inspiring buildings that can adapt to educational and technological change … that will not happen if we do not design spaces in schools that are flexible and will facilitate various patterns of group working'[81]

Different approaches to achieve flexibility are discussed in Building Bulletin 95[63] and summarised in Table 3.2:

Table 3.2: Design approaches for flexibility[63]

Approach	Description	Issues
Loose fit	Making classrooms large enough to cater for range of users and activities, avoiding too close a fit to any one space	Requires larger area, risk of lack of pedagogic scheme
Moveable partitions	Installed between spaces to enable different spaces to be created when needed	Expensive, effectiveness of sound insulation needs to be considered
Range of different sized spaces	Different rooms are booked as needed by mutual agreement	Difficult to manage

'Classrooms of the Future' is an initiative to develop innovative classroom designs which 'challenge current thinking' on school building design'[81]. Flexibility is a key design issue in all projects, with many classrooms being linked by moveable partitions.

Although the emphasis on flexibility has prompted school designers to consider elements of open planning in schools (see following section), a return to the fully open plan 'school without walls' seems unlikely:

'Pupils need to be able to work undisturbed in a quiet place (usually an enclosed room)....and there are times when an open resource and work area is not appropriate....There will always be a need for some enclosed spaces in a school. Open plan areas can be very successful but only for some activities and they rely on a reasonable level of behaviour by occupants to avoid disturbance'[63].

In addressing the issue of the future of school building design, the DfES (now DCSF) launched a compendium of 'Exemplar Designs'[82], examples of high quality school design by eleven leading architectural practices, intended to provide 'an inspiring basis for thinking about future provision for every primary and secondary school'[63]. Short-term flexibility was included in the key design requirements. As a result, the design teams saw open plan arrangements being more common in the future[82]. However the brief also specified for the provision of small (enclosed) group rooms to achieve adequate acoustically isolated areas. In order to accommodate both traditional, didactic teaching as well as project-based and individual methods, the teams made use of features such as moving walls, folding/sliding partitions and relocatable learning 'pods' to create long-term adaptability.

As a move towards neo-progressive educational methods is envisaged, with open planning becoming re-accepted as a design to provide flexibility, it seems inevitable that issues with noise and distraction need to be addressed, whilst maintaining the more desirable elements of open plan design.

3.5 Future open plan classrooms: Neo-Plowden?

Heppel[80] identifies that although even enclosed classrooms are no longer one-teacher, one-group spaces, open plan designs 'have not been properly placed back into a portfolio of design opportunities for UK schools'[76]. New classroom designs in other countries have large, flexible, open spaces[80], in order to accommodate neo-progressive educational philosophies. Two high profile examples of these are discussed below.

3.5.1 Hellerup School, Copenhagen

Hellerup, opened in 2002, is an extremely innovative school both architecturally and educationally. The school is designed for 750 pupils aged 6-16 years. The pedagogy is based on a 'novel teaching paradigm'[83], which largely reflects elements of progressive and neo-progressive education, namely:

- Large degree of pupil choice and control
- Team teaching
- Integrated day (multiple activities on offer within one lesson)
- Project based curriculum
- Personalised learning
- Informal, 'discovery' learning

The school is largely open plan with a complex system of wooden stairs, balconies and bridges at the centre, some of which are wide enough to be used as seating areas for presentations and performances. Extensive timber finishes are perforated to provide acoustic absorption, in order to control reverberant noise buildup and create a 'calm and soothing atmosphere[84]. Spaces are zoned into several home areas which open off a central common area at the heart of the building.

Each home area has three classbases holding 25 students which are large enough to be used by whole classes and smaller groups[83]. Every student has an area of around 9 m^2, which is considerably higher than the minimum area guidelines for UK schools[64]. The furniture in these spaces is designed on a child-like scale to create a more domestic atmosphere, much as at Eveline Lowe School. Octagonal pods formed from screens are provided around the school for withdrawal of individuals or small groups, but these are still open on one side[84]. The different spaces are generally defined by partitions and furniture such as mobile cupboards and shelves. The layout and furniture can be changed during the school year (often customised by the students themselves)[83].

The design has received widespread international acclaim, although it should be noted that this experimental school is likely to be successful as a result of some essential design and management techniques shown in Table 3.3.

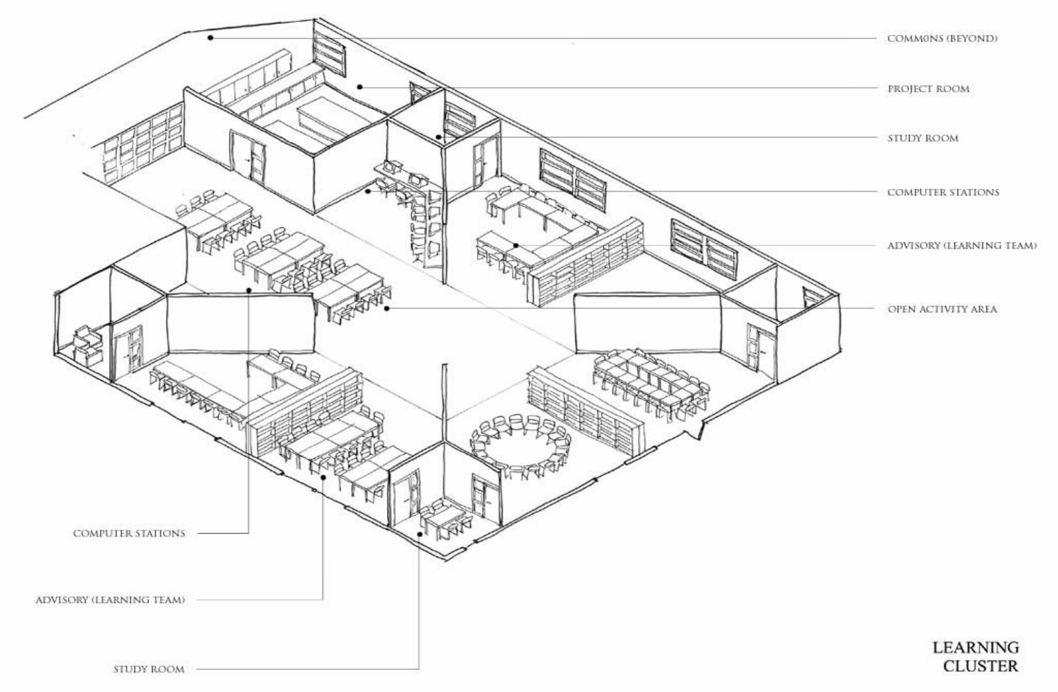
Table 3.3: Design and management techniques at Hellerup school, Denmark[83, 84]

Management techniques	Design techniques
Pupils made responsible for their own environment	Pupils and staff actively involved in design process
Specific behaviour patterns (eg occupants take off shoes inside the school)	Smaller class sizes (average 25 pupils per class) and significantly more space per student (9.12 m^2) than traditional classrooms
Parents are generally highly motivated and take an active role in monitoring their children's progress	Extensive acoustic treatment

3.5.2 Truman High School, Washington DC

This is a small high school in the U.S (102 students), committed to project-based learning methods and integrated subject programming (Figure 3.6).

Figure 3.6: Truman High School, Washington DC (2003)[85]

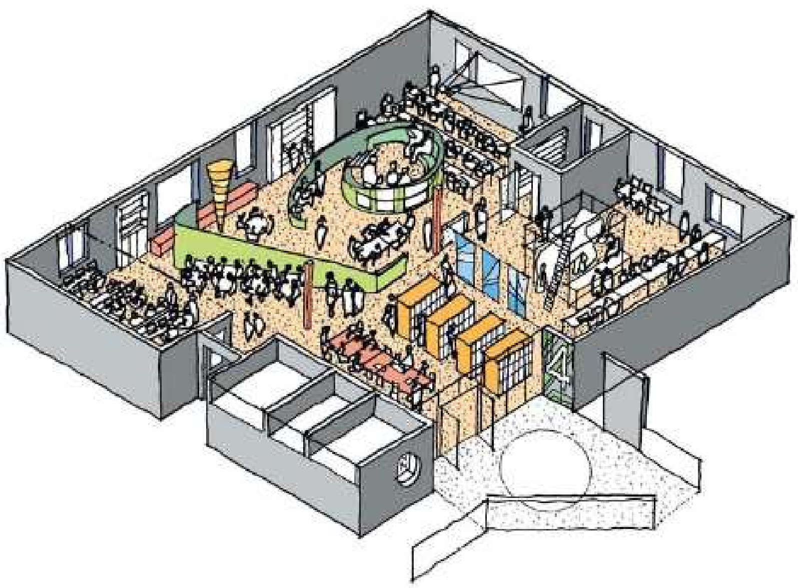


The school is of square open plan design, consisting of a large central area with use of partial height walls to create six different learning 'advisories' in a radial arrangement[73]. Students spend a significant amount of time out on work placements, which allows learning to take place in small groups with fewer students, resulting in lower noise levels. Further to the acoustic treatment within the space to control noise levels, monitoring of student noise is 'a matter of individual responsibility'. Masking sound is also provided through manipulation of existing mechanical ventilation noise. Four small enclosed study rooms within each advisory and one large shared enclosed project room are essential to control noise levels.

3.5.3 DfES Exemplar designs

Similar open plan spaces feature on the agenda of many of the DfES Exemplar designs[82] as shown in Figure 3.7. The brief required all designs to provide minimum areas set out in BB99[64]. Most of the examples demonstrate both open plan and enclosed options for the designs. As above, small enclosed study rooms within the open plan space are still considered essential for withdrawal.

Figure 3.7: Cluster design in open plan arrangement[82]

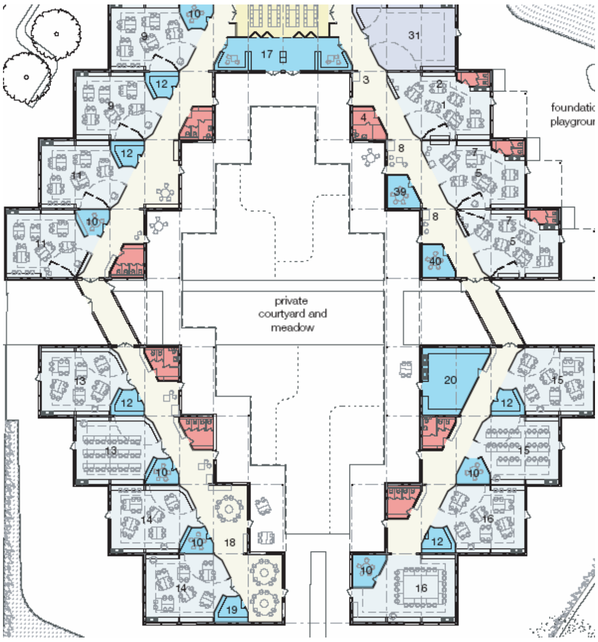


The exemplar primary school design in Figure 3.8 shows a typical flexible arrangement and layout to accommodate both traditional and open learning. The open plan 'heart' of the school provides resource areas and enclosed group rooms, with an option for 49 m^2 classbases to open off this central area (spaces 15 and 16) in combination with shared practical space (6). However the design report indicates that the open plan options do not necessarily comply with current acoustic building regulations for the full combination of expected simultaneous teaching activities in adjacent spaces[86]. Timetabling is identified as key to prevent conflicts of use occurring between activities in the heart of the building and in the classbases.

Figure 3.8: Walters & Cohen Primary School exemplar[82]

An alternative exemplar primary school design shown in Figure 3.9 indicates semi-open plan layout options achieved through use of rotational partitions which can be moved back to increase the size of the opening and provide shared teaching space. Partial height walls are used between classbases. Again, the acoustic assessment provided by the design team was carried out for a limited combination of adjacent activities[86].

Figure 3.9: Marks Barfield primary school exemplar[82]



3.5.4 *City Academies*

City Academies form a key part of the BSF programme. Bold innovation in design is encouraged and is regarded as being more likely to raise standards[78]. Some designs have major open plan design elements, including Bexley Business Academy, opened in 2003 and nominated for the RIBA Stirling Prize 2004 (Figure 3.10). Eight 51 m^2 classbases open directly onto a large atrium via very large openings (82% of full classbase width). The ground floor of the atrium is used as a resource area for teaching design and technology, where noisy work takes place.

As part of this work, the school was visited in 2004. High levels of noise were generated in the atrium, and circulation routes directly outside the classbases. The current architectural trend for exposed concrete, glass, and steel also limits the amount of surface space available for acoustic treatment and creates a high reverberant noise level. There was little evidence of co-operative teaching and management in place, and whole class didactic teaching was observed for most of the school day. This created severe problems with noise, distraction and speech intelligibility, as evidenced anecdotally by both teachers and pupils. Following criticism of these high profile 'glass palace' designs,[87, 88] plans were announced in 2007 to enclose the classbase fronts by installing glazed partitions[89] – replicating the fate of the Plowden Classrooms of the 1970s.

Figure 3.10: Bexley Business Academy (2003)

3.6 Conclusions

This review has shown that as a result of new 'neo-progressive' trends in teaching practice, such as personalised and project based learning, open and flexible style plans are returning to the forefront of classroom design in a revised 'neo-Plowden' form. However the prevalence of open plan designs seen in the 1970s is unlikely to be repeated. Although whole class teaching is far more widespread than in the 1970s, informal approaches to this teaching style make semi-open plan designs with large classbases more compatible with this type of practice.

Successful designs have recognised the need for specialist teaching strategies to be used, in combination with provision of lower occupant densities and restricted openings. However, adoption of open planning on a large scale without due consideration of acoustic design and teaching strategies has already demonstrated a repeat of the fate of the Plowden designs of the 1970s.

The review has identified a need to assess the acoustics of open plan classrooms in existing primary schools with respect to modern and future teaching and learning methods, to ensure that the learning environment is acoustically fit for purpose.

Having explored the history and design development of open plan classrooms, a review of noise, room acoustics and speech communication in open plan classrooms follows in Chapters 4 and 5.

Chapter 4: Noise in open plan classrooms

4.1 Introduction

This chapter discusses noise experienced in open plan classrooms, in the context of measured and subjectively perceived noise levels, compared with noise measured in enclosed classrooms. The effects of noise on teaching and learning are discussed, including effects on vulnerable listener groups. Recommended noise criteria and methods of noise control through best design practice are reviewed from the available literature.

Noise and room acoustics are consistently cited by occupants as a significant concern in schools, whether open plan or enclosed design[90-93]. The majority of studies focusing specifically on acoustics in open plan classrooms were carried out during the 1970s, and many of these concentrated on fully open plan designs with no fixed divisions between teaching areas. There is a paucity of data relating to more recent designs. Excessive noise levels and lack of acoustic privacy have been frequently identified as the most undesirable aspect of open plan schools [13, 22, 39, 40, 94-99].

Although noise levels and distraction were identified as a significant problem of open plan design, early Building Bulletin guidance documents[14, 17, 26, 29, 100] largely relied on anecdotal and subjective evidence rather than objective measurement of noise levels in the classroom spaces. However several research studies carried out objective measurements of background noise levels and related the data to subjective surveys in relation to distraction, annoyance, acoustic comfort and satisfaction, and also to performance indicators such as test ratings and specific cognitive processing tasks. These studies are discussed in detail in Section 4.2.

4.2 Effects of noise

There is a wealth of research examining the effects of noise (mainly from external environmental sources) on all aspects of performance in classrooms. A significant negative relationship has been found between noise levels and learning attainment[92, 101-106], cognitive processing[107, 108], reading[13, 105, 109-116], and to a lesser extent, numeracy tasks[9,19,23]. Noise has also been found to affect other performance related aspects such as attention[117], concentration[102-104] and memory[105]. Irrelevant speech has been shown to have a profound effect on literacy tasks by children[118].

Other reported non-auditory effects of noise in the classroom include stress[91, 101], raised blood pressure[119] and motivational effects such as learned helplessness[119]. Different groups of children have been found to be affected differently by noise. For example, whilst older children were found to be more aware of external noise, younger children were more annoyed by it[120]. Children with sensory hypersensitivity, for example those with Autistic Spectrum Disorders (ASD), may be more easily distracted by noise. Other groups of listeners vulnerable to the specific effect of noise on speech perception are discussed in Chapter 5.

Very few studies have quantified the effects of noise on performance in open plan schools. Weinstein's carefully designed experiment[35] assessed the effect of naturally occurring background noise on students' reading performance within a fully open space school, whilst controlling for factors such as fatigue, individual ability, class teacher, and time of day. The study found no significant effect on reading error rate between 'quiet' and 'noisy' periods of intrusive noise from adjacent classbases, but a slight tendency to work more slowly in noisy periods. However the study emphasised that results were not necessarily applicable to schools where background noise levels are higher, and that noise was still likely to affect annoyance and speech communication, and to reduce the number of available teaching options. A separate study by Barnett[121] into the effect of noise on attention found that children in an open space classroom performed significantly better in a test of selective attention in the presence of auditory distractions than those in an enclosed classroom with a similar density of pupils per unit area.

In Shield and Dockrell's study of children's perceptions of noise in UK primary schools[120], children reported that the most difficult listening scenario was when other children were making a noise outside the classroom. In open plan schools, speech from adjacent teaching areas has been cited as the most common cause of disturbance[39, 40, 98, 122] and was perceived by both teachers and pupils to be a problem[13, 35]. The level of distraction in open plan schools is attributed to 'individual perception, social conversation, movement and noise'[13]. Irrelevant speech has been shown to be a particularly distracting source of noise compared to equivalent noise levels from other sources[123] due to the associated meaning in speech[124], thus making open plan schools particularly vulnerable to this effect.

4.3 Occupied noise levels

The dominant source of noise in general classrooms has been found to be the noise generated by the children themselves as they take part in a range of classroom activities[19,37,38]. Noise from external sources, whilst acting as a 'distractor' to pupils, was found to affect the occupied internal noise level only when pupils were engaged in the quietest activities[104, 125].

4.3.1 Enclosed classrooms

A summary of measured noise data for occupied enclosed classrooms using comparable measurement techniques and parameters is shown for a range of different classroom activities in Table 4.1. A wide range of noise levels arises in occupied classrooms, depending on the type of activity taking place. Extensive reviews of available data note that often studies did not describe the precise measurement method used[104,126] (for example the type of noise descriptor used, measurement duration and location, and specific classroom activities/scenarios measured). A difference of around 15-20 dB occurs between the quietest and noisiest measured activities[104], indicating that it is crucial to consider the specific type of activity taking place during measurements.

For quiet classroom activities, with occupants involved in silent reading or a test, the literature agrees a consistent average noise level of 56 dB L_{Aeq} across different types of classroom situations from primary classrooms[104, 125, 127] to university lecture rooms[128]. Lower average occupied levels of around 43 dB L_{Aeq} were recorded by Bradley[129-131] with 'no student activity', although this is more representative of the noise contribution from children when quiet, still and listening to their teacher rather than as a standalone activity.

Table 4.1: Measured occupied noise levels in enclosed classrooms

Reference	Number of classrooms (n)	Mean L_{Aeq} (range) dB	Activity
Sato & Bradley[129, 131] 2004	41	44	No student activity
Shield & Dockrell[125] 2004	110	56 61 65 72 73 77 72	Silent reading/exam One person speaking Individual work (most common) Individual work and movement Group work Group work and movement Overall average
Picard & Bradley[126] 2001	1	71 (39-87) 61	28 pupils in co-operative instruction Written exam (including instructions)
Mackenzie[**127**] & Airey[132] 1995	56[+]	56 (31-68) 77 (52-101) 70 (42-84)	Pupils silent Pupils working Teacher talking
Hay[133] 1995	7	58-72	Children talking and working
Moodley[134] 1989	24	65 (48-81)	No specific activity description
Bradley[130] 1986	10	42 (38-45)	Average 24 students (12-13 years) in each class No noise producing activity
Barnett[121] 1982	1	61 (59-82)	1 teacher and 30 children working in small groups.
Finitzo-Hieber[124] 1981		58-60	25 students, 1 teacher. No specific activity description
Kyzar[36] 1971	4	60* (58-63)*	'Conventional' schools. No specific activity given.
Fitzroy & Reid[135] 1963	15	51	High School. No specific activity description

[+]Study included treated open plan classrooms

*5 dB conversion factor from dB(L) to dB(A) applied for comparison purposes, after Picard and Bradley[126]

The noise level measurements by Kyzar[36], Fitzroy and Reid[135] and Finitzo-Heber[124] do not provide a description of the type of teaching activity taking place, however comparison with Shield and Dockrell's data[125] suggests that the measurements were likely to have been carried out when the teacher was instructing a class of children who were quiet and listening to the teacher, that is one person speaking at a time, typical of 'conventional' teaching described by Kyzar[36].

Shield and Dockrell[125] recorded the most commonly occurring activity as children sitting and working at tables with some interaction between them. This is consistent with recent reviews of classroom organisation as discussed in section 3.2. Given the available literature from surveys using a robust sample of classrooms, Shield and Dockrell[104] suggest that a representative value for 'typical' classroom activity in UK primary schools is 65 dB L_{Aeq}.

For group work activities and 'co-operative instruction' periods, the average occupied noise level increases to exceed 70 dB L_{Aeq} [125, 129], and around 77 dB L_{Aeq} when activities include movement. This agrees with Mackenzie[127] and Airey's[132] levels of 70-77 dB L_{Aeq} recorded for 'pupils working', described in the study as 'typical group working conditions where children were permitted to talk in reasonable voices'[132]. From this it can be inferred that the upper level of 72 dB(A) recorded by Hay[133] for children talking is likely to relate to group-work activities.

Picard and Bradley[126] note that the proximity of classmates will probably ease speech understanding within each working group for co-operative instruction. Teachers are unlikely to attempt to address the class during these periods of activity noise, without first prompting the class for quiet (either by raising their voice temporarily or by using non-verbal cues for attenuation). Therefore this type of group activity needs to be considered separately from a more critical listening situation such as a teacher addressing the whole class.

It has been suggested that classroom noise levels increase as the age of the children decreases[126], with considerably higher noise levels for nurseries/kindergarten[134]. However this was not evident in Shield and Dockrell's[125] large scale study, or Sato and Bradley's study[131], once specific classroom activities were taken into account.

Shield and Dockrell[125] did find significant positive correlations between noise levels and the number of children present in each class. The number of children, or pupil density, in a classroom becomes a particularly important factor affecting the noise level in open plan classrooms, as discussed in the following sections.

4.3.2 Open plan classrooms

A summary of measured data for occupied open plan classrooms using comparable measurement techniques and parameters is shown for a range of different classroom activities in Table 4.2. Although previous studies comparing open plan and enclosed classrooms reported that noise levels were perceived to be considerably higher in open plan classrooms[21,33], inspection of Table 4.2 suggests that the measured noise levels in open plan classrooms are similar to those typically measured for active periods in enclosed classrooms (that is around 65 dB for working at tables, 70-77 dB for co-operative instruction).

Of the four studies which compared open plan and enclosed noise levels directly (Kyzar[36], Barnett[121], Finitzo-Hieber *et al*[124], Mackenzie and Airey[132, 136] and Fitzroy and Reid[135]) only Finitzo-Hieber's study[124] found significantly higher average noise levels in open plan classrooms (> 3 dB), however the open plan measurements consisted of noise levels for 100 children sharing a fully open plan area, which is not typical of today's open plan designs. Barnett[121] compared an enclosed classroom of 30 children with an open plan classroom consisting of two groups of 30 children, but with a similar student density. No significant difference was found between open plan and enclosed average noise levels. This is consistent with the results of Kyzar[36] and Fitzroy and Reid[135] (difference of less than 2 dB between average results for open plan and enclosed studies).

Table 4.2: Measured occupied levels in open plan classrooms

Reference	Number of classrooms	Average noise level (range) dB	Comments
Charlton-Smith[137] 2005		66 (64-69)	Semi-open with large openings; full height partitions carpeted floors untreated ceilings
		63	Sliding partitions; carpeted floors and absorbent ceilings
		64 (60-68)	Semi-open; partial height partitions; Carpeted floors and absorbent ceilings
Charlton-Smith[138] 2003		58 (55-60)	Semi-open; partial height partitions (absorptive ceiling and carpeted floors)
		62 (48-71)	Semi-open; full height partitions (absorptive ceilings and carpeted floors)
Building Bulletin 93[1]	1	(66-75)	Primary classroom – project work, literacy and numeracy sessions
MacKenzie[136] and Airey[132] 1995	14	57 (49-70)	Primary classrooms – pupils silent
		64 (49-74)	Primary classrooms – teacher talking
		72 (60-84)	Primary classrooms – pupils working
School sound level study[42] 1986	36	63 (52-69)	Fully open plan elementary schools; very active periods (at least four class groups)
		62 (54-73)	Fully open plan secondary grade schools; very active periods (at least four class groups)
Barnett[121] 1982	1	60 (58-62)	2 classes of 30 children moving freely between classrooms, but same pupil density as enclosed classroom
Finitzo-Hieber[124] 1981		66-73	Fully open plan; 100 students, 10 teachers
Yerges[122] 1976	5	55 (54-71)	Fully open plan schools; 'normal classroom activities'
Walsh[22]			Fully open plan high schools;
		47-62	Carpeted; absorbent ceiling
		54 – 67	Carpeted; reflective ceiling
Kyzar[36] 1971	4	61* (57-65)*	Fully open plan schools
Fitzroy and Reid[135] 1963	15	53	High school. No specific activity description

*5 dB conversion factor from dB(L) to dB(A) applied for comparison purposes, after Picard and Bradley[126]

Airey[139] found that during active periods, the noise level in open plan classrooms was actually 5 dB lower than in enclosed classrooms. This was attributed to the lower reverberation times occurring in open plan classrooms due to increased use of acoustic absorption, in addition to anecdotal evidence of teachers in open plan classrooms spending more time and effort controlling pupils and 'restricting lessons to quieter activities to avoid disturbing other classes'[139]. The reduction in noise levels due to absorbent ceilings (3-5 dB(A)) is apparent in the data in Table 4.2 (see Charlton-Smith[138] and Walsh[22]).

However the standard deviation of Barnett's results[121] indicate that there was more fluctuation in open plan noise levels, attributed to the fact that pupils moved in and out of the classroom space more frequently than in the enclosed classroom. This again is supported by the larger range of noise levels measured in open plan classrooms by Kyzar[36] , Fitzroy and Reid[135] and Yerges[122].

Conversely, Airey'[139] found that noise levels in open plan classrooms were more uniform than enclosed classrooms throughout the day, since there were always activities taking place in the adjacent classbases. This is more representative of the modern open plan classroom, where pupil movement in and out of the classbase itself is less likely to occur. This effect was observed in another case study published in Building Bulletin 93[1], with a smaller difference between L_{A10} and L_{A90} levels when open plan areas were fully occupied, compared to when only one classbase was in use. The need for a relatively uniform sound level was identified as being important in several studies to avoid distraction[41, 42, 140]. A fluctuating noise level was shown to be significantly more annoying to teachers and pupils than a more consistent noise at the same average level[141].

Whilst observing that noise was a problem in Plowden schools of the 1970s, Durlak[142] commented that 'the problem is by no means non-existent in self contained classrooms'. This is also relevant to enclosed primary school classrooms of today following the increase in the number of adults in the classroom teaching different groups simultaneously, as noted by Heppel[80] (see Chapter 3). Bennett[20] draws attention to Brunetti's argument that although noise is more of a problem in open plan classrooms, 'the type of activity taking place is more important than the [design of the] space, and a high level of noise does not necessarily result in distraction'[143].

Weinstein[35] suggested that the reported perceived increase in noise levels in open plan schools 'may reflect a lack of control over the intrusive noise levels as much as the loudness level *per se'*. That is, teachers trying to address a class of pupils who are quiet and attentive need to compete with the intrusive noise level arising from activities in adjacent classbases. Airey[139] found that average noise levels for cellular and open plan rooms were similar when pupils were working quietly, although again teachers spent more time co-ordinating activities in adjacent classbases to achieve this.

4.4 Intrusive noise levels

The above discussion demonstrates that, for open plan classrooms, it is often more critical to consider the *intrusive* noise level arising from adjacent activities, in order to assess speech intelligibility, rather than overall noise levels occurring in the main classbase during active periods, which are unlikely to be significantly higher than those experienced in enclosed classrooms.

Often, predictions and measurements of objective speech intelligibility in open plan classrooms are carried out without considering background noise realistically[1]. Measuring the objective speech intelligibility in unoccupied conditions (ambient noise level only) would result in an overestimation of speech intelligibility. Conversely if the total measured occupied noise level is considered (which includes the noise contribution from the teacher's voice), the objective speech intelligibility would be underestimated.

Measurement of the intrusive noise level when the main classbase is occupied is usually difficult under natural conditions since even when the class is involved in a quiet activity, there is usually some contribution from the teacher's speech, which needs to be considered as the signal rather than the noise level. Therefore the intrusive noise level is more commonly measured with the main classbase unoccupied.

Table 4.3 shows results of two studies in which intrusive noise levels were measured in an unoccupied main classbase in a fully open plan school whilst 'normal' activities occurred in adjacent classroom spaces. Both classrooms were carpeted. The classroom in Kingsbury's[39] survey had an acoustic ceiling installed. Although no specific description of the adjacent activity is given, Kingsbury's data agrees very closely with Weinstein's[35] data for when adjacent spaces were quiet. The data supports the suggestion that when the main classbase is involved in active periods such as group work (around 70-77 dB from Table 4.1), the additional intrusive noise level from adjacent classbases (around 60 dB from Table 4.3) is not likely to increase the overall occupied noise level. However for critical listening periods in the main classbase, the intrusive noise level may become problematic during active periods in adjacent classbases

Table 4.3: Measured intrusive noise levels in open plan classrooms

Reference	Number of classbases in unit	Average L_{Aeq} (range) dB	Comments
Weinstein[35]	5	60 (55-66) 47 (45-49)	Adjacent spaces active Adjacent classes quiet
Kingsbury[39]	6	47-49	'Normal' activities

The long term measured noise levels used above give no indication of the fluctuation of speech-to-noise ratio with different adjacent classroom activity and different listening positions. A carefully considered approach to measurement methodology is necessary to obtain meaningful results that are relevant to classroom activities and organisation in the modern open plan classroom. A suitable methodology approach is discussed in Chapter 7.

4.5 Recommended criteria

Criteria for background noise levels in open plan classrooms need to consider distraction and annoyance, speech intelligibility within the classbase, and masking for speech privacy between classbases. Recommended criteria vary across the literature. This is likely to be due to differences in subjective methods to measure annoyance and distraction, and individual differences in noise tolerance. Generally studies did not take into account the difference between overall background level (including main classbase activities) and intrusive noise level, or consider the role of classroom management and organisation in controlling noise levels.

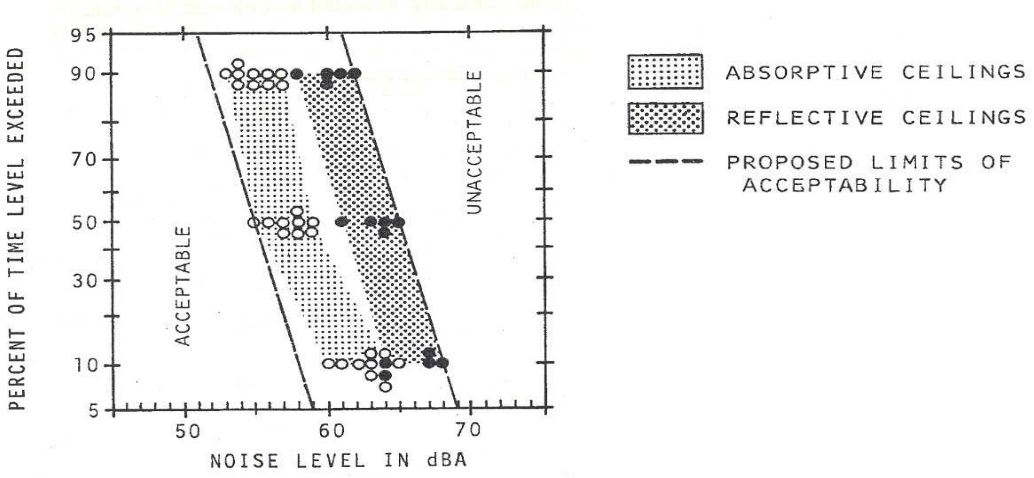
Minimum recommended noise level criteria to provide sufficient masking noise for speech privacy between classbases ranges between 40[122] and 50[42] dB(A). This could be considered as a criterion for the maximum indoor ambient noise level (due to external noise sources and building services), although Table 4.3 indicates that a maximum level of around 40 dB(A) would be necessary to ensure that the ambient noise level does not increase the overall intrusive noise level, thus reducing speech intelligibility within the main classbase.

An occupied noise level between 50 and 70 dB(A) was recommended for classbases engaged in similar activity to avoid interference[42], and to avoid impairment of language development[144]. An alternative study recommended a maximum average noise level of 60 dB(A)[141]. Although not apparent from the paper, it is assumed that this refers to an intrusive noise level, as clearly a maximum overall level of 60 dB(A) would preclude all but the quietest classroom activities from being carried out in the main classbase.

Walsh[22] measured background noise levels in open plan schools and related these to teachers' subjective dissatisfaction levels. The criterion for acceptability was based on previous work on open plan offices by Keighley[145, 146], who proposed a maximum acceptable dissatisfaction level whilst accounting for differences in individual noise tolerance, that would ensure that only a minority of the population is likely to be dissatisfied. The proposed minimum borderline limit to ensure a satisfied majority was proposed to be 58% of the population (50% plus twice the measured standard error of the estimate), with a proposed desirable standard in practice relating to at least 68% satisfaction/acceptability. Walsh found that the proposed maximum dissatisfaction level (32%) corresponded to a maximum background noise level in open plan classrooms of between 55 and 65 dB(A).

Walsh[22] also investigated the fluctuation of measured noise levels throughout the day (NB time period for measurements not specified in study). A typical distribution plot is shown in Figure 4.1 for measured L_{A50} levels, L_{A90} levels and L_{A10} levels. The slopes given by the $L_{A10}/L_{A50}/L_{A90}$ plots indicate how much noise levels may fluctuate from a uniform noise level (which would be represented as a vertical line). Walsh proposed limits of acceptability as shown by the dashed lines in Figure 4.1. The lines define three regions of acceptability corresponding to 'acceptable', 'marginal' and 'unacceptable' distraction and annoyance. The marginal area corresponds to 55-65 dB L_{A50}. Those schools with measured noise levels which fell into the region of unacceptability (not indicated in the example on Figure 4.1) were found to have 'strong teacher dissatisfaction'[22] with the acoustics of the teaching spaces. This concept will be used later in the thesis in an analysis of measured intrusive noise levels in open plan classrooms.

Figure 4.1: Percentile noise levels in open plan classrooms[22]



4.6 Control of noise and sound propagation

Control of sound transmission in open plan classrooms is measured objectively either by the sound attenuation between two spaces or the attenuation per doubling of distance. For semi-open plan schools, at least 15-20 dB attenuation is recommended between teaching groups[122, 147] and 5-8 dB attenuation per doubling of distance within a classbase[147]. Use of screens or semi open partitioning would be necessary to achieve this performance.

Whilst the preferred design approach for enclosed classrooms is to leave a central portion of the ceiling reflective in order to reinforce the speech signal with early reflections from this surface, in open plan classrooms it is considered to be more important to maximise sound absorption to surfaces throughout the classbase, in order to minimise noise transmission between classbases. Petersen[147] recommends use of a Class A absorber with a maximum ceiling height of 3.5 metres to ensure that the surface functions as an effective absorber. This is consistent with earlier studies of fully open plan classbases[22, 42,148].

It should be noted that the recommended sound attenuation cannot be achieved by means of absorptive surfaces alone. Kingsbury[99] measured around 4.5 dB per doubling of distance in a typically highly absorptive fully open plan classroom. Kyzar[36] measured 6-9 dB attenuation between teaching spaces in classrooms with only temporary or moveable divisions (cabinets, bookcases or other furniture). Similarly Yerges[122] measured less than 10 dB attenuation between groups in fully open plan classrooms. Some form of partitioning (that is, semi-open plan arrangement) is therefore necessary to achieve the recommended attenuation between classbases.

Arranging the classbases in a linear rather than square arrangement was shown to achieve maximum attenuation without barriers[26, 138, 149]. Use of barriers to cut off the line of sight between source and receiver were recommended, with a recommended height of at least 1.6[40] – 2.0[141] m and mass of at least 10 kg/m^2, although it was noted in one study that use of partitioning might encourage noise, with individuals behaving ‘as though they were in totally enclosed areas’[150].

Carpeted flooring is recommended in most studies[22, 42, 151], but this is mainly to control footfalls and other impact noise (for example from furniture movement) rather than absorption of airborne noise[22]. A resilient floor covering is also recommended as an alternative[147]. Whilst curtains to classbase openings may be used to provide visual separation, their acoustic effectiveness is negligible.

A major factor in the control of distraction from noise was identified to be occupant density rather than the total amount of space provided or type of acoustic treatment or partitioning used in a space[9,11,54,62]. Walsh[22] demonstrated reductions in classroom noise level of 3-5 dB(A) due to the presence of an acoustically absorbent ceiling, whilst more significant reductions of 6-10 dB(A) were achieved following reductions in the number of students in the class, as would be expected. Walsh[22] demonstrated that the average background noise level increased with pupil density, but then decreased as the density approached that of a traditional enclosed classroom, attributed to the increased sound absorption provided by the children themselves and the reduced level of student activity due to less available space. The measured data were found to be consistent with other research studies and represented a range of different open plan designs.

Significantly more floor area is required for open plan classrooms than enclosed classrooms, with 4-5 m^2 per child recommended in the literature[22, 40, 110]. However, Bennett[20] showed that the average floor area per place in schools actually reduced from 3.8 m^2 per child in 1968, to 3.0 m^2 in 1974-1975 (when open-plan Plowden designs proliferated), as based on DES source data[152]. The actual observed amount of space available in Bennett's open plan study ranged from 2.0-4.5 m^2.

The current BB99[64] guidance for 2.1 m^2 basic teaching area per primary school child appears to be around half of the area recommended for open plan classrooms, although it should be noted that the literature does not provide details of how floor area provision is calculated. However, even if all accommodation (including non teaching space) is included in the calculation, the BB99 guidelines would only amount to 3.2 m^2 per child which is still considerably below the recommendations for open plan schools. It is interesting to note that almost three times this amount (9 m^2 floor area per child) was provided in the well-received Hellerup School, as discussed in Chapter 3[83].

As well as alterations to the physical environment and building fabric, noise in the classroom may be controlled by approaches to classroom organisation and management[58]. In a survey of enclosed primary classrooms[153], the most common classroom strategy reported by teachers to combat external noise was raising the voice (33%), followed by specific non-verbal attention gaining strategies (22%). Similar data for open plan classrooms is currently not known.

4.7 Conclusions

The literature provides evidence that noise (arising from both environmental sources and typical classroom noise) has a significant deleterious effect on the learning process. Noise has been cited as one of the most undesirable aspects of open plan schools, however a comparison of the occupied noise data from the literature suggests that overall average measured noise levels in open plan classrooms are similar to those occurring during active periods in modern enclosed classrooms.

If it concluded that the fluctuation of noise level is likely to be more important to avoid distraction in open plan classbases, and criteria to control this can be expressed in percentile intrusive noise levels.

The intrusive noise level arising from adjacent activities (with the main classbase quiet or unoccupied), is the most important consideration in terms of speech intelligibility within open plan classbases. A maximum recommended intrusive noise level of 60-65 dB L_{Aeq} is assumed from the literature. Minimum noise criteria (≥ 40 dB L_{Aeq} recommended) to provide sufficient masking of speech from adjacent classbases also needs to be considered.

In order to achieve sufficient attenuation between classbases (15-20 dB recommended), some form of partitioning (semi-open plan arrangement) is necessary in practice. In addition to semi open partitioning, the most effective noise control methods include provision of a limited height acoustically absorbent ceiling, arranging the classbases to maximise attenuation (linear arrangement), controlling occupant density (or the amount of open space), and effective classroom management.

This Chapter has explored the effect of noise on classroom users, noise criteria, and noise control methods. Noise levels also significantly affect speech intelligibility within the classroom, and speech privacy between classrooms. A discussion of this aspect of classroom noise is included in the next chapter.

Chapter 5: Speech communication

5.1 Introduction

Speech intelligibility within a classroom depends on the following factors:

- Speech characteristics/talker proficiency
- Listener proficiency and absence of any hearing loss
- Noise
- Room acoustics

Each factor is discussed in turn in the following sections. In open plan classrooms it is also necessary to consider the speech privacy between classbases, (the extent to which instructional speech from adjacent classrooms can be understood by participants in the main classbase). ‘Privacy’ means that speech from another space cannot be understood, although it may be audible.

Objective intelligibility testing of natural speech in rooms may be either:

- Directly subject based (panel of listeners identify speech material presented into the room by human speaker or broadcast through a loudspeaker)
- Indirectly acoustic based (measuring acoustic parameters that correlate well with subject based speech intelligibility scores)[154].

Subjective rating methods are also used as a tool ‘to enable a general view of the listening situation’[154]. This approach is considered separately in Chapter 9.

In order to be repeatable and reliable, subjective based intelligibility tests for children in classrooms require a large sample of appropriate subjects, age-appropriate selection of word stimuli and test method (for example, graphically illustrated rather than written words) and careful planning to ensure that the tests are not influenced by other factors (such as fatigue and order of presentation). For this reason they are generally time consuming and expensive to carry out in real classrooms.

Acoustic based speech intelligibility parameters have been standardised[155-158] and mandatory criteria are set out in current UK design standards for open plan schools[1].

Therefore this type of testing is becoming more widely used by practitioners in the field. This study focuses on relevant acoustic based speech intelligibility parameters, which are discussed in the following sections.

5.2 Speech spectrum and talker proficiency

Talker proficiency depends on training and the ability to articulate correctly[159]. The speech signal is usually delivered by the teacher, who would attempt to deliver the spoken signal adequately. During discussion work, children's voices (which differ considerably in terms of articulation and vocal effort) also contribute as the speech signal. Techniques such as repeating a child's answer for the benefit of the rest of the class are commonly used to manage this issue. Therefore, teacher-to-student communication is considered to be the most critical aspect of speech communication in classrooms.

For objective speech intelligibility measurements and calculations, standardised speech characteristics are normally used, and it is assumed that talker proficiency is 100%. However there is a wide variation in teachers' voice characteristics such as speech spectrum, level and directivity pattern, as discussed below.

In open plan classrooms there is an optimum balance to be achieved between providing adequate speech signal level to listeners within the classbase, without producing unwanted vocal strain, and controlling the speech signal to maintain speech privacy between classbases. Classroom management techniques, such as roaming tactics[160] and gathering the class closely together on the carpet[6, 57, 62, 131], are commonly used to ameliorate this problem in primary classrooms. Again it should be noted that roaming tactics are preferable for individual or small group instruction rather than whole class teaching, to avoid teacher-to-student communication when the teacher's face cannot be seen.

Early measurements of long-term average speech spectra were measured at 1 m from the talker for different talkers (males, females and children), for different vocal efforts in quiet anechoic laboratory conditions[2-4]. This research has been developed into the standardised octave band sound pressure levels for various vocal efforts at 1 m in front of the speaker's lips in the free field, as defined in ANSI 3.5:1997[161], shown in Table 5.1.

The scope of ANSI 3.5 is limited to natural speech in quiet conditions, averaged across a group of talkers and a group of listeners of both genders. BS EN 60268-16[162] defines spectrum shapes (relative to the overall dB(A) level) for male and female talkers for use when a particular gender needs to be assessed.

Table 5.1: Standardised sound pressure levels for vocal effort[158]

Vocal effort	SPL (dB) at 1 m for octave band centre frequency (Hz)							Overall dB(A)
	125	250	500	1k	2k	4k	8k	
Normal	51.2	57.2	59.8	53.5	48.8	43.8	38.6	59.5
Raised	55.5	61.5	65.6	62.3	56.8	51.3	42.6	66.5
Loud	58.0	64.0	70.3	70.6	65.5	59.9	48.9	73.7
Shout	59.0	65.0	74.7	79.8	75.8	68.9	58.2	82.3

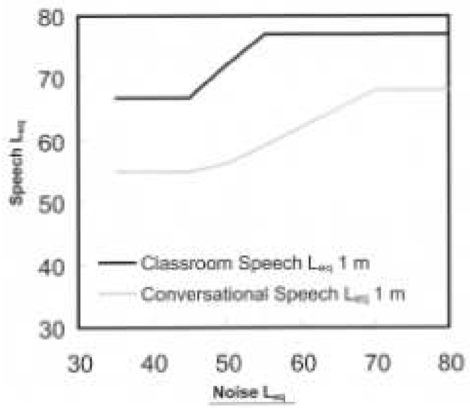
The precise vocal effort used depends on the talker and the type of communication situation. Setting the speech spectrum to an absolute level relative to quiet conditions does not account for the Lombard Reflex[163] (the observed effect of people subconsciously raising their speech levels in increasing levels of background noise).

Previous research into teachers' voice levels in classroom noise show that it is 'neither natural nor expected for teachers conversing in noise levels above 50 dB(A) to use a 'normal' voice effort'[164]. For critical communication situations (eg classrooms), the measured Lombard effect ranges from 0.4 - 0.8 dB per dB increase in noise[4,9-12].

BB93[1] states that the average sound pressure levels defined in ANSI 3.5[161] for raised voice effort (66.5 dB(A)) should be assumed for teacher-to-student communication, for both male and female talkers.

Measured data for teachers' average long term speech levels (L_{Aeq} at 1 m) range from 65 dB(A) in secondary schools[165] to 65-72 dB(A) in primary schools[131, 166, 167]. This research is consistent with Nelson's illustration of typical speech levels in classrooms, (Figure 5.1)[160]. Whilst standardised speech levels for 'raised' vocal effort (67 dB(A)) may be appropriate for teachers in noise levels of up to 45 dB(A), the Lombard effect is clearly observable between 45 - 55 dB(A), which is consistent with other studies[4,13-15].

Figure 5.1: Levels of speech in classroom vs. conversational environments[160]



Nevertheless, it is important to protect teachers against the risk of vocal strain for extended periods, resulting in vocal fatigue and voice disorders, a recognised occupational hazard amongst the teaching profession[126, 168-171]. A large scale study of 1243 teachers and 1288 non-teachers in the US[170] showed that a significantly greater proportion of teachers (11%) reported voice problems compared to non-teachers (6%), and the prevalence of problems increases with age, with women being more susceptible to voice problems than men[172]. A detailed literature review revealed that comparable data are not available for the UK[171].

In order to evaluate the quality of speech 'communicability', ISO 9921[156] provides a subjective assessment for various vocal effort ($L_{S, A, 1 m}$) shown in Table 5.2.

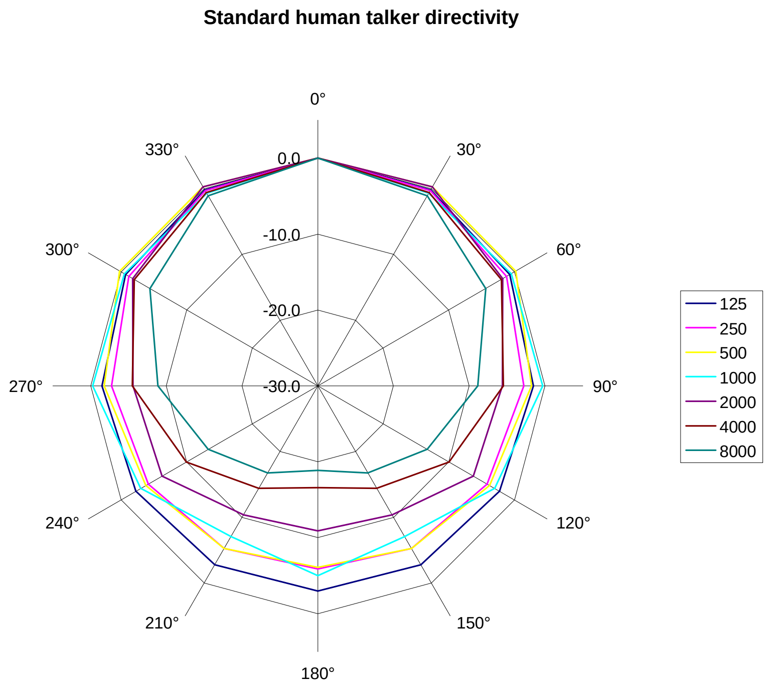
Table 5.2: ISO 9921[156] assessment of speech communicability

Vocal effort	$L_{S, A, 1 m}$ (dB)	ISO 9921-1 communicability assessment
Maximum shout	90	Insufficient
Shout	84	Unsatisfactory
Very loud	78	Sufficient
Loud	72	Satisfactory
Raised	66	Good
Normal	60	Very good
Relaxed	54	Excellent

A raised vocal effort of 66 dB(A) is considered to be ‘Good’. Other studies[126] recommend a vocal effort of 60 dB(A) at 2 m in classrooms for ‘acceptable’ conditions. This is consistent with around 66 dB(A) at 1 m, if the decrease in speech level is assumed to be 6 dB per doubling of distance (valid for indoor classroom conditions up to 8 m according to BS EN ISO 9921[156]). In view of this, a standardised ‘raised’ vocal effort is an appropriate compromise between achieving the necessary voice level required for speech intelligibility and minimising the risk to teacher’s health, and is deemed acceptable for teacher-to-student critical listening with the main classbase quiet and listening to the teacher[1].

The directivity of human speech is also important in simulating or predicting the generated sound fields around human talkers. Comprehensive and detailed measurements of the horizontal and vertical sound fields around 40 adult talkers were measured in anechoic conditions by Chu and Warnock[173]. The directivities are similar for both normal and loud voice levels, and between male and female voices. The measured directivity levels averaged over all subjects at each octave band frequency are shown in Figure 5.2.

Figure 5.2: Measured directivity levels (dB) of average human talker[173]



5.3 Speech recognition by vulnerable listeners

Typically the speech recognition ability of listeners in the classroom depends on hearing ability, age and linguistic experience. For objective speech intelligibility measurements and calculations, listener proficiency is typically assumed to be 100%. It is possible to account for individual differences in listener proficiency by applying corrections to the calculated result. In classroom design it is necessary to consider a minimum criterion for objective speech intelligibility to accommodate the expected range of listening proficiency.

It has been shown that children (particularly in primary school years[126, 174-176]) are more susceptible to poor acoustic conditions than adults. Spoken word recognition in noise and reverberation appears to improve with increasing age as language develops[1,9,19,21,23-25,176], and does not reach an adult level until around 13-15 years in either noisy or reverberant conditions[1,9,22,26,177], and until the late teenage years in combined reverberation and noise[22,178, 179].

Other types of learners who are particularly vulnerable to the effects of noise on speech perception include children who are hearing impaired[104, 180], children with English as an additional language (EAL)[25, 27, 160, 177, 181, 182], children with Autistic Spectrum Disorders[183] (ASD), children with language, learning and reading disorders[3,31-33184, 185], and also children with mild hearing loss[160] and middle ear problems[186].

5.4 Noise

The degree to which noise masks the speech signal depends on:

- Intensity of the masking noise relative to that of the speech signal
- Spectral characteristics of the speech signal and the noise
- Temporal fluctuations in the noise level relative to the speech signal

Noise from irrelevant speech is particularly detrimental to reception of the target speech signal because the signal and the noise share similar spectral characteristics and temporal variations. As discussed in Chapter 4, it is necessary to consider the intrusive noise level to assess speech intelligibility in open plan classrooms accurately.

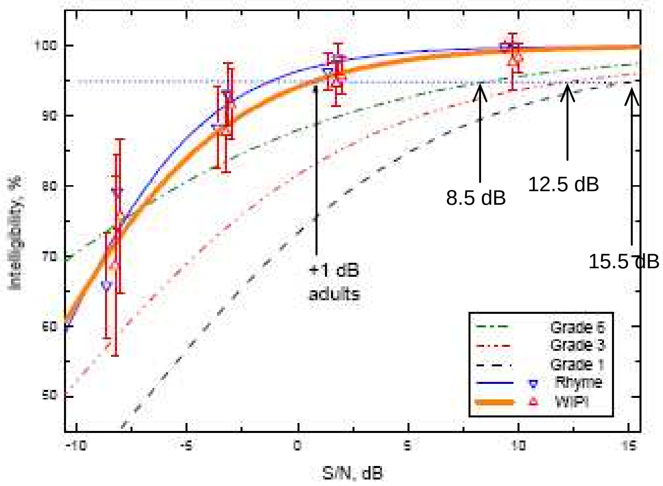
The relative intensity of the speech level to the noise level is quantified by the speech-to-noise ratio (SNR) in each frequency band. The importance of each frequency band's contribution to intelligibility needs to be considered. Various objective parameters commonly used to describe speech intelligibility, such as Articulation Index (AI) and Speech Intelligibility Index (SII) are based on this concept. It is generally agreed that, provided reverberation time is reasonably well controlled, speech-to-noise ratio has a greater effect on intelligibility[187], although it is also necessary to consider the effect of reverberation and room acoustics to fully describe the speech intelligibility in a room.

It has been shown that adult listeners are able to 'glimpse' speech cues in quieter sections of temporally fluctuating, interrupted noise, resulting in a perceptual advantage known as a 'release of masking'[188]. However Stuart[189] showed that children did not experience an equivalent perceptual advantage to that of adults at poorer signal-to-noise ratios. Furthermore, the release of masking effect disappears as the number of interfering talkers increases. Whilst a single competing talker provides around 6-8 dB less masking than stationary noise at equivalent SNR[190, 191], for a large number of talkers (for example classroom babble), a reduction in speech intelligibility is observed that is comparable to continuous broadband noise, and the interfering noise can be characterised by the long term average speech spectrum[192, 193]. The long term variation in noise level with changing classroom activity does however need to be considered.

Picard and Bradley's review indicated that typical speech-to-noise ratios in classrooms ranged from +3 dB to +7 dB[126]. Lower SNRs of around -5 dB were achieved for the lower years, and activities involving chatter and other speech like noises of the children[126]. However the measurement method varied considerably between studies, therefore it is not difficult to draw any firm conclusions from this. Sato and Bradley's more recent study[131] of 27 elementary classrooms using a consistent and sophisticated measurement method (see Section 5.7.1) found that A-weighted speech-to-noise ratios varied from 3-16 dB, with a mean of 11 dB, for enclosed classrooms. The measurements were calculated for classroom activities typically involving children listening to their teacher talking.

Normal-hearing young adults have been shown to understand familiar spoken material presented in speech-to-noise ratios of around 0 dB[158, 193-196]. However children's speech perception does not become adult-like until approximately fifteen years of age[177]. Blandy and Lutman[179] observed that speech recognition in noise was significantly worse for seven year olds than for otologically normal adults, despite the younger group having significantly better hearing threshold levels. Several studies have shown that speech recognition in noise improves systematically with age. The results of Bradley and Sato's[176, 195] experimental study of children speech intelligibility scores in real classrooms with relatively low reverberation times (average unoccupied RT = 0.45 seconds) is shown in Figure 5.3. Nominally grade 6 ≈ 11 year olds; grade 3 ≈ 8 year olds; grade 1 ≈ 6 year olds. The average results of the study indicate that between 8 dB to 15 dB SNR is required for young children to obtain intelligibility scores equivalent to those of young adults, depending on age, with younger listeners requiring significantly higher speech-to-noise ratios to achieve equivalent intelligibility scores.

Figure 5.3: Bradley and Sato's results of speech intelligibility vs. age[176, 195]



Several studies have shown that adult native listeners outperform adult non-native listeners in speech intelligibility tests in noise[190, 197], with an average improvement in SNR of +7 dB necessary for adults unfamiliar with the instructional language to gain equivalent scores to adult native listeners[126, 160, 181, 197, 198]. Non-native children are identified as being at 'double jeopardy' to the effect of classroom noise[177], given the underdeveloped auditory processing system of younger listeners. A recent study showed that noise had a detrimental effect on word intelligibility scores for both native and non-native listeners, with noise having a significantly greater detrimental impact on performance for the non-native listeners[177]. The study implies that at SNRs of less than 10 dB, speech identification becomes significantly more difficult for typically developing EAL learners than for their native monolingual peers[177].

For children with mild hearing loss, +12 dB SNR has been recommended in the literature[160].

5.5 Reverberation and room acoustics

The reflected component of sound in a classroom affects speech intelligibility differently depending on the time the reflections arrive at the listener's ear. Useful early reflections (arriving within 50 ms of the direct sound) integrate with the direct sound to reinforce the speech signal which improves SNR and intelligibility, and eases vocal effort. This is known as the Haas effect[199].

Late reflections (arriving after 50 ms of the direct sound) contribute to the reverberant component of the sound to prolong the spectral energy of the vowel sounds, causing a blurring of succeeding consonants (and even entire words) which reduces intelligibility of the speech signal[200]. The reverberant component in a room is generally characterised by the reverberation time, T_{60}. Increased late reflections (and hence longer reverberation times) also increase the reverberant noise level in a room, and fill in the temporal gaps in the noise, thus decreasing the effective speech-to-noise ratio and hence speech intelligibility. The effect of reverberation time on the reverberant component of the noise level is particularly pertinent to open plan classrooms, where it is important to control the intrusive noise level from adjacent classbases.

However very short reverberation times reduce the overall reverberant speech signal level and the audibility of consonant sounds, due to an absence of eary reflections to support signal strength[126]. It is therefore important to achieve an optimum reverberation time in classrooms to balance the effects that reverberation has on both the speech signal and interfering noise.

5.6 Speech privacy between classbases

It is not usually necessary to ensure that speech privacy is maintained in classroom situations, in order to maintain confidentiality, as for in some office situations. However it is nonetheless commonly used in open plan design to describe the extent to which the transmitted speech source in the main space is masked by the background noise in the receiving position, that is, how intelligible speech arriving from adjacent spaces will be. This measure is ultimately linked to how distracting the intrusive speech will be[201], as discussed in section 5.8.3.

It is useful to consider this measure between open plan classbases (in addition to speech intelligibility within classbases) in order to ascertain, for example, whether when two adjacent classes are engaged in whole class teaching, irrelevant speech from adjacent teachers' voices will become intelligible and hence confusing and distracting.

Speech privacy depends on a combination of the sound attenuation achieved between spaces (see Section 4.3), and the continuous background (masking) noise in the receiving space.

Sound attenuation between two spaces is commonly measured by the sound level difference, D, in each octave bands as described in BS EN ISO 140-4[202]. These are normally represented by a single figure rating, the standardised weighted level difference, D_w, as defined in BS EN ISO 717-7[203]. Although background noise levels in open plan classrooms arise from a number of sources including the occupants themselves, classroom activity noise tends to vary throughout the day and is not a reliable source of continuous masking noise in respect of speech privacy. Therefore the ambient noise level (arising from external sources and building services) is more commonly used as a minimum continuous noise level in speech privacy calculations.

5.7 Objective speech intelligibility parameters

A number of objective acoustic parameters exist to describe speech intelligibility. These vary in measurement and calculation complexity, and correlate with differing degrees of accuracy to subject based intelligibility tests. More complex parameters have recently been standardised[155, 156] following advances in instrumentation and computational power.

It should be noted that initial validation studies of acoustic based parameters were generally carried out using adult subjects. Validation studies with children in classrooms have mainly concentrated on children aged 8 years and over[130, 136, 156], and less is known about their ability to predict the acoustic quality of classrooms as perceived by younger children (see Section 5.4 for suggested required improvements in speech-to-noise ratio for younger and vulnerable listeners in classrooms).

5.7.1 Speech-to-noise ratios

Simple speech-to-noise ratio parameters may be calculated by the difference between the measured speech level and noise level at the receiver position. It should be noted that these do not take into account the effect of reverberation and room acoustics.

Teachers' speech levels recorded in a natural classroom situation generally include contributions from the classroom activity noise levels which may lead to an overestimation of the speech-to-noise ratio. Hodgson[204] has proposed a more sophisticated measurement method which extracts separate statistical distributions of speech and noise from the overall measured distribution of occupied classroom noise. Whilst this is a useful technique for enclosed classrooms, it has not proved successful in open plan classrooms where unwanted speech sounds cannot be separated from the speech signal due to poor isolation between adjacent classbases[131, 167].

For this reason it is usually more common to consider the measured speech level from a standardised generated test signal level, L_S, and measured samples of the noise level L_N (for various classroom activities), at the receiver position (listener's ear). The equivalent continuous sound pressure level, L_{eq} is commonly used to measure these parameters, over a suitable time period[162].

Three different speech-to-noise parameters are considered as part of this study; S/N(A), S/N_w and SIL as discussed below.

The A-weighted speech-to-noise ratio, S/N(A), defined as the difference between the overall A-weighted speech level ($L_{S,A,L}$) and the overall A-weighted noise level (L_{AN}), has been shown to predict subjective intelligibility scores with similar accuracy to more complex parameters[130].

The weighted speech-to-noise ratio, S/N_w, is calculated from the measured octave band L_{eq} values by weighting the linear speech-to-noise ratio in each octave band according to the band's contribution to speech intelligibility, w_k, (after Steeneken and Houtgast[205]) as shown in Table 5.3, to obtain a single figure value.

Table 5.3: Weighting network for S/N_w

Octave band centre frequency (Hz)	125	250	500	1k	2k	4k	8k
w_k	0.13	0.14	0.11	0.12	0.19	0.17	0.14

The speech interference level (SIL) is a simple method to assess speech intelligibility in a direct communication situation in noise, based on the concept originally proposed by Beranek[206] and developed by Lazarus[207, 208], and standardised in ISO 9921-1 (1996)[209] and ISO 9921 (2003)[156]. The SIL is determined by the difference between the overall A-weighted speech signal level ($L_{S,A,L}$) and the 'speech interference level of noise' (L_{SIL}), at the listener's position. L_{SIL} is defined as the arithmetic average of the noise levels in the 500, 1k, 2k and 4k Hz octave bands under typical conditions.

5.7.2 Articulation Index (AI) and Speech Intelligibility Index (SII)

Articulation Index (AI), as defined in ANSI standard 3.5 1969[157, 210], was first outlined as a measurement method by French and Steinberg[211] in 1947 and was developed into a calculation procedure by Kryter[212, 213] in the 1960s. AI was the most powerful tool available for predicting speech intelligibility and/or speech privacy during this time. It is essentially based on the available speech-to-noise ratio at the listener's ear as measured in octave or third octave bands (other band measurement schemes are also described), with the SNR in each band weighted according to the different contributions of each frequency band to intelligibility. A single figure rating is obtained between 0 and 1, with AI=1 indicating perfect intelligibility.

A major revision to the original ANSI 3.5 standard[210] in 1997[203] now defines an alternative objective calculation parameter, the Speech Intelligibility Index (SII). The calculation procedure for this parameter was developed from the AI concept to determine the proportion of the total number of speech cues available to the listener in order to rate the speech intelligibility of a natural communication system. SII values are typically around 0.05 larger than corresponding AI values[201].

Speech privacy, P, may be thought of as the inverse of the intelligibility index, that is, P = 1 – AI or 1 – SII. Analogous to this is that speech privacy increases as AI or SII tends to zero, and therefore AI or SII is commonly used to describe Speech Privacy, with SII (or AI) = 0 indicating perfect speech privacy.

It should be noted that neither of the parameters account for the effects of time-domain distortions such as reverberation and echoes, and for this reason, STI is more commonly used to describe intelligibility within a room (see below).

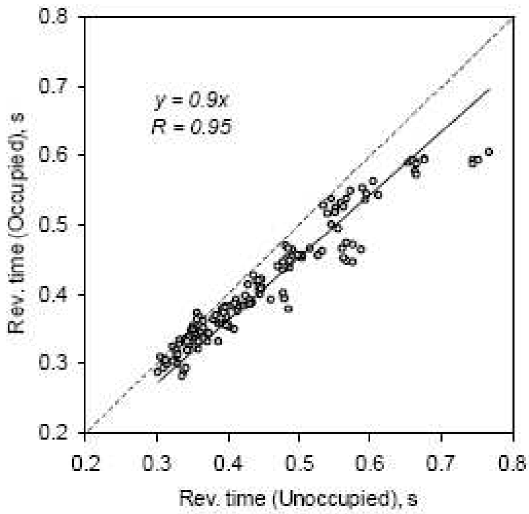
5.7.3 Reverberation time and early decay time

Reverberation time needs to be considered in combination with speech-to-noise parameters in order to describe the speech intelligibility in a room. Reverberation time (T) is defined as the time required for the sound pressure in a room to decay by 60 dB, at a rate of decay given by the slope of the integrated impulse response curve, from 5 dB below the maximum initial level to either 35 dB below (T_{30}), or 25 dB below (T_{20}). During measurements it is important to note whether the room is occupied or unoccupied, and furnished or unfurnished, as these factors have a significant effect on measured reverberation time.

The Early Decay Time (EDT, also known as T_{10}) is based on the initial 10 dB of the decay and is more closely related to the subjective reverberance of the room[130,214]. Bradley[130] found that for typical classrooms, measured EDT and T_{30} values were very similar except at low frequencies (which has less influence on speech intelligibility for normal hearing listeners). Therefore reverberation time standards for classrooms are generally expressed by conventional T_{30} parameters.

Bradley[131, 215] compared measured occupied and unoccupied reverberation time in 43 elementary classrooms and found that RT decreased when occupied as shown in Figure 5.4. Similar results were found for EDT. Bradley suggested a decrease in RT of approximately 10% when occupied as indicated by the linear relationship. This relationship is consistent with studies which measured reverberation time in open plan classrooms[138, 139]. However closer inspection of Figure 5.4 also reveals that a non-linear relationship is evident after 0.6 seconds, suggesting that the absorption due to occupants may help to control RT more effectively after this point.

Figure 5.4: Bradley's measured occupied vs. unoccupied RT in classrooms[176]



5.7.4 Balance between early and late arriving energy

Early-to-late energy ratios are based on squared impulse responses to examine the proportion of early, useful arriving energy (arriving within 50 ms of the direct sound for speech purposes), to either the late detrimental energy arriving after 50 ms of the direct sound (C_{50}), or total arriving energy (D_{50}). Whilst these are referenced in ISO 3382[214] as parameters which correlate with subjective aspects of auditorium acoustics and other reverberant environments, no standardised rating scale is given.

Furthermore these methods do not take into account signal-to-noise ratio and therefore cannot be used as sole descriptors of speech intelligibility in classrooms. C_{50} is related to D_{50} by Equation 1.

Equation 1: Relationship between C_{50} and D_{50}

$C_{50} = 10 \log [D_{50} /(1- D_{50})]$ dB

Bradley[130] defined a Useful-to-Detrimental ratio (U) which combined the early-to-late sound energy ratio with the signal to noise ratio. An early time limit of 50 milliseconds (U_{50}) was found to be most accurate in predicting subject-based intelligibility scores in typical classrooms[130], with a U_{50} value of +1.0 dB corresponding to 100% intelligibility. U_{50} values have been found to have equivalent prediction accuracy to STI[130]. However STI is a standardised measurement parameter[162] and is used in construction standards and guidelines for schools[1, 216] (see Chapter 6), and has therefore been more widely adopted.

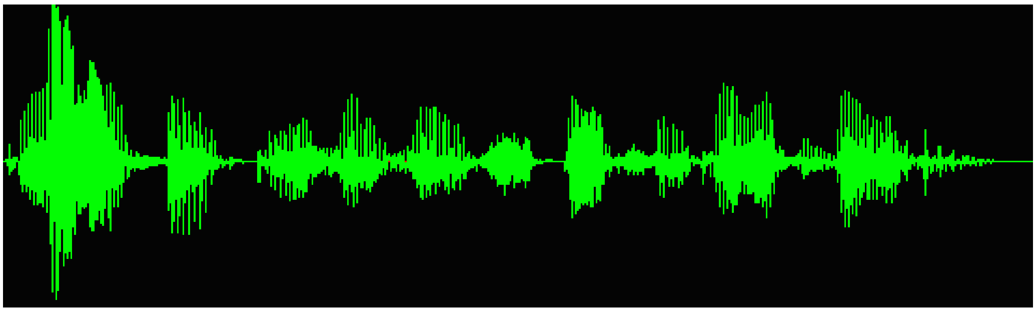
5.7.5 Speech Transmission Index (STI)

STI accounts for the reverberation in a room as well as the speech-to-noise ratio. The technique allows the parameter to be measured directly as well as calculated/predicted (although ANSI 3.5:1997[161] describes a method of measuring SII based on the modulation transfer function, it is not widely used[217]).

Developments in measurement method and instrumentation have allowed the STI technique to become more widely adopted[154], and over the past 10-15 years, it has become 'the *de facto* standard for measuring the intelligibility of public address and other related voice communication systems'[154]. STI is based on the modulation transfer function concept, m(*F*) originally developed by Steeneken and Houtgast[205]. STI theory is discussed below.

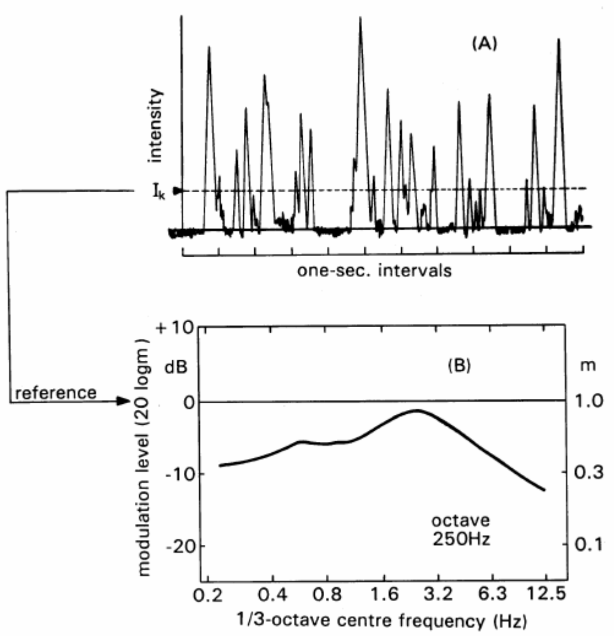
Speech syllables consist of bursts of sound energy, corresponding to an amplitude modulated signal, with gaps between bursts being 'the key to comprehension'[218]. An example waveform for speech in anechoic, quiet conditions (that is, without degradation of the signal due to noise or reverberation) is shown in Figure 5.5, which demonstrates an amplitude modulated type signal.

Figure 5.5: Typical speech signal in anechoic conditions



Such signals are more conveniently represented as an intensity signal (the squared amplitude signal), given as an intensity envelope and shown in the upper graph (A) in Figure 5.6 for speech in more realistic (reverberant) conditions. Both noise and reverberation act to fill the gaps between speech bursts, leading to a reduction in intelligibility. Intelligibility is affected by slow intensity fluctuations (1 - 15 Hz) which occur as a result of geometric transformation patterns of the vocal tract[217]. The equivalent signal is shown in the frequency domain in the lower graph (B) in Figure 5.6, relative to the mean intensity of the signal, known as the envelope spectrum.

Figure 5.6: Example intensity envelope of speech (after Wijngaarden[217])



Noise and reverberation affect only the depth of the modulation without changing its shape. Loss at any of the modulation frequencies implies loss of information[217]. The modulation transfer function, *m(F)* is expressed as the ratio of the envelope spectrum of the signal at the output of the system (m_0) to the envelope spectrum at the input (m_i)[162] as illustrated in Figure 5.7. If the two envelope spectra are the same, then *m(F)* = 1 and no signal degradation has occured[217]. However the smaller the *m*(F) becomes, the more the signal has been distorted by effects such as echoes, reverberation and noise.

The modulation transfer function, m(*F*), is obtained for 14 different modulation frequencies (k) between 0.63 Hz and 12.5 Hz, and, because different frequency bands contribute differently to overall intelligibility, for seven octave bands (f) from 125 Hz to 8 kHz, to form a matrix of 98 m(*F*) values, $m_{k,f}$ shown in Table 5.4.

Figure 5.7: Illustration of m(*F*) concept (for single octave band)[155]

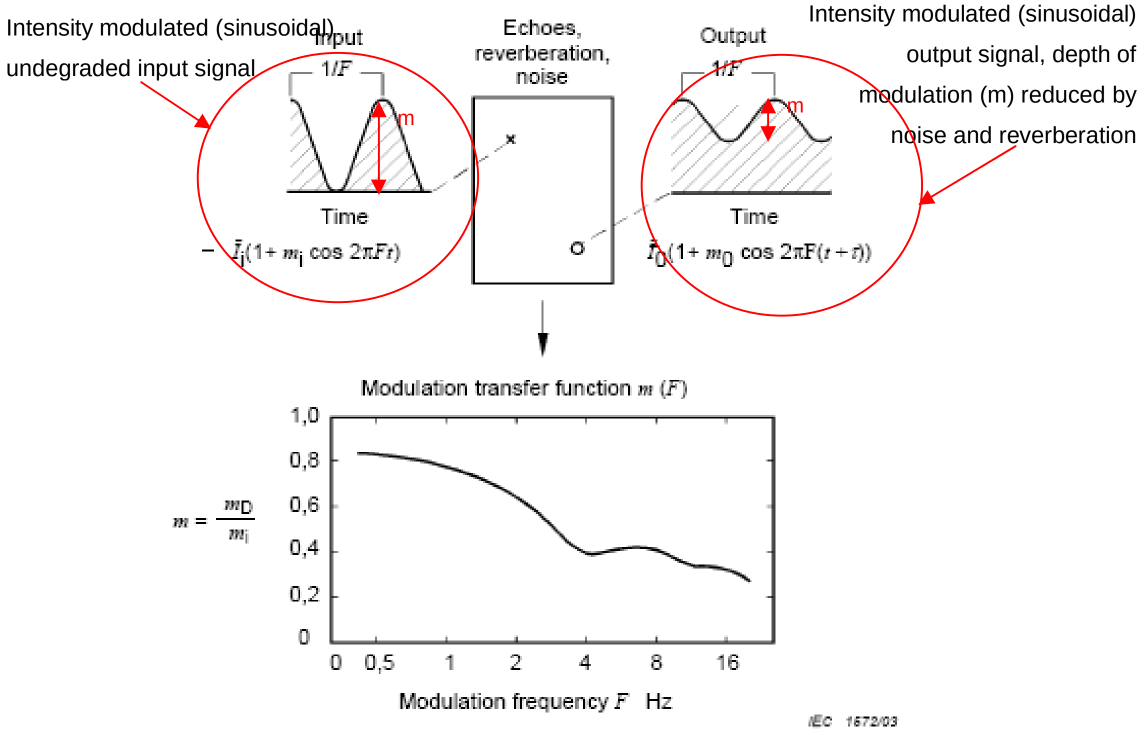
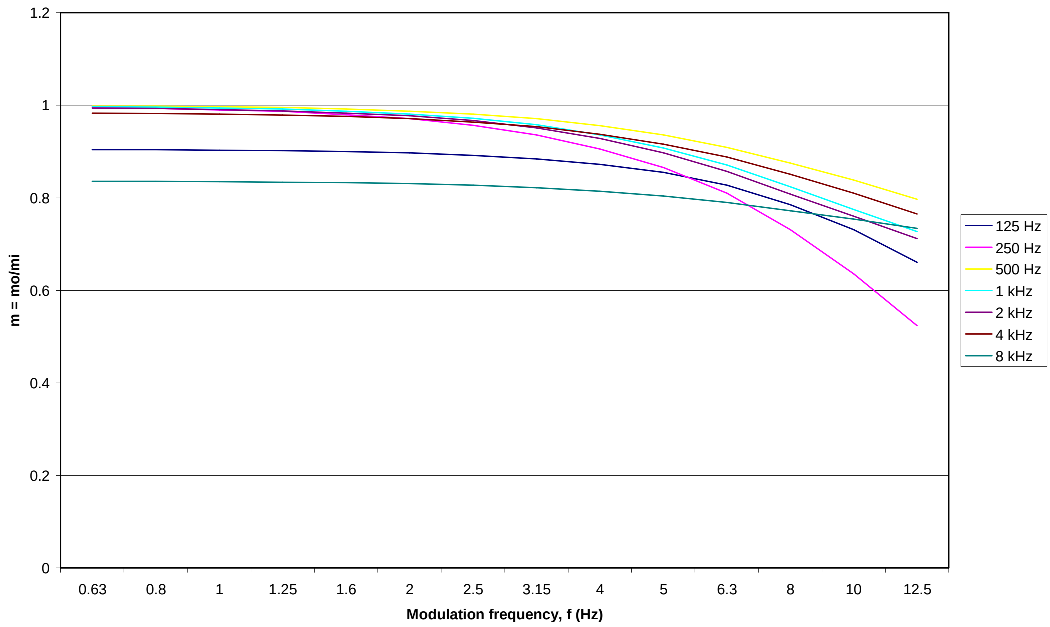


Table 5.4: m(*F*) matrix for derivation of STI

	Octave band frequency, k (Hz)						
Modulation frequency, f (Hz)	125	250	500	1k	2k	4k	8k
0.63	$m_{k,f}$						
0.80							
1.00							
1.25							
1.60							
2.00							
2.50							
3.15							
4.00							
5.00							
6.30							
8.00							
10.0							
12.5							

As a rule, the m(F) values within each octave band decrease with increasing modulation frequency. Constant or slightly reducing values with modulation frequency indicate that noise is the main effect. This is because speech-to-noise ratio is independent of modulation frequency[162]. The example m(F) matrix in Figure 5.8 was measured in a classroom with short, controlled reverberation times (mid frequency reverberation time, T_{mf} = 0.3 seconds), where in general m(F) values reduce only slightly with modulation frequency (at modulation frequencies of 5 Hz and above), and hence noise is the dominant effect. It is also apparent from this example that the signal is most affected by noise at the extreme ends of the frequency range (125 Hz and 8 kHz).

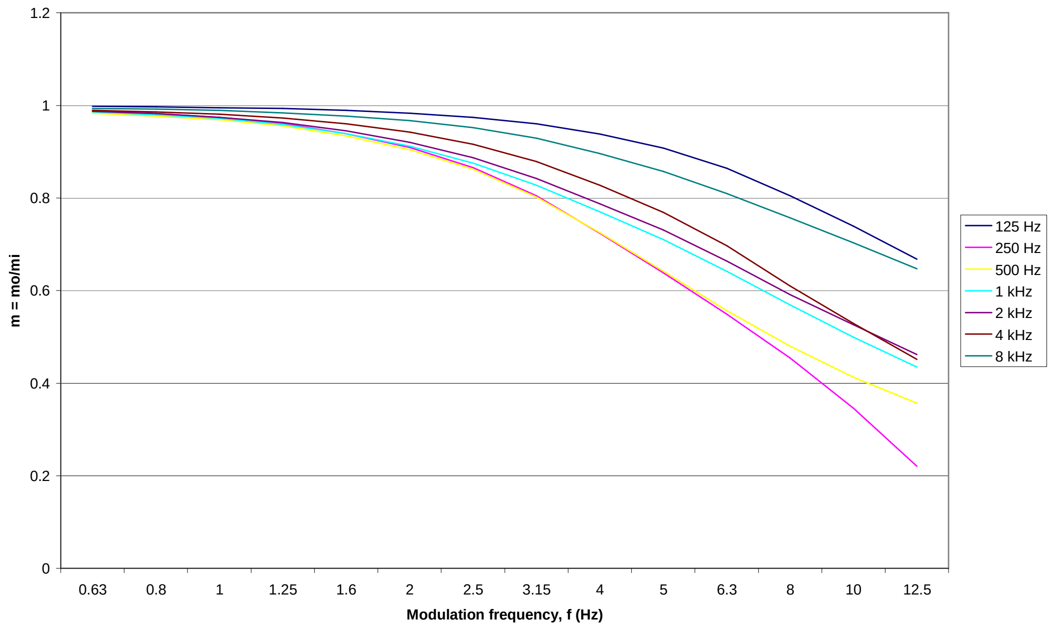
Figure 5.8: Example m(F) for School 10 (T_{mf} = 0.3 seconds)



Larger reductions in m(F) with increasing modulation frequency indicate that reverberation is the main effect. This is due to the faster fluctuations being more relatively affected by reverberation[162]. The example m(F) matrix in Figure 5.9 was measured in a classroom with comparatively longer reverberation times than for the classroom in Figure 5.8 above (mid frequency reverberation time, T_{mf} = 0.6 seconds). Here, it is apparent that the m(F) reduction is greater at modulation frequencies of 2 Hz upwards, and therefore reverberation appears to have a more significant effect than speech-to-noise ratio.

Strong reflections are indicated by large reductions that first reduce and then increase with modulation frequency[162].

Figure 5.9: Example m(F) for School 2 (T_{mf} = 0.6 seconds)



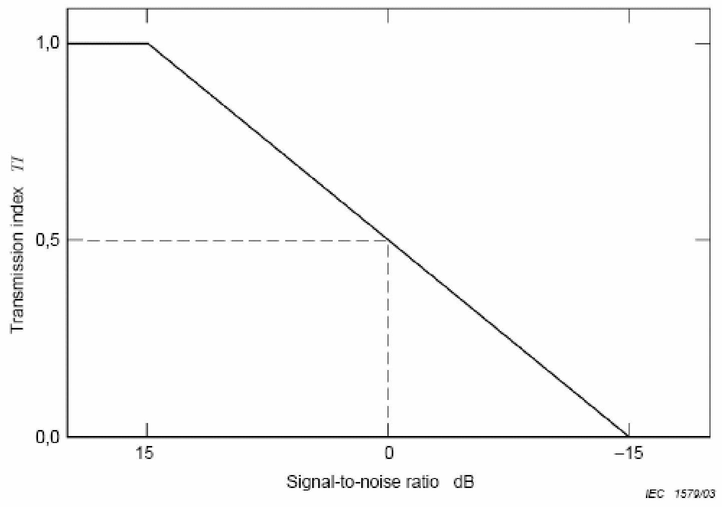
Each m(*F*) value is interpreted in terms of an 'apparent signal-to-noise ratio'[162], $SNR_{m,k}$, given by Equation 2, which is irrespective of the actual sources of disturbance (reverberation and/or noise).

Equation 2: Apparent signal-to-noise ratio

$$SNR_{m,k} = 10\log\left(\frac{m(F)}{1-m(F)}\right)$$

The Transmission Index, TI, is obtained by averaging the $SNR_{m,k}$ values in each octave band, k (that is, each modulation frequency is given equal weighting). In theory the apparent SNR within the range -15 dB to +15 dB is linearly related to the TI, as shown in Figure 5.10[162]. Apparent speech-to-noise ratios outside the range ±15 dB are truncated to 1 or 0 as appropriate, forming a plateau in TI, owing to the compression of the human hearing mechanism. Each TI value is normalised and weighted according to the contribution to speech intelligibility of each octave frequency band, k, as given in Table 5.3, to achieve STI, a dimensionless quantity between 0 and 1.

Figure 5.10: Theoretical relationship between TI and signal-to-noise ratio[162]



The method of calculation of the Speech Transmission Index is standardised in IEC 60268-16[162], which is currently being revised. Whilst there are some limitations to using STI for measurement of PA systems with electronic amplification (due to errors arising from irregular frequency response, equalisation, compression, and distortion), alternative techniques such as STIPa[162] have been specifically developed for this use. STI has been accepted as an accurate method for assessing the suitability of room acoustics for direct speech communication with no electronic amplification[217]. Although STI measurement methods are specified for monaural rather than binaural listening, which can cause an underestimation for certain situations (for example where the speech and noise arrive from different directions), the error becomes smaller as the overall level of intelligibility increases[154]. Additional weighting factors may also be incorporated which account for auditory masking and weighting for male and female speech, to obtain the revised speech transmission index, STI_r[162, 219, 220].

5.7.6 RASTI

The Room Acoustics Speech Transmission Index (RASTI)[162], formerly known as RApid Speech Transmission Index[162], is a simplified version of the STI method which uses only two octave bands (500 Hz and 2 KHz), and fewer modulation frequencies for analysis. The method is considered to be useful for most person-to-person communications in room acoustic applications, as it does not lead to significant error under high speech-to-noise ratios. However the method does not take account of irregularities in the long term average spectrum of the noise, generally resulting in a significant overestimation of the speech intelligibility in the presence of noise[154, 221].

5.8 How are the parameters related?

5.8.1 STI/SIL/SII scores for intelligibility

STI has been shown to correlate well with subject based measures of speech intelligibility for adult listeners with normal hearing[222,219, 223, 224]. A five point rating scale has been standardised to determine the quality of the communication situation (see Table 5.5)[155, 156]. The relationship between this rating scale and various objective intelligibility scores are also shown in Table 5.5.

Table 5.5: ISO 9921[156] intelligibility rating scale

Intelligibility rating	Sentence score	STI	SIL	SII
Excellent	100	> 0.75	21	-
Good	100	0.60 to 0.75	15 to 21	> 0.75
Fair	100	0.45 to 0.60	10 to 15	-
Poor	70-100	0.30 to 0.45	3 to 10	< 0.45
Bad	< 70	< 0.30	< 3	-

Corrections to the scale may be applied to account for the effect of the vocal effort of the speaker, accents and non-native speakers[156, 197, 217]. For example, for non-native speakers who are experienced, daily users of their second language, a minimum criterion of STI 0.86 is recommended in order to achieve 'good' equivalent speech intelligibility[197] (that is, equivalent to STI > 0.60 for a native, normal hearing adult listener).

Similarly, ISO 9921-1[209] gives an assessment of speech intelligibility against S/N(A) (based on monosyllabic word and sentence tests of adult listeners with normal hearing) as shown in Table 5.6. However this does not account for the effect of room acoustics, for example the assessment would only be appropriate for spaces with relatively short reverberation times. It would not be appropriate to apply this assessment to young children or other vulnerable listeners.

Table 5.6: ISO 9921-1[209] assessment of speech intelligibility and S/N(A)

S/N(A) at listener's position (dB)	Assessment
< -6	Insufficient
-6 to -3	Unsatisfactory
-3 to 0	Sufficient
0 to +6	Satisfactory
+6 to +12	Good
+12 to +18	Very Good
>18	Excellent

5.8.2 Reverberation time

Studies have found that speech intelligibility is not very sensitive to small deviations from optimum RT values[126]. Rather, a trade-off is observed between speech-to-noise ratio and reverberation time, with shorter reverberation times compensating for lower speech-to-noise ratios. This was illustrated theoretically by Houtgast[225] who depicted equal contours of STI for different combinations of reverberation time and speech-to-noise ratio shown in Figure 5.11. This was supported experimentally by Bradley[130] as shown in Figure 5.12.

Figure 5.11: Houtgast's theoretical equal contours of STI[225]

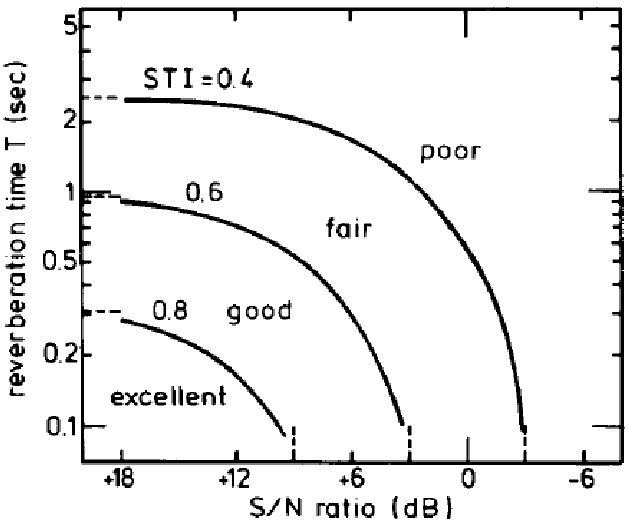
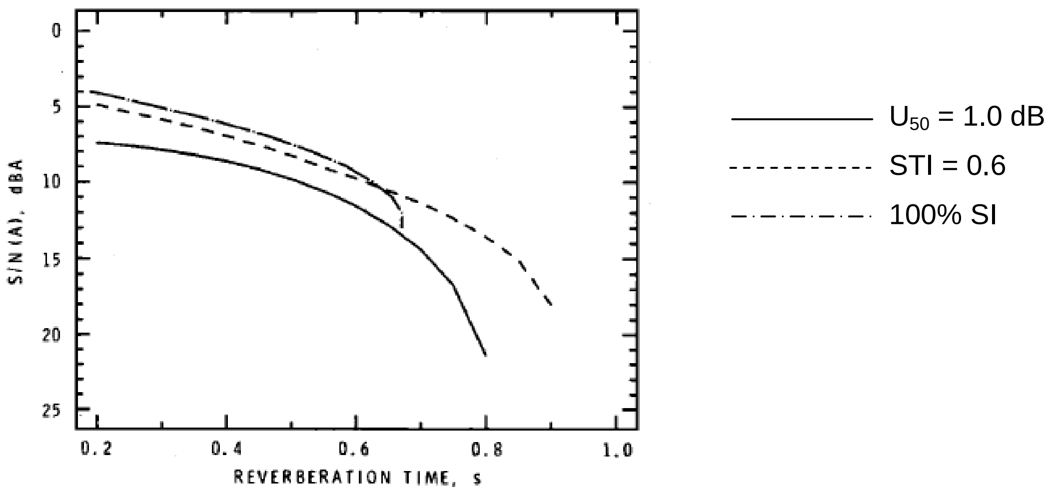
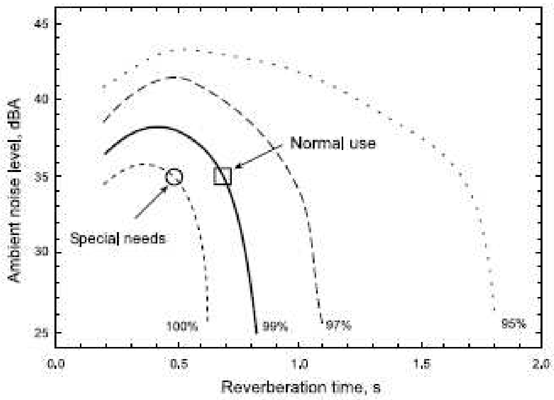


Figure 5.12: Bradley's experimental RT/SNR vs. equal SI contours[130]



Many studies found that speech intelligibility continuously improved as RT decreased to 0 seconds, that is, an optimum reverberation time of zero[124, 178, 226], as suggested by the curves in Figure 5.11 and Figure 5.12. However this does not account for the beneficial effect of early reflections in increasing the overall speech level in the direct field to improve speech intelligibility and ease vocal effort. Bradley's subsequent equal U_{50} curves (presented in Figure 5.13 as equivalent intelligibility scores) demonstrate that non-zero reverberation times are optimum for typical classrooms. Provision of strong beneficial early reflections leads to a non-zero optimum reverberation time[130].

Figure 5.13: Bradley's equal speech intelligibility contours for classrooms[194]



Alternatively, Hodgson and Nosal's study[227] also considered the analogous negative effect of reverberation on the total noise level and the distance between the listener, speaker and noise source. Non-zero optimum RTs were predicted when the listener was closer to the noise source, but zero optimum RTs were predicted when the listener was closer to the speech source[227]. This finding suggests that for open plan classrooms, where children are typically gathered around the teacher for critical listening and the main source of noise is intrusive adjacent classroom noise, optimum reverberation times may tend to zero.

EDT was found to be more closely related to STI and other similar parameters than conventional reverberation time, T_{30}[130, 187, 228, 229]. This finding has been incorporated into ISO 9921[156], which sets out a method for *predicting* the modulation transfer function, $m_{rev}(F)$, in the reverberant soundfield assuming exponential decay as shown in Equation 3.

Equation 3: Prediction of m(F) in reverberant field

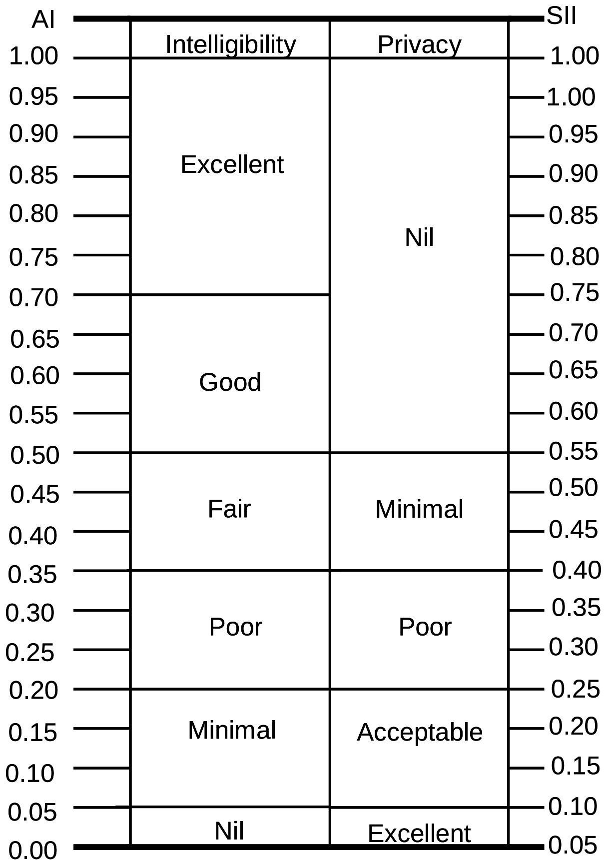
$$m_{\mathrm{rev}}(F) = \frac{1}{1 + 10^{-\mathrm{SNR}/10}} \cdot \frac{1}{\sqrt{1 + (2\pi F T/13.8)^2}}$$

where T is EDT rather than T_{30}. EDT was found to be a stronger determinant of STI than T_{30} in the author's study of a hospital school[230], where classbases were open to a very large public atrium with a coupled reverberation time. Even though very long T_{30} reverberation times were measured in the classbases (around 2.9 s due to the large volume and reflective surfaces in the atrium), the unoccupied STI in quiet was still in excess of 0.6 due to the short EDT (around 0.4 seconds due to localised absorption, furniture and fittings in the classbases).

5.8.3 SII and AI ratings for intelligibility/privacy

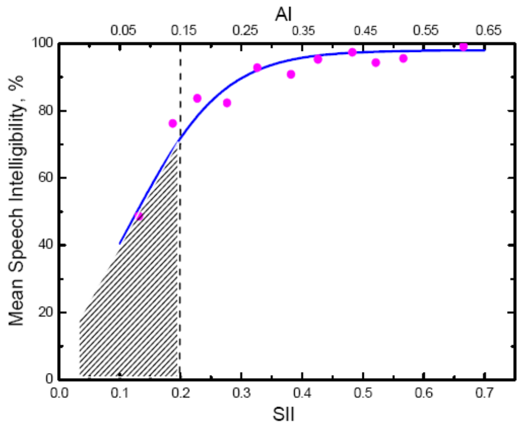
Recommended AI/SII criteria for normal hearing adult listeners vary across the literature[164, 39, 40, 141, 207, 231]. The proposed ratings for intelligibility and privacy from the various sources have been summarised in Table 5.7. A rating of AI < 0.15 (or SII < 0.20) has historically been accepted as an appropriate design goal for open plan offices[201].

Table 5.7: Recommended AI/SII for open plan classrooms



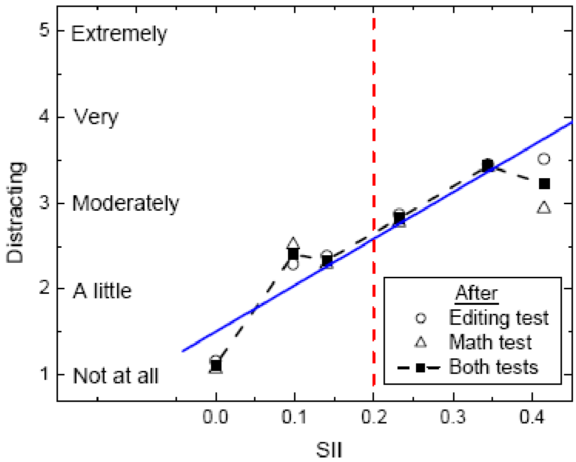
In order to address the paucity of work relating to speech privacy, Bradley[201] carried out speech intelligibility tests on 29 adult subjects in simulated open plan office conditions using 100 simulated speech/noise conditions and showed that AI/SII was related to subjective speech intelligibility sentence scores as shown in Figure 5.14. A rating of SII < 0.2 was shown to relate to around 70% sentence intelligibility. Further subjective tests revealed that the subjects evaluated conditions of SII < 0.2 as being a little less than 'acceptable'. Conditions of SII < 0.1 corresponded to 'acceptable' speech privacy evaluations.

Figure 5.14: Relationship between AI/SII and speech intelligibility scores[210]



Bradley also investigated perceived distraction from each simulated condition (attenuated speech plus ambient noise sources), by asking the 29 subjects to rate how distracting they found each condition immediately after completing an arithmetic or editing task. The results, shown in Figure 5.15, indicate that conditions of SII < 0.2 corresponded to 'a little distracting' and 'moderately distracting'. The regression line appears to indicate that conditions of SII < 0.1 would be expected to relate to less than 'a little distracting'.

Figure 5.15: Mean distraction ratings of perceived privacy during tasks[201]



However it should be noted that this test was limited to adult subjects in office type conditions. It is not known whether perceived privacy and distraction would be similar for children in classroom situations. Further research is required to establish this.

5.7 Conclusions

Teacher-to-student communication is considered to be the most critical form of speech communication in primary classrooms. The intelligibility of natural speech within open plan classrooms depends on the combination of active speech-to-noise ratio (which fluctuates depending on the activity and listening situation in the main and adjacent classrooms) and room acoustic characteristics, generally described by reverberation time (more specifically, Early Decay Time). In open plan classrooms it is also necessary to consider speech privacy between classbases, which depends on attenuation between classbases and the ambient masking noise level.

Provided that reverberation times are reasonably well controlled in classrooms, the speech-to-noise ratio is generally a more important determinant of speech intelligibility in classrooms. In an open plan classroom, lower reverberation times are important to control the reverberant intrusive noise level from adjacent classbases as well as improving the intelligibility of the speech signal. The provision of strong early reflections to support the teacher's speech level may be less important given the expected organisation and management in a typical open plan primary classroom. This is investigated further in Chapter 8.

The typical acoustic characteristics of teachers' speech in classrooms have been explored to ensure that assessment methods are representative of realistic situations in the classroom whilst minimising risk of vocal strain, and providing sufficient speech privacy between classbases.

Objective acoustic based speech intelligibility parameters may be classified by speech-to-noise ratio based parameters (S/N(A), S/N_w, SIL, SII, AI), room acoustics based parameters (T_{30}, EDT, C_{50}, D_{50}) or parameters which combine both (STI, RASTI, U_{50}). The latter are more suitable for use in open plan classrooms as they automatically account for the compensation of lower speech-to-noise ratios with lower reverberation times to provide equivalent speech intelligibility.

The relationship between these objective parameters and their relation to subjective intelligibility scores has been discussed. Rating scales for otologically normal adult listeners to assess the quality of a particular environment (such as STI, RASTI, SII, AI and S/N(A)) have also been described. However these scales are not necessarily appropriate to describe speech intelligibility by primary school aged children. Therefore further investigation is required.

Listeners who are more vulnerable to the effects of poor acoustics and noise in primary classrooms include younger children, hearing impaired children, children with English as an additional language, children with learning disorders and children with mild temporary hearing problems. These groups require significantly better acoustic conditions than their ‘normal’ peers or adult listeners. Since these groups comprise a significant proportion of a typical class at any time, good acoustic conditions need to be provided in all classrooms to enable an inclusive learning environment. Appropriate criteria for objective acoustic parameters need to be developed and verified to ensure that they are suitable for a primary school setting.

Specific recommended acoustic criteria for learning environments, and current standards and guidance for open plan classrooms, are discussed in the next chapter.

Chapter 6: Standards and guidance

6.1 Introduction

Early investigations into fully open plan classrooms sought to establish basic design methods to provide adequate speech intelligibility within classbases, and adequate speech privacy between classbases[39, 40, 99, 232] (see Chapter 5). The general design procedure involved calculating zones within fully open plan classrooms where reliable conversations could take place, and zones where overheard speech would be distracting[232]. The classroom layout would then be planned around these zones to provide reasonable acoustic conditions. However it is difficult to account for the dynamic nature of the classroom activities which take place in practice using these design methods.

Design criteria for classrooms have been developed from the research findings[104, 125, 126, 130] discussed in Chapters 4 and 5 (generally focussing on enclosed classrooms), and many countries have now adopted these criteria as either guidance or mandatory performance standards for school buildings.

In the UK, architectural design advice for school buildings has long been available in the form of 'Building Bulletins' published by the Government Education departments over the years. Many of the early Building Bulletins[14, 17, 29, 100] were somewhat subjective and focused on individual case studies. Building Bulletin 51[232], published in 1975, was the first to provide more specific guidance to provide good acoustic conditions in schools. Further guidance for environmental design in schools (including acoustics) was published in Design Note 17[233] in 1979. This document was later superseded by Building Bulletin 87 in 1997[234].

Schools have been included within the scope of the UK Building Regulations since 2003, with mandatory acoustic performance standards for teaching spaces set out in Section 1 of Building Bulletin 93 (BB93)[1]. These are discussed in detail in the following sections.

6.2 Recommended design criteria

6.2.1 Speech intelligibility

Design criteria for speech intelligibility in enclosed spaces are widely expressed as combinations of minimum speech-to-noise ratios (or maximum background noise levels based on an assumed speech level), and maximum mid-frequency reverberation times[126].

Literature generally recommends providing at least 15 dB speech-to-noise ratio throughout the classroom (with reverberation time controlled to 0.5 s) to ensure that all participating listeners are able to receive the signal without degradation[160,126, 225, 235]. This is supported by the studies of Houtgast[225] and Bradley[130], which showed that, classrooms with occupied reverberation times of less than 1.2 seconds, children's speech intelligibility scores improved as speech-to-noise ratio increased to +15 dB(A), before reaching a plateau. Criteria need to represent the intended listening population, and alternative speech-to-noise ratios may be appropriate as discussed in Chapter 5.

For enclosed classrooms, maximum criteria for ambient internal noise levels are derived to provide sufficient speech-to-noise ratio, based on standard voice spectra and assuming that the class are quiet and listening to the teacher during lessons. However this method is not appropriate for open plan classbases where the background noise level also includes intrusive noise from adjacent classbases. For open plan classbases, the optimum internal ambient noise level is a compromise between providing sufficient masking noise for speech privacy, whilst not increasing the intrusive noise level significantly.

For general classrooms, the literature agrees a maximum *occupied* mid-frequency RT of 0.4-0.5 seconds[8, 11-13] for a SNR of +15 dB, although the trade off between RT and SNR should be noted (see Chapter 5). Bradley[130] also recommends a minimum criterion of 0.4 seconds, to account for the non-zero optimum RT (see Chapter 5). However in open plan design, it is likely that control of reverberant noise from adjacent classbases is more important than providing strong early reflections to support the teacher's speech, (since the class are often gathered close to the teacher during critical listening activities). In this case lower RT criteria may be preferable. For example, Petersen[147] recommends a maximum reverberation time of 0.3-0.4 seconds for open plan classrooms.

Reverberation time criteria are commonly specified in terms of unoccupied and either furnished or unfurnished spaces, to facilitate more robust prediction and design methods.

For open plan classrooms with dynamic learning activities and varying intrusive noise levels, it is more appropriate to use a design criterion which combines both speech-to-noise ratio and reverberation in a single parameter, and for this reason the standardised Speech Transmission Index is commonly specified. Petersen[147] recommends STI ≥ 0.6 for intelligibility within classbases, which corresponds to 'Good' speech intelligibility for normal hearing adult native listeners. Again, care should be taken that the criterion is appropriate for the intended listening population.

Crandell and Smaldino[236] recommend that children should be situated within approximately 6 ft (2m) of the teacher (source) to receive maximum intelligibility within the direct sound field. Although this is not possible for teaching typical class sizes when seated at desks without sound amplification, it is easier to achieve when children are closely gathered around the teacher on the carpet. Kingsbury[39] and Choudhury[141] recommended keeping all students within about 20 feet (7 m) of their teacher.

6.2.2 Speech privacy between classbases

Petersen[147] recommends a maximum criterion for speech privacy between classbases of STI ≤ 0.2, in order to avoid speech arising from adjacent classbases becoming intelligible and hence distracting/confusing. An attenuation of at least 15-20 dB between classbases is recommended to achieve this criterion, or 5-8 dB per doubling of distance[201] (see section 4.6).

However, Bradley[201] has questioned the use of STI as a parameter to describe speech privacy, preferring to use SII which just includes masking from only noise rather than reverberation. Bradley[201] proposes a criterion of SII < 0.2 (equivalent to

AI 0.15) as a reasonable criterion for privacy in open plan offices, although it should be noted that these studies were carried out with adult office workers, and so would not necessarily represent the subjective impressions of children in a learning situation, particularly for vulnerable listeners. For this group, a lower SII criterion, corresponding to a better subjective privacy, is likely to be more appropriate.

6.3 UK Standard – Building Bulletin 93

Since 2003 schools in the UK have been included within the scope of the Building Regulations, with mandatory acoustic performance standards for teaching spaces. Requirement E4 of Approved Document E[237] states that:

> 'Each room or other space in a school building shall be designed and constructed in such a way that it has the acoustic conditions and the insulation against disturbance by noise appropriate to its intended use'[237]

The normal way of satisfying this requirement is to meet the performance standards given in Section 1 of BB93[1]. The performance criteria are largely based on research and extensive surveys in existing classrooms, and aim to facilitate good speech intelligibility within classrooms and prevent interference from noise in other areas of the school.

BB93 criteria for open plan teaching areas and primary school classbases are set out in Table 6.1. Speech intelligibility in open plan classrooms cannot be assured from the usual noise and reverberation time criteria as discussed above. Instead, BB93[14] requires STI in the classroom to be predicted using a 3D computer model or other suitable method, based on a specific open plan layout and activity plan. The required minimum BB93[1] performance standard of STI = 0.6 corresponds to 'good' or excellent' conditions for normal hearing adult listeners[156]. This criterion should be achieved for teacher/pupil, pupil/teacher and pupil/pupil communication situations.

Criteria for reverberation times are set out in terms of the maximum mid-frequency reverberation time, T_{mf} (arithmetic average of the reverberation time in the 500, 1k and 2k Hz octave bands), measured for the unoccupied and unfurnished classroom. The criterion of 0.6 seconds is likely to correspond to an occupied, furnished RT of around 0.4-0.5 seconds, in line with recommended criteria discussed above. The maximum RT criterion for open plan teaching areas is considerably higher at 0.8 seconds. The appropriate standard for a primary school classbase within a semi-open plan unit is open to interpretation.

Table 6.1: BB93 criteria

Criterion	Open plan teaching areas	Primary school classbases
STI	>0.6	-
T_{mf}	< 0.8	<0.6
Ambient noise level	≤ 40 dB	≤ 35 dB

Although open plan classrooms are expected to be highly flexible in terms of the room layout and teaching activity, a degree of planning and organisation is always necessary for the classrooms to operate successfully. In addition to the prediction of STI in open plan classrooms, BB93[1] requires an expected ‘open plan layout’ and ‘activity plan’ to be submitted as part of the design, to include the following:

- Teaching positions for oral presentation
- Student seating plan
- Learning base areas
- Number of oral presentations at any one time (students and teachers)
- Number of student discussions at any one time
- Number of people walking though space during lessons
- Machinery/equipment operating in open plan space

Compliance with the BB93 requirement for open plan classroom may be demonstrated to the Building Control Body by carrying out measurements of STI in accordance with BS EN 60268-16[162], for one in ten student positions in each open plan space.

The accurate representation of classroom activity noise, speech power levels, speaker orientation and directivity is critical for the correct prediction of STI in open plan classrooms. The model should incorporate an overall background noise level to include noise from all activities in the main classbase and adjacent classbases except for the person talking (teacher or student). This is established from the expected open plan layout and activity plan[1] which the designer should establish with the client. Effective management of the open plan space is therefore critical for the space to work acoustically.

BB93 provides guidance on prediction/measurement of STI in open plan primary classrooms, as shown in Table 6.2. The minimum and maximum STI should be calculated for the worst-case situations shown in Table 6.2. A seated height of 1.0 m is applicable to primary school classrooms (1.2 m for secondary classrooms). BB93 requires directivity levels[173] for an average human talker (as discussed in Chapter 5) to be used in acoustic prediction models of open plan classrooms.

Table 6.2: Summary of BB93 STI prediction/measurement procedure[1]

Situation	Source details					Receiver details	
	No. mmts	Height (m)	Location	Orientated towards:	Vocal effort	Height (m)	Location
T to S	1	1.65	as open plan layout	centre of group	'raised'	1.00	every seat
S to T	3	1.00	furthest from teacher	teacher	'raised'	1.65	as layout
S to S	3	1.00	typical	teacher	'raised'	1.00	every other seat
S to S	3	1.00	typical	other student	'normal'	1.00	>3m from talker

*T = Teacher; S = Student

6.4 International standards and guidance

Current criteria from international standards and guidance which are relevant to open plan primary classrooms are summarised in Table 6.3. Specific reference to 'open plan' classrooms is given in Danish[216] and Swedish[238] standards. Other documents simply refer to large group teaching spaces[239, 240] (including auditoria), or large core learning spaces[240], and these standards may not necessarily be appropriate to open plan designs.

With the exception of the UK[1] and Danish guidance[216], all standards are set out in terms of combined unoccupied reverberation times and maximum ambient noise levels. The general intention is to maintain a speech-to-noise ratio of at least 15 dB, (on the basis that teacher's speech level is at least 50 dB at all points in the room, and the maximum background noise level is 35 dB[196]) and achieve reverberation times that will not significantly reduce speech intelligibility at this speech-to-noise ratio. Use of STI in the UK standard is discussed above. For the Danish Guidance[216], STI criteria are given for both intelligibility within groups, and speech privacy between groups.

Table 6.3: International standards/guidance

Country	Room description	RT (s)	Maximum ambient L_{Aeq} (dB)	STI
Australia/NZ[241]	Primary school classrooms	0.4-0.5**		-
Denmark[216]	Open plan classrooms	<0.3-0.4^{+}	30	> 0.6 (within) < 0.2 (between)
Finland[239]	Large group teaching space	0.6-0.9^{++}	33 (services) 35 (external)	- -
Norway[240]	Large group teaching space	0.4^{+}		-
Sweden[238]	Open plan lecture space	0.4^{++}	30 (services) 30 (traffic)	- -
USA[196]	Core learning spaces: 283 - 566 m^3 < 283 m^3	 0.7* 0.6*	 35 35	 - -
WHO[242]	Classrooms	0.6	35	-

* RTs in 500,1k and 2k Hz bands for unoccupied, furnished spaces

**RTs in 500 and 1 k Hz bands for unoccupied spaces

$^{+}$125 - 4k Hz unoccupied spaces. 30% increase tolerable at 125 Hz
$^{++}$250 - 4k Hz unoccupied, furnished spaces

Like BB93[1], most of the international standards and guidance permit the use of open plan designs, to provide maximum design flexibility. However guidance given in ANSI 12.60[196] actively discourages use of open plan classrooms:

> *'Open plan classroom design should be strongly discouraged since the resulting background noise levels as a result of activities by students in other core learning spaces within an open classroom setting are highly likely to exceed background noise criteria[196]'*

However, it is unlikely that background noise criteria could be maintained for active enclosed classrooms even under the quietest occupied conditions, given typical measured average noise levels of 38-45 dB L_{Aeq} [130, 167] when classes are silent and listening to their teacher (see Chapter 4).

Clearly, STI enables the occupied activity noise level to be considered, and gives more flexibility to enable lower speech-to-noise ratios to be compensated by lower reverberation times in order to maintain speech intelligibility. This is reflected by the lower RT criterion given in the Danish guidance[216], and the criteria given for Norwegian[240] and Swedish[238] guidance. It should be noted that reverberation times are likely to reduce by 0.1-0.2 seconds when occupied[129].

6.5 Conclusions

Speech intelligibility in open plan classrooms cannot be assured from the usual combined speech-to-noise ratio and reverberation time criteria, therefore criteria need to be defined in terms of a suitable objective parameter (such as STI) which accounts for both of these aspects of speech intelligibility. This has only been addressed in standards and guidance by the UK (in BB93[1]) and Denmark[216]. Parameters for speech privacy between open plan classbases should also be addressed, and this has only been covered by the Danish[216] guidance.

Provided that the speech intelligibility and speech privacy in open plan classrooms is suitably assessed (using a realistic classroom layout and activity plan), to meet relevant speech intelligibility criteria detailed in this section, it should be possible to give open plan classrooms due consideration as an effective learning environment. Careful classroom management is likely to be necessary to achieve this. The methodology developed for assessing STI in open plan classrooms is discussed in the next Chapter.

Chapter 7: Objective survey methodology

7.1 Introduction

One of the research objectives was to develop suitable measurement procedure for STI in open plan classrooms in accordance with BB93[1] and BS 60268-16[162], and within the resources of the research project. Laboratory investigations were carried out to ensure that the equipment was suitable and the methodology was accurate and repeatable.

The validated STI measurement procedure is discussed in detail in this Chapter. The general objective survey procedure is also discussed including the following:

- selection of classrooms
- physical details of classrooms
- findings from pilot studies
- measurement of other room acoustic parameters

In addition, a suitable method for assessing speech privacy between classbases is described in order to assess the intelligibility of irrelevant speech (from teachers in adjacent classrooms) in the main classbase when critical listening is taking place.

7.2 Basis of assessment

This study focuses on teacher-to-student communication as the most critical aspect of speech communication within the classroom (Chapter 5). The measurement procedure described in this section was based on typical classroom arrangement and management occurring in contemporary open plan primary classrooms (Chapter 3), namely:

- Mainly whole class instruction and individual work activities
- Group work occurs, but less often
- Teachers generally coordinate teaching activities to avoid activity conflicts
- Whole class teaching often takes place on a carpet area (class gathered closely around the teacher)
- When class is seated at tables, individual or group learning often takes place
- During this time, teachers walk around the room to give individual or small group instruction, shortening communication distances

- During individual/group work, the teacher will quieten the class to capture the children's attention before instructing them
- Non-verbal cues often used as an attention gaining strategy

The following categories of classroom activity occurring in adjacent classbases were identified, after Shield and Dockrell[125]:

1. Silent reading or test
2. One person speaking at any one time (whole class teaching)
3. Individual work at tables – independent work with some talking
4. Individual work with movement
5. Group work at tables
6. Group work with movement

Given the above observations, possible combinations of activities occurring in open plan classrooms are illustrated in Table 7.1, where 'critical listening' situations for teacher–to-student communication are highlighted. The 'best' and 'worst' case situations are also indicated. For other listening situations, the main design issue is to control noise levels in order to avoid distraction and annoyance (and other effects on cognitive processing), rather than achieving high levels of speech intelligibility between teacher and student.

Table 7.1: Teacher-to-student communication in open plan primary classrooms

		Adjacent classbases: dominant activity		
		Whole class	Work at tables	Work at tables with movement
Main classbase activity	Whole class	Coordinated activities (best case)	Uncoordinated activities	Uncoordinated activities (worst case)
	Individual work	Less critical – main issue here is control of noise levels, to avoid distraction and annoyance and effects on cognitive processing		
	Group work	Communication distances shorter than for whole class and communication more informal; need to control noise levels as above		

On this basis, the following procedure for measuring STI in open plan classrooms has been designed with critical listening situations and teacher-to-student communication in mind.

7.3 Measurement of STI

STI was originally conceived to be measured using a modulated sinusoidal test signal with a speech-shaped frequency spectrum (Chapter 5). The test signal would be transmitted *via* a sound source at the talker position to a microphone at the receiver (listener) position[162].

However, Houtgast and Steekenen[243] showed that for a noiseless system, the modulation transfer function, m(f), could also be derived from the normalised Fourier component of the squared impulse response, $h^2(t)$, divided by the total energy of the squared impulse response, see Equation 4. This allowed STI to be measured using a computer based system with dedicated impulse response analysis software.

Equation 4: Determination of m(f) by impulse response

$$m(f) = \frac{\left|\int_{-\infty}^{+\infty} h^2(t) e^{j2\pi ft} dt\right|}{\int_{-\infty}^{+\infty} h^2(t) dt}$$

Steeneken and Houtgast[205] also showed that the modulation transfer function is independent of the signal to noise ratio, and therefore the true value of STI in the presence of ambient noise and reverberation may be determined from two independent measurements; the noiseless system impulse response (S/N >15 dB), and the actual system signal to noise ratio, S/N, as shown in Equation 5. This is convenient for simulation of results when realistic background noise levels cannot be experienced during a measurement situation.

Equation 5: Determination of m(f) by impulse response and speech-to-noise ratio

$$m(f) = \frac{\left|\int_{-\infty}^{+\infty} h^2(t) e^{j2\pi ft} dt\right|}{\int_{-\infty}^{+\infty} h^2(t) dt} \left(1 + 10^{(-S/N)/10}\right)^{-1}$$

Rife[244] has shown how maximum length sequence (MLS) signals may be used for measuring impulse responses and hence the modulation transfer function. The MLS signal is a deterministic pseudorandom binary sequence signal. The autocorrelation function of this signal is a periodic ideal Dirac impulse, hence the deconvolved impulse response is not contaminated by system noise. Therefore the impulse response part of Equation 5 does not need to be completely noiseless when measured using the MLS technique.

All room acoustic parameters were measured using the WinMLS 2004 software analyser which calculates various room acoustic parameters based on measurement of the room impulse response. The impulse response of the room is digitally recorded using the PC's own processor and a high quality soundcard (see section 7.7.2 for details).

In order to measure STI accurately in classrooms, the spectrum, level and directivity of the source signal need to be accounted for, as well as the effect of classroom occupants on STI (noise generation and absorption). Each factor is discussed in more detail in the following sections.

An MLS excitation signal was used for STI measurements. The average spectrum and level distribution of speech is represented by shaping the output signal using a filter within WinMLS. Using the autocorrelation properties of the MLS signal, a Hadamard transformation (a type of Fast Fourier Transform for use on binary signals) is performed to obtain the noiseless room impulse response. This measurement method is much faster and more flexible since only one impulse response measurement needs to be performed at each position (for which a range of S/N conditions may exist). From this, the STI/RASTI value can be calculated by correcting for the actual speech-to-noise ratio measured in various conditions as part of the post processing phase, removing the need to simulate occupancy noise directly during the impulse response measurement, which can be time consuming and often inaccurate.

7.3.1 Test source spectrum level

In order to simulate the raised speech signal of a typical teacher, the test signal was set to 66.5 dB L_{Aeq} at 1 m from the source to represent ANSI 3.5[158] levels for raised speech in accordance with BB93[1] (see Chapter 5). It should be noted that the ANSI

3.5 standard speech spectrum levels are primarily intended for communications with 'the listener facing the talker'[161] in 'relatively free fields'[161], and 'low reverberant conditions'[161], that is, a room in which the contribution of the reverberant field of the source at the receiver position is small compared with that of the direct field. This is a reasonable assumption for open plan primary classrooms at 1 m from the source, where unoccupied furnished reverberation times are generally low and source positions are generally at least 1 m from any reflecting surface. Furthermore, ANSI 12.60[196] states that 'the average A-weighted sound level (of teacher's speech) is 67 dB at 1 m in a quiet classroom' which supports this assumption.

Each measurement was inspected to ensure that the test signal was sufficiently higher than the ambient noise level for the measured impulse response to be of sufficient quality (see section 7.6.4 for further details).

BS60268-16[162] states that a check should be carried out to ensure that the test signal spectrum is correct to within ± 1 dB over the range 88 Hz to 11.3 kHz, and to 'adjust the equalization (if any) of the test loudspeaker, as necessary, to satisfy this requirement'. Although equalisation was not applied in the measurement chain, a filter was applied to the output signal within WinMLS to simulate 'raised' speech. The spectrum of the signal was measured at 1 m from the source and inspected to determine any deviation from the ANSI 3.5[158] standard spectrum for raised speech. A correction was applied to the speech spectrum at the receiver position if necessary during post processing, when manually entering data for the speech spectrum.

7.3.2 Source directivity and frequency response

In order to assess the intelligibility of human talkers, the directivity of the source must approximate that of the human head and mouth. BS EN 60268-16[162] recommends a mouth simulator conforming to ITU-T Recommendation P.51[245] for the highest accuracy. This document specifies the acoustical and electrical characteristics of a sound source at 25 mm from the lip ring, and for this reason is mainly used for testing telephone mouthpieces or similar communication networks at close quarters. Typical source/receiver distances in a classroom range from 1 m to 8 m and it is uncertain whether a mouth simulator conforming to ITU P.51[245] would generate an accurate sound field for receiver positions in this range. In order to improve the accuracy of results, other studies have recommended use of a combined head and torso simulator conforming to ITU-T recommendation P.58[246].

Mapp[247] showed that the maximum error between a typical P.51 mouth simulator and a combined P.58 head and torso simulator was 0.03 STI at on-axis receiver positions. This error is not significant, since the typical standard deviation for a repeated STI measurement under steady conditions is about 0.02[162]. It is also worthy of note that Bradley[248] calculated that the just noticeable difference (JND) for speech transmission index was 0.03 in controlled experimental conditions (and more for practical situations). Thus it is unlikely that a using a mouth simulator rather than a head simulator would produce significant error in practical measurement of classroom STI.

As an alternative, BS EN 60268-16[162] describes a small single source, high quality loudspeaker with a cone diameter not exceeding 100 mm, with a cabinet approximating the dimensions of the human head. A typical head-sized loudspeaker becomes too directional at high frequencies, resulting in an over-estimation of STI[247]. Although using a single cone device is preferable for more accurately replicating a point source, Mapp[247] showed that using an additional small tweeter with crossover could reduce the directionality at high frequency, which is beneficial.

Laboratory investigations were carried out as part of this research to determine the accuracy of a small dual source high quality loudspeaker, with a main cone of 100 mm diameter and a tweeter of 30 mm diameter. The loudspeaker cabinet was enclosed by a well sealed heavy metal casing and measured 210 x 145 x 115 mm, approximating the dimensions of the human head, as described by BS 60268-16[155].

The loudspeaker was positioned at a height of 1.6 m above the floor of the anechoic chamber, at least 1 m from any reflecting surface. The sound pressure level frequency response was measured at 1 m from the speaker cone in the 0° on axis position. An MLS test signal was used. The measured frequency response from 100 Hz – 10 kHz is presented in Figure 7.1. The response is fairly flat within the range 160 Hz – 4 kHz, and the drop off at the extreme ends of the spectrum is comparable to that of the standard GRAS-44A mouth simulator, see Figure 7.2.

Figure 7.1: Measured frequency response of test loudspeaker

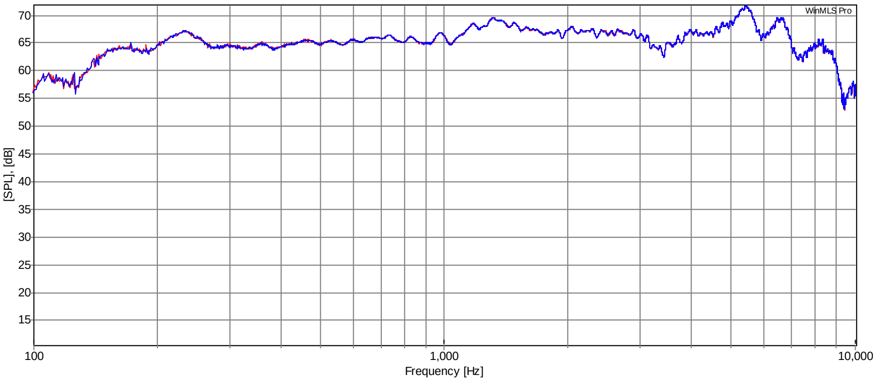
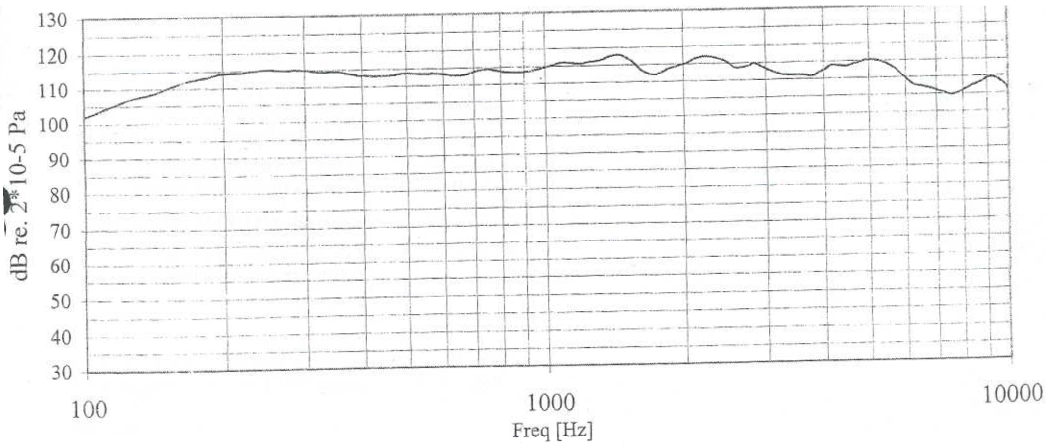


Figure 7.2: Frequency response of standard GRAS-44A mouth simulator[249]



The horizontal directivity pattern of the loudspeaker was measured in the anechoic chamber. The speaker was rotated about the horizontal axis in steps of 30 degrees, and the frequency response was measured (using WinMLS) at 1 m from the cone at the 0° on axis position in accordance with BS EN 60268-5[250]. The speaker cone and microphone were both positioned at a height of 1.5 m above the floor.

The directivity index, DI at the on axis (0°) position was calculated from 125 Hz – 8 kHz according to Equation 6:

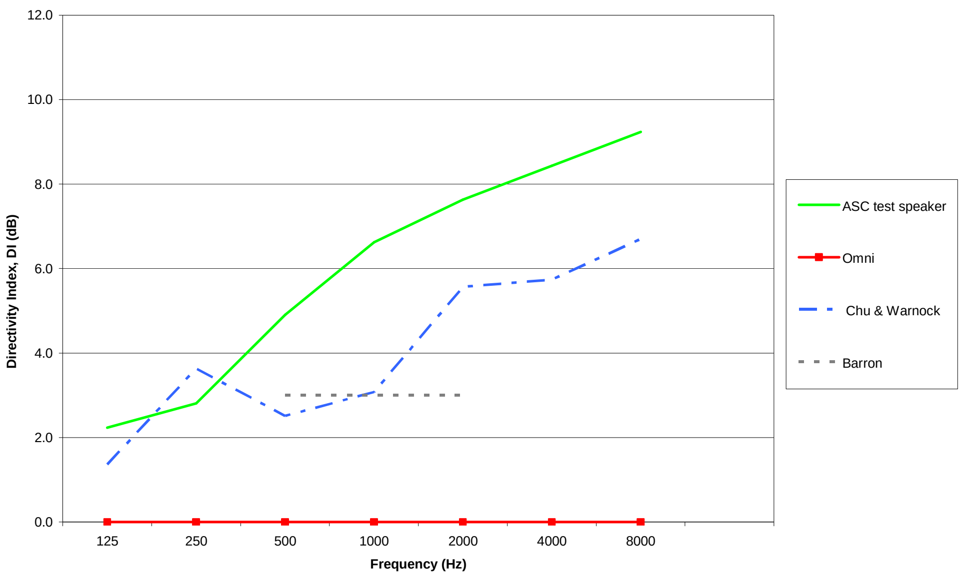
Equation 6: Relationship between DI and Q

$DI = 10\log_{10}Q$,

where Q is the ratio of the sound pressure level in the direction of interest, to the sound pressure level logarithmically averaged over all angles. Figure 7.3 shows the calculated directivity index measurements of the ASC test speaker at the on axis position (straight ahead), compared to that measured for a set of human talkers (Chu and Warnock[173]), the average mid frequency values given by Barron[251], and an omni-directional speaker.

The test loudspeaker is too directional compared to that of an average human talker, with the greatest deviation occurring at 1 kHz. The reduction in directivity index of the test loudspeaker due to crossover occurs above 8 kHz, and so is less useful for STI applications.

Figure 7.3: Directivity index of test loudspeaker



The directivity level in decibels was measured according to the sound pressure level at each rotation position relative to the on axis (0°) position. The directivity levels at 125 Hz – 8 kHz are presented in Figure 7.4 together with Chu and Warnock's[173] measured directivity for the average human voice in anechoic conditions. The directivity of the loudspeaker was consistent with an average human talker at lower frequencies, but became too directional at higher frequencies, supporting the findings shown in Figure 7.3.

Within ±30° of the on axis (0°) position, no significant difference (< 3 dB) occurred between the directivity patterns between 125 and 4 kHz. Within ±60° of the on axis position, a significant difference (> 3 dB) occurred at frequencies of 1 kHz upwards.

BB93[1] requires STI measurements/predictions in open plan classrooms to be carried out with the sound source facing the centre of the student group. Students are typically located within ±60° of the on axis (0°) teaching position.

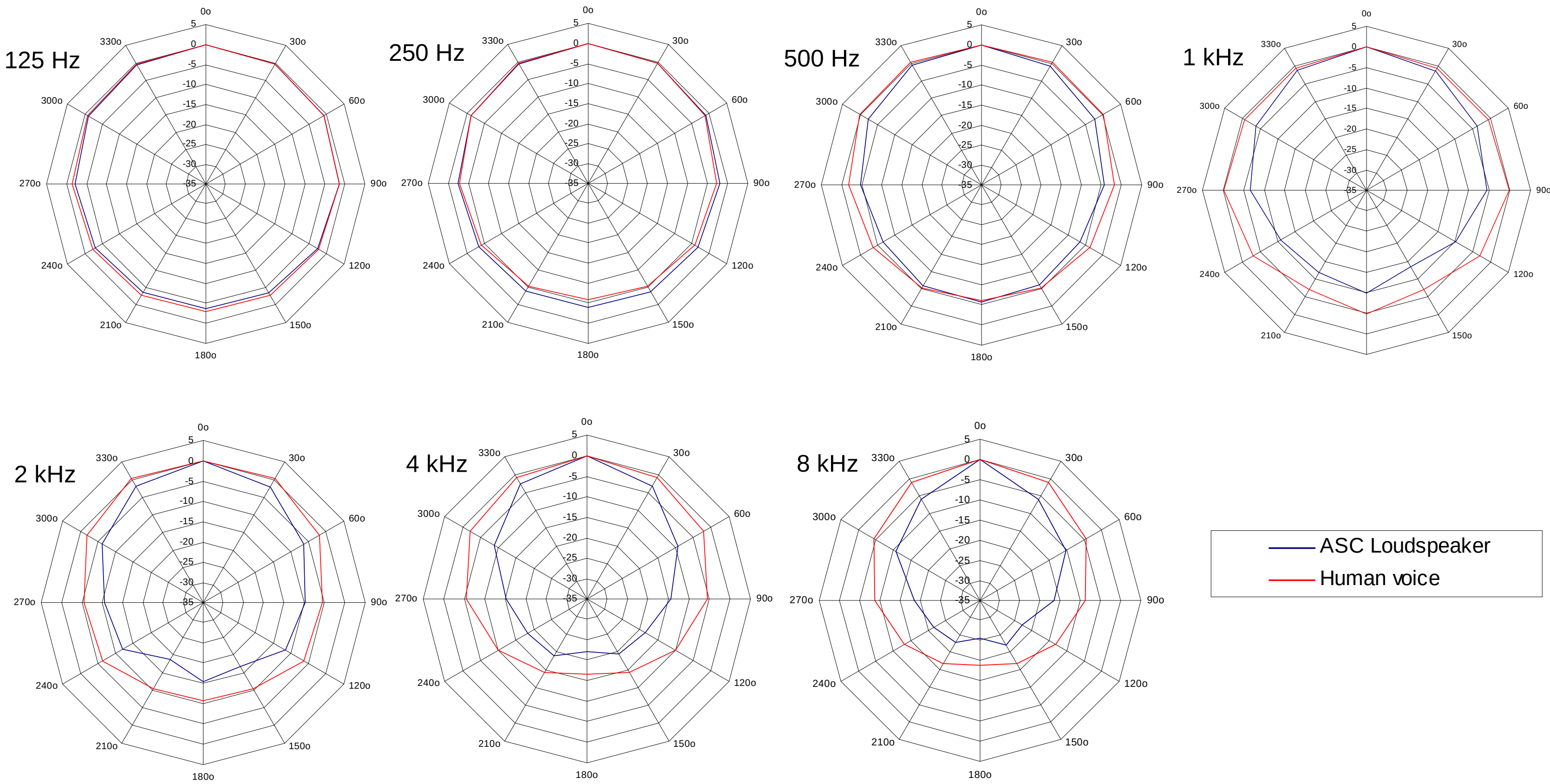
An investigation was carried out to examine whether differences in the test source directionality would have a significant effect on STI results. The performance of the test loudspeaker was compared with a GRAS-44A mouth simulator complying with P.51[245]. The test source height was set to 1.65 m above ground level in accordance with BB93[1]. STI was measured for six receiver positions (1.2 m above ground level) in a classroom environment for both on axis (within ±30º of the source position) and off axis positions (within ±30-60º of the source position) as indicated in Table 7.2.

Table 7.2: STI results using mouth simulator *vs.* test loudspeaker

Position	Mouth simulator	Test Loudspeaker	Error
S1R1 (on)	0.72	0.73	0.01
S1R2 (off)	0.66	0.68	0.02
S1R3 (off)	0.66	0.68	0.02
S1R4 (off)	0.65	0.70	0.05
S1R5 (on)	0.72	0.71	0.01
S1R6 (on)	0.69	0.71	0.02
Mean	0.68	0.70	0.02

Use of the cabinet loudspeaker resulted in higher STI results, as expected. The mean error between the artificial mouth and small loudspeaker for the six positions was 0.02 STI, which is equal to the typical standard deviation of STI for measurements at a fixed position under steady condititions[162], and smaller than the JND (STI 0.03). On the basis of these results, the head sized loudspeaker was considered valid for use as a test source.

Figure 7.4: Directivity levels (dB) test speaker vs. average human voice



7.3.3 Effect of occupancy (noise)

The overall noise level due to all teaching and study activities in the open plan space may be split into two parts; the intrusive noise level (from adjacent classbases plus ambient noise level), and the noise from the occupants in the main classbase itself (excluding the teacher's or speaker's voice).

If the occupants within the main classbase are assumed to be quiet and listening to the teacher (engaged in a critical listening activity), the intrusive noise level is likely to be dominant, especially when adjacent activities are uncoordinated. Therefore the intrusive noise level alone was measured during the survey, with the main classbase unoccupied, and the effect of occupancy noise was accounted for separately during post processing.

The equivalent continuous noise level parameter (L_{eq}) was used to measure the intrusive noise level. Noise surveys of office environments have found the L_{eq} parameter to be most highly correlated to subjective auditory sensation[252]. It is also important to consider the fluctuation in STI with time (this varies with the type of teaching activity and with general fluctuation of noise). Mapp[247] has suggested that use of a statistical parameter L_n may more accurately account for the effect of fluctuating background noise on speech intelligibility. However further studies are necessary to determine which parameters should be used and whether these are significantly better predictors than L_{eq}. Therefore L_{eq} was used in line with methodologies used in other studies[1]. The fluctuation in noise level is dealt with by working with multiple STI measurements calculated from a large number of noise samples at the same measurement position for the same activity type.

In order to assess the effect of main classbase occupancy noise using a controlled method, a standard spectrum for occupied classroom noise with no student activity was added to the measured intrusive noise level. This background noise level was used to correct unoccupied STI results during post processing. The spectrum was based on a published measured octave band spectrum[131, 195], for children quiet in a classroom.

7.3.4 Effect of occupancy (absorption)

Occupancy also increases the absorption in a classroom and hence decreases reverberation time. This would in turn improve STI. However a study by Mapp[247] showed that for most positions, increased absorption due to room occupancy did not affect the STI significantly. For furnished classrooms with relatively low reverberation times, the additional reduction in reverberation time due to occupants is small (see Figure 5.4). The deleterious effect of occupancy noise on STI would far outweigh any advantage to be gained from increased absorption due to occupancy. Therefore unoccupied measurements are taken to represent a worst case scenario in terms of absorption.

7.4 Measurement of other room acoustical parameters

The WinMLS system also offers the logarithmic sine sweep excitation method, which is generally more robust than the MLS signal in variable background noise[253]. Therefore this type of signal was used for measurement of other room acoustical parameters such as reverberation times (T_{30} and EDT) and early-to-late energy ratios.

The MLS signal was used for STI measurements in order to represent spectral characteristics of speech directly in the signal.

7.5 Measurement of speech privacy

Speech privacy between classbases was assessed by a combination of field measurements (measured sound level difference between classbases and ambient noise level) and calculated assessment (calculation of speech intelligibility index, SII in accordance with ANSI 3.5[158]). The SII was calculated for when the teacher (source) was speaking at their normal speaking position, with children in adjacent classbases (receivers) gathered closely around their teacher. This typically took place on the carpet during critical listening and whole class teaching periods, as noted in section 7.1 and as informed during pilot studies and initial visits to schools.

The method assumes that noise and speech sources are omni-directional, listening is monaural and the speech and noise sources are independent of each other.

The SII is computed from the equivalent speech spectrum level E', and equivalent masking spectrum level Z_i at the receiver position. The equivalent internal noise spectrum is also taken into account to calculate the equivalent disturbance spectrum level, D_i. For the purposes of this assessment, all children were assumed to be otologically normal, and the equivalent hearing threshold *T'* was assumed to be 0 dB across all frequencies. Therefore the disturbance spectrum level $D_i = Z_i$.

In accordance with ANSI 3.5[158], the apparent speech-to-noise ratio in each frequency band f_i is converted into a band audibility function A_i and weighted according to its band importance function I_i (the proportion of the band's contribution to speech intelligibility). For the third octave band method (used in this study), SII is the summed product of the band importance function and band audibility function A_i given in Equation 7 over *n* third octave bands from 160 Hz – 8 kHz.

Equation 7: Speech Intelligibility Index (SII)

$$SII = \sum_{i=1}^{n} I_i A_i$$

The band audibility function is calculated from the apparent speech-to-noise ratio in band *i* normalised to a range of between +15 dB and -15 dB This value is adjusted to take into account the speech level distortion factor (accounting for the corresponding decrease in intelligibility at very high speech levels). However this correction factor was not pertinent to this study, which investigated 'raised' and 'loud' vocal efforts only.

The initial assessment was carried out for a 'raised' vocal effort (67 dB(A) at 1 m) in accordance with the BB93 procedure for assessing speech intelligibility in an open plan classbase. However, since teachers' voice levels have been found to be considerably higher than this[166] (see Chapter 5), the assessment was also carried out for a 'loud' vocal effort (74 dB(A) at 1 m) , to account for a worst-case scenario.

For purposes of this assessment, the measured third octave band internal indoor ambient noise level ($L_{Aeq,5min}$) was used for the equivalent noise spectrum level, *N'*. The equivalent speech spectrum level, E', was specified based on the standard speech spectrum, U_i, at 1 m from the talker's lips (for both 'raised' ($U_{i\ (raised)}$) and 'loud' ($U_{i\ (loud)}$) vocal efforts) and the measured sound level difference, *D*, between source and receiver positions in each third octave band, as given by Equation 8. Further details of the measurements of D are discussed in section 7.7.3.6.

Equation 8: Equivalent speech spectrum level E'

$$E'_i = U_i - D$$

The equivalent noise masking spectrum level, Z_i, was also calculated to account for the masking of the speech produced by the equivalent noise spectrum level, N', including within band masking, spread of masking and self speech masking, as described in ANSI 3.5[161].

7.6 Pilot studies

Pilot surveys were carried out in three semi-open plan primary schools, in order to verify the observation procedure and noise data collection method. STI and other room acoustic measurements were carried out for one of the primary schools, in a two classbase unit. A survey was also carried out (as part of a team carrying out a post-occupancy survey for the DfES[254]) in a semi-open plan Academy school which had many classbases with large openings onto a reverberant atrium. This helped to compare and contrast measurement methods.

The type of teaching activity and any other events taking place in both the main classbase and the adjacent classbases were recorded during the survey. The six categories (see Section 7.2) were found to adequately represent the range of activities taking place in the classrooms, with the addition of circulation (teachers or pupils passing through the classroom space). For the primary schools, the most frequent activity recorded was individual work at tables, with group work taking place far less often.

For the Academy study[254], continuously logged 5-minute L_{eq} measurements of the background noise level were measured in an unoccupied classbase at a single fixed position. This was initially considered to be a reasonable time period to capture different classbase activities in a secondary school. Measurements of the STI were carried out in unoccupied ('noiseless') conditions using a MLSSA system analyser with pre-filtering to obtain the speech spectrum shape, set to 66.5 dB(A) at 1 m. A mouth simulator conforming to ITU-T Recommendation P.51[245] was used as the test source. The average noise spectrum recorded throughout the day (during teaching time) was used to simulate occupancy noise *via* a loudspeaker broadcast in an adjacent area. However on reflection this method was not considered to be sufficiently refined to account for variations in STI as background noise level varied with changing activity.

For measurements in the two-classbase primary school unit, STI measurements were carried out in unoccupied conditions, using a similar measurement method to that described above (mouth simulator test source, simulation of the background noise included in the test measurement by broadcasting noise through a loudspeaker). The averaged noise level used for simulation was calculated from sampled noise levels from a single activity: main classbase quiet and listening to their teacher; adjacent classbase working and moving around the classroom. However on reflection this was considered to be flawed since the measured noise level included contributions from the teacher's voice in the main classbase (the signal), resulting in inaccurately low STI results.

Simulating background noise directly in the STI measurement (based on a long term average noise level) is a time-consuming procedure which does not realistically simulate the fluctuating noise present in a real classbase, which varies considerably with activity and receiver position. Furthermore, measuring the noise level at just one position in the classroom does not give an indication of how the noise level varies between seat positions which could result in significant differences in STI around the classroom. Calculation of the STI for each individual measured noise sample was considered to provide more accurate information about how the STI fluctuates with noise and teaching activity.

The five minute measurement period used was often not sufficient to account for changes in classroom activity in primary settings. For two of the primary schools, a shorter two minute measurement period was used in order to capture a single activity type before the dominant activity in adjacent classrooms changes. Previous studies have shown that this measurement period gives a good indication of the fluctuations of noise within a classroom, and does not interfere with teaching or children's concentration[125]. Therefore a two minute time period was used for sample measurements in the main study.

7.7 Survey procedure

7.7.1 Selection of classrooms

The objective survey took place between 2003 and 2005. In the first instance, all Local Education Authorities (LEAs) in England were contacted to identify schools which featured open plan classrooms (see Chapter 3).

Many new build open plan classrooms were still under construction at the time of the survey (for example, the first 100 schools of the Building Schools for the Future project were not due to open until 2007[255]). Furthermore, many recently completed open plan classroom designs were part of high profile projects (for example City Academies). These schools were often concerned that the published results of an acoustic assessment could damage the reputation of the building. As a result, all schools that were included in the survey were either Plowden (1970s) or Post-Plowden (1990s) designs.

Information was gathered on 122 open plan schools across the country based on the replies from the Local Education Authorities, results of the literature review, and contacts made during the research project. Logistical constraints biased school selection towards London and the South of England as shown in Figure 7.5. A total of 19 primary schools were visited to assess the suitability of the classroom designs, and to determine whether head teachers were willing to take part in the survey. Three primary schools and one secondary school were selected for pilot survey work and 12 schools were selected for inclusion in the full survey.

Figure 7.5: Location of schools in survey (including pilot studies)

Measurements of STI and other room acoustic parameters were carried out in 42 open plan classbases (Years 1-6) in 12 primary schools. All classrooms were of semi-open plan or flexible open plan design. Fully-open plan classrooms generally no longer feature in the current UK school building stock. The open plan units in the survey accommodated between 2 and 14 classbases.

7.7.2 Equipment List

- Larson Davis Type 824 Sound Level Meter
- B & K Calibrator
- Earthworks Type M30BX ¼ inch omni-directional measurement microphone with built in pre-amp powered by 1.5 V AA battery
- WinMLS 2004 (impulse response based room acoustic measurement software)
- DELL Latitude Laptop (Pentium III)
- Digigram VXpocket v2 Soundcard
- Dodecahedron omni-directional loudspeaker
- C Audio SR707 power amplifier
- ASC MKIII powered monitor serial no. 369 (cabinet loudspeaker)

7.7.3 Measurement procedure

7.7.3.1 Ambient noise level

The ambient noise level ($L_{Aeq,5min}$) was measured in the centre of each classroom with a sound level meter, after the school day had finished (5-6 pm during peak traffic hours), with all spaces unoccupied. Background noise sources were fairly consistent in all classrooms throughout the school day, therefore the 5-minute sample period can be considered a reasonable indicator of the $L_{Aeq,\ 30min}$ performance standard required by BB93[1] for ambient noise.

7.7.3.2 Intrusive noise level

The intrusive noise level was measured using a hand held sound level meter in three positions in each main unoccupied classbase: at the 'back' of the classbase near the opening (worst case), in the 'middle' of the classbase; and at the 'front' on the carpet near the teacher's usual speaking position (best case).

Both octave band ($L_{eq,2min}$) levels and overall ($L_{Aeq,2min}$) levels were obtained for the intrusive noise level. Statistical parameters (L_{A10}, L_{A20}, L_{A30}, L_{A40}, L_{A50}, L_{A90}), maximum $L_{Amax(2min)}$ and minimum $L_{Amin(2min)}$ parameters were also recorded.

Intrusive noise levels were measured when each main classbase became unoccupied, typically when the main class left the room to attend lessons in other parts of the building (eg PE, IT or 'circle time'). Unoccupied periods typically lasted for 30-45 minutes. The dominant activity category occurring in adjacent classbases was recorded during each measurement (see 7.2).

7.7.3.3 STI/RASTI

WinMLS measurements of STI and RASTI were obtained for the unoccupied main classbase and noise was accounted for during post processing as described in section 7.3.3. The head sized loudspeaker described and tested in section 7.3.2 was used as the test source, facing into the centre of the student group, in accordance with BB93[1]. A single source position was used which represented the point most frequently used by the teacher for addressing the whole class e.g. in front of the main writing board in accordance with BB93[1]. At least 6 receiver positions were used in accordance with BB93, with positions representing the range of seating available to the children. The intrusive noise measurement nearest to the receiver position was used to calculate STI and speech-to-noise ratio.

7.7.3.4 Speech-to-noise ratio

Speech-to-noise ratio parameters were calculated from the measured octave band test signal levels at the receiver position and the measured intrusive noise level at the receiver position. The speech-to-noise ratio was calculated for every intrusive noise level sample. S/N(A), S/N_w, and SIL parameters were calculated as described in Chapter 5.

7.7.3.5 Reverberation time and early to late sound ratios

Both octave (125 Hz – 8 kHz) and third octave (100 Hz – 5 kHz) measurements of T_{30} were obtained using WinMLS in accordance with BS 3382[214], using a sine sweep excitation signal to measure the impulse response as described in section 7.3. The difference between the initial level and noise floor was at least 45 dB for all impulse responses between 100 - 5k Hz. An omni-directional loudspeaker was used as the test source, located at a height of 1.6 m. Three receiver positions and two source positions were used. The microphone was set at a height of 1.2 m above ground level.

Octave band measurements at 500, 1k, and 2k Hz were averaged to obtain the mid-frequency reverberation time, T_{mf}, used in BB93[1] as a performance standard. Measurements of the mid-frequency early decay time, EDT_{mf}, were also obtained using a similar procedure.

D_{50} was directly calculated from the measured impulse response using WinMLS. C_{50} was calculated from the D_{50} results using Equation 1 (Chapter 5). Octave band measurements at 500, 1k and 2k Hz were averaged to obtain D_{50} and C_{50} at mid-frequencies.

7.7.3.6 Airborne sound attenuation

The airborne sound level difference, D, between classbases was measured with reference to ISO 140-4[202], to provide an indication of the sound attenuation between classbases, in order to assist with speech privacy assessments.

An omni-directional loudspeaker was used as a test source in a single location, placed in the normal source position and mounted on a tripod at a height of 1.6 m above floor level. A high level of continuous pink noise (90-100 dB) was generated using the WinMLS PC based system and power amplifier, and sent to the omni-directional loudspeaker output. Space and time averaged sound pressure level measurements were recorded using the sound level meter in the source room (in the vicinity of the source position) and receiving room (in the vicinity of the typical listening positions).

All measurements were made using the moving microphone technique with a sample time of 30 seconds. Measurements were taken at least 1.5 m from the loudspeaker and wall, floor and ceiling surfaces. The background noise level in the receiving room was also measured to ensure that receiving room levels were at least 10 dB above the background noise (a correction was applied if this was not the case as described in ISO 140-4[202]).

To obtain the sound level differences in each octave band, the received noise level was subtracted from the source noise level. The standardised weighted level difference (D_w) was calculated from the measured sound level differences in third octave bands from 100 - 3.15k Hz, in accordance with BS EN ISO 717-1[203].

7.7.4 Reproducibility, averaging and calibration

Provided that the same internal set-up in WinMLS is used and the procedure as laid out in this document is followed, measurement results for unoccupied STI and other acoustic parameters should be fully reproducible. The most important settings in WinMLS are duration of measurement, test signal type, sampling rate (48 kHz), and no pre-averaging.

For STI/RASTI measurements, the MLS test signal was used with pre-emphasis applied to the output signal only (STI/RASTI filter), with a maximum decay time plus system delay of 2.2 seconds, and a measurement duration of 4.4 seconds (selected to obtain a balance between processing time and robustness against background noise). WinMLS automatically determines the optimum MLS cycle length and number of averages in the time domain from these settings, controlling user input variation for better reproducibility of results.

At outlying frequencies (125 Hz and 8 kHz), it was not always possible to achieve a signal-to-noise ratio greater than 15 dB in unoccupied classrooms for some measurements furthest from the noise source with the test signal set to 67 dB(A) at 1 m. However a preliminary study[256] has shown that for low reverberation times (< 1 second), considerably lower speech to noise ratios of around 3-4 dB may be tolerated with an MLS signal at these frequencies without any significant difference in calculated MTF and STI results. Therefore this was not considered to affect results significantly.

STI measurements for each location were post-processed with each measured intrusive noise sample for a particular location to obtain a separate STI value for each noise sample. This method gives a better picture of the variance of STI with intrusive noise level and speech-to-noise ratio. Since intrusive noise levels are naturally variable, this aspect of the measurement procedure would not be fully reproducible, however mean results are likely to be comparable given a sufficient sample size.

For reverberation time measurements, a sine sweep signal was used with no emphasis (and no averaging), with a measurement duration of 10 seconds. A high output signal level (90-100 dB) was used to ensure that the effective decay range was at least 30 dB for all frequencies. Reverberation time measurements in the classroom were made sequentially and results averaged to give overall results for the room. The individual reverberation time obtained for each position was also compared to the corresponding unoccupied STI measurement to investigate spatial effects.

A single STI measurement was carried out at each position, since a previous pilot study[257] showed that there is very little variation in repeated measurements at a single receiver position in unoccupied classrooms for these parameters, even in higher background noise conditions (maximum STI variation = 0.003, maximum T_{mf} variation = 0.02 seconds).

No absolute calibration is required for room impulse response measurement, since the response compares the output signal relative to the input signal. However a closed loop calibration of the system was carried out prior to measurement in classrooms, and a correction was applied to account for the delay of the soundcard itself (38 ms).

For airborne sound insulation and noise measurements, microphone and sound level meter calibrations were carried out before and after each measurement session to check that no significant drift occurred (≤ 0.1 dB).

7.7.5 Physical data

In addition to the objective acoustic measurements, physical classroom data were recorded in order to provide supporting information for analysis of results. Architectural plans were obtained for each classroom with permission from the schools, and these were used in conjunction with observations during the survey to determine the following:

- Room geometry (dimensions, shape, ceiling height etc)
- Room volume
- Room surface finish details
- Furniture layout and seating arrangement
- Source/receiver locations
- Classbase design and layout type

All classbases were furnished with chairs, desks, shelves, soft seating and other fittings (including books and wall displays), which is typical of primary school classrooms.

Each classbase was categorised by a design type; linear, cluster or annular (see glossary for definitions). Figure 7.6 - Figure 7.8 show example layout plans for each design type.

Figure 7.6: Example linear layout: 3 classbase unit

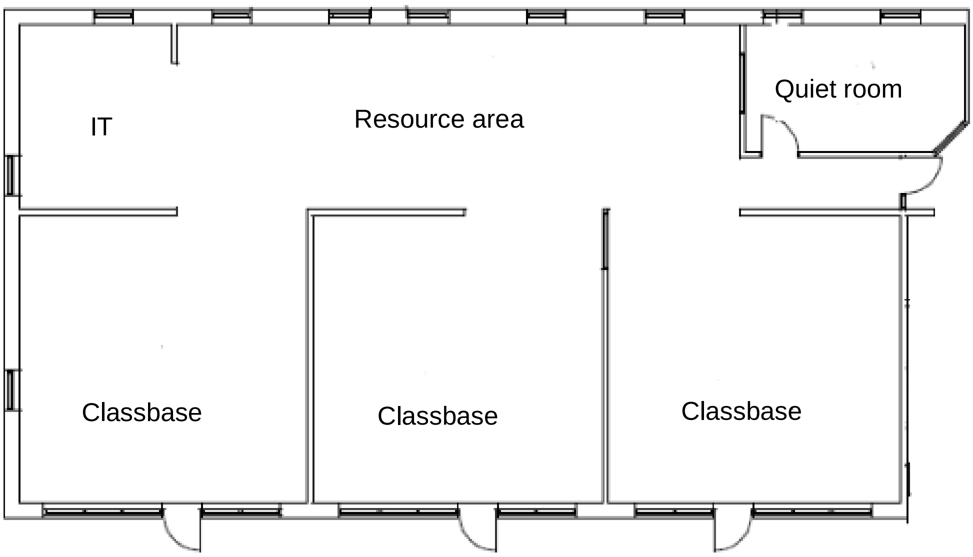


Figure 7.7: Example cluster layout: 3 classbase unit

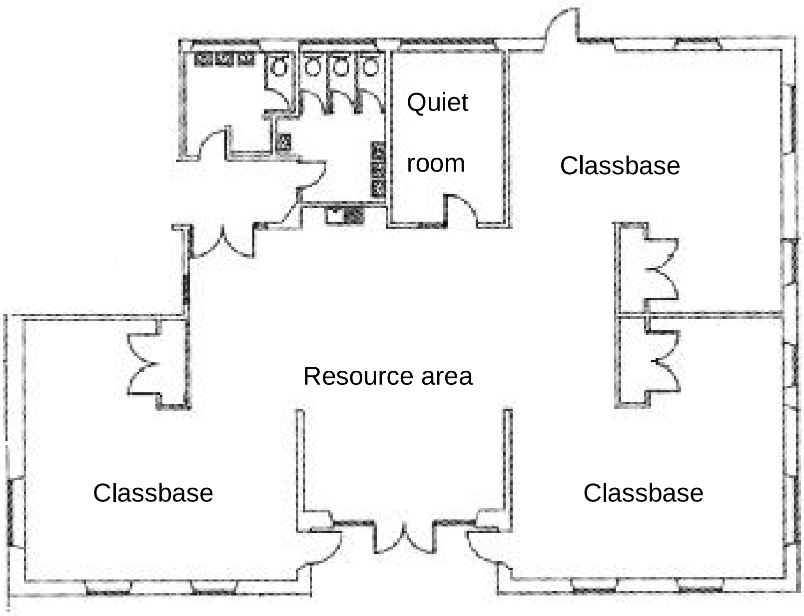
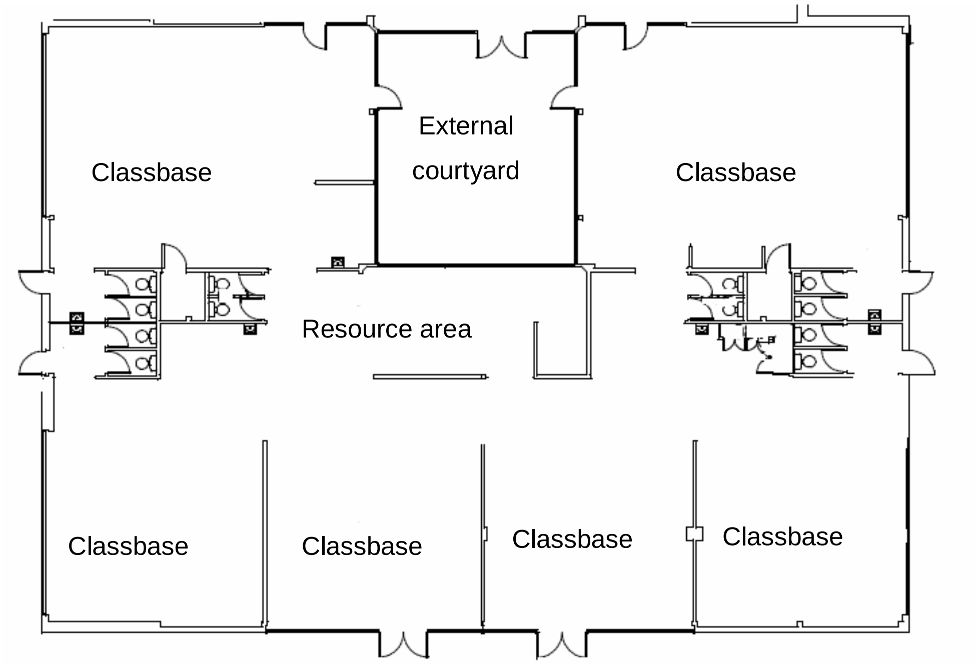


Figure 7.8: Example annular layout



Details of the classrooms included in the survey are summarised in Table 7.3. School plans of the classrooms included in the survey are shown in Appendix A.

The most prevalent type of design in the classroom was the semi-open plan unit with separate classbase space for main teaching of each class and shared resource space and/or quiet rooms, as found by Bennett[20]. Units were designed for between two and 14 teachers.

Table 7.3: Summary of classbase details

School	Classbases in survey	Built	Year groups in survey	Design	Layout	No. Classbases in unit	Floor	Total open area of unit (m2)	Density (m2 per pupil)	Approx. classbase volume (m^3)	Average class size (number of pupils)	Wall finish	Ceiling finish	Quiet room (Y/N)	Carpet area (Y/N)
1	1	1976	2	Semi	Annular	5	Lino	245	1.6	105	30	PL	MFT	N	Y
2	3	1997	2	Semi	Linear	3	Carpet	187	2.1	118	29	BLKp	PL	Y	Y
3	3	1992	2-3	Semi	Cluster	3	Carpet	203	2.6	111	26	BLKp	MFT	Y	Y
4	3	1992	2-3	Semi	Cluster	3	Carpet	203	2.6	111	26	BLKp	MFT	Y	Y
5	3	1972	2-3	Semi	Annular	5	Carpet	478	2.8	145	28	PL	MFT	N	Y
6	9	1992	3-6	Semi	Cluster	5	Lino	244	1.6	136	30	BLKf	PL	N	Y
7	8	1990	3-6	Semi	Linear	14	Carpet	942	2.4	150	28	PL	ML	N	Y
8	3	1991	3-4	Flexible	Cluster	3	Carpet	183	2.1	204	30	BLKf	PL	N	Y
9	3*	1976	2-4	Semi	Annular	6	Carpet	302	2.2	104	23	BRKf	MFT	Y	Y
10	3	1974	1-2	Semi	Linear	3	Lino	134	1.7	104	27	BRKp	WFB	Y	Y
11	2	1973	3	Semi	Linear	2	Lino	141	2.4	130	30	BRKf	MFT	Y	Y
12	1	1976	1	Semi	Cluster	4	Lino	255	2.5	245	26	PL	PL	Y	Y

*N.B. One classbase was enclosed with a single door, however the door was usually kept open during normal teaching time

PL = painted plaster; BLKp = painted blockwork; BLK_f = fairfaced blockwork; BRK_p = painted brickwork; BRK_f = fairfaced brickwork; MFT = suspended mineral fibre tile; ML = corrugated perforated metal; WFB = wood fibre board

7.8 Conclusions

A methodology has been presented for measurement of STI (and RASTI) for critical teacher-to-student speech communication in open plan classbases in primary schools, in accordance with Building Bulletin 93[1] and other relevant standards[155, 156, 214]. The measurement procedure has been informed by results of pilot studies and validated by experimental laboratory work. A procedure has also been described for measurement of other room acoustic parameters (T_{30}, EDT, D_{50} and C_{50}) within open plan classbases, in accordance with Building Bulletin 93[1] and ISO 3382[214].

Both measurement procedures use a PC based system and commercially available software (WinMLS2004) to measure the room impulse response in unoccupied classbases and calculate STI, RASTI and other room acoustic parameters. The STI method uses an MLS signal (where the typical characteristics of teachers' speech are simulated within the signal), and a head sized loudspeaker source which has been validated by experimental laboratory results. The effect of intrusive noise is accounted for separately during post processing of the STI measurements, using measured intrusive noise levels during active periods (main classbase unoccupied) to correct for the active speech-to-noise ratio. Main classbase occupancy noise is also taken into account using a standard spectrum for critical listening activities. The room acoustic parameters method uses a sine sweep signal and an omni-directional loudspeaker.

A method for determining speech privacy of teachers' speech between classbases has been developed in accordance with ANSI 3.5[158] for critical listening periods as informed by the literature review (Chapter 3) and observations from pilot studies and initial school visits. The procedure uses a combination of field measurements (third octave band level difference, D and ambient noise level), and calculated results (calculation of speech intelligibility index, SII).

The school selection process and physical details of the 42 classbases used in the survey have been fully detailed in this Chapter. The results of the objective acoustic measurements are discussed in Chapter 8.

Chapter 8: Objective survey results

8.1 Introduction

Measured objective acoustic data relating to speech intelligibility within classbases and speech privacy between classbases are presented and discussed in this section. All measurements have been carried out in accordance with the procedure detailed in Chapter 7.

The objective parameters presented in this Chapter include ambient and intrusive noise levels, STI, RASTI, speech-to-noise ratio parameters, (S/N_w, S/N(A), SIL) reverberation time (T_{30} and EDT), early sound ratio (C_{50}), speech privacy (SII) and standardised weighted sound level difference, D_w.

The effect of factors such as adjacent activity, position in the classbase, occupant density, unit size and acoustic finishes on intrusive noise level have been investigated, in order to achieve adequate speech intelligibility in the classbase, and to minimize distraction and annoyance.

Factors such as sound level difference, masking noise and classbase layout are also considered in order to provide sufficient speech privacy between classbases as recommended in the literature.

The relationships between measured STI, RASTI, speech-to-noise ratio, reverberation time and other room acoustic parameters have also been investigated to establish optimum criteria in order to achieve BB93[1] performance standards and other standards in the literature (such as enhanced criteria for vulnerable listeners). A management plan and activity matrix is also presented in order to achieve BB93 compliance under optimum acoustic conditions.

8.2 Observed classroom activity

For the 561 intrusive noise samples obtained in all 12 schools measured, the most common classroom activity occurring during measurements was individual work at tables (56%), followed by one person talking at any one time (whole class teaching - 25%), and individual work with movement (15%). Group work (either at tables or with movement) occurred much less frequently (4%). These results were broadly consistent with other studies (see Chapter 3); therefore the samples were considered to be representative of teaching activities occurring in UK primary school classrooms during a typical school day.

8.3 Noise levels

Measured noise parameters are considered separately according to their effect on speech privacy between classbases, speech intelligibility within classbases, and likely distraction and annoyance.

Ambient noise levels have been summarised and compared with BB93 performance standards in this section. These have been used in speech privacy calculations and are discussed in further detail in section 8.11.

Intrusive noise level results comprise overall L_{Aeq}, octave band L_{eq} parameters (which are used in the calculation and measurement of speech intelligibility parameters), and percentile noise level parameters (L_{A10}, L_{A90} etc) which may be used to indicate levels of distraction and annoyance from intrusive noise. Factors such as adjacent classbase activity, measurement or receiver position in the classbase, unit size and ceiling absorption have been investigated to quantify their effect on intrusive noise level.

It should be noted that intrusive noise levels measured in the three flexible classbases and the enclosed classbase (see Table 7.3), were carried out with doors open.

8.3.1 Ambient noise levels

The mean ambient noise level across all unoccupied classrooms was 35 dB $L_{Aeq,5min}$, with levels ranging between 33 and 40 dB. Results were generally consistent between schools and classrooms (σ = 1.6 dB). Assuming that the 5-minute samples are a reasonable indicator of the $L_{Aeq,30min}$ performance standard required by BB93[1] for ambient noise, all classrooms would comply with the maximum criterion for ambient noise levels in open plan teaching spaces of 40 dB(A).

In addition, 64% of the surveyed classrooms met the BB93[1] standard of 35 dB(A) for primary school classbases. Those which exceeded this criterion (classbases in four schools) had subjectively higher levels of building services noise, or elevated levels of external (traffic) noise due to poor façade insulation.

Given that the ambient noise levels measured are low, it is reasonable to assume that the dominant source of intrusive noise was due to activity noise occurring within adjacent classbases, and that ambient noise levels did not influence the STI results significantly.

8.3.2 Intrusive noise

8.3.2.1 Equivalent continuous noise levels, $L_{Aeq(2min)}$

Mean intrusive $L_{Aeq(2min)}$ noise levels (main classbase unoccupied) are presented in Table 8.1 for each adjacent classbase activity 2 to 6 as categorised by Dockrell and Shield (see Chapter 7). It should be noted that activity 1 (silent reading) did not occur as a dominant adjacent activity during the measurements.

Table 8.1 indicates a general trend for intrusive noise levels to increase with increasing activity in adjacent classbases, from 47 to 62 dB(A). This is supported by the significant positive correlation found between adjacent activity ranking (2-6) and average intrusive noise level (rho = 0.56, n = 561, $p < 0.001$).

The mean intrusive noise level for group work at tables (activity 5) does not follow the upward trend, however since this activity did not occur very often, the sample sizes are very low and results cannot be considered to be statistically reliable. The mean noise level for group work at tables is comparable with the noise level for individual work at tables (activity 4), which is unsurprising since for both tasks pupils are typically allowed to talk informally to each other. It appears to be the inclusion of movement in an activity that generates significantly higher average noise levels. This is discussed later in this section.

Table 8.1 Summary of intrusive noise levels

Adjacent activity	Mean $L_{Aeq,2min}$ (dB)	Number of samples, n	σ (dB)
1. Silent reading or test	N/A	N/A	N/A
2. One person talking (whole class teaching)	47	140	4.8
3. Individual work at tables	54	316	5.4
4. Individual work with movement	57	83	4.4
5. Group work at tables	53	7	5.6
6. Group work with movement	62	15	6.7

The measured average data for 'one person talking' falls within the range of Weinstein's[35] measured intrusive noise level data for a six classbase unit when adjacent spaces were 'quiet' (45-49 dB see Table 4.3). Similarly, the measured data for activities 4 and 6 involving movement fall within the range of Weinstein's data for 'active' adjacent classbases (55-66 dB see Table 4.3).

Intrusive noise levels were considered in more detail by investigating the spectral characteristics of the measured data. The mean spectral levels for intrusive noise (main classbase unoccupied) are presented as bars in Figure 8.1 and Figure 8.2. Standardised speech spectra for 'raised' vocal effort at 1 m (normalised to the overall measured A-weighted level), are also indicated as lines for each activity.

For activities 2 and 3 shown in Figure 8.1, the close agreement between the standard raised voice spectrum and measured intrusive noise between 250 Hz and 4 kHz (within 2.0 dB) suggests speech from raised vocal efforts was likely to dominate the noise climate within this range. A greater difference (3-8 dB) occurs at the extremities of the frequency range, (125 Hz and 8 kHz), suggesting that other sources may have been more dominant at these frequencies (such as external, services and equipment noise).

Conversely, for work at tables with movement (activity 4, see Figure 8.2), the agreement between the standard raised voice spectrum and measured intrusive noise level is close (within 2.0 dB) between 125-8k Hz, suggesting that raised speech was dominant across the whole frequency range for this activity.

Figure 8.1: Mean spectral intrusive noise levels (whole class, work at tables)

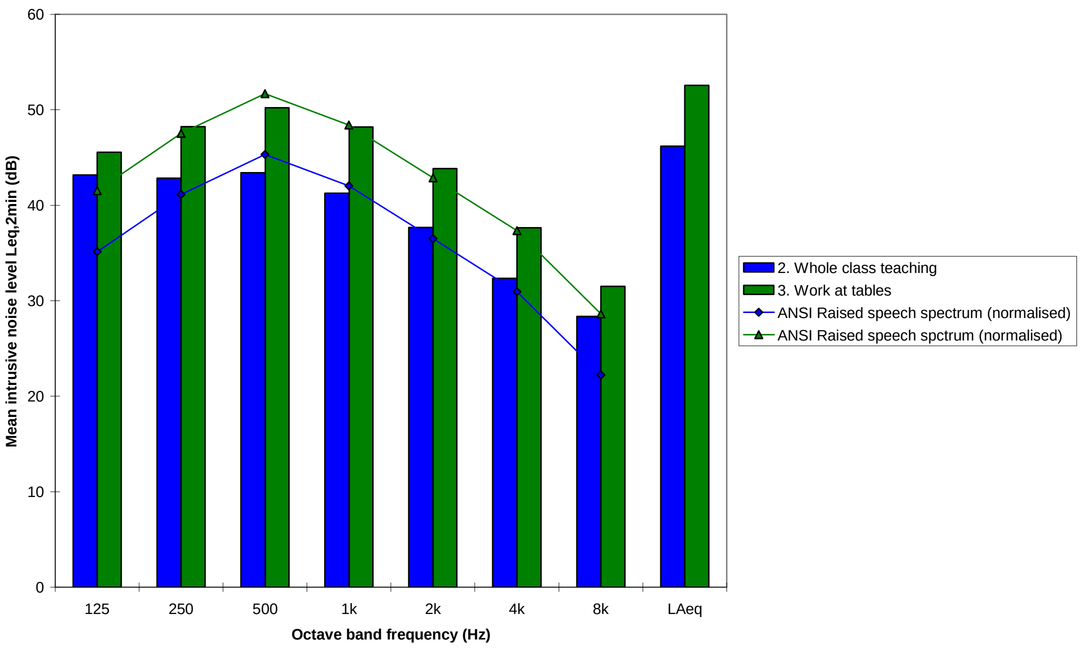
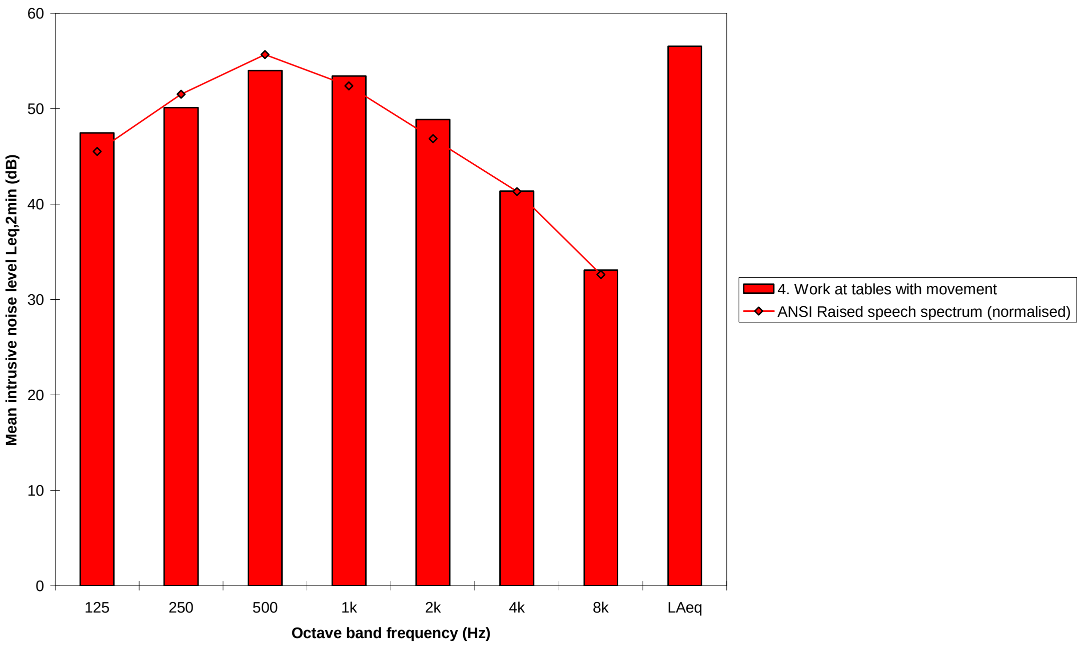


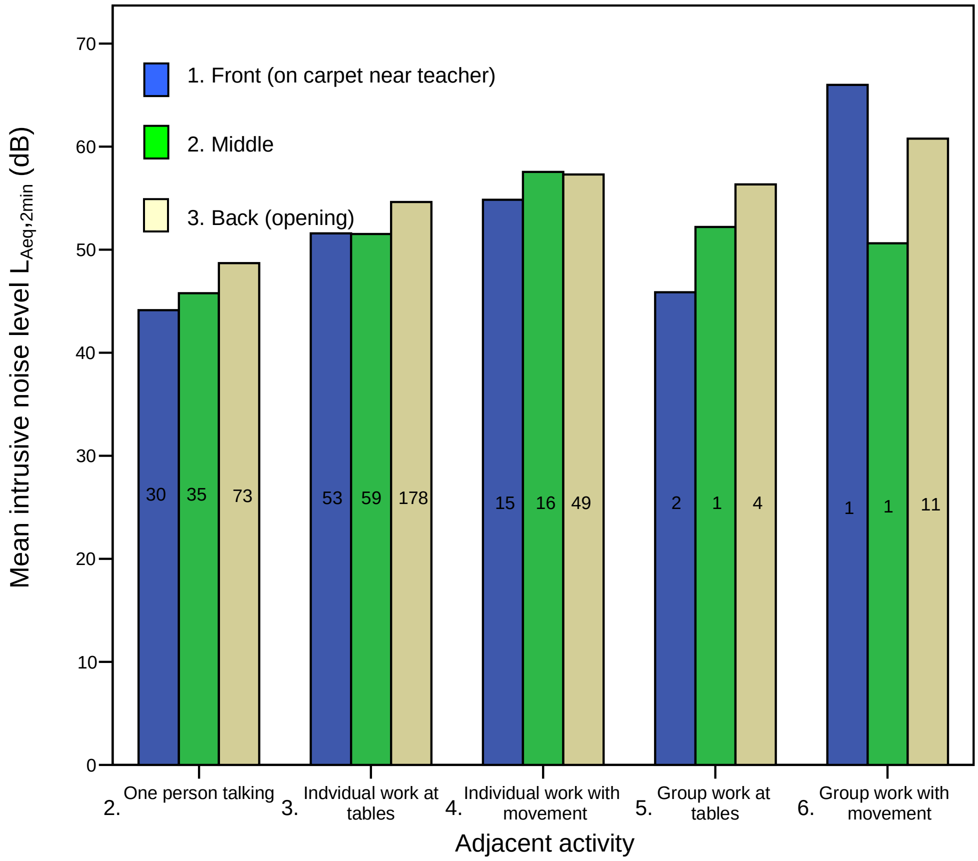
Figure 8.2: Mean spectral levels for work at tables with movement



The intrusive noise level at different positions around the classbase needs to be considered to assess the variation in speech-to-noise ratio (and hence speech intelligibility) around the classbase. This was investigated by measuring at three positions defined as ‘front’ (1),‘middle’ (2) and ‘back’ (3) (see Chapter 7).

In Figure 8.3 the mean intrusive noise levels obtained for each different adjacent activity are broken down into each measurement position (the number of samples n is indicated on each bar).

Figure 8.3: Summary of mean intrusive noise levels by activity and position

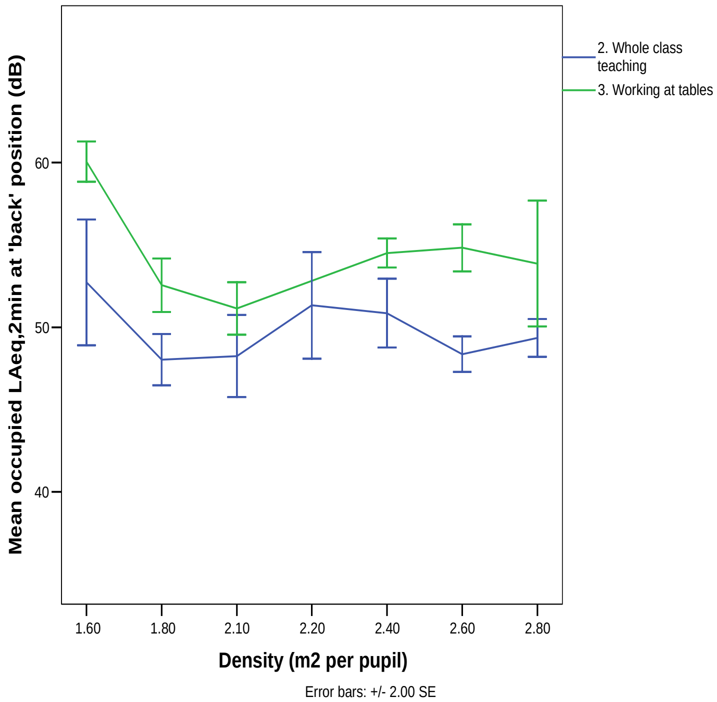


In general, noise levels for each intrusive activity tend to increase as the position moves from the 'front' of the class (nearer the teacher) to the 'back' of the class (nearer the opening and intrusive noise source). Again, measurements with low noise samples are not considered to be statistically reliable. This observation is supported by the significant positive correlation found between average intrusive noise level and position ranking in the classroom (rho = 0.32, n = 764, $p < 0.001$). Moving from the 'front' to the 'back' of the classbase has a detrimental effect on the speech-to-noise ratio, where speech levels are lowest and intrusive noise levels are highest. This is discussed further in following sections.

In addition to adjacent classbase activity and receiver position in the classbase, a major factor in determining the intrusive noise level is reported to be occupant density, or area per pupil (Chapter 4). The basic teaching area per pupil was calculated for each unit by dividing the total basic teaching area in m^2 (including classbases and shared resource space but excluding circulation and enclosed group rooms) by the number of pupils in each classbase (informed by the teachers' survey, see Chapter 10).

The mean L_{Aeq} noise level (main classbase occupied) measured at the rear of the classbase (near the classbase opening) is plotted against the calculated area per pupil in Figure 8.4 (error bars indicate 2 standard errors).

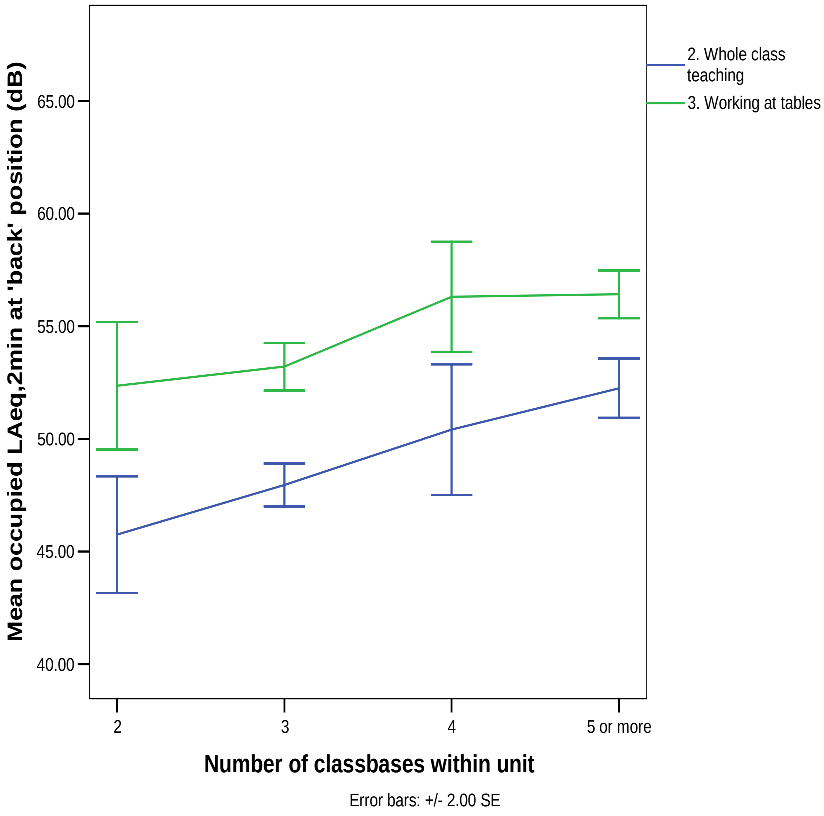
Figure 8.4: Mean noise level vs. floor area per pupil (main classbase occupied)



For unit densities approaching 2.1 m^2 per pupil (the minimum provision for new primary school buildings as set out in Building Bulletin 99[64], see Chapter 3), there is a clear trend for the average noise level to decrease as floor area per pupil increases, which is expected. However as floor area provision increases above the BB99[64] minimum provision, the downward trend is not continued and average noise levels are actually seen to increase. This suggests that occupant density is not a good predictor of intrusive noise level for sparsely populated units (> 2.1 m^2 per pupil). There may be a number of reasons why this occurs. It could be that the method for calculating student density is not sufficient as it may not represent the exact number of pupils active in the open plan space during the time of measurement. It is also possible that occupants' behaviour differs as density decreases, with occupants in very sparsely populated units behaving as if operating in an enclosed space. Other factors, such as the layout of the unit and distance between classbase openings are likely to affect the intrusive noise level (as discussed in section 8.11). The number of classbases within each open plan unit is also likely to be an important factor in determining the intrusive noise level occurring in the classbase. Other acoustic factors, such as reverberation time, are discussed in following sections.

The effect of unit size was investigated by plotting overall L_{Aeq} noise levels (main classbase quiet and occupied) measured at the 'back' of the classbase according to the number of classbases within each unit (Figure 8.5). Error bars indicate a range of ±2 standard errors.

Figure 8.5: Mean intrusive noise level vs. number of classbases.



The mean noise level tends to increase as the number of classbases increases, for both whole class teaching and work at tables. This suggests that unit size may be a more suitable predictor of noise level than floor area per pupil for more sparsely populated units. This could be attributed to larger units being less self-contained, and hence additional noise sources (over and above pupil and teaching activity noise) are likely to occur more often, such as circulation.

To determine whether the increase in noise level with unit size was significant, statistical t-tests were carried out to compare difference between unit sizes.

A significant difference in mean intrusive noise level was obtained between units of either 2 or 3 classbases, and units of 4 or more classbases, for one person talking ($t = 5.7$; $df = 70$; $p < 0.001$), individual work at tables ($t = 4.5$; $df = 12$; $p < 0.001$) and individual work with movement ($t = 2.5$; $df = 58$; $p < 0.05$), with significantly higher noise levels for units or 4 classbases or more.

No significant difference in mean intrusive noise level was found between units of 2 and 3 classbases, for either one person talking ($t = -2.0$, $df = 34$; $p = 0.05$), working at tables ($t = -0.24$, $df = 63$; $p = 0.72$) or individual work with movement ($t = 0.27$; $df = 9$; $p = 0.78$). Similarly, no significant difference was found for intrusive noise levels between four and 5 or more classbase units, for either one person talking ($t = -1.4$, $df = 35$; $p = 0.185$), working at tables ($t = 0.11$, $df = 115$; $p = 0.91$) or individual work with movement ($t = 1.6$; $df =47$; $p = 0.12$).

Therefore, in further analyses, results were analysed by grouping measurements into ‘limited’ units (2-3 classbases) and ‘large’ units (4 or more classbases).

As shown in Table 8.2, the average intrusive noise level at the back of the classbase was found to be on average 5 dB lower in limited units for whole class work, 4 dB lower for individual work at tables, and 4 dB lower for individual work with movement.

Table 8.2: Mean intrusive noise level at ‘back’ of classroom

Adjacent activity	Limited units			Large units		
	Mean $L_{Aeq,2min}$ (dB)	n	σ (dB)	Mean $L_{Aeq,2min}$ (dB)	n	σ (dB)
2. One person talking	46	36	4.0	51	37	3.7
3. Individual work at tables	52	65	4.9	56	117	4.6
4. Individual work with movement	55	11	5.8	59	49	4.4

The L_{Aeq} intrusive noise level measurements presented above are pertinent to the assessment of speech-to-noise ratio and hence speech intelligibility within classbases, that is, the ability to hear the teacher (or peers). However another important aspect of intrusive noise is its effect on annoyance and distraction when working in the classbase, discussed below.

8.3.2.2 Percentile noise levels

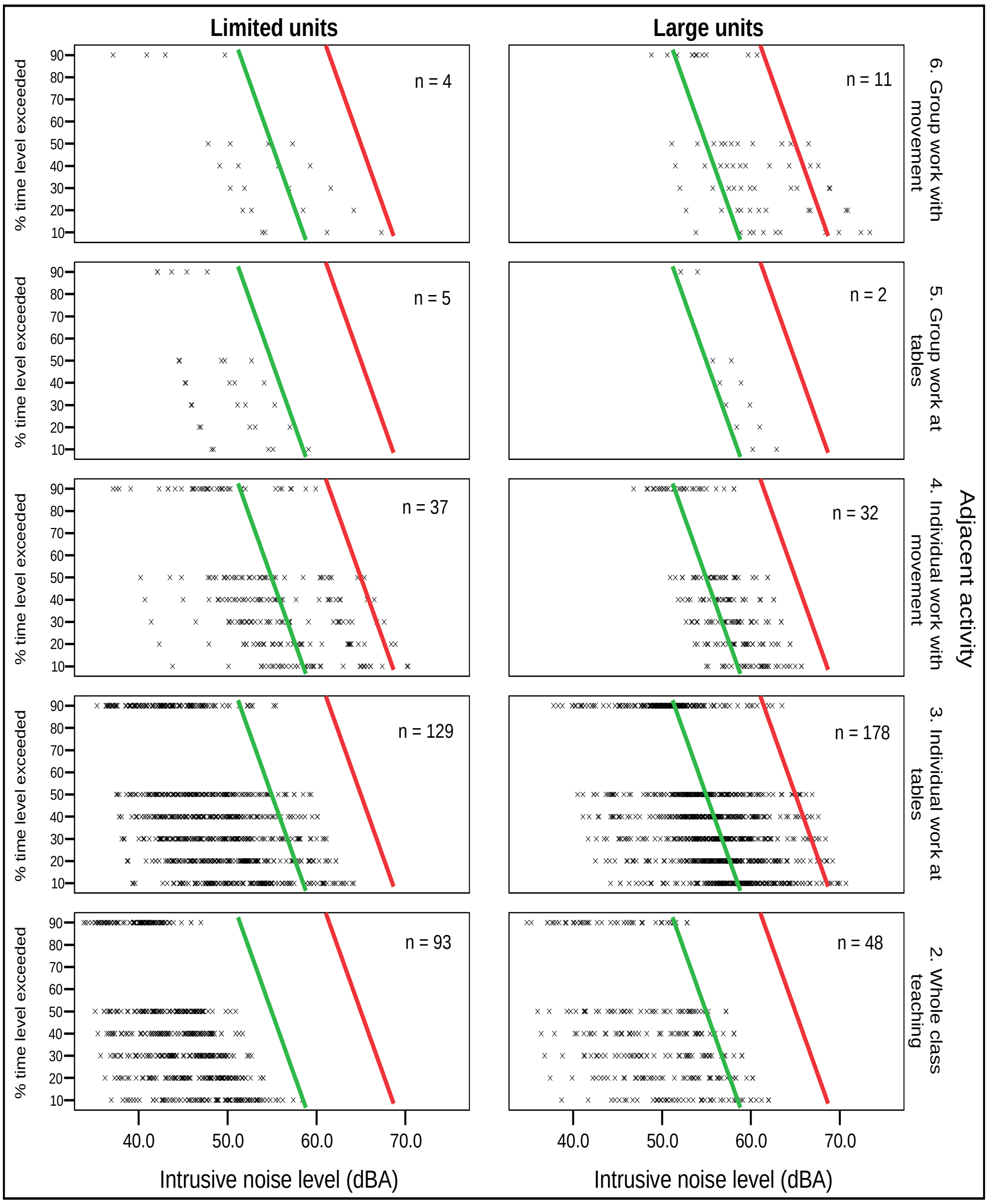
The degree of annoyance and distraction from intrusive noise is related to the fluctuation in intrusive noise level, as discussed in Chapter 4. This may be investigated by considering the distribution of percentile noise level parameters L_{A10}, L_{A20}, L_{A30}, L_{A40}, L_{A50} and L_{A90}. Each parameter indicates the intrusive noise level exceeded for a certain percentage of the two minute sample measurement period (10%, 20%, 30%, 40%, 50%, and 90% respectively).

The measured percentile intrusive noise levels (main classbase unoccupied) were plotted as a function of the percentage of time that the level was exceeded. Figure 8.6 shows the percentile levels for each different adjacent activity, and for limited and large units. Walsh's[22] recommended regions of acceptability (section 4.5) to avoid distraction and annoyance are also indicated by the sloped lines which differentiate the regions 'acceptable' (to green line), 'marginal' (between green and red line) and 'unacceptable' (exceeding red line).

For most adjacent activities, percentile noise levels for large units are generally higher than for limited units. For whole class teaching, percentile levels are within 'acceptable' or 'marginal' regions for annoyance/distraction, for both limited and large units. Whilst 'acceptable' or 'marginal' levels of annoyance/distraction are obtained for individual work at tables for limited units, some samples for this activity fall into the 'unacceptable' range for large units. This is also the case for work at tables with movement, for limited units. It is more difficult to analyse the results for activities 5 and 6 by inspection since the sample size is small and the variance is greater. Mean results were plotted in order to investigate this further.

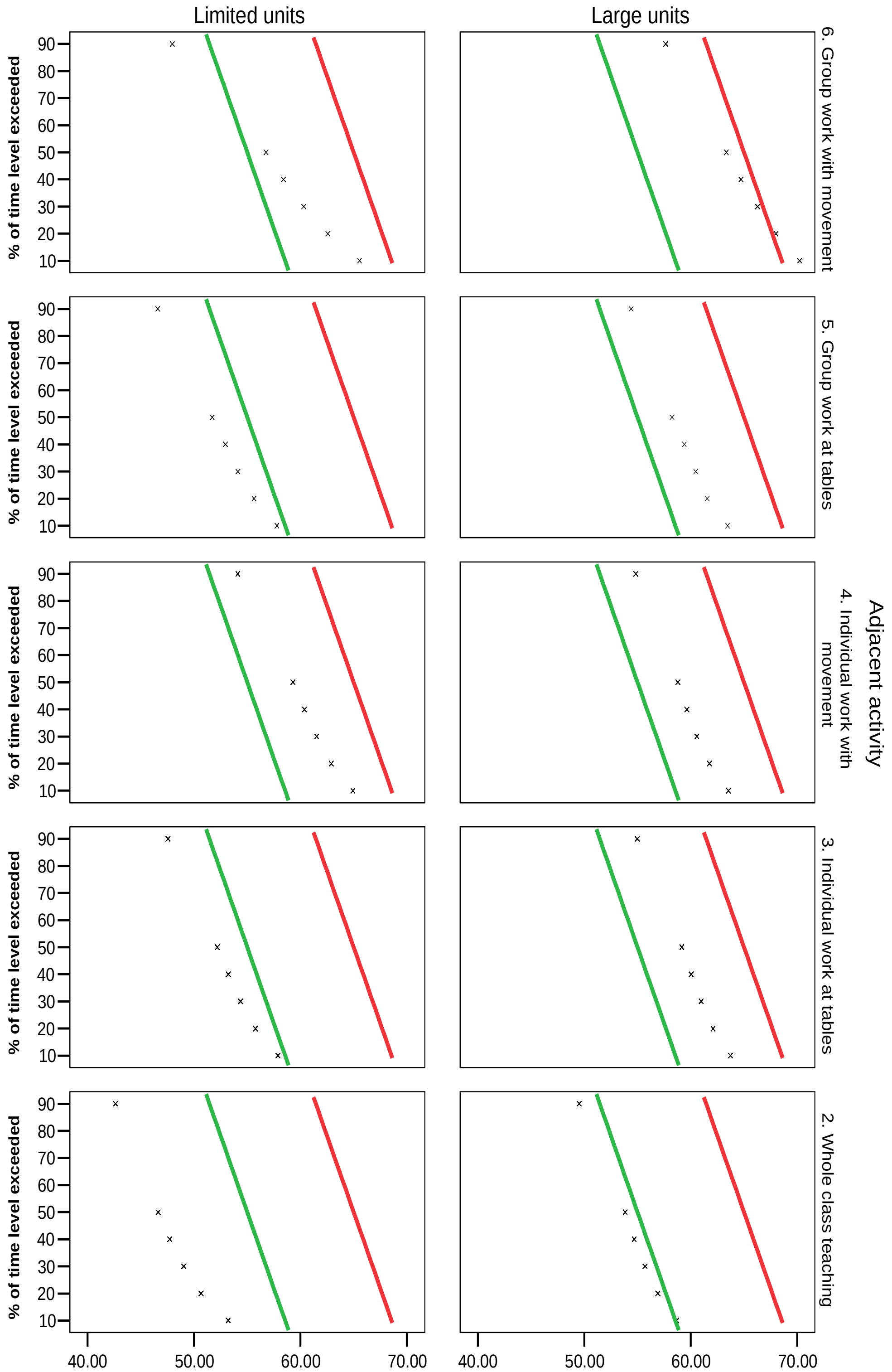
Figure 8.7 shows mean plus standard deviation results by activity and unit type in order to provide a likely upper range for intrusive noise level. These results show that, for limited units, the mean percentile levels for activities 3 and 5 (individual or group work at tables) are very similar (within 1.0 dB). Similarly, the mean percentile levels for activities 4 and 6 (individual or group work with movement) are also similar for limited units.

Figure 8.6: Percentile intrusive noise levels for limited and large units



The mean results (Figure 8.7) demonstrate that units need to be restricted to limited units to maintain acceptable levels of annoyance/distraction when adjacent classbases are working at tables (either group work or individual work). Limited units also appear more likely to maintain 'marginal' levels of annoyance/distraction when classbases are moving around the classroom (for group work). Mean results for activity 4 are similar for both limited and large units, however a large degree of scatter is apparent for limited units (see Figure 8.6).

Figure 8.7: Percentile noise levels (mean plus one standard deviation)

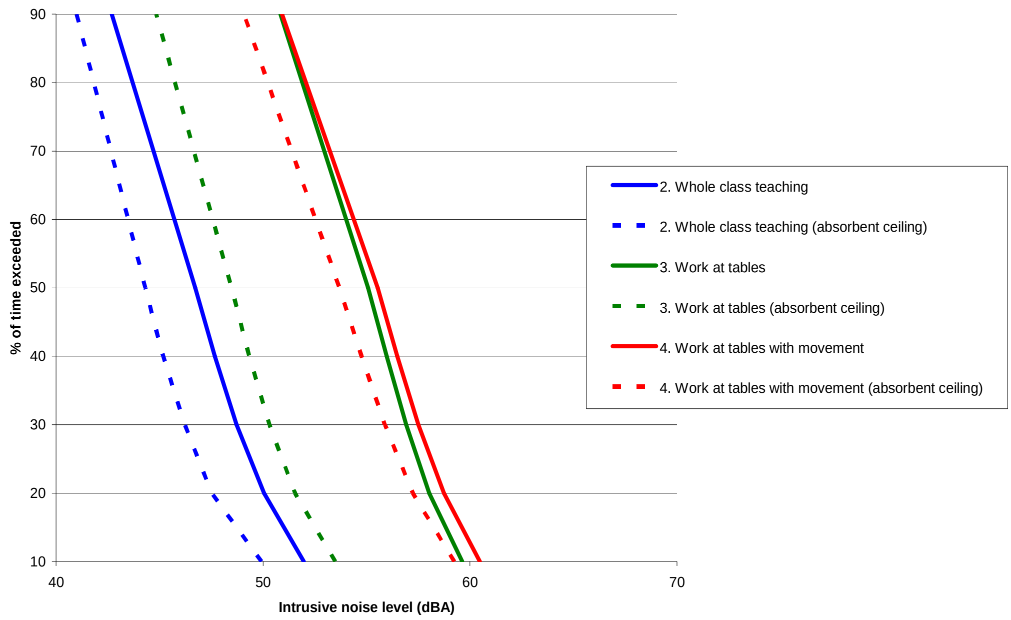


Whilst open plan unit size has a significant effect on intrusive noise levels as discussed above, provision of acoustic absorption (typically installed on the ceiling) is also important to control noise levels (see section 4.6).

This factor was investigated by comparing average intrusive noise levels measured in semi-open plan classrooms with acoustically absorbent ceilings such as mineral fibre tile, perforated metal or wood fibre board (25 semi-open classbases as detailed in Table 7.3), and those with acoustically reflective ceilings such as painted plaster (13 semi-open classbases).

Figure 8.8 shows mean percentile noise levels plotted as a function of adjacent classbase activity for classbases with and without acoustically absorbent ceilings. Average intrusive percentile noise levels for each activity are considerably lower for classbases with acoustically absorbent ceilings, as expected, with an average 2-3 dB reduction in noise level for activities 2 and 4, and a 6-7 dB reduction for activity 3.

Figure 8.8: Intrusive percentile noise levels *vs.* ceiling type



8.4 STI

In order to provide an initial indication of the dominant factor affecting STI (noise, reverberation or echoes, see section 5.7.5), a cursory inspection of the values in each modulation transfer function matrix was carried out after each measurement. In general the m values in each octave band (f) reduced only slightly as the modulation frequency (k) increased. This suggested that STI was generally more significantly affected by noise rather than reverberation.

STI results for the main classbase unoccupied are presented and discussed first since these are based on measured in-situ data. Results for the main classbase occupied were predicted by post processing the results based on a standard spectrum used for children quiet and listening to the teacher (see Chapter 7) and are discussed separately.

8.4.1 Unoccupied main classbase

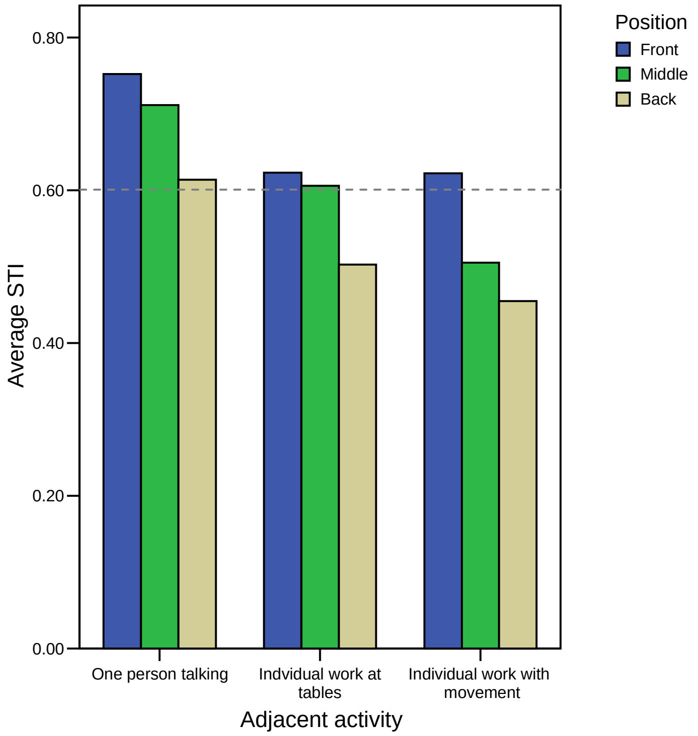
The mean measured STI results are shown in Table 8.3. These data are based on the actual intrusive noise level recorded for each sample measurement position (‘front’, ‘middle’, ‘back’) for different adjacent activities. The standard deviation is included to describe STI since the mean results alone are not sufficient to describe the degree of variation in STI over multiple measurements.

Table 8.3: Mean STI results measured for main classbase unoccupied

Adjacent activity	Position	n	Mean unoccupied STI	σ
2. One person talking	Front	30	0.75	0.07
	Middle	35	0.71	0.07
	Back	68	0.61	0.09
3. Individual work at tables	Front	53	0.62	0.16
	Middle	59	0.61	0.11
	Back	156	0.50	0.12
4. Individual work with movement	Front	9	0.62	0.09
	Middle	13	0.51	0.10
	Back	39	0.46	0.11

Figure 8.9 shows the mean STI achieved for each type of activity at each position, respectively. Note that the results for group work have not been included in the graph, since the results are statistically unreliable. As expected, there is a general trend for the STI to decrease with increasing level of activity, and as the position moves towards the ‘back’ of the class (further away from the speech source and nearer to the noise source). For this data set (including group activities), a significant negative correlation was found between STI and activity (rho = -0.47, n = 508, $p < 0.001$), and between STI and position (rho = -0.46, n= 475, $p < 0.001$).

Figure 8.9: Mean STI for activity and position



Average STI results with the main classbase unoccupied are considered as a preliminary indication of the likely activity plan necessary for BB93 compliance. For coordinated activities (adjacent classbases engaged in whole class teaching with one person talking at any time), the average measured STI exceeded the BB93 criterion of STI > 0.6 for all positions, indicating that whole class teaching at desks may be feasible under these circumstances. For individual work at tables taking place in adjacent classbases, the BB93 criterion was achieved for the front and middle positions. For individual work with movement the criterion was achieved for the front position only. At the back of the class (near the opening), the criterion was not achieved for either of these activities. Therefore during critical listening tasks, if adjacent activities are not coordinated, children should be gathered closer to the teacher, away from the opening.

Since intrusive noise levels for group work at tables have been shown to be similar to individual work at tables, STI results are likely to be comparable (although further data would be required to support this). Due to the likely higher noise levels for group work activities involving movement, the STI criterion is not likely to be met for this activity.

8.4.2 Occupied main classbase

The mean STI results calculated are shown in Table 8.4 for each adjacent activity and position. It should be noted that the calculated results for the main classbase occupied use a standard spectrum for occupancy (see Chapter 5) and can only give an approximate indication of the STI likely to be achieved in realistic conditions. However this method allows a standard comparison to be made between classbases for critical listening conditions. The calculated overall occupied results suggest that BB93 compliance would only be achieved for coordinated activities in the front and middle positions.

Table 8.4: Mean STI results calculated for main classbase occupied

Adjacent activity	Position	n	Mean occupied STI	σ
2. One person talking	Front	30	0.70	0.06
	Middle	35	0.67	0.06
	Back	68	0.58	0.08
3. Individual work at tables	Front	53	0.59	0.14
	Middle	59	0.57	0.09
	Back	156	0.48	0.11
4. Individual work with movement	Front	9	0.59	0.07
	Middle	13	0.49	0.09
	Back	39	0.44	0.10

The calculated reduction in STI due to the addition of main classbase occupancy noise is shown in Table 8.5. The STI decreases by 0.02 - 0.05 when noise due to occupants within the main classbase is taken into account.

Table 8.5: Reduction in STI due to main classbase occupancy noise

Adjacent activity	Position	n	Mean reduction in STI
2. One person talking	Front	30	0.05
	Middle	35	0.04
	Back	68	0.03
3. Individual work at tables	Front	53	0.03
	Middle	59	0.04
	Back	156	0.02
4. Individual work with movement	Front	9	0.03
	Middle	13	0.02
	Back	39	0.02

There is generally a greater difference between unoccupied and occupied results for activity 2, and for positions at the front of the classroom, since intrusive noise levels are lower for these situations, and the noise level due to occupants in the main classbase makes a greater contribution to the total background noise level.

For noisier intrusive activities and positions towards the back of the room (more critical measurement positions), the intrusive noise level is dominant and hence a smaller difference occurs between the occupied and unoccupied main classbase results. This difference is comparable to the JND and typical standard deviation under fixed conditions (see Chapter 7). Therefore the measurement procedure used (main classbase unoccupied) would be a reasonable method for assessment of critical worst case measurement positions without needing to correct for main classbase occupancy noise.

Occupied STI results were considered separately for classbases in limited units (n = 17) and large units (n = 25), as shown in Figure 8.10 and Figure 8.11. A higher correlation was found between STI and dominant classroom activity for limited layouts (rho = -0.50, n = 223, $p < 0.001$), than for larger layouts (rho = -0.38, n = 285, $p < 0.001$).

Occupied mean STI results are significantly better for limited units than for large units ($F_{1,509} = 100$, $p < 0.001$). For limited units, generally the same conditions to achieve BB93 compliance are necessary as for when the main classbase is unoccupied (see above).

For the larger units, compliance is only achieved for coordinated activities for the front and middle positions. Although compliance is indicated for individual work with movement for the front position here, the result should be treated with caution as the small number of samples is unlikely to be statistically reliable.

Figure 8.10: Mean occupied STI for limited layouts

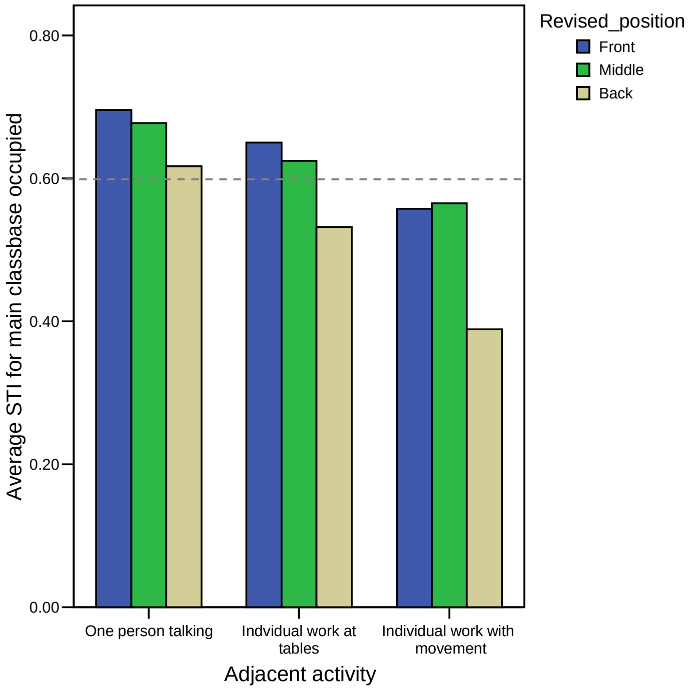
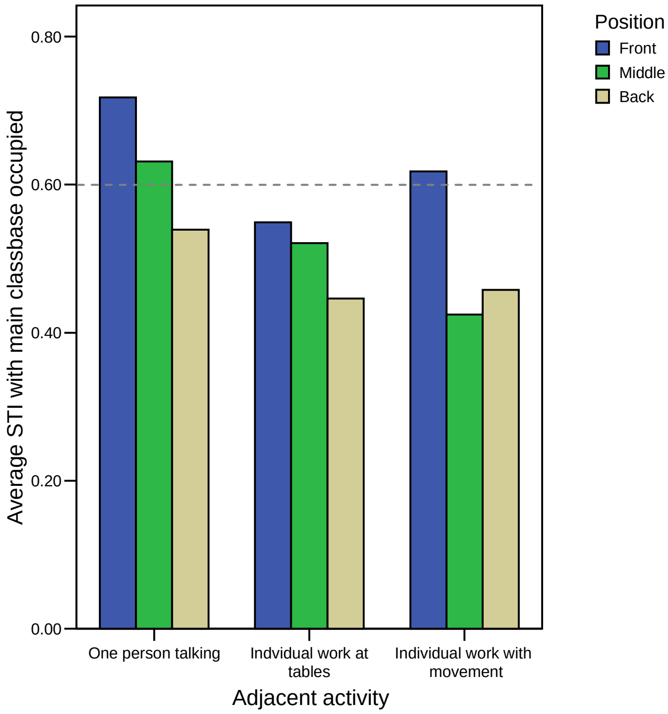


Figure 8.11: Mean occupied STI for large layout



8.5 RASTI

Figure 8.12 shows the relationship between occupied STI and RASTI. A strong correlation was found between STI and RASTI ($r = 0.96$; $n = 515$; $p < 0.001$) as expected. As indicated in Table 8.6, the mean occupied RASTI values exceeded occupied STI results by 0.05-0.09, depending on the type of adjacent activity and position. The correlation between RASTI and activity ($rho = -0.47$, $n = 506$, $p < 0.001$) and RASTI and position ($rho = -0.43$, $n = 473$, $p < 0.001$) was similar to that for STI results. The difference between STI and RASTI is generally due to speech-to-noise ratios being over-estimated for RASTI, since this method uses only two octave bands (500 Hz and 2 kHz) for analysis.

Use of RASTI to assess the BB93 criterion for open plan classrooms would indicate BB93 compliance in some cases where the equivalent STI rating would not. Inspection of the line of best fit and 95% confidence intervals in Figure 8.12 indicates that a RASTI value of at least 0.75 would need to be achieved to ensure compliance with BB93.

Figure 8.12: Scatterplot of occupied STI and RASTI

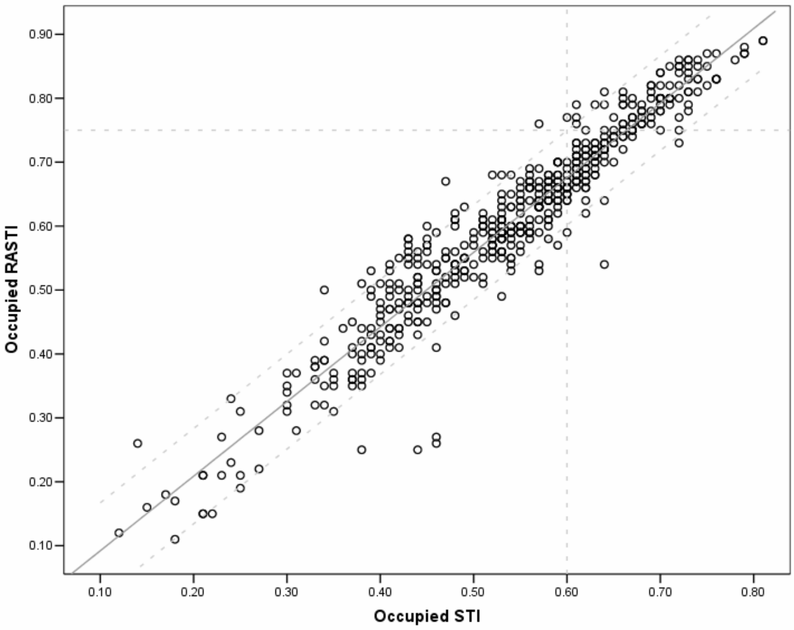


Table 8.6: Comparison of mean occupied RASTI and STI results.

Adjacent activity	Position	n	Mean increase (RASTI - STI)
One person talking	Front	30	0.08
	Middle	35	0.09
	Back	68	0.09
Individual work at tables	Front	53	0.05
	Middle	59	0.09
	Back	156	0.05
Individual work with movement	Front	9	0.08
	Middle	13	0.06
	Back	39	0.05

8.6 Speech-to-noise ratio

The mean speech-to-noise ratio results, S/N(A) and S/N_w, for both unoccupied (measured) and occupied (estimated) conditions are shown in Table 8.7. Standard deviations are shown in parentheses. Again the results for group work have not been included due to the small sample set. As expected, the speech-to-noise ratio decreases with increasing level of activity, and as the measurement location approaches the 'back' of the class.

For the (predicted) occupied case, speech-to -noise ratios were up to 3 dB lower than for unoccupied results, with the largest difference occurring for quiet activities (one person talking) nearest the front of the classroom. The mean occupied speech-to-noise ratios achieved for these cases (12-15 dB) are likely to achieve the BB93 criterion for STI, and are therefore not critical. The difference was less pronounced (0-1 dB) for the other cases.

Table 8.7: Mean speech-to-noise ratio results

Adjacent activity	Position	n	Unoccupied results S/N(A) dB	Unoccupied results S/N_w dB	Occupied results S/N(A) dB	Occupied results S/N_w dB
2. One person talking	Front	30	18 (4.4)	14 (3.6)	15 (3.0)	10 (2.3)
	Middle	35	14 (3.2)	11 (3.2)	12 (2.1)	9 (2.0)
	Back	71	9 (4.9)	7 (4.2)	8 (3.8)	6 (3.3)
3. Individual work at tables	Front	53	10 (6.7)	8 (5.7)	9 (5.9)	6 (4.8)
	Middle	59	9 (4.7)	7 (4.0)	8 (4.0)	5 (3.4)
	Back	155	4 (5.5)	2 (4.6)	3 (4.9)	2 (3.9)
4. Individual work with movement	Front	9	10 (3.2)	7 (2.4)	9 (2.9)	6 (2.2)
	Middle	13	4 (4.4)	3 (3.5)	4 (4.3)	2 (3.2)
	Back	41	2 (4.9)	0 (4.1)	2 (4.5)	0 (3.6)

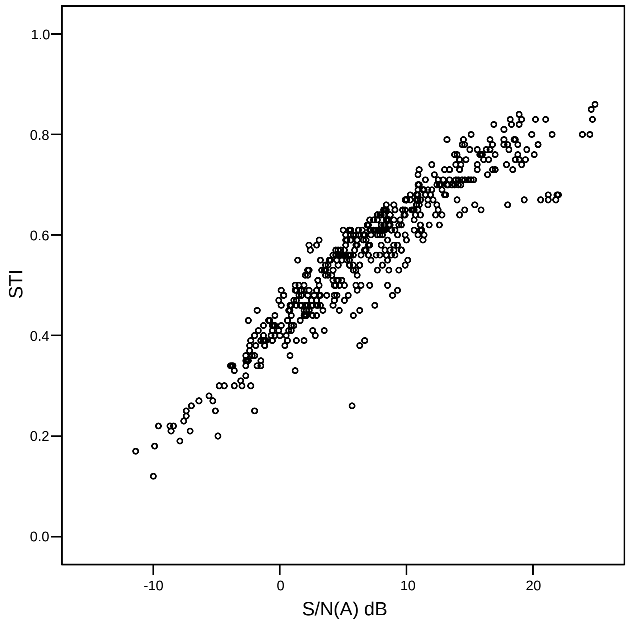
The mean S/N(A) results are 1-4 dB higher than the mean S/N_w results. This is because the A-weighting network used for S/N(A) takes account of the observed effect that the human hearing system is less sensitive to perceived loudness at lower frequencies. However the weighting factors used for S/N_w (see Table 5.3) show that contributions at lower frequencies (125 and 250 Hz) have a higher weighting than those at mid-frequencies (500 and 1 k Hz).

Average occupied S/N(A) results for coordinated whole class teaching (one person talking) were compared with Bradley and Sato's[176] study of enclosed classrooms (Figure 5.3). This suggests that, provided activities are coordinated, adequate conditions to achieve 95% speech intelligibility could be achieved at all classroom positions for average 11 year olds (8.5 dB required), at the front and middle positions for average 8 year olds (12.5 dB required), and at the front position only for average 6 year olds (15.5 dB required).

A significant negative correlation was found between S/N(A) and activity category (ρ = -0.49, n = 512, $p < 0.001$), and between S/N(A) and position (rho = -0.44, n = 699, $p < 0.001$). A similar correlation was found between S/N_w and activity category (rho = -0.48, n = 513, $p < 0.001$), and between S/N_w and position (rho = -0.42, n = 699, $p < 0.001$).

A strong positive correlation was found between STI and S/N(A) (r = 0.94, n = 508, $p < 0.001$), and between STI and S/N_w (r = 0.96, n = 508, $p < 0.001$). The scatter diagram in Figure 8.13 shows that a strong linear approximation exists between STI and S/N(A) up to around S/N(A) = 15 dB, after which a plateau is reached, in line with STI theory (Chapter 5). The effect of reverberation time on this relationship is explored further in section 8.9. S/N_w was better correlated to STI than S/N(A) for obvious reasons, as STI theory uses the same weighting network as S/N_w.

Figure 8.13: Relationship between STI and S/N(A)



The linear relationship between STI and speech-to-noise ratio was investigated further by excluding those S/N values in excess of 15 dB, since a linear relationship no longer applies in this range. The relationship between STI and S/N(A) is shown in Figure 8.14, which also displays the 95% confidence intervals. This suggests that in order to achieve the BB93 criterion of STI > 0.6, a speech to noise ratio of between 8 and 13 dB S/N(A) would be required. Similar analysis for S/N_w (Figure 8.15) suggests between 6 and 11 dB S/N_w would be necessary to achieve the BB93 criterion.

Figure 8.14: STI *vs.* S/N(A) (-15 dB to +15 dB range)

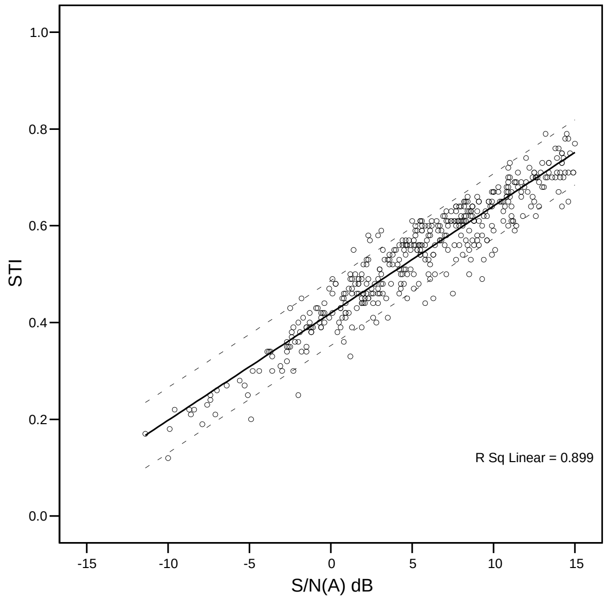
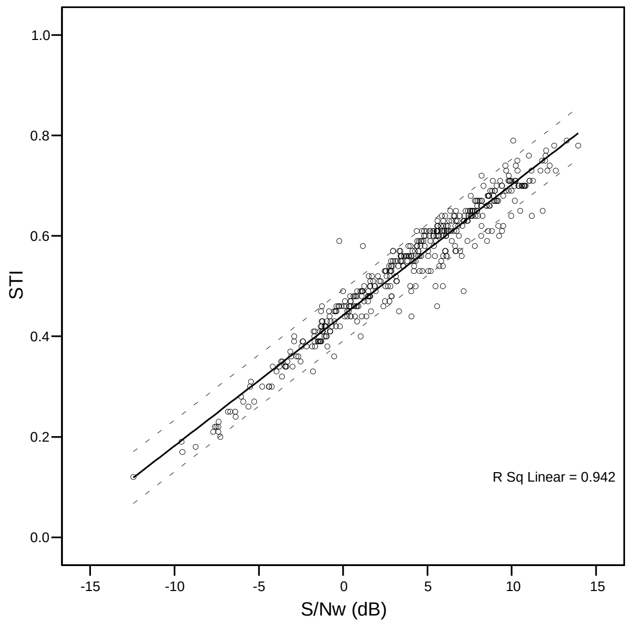


Figure 8.15: STI *vs.* S/N$_w$ (-15 dB to +15 dB range)



It should be noted that although speech-to-noise ratios in this range could be considered adequate for adults and older children (over 12 years old), with normal hearing, a higher S/N(A) is usually recommended for younger children and more vulnerable listeners to achieve equivalent scores in speech intelligibility (Chapter 5). In view of this, it could appear that the BB93 standard of STI 0.6 is not sufficient to achieve the required S/N(A) for these groups. However, some trade off between S/N(A) and reverberation time is apparent as discussed in Chapter 5 and section 8.9.

8.7 Reverberation time

Both unoccupied T_{30} and EDT results are presented in this section and their effect on STI is investigated. Mid-frequency reverberation times (T_{mf}) are presented for comparison with BB93[1] performance standards.

Mean unoccupied mid-frequency reverberation time results ($T_{mf(furnished)}$ and $EDT_{mf(furnished)}$) for each school are presented in Table 8.8. Results have been averaged for each school over all measurement positions and classbases. The standard deviation for each school is also presented in parentheses.

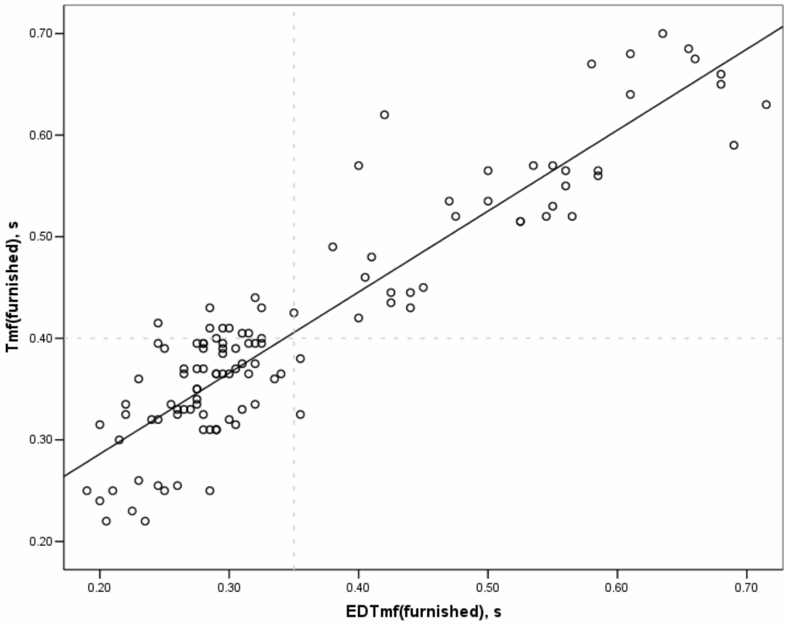
Table 8.8: Unoccupied T_{mf} and EDT_{mf} results (furnished)

School	Mean T_{mf}, s (% σ)	Mean EDT_{mf} (% σ), s	No. classbases measured	Carpet?	Absorbent ceiling?	Approximate classbase volume (m^3)
9	0.26 (15.9)	0.24 (17.4)	3	Y	Y	104
1	0.31 (9.8)	0.26 (12.3)	1	N	Y	105
10	0.31 (14.3)	0.30 (12.3)	3	N	Y	104
11	0.33 (3.8)	0.25 (11.1)	2	N	Y	130
3	0.34 (8.7)	0.28 (12.7)	3	Y	Y	111
5	0.35 (6.3)	0.28 (13.0)	3	Y	Y	145
4	0.38 (9.4)	0.29 (8.2)	3	Y	Y	111
7	0.40 (4.6)	0.30 (10.1)	8	Y	Y	150
6	0.47 (8.2)	0.45 (11.6)	4	N	N	136
8	0.56 (3.3)	0.55 (4.7)	3	Y	N	204
2	0.61 (12.0)	0.61 (15.6)	3	Y	N	118
12	0.64 (6.2)	0.55 (20.6)	1	N	N	245

T_{mf} results were generally fairly consistent between measurement positions and classrooms for each school. However EDT_{mf} generally showed a greater degree of variation between measurement positions than T_{mf}. The mean EDT_{mf} was up to 0.1 seconds lower than the mean T_{mf}. A strong correlation was found between T_{mf} and EDT_{mf} for the mean values in each classroom ($r = 0.91$, $n = 114$, $p < 0.001$), as expected.

As shown in Figure 8.16, a value of $EDT_{mf(furnished)} = 0.35$ corresponds to a value of approximately $T_{mf(furnished)}$ 0.40 seconds as indicated by the line of best fit.

Figure 8.16: Relationship between T_{mf} and EDT_{mf}

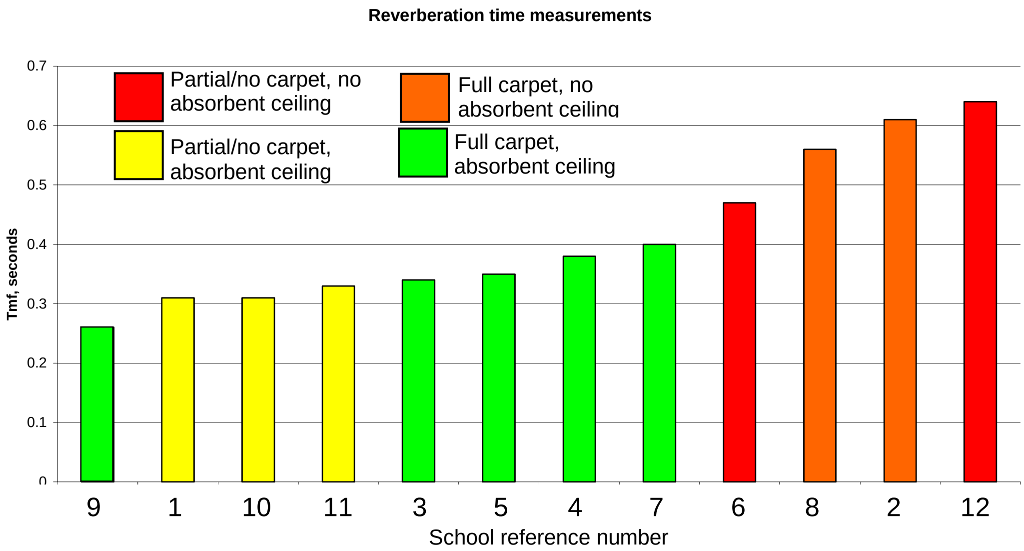


$T_{mf(furnished)}$ results are displayed in Figure 8.17, which also highlights the basic type of acoustic finishes (carpet, absorbent ceiling or both) in each classroom. This shows that classrooms with absorbent ceilings (with or without carpet) achieve a maximum reverberation time of $T_{mf(furnished)}$ 0.4 s (as recommended by Danish[216] and Swedish[238] guidance for open plan classrooms, see Chapter 6). Classrooms without absorbent ceilings exceed this criterion. Carpet does not appear to be essential to control reverberation time, as expected (Chapter 4), but is beneficial to control footfall noise.

All classrooms met the BB93[1] maximum criterion for open plan teaching areas (maximum $T_{mf(unfurnished)}$ 0.8 seconds) and all except two schools met the BB93 requirement for primary school classbases (maximum $T_{mf(unfurnished)}$ 0.6 seconds). It should be noted that measurements were carried out in furnished classbases, and the reverberation time is likely to be slightly higher when measured without furniture or fittings in place (as required by BB93[1]). However, those rooms with absorbent ceilings (with or without carpet) are still likely to meet BB93 requirements for primary school classbases.

RT criteria given in ANSI 12.60[196] are expressed in terms of unoccupied, furnished spaces (see Chapter 6), with a maximum mid-frequency reverberation time criterion of 0.6 seconds for classrooms less than 283 m^3. This criterion is satisfied for all but two schools, both of which do not have sound absorbent ceilings.

Figure 8.17: T_{mf} results by school



The effect of reverberation time on STI was analysed by considering the unoccupied (ambient) STI. Since the entire open plan unit was unoccupied during these measurements, the speech-to-noise ratio is generally in excess of 15 dB and therefore the STI is only affected by room acoustic effects generally described by reverberation time.

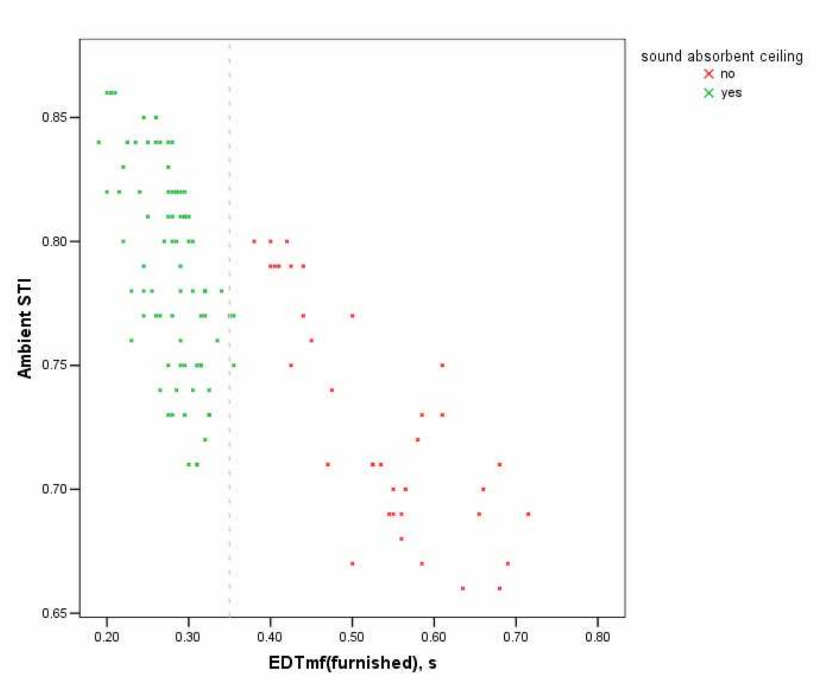
A significant negative correlation was found, with STI being slightly more strongly correlated to EDT_{mf} (r= -0.75, n = 114, p <0.001) than T_{mf} (r = -0.72, n = 114, p < 0.001), as expected (see section 5.8.2). Figure 8.18 shows the relationship between EDT_{mf} and ambient STI. The results fall into two distinct regions – those classbases with reflective ceilings (highlighted in red) which have EDTs in excess of 0.35 seconds, and those with acoustically absorbent ceilings (highlighted in green) which have EDTs of less than 0.35 s (to the nearest 0.01 seconds). For the latter case, the corresponding ambient STI achieved is at least 0.71 for all measurements. For classbases with acoustically reflective ceilings, the STI falls below 0.7 for higher early decay times (> 0.6 s).

Classbase volume was also shown to affect measured reverberation time, with a reasonably strong positive correlation with volume for both T_{mf} (r = 0.64, n ==117, p < 0.001) and EDT_{mf} (r = 0.50, n =117; p < 0.001).

For the occupied case, speech-to-noise ratio and hence STI is degraded by the presence of intrusive noise. The ambient STI therefore needs to be as high as possible to ensure that the BB93 criterion is still achievable when the classbases are occupied (whilst being in line with the limitations of the design cost).

The cut off point between the two design types (acoustic ceiling vs. no acoustic ceiling) is around $EDT_{mf(furnished)}$ 0.35 seconds which would be a practical optimum design criterion to ensure sufficient ambient STI. This corresponds to a $T_{mf(furnished)}$ of around 0.40 seconds (see Figure 8.16).

Figure 8.18: Ambient STI *vs*. Early decay time



8.8 Early-to-late sound ratio

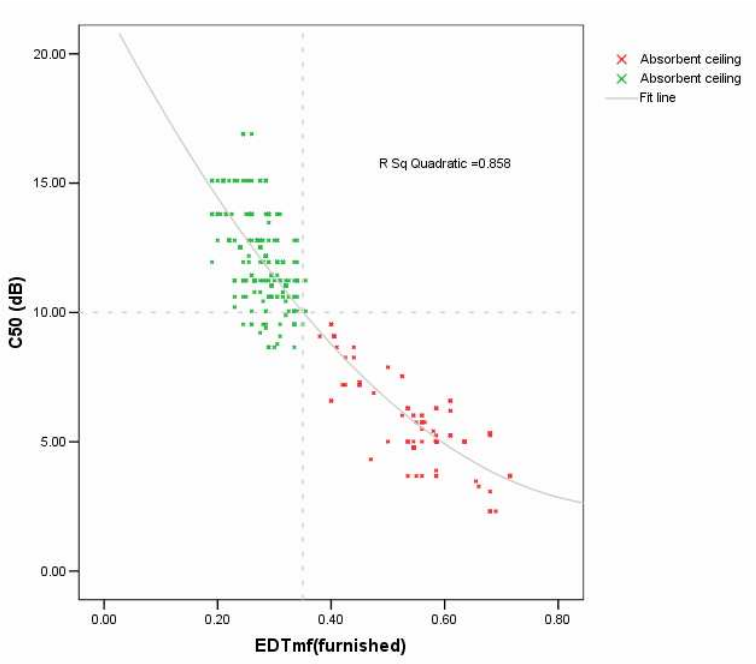
Early-to-late sound ratios were inspected by converting the measured D_{50} parameter in unoccupied classrooms to C_{50} as given by Equation 1. C_{50} is based on a logarithmic scale and measurements of C_{50} in classrooms have been found to be closely related to EDT based on a second order relationship[130, 131]. It should be noted that C_{50} does not take account of intrusive noise and therefore has limited use in determining speech intelligibility for open plan classbases. However C_{50} may be useful to determine ambient STI.

The correlation found between ambient STI and C_{50} ($r = 0.82$, $n = 242$, $p < 0.001$) was stronger than that found for EDT, indicating that C_{50} may be a better predictor of ambient STI.

A strong negative correlation was found between C_{50} and $EDT_{mf(furnished)}$ as indicated for the second order regression line in Figure 8.19 ($R^2 = 0.86$, $p < 0.001$), agreeing closely with Sato & Bradley's recent study[130, 131]. The correlation with T_{mf} was lower ($R^2 = 0.80$, $p < 0.001$), indicating that EDT is a stronger determinant of clarity than T_{30}.

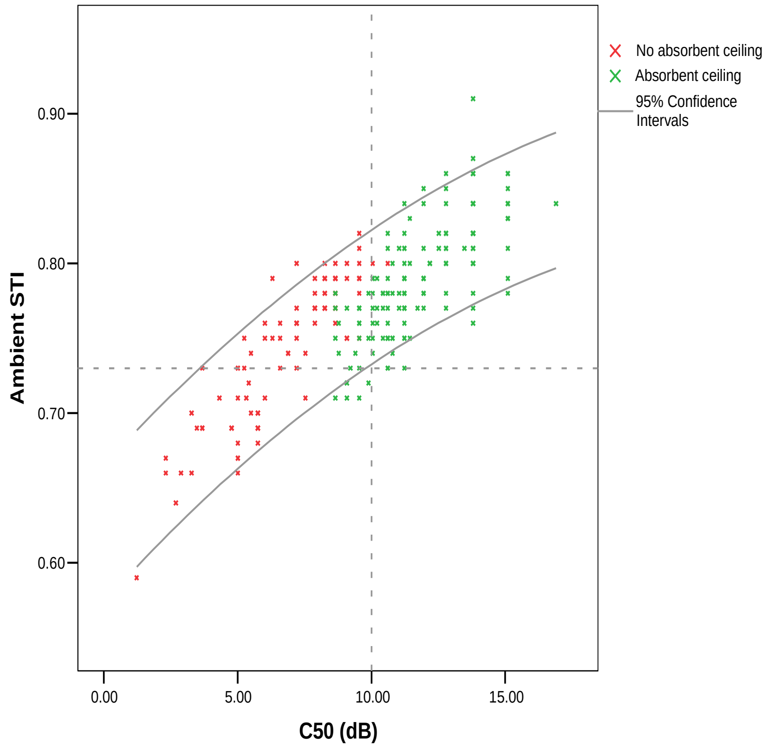
Values of EDT ≤ 0.35 s correspond to approximately $C_{50} \geq 10$ dB as measured from the regression line, which represents near perfect room acoustics conditions[187] (without the presence of noise). This is achieved for the majority of measurements in classbases with acoustically absorbent ceilings, but not for classbases with acoustically reflective ceilings. It could be inferred from this that the beneficial effect of providing an acoustic ceiling to control noise intrusion from adjacent classbases is likely to compensate for any negative effect on speech intelligibility resulting from the absence of a reflective surface to provide strong early reflections to support the teacher's speech. This is probably due to relatively short source to receiver distances involved for this type of classroom design (mean rear receiver position 5.6 m from source).

Figure 8.19: Relationship between C_{50} and $EDT_{mf(furnished)}$



The second order relationship between C_{50} and ambient STI is shown in Figure 8.20. The 95% confidence intervals from the regression line suggest that values of $C_{50} \geq 10$ dB correspond to ambient STI values of at least 0.73. In practice, STI 0.70 is likely to be a practical design criterion for ambient STI to ensure that BB93 criterion can be met in the presence of occupancy noise (given a reasonable management plan).

Figure 8.20: Relationship between C_{50} and ambient STI



8.9 Relationship between STI, S/N and RT

Multiple regression analysis was carried out to investigate the relationship between STI, speech-to-noise ratio, and reverberation time (main classbase unoccupied). Again, the dataset was screened to exclude those values with a speech-to-noise ratio in excess of 15 dB, since a linear relationship does not apply outside this range (Chapter 5). S/N_w accounted for 91% of the variance in STI ($F_{1,167} = 1699$, $p < 0.001$). EDT_{mf} accounted for a further 3% of the variance ($F_{1,166} = 103$, $p < 0.001$). The regression equation is given in Equation 9 and summarised in Table 8.9.

Equation 9: Relationship between STI, S/N$_w$ and EDT$_{mf(furnished)}$

$$STI = 0.024(S/N_w) - 0.155(EDT_{mf}) + 0.513$$

Table 8.9: Multiple regression equation for predictors of STI (S/N$_w$ and EDT$_{mf}$)

Predictor	*B*	Standard error *B*	Beta	95% confidence interval for *B* (lower bound)
S/N$_w$	0.024	0.001	0.879	0.023
EDT$_{mf}$	-0.155	0.015	-0.200	-0.186

Since S/N(A) and T_{mf} are more commonly used to rate speech intelligibility in classbases, multiple regression analysis was also carried out for these variables. For this analysis S/N(A) accounted for 88% of the variance in STI, ($F_{1,167}$ = 1240.14, p < 0.001), and T_{mf} accounted for a further 2% of the variance ($F_{1,167}$ = 35.65, p < 0.001). The regression equation for these predictors is given in Equation 10 and summarised in Table 8.10.

Equation 10: Relationship between STI, S/N(A) and T$_{mf(furnished)}$

$$STI = 0.021(S/N(A)) - 0.131(T_{mf}) + 0.481$$

Table 8.10: Multiple regression equation for predictors of STI (S/N(A) and T$_{mf}$)

Predictor	*B*	Standard error *B*	Beta	95% confidence interval for *B* (lower bound)
S/N(A)	0.021	0.001	0.880	0.020
T_{mf}	-0.131	0.022	-0.156	-0.175

Inspection of the regression equations shows that, if reverberation time is controlled to EDT$_{mf(furnished)}$ ≤ 0.35 s (see Figure 8.18), the minimum S/N$_w$ to achieve BB93 compliance is 6 dB. The equivalent minimum S/N(A) value to achieve BB93 compliance (T_{mf} ≤ 0.40 seconds, see Figure 8.16) is 8 dB.

Figure 8.21 to Figure 8.23 show the relationships between STI and the measured speech-to-noise parameters S/N(A), SIL, and S/N$_w$ respectively. A linear relationship is evident up to a certain point (approx 10-20 dB depending on the parameter) before the STI begins to plateau.

Results are split into data for shorter, 'optimum' reverberation times ($T_{mf,\ furnished}$ ≤ 0.40 seconds highlighted in green) and longer reverberation times ($T_{mf,\ furnished}$ > 0.40 seconds highlighted in blue). The correlation coefficients for each relationship are shown in the figures. For longer reverberation times, the STI begins to level off at higher speech-to-noise ratios, since the STI becomes limited by the reverberation time at this point. However for shorter reverberation times, the linear relationship continues to hold for higher speech-to-noise ratios, resulting in a ‘double tail’ relationship.

The results for S/N(A) and SIL show a very similar relationship and correlation (r = 0.93 for shorter controlled reverberation times) and there appears to be no significant difference in accuracy between use of S/N(A) and SIL as a predictor of STI. S/N(A) would therefore be preferable for use as a predictor since this is a simpler parameter to calculate. Inspection of the 95% confidence interval for the linear line of best fit shows that at least 21 dB SIL would be required to ensure BB93 compliance.

The relationship between S/N_w and STI shows a stronger correlation (r = 0.96 for controlled reverberation times), than S/N(A), the relatively small diferrence between correlation coefficients would suggest that S/N(A) is an acceptable parameter to use for practical design purposes.

Figure 8.21: STI *vs.* S/N(A)

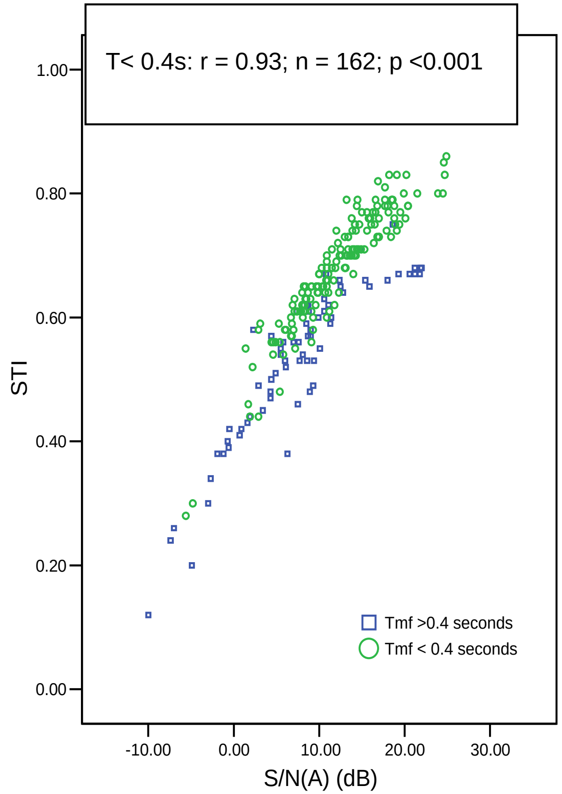


Figure 8.22: STI *vs.* SIL

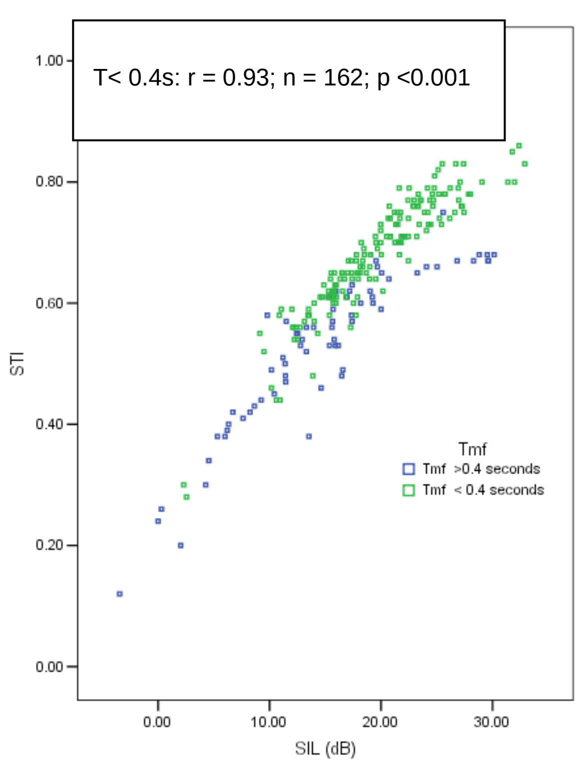
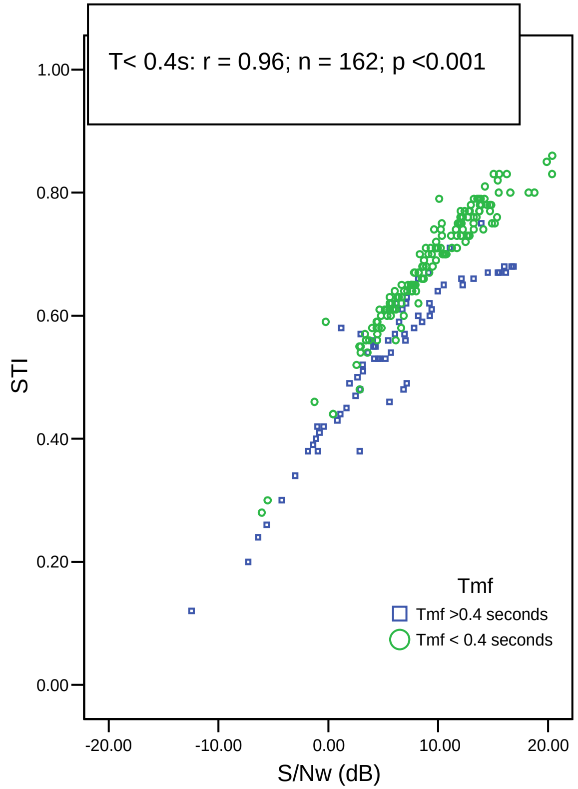


Figure 8.23: STI *vs.* S/N$_w$



8.10 Activity plan for optimum conditions

The above analysis has revealed that to achieve optimum speech intelligibility in open plan classrooms, reverberation time should be controlled to $EDT_{mf(furnished)} \leq 0.35$ s or $T_{mf(furnished)} \leq 0.40$ s and units should be shared by fewer than four classbases. Under these optimum conditions, a suitable activity plan for control of intrusive noise may be derived.

Mean results for occupied STI under optimal conditions are shown in Table 8.11. Comparison with Table 8.4 demonstrates that the results under optimum design conditions are more robust in terms of BB93 compliance, as indicated by the 'mean – σ' value. Using this measure rather than the mean value alone also allows some compensation for the error due to the directionality of the test loudspeaker to be taken into account (estimated to be approximately STI 0.02, see Chapter 7).

Clearly the results for individual work with movement need to be treated with caution due to the small sample size, and further data would be required to determine whether BB93 compliance could be ensured under optimum conditions.

Table 8.11: Mean occupied STI results achieved under optimum conditions*

Adjacent activity	Position	n	Mean occupied STI	Mean - σ
2. One person talking	Front	18	0.72	0.68
	Middle	25	0.68	0.63
	Back	26	0.66	0.60
3. Individual work at tables	Front	69	0.66	0.61
	Middle	20	0.64	0.58
	Back	26	0.54	0.45
4. Individual work with movement	Front	1	0.69	-
	Middle	3	0.60	0.58
	Back	1	0.39	-

*($T_{mf(furnished)}$ < 0.4 seconds; unit size less than 4 classbases)

The corresponding activity plan for this analysis is given in Table 8.13. Figure 8.24 - Figure 8.26 illustrates some situations when BB93 compliance can be achieved, according to Table 8.13. The key to symbols used in these figures is given in Table 8.12.

The analysis shows that, for classbases with optimum design conditions, during critical listening periods in the main classbase, BB93 compliance is likely to be achieved for all classroom positions when adjacent activities are coordinated (see Figure 8.24).

When adjacent classbases are working individually at tables, the main class should be gathered closely around the teacher on the carpet areas to facilitate BB93 compliant listening conditions (Figure 8.25).

Teachers should plan activities between classbases so that work involving movement around the classroom is coordinated and does not take place when other classbases are involved in critical listening periods such as whole class teaching (Figure 8.26).

When the main classbase is involved in non critical listening activities, acceptable levels of annoyance and distraction are likely to be achieved when adjacent classbases are working at tables (individual or group work) in optimum (limited) classroom designs (Figure 8.7). Marginal levels of annoyance and distraction may occur when adjacent classbases are involved in more active periods involving movement around the classroom.

Table 8.12: Key to symbols for Figure 8.23 - Figure 8.25

Symbol	Key
*	Teacher (source) position
	Pupil involved in whole class teaching
	Pupil involved in individual work at tables
	Pupil involved in individual work at tables with movement around the classroom
	Teacher's movement around classroom for instruction to individuals/groups (example only)

Table 8.13: Matrix of use for BB93 compliance under optimum design

		Activity in adjacent classbase(s)				
		2. Whole class teaching	3. Individual work at tables	4. Individual work with movement	5. Group work at tables	6. Group work with movement
Activity in main classbase	2	Compatible for all positions*	Gather class closely around teacher	To be avoided**	To be avoided	To be avoided
	3	To be avoided	Acceptable levels of annoyance/distraction	Marginal levels of annoyance/ distraction	Acceptable levels of annoyance/distraction	Marginal levels of annoyance/ distraction

*Although BB93 compliance achieved, S/N(A) values indicate speech intelligibility scores may not be adequate for all ages at all positions (see Table 8.14)

**Further data required to determine BB93 compliance for positions closest to teacher

Figure 8.24: Recommended activity plan – coordinated whole class teaching

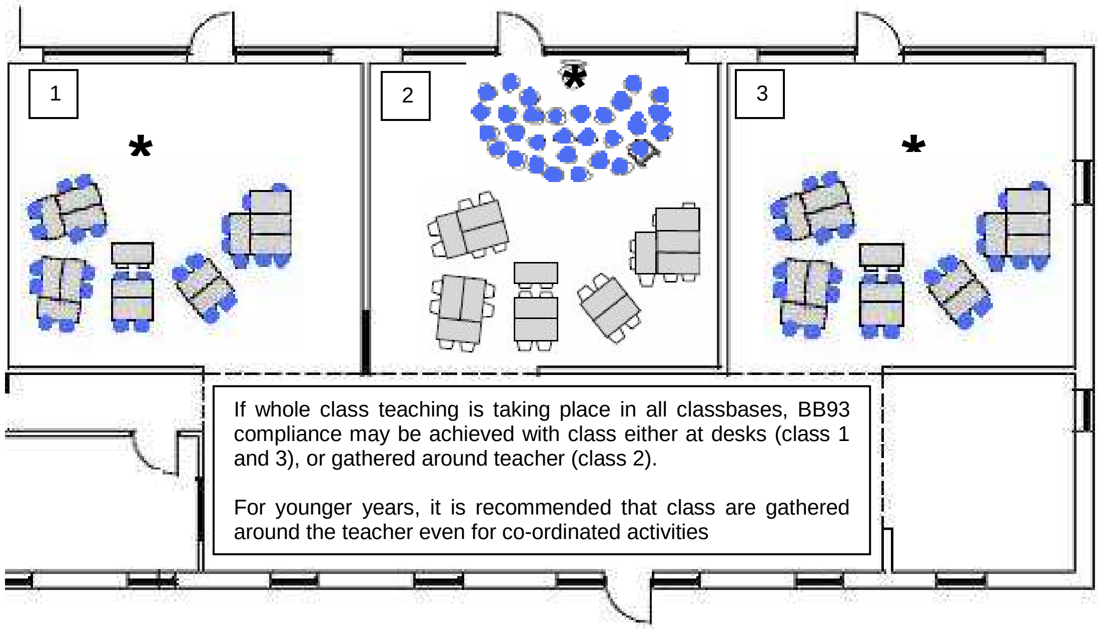


Figure 8.25: Recommended activity plan – uncoordinated whole class teaching

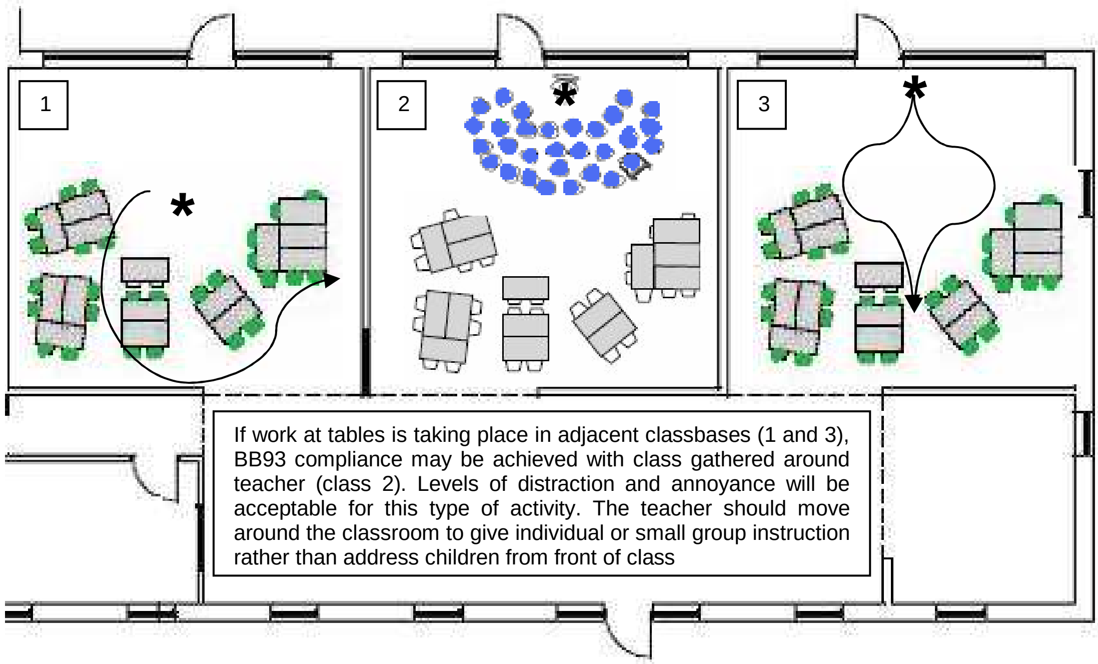
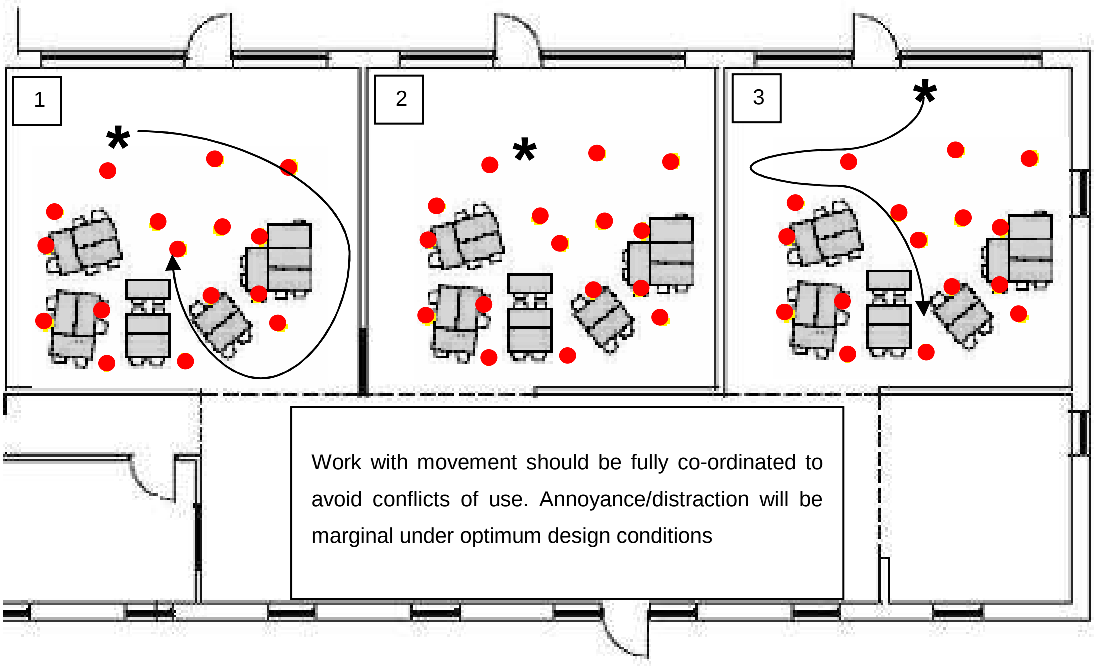


Figure 8.26: Recommended activity plan – work with movement



Considering the minimum average S/N(A) required for younger children to achieve equivalent speech intelligibility scores to those of adults[176, 215], enhanced STI criteria for younger listeners to achieve equivalent speech intelligibility (based on equation 10 and optimal conditions) are presented in Table 8.14.

Table 8.14: Proposed STI criteria for different ages

Age (years)	Minimum S/N(A) (dB) after Bradley[176]	Minimum corresponding STI under optimum conditions (from equation 10)
11	8	0.60
8	12	0.68
6	15	0.75

The proposed enhanced criteria also represent a more suitable criterion for non-native listeners with experienced, daily use of English as an additional language, as proposed by Wijngaarden[197].

8.11 Speech privacy

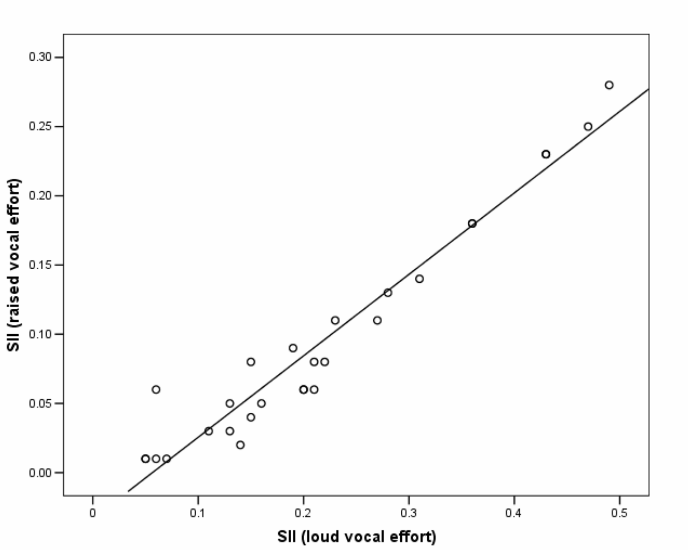
In addition to assessment of speech intelligibility in the main classbase for critical listening, speech privacy between classbases was assessed for coordinated critical listening periods. That is, the extent to which teachers' speech in adjacent classbases can be understood in the main classbase whilst the main class are gathered on the carpet for whole class teaching. The speech intelligibility index (SII) was used to calculated speech privacy (see Chapter 7 for further details).

SII was calculated between 41 pairs of semi-open classbases, and 5 pairs of classbases with enclosed or sliding doors, for both ‘raised’ and ‘loud’ standardised vocal efforts, based on measured airborne sound insulation and ambient noise levels as described in Chapter 7. Both adjacent and non-adjacent classbase pairs were assessed. For classbases with closing elements such as sliding doors, the SII for both ‘raised’ and ‘loud’ conditions was SII 0 with doors closed, as expected. Classbases with enclosed or sliding doors were excluded from the rest of the analysis.

8.11.1 SII criteria

For SII values in excess of 0, a strong linear relationship was observed between SII for ‘raised’ and ‘loud’ vocal efforts, as shown in Figure 8.27 ($r = 0.97$, $n = 28$, $p < 0.001$). SII values of zero (achieved for non-adjacent classbase pairs and flexible open plan units) were excluded from the analysis since it is impractical to achieve this condition between adjacent classbase pairs in a semi-open plan unit. A plateau effect is observed as SII values tend to zero. This results after truncation of the signal-to-noise ratio (SNR) to a range of +15 and -15 dB in the ANSI 3.5[161] calculation procedure.

Figure 8.27: SII ‘raised’ *vs.* SII ‘loud’



A value of SII ‘loud’ = 0.2 corresponds approximately to SII ‘raised’ = 0.10. According to Bradley[201], a value of 0.10 SII corresponds to an average sentence intelligibility score of around 40% and is rated as ‘excellent’ speech privacy and ‘little’ distraction, as discussed in Chapter 5. This is likely to be a much more appropriate criterion for critical learning in educational settings in order to avoid distraction (refer to Figure 5.15). From the above findings, two key criteria may be considered to provide adequate speech privacy for learning:

- $SII_{Loud} < 0.20$: Worst-case – to provide reasonable speech privacy against loud speech (see Chapters 5 and 6).
- $SII_{Raised} < 0.10$: Best practice – to provide excellent levels of speech privacy in critical learning conditions for typical raised speech. Some management of teacher’s vocal effort required to achieve this condition.

8.11.2 Sound insulation

SII was compared with the measured sound level difference between critical listening areas. Both D_w and sound attenuation between classbases were investigated in order to compare with parameters given in the literature. Sound attenuation, A, was taken simply to be the difference between the total sound pressure level at the source position and the total sound pressure level measured at the receiver position (in dB). Sound insulation measurements in excess of 32 dB (achieved for non-adjacent classbases) were excluded from the analysis since these did not represent the performance that could be achieved between nearest adjacent classbases in a semi-open arrangement in practice.

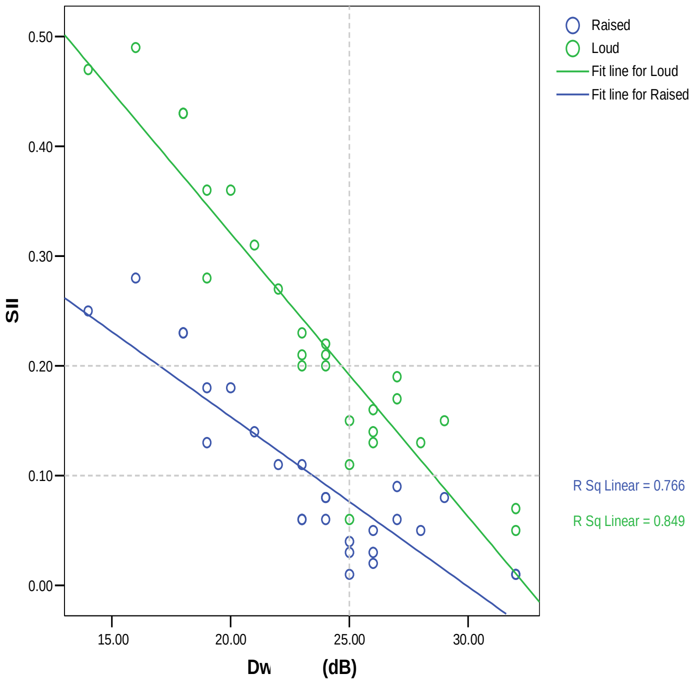
A strong negative correlation was found between SII and all level difference/attenuation parameters, as shown by the correlation coefficients in Table 8.15. SII was most strongly correlated to D_w and less strongly related to sound attenuation, A.

Table 8.15: Correlation between SII and sound insulation between classbases

	SII_{Raised} (n = 27)	SII_{Loud} (n = 30)
D_w (dB)	$r = -0.87$, $p < 0.001$	$r = -0.88$, $p < 0.001$
Attenuation, A (dB)	$r = -0.81$, $p < 0.001$	$r = -0.82$, $p < 0.001$

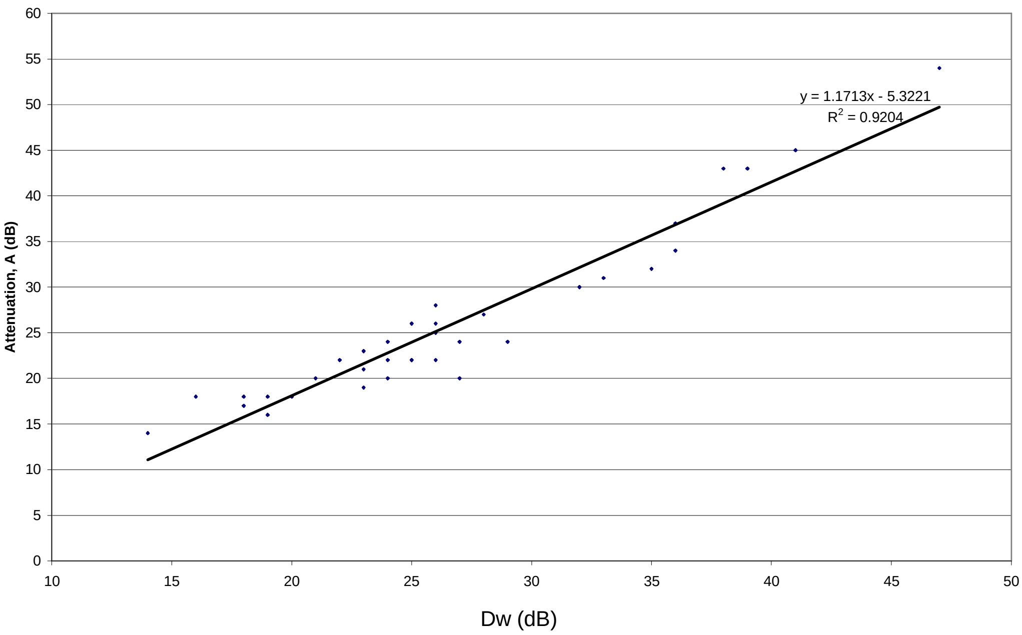
Figure 8.28 illustrates the relationship between SII and measured D_w between classbases, indicating that a weighted level difference of at least $D_w = 25$ dB would achieve both speech privacy criteria.

Figure 8.28: SII *vs.* sound level difference



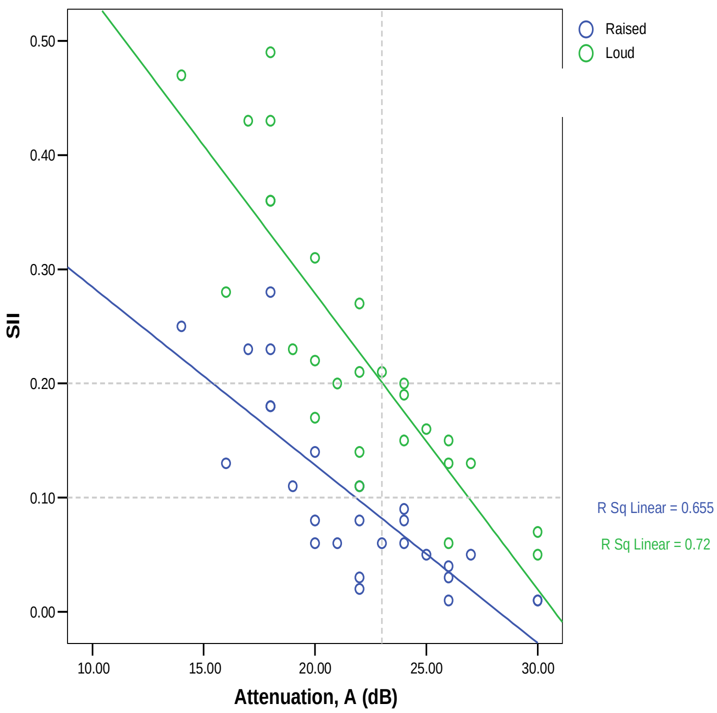
Values of D_w are plotted against attenuation, A in Figure 8.29, which demonstrates a strong positive correlation. A value of D_w = 25 dB corresponds to an attenuation, A of 24 dB as indicated by the line of best fit.

Figure 8.29: Measured D_w *vs.* Attenuation, A



Sound attenuation, A between classbases is plotted against SII in Figure 8.30. The minimum attenuation required to achieve the proposed speech privacy criteria (SII_{loud} 0.20; SII_{raised} 0.10) would be A = 23 dB, as illustrated. Both proposed targets exceed the recommendation of at least 15-20 dB attenuation between classes in the literature[122, 147]. It is worth noting that a sound attenuation of 15 dB corresponds to around SII_{raised} = 0.20. This is compatible with 'acceptable' privacy levels and meets Petersen's[147] recommendations which have been incorporated into Danish Guidance[216] (see Chapter 6). However, a higher level of attenuation is preferable to provide reasonable privacy against loud speech, and improve conditions for vulnerable listeners (see Chapter 6).

Figure 8.30: SII *vs.* attenuation



8.11.3 Masking noise

Figure 8.31 shows the relationship with the ambient continuous background noise level, $L_{Aeq(5min)}$, (D_w < 30 dB considered only). Classbases with higher ambient noise levels (≥ 35 dB L_{Aeq}) are shown to achieve lower SII values and hence better speech privacy, since masking noise is higher.

Whilst higher masking noise levels provide better speech privacy, there is a compromise between this and controlling ambient noise for adequate speech transmission of the relevant speech signal to receivers within the classbase. Therefore a design range of 35-40 dB L_{Aeq} is recommended to achieve good conditions for both speech privacy between classbases and speech intelligibility within classbases. The SII and corresponding sentence intelligibility scores (after

Bradley[201]) for classbases which achieve 35-40 dB L_{Aeq} and $D_w \geq 25$ dB are shown in Table 8.16.

Figure 8.31: SII and D_w *vs.* ambient noise

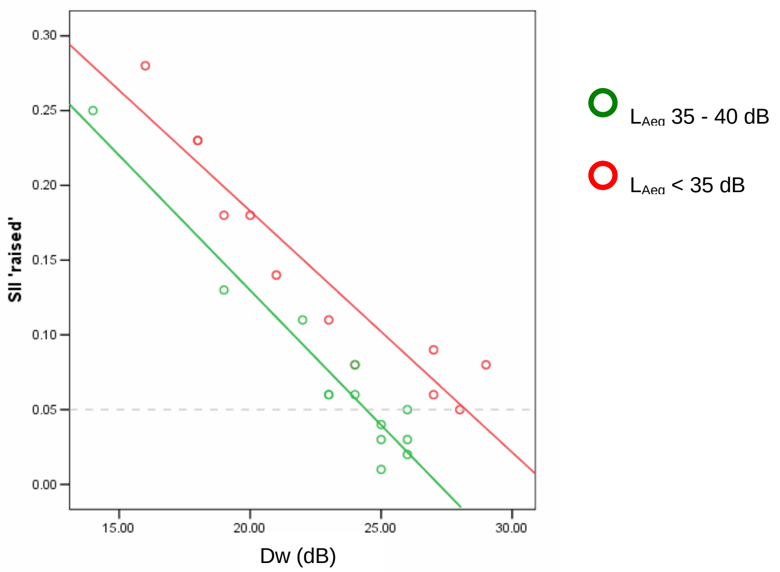
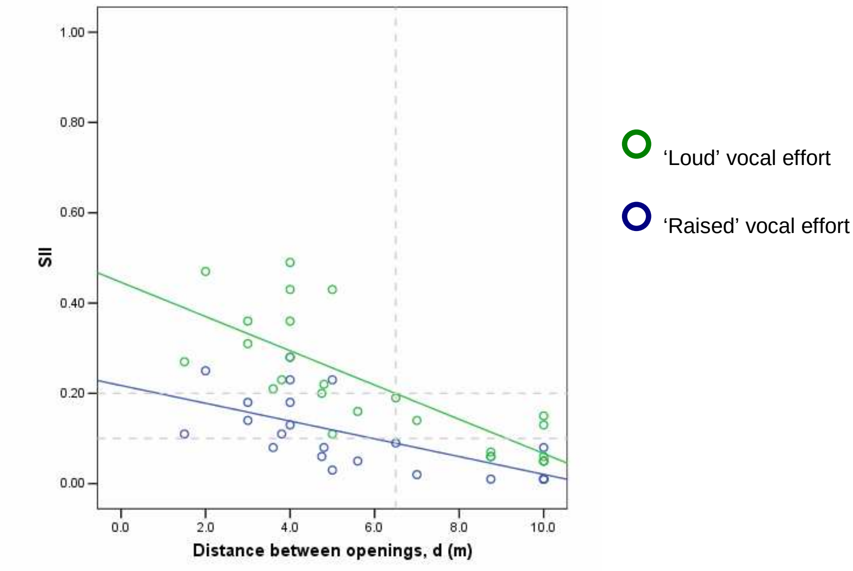


Table 8.16: SII and corresponding sentence intelligibility

	SII	Average sentence intelligibility from Bradley[201]
'Loud' vocal effort	< 0.15	< 55%
'Raised' vocal effort	< 0.05	< 20%

SII is also significantly negatively correlated to the distance between classbase openings, d, for both 'loud' vocal effort ($r = -0.75$, $n = 29$, $p < 0.001$) and 'raised' vocal effort ($r = -0.67$, $n = 24$, $p < 0.001$). Figure 8.32 indicates that a distance of at least 6.5 m between openings would achieve adequate speech privacy for both 'raised' and 'loud' vocal efforts.

Figure 8.32: SII *vs.* distance between openings



8.11.4 Design and layout

The SII achievable between classrooms is highly dependent on the classroom design and layout. This is analysed in further detail to develop key design recommendations for providing sufficient speech privacy for learning.

A significant difference was found between speech privacy performance and unit size ($F_{1,32}$ = 17.8, $p < 0.001$). The SII achieved for limited units was deemed to be acceptable (mean SII_r = 0.06; σ= 0.03), whereas the mean performance for large units exceeded the recommended maximum criterion for raised speech (mean SII_r = 0.16; σ= 0.08).

Existing typical classroom design layouts were inspected to determine key issues to achieve the design conditions necessary to provide sufficient speech privacy for coordinated critical listening. A selection of example layouts and practical design recommendations are discussed below. The figures have been marked up with critical design conditions as shown in Table 8.17.

Table 8.17: Key to symbols for Figure 8.33 - Figure 8.40

Symbol	Key
*	Teacher (source) position
	D_w (dB) between classbases
	Distance between classbase openings (m)

8.11.4.1 Linear/Annular units

The data show that linear units require staggered openings in order to maximise the distance between openings and achieve adequate design conditions, as shown in Figure 8.33. Staggered openings are indicated between classbases 2 and 3, which achieve the design criteria for adequate speech privacy. Non-staggered openings are indicated between classbases 1 and 2, which do not achieve the required design criteria.

Figure 8.33: Linear layout; staggered *vs.* non staggered openings

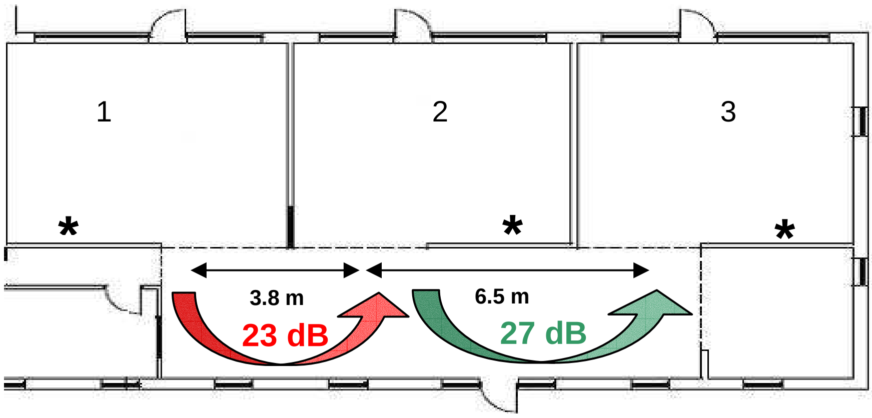
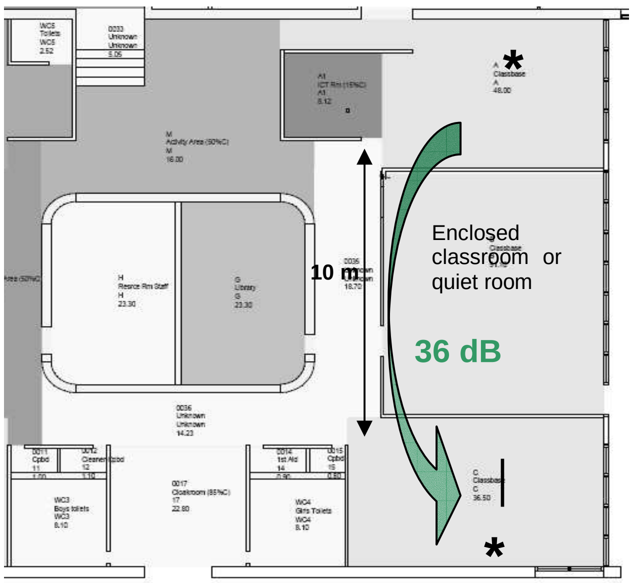


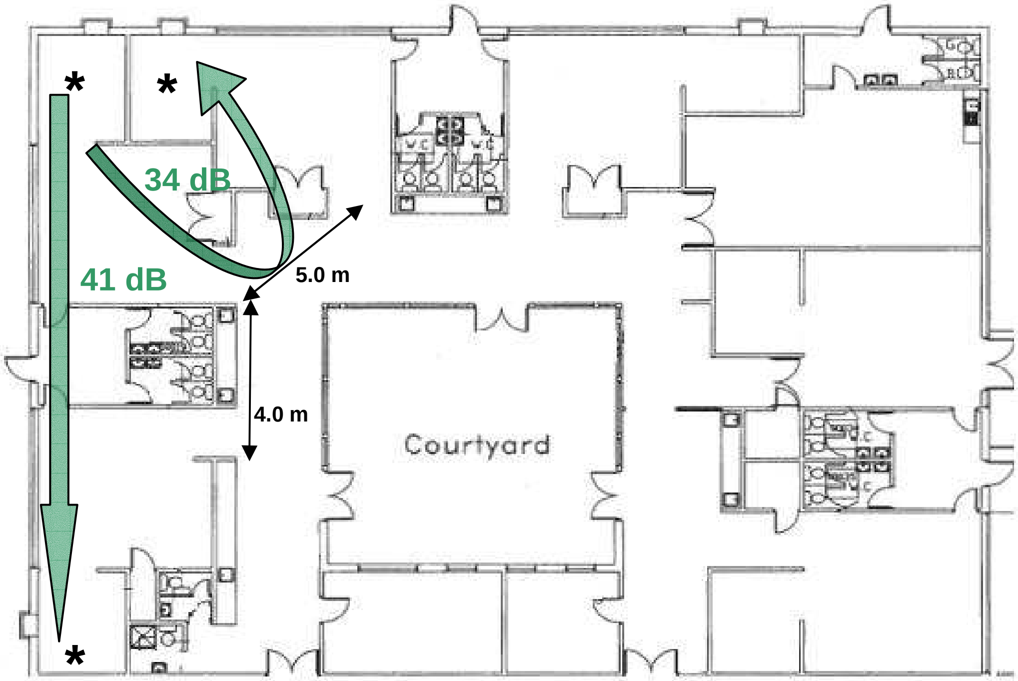
Figure 8.34 shows how buffer space, such as an enclosed teaching space or quiet room, may be used between classbases to maximise the distance between openings and achieve design criteria.

Figure 8.34: Enclosed room used as a buffer space



Although the minimum distance between classbase openings is not achieved for the layout in Figure 8.35, sufficient sound insulation and speech privacy is achieved by use of 'niched' retreat areas, located away from classbase openings in order to create a quieter 'carpet' area for the class to gather on during critical listening activities.

Figure 8.35: Cloakroom used as buffer space & 'niched' carpet areas

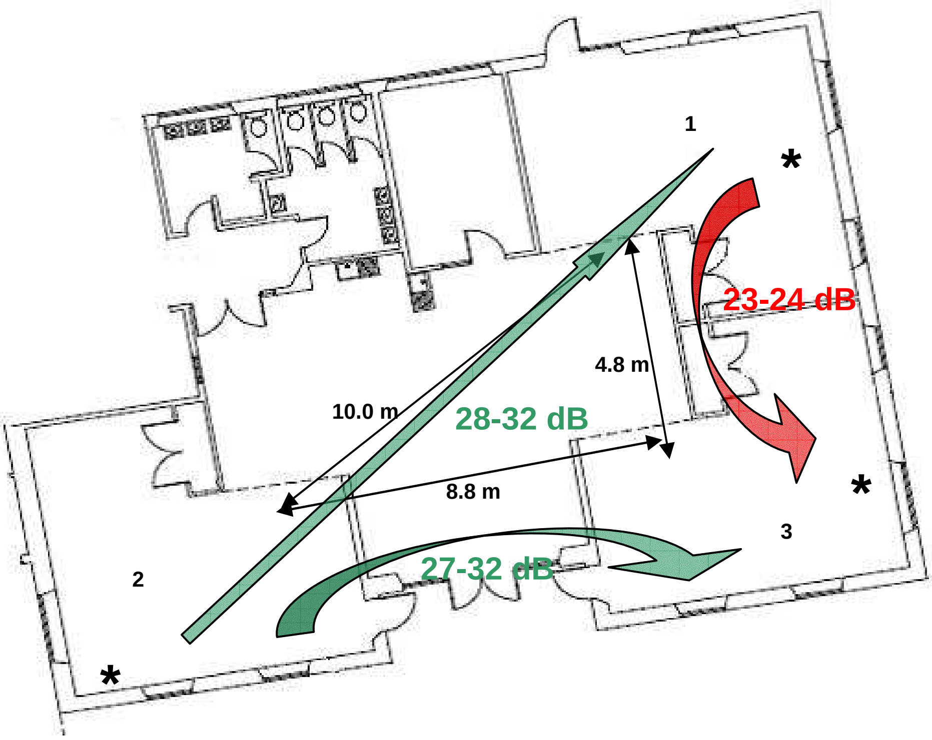


8.11.4.2 Cluster units

It is generally more difficult to achieve the necessary criteria between adjacent spaces in a clustered unit, since at least one pair of classbase openings is typically closer together, with openings facing each other.

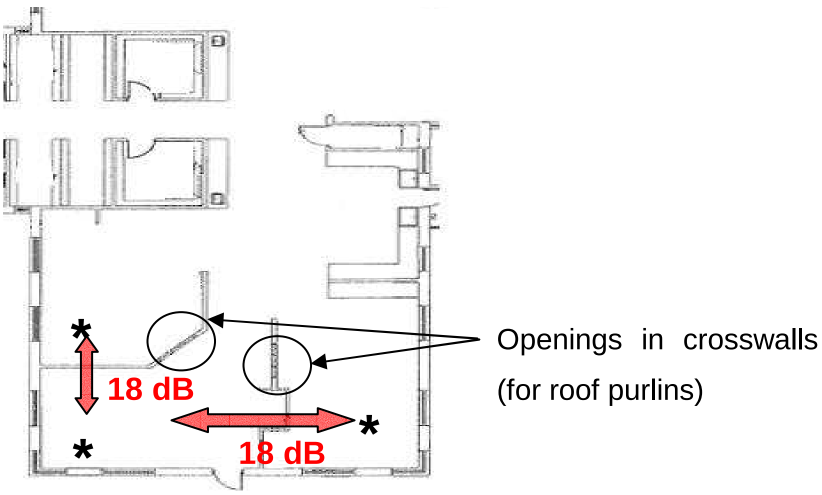
Figure 8.36 shows a typical 3 classbase cluster unit arranged around a shared resource space. This layout typically consists of two or more closely joined classbases, with openings facing each other, plus one or more detached units at the opposite end of the resource space. Whilst it is relatively easy to achieve sufficient separation between the detached classbase and adjacent classbases (classbases 1 and 2), it is more difficult to achieve sufficient separation between adjacent spaces (classbases 1 and 3).

Figure 8.36: Cluster unit - resource as buffer space



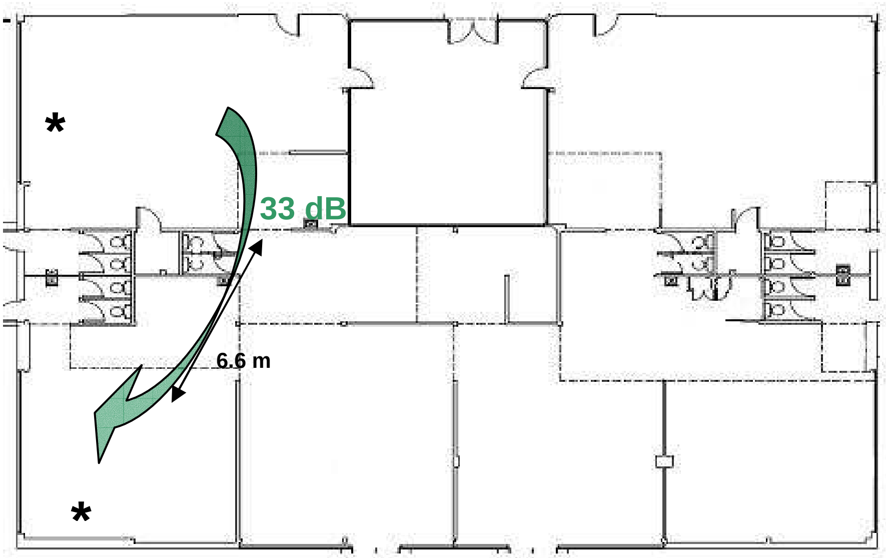
Speech privacy is also degraded by the presence of openings in crosswalls as circled in Figure 8.37. In this case, crosswalls have openings to allow steel roof purlins to pass through.

Figure 8.37: Openings in crosswalls



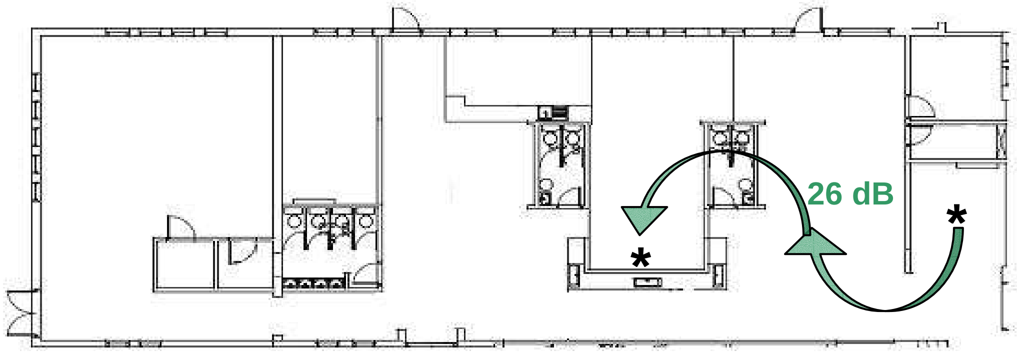
Again it is important to make use of buffer space between classrooms, in order to maximise the distance between openings (see Figure 8.38). The advantage of using 'niched' retreat areas as discussed above is demonstrated for cluster layouts in Figure 8.39.

Figure 8.38: Toilet block and storeroom used as buffer space



* N.B. users of this school reported problems with noise from flushing toilets. Toilets should be separated from the main classbase using a lobbied door arrangement

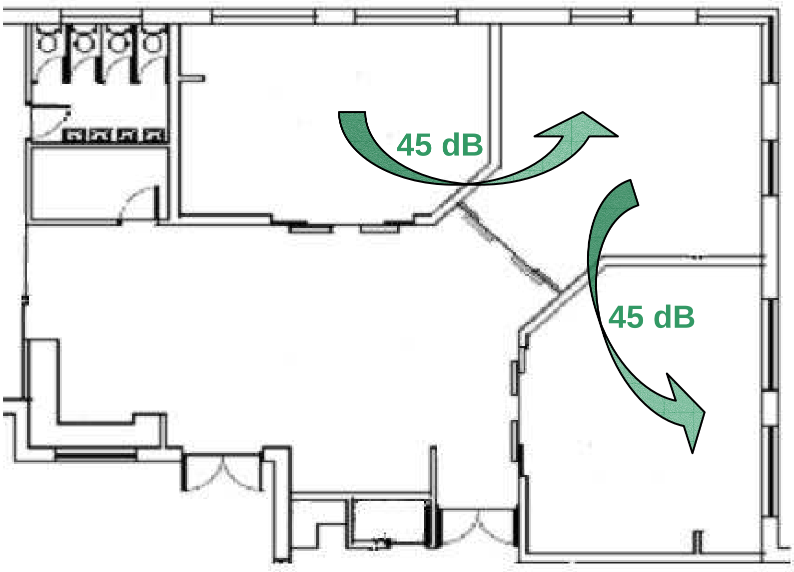
Figure 8.39: Niched' carpet areas enclosed on three sides and staggered



8.11.4.3 Enclosed units

Clearly, designs with flexible open plan layouts (where classbases can be opened or enclosed by means of sliding partitions or doors) achieve the highest levels of sound insulation and hence speech privacy when doors are closed as shown in Figure 8.40.

Figure 8.40: Flexible open plan space with sliding doors



8.11.5 Other recommendations

In addition to classroom layout, further design issues also need to be addressed to achieve sufficient sound insulation between adjacent classbases and hence speech privacy for critical listening.

The construction of the partition should achieve sufficient sound insulation to ensure that noise transmission is not significant through the partition itself (at least R_w 40 dB is recommended to achieve this). Interface details also need to be carefully considered to maintain this performance.

Noise from buffer spaces should be minimised. Buffer spaces should be enclosed if high noise levels are expected.

In order to maintain the recommended ambient noise level, it may be necessary to consider use of electronic masking noise systems where the ambient noise level is less than 35 dB L_{Aeq}.

8.12 Conclusions

This Chapter has shown that optimum design criteria to facilitate BB93 compliance (STI ≥ 0.6) for teacher-to-student speech intelligibility within classbases are as follows:

- Open plan unit should contain no more than 3 classbases
- ≥ 2.1 m^2 basic teaching area per child
- Reverberation time: should be less than $T_{mf(furnished)}$ ≤ 0.40 s
- Early decay time: should be less than $EDT_{mf(furnished)}$ ≤ 0.35 s
- C_{50} ≥ 10 dB
- Acoustic finishes: An acoustically absorbent ceiling is recommended to achieve reverberation time criteria. Carpet is preferable to control footfall noise but not essential to control reverberation time
- Ambient STI (excluding noise): practical design target of STI ≥ 0.70 recommended to ensure STI can still be met in presence of managed occupancy noise
- If RASTI is used as an alternative assessment tool to STI, a value of at least 0.75 should be achieved to ensure BB93 compliance.

Compliance with BB93 requires a suitable management plan as well as acoustic design conditions outlined above. Given the above optimum design conditions, a managed activity matrix has been determined to control intrusive noise levels to achieve compliance with BB93 and minimise distraction and annoyance. Activities involving movement should be coordinated between classbases to avoid conflicts of use. Distraction and annoyance in this configuration would be marginal.

For critical listening activities (whole class teaching), when activities are not coordinated, children need to be gathered closely around the teacher, away from classbase openings. Many elements of the activity management plan are already commonly in place in effective primary school practices, whether in closed or open plan classrooms.

Although the activity matrix and design criteria are sufficient to achieve BB93 compliance (STI 0.6), it should be noted that this criterion may not necessarily be sufficient to ensure good speech intelligibility scores for all ages of children, as noted by the S/N(A) values achieved. For example, whilst adequate speech-to-noise ratios would be achieved for 11 year olds at all positions when all classbases are involved in coordinated whole class teaching, very young children (6 year olds) are likely to struggle at positions at the back of the classbase even when all classbases are involved in whole class teaching. Enhanced STI criteria appropriate for younger school children and users of English as an additional language (STI 0.68-0.75) have been proposed to address the enhanced criteria. The teacher should gather young children closely together on the carpet during coordinated whole class teaching to achieve this.

Optimum SII criteria in order to achieve sufficient speech privacy between adjacent carpet areas for coordinated critical listening tasks have been determined for ‘raised’ vocal effort (SII ≤ 0.1) and ‘loud’ vocal effort (SII ≤ 0.2). Design recommendations to achieve these criteria are as follows:

- Ambient noise level: between 35-40 dB(A) (to achieve sufficient masking whilst maintaining speech intelligibility within classbases)
- Minimum sound insulation between critical listening areas: $D_w \geq 25$ dB
- Minimum sound attenuation between critical listening areas: A ≥ 23 dB

In order to achieve the attenuation criteria above, a distance of at least 6.5 m is recommended between classbase openings. It is also easier to achieve sufficient attenuation using a linear arrangement rather than a cluster arrangement, with use of staggered openings and niched carpet areas.

Some management is also required to achieve adequate speech privacy under these conditions. Keeping vocal effort at a ‘raised’ level will ensure adequate speech transmission of the relevant speech signal to the children within the classbase (given the correct management plan), without disturbing those in adjacent classbases or causing unnecessary vocal strain. The recommendations also allow for reasonable speech privacy against ‘loud’ vocal effort, allowing for some natural variation in vocal effort between teachers, and occasional increase in vocal effort. Training should be provided to raise awareness of the management strategies required to enable a successful classroom design.

The speech-to-noise ratio was shown to account for a far greater proportion of the variance in STI scores than reverberation time, which is consistent with the results of other studies[176, 215]. Speech-to-noise ratio parameters (SIL, S/N(A) and S/N_w) were shown to be accurate predictors of STI under controlled reverberation times ($T_{mf,\ furnished}$ < 0.4 s). However these alternative predictors should be used as an additional tool to assess speech intelligibility against BB93 compliance rather than as a substitute for STI.

Chapter 9: Subjective survey – Children

9.1 Introduction

A questionnaire was designed and developed to investigate children's perceptions of noise and acoustic conditions in open plan classrooms. The questionnaire was administered to at least one in three randomly selected children from each of the 41 primary school classbases used in the objective survey. In addition, for two of the surveyed schools, questionnaires were given to all children in the classroom.

The design and development of the questionnaire and survey procedure is discussed in detail in this Chapter. The questionnaire was designed with reference to ISO/TS 15666:2003[258]. Results are analysed by comparing responses with physical variables (such as open plan unit size and quiet room access) and by comparing responses of vulnerable listener groups with those of their 'typical' peers. Results are also compared with those of a similar previous study involving enclosed primary classrooms.

Results have also been compared with objective data to investigate the relationship, if any, between measured objective acoustic parameters (STI, intrusive noise, reverberation time) and perceived listening conditions.

9.2 Design and development of questionnaire

9.2.1 Aims and objectives

The main objectives of the children's questionnaire were as follows:

- To establish main sources of background noise experienced in open plan classrooms
- To investigate subjective impressions of speech communication in open plan classrooms in different listening situations (ability to hear teacher, ability to hear peers)

Further information was also collected to investigate possible differences in responses as follows:

- Age
- Sex
- Reported (long term) hearing problems
- Hearing aid use
- First and additional languages spoken
- Physical classroom variables (open plan unit size, quiet room access)

9.2.2 Questionnaire design

The questionnaire structure was based on a previous questionnaire developed for a large scale research study (2036 subjects in London primary schools) by Dockrell and Shield[120]. This study investigated precision and consistency of children's responses and showed that primary school aged children were able to discriminate across classroom conditions in terms of teacher and peer audibility, and that teachers' perceptions were well matched to those of the children in their class[120].

Children were also shown to be able to discriminate between different noise sources accurately and report annoyance from these noise sources. The original questionnaire was rigorously tested through two phases of pilot studies (including interviews with teachers and pupils) to construct a valid, reliable and developmentally appropriate tool for use by primary school age children[120].

The questionnaire used for this study was adapted from Dockrell & Shield's[120] questionnaire to investigate noise sources and listening situations specific to open plan environments, including the presence of intrusive speech from teachers and children in adjacent classbases. A copy of the questionnaire is included in Appendix B. The four page questionnaire was divided into three sections.

The first section gathered personal information. This was strictly limited to information necessary to investigate research objectives. First names and school/class details were collected for purposes of identification in the analysis only.

The second section examined the types of sound sources children were exposed to at school. After Dockrell and Shield[120], children were asked for each sound a) whether they heard the sound and b) if they heard the sound source whether they were ever annoyed by it. Questions were accompanied by a graphic representation of the sources to contextualise questions followed by a tick box for the children to record their response[120]. The questions in this section were presented as dichotomous yes-no answers to aid completion by younger children. The section was preceded by a trial question to familiarise the children with the questionnaire and to allow for any problems or questions raised by the children to be addressed.

The third section examined listening situations across five different contexts. Children rated how well (in general) they could hear what their teacher was saying when their class was quiet and listening to their teacher whilst adjacent classes were:

- Doing a test (quiet)
- Working at tables
- Working at tables and moving around the classroom

Children also rated how well (in general) they could hear their peers speaking in the classroom when they were:

- Answering the teacher
- Working in groups

This section used a five point Likert scale (1- very well, 5 – not at all) transformed into a 'smiley faces' rating scale, after Arnold and Canning[259]. The question structures of both sections have been shown to be understood by children of primary school age range (year 2-6) and children's responses to both sections have been shown to be reliable[120, 259].

Variables relating to classroom design were completed for each respondent by the researcher (that is, the author) to ensure that terminology was applied consistently and correctly, which also reduced the children's work input.

9.3 Participants

The sample consisted of primary school pupils in the 42 classbases in which acoustic data had been gathered, plus two additional classes. The target sample rate to provide a representative sample was at least one in three based on a maximum class size of 30 children. The number of participants and questionnaire responses from each school is summarised in Table 9.1. The number of children that participated in the study was 749. Two of the questionnaires were not returned substantially completed; therefore these were discarded from the survey, reducing the total number of responses to 747.

In ten of the schools, questionnaires were administered by the researcher (a total of 261 responses, see Table 9.1 for further details). A sample of children was selected randomly by the teacher. In two of the schools (6 and 7), questionnaires were administered by teachers (n = 488, see Table 9.1). Every child in attendance on the day of the survey took part in the questionnaire. Two additional classbases (outside the objective survey) in these schools also participated in the study. Responses from 39 children in four classbases (three in school 8, one in school 9) with enclosed or sliding doors were omitted from the analysis, reducing the sample size to 708.

There was a concern that the large number of teacher-administered questionnaires (n= 488) from two of the schools (6 and 7), may bias the results towards a certain design or type of school. To control for possible effects of this, the sample size was controlled by randomly selecting 10 responses from each class using SPSS analysis software (n = 190). Checks were carried out on the data to ensure that there was no significant difference between the mean scores and distributions from the randomly selected samples and the whole class sample. This enabled the sample sizes between teacher and researcher administered surveys to be matched. This resulted in a valid sample size of 410 completed responses for analysis, see Table 9.2. The final sample consisted of 44% boys and 55% girls (missing information 1%). The year group distribution for the sample was Year 1, 5.4%; Year 2, 32%; Year 3, 25.6%; Year 4, 17.3%; Year 5, 2.4%; Year 6, 16.8% (missing information 0.5%).

Table 9.1: Children's questionnaire responses

School	Number classbases in school	Number of classbases objectively surveyed	Number of classbases in children's survey	Number valid responses collected/returned	Minimum sample rate per classroom*
1	5	1	1	20	2 in 3
2	9	3	3	30	1 in 3
3	6	3	3	30	1 in 3
4	6	3	3	29**	32%
5	9	3	3	30	1 in 3
6	10	9	10	262	100%***
7	14	8	9	226	100%***
8	9	3	3	29**	32%
9	6	3	3	30	1 in 3
10	8	3	3	30	1 in 3
11	8	2	2	20	1 in 3
12	7	1	1	11	1 in 3
Total	97	41	44	747	-

*Based on maximum class size of 30 pupils

**One questionnaire not completed therefore discarded from sample

***Every child in class in attendance on day of survey

Table 9.2: Children's questionnaire response – final sample for analysis

School	Number classbases in school	Number of classbases in children's survey	Number valid responses collected/returned	Minimum sample rate per classroom*
1	5	1	20	2 in 3
2	9	3	30	1 in 3
3	6	3	30	1 in 3
4	6	3	29**	32%
5	9	3	30	1 in 3
6	10	10	100	100%***
7	14	9	90	100%***
9	6	2	20	1 in 3
10	8	3	30	1 in 3
11	8	2	20	1 in 3
12	7	1	11	1 in 3
Total	88	40	410	-

*Based on maximum class size of 30 pupils

**One questionnaire not completed therefore discarded from sample

***Every child in class in attendance on day of survey

9.4 Procedure

9.4.1 Researcher administered

Children were taken out of the classroom in small groups (10 maximum) during the school day in order to complete the questionnaire. At the beginning of each session, children were briefly introduced to the project followed by a thorough explanation of the questions and the way each answer should be recorded. Each question was read aloud, and when the whole group was finished the next question was read aloud. Children were assured that there were no right or wrong answers and that their answers would remain confidential. Children were encouraged to give their own individual answer. The questionnaire took between 10 and 20 minutes to complete depending on age.

Two classbases consisted of year 1 children. Although previous studies[120, 259] had confirmed that the questionnaire was developmentally appropriate for years 2-6, younger years were not investigated. Therefore, for this younger group of children, the questionnaire was administered individually to ensure that each child understood the task.

9.4.2 Teacher administered

The questionnaire was administered by the teacher to the whole class during the school day. Teachers were asked to follow the same procedure as described above. The questionnaire was reported to take between 20 and 30 minutes to complete depending on age.

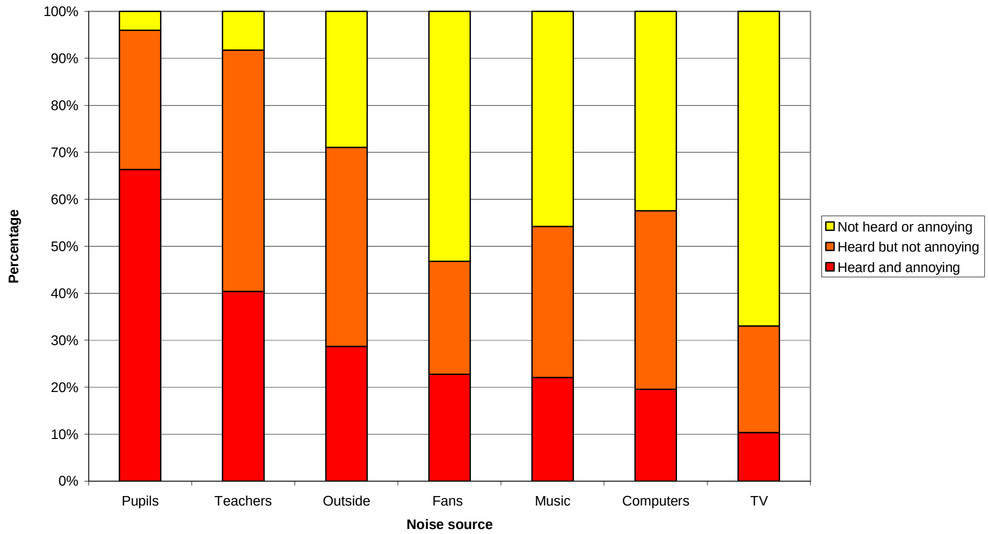
Due to an error in the administration of the questionnaire for school 6, information on exposure/annoyance from the full range of noise sources was not collected, however information on exposure/annoyance from pupil/teacher noise sources was included.

9.5 Results

9.5.1 Noise sources

Children's perception and reported annoyance of different noise sources around the school are shown in Figure 9.1. The responses from school 6 have been left out of this analysis for reasons reported above, resulting in 310 valid responses to noise sources.

Figure 9.1: Children's reported exposure to classroom noise sources



Noise from pupils and teachers operating in other adjacent class groups were the most frequently reported noise sources to be perceived by children (>90%). External noise was the next most frequently perceived noise source. All other listed internal noises were heard by less than 60% of the children, with building services noise ('fans and other machines') and televisions being the least frequently perceived noise source (<50%).

The percentage of children reporting annoyance for each source (red bars shown in Figure 9.1) was considered to be equivalent to a dissatisfaction rate. This was compared with acceptability criteria previously proposed by Walsh[22] and Keighley[145, 146] (maximum 32% dissatisfaction rate for acceptability, see Chapter 4).

Noise from pupils in other classbases was reported to be the most annoying of the sources investigated in the survey (over 60% of children annoyed). Other teachers' voices were also a major source of annoyance (over 40% annoyed). This suggests that overall, noise from pupils and teachers in other classbases was unsatisfactory since over 32% of respondents reported annoyance.

Annoyance from all other sources suggests that noise from other sources was reasonable, since on average less than 32% of children reported being annoyed by these sources.

9.5.2 Listening ratings

9.5.2.1 Ability to hear teacher

The distribution of listening ratings for children's ability to hear their teacher in different listening situations is shown in Figure 9.2. The full rating scale was used by the children. Mean listening ratings and standard deviations are shown in Table 9.3 (1 = hear very well; 5 = not at all).

Children's ability to hear the teacher varied with different adjacent activities, with adjacent children 'quiet and doing a test' reported as the best listening condition, and adjacent children working at tables and moving around the classroom reported as the worst. As shown in Table 9.3, when adjacent activity increases, (and hence intrusive noise level rises), mean ability to hear the teacher decreases.

Table 9.3: Children's mean listening ratings for ability to hear the teacher

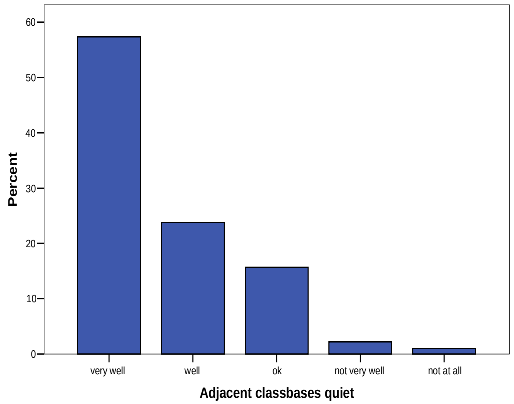
How well can you hear your teacher when:	N	Mean	σ	% children not hearing very well or at all
1. Adjacent classes quiet (doing a test)	408	1.7	0.89	3
2. Adjacent classes working at tables	407	2.4	1.04	16
3. Adjacent classes working at tables and moving around classroom	407	3.1	1.15	38

The percentage of children who reported listening ratings of '4' (cannot hear teacher very well) or '5' (cannot hear teacher at all) are also reported in Table

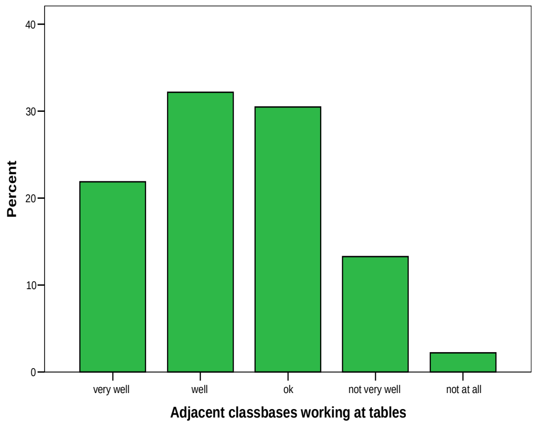
9.3. This may be considered as a dissatisfaction rate. After Walsh[22] and Keighley[145, 146], this suggests that overall, listening conditions were satisfactory when adjacent classbases were involved in quiet activity or working at tables, but not adequate when adjacent classbases were involved in noisier activities including movement around the classroom (dissatisfaction rate > 32%).

Figure 9.2: Reported ability to hear teacher

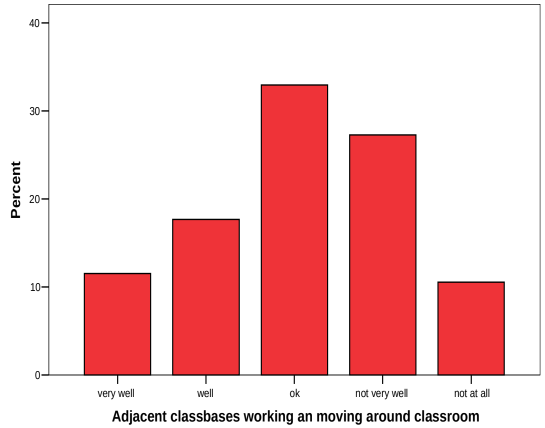
1. Adjacent classes quiet



2. Adjacent classes working at tables



2: Adjacent classes working at tables and moving around the classroom



Listening scale:

1= very well
2 = well
3 = ok
4 = not very well
5 = not at all

9.5.2.2 Ability to hear peers

The distribution of listening ratings for children's ability to hear their peers is shown in Figure 9.3. The full rating scale was used by the children. Mean listening ratings and overall dissatisfaction rates are shown in Table 9.4.

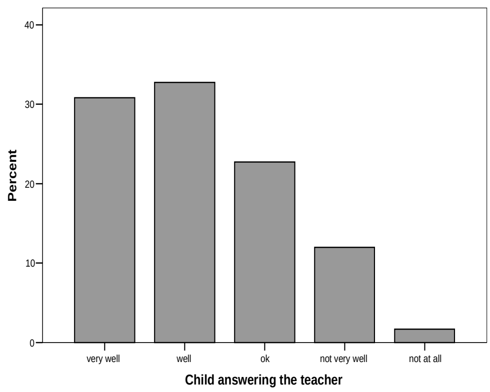
The percentage of children who reported poor listening ratings of '4' or '5' indicate that on average listening conditions were satisfactory for both group work and when a child was answering the teacher (below 32% dissatisfaction level). Further analysis of results is carried out in section 9.6.

Table 9.4: Children's mean listening ratings for ability to hear peers

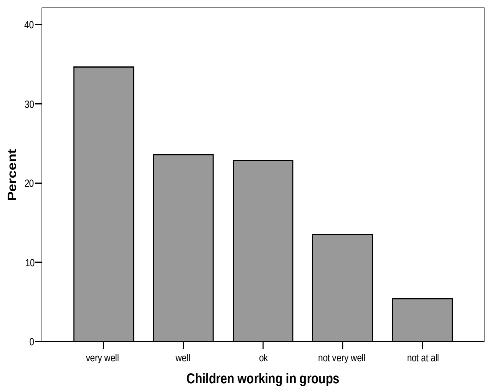
How well can you hear your classmate(s) when:	N	Mean	Std. Dev.	% children not hearing very well or at all
4. The teacher is asking a question and they are giving an answer	409	2.2	1.06	14
5. You are working in groups	407	2.3	1.23	19

Figure 9.3: Reported ability to hear peers

4. When child is answering the teacher



5. When children are working in groups



Listening scale:

1= very well
2 = well
3 = ok
4 = not very well
5 = not at all

9.6 Analysis

Overall questionnaire results were first compared with those of a similar study of enclosed classbases[260, 261] to examine possible differences in response.

Specific listener groups were then identified as discussed in Chapter 4 (children with reported hearing difficulties and children with English as a second language) and responses were compared with those of their ‘typical’ peers. The effect of age was investigated by comparing a large number of responses from one school to control for the physical design characteristics of the classbases.

Physical classroom design factors such as unit size and provision of quiet rooms were also investigated. Listening ratings were also compared with objective data reported in Chapter 8 (STI, intrusive noise level and reverberation time) to examine possible relationships with objective data and perception of the acoustic environment.

Since the listening score data were not normally distributed, nonparametric statistical analysis (χ^2 and Mann-Whitney U test) was carried out to test for differences between listening ratings. Tests were considered to be significant at the 5% level ($p < 0.05$).

9.6.1 Comparison with enclosed classrooms

The results of the survey were compared with responses from a previous subjective study involving enclosed classrooms[260, 261].

For the enclosed study, the questionnaire was administered to children in 41 classrooms in 10 primary schools across Hertfordshire, totalling 1008 pupils. Every child in the classroom attending on the day of the survey took part. The questionnaires were administered to the pupils in small groups using a similar method to that described in Section 9.4.

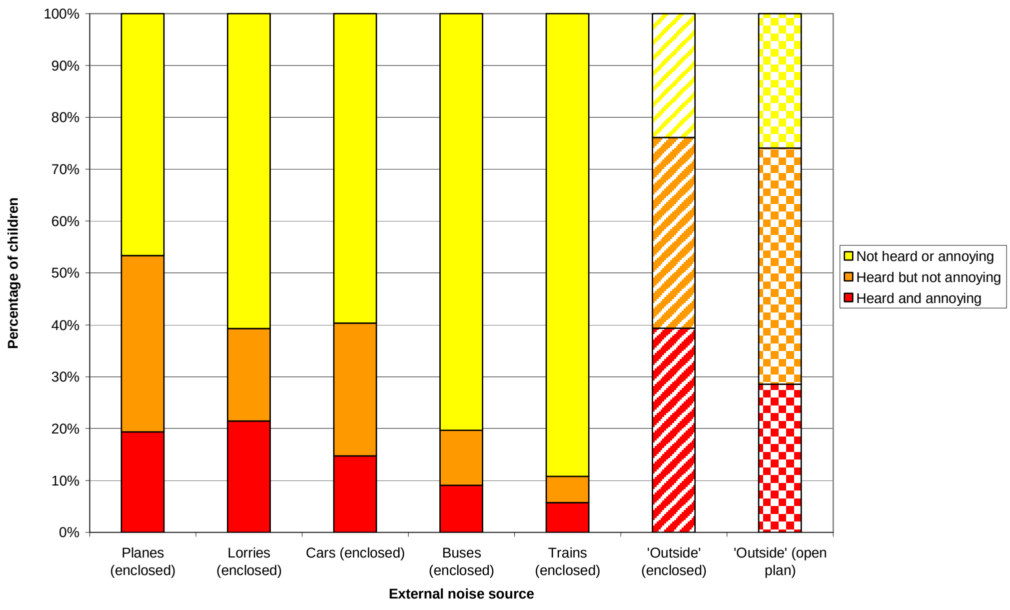
Although the overall structure of the enclosed questionnaire was similar to that used in the open plan study, the questions differed somewhat as a result of the different research objectives for each study. Personal information was gathered in Section One of the enclosed questionnaire. Section Two focused on a number of individual external noise sources. Internal sources of classroom noise included musical instruments, televisions, phones and stereos but not speech from children or teachers outside the classroom.

A more comprehensive list of 11 different listening situations was used for Section Three of the enclosed questionnaire. Listening situations which were considered valid for comparison with the open plan study included:

- How well can you hear the teacher when there is no noise outside or inside the classroom?
- How well can you hear the teacher when children are making a noise outside the classroom?
- The teacher is asking a question and a classmate replies. How well can you hear your classmate?
- You are working in groups. How well can you hear what your group is saying?

Reported hearing and annoyance from external noise sources for both open plan and enclosed classrooms is shown in Figure 9.4. Responses from individual external noise sources for the enclosed classroom study were combined (striped bar) in order to make a direct comparison with the question used in the open plan study which referred to general external noise ('noise from outside the classroom' – checked bar).

Figure 9.4: Reported hearing/annoyance from external noise sources



Whilst there was no significant difference between reported hearing of 'noise from outside the classroom' (χ^2 = 2.72; df = 1; p < 0.10), there was a significant difference between reported annoyance from external noise sources (χ^2 = 11.35; df = 1; p = 0.001), with a larger proportion (>32%) of children in enclosed classrooms reporting annoyance.

Mean listening ratings for ability to hear the teacher for enclosed classrooms are presented in Table 9.5. These were compared to the open plan results in Table 9.3. A significant difference was found between enclosed classrooms (Table 9.5 question 1) and open plan classrooms (Table 9.3 question 1) in quiet listening conditions (U = 142244, p < 0.001). This suggests that for this listening situation, average listening ratings were significantly better for children in enclosed classrooms (although both designs indicate very low dissatisfaction rates of less than 5%).

For the situation when children were making a noise outside the main classroom Table 9.5 question 2), only limited comparisons can be made, since the enclosed study did not specify the type of activity noise outside the classroom. However it is apparent that, as for open plan classrooms (Table 9.4 question 2 and 3), average reported ability to hear the teacher decreases as a result of children making a noise outside the classroom.

Table 9.5: Mean listening ratings/dissatisfaction rates: enclosed classrooms

How well can you hear your teacher when:	n	Mean score	σ	% children not hearing very well or at all
1. Very quiet inside and outside classroom	932	1.3	0.74	3
2. Children are making a noise outside the classroom	933	2.9	1.10	33

Mean listening ratings and overall dissatisfaction rates for children's ability to hear their peers are shown in Table 9.6 for both open plan and enclosed classrooms. No significant difference was found between enclosed and open plan classrooms for either listening situation. Dissatisfaction rates indicate that overall ability to hear peers was satisfactory for both open plan and enclosed classrooms.

Table 9.6: Ability to hear peers/mean listening ratings and dissatisfaction rates

	Open plan classbases		Enclosed classrooms		U-test Sig. p
Situation:	Mean(σ), n	% Dissatisfied	Mean(σ), n	% Dissatisfied	
4.Classmate answers	2.2 (1.06), 409	14	2.2 (1.03), 932	12	0.54
5. Working in groups	2.3 (1.23), 407	19	2.4 (1.16), 939	19	0.36

9.6.2 Vulnerable listeners

Groups of children considered to be particularly vulnerable to the effects of intrusive noise in the classroom include children with reported hearing difficulties, children with English as an additional language and very young children (see Chapter 5). Further analysis was carried out to investigate possible differences in ability to hear in different listening contexts for vulnerable listeners.

It is also likely that classroom noise would have a significant effect on other types of vulnerable listener such as children with special education needs[118]. However since this information was not collected in the questionnaires it was not possible to investigate this effect.

9.6.2.1 Effect of hearing difficulties

Less than ten percent (9.1%) of children reported having problems with their hearing. When the questionnaires were administered it was made clear to the children that 'hearing problems' included long term rather than temporary hearing problems (such as having a cold). The degree of hearing loss or type of impairment was not specified; however it is likely that most reported hearing problems would have been related to mild hearing loss. This is supported by the small number of children who reported wearing a hearing aid (0.5%). The small sample size of hearing aid users was not considered large enough for further analysis.

The mean ratings for the various listening situations are reported for both normal hearing and 'problem hearing' groups in Figure 9.5 and Table 9.7.

Results showed that mean reported ability to hear the teacher was significantly worse for children who reported having hearing problems when the adjacent class was taking a test (U = 14572.0, $p < 0.001$), working at tables (U = 16188.5, $p = 0.021$), and working at tables and moving around the classroom (U = 15207.5, $p = 0.005$). The standard deviation of responses from the group with hearing problems was considerably higher than that of their typical hearing peers in quiet conditions (see Table 9.7).

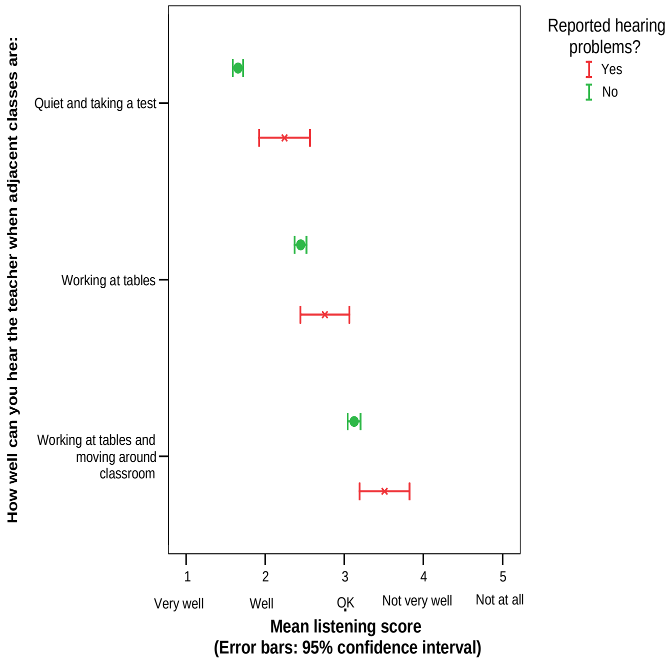
For children with hearing problems, dissatisfaction rates rose to above 32% for adjacent classbases working at tables. This suggests that, whereas in the overall sample a satisfactory majority of ‘normal’ hearing children are able to hear the teacher reasonably well in this listening situation, it is not appropriate for children with reported hearing problems.

No significant differences were found between groups for ability to hear peers in the classbase (either answering the teacher or working in groups, see Table 9.7).

Table 9.7: Effect of reported hearing problems

	No hearing problems			Hearing problems			Sig. p
	Mean	σ	% not hearing very well or at all	Mean	σ	% not hearing very well or at all	
How well can you hear your teacher when adjacent classes are:							
Quiet (test)	1.7	0.84	2	2.2	1.2	16	< 0.001
Working at tables	2.4	0.98	14	2.8	1.2	33	< 0.05
Working at tables and moving around	3.1	1.1	38	3.5	1.2	56	< 0.05
How well can you hear you classmate when:							
They are giving an answer	2.3	0.98	11	2.5	1.1	19	NS
You are working in groups	2.3	1.2	17	2.6	1.2	24	NS

Figure 9.5: Effect of hearing problems



9.6.2.2 Effect of English as an additional language (EAL)

The distribution of children with EAL by school is shown in Table 9.8. The percentage of pupils with EAL in each school's Local Education Authority in 1996/1997 as reported by the DCSF[262] is also indicated. The proportion of children reporting EAL is broadly in line with the expected proportion as indicated by the percentage in each Local Education Authority.

Table 9.8: Children with EAL

School	% of children in survey reporting EAL	Local Education Authority	% of pupils with EAL in Local Education Authority[262]
1	0	South Gloucestershire	1
2	3	West Sussex	2
3	10	West Sussex	2
4	3	West Sussex	2
5	0	West Sussex	2
6	0	South Gloucestershire	1
7	0	Hampshire	1
9	0	Suffolk	1
10	80	Tower Hamlets	56
11	0	Hertfordshire	4
12	0.0	South Gloucestershire	1
All	9.4	-	-

Of those with English as an additional language, the most common additional languages spoken at home were of Indian origin (78%). The majority of children with EAL (83%) were from a single school (school 10) in inner-city London.

Listening ratings were compared to test for possible differences between EAL and native listeners for ability to hear the teacher and ability to hear peers. No significant difference was found between listening ratings for native and EAL listeners for any of the listening scenarios ($p > 0.05$ for all listening scenarios). This is consistent with the results of Dockrell and Shield's study[118] which investigated the effect of classroom babble on task performance in the classroom. No obvious pattern of additional deficit was evident for children with EAL, for either verbal or speed of processing tasks, although the sample was also small for this study.

The age of the EAL listeners ranged from 6-8 years with a mean age of 7.8 years. It is possible that EAL listeners would be more vulnerable to the effects of intrusive noise on speech intelligibility at an earlier age, when language is at an earlier stage of development. Further work with more carefully selected subjects would be required to fully investigate this.

9.6.2.3 Effect of age

In order to test for the possible effect of age on listening ratings and control for the effects of classroom design, responses were analysed from a single school (school 7), where the questionnaire had been administered to every child in attendance from years 2 to 6 (217 children). The nine classbases included in this sample were very similar in design (semi-open plan linear arrangement) and acoustic conditions were consistent across classbases (T_{mf} 0.38-0.41 seconds, ambient STI > 0.7 for all classbases). Ages of the children were grouped into pupils between 6-7 years and pupils between 8-11 years. Mean listening ratings are reported in Table 9.9.

Listening ratings for quiet adjacent activities may be considered as a base case for listening acuity, without the presence of intrusive noise. For this situation, younger children reported that hearing the teacher was significantly more difficult ($U = 3034$, $p < 0.001$). The standard deviation in listening ratings was larger for the younger age group. This finding is consistent with Dockrell and Shield's findings (for enclosed schools)[120].

Table 9.9: Mean listening ratings for different age groups

	6-7 years			8-11 years			Sig.
	Mean	σ	n	Mean	σ	n	p
How well can you hear your teacher when adjacent classes are:							
Quiet (doing a test)	1.90	0.81	61	1.38	0.66	156	<0.001
Working at tables	2.23	1.06	61	2.30	0.80	155	NS
Working at tables with movement	3.11	1.29	61	3.02	0.99	156	NS
How well can you hear you classmate when:							
They are giving an answer	2.31	0.93	59	2.21	0.84	155	NS
You are working in groups	2.44	1.21	59	2.14	1.05	154	NS

However, in the presence of intrusive noise from adjacent groups (working at tables and with movement), no statistically significant difference was found between listening ratings for the two age groups. Furthermore no statistically significant difference was found between age groups for when the children were working in groups, which is consistent with Dockrell and Shield's findings[120].

No significant difference was found between age groups for ability to hear a classmate speaking, although conversely Dockrell and Shield[120] found that younger children reported that hearing the teacher was significantly more difficult in this situation.

9.6.3 Physical variables

9.6.3.1 Effect of open plan unit size

Following the findings from the objective survey (Chapter 7), responses from children in large units (4 or more classbases) and limited units (less than 4 classbases) were compared. Children's reported hearing and annoyance from other teachers' voices (Figure 9.6) and other pupils (Figure 9.7) is shown below.

There was a significant difference between unit size and reported frequency of hearing both teachers and pupils in adjacent classbases. Children in large units were significantly more likely to report hearing other teachers voices (χ^2 = 5.41; df = 1; p = 0.02) and pupils from other classbases (χ^2 = 5.54; df = 1; p = 0.02), than children in limited units. Children in larger units were also significantly more likely to report annoyance from other teachers voices (χ^2 = 9.36; df = 1; p = 0.002) than children in limited units. However no significant difference was found between unit size and annoyance from pupils in other classbases.

Figure 9.6: Reported hearing and annoyance from other teachers *vs*. unit size

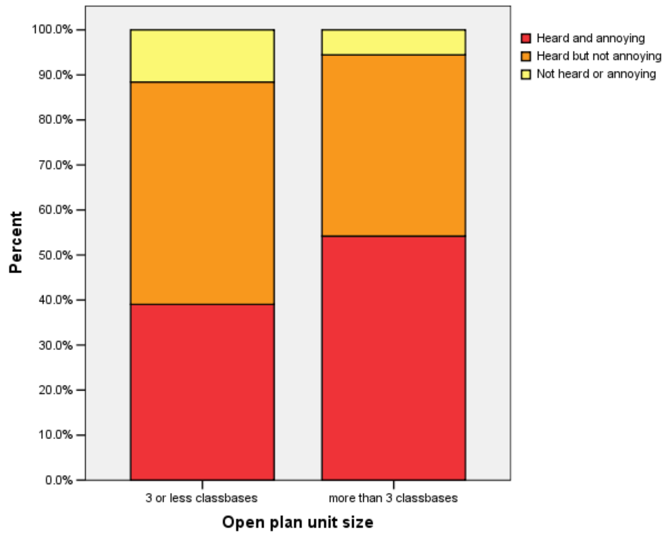
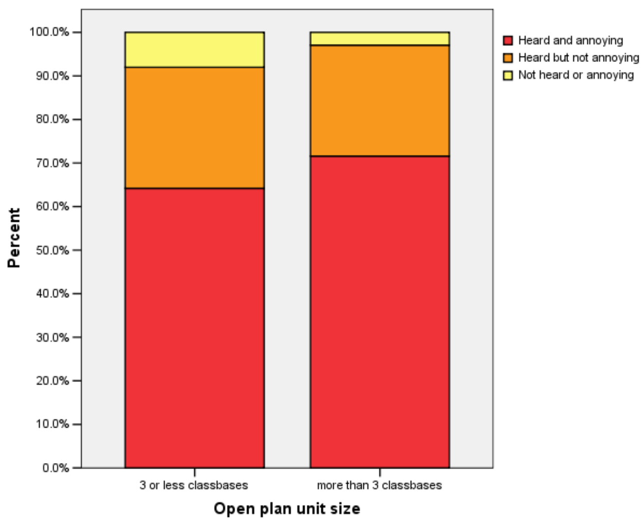


Figure 9.7: Reported hearing/annoyance from other pupils *vs.* unit size



Mean listening ratings for the two groups are reported in Table 9.10. Mean listening ratings were generally worse for children in larger units than for those working in limited units. A significant difference was found between limited and larger units for ability to hear the teacher when the adjacent classroom was working and moving around the classroom (U = 19159, $p < 0.01$) and for ability to hear another child answering the teacher (U = 19329, $p < 0.01$). No significant difference was found for other listening scenarios.

Dissatisfaction rates between large and limited units (% children hearing not very well, or not at all) were similar when adjacent classbases were quiet, but were significantly greater for larger units with intrusive noise present. Dissatisfaction rates rose to unacceptable levels (above 32%) for larger units when adjacent activities involved movement, but stayed at a reasonable level (<32%) for limited units.

Table 9.10: Mean listening ratings – effect of open plan unit size

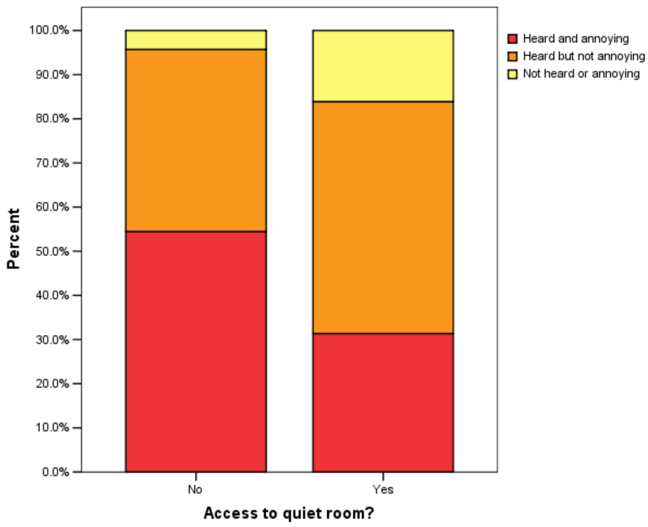
	Limited units (n = 168)			Large units (n=278)			Sig.
	Mean	σ	% hearing not very well or at all	Mean	σ	% hearing not very well or at all	p
<u>How well can you hear your teacher when adjacent classes are:</u>							
1. Quiet (test)	1.62	0.87	4	1.67	0.91	4	NS
2. Working at tables	2.33	0.96	10	2.44	1.08	18	NS
3. Working at tables and moving around	2.88	1.15	26	3.16	1.11	42	0.007
<u>How well can you hear you classmate when:</u>							
4. They are giving an answer	2.02	1.06	13	2.27	1.03	13	0.007
5. You are working in groups	2.25	1.17	14	2.31	1.23	20	NS

9.6.3.2 Effect of quiet room access

Children's responses to hearing and annoyance from other teacher's voices for the two types of classroom are shown in Figure 9.8. Children in units without quiet rooms were significantly more likely to report hearing other teacher's voices (χ^2 = 17.0; df = 1; $p < 0.001$) than children in units with quiet rooms. Children in units without quiet rooms were also significantly more likely to report annoyance from teachers' voices (χ^2 = 18.0; df = 1; p < 0.001), than children in units with quiet rooms.

No significant association was found between quiet room access and reported frequency of hearing pupils in adjacent classbases (χ^2 = 1.41; df =1; p = 0.23), or reported annoyance from pupils in other classbases (χ^2 = 2.23; df =1; p = 0.14).

Figure 9.8: Reported hearing/annoyance from teachers *vs.* quiet room access



Mean listening ratings for the two groups are reported in Table 9.11. Mean listening ratings were generally worse for children without quiet room access than those with quiet room access. A significant difference was found for ability to hear the teacher when the adjacent classrooms were quiet (U = 15394, p < 0.05) and when adjacent classes were moving around the classroom (U = 14496, p < 0.05). No significant difference was found for other listening scenarios.

Dissatisfaction rates (% children hearing not very well or not at all) were similar (≤4%) when no intrusive noise occurred outside classrooms (scenario 1), but were considerably greater for classbases without quiet room access when intrusive noise was present (scenarios 2 and 3). Dissatisfaction rates rose above 32% for classbases without quiet room access when adjacent activities involved movement, but stayed at a reasonable level (<32%) for classbases with quiet room access.

Table 9.11: Mean listening ratings – effect of quiet room access

	No quiet room access (n=307)			Quiet room access (n=120)			Sig.
	Mean	σ	% hearing not very well or at all	Mean	σ	% hearing not very well or at all	p
How well can you hear your teacher when adjacent classes are:							
1. Quiet (test)	1.73	0.90	3	1.51	0.83	4	0.05
2. Working at tables	2.43	1.02	16	2.31	0.99	10	NS
3. Working at tables and moving around	3.15	1.11	41	2.80	1.11	22	0.01
How well can you hear you classmate when:							
4. They are giving an answer	2.27	1.02	12	2.08	1.08	14	NS
5. You are working in groups	2.40	1.24	21	2.15	1.11	12	NS

9.6.4 Comparison with objective data

9.6.4.1 General findings

General findings from the objective survey were compared with the findings of the children’s questionnaire survey.

Noise from pupils and teachers operating in other adjacent class groups were the most frequently perceived noise sources, and this is supported by the finding that measured intrusive noise spectra matched that of typical raised speech (Figure 8.1).

Measured ambient noise levels were relatively low in all classbases, and this is reflected by the low level of reported annoyance from sources such as external noise, building services and classroom equipment.

Overall mean listening ratings for ability to hear the teacher as described above support the findings from the objective survey, that is, speech intelligibility (STI) decreases with increased activity in adjacent classbases. The corresponding subjective ratings of STI compare well with mean subjective listening ratings, as shown in Table 9.12. Since the subject's usual listening position in the classroom wasn't collected, it was not possible to compare perceived listening ability with the variation of objective speech intelligibility around the classroom.

Table 9.12: Comparison of measured STI and mean rated ability to hear teacher

Adjacent activity	Mean occupied STI	ISO 9921[156] Subjective Rating	Mean subjective listening rating	Corresponding listening scale rating
Quiet (whole class teaching or test)	0.63	Good	1.7	'Very well – well'
Working at tables	0.52	Fair	2.4	'Well – OK'
Working at tables with movement	0.47	Fair	3.1	'OK'

The differences in mean listening ratings between large and limited units also support the objective findings that mean occupied speech intelligibility is significantly higher in limited units than large units, as shown in Table 9.13.

Table 9.13 Comparison of STI and mean rated ability to hear teacher by unit size

	Limited units		Large units	
	Mean listening rating	Mean occupied STI	Mean listening rating	Mean occupied STI
1. Quiet (test)	1.6 Very well – Well	0.65 Good	1.7 Very well – Well	0.57 Fair
2. Working at tables	2.3 Well – OK	0.57 Fair	2.4 Well – OK	0.49 Fair
3. Working at tables and moving around	2.9 Well – OK	0.53 Fair	3.2 OK – Not very well	0.43 Poor

Mapp[154] notes that it is usually difficult to compare subjective based rating ratings with objective data as subjective judgement is influenced by many other factors[154]. This is especially true in practical settings rather than controlled laboratory conditions. Subjective data is usually presented in the form of mean opinion ratings for comparison with objective data[154]. A large degree of scatter (low correlation coefficient) is normally found for such comparisons[106, 198], and it should be noted that any relationship found between acoustic data and listening ratings could be due to other non-acoustic factors such as personal listening acuity. However significant correlations between objective and subjective data may be considered to support overall findings from objective data.

In order to study the impact, if any, of the measured acoustic parameters on the children's perceived listening ratings, mean acoustic parameters for each classbase (averaged for all three measurement positions) were correlated with mean listening ratings from each class.

9.6.4.2 Correlation with intrusive noise levels

The Pearson correlation coefficients between listening ratings and occupied noise level (main classbase quiet) are shown in Table 9.14. Only the equivalent continuous noise level is presented below since other noise parameters were not significantly correlated with listening ratings.

Table 9.14: Correlation between mean listening ratings and L_{Aeq} by activity

			Mean occupied L_{Aeq}			
			All activities	Whole class teaching	Working at tables	Working at tables with movement
Ability to hear:	Teacher	1. Quiet	NS	NS	NS	NS
		2. Working at tables	0.40*	NS	0.40*	NS
		3. Working at tables with movement	0.51**	NS	0.48**	NS
	Peers	4. Child answers	0.50**	NS	0.41*	NS
		5. Groups	0.37*	NS	0.40*	NS

*Significant at 5% level
**Significant at 1% level

No significant relationship was found between average ability to hear the teacher and intrusive L_{Aeq} noise level when adjacent classes were involved in quiet activities (such as a test). This would be expected, as listening ability for this situation is likely to be more affected by other acoustic factors (such as vocal effort, distance from teacher, and other room acoustic conditions), individual listening acuity and other non-acoustic factors.

A significant positive correlation was found between mean occupied L_{Aeq} (all activities and locations) and average listening scores when adjacent classbases were more active, that is, as noise levels increase, the listening score rating increased and hence overall ability to hear the teacher decreased (1 = hear very well; 5 = not at all). The correlation was higher and more significant for adjacent activities involving movement, suggesting that this listening situation was most affected by intrusive noise. When noise from different adjacent activities was considered separately, listening ratings were only significantly correlated to intrusive L_{Aeq} from work at tables.

No significant relationship was found for intrusive noise from specific activities involving movement. This may be due to the small sample size (n = 19).

A significant relationship was found between overall noise level (from all activities) and ability to hear peers (both child answering and working in groups).

The high degree of scatter (correlation coefficient < 0.5) is likely to be due in part to variation in noise and other acoustic conditions around the classbase. When noise measured at different positions in the classbase was taken into account, as shown in Table 9.15, stronger correlations were observed. Perceived listening ability was most strongly correlated to noise levels measured at the front of the classroom. Recall that listening scenarios for ability to hear the teacher are based on the situation when 'the class is quiet and you are listening to your teacher'. As discussed in previous chapters, in primary school practice it is common for this type of whole class activity to take place on the carpet with the class gathered closely around the teacher (corresponding to the 'front' position). This is also likely to be the case for when the teacher is asking a question and the classmate is giving an answer. The stronger correlations for the front of the classroom (r = 0.52 - 0.66) supports this.

Table 9.15: Correlation between mean listening ratings and L_{Aeq} by position

			Mean occupied L_{Aeq}			
		Adj. activity	All positions	Front	Middle	Back
Ability to hear:	Teacher	1. Quiet (Test or whole class)	NS	NS	NS	NS
		2. Working at tables	0.40*	0.57**	NS	0.45*
		3. Working at tables with movement	0.51**	0.66**	NS	0.52**
	Peers	4. Child answering question	0.50**	0.58**	0.45*	0.47**
		5. Working in groups	0.37*	0.52*	0.44*	0.36*

*Significant at 5% level
**Significant at 1% level

9.6.4.3 Correlation with STI

The Pearson correlation coefficients between listening ratings and mean occupied STI are shown in Table 9.16. It should be noted that STI is assessed for standard 'raised' vocal effort for a fixed position.

As above, a significant negative correlation was found between listening ratings and STI at positions at the front of the classroom, that is, as STI decreases, the listening score rating increased and hence overall ability to hear the teacher decreased (1 = hear very well; 5 = not at all). No significant relationship was found between STI and ability to hear the teacher for quieter activities, as expected.

Table 9.16: Correlation coefficients between mean listening score and STI

		Adjacent activity	Mean occupied STI All positions	 Front	 Middle	 Back
Ability to hear:	Teacher	1. Quiet	NS	NS	NS	NS
		2. Working at tables	NS	-0.54**	NS	NS
		3. Working at tables with movement	-0.40**	-0.70**	NS	NS
	Peers	4. Child answering question	0.50**	-0.70**	-0.47*	-0.47**
		5. Working in groups	NS	-0.57**	NS	NS

*Significant at 5% level; **Significant at 1% level

The mean children's listening ratings do not take account of variation in perception around the classroom, and as the questionnaires did not gather information about the child's usual listening position, it is not possible to investigate this directly. Nor do the results account for actual vocal effort used and the effect of the teacher moving around the classroom to address the whole class. However the significant relationships shown here may be used to support the findings of the objective survey.

9.6.4.4 Correlation with reverberation time

No significant correlations were found between average listening ratings and reverberation time (either T_{mf} or EDT_{mf}). Nor was any significant difference found for mean listening ratings between classbases with high reverberation times (T_{mf} > 0.4 s) and low reverberation times ($T_{mf} \leq 0.4$ s). The measured reverberation times for the classbases were all fairly low (see Chapter 8). This supports the finding that, provided reverberation time is not excessive, RT is a less significant factor in determining ease of speech perception in open plan classrooms.

9.6.4.5 Comparison with Speech Privacy, SII

The effect of speech privacy (SII measured between receiving room and nearest adjacent source room) on children's reported hearing of and annoyance from other teacher's voices was also investigated. Responses from children in classbases achieving proposed speech privacy criteria discussed in Chapter 8 (SII_r ≤ 0.1; SII_L ≤ 0.2) were compared with those in classbases with poorer speech privacy, as shown in Figure 9.9 and Figure 9.10.

Figure 9.9: Hearing/annoyance from teachers' voices *vs.* SII_L criterion

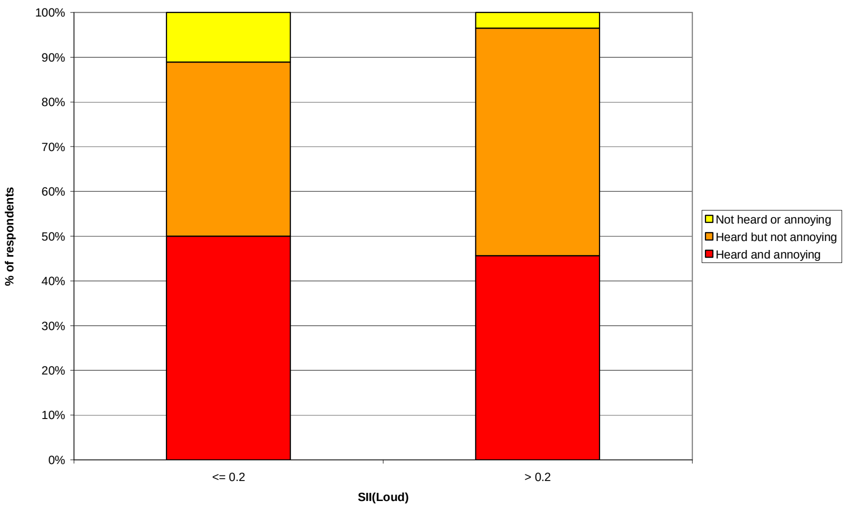
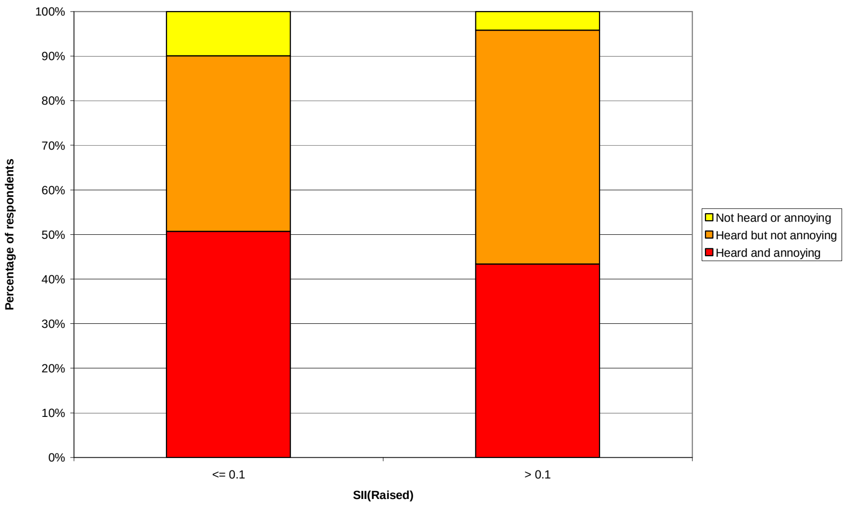


Figure 9.10: Hearing/annoyance from teachers' voices *vs.* SII_r criterion

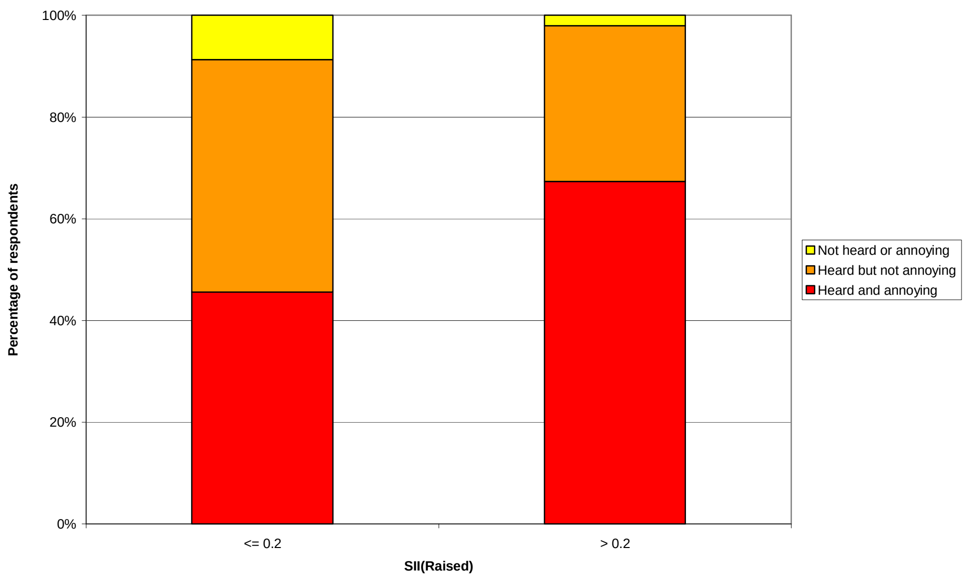


Significantly fewer children in classbases which achieved the proposed speech privacy criteria reported hearing other teachers' voices compared to those in classbases with poorer speech privacy performances. This was the case for both the loud speech criterion (χ^2 = 8.1; df =1; p = 0.004), and the raised speech criterion (χ^2 = 4.5 ; df =1; p = 0.03).

Conversely, a larger percentage of children in classbases achieving proposed speech privacy criteria appeared to report annoyance from other teachers' voices. However this difference was not found to be statistically significant for either the raised speech criterion (χ^2 = 1.8; df =1; p = 0.18) or the loud speech criterion (χ^2 = 0.67; df =1; p = 0.41).

The effect of speech privacy on reported annoyance from other teacher's voices was investigated further by comparing responses from children in classbases achieving $SII_r \leq 0.2$ and those achieving $SII_r > 0.2$. As discussed in Chapter 8, this criterion is compatible with 'acceptable' privacy levels described in the literature and meets Petersen's[147] recommendations which have been incorporated into Danish Guidance[216] (see Chapter 6). Responses are shown in Figure 9.11. A significantly greater percentage of children in classbases with $SII_r > 0.2$ reported annoyance from other teachers than those in classbases which achieved $SII_r \leq 0.2$ (χ^2 =8.05; df =1; p = 0.005).

Figure 9.11: Hearing/annoyance from other teachers' *vs.* SII_r revised criterion



9.7 Conclusions

The results of the survey show that children in open plan classrooms generally perceive themselves to be significantly annoyed by intrusive speech from pupils and teachers in adjacent classbases, in terms of noise annoyance, and ability to hear the teacher during critical listening situations.

Children's perceived ability to hear their teacher in open plan classrooms decreases as activity in adjacent classrooms increases to involve movement. Children's perceived ability to hear the teacher in enclosed classrooms is also detrimentally affected by children's noise outside the classroom, although further research would be required to compare directly the extent to which speech communication is affected.

Whilst overall, the proportion of children reporting poor ability to hear the teacher during critical listening appears to be acceptable when adjacent activities are quiet or working at tables, higher unacceptable levels of dissatisfaction arise when adjacent activities involve movement. This supports the conclusions of the objective survey (see Table 8.13).

When adjacent classrooms are quiet, children in enclosed classbases report significantly better listening conditions than in open plan classrooms. However this result should be treated with some caution since differences in the question phrasing could result in different interpretations and hence responses. A dedicated study would be necessary to enable a more direct comparison between open plan and enclosed classrooms.

Classroom design (open plan or enclosed) does not appear to significantly affect ability to hear peers, either for a child answering the teacher, or when working in groups. For the group work scenario, the noise climate is likely to be dominated by noise from children within the main classbase itself, and intrusive noise from adjacent open plan classbases is less likely to have an effect.

Children in enclosed classrooms are significantly more likely to report annoyance from external noise sources than children in open plan classbases, even though there is no significant difference between both groups' reported hearing of external noise. Further work would be required to determine why this may be the case. It is probable that in open plan classrooms, where the noise climate is dominated by intrusive speech rather than external noise, children are less likely to be aware of and annoyed by external noise. Children in enclosed classrooms may also be more sensitised to external noise and therefore more likely to report annoyance. This result is supported by that of a previous study [120] which compared external noise levels with children's' perceived ability to hear the teacher, and found that external noise levels only affected listening ratings when other confounding noise sources such as other children were not present[120].

Results of the subjective survey support the objective finding that open plan designs should be limited to 3 classbases within each unit, since for this type of design, hearing of teachers and pupils in adjacent classbases is reported less frequently and overall rated ability to hear the teacher is significantly more favourable. This is likely to occur simply as a result of lower circulation and occupancy levels in the smaller units, and hence lower intrusive noise levels. This type of design is also likely to produce lower dissatisfaction rates in the presence of intrusive activity noise, and significantly better ability to hear the teacher when adjacent activities involve movement.

Similarly, results suggest that all classbases in the unit should have access to a shared quiet room, since children are less likely to report hearing and annoyance from other teachers' voices, and more likely to report significantly higher and more satisfactory listening ratings when adjacent activities involve movement.

In the present study, younger children (6-7 years) found it significantly more difficult to hear the teacher in quiet than older years (8-11) and this is consistent with previous studies of enclosed classrooms[120].

No significantly adverse affects were found for children with English as an additional language, however further work would be required to investigate this.

Significant correlations were found between mean reported classroom listening ratings and mean measured intrusive noise level and STI at the 'front' of the classroom, for adjacent work at tables and work involving movement. This suggests that, whilst children's listening ability in quiet is affected by a number of individual factors specific to the child (such as age and hearing acuity), reported listening ability is significantly affected by the acoustic environment when children in adjacent classbases become more active.

Significant associations were also found between children's reported hearing of teachers in adjacent classbases and measured speech privacy, SII, when proposed SII criteria discussed in Chapter 8 were considered ($SII_r \leq 0.1$; $SII_L \leq 0.2$). Significant differences between reported annoyance from other teachers' voices did not occur until the speech privacy criterion exceeded SII_r 0.2.

Chapter 10: Subjective survey – Teachers

10.1 Introduction

A questionnaire was designed and developed to investigate teachers' attitudes, teaching and coping strategies, perceptions of noise and ease of speech communication in open plan classrooms. The questionnaire was administered to each member of teaching staff operating in the 12 open plan schools which took part in the objective acoustic survey (a total of 108 teaching staff operating in 97 classbases).

The design and development of the questionnaire and survey procedure are discussed in detail in this chapter. The questionnaire was designed with reference to ISO/TS 15666:2003[258]. Results are analysed by comparing responses with physical variables (such as open plan unit size and quiet room access), and by comparing responses of teachers using different teaching strategies.

Where possible, results have been compared with Bennett's[20] 1975-1978 survey of Plowden classrooms, the results of the children's survey (Chapter 9), and results of the objective survey (Chapter 8).

10.2 Design and development of questionnaire

10.2.1 Aims and objectives

The main objectives of the teacher questionnaire were as follows:

- Investigate teachers' opinions of open plan classrooms (acoustic and non-acoustic factors)
- Establish main sources of background noise experienced by teachers in open plan classrooms
- Investigate teachers' subjective impressions of noise levels in open plan classrooms
- Investigate teachers' subjective impressions of distraction and speech communication in open plan classrooms
- Investigate teachers' reactions to noise and coping strategies used to ameliorate noise levels

Further to this, a number of sub-questions were also formulated to investigate possible underlying variables affecting the main research questions. These included questions relating to teaching strategy such as classroom organisation, teaching methods, quiet room use, line of sight into adjacent classbases, and sound field system use.

10.2.2 Questionnaire design

The questionnaire structure was based on a questionnaire developed by Dockrell and Shield[120]. A copy of the questionnaire is attached in Appendix C.

The six-page questionnaire consisted of seven sections as follows:

1) Background - gathered general information on age and teaching experience.
2) Attitudes - investigated the type of teaching organisation and teaching methods used by the teacher, and other organisational aspects such as pupil grouping and seating arrangements, use of quiet rooms and sound field systems.

   The last question in this section investigated general attitudes towards open plan classrooms, which was informed by the teacher questionnaire developed by Bennett *et al*[20]. This allowed results to be compared with Bennett's original survey. The questions investigated attitudes to open plan *vs.* enclosed schools using a set of statements to be answered on a five point Likert scale (1: strongly agree to 5: strongly disagree). The number of statements included in the present study was reduced from the original 22 statements of Bennett's study[20] to 13 statements most relevant to this study. The questions included 12 non-acoustic statements, and one statement relating to noise.
3) Acoustic environment - investigated noise sources experienced in the classbase and perceived noise levels in different areas of the classroom. Further questions also investigated perceived distraction from noise, and ease of speech communication in different situations. Section 3 questions were developed on the basis of a 7 point Likert scale as used by Dockrell and Shield[120], with 1 being 'too quiet' and 7 being 'too noisy'.
4) Hearing impaired students – investigated the number of hearing impaired children in the classroom and ease of listening for hearing impaired children as perceived by teachers.
5) Coping with noise – investigated strategies used by teachers to cope with noise and any voice problems experienced as a result of noise.
6) Further information (optional)
7) Classbase design information (age, design layout, number of classbases in unit) was completed separately by the researcher to ensure that terminology was applied consistently and correctly, and to reduce the teachers' work input.

10.2.3 Pilot testing

A draft version of the questionnaire was given to four teachers in one school for comment. These teachers operated in a small open plan village school (not included in the main sample). The teachers provided useful feedback on the structure of the questionnaire and interpretation of questions. As a result of feedback it was found that some of the terms used by Bennett[20] to describe teaching methods were outdated and sometimes ambiguous. Alternative terminology was suggested so that the terms would be more universally understood by teachers. The teachers felt that the questionnaire should be limited to five short sections in order to improve the likely response rate from the sample.

A revised questionnaire incorporating the user feedback was issued to the main sample of teachers. The final draft of the questionnaire was approved by each head teacher before being issued to members of teaching staff. It took approximately 20 minutes for teachers to answer all the questions.

All participants were informed that the survey results would be reported anonymously. Names of teachers were collected for identification of individual responses within the analysis, and full details did not have to be given.

10.3 Participants and class details

A copy of the questionnaire was issued to every teacher working at the schools which took part in the objective survey. A total of 84 questionnaires were returned, yielding a response rate of 78%. Of the returned sample, 35 (42%) were from teachers operating in the classbases in which acoustic data had been gathered.

The other 49 responses (58%) were from teachers who operated in classbases outside the objective survey. However, the classroom layout, design and acoustic finishes were generally consistent between classbases within each school. Table 10.1 shows a breakdown of response rates by school.

Table 10.1: Breakdown of questionnaire responses

School	No. classbases in school, n	No. questionnaires administered, n	Number of questionnaire returns, n (%)			Number of classbases objectively surveyed, n	Return from objectively measured classbases (%)
			Within objective survey	Outside objective survey	Total		
1	5	5	0	0	0	1	0
2	9	9	3	5	8	3	100
3	6	6	1	2	3	3	33
4	6	6	1	3	4	3	33
5	9	12*	3	9	12	3	100
6	10	10	7	0	7	8	88
7	14	21*	10	10	20	8	125*
8	9	9	3	3	6	3	100
9	6	7*	3	4	7	3	100
10	8	8	2	4	6	3	67
11	8	8	1	4	5	2	50
12	7	7	1	5	6	1	100
Total	97	108	35 (42%)	49 (58%)	84 (78%)	41	85

*N.B. More than one teacher operated in some classbases

10.3.1 Age

The age range of the 84 respondents is shown in Table 10.2. The median age range was 26-35.

Table 10.2: Age range of teachers

Age range (years)	Frequency	%
21-25	13	15.5
26-35	32	38.1
36-45	14	16.7
46-55	19	22.6
56-60	6	7.1

10.3.2 Experience

Of the 83 responses to this question, the length of time that teachers had been qualified for is shown in Table 10.3.

Table 10.3: Teaching experience

Range of experience	Frequency	%
Teaching assistant	7	8.4
<2 years	9	10.8
2-5 years	20	24.1
5-10 years	20	24.1
10 years +	27	32.5

The year of qualification was calculated from the length of teachers' experience in open/closed plan classrooms. The results of this are shown in Table 10.4. The results show that the majority of those questioned had qualified after the introduction of the National Curriculum in 1988 and after the publication of the Alexander Report in 1992 which placed emphasis on whole class teaching methods. Over one third of respondents had qualified since the introduction of the 1998 National Literacy and Numeracy Strategies.

Table 10.4: Year of qualification

Year qualified	Frequency	%
1968 to 1980	8	10.0
1981 to 1990	10	12.5
1991 to 2000	37	46.3
2001 to 2005	25	31.3

10.3.3 Class size

Of the 76 responses to this question, the maximum class size was 31 pupils. The mean class size was 28 pupils. This slightly exceeds the UK national average class size for primary schools of 26 children[263]. Results are shown in Table 10.5.

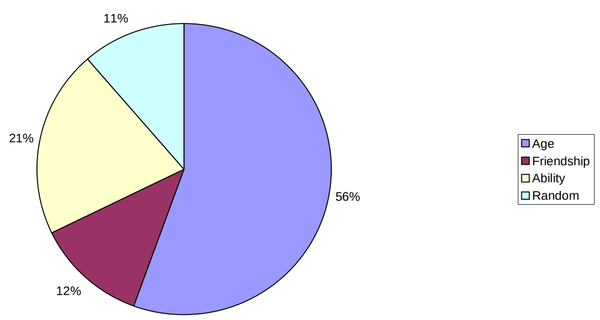
Table 10.5: Number of children in class

	Frequency	%
Less than 25	8	10.5
25-27	16	21.1
28-30	51	67.1
31+	1	1.3

10.3.4 Pupil grouping

The majority of classes were assigned by age (56 %), followed by ability (21 %), as shown in Figure 10.1

Figure 10.1: Class grouping method



10.3.5 Class age

Most teachers operated within a single classbase which is typical for primary schools. Some classbases contained mixed year groups. Therefore class age is grouped by Foundation stage (3-5 years), Key Stage 1 (5-7 years, Year 1-2), and Key Stage 2 (7-11 years, Year 3-6). Results are shown in Table 10.6.

Table 10.6: Age of class taught

Year group	Frequency	%
Foundation	20	24.7
KS1	31	38.3
KS2	30	37.0
Total	81	100.0

10.4 Hearing impaired pupils

Only 9 teachers (11%) were aware of one or more hearing impaired child in their class. Although not directly comparable with children's responses since not all teacher and children questionnaires were matched to the same classbase, this is comparable to the proportion of children who reported having hearing problems (9.1%). This sample size was considered too small to include in further analysis.

10.5 Teaching strategies

10.5.1 Planning and organisation

The type of classroom organisation reported by teachers is shown in Table 10.7. The majority of respondents (95%) described planning and organisation in terms of a single response, however 5% gave two responses. In order to elicit a single response per teacher, the types of organisation were regrouped as shown in Table 10.7 and as follows ('other' responses were excluded from further analysis):

- Strategy 1: Independent (n=11)
- Strategy 2/3/4: 'Mixed mode' (n = 50)
- Strategy 5/6: Cooperative (n = 13)

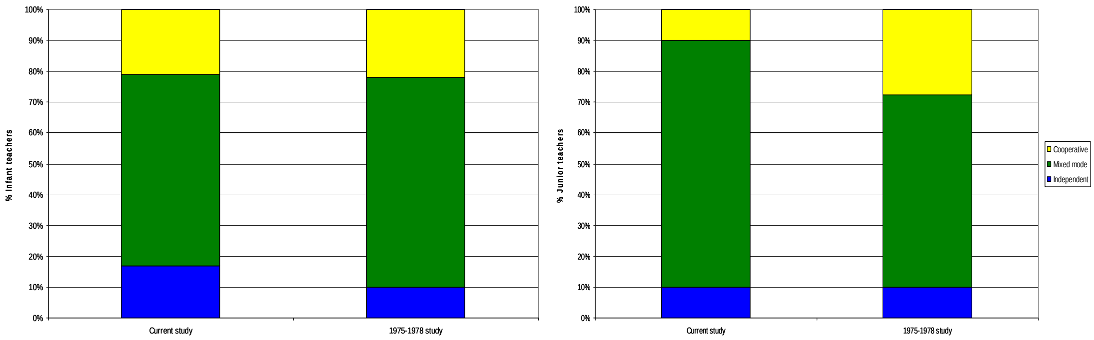
Reported teaching organisation is shown in Figure 10.2 for infant (foundation and KS1) and junior (KS2) teachers. The results of Bennett's 1975-1978 study[20] are also given for comparison with current trends.

Table 10.7: Teachers' planning and organisation

Strategy option	Description	1st Choice	2nd choice	
			Option 4	Option 6
1	Independent instruction	11	-	1*
2	Mainly independent instruction but plan cooperatively sometimes	47	-	-
3	Independent instruction for basic subjects but cooperate on project work	-	1*	-
4	Independent instruction for project work but cooperate on basic subjects	1	-	-
5	Cooperative team teaching with teacher specialist subjects	8	-	2**
6	Cooperative team teaching with no teacher specialist subjects	3	-	-
7	Other	2	-	-

*This reported combination was considered as 'mixed mode' organisation for purposes of analysis
**This reported combination was considered as 'cooperative team teaching'

Figure 10.2: Teachers' organisation



The results show that the majority of teachers surveyed used 'mixed mode' organisation, that is, operating mainly independently but co-operating at certain times. This was also the most frequent organisation found in Bennett's[20] study. Results of the present study indicate a slight shift from Bennett's[20] 1975-1978 study, with more infant teachers involved in independent instruction, and fewer junior teachers involved in cooperative organisation.

10.5.2 Teaching methods

Teachers were asked to select one or more of the following to describe their teaching method:

1) Mainly didactic instruction with whole class (WC)
2) Teacher directed project based learning (PBL_T)
3) Child centred project based learning (PBL_C)
4) Teacher directed integrated day (ID_T)
5) Child centred integrated day (ID_C)
6) Other (O)

Responses are reported in Table 10.8. Nearly half (47%) of the respondents chose more than one option to describe their teaching methods, indicating that mixed mode teaching methods occurred in many cases.

Table 10.8: Teaching methods

Method	First Choice (n)	Additional choice (n)			
		2 PBL_T	3 PBL_C	4 ID_T	5 ID_C
1 WC	11	10	2	3	-
2 PBL_T	4	-	11	2	2
3 PBL_C	5	-	-	2	-
4 ID_T	10	-	-	-	6
5 ID_c	-	-	-	-	-
6 O	5	-	-	-	-

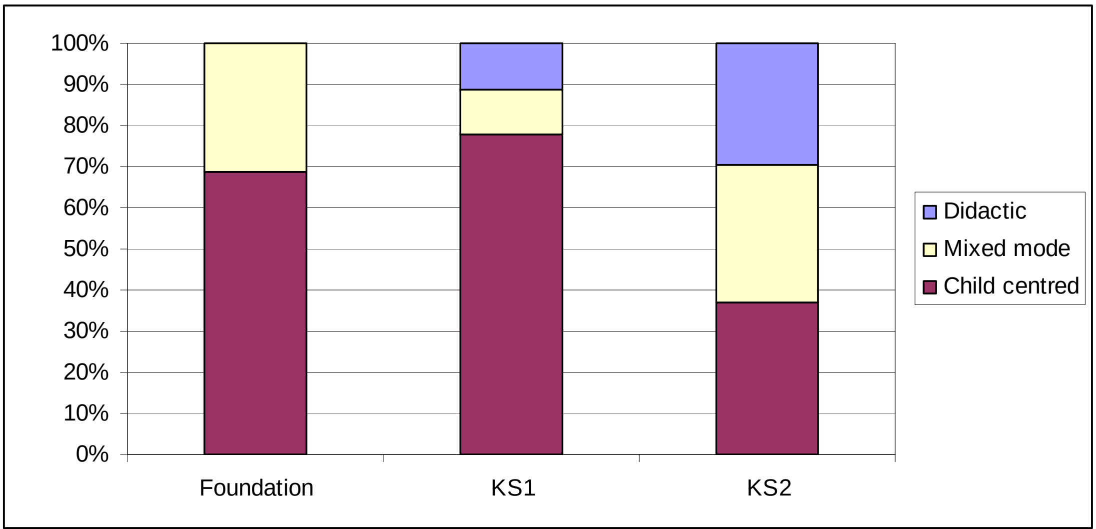
‘Other’ stated responses were ‘a variety’ (n = 4), or a ‘mixture’ (n = 1) of methods. These responses were considered to indicate a ‘mixed mode’ method. Options 2 to 5 were considered to be similar since all methods involve techniques central to the child-centred paradigm (Chapter 1). The types of teaching method were regrouped as shown in Table 10.9 to elicit a single response from each teacher. The majority of teachers used child-centred methods (58 %). The rest used didactic teaching, either solely (15%) or in combination with other methods (mixed mode 27%).

Table 10.9: Teaching methods (single response)

Method	Frequency	%
Didactic, Whole class	11	15
Child centred	42	58
Mixed mode	20	27
Total	73	100
Missing	7	-

The type of reported teaching method was broken down into class age as defined in section 10.3.5. Results are shown in Figure 10.3 which shows that the highest proportion of didactic teaching occurs in older class groups (Key Stage 2). This group also has the lowest proportion of reported child centred teaching methods, as expected. It should be noted that Bennett[20] did not investigate the specific type of teaching method used, therefore results could not be compared to the 1975-1978 study.

Figure 10.3: Reported teaching method by age group



10.6 Physical design of teachers' classrooms

The design of each teacher's classroom was categorised by the degree of openness (from fully open plan to enclosed, see Chapter 1 for definitions), and the era of the school design ('Plowden' (1960-1979) or 'Post-Plowden' (1990-1999), see Chapter 1 for definitions). This is summarised in Table 10.10. The majority of teachers operated in semi-open plan classrooms, either with or without quiet rooms, which is in line with Bennett's[20] findings. Responses from teachers operating in enclosed classrooms were excluded from the rest of the analysis (total number of valid responses reduced to 80).

Table 10.10: Classroom design and age

	Type of school (era)	
Design	Plowden	Post Plowden
Fully open plan	0	0
Semi-open plan	11	27
Semi-open with quiet rooms	18	15
Flexible open plan	3	6
Enclosed	4	0

The size of open plan unit that teachers operated in was defined as ‘large’ or ‘limited’ following the results of the objective survey (see Chapter 8). 56% of teachers operated in large units (4 classbases or more) and 44% operated in limited units (fewer than 4 classbases). This information was used in later analysis.

Details of the size and layout of unit that teachers operated in are summarised in Table 10.11. See Chapter 7 for definitions of classroom layouts.

Table 10.11: Number teachers operating in each type of unit

Type of layout	Unit size	
	Limited	Large
Cluster	23	19
Linear	12	14
Annular	0	12
Total	35	45

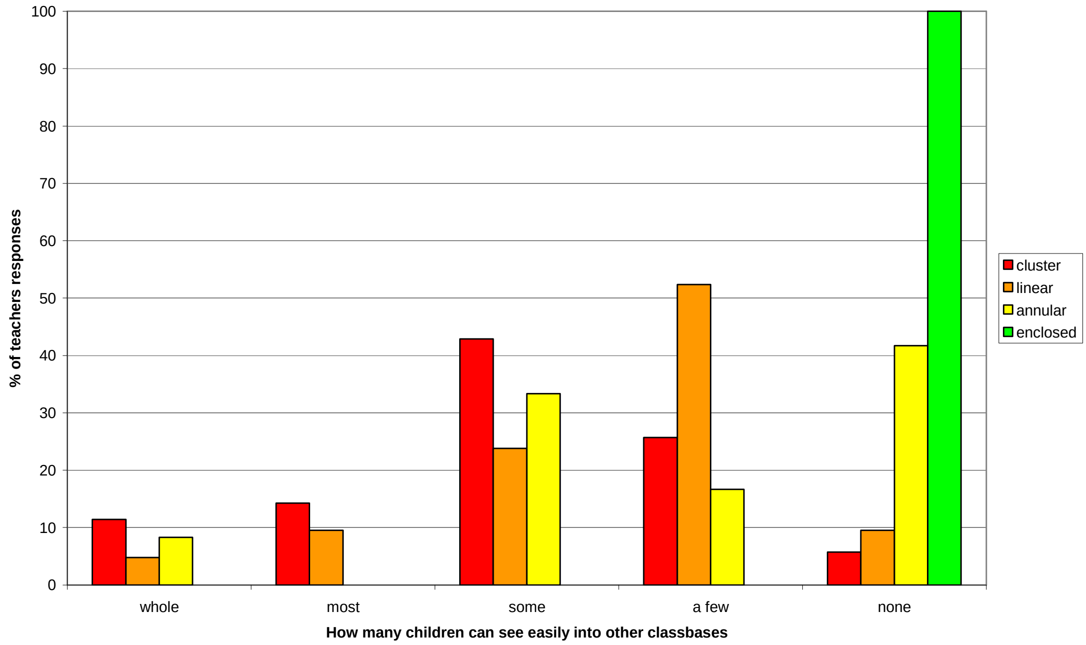
Teacher’s reported use of quiet rooms is shown in Table 10.12. Over half (56%) of respondents reported that they did not have use of a quiet room. Of the 37 respondents that reported having use of a quiet room, 37% said they used it only very occasionally, but 49% said they used it frequently (several times a week or more). This information was used in later analysis.

Table 10.12: Quiet room use

How often do you use quiet room? (%)				
No access	Very occasionally	Once a week	Several times a week	Every day
56.6	15.7	6.0	10.8	10.8

Teachers were asked how many children in their class could see easily into adjacent classbases. The results are reported by layout type in Figure 10.4. The distributions of responses from teachers in different layout types were compared. The results indicate that more children had a direct line of sight into adjacent classbases in cluster layouts (mode = ‘some’) than linear layouts (mode = ‘a few’), as expected. The responses from teachers in enclosed layouts confirmed that no children could see into adjacent classbases, as expected. This information was used to investigate responses on visual distraction later in the analysis.

Figure 10.4: Proportion of class seeing into other classbases vs. layout



Only 6 teachers (7%) said they used a sound field system in their classroom. Of these, two said they used the sound field system occasionally and three said they used it most of the time. This small sample was considered too small to include in further analysis.

10.7 Opinions and attitudes

10.7.1 Overall responses

Overall responses to the thirteen statements designed to gauge opinion on open plan classrooms are reported by considering mean opinion scores and distributions.

The distributions of responses to each question regarding opinions on open plan classrooms are presented in Figure 10.5. The maximum possible rating was 5 (strongly agree) and the minimum possible rating was 1 (strongly disagree). The full scale was used by the teachers, except for the statements 'Work standards are higher' (range of answers = 1-4).

Mean, median, and modal ratings, standard deviation and measures of skew are presented in Table 10.13. Mean, median and modal ratings were similar, and the skew was within the range ±1, indicating that the results could be considered to approximate a normal distribution. Therefore parametric tests were carried out on the data in further analysis.

Table 10.13: Overall opinions on open plan classrooms

Statement	Mean	Median	Mode	σ	Skewness	Kurtosis
a) Wider range of activities	3.3	4	4	1.20	-0.42	-0.73
b) Children more independent and responsible	3.5	4	3 and 4	0.97	-0.28	-0.22
c) Work standards are higher	2.6	3	3	0.77	-0.50	-0.02
d) More distracted by noise	3.5	4	4	1.20	-0.49	-0.83
e) More visually distracted	3.3	3.5	4	1.18	-0.26	-0.90
f) Children benefit socially	3.5	4	4	0.96	-0.22	-0.52
g) More discipline problems	2.5	2.5	3	1.05	0.21	-0.57
h) Greater continuity for children	3.3	3	3	0.76	0.08	0.63
i) Better pastoral care for children	3.3	3	3	0.86	-0.11	0.40
j) Teachers more confident	3.2	3	3	0.97	0.21	-0.31
k) NQTs better progress	3.2	3	3	1.07	-0.13	-0.36
l) Better pupil supervision	3.1	3	4	1.04	-0.51	-0.58
m) Children more secure	3.0	3	3	0.98	-0.29	0.06

Figure 10.5: Distribution of opinion ratings

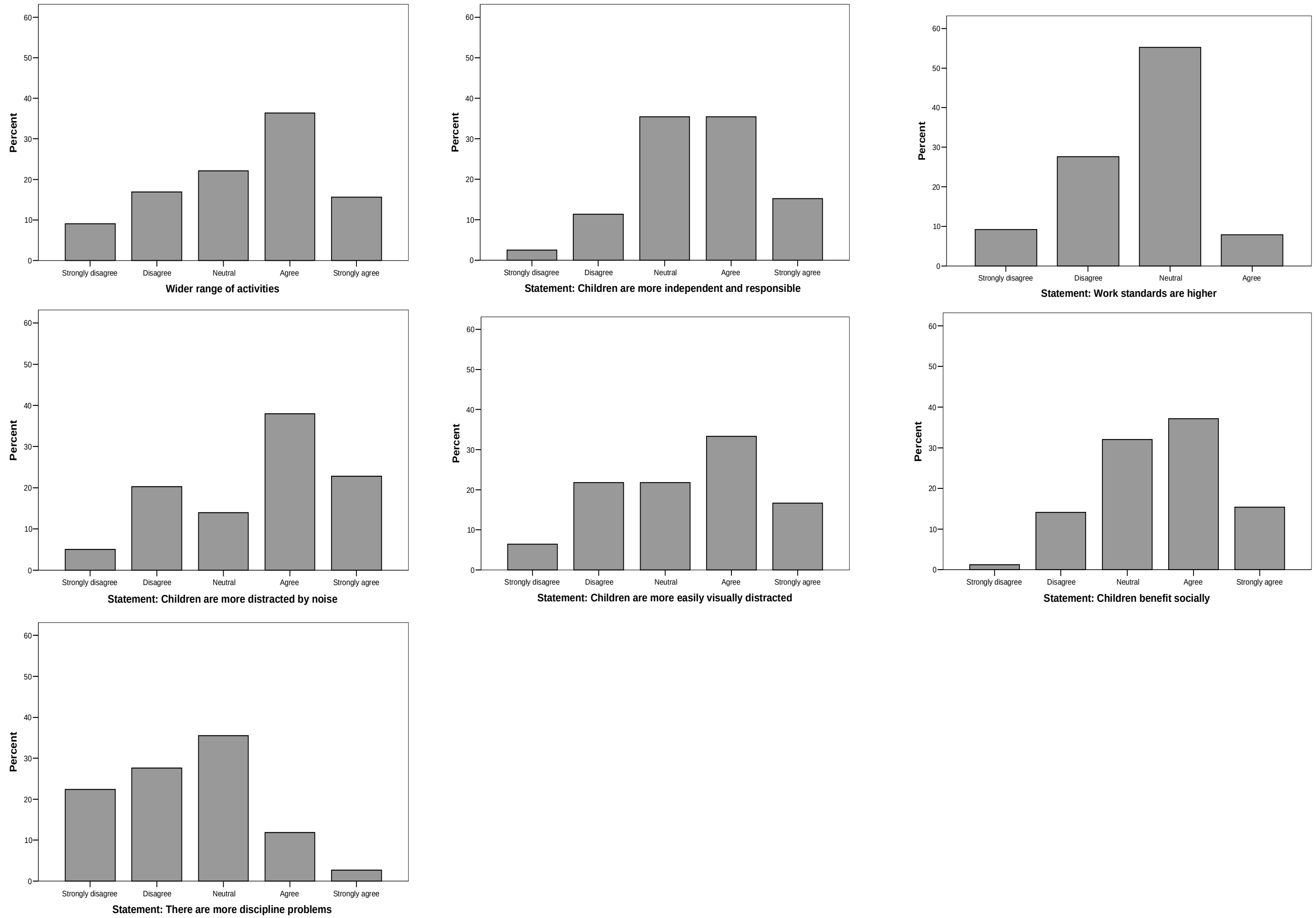
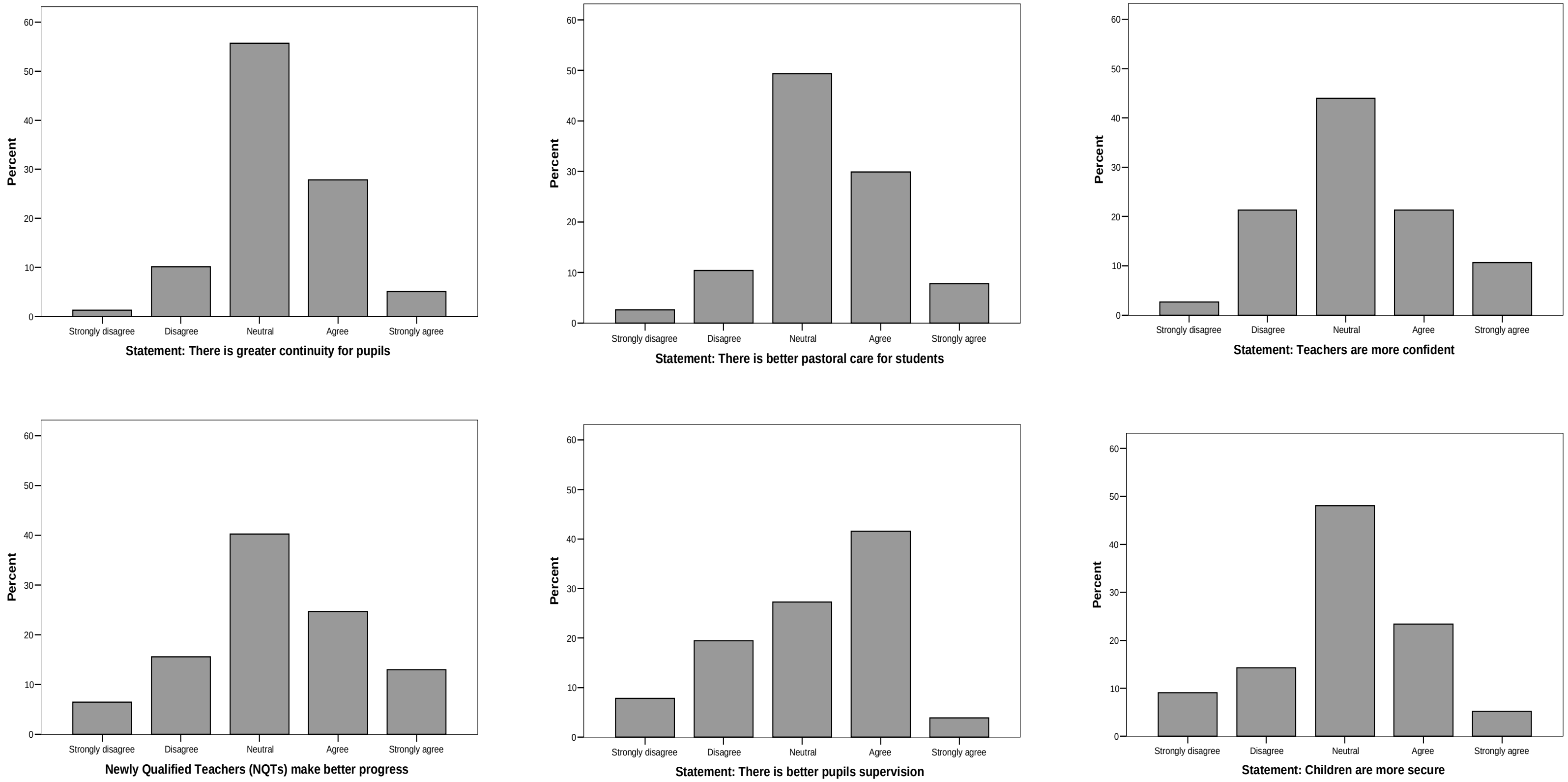


Figure 10.4 (continued): Distribution of opinion ratings



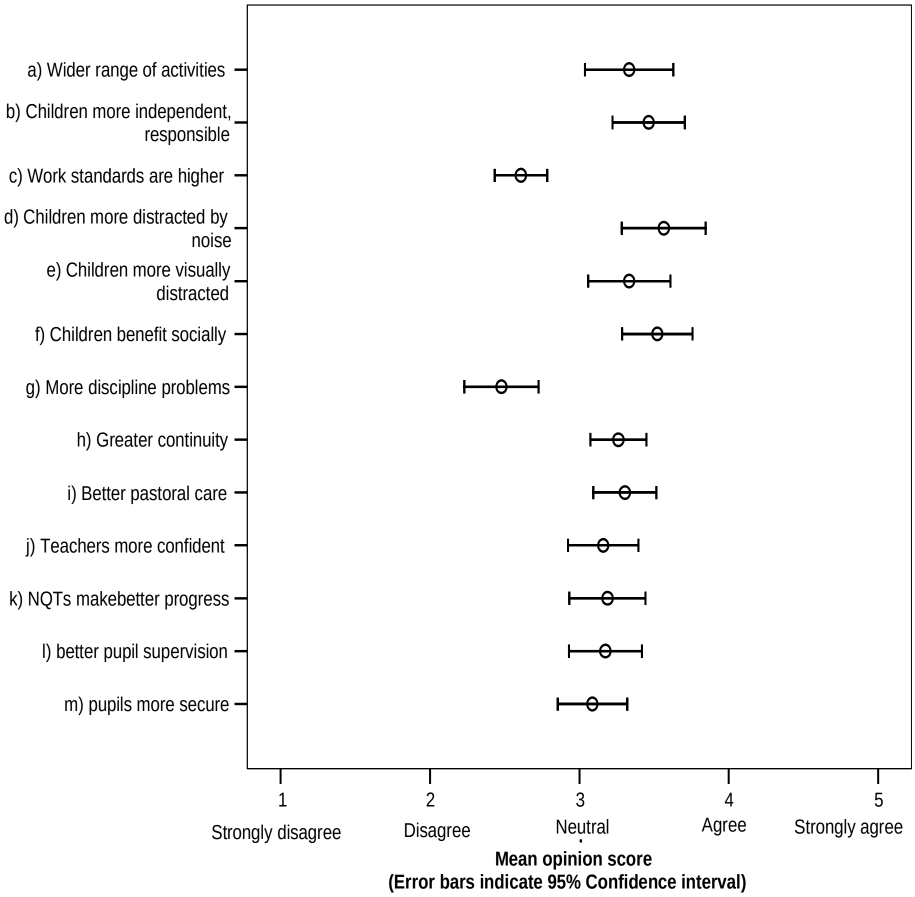
Considering statements with which teachers most strongly agreed or disagreed (indicated by median and mode results), in general teachers tended to agree that open plan classrooms enabled a wider range of activities to take place, and that children were more independent and responsible, and benefited socially.

However, teachers also tended to agree that children were more easily distracted, both visually and by noise.

Teachers generally did not feel that discipline was any more of a problem in open plan classrooms, or that work standards were any different.

Mean overall opinion scores and 95% confidence intervals (shown as error bars) are presented in Figure 10.5.

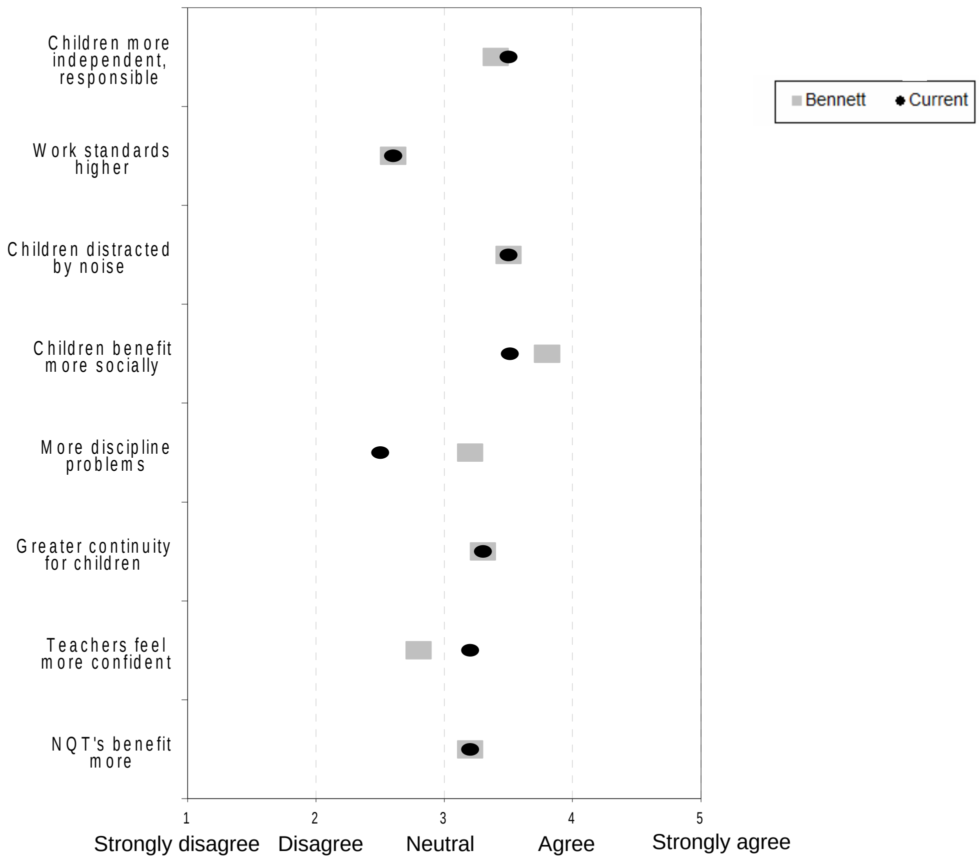
Figure 10.6: Mean opinion scores



Where the statements were comparable with those of Bennett's[20] study, mean opinion scores from each study are shown in Figure 10.7. Mean scores from Bennett's 5 point opinion scale were reversed where necessary to enable a consistent scale for direct comparison with the current study. Results for each type of primary school reported by Bennett (infant, first, junior, primary) have been combined by weighting the mean scores according to the number of responses from each school to achieve an overall score for comparison with the current study.

Mean scores are remarkably similar for five of the eight comparable statements, with teachers from both studies generally agreeing that children were more independent and responsible and benefited socially, but were more distracted by noise. Although teachers from both studies felt that work standards were no higher in open plan classrooms, there was a discrepancy between opinions on discipline, with teachers in the 1975-1978 study tending to feel more neutral, and teachers in the current study tending to disagree that discipline was any more of a problem than in enclosed classrooms.

Figure 10.7: Mean opinion scores: Current *vs*. Bennett study



10.7.2 Factor analysis

A high degree of correlation was found between some of the thirteen opinion statements. In order to reduce the data for analysis, a principal components factor analysis was carried out on the statements to identify underlying variables for further analysis (see Appendix D for details). This allowed the original thirteen opinion statements to be reduced to six 'opinion factors' as detailed in Appendix D. Statements h, i, j, l, m were combined into a single factor attributed to benefits for teachers and teacher-pupil relationship (factor 1). Statements a, b and f were combined into a second opinion factor attributed to benefits for children (factor 2). All other statements were considered separately The statement 'NQTs make better progress' was excluded from further analysis as this was not considered pertinent to the main research questions.

Table 10.14 summarises how the thirteen statements were reduced to six 'opinion factors' for further analysis. New component ratings were computed by multiplying the case's original variable value by the component score coefficient. A value close to zero indicates a neutral response. The higher the score is, the stronger the agreement with the opinion statement, and the more negative the score is, the stronger the disagreement.

Table 10.14: Rotated factor loadings on variables (% of variance)

Opinion factor	Statement(s)	Component score coefficient
1. Benefits for teachers and teacher-pupil relationship (70% of variance)	i) Better pastoral care	0.220
	l) Better pupil supervision	0.242
	h) Greater continuity	0.250
	m) Pupils more secure	0.234
	j) Teachers more confident	0.252
2. Benefits for children (75% of variance)	a) Wide range of activities	0.388
	b) Children are more independent and responsible	0.383
	f) Children benefit socially	0.383
3. Distraction from noise	d) More distracted by noise	Considered separately
4. Visual distraction	e) More visually distracted	Considered separately
5. Discipline	g) There are more discipline problems	Considered separately
6. Work standards	c) Work standards are higher	Considered separately
	k) NQTs make better progress	Not included

These opinion factors are analysed in more detail by comparing sub-variables related to either teaching strategy or physical design variables as summarised in Table 10.15. Analysis of variance (ANOVA) was carried out to examine the impact, if any, of the subvariables on each research question. Significant differences were considered at the $p < 0.05$ level.

Table 10.15: Subvariables for analysis

Teaching strategy	Physical design
• Organisation (independent instruction; mixed mode; co-operative)	• Unit size (large; limited)
• Teaching method (didactic; mixed mode; child centred)	• Quiet room access

10.7.2.1 Opinion Factor 1 – Benefits for teachers

One way ANOVA analysis found no significant difference between perceived benefits for teachers and the type of teaching strategy (either classroom organisation or teaching method).

A significant difference was found between perceived benefits for teachers/teacher-pupil relationship and open plan unit size ($F_{1,64} = 9.24$, $p < 0.05$), with teachers operating in limited units being significantly more likely to agree that open plan schools provided advantages for teachers than those operating in larger units. Mean component scores are shown in Figure 10.8. There was no significant difference in mean ratings for quiet room access.

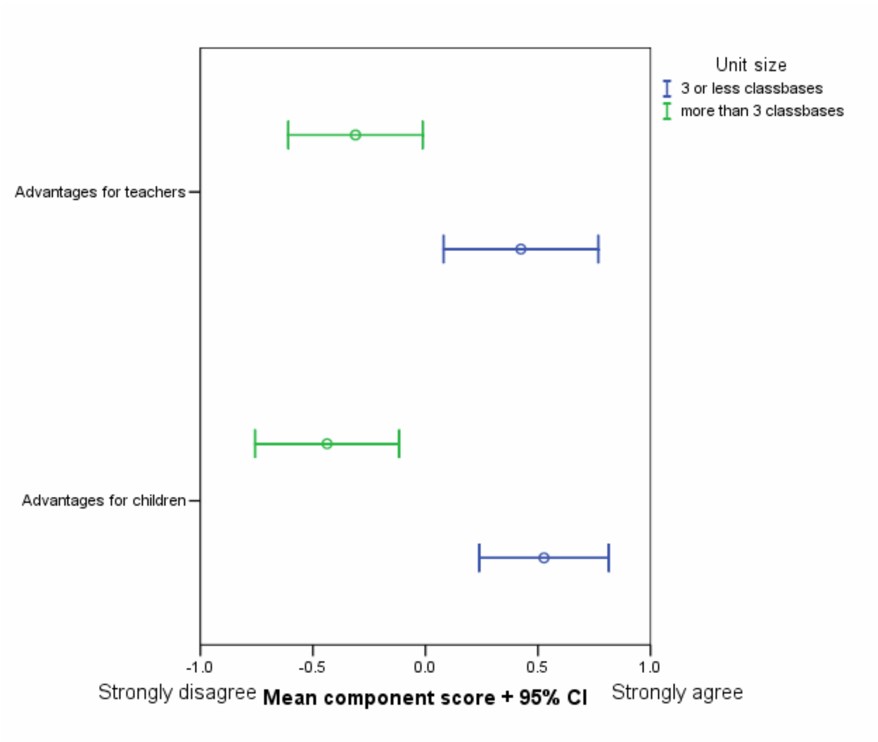
10.7.2.2 Opinion Factor 2 – Benefits for children

A statistically significant difference was found between perceived 'benefits for children' and classroom organisation, ($F_{2,60} = 4.87$, $p < 0.05$). A Bonferroni adjustment showed that the difference was only significant between teachers operating solely independently, and teachers using solely co-operative team teaching ($p = 0.018$). Teachers who planned solely co-operatively were significantly more likely to agree that open plan schools provided advantages for children than teachers operating independently. No significant difference was found between mixed mode and other types of organisation.

A statistically significant difference was also found between perceived 'benefits for children' and teaching method ($F_{2,60} = 3.93$, $p < 0.05$). A Bonferroni adjustment showed that the difference was only significant between teachers using solely didactic methods, and teachers using solely child centred methods ($p = 0.006$). Teachers using child centred methods were significantly more likely to agree that open plan schools provided advantages for children than teachers using didactic methods. No significant difference occurred for mixed mode teaching.

A significant difference was found between perceived advantages for children and open plan unit size ($F_{1,67} = 6.93$, $p < 0.05$) with teachers operating in limited units being significantly more likely to agree that open plan schools provided advantages for children than those in larger units. Mean component scores and 95% confidence intervals are shown in Figure 10.8. There was no significant difference in mean ratings for quiet room access.

Figure 10.8: Mean component score ratings *vs.* unit size

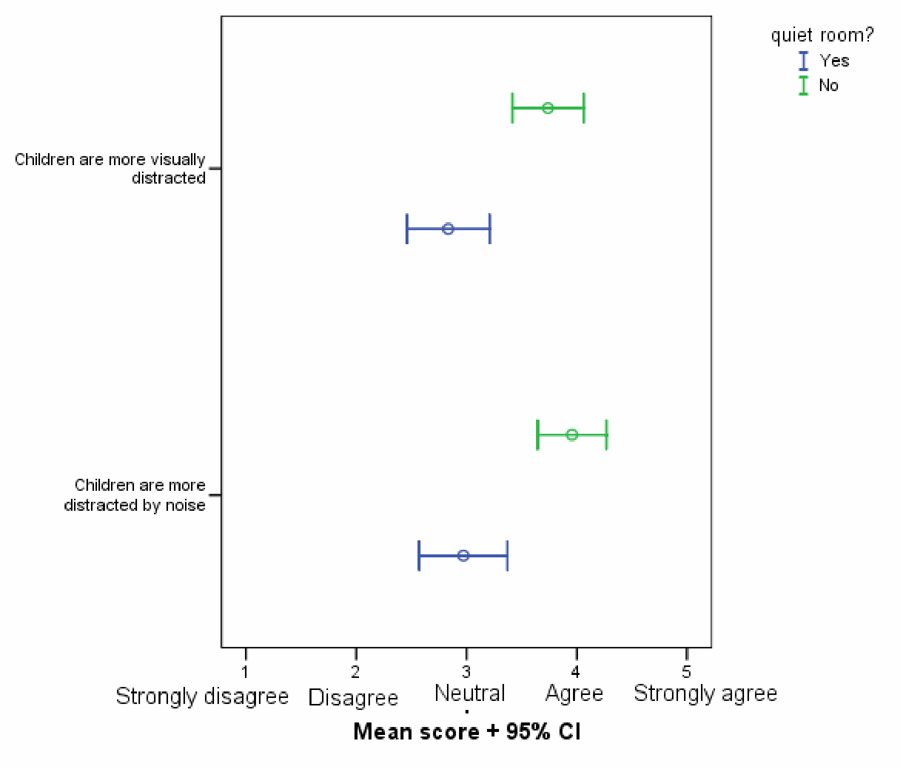


10.7.2.3 Opinion Factor 3 – Distraction from noise

No significant difference was found between perceived opinions on noise distraction and teaching strategy variables.

A significant difference was found between quiet room access and opinions on noise distraction ($F_{1,70}$ = 6.61, $p < 0.05$). Teachers without access to quiet rooms were significantly more likely to agree that children were more easily distracted by noise in open plan schools than teachers with quiet room access. Mean ratings are shown in Figure 10.9.

Figure 10.9: Mean ratings: Noise and visual distraction



A significant difference was also found between perceived opinions on noise distraction and unit size ($F_{1,77}$ = 7.16, p < 0.05). Teachers in large units were significantly more likely to agree that children in open plan classrooms were more easily distracted by noise than teachers in limited units.

10.7.2.4 Opinion Factor 4 – Visual distraction

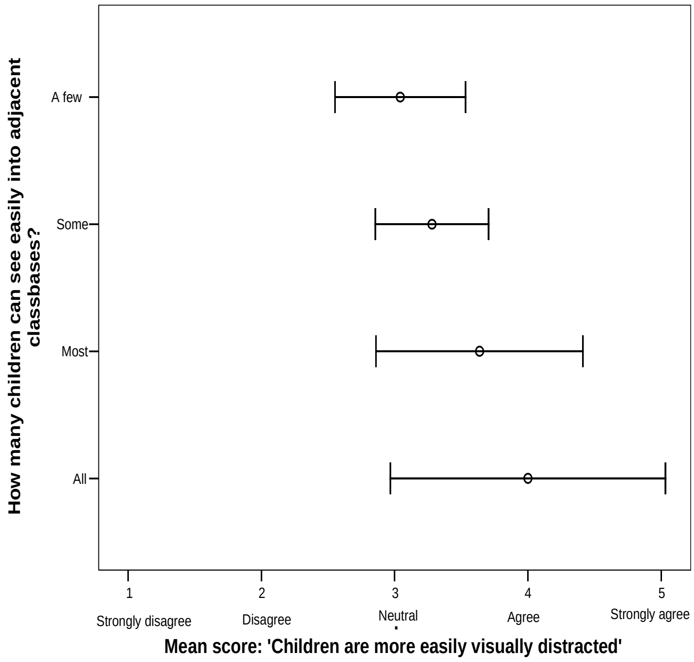
No significant difference was found between perceived opinions on visual distraction and teaching strategy variables.

A significant difference was found between quiet room access and perceived visual distraction ($F_{1,69}$ = 7.09, p < 0.05). Teachers without access to quiet rooms were significantly more likely to agree that children in open plan schools were more easily visually distracted than teachers with quiet room access. Mean ratings are shown in Figure 10.9 above.

Perceived visual distraction was also significantly affected by unit size ($F_{1,69}$ = 4.70, p < 0.05), with teachers in larger units being significantly more likely to agree that children were more easily visually distracted than teachers in limited units.

Teachers' opinions of visual distraction were also compared with the reported proportion of the class that could see easily into adjacent classbases as shown in Figure 10.10. Mean opinion scores and 95% confidence intervals (shown as error bars) are presented. The mean scores show that as the proportion of children who can see into other classbases increases, teachers are more likely to agree that visual distraction is a problem in open plan classrooms, as expected.

Figure 10.10: Mean score for visual distraction



10.7.2.5 Opinion Factor 5 – Discipline

No significant difference was found between perceived discipline problems and teaching strategy. Similarly, no significant difference was found between perceived discipline problems and physical design variables.

10.7.2.6 Opinion Factor 6 – Work standards

No significant difference was found between perceived work standards and either teaching strategy variables or physical design variables.

10.8 Perceived noise environment

Responses to the types of noise sources experienced in the classroom and the perceived volume of noise in different classroom areas are discussed in this section.

10.8.1 Noise sources

Teachers were asked to indicate dominant sources of noise in the classroom during a typical lesson. The response is shown in Table 10.16. It should be noted that some teachers (44%) selected more than one answer, therefore the percentage of teachers reporting each source adds up to more than 100%.

The most commonly reported sources were classroom babble in the teacher's own classroom (reported by 83% of teachers) and from other classes (62% of teachers). 'Other teacher's voices' was also a frequently reported noise source (37%). All other non-speech sources were reported much less frequently (11% or less), indicating that interfering speech was the main source of intrusive noise.

Table 10.16: Noise sources in classrooms

Noise source	Frequency	% of teachers reporting source
Babble (within own classbase)	70	83
Babble (from adjacent classbases)	52	62
Other teachers' voices	31	37
Classroom equipment	9	11
External noise	6	7
Building services (plant)	4	5
Other	5	6

10.8.2 Volume of noise

Histograms of overall responses to each question regarding volume of noise in various areas of the classroom are presented in Figure 10.11. The maximum possible rating was 7 (too noisy) and the minimum possible rating was 1 (too quiet). The scale was not used fully, with a score of 1 not being used for any of the situations. This is consistent with neutral-negative scales typically achieved for socio-acoustic survey results[258].

Mean, median, and modal ratings, standard deviation and measures of skew are presented in Table 10.17. For general classroom, carpet and other teaching areas, mean, median and modal values were similar, and the level of skewness was not significant (within ±1.0), indicating that the data approximated a normal distribution. However, for the quiet room, the data was significantly skewed, and therefore parametric test results (which assume a normal distribution) for this result need to be treated with caution.

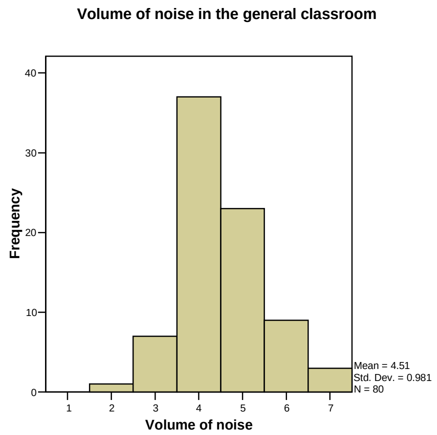
Table 10.17: Volume of noise in classroom

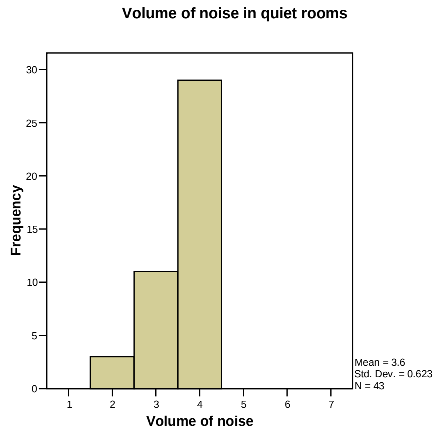
Volume of noise in:	Mean	Median;Mode	σ	Skewness	Kurtosis	% Dissatisfied
General classroom	4.5	4;4	0.98	0.46	0.41	15
Carpet	3.9	4;4	0.86	0.00	0.87	5
Quiet room	3.6	4;4	0.62	-1.35	0.81	0
Other teaching areas	4.7	4;4	0.99	0.44	0.05	24

The percentage of teachers selecting a rating of 6 or 7 for this question is also reported in Table 10.17. This may be considered as a dissatisfaction rate. The overall dissatisfaction rate was highest for 'other teaching areas' but was considerably less than 32% for all of the different areas. After Walsh[22] and Keighley[145, 146], this suggests that overall, the average reported volume of noise was acceptable. This result was investigated in further detail below.

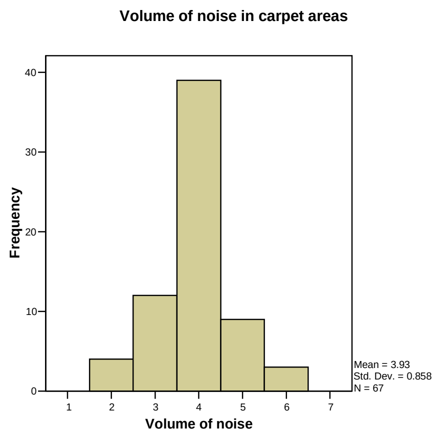
A repeated measures ANOVA test indicated that there was a statistically significant difference between ratings across different areas ($F_{3,114} = 19.2$, $p < 0.001$). However the *post hoc* Bonferroni adjustment showed that no significant difference occurred between the carpet area and quiet room, and between the general classroom and 'other' teaching areas. The largest mean difference occurred between the general classroom and quiet room (0.72), and between 'other areas' and quiet room (-0.82).

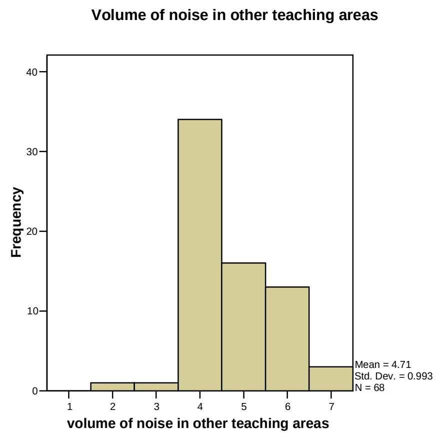
Figure 10.11: Distribution of perceived volume of noise





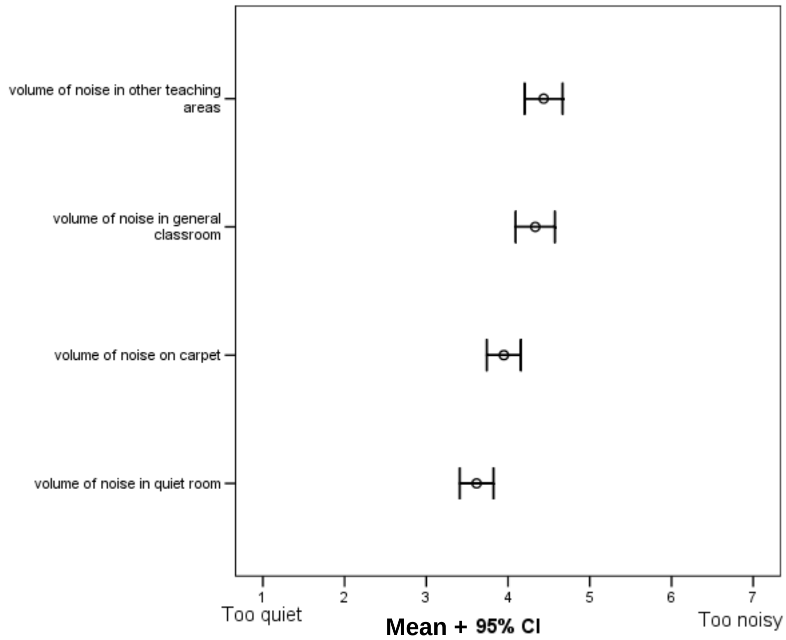
Rating scale: 1= 'too quiet'; 7 = 'too noisy'





Mean ratings and 95% confidence intervals (indicated by the error bars) are illustrated in Figure 10.12. This indicates that in general teachers perceived noise levels to be highest in 'other' teaching areas (for example adjacent classbases and resource areas), followed by the general classroom (main classbase itself).

Figure 10.12: Mean ratings of volume of noise in classroom areas



10.8.2.1 Effect of teaching strategy

No significant difference was found between perceived noise level in the different areas of the classroom and teaching strategy (classroom organisation or teaching method).

10.8.2.2 Effect of physical design variables

A significant difference was found between reported noise levels in 'other' teaching areas and quiet room access ($F_{1,60} = 4.48$; $p < 0.05$), with teachers with quiet room access being significantly more likely to report lower noise levels in other teaching areas (see Table 10.18). Dissatisfaction rates were considered unacceptable (>32%) for noise levels in other teaching areas for teachers in units without quiet room access.

No significant difference was found for other areas of the classroom, although dissatisfaction rates were generally higher in units without quiet room access.

Table 10.18: Mean scores for volume of noise *vs.* quiet room access

	Rating of volume of noise (1 = too quiet; 7 = too noisy)						
	Quiet room access			No quiet room access			
Area:	Mean (σ)	n	% Dissatisfied	Mean (σ)	n	% Dissatisfied	Sig. p
General classroom	4.3 (0.68)	36	6	4.7 (1.2)	44	17	NS
Carpet area	3.9 (0.60)	34	0	3.9 (1.1)	33	9	NS
Quiet room	3.7 (0.59)	33	0	N/A	-	N/A	N/A
Other teaching areas	4.3 (0.59)	32	6	5.1 (1.2)	36	39	< 0.05

A significant difference was also found between unit size and perceived noise levels for both carpet areas ($F_{1,58}$ = 38.4; $p < 0.001$) and 'other' areas ($F_{1,60}$ = 4.4; $p < 0.05$). Teachers operating in limited units were significantly more likely to report lower perceived noise levels in these areas than teachers in larger units, as indicated by the mean scores in Table 10.19. Furthermore, dissatisfaction rates were also higher in larger units than limited units (except in quiet rooms where the dissatisfaction rate was 0% for both cases). Reported dissatisfaction rates for 'other teaching areas' indicated that noise levels in adjacent teaching spaces rose to an unacceptable level (>32%) in large units, but stayed at an acceptable level in limited units (see Table 10.19).

Table 10.19: Mean scores for volume of noise *vs.* unit size

	Rating of volume of noise (1 = too quiet; 7 = too noisy)						
	Limited units			Large units			
Area	Mean (σ)	n	% Dissatisfied	Mean (σ)	n	% Dissatisfied	Sig. p
General classroom	4.3 (0.96)	35	9	4.7 (0.98)	45	20	NS
Carpet area	3.6 (0.78)	33	0	4.2 (0.85)	34	9	< 0.001
Quiet room	3.7 (0.56)	25	0	3.5 (0.71)	18	0	NS
Other teaching areas	4.4 (0.83)	32	9	5.0 (1.04)	36	36	< 0.05

10.8.2.3 Comparison with 1975-1978 study

Ratings for volume of noise in various areas in the current study were compared with the responses to a question used in Bennett's[20] 1975-1978 study which required teachers to rate different teaching areas on a 5 point ‘semantic differential’ scale, which included the bi-polar scale descriptor ‘noisy - quiet’ (1 = noisy; 5 = quiet).

An attempt was made to convert the scores to a similar scale by first reversing the mean scores of the current study to a negative-positive scale, then dividing the mean score by a factor of 1.4 (= 7 point scale divided by 5 point scale). Since the current study used a different scale descriptor, it is not valid to directly compared the converted scores of the current study (1 = *too* noisy; 5 = *too* quiet) with Bennett’s[20] study (1 = noisy; 5 = quiet). However, the comparison might provide some indication of whether overall opinions tended to deviate in a certain direction from a neutral response (3). Therefore scores of less than 3 indicate a ‘somewhat noisy’ environment, whilst scores of more than three indicate a ‘somewhat quiet’ environment.

Table 10.20: Volume of noise ratings - current study *vs.* Bennett[20]

Volume of noise in:	Current converted scale (1 = ’too noisy’; 5 = ‘too quiet’)	Bennett[20] (1= ’noisy’; 5 = ‘quiet’)	
		Infant	Junior
General teaching area	2.5	2.6	2.7
Carpet	2.9	-	-
Quiet room	3.1	2.5	2.3
Other teaching areas	2.4	-	-
Practical/wet area	-	2.3	2.1

The converted scores suggest that there was some agreement between the two studies that ‘general teaching areas’ were ‘somewhat noisy’. The notable difference between the two studies is that for the current study, quiet rooms are rated overall as near neutral (neither noisy nor quiet), whereas in Bennett’s study they were rated by both infant and junior teachers to be ‘somewhat noisy’. There appears to be an improvement in the overall perceived noise level in quiet rooms.

10.9 Distraction

Histograms of overall responses to distraction from other teaching groups and noise outside the school are presented in Figure 10.13. The minimum possible rating was 1 (not at all distracting) and the maximum possible rating was 7 (extremely distracting). The full scale was used for both questions.

Mean, median, and modal ratings, standard deviation and measures of skew are presented in Table 10.21. The percentage of teachers dissatisfied (those reporting ratings of 6 or 7) is also given.

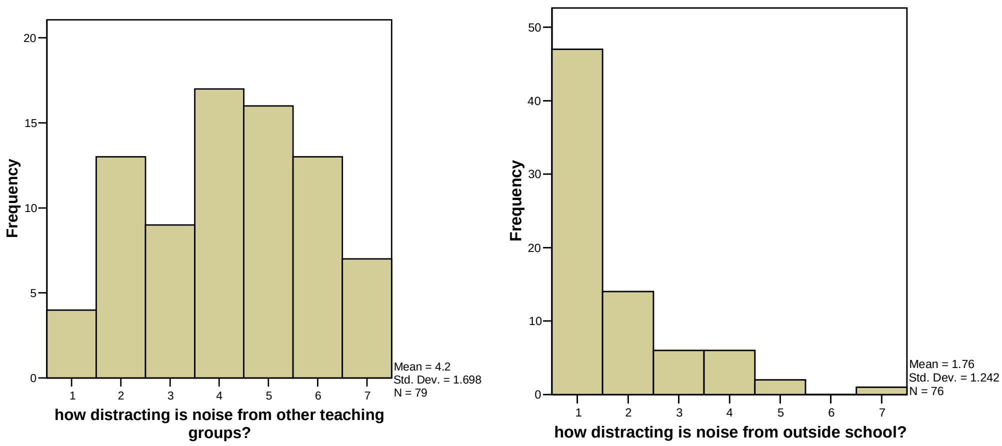
Table 10.21: Distraction from noise

How distracting is noise from:	Mean	Median;Mode	σ	Skewness	Kurtosis	% Dissatisfied
Outside the school	1.8	1;1	1.24	1.923	3.863	4
Other teaching groups	4.2	4;4	1.70	-0.132	-0.924	25

For 'noise from outside the school', there appears to be an outlier from a single respondent (see Figure 10.13). The skewness for the distribution is also significantly positive, and the value of kurtosis is very high, indicating that the data distribution is not normal and hence parametric testing would not be appropriate. In general respondents felt that noise from outside the school was not distracting.

Responses to 'noise from other teaching groups' were considered to approximate a normal distribution and therefore further parametric tests were carried out. Overall, only 25% of respondents reported high levels of distraction (scores of 6 or 7) from other teaching groups.

Figure 10.13: Responses to distraction from noise



1 = Not at all distracting; 7 = Extremely distracting

10.9.1 Effect of teaching strategy

No significant difference was found between perceived distraction from noise and classroom organisation.

A significant difference was found between perceived distraction from intrusive activity noise and teaching method ($F_{1,65}$ 4.28; $p < 0.05$). Bonferroni *post hoc* tests showed that the significant difference occurred between teachers using solely child centred and solely didactic methods (p = 0.028), and between solely child centred and mixed mode methods (p = 0.004). There was no significant difference between didactic and mixed mode methods.

Mean scores in Table 10.22 show that teachers using solely didactic methods were significantly more likely to report higher levels of distraction from noise in other teaching areas than teachers using solely child centred methods. The dissatisfaction rate for teachers using didactic methods was also considerably higher and considered to be unacceptable (dissatisfaction > 32%).

Table 10.22: Mean scores for distraction *vs.* teaching method

Rating of distraction from noise in other teaching areas (1 = not at all distracting; 7 = extremely distracting)						
Didactic			Child centred			Sig. p
Mean (σ)	n	% Dissatisfied	Mean (σ)	n	% Dissatisfied	
5.0 (1.2)	10	40	3.6 (1.7)	42	12	< 0.05

10.9.2 Effect of physical design

A significant difference occurred between perceived distraction from noise from other teaching groups and quiet room access ($F_{1,70} = 4.84$; $p < 0.05$). Mean scores in Table 10.23 show that teachers with quiet room access were significantly more likely to report lower levels of distraction than teachers without quiet room access. Dissatisfaction rates were also in excess of 32% and considered unacceptable for teachers without quiet room access, but were considered acceptable for teachers with quiet room access.

Table 10.23: Mean scores for distraction *vs.* quiet room access

Rating of distraction from noise in other teaching areas (1 = not at all distracting; 7 = extremely distracting)						
Quiet room access			No quiet room access			Sig. p
Mean (σ)	n	% dissatisfied	Mean (σ)	n	% dissatisfied	
3.5 (1.6)	36	11	4.8 (1.6)	43	37	< 0.05

A significant difference occurred between perceived distraction and unit size ($F_{1,70}$ = 5.3; $p < 0.05$). Mean scores in Table 10.24 show that teachers in limited units were significantly more likely to report lower levels of distraction from noise than those in large units. Dissatisfaction rates were also in excess of 42% and considered unacceptable for teachers operating in large units, but were almost negligible (≤ 3%) for teachers operating in limited units.

Table 10.24: Mean scores for distraction *vs.* unit size

Rating of distraction from noise in other teaching areas (1 = not at all distracting; 7 = extremely distracting)						
Limited units			Large units			Significance
Mean (σ)	n	% dissatisfied	Mean (σ)	n	% dissatisfied	p
3.4 (1.5)	34	3	4.8 (1.7)	45	42	< 0.05

10.10 Speech communication

Histograms of overall responses to the questions regarding speech communication in various areas are shown in Figure 10.4. The full scoring range (1 = not at all easy; 7 = extremely easy) was used. Mean ratings are presented in Figure 10.15 and Table 10.25. All situations were considered to approximate a normal distribution since no significant skewness or kurtosis was present. The percentage of teachers reporting scores of 1 or 2 are also shown in Table 10.25. This was considered as a dissatisfaction rate.

Mean ratings were in excess of 4 (neutral), indicating that teachers perceived speech communication to be fairly easy for all situations.

Figure 10.14: Reported ease of speech communication

1 = not at all easy; 7 = extremely easy

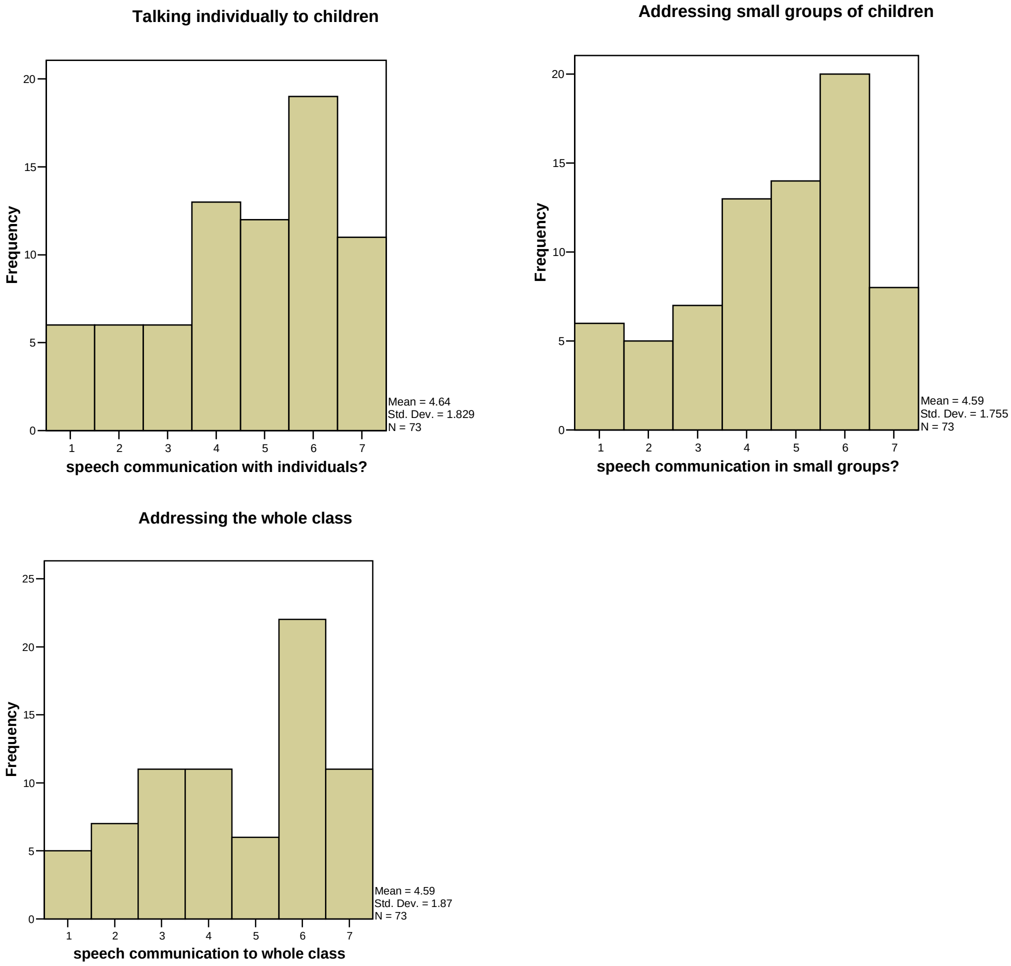
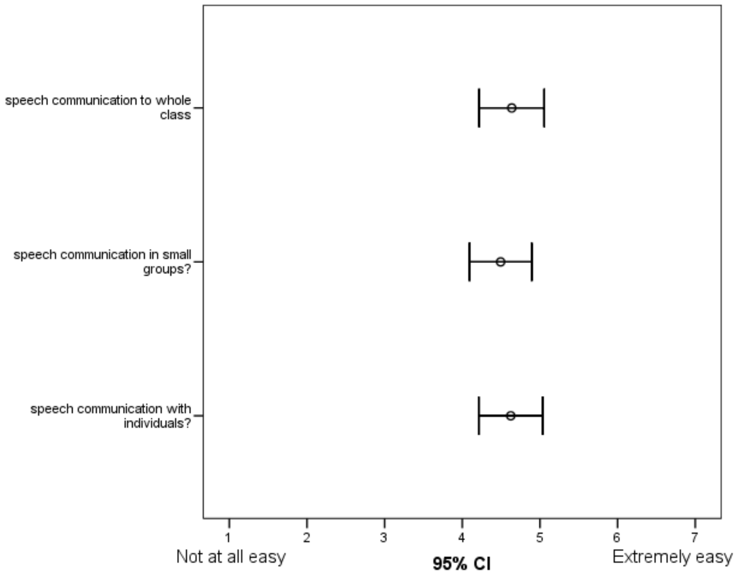


Table 10.25: Speech communication

How easy is speech communication to:	Mean	Median;Mode	σ	Skewness	Kurtosis	% Dissatisfied
Individuals	4.64	5;6	1.83	-0.56	-0.7	17
Small groups	4.59	5;6	1.76	-0.60	-0.56	15
Whole class	4.59	5;6	1.87	-0.40	-1.06	16

Figure 10.15: Speech communication - mean ratings



Mean responses for the different situations were very similar and highly correlated to each other as shown by the correlation coefficient (ρ) in Table 10.26. A repeated measures analysis of variance showed that there was no significant difference in mean ratings across the different situations ($F_{2,144}$ = 0.097, p = 0.908).

Table 10.26: Correlation between speech communication situations

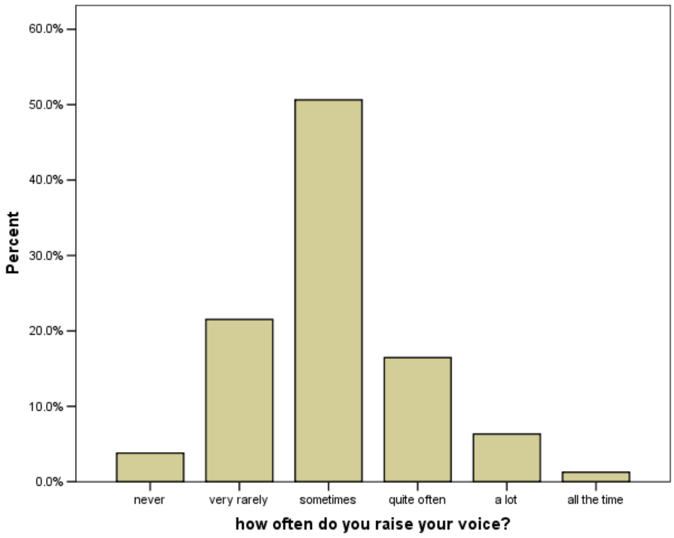
Between	ρ	Significance, p	N
Individuals and small groups	0.85	< 0.001	77
Individuals and whole class	0.68	< 0.001	77
Small groups and whole class	0.70	< 0.001	77

No significant difference was found between ratings of speech communication and teaching strategy or physical variables.

10.11 Reactions and coping strategies

The response to the question ‘how often do you raise your voice above a comfortable speaking level?’ is shown in Figure 10.16. The responses demonstrate a normal distribution, centred on a mean of 3.04 (corresponding to ‘Sometimes’). Nearly one quarter (24%) of teachers reported having to raise their voice ‘quite often’ or more.

Figure 10.16: Frequency of raising voice level



No significant difference was found between the frequency with which teachers raised their voice above a comfortable speaking level and either teaching strategy or physical variables.

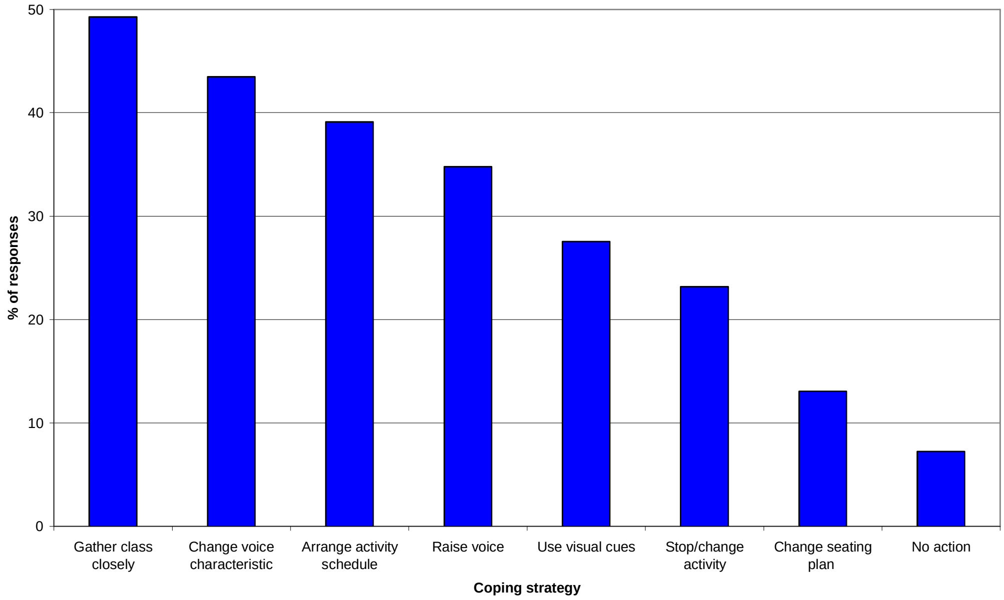
Reported coping strategies in the event of noise conflicting with adjacent activities are presented in Figure 10.17. The majority of respondents (70%) used more than one option to describe their coping methods, therefore percentages total more than 100%.

The most frequently reported coping method was for the teacher to gather the class closely around them, which would reduce communication distance and improve speech-to-noise ratio. This technique was observed frequently by the author during the survey, with the teacher usually gathering the class together on the carpet (usually away from the classbase openings) for whole class teaching.

It is interesting to note that more teachers reported changing the characteristic of their voice (43%) to cope with noise, rather than raising it (35%). This is encouraging, since this technique would not increase the overall intrusive noise level and hence would not have a detrimental impact on speech intelligibility/privacy or cause unnecessary voice strain.

Another frequently cited technique is to pre-arrange a compatible activity schedule with other teachers so that the noise conflict does not occur in the first place (39%).

Figure 10.17: Coping methods



N.B. ‘Other’ responses were as follows: ‘Put obstacles in the way’ (n=1), ‘move to enclosed classroom’ (n=1), ‘close flexible partition’ (n=1), ‘send message to other class to ask for quiet’ (n=2), ‘anything and everything!’ (n=1)

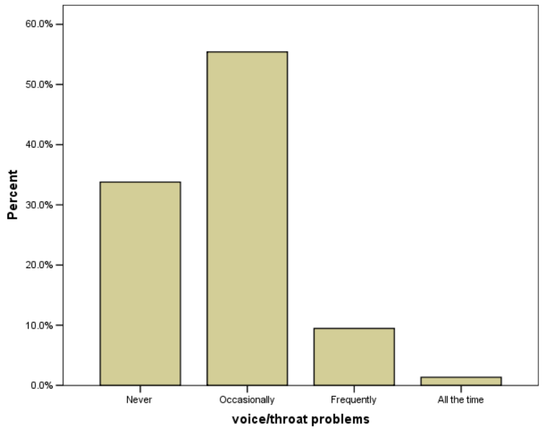
The results of the current study contrast with those of Dockrell & Shield’s survey of enclosed primary classrooms, where the most common classroom strategy reported by teachers to combat noise was to raise their voice (33%), followed by specific non-verbal attention gaining strategies (22%).

Those teachers who stated that they raised their voice as a coping strategy reported raising their voice above a comfortable speaking level significantly more often, as expected ($F_{1,78} = 20.8$, $p < 0.001$).

The frequency of teachers suffering from voice or throat problems is shown in Figure 10.18. 10% of teachers reported that they suffered from voice/throat problems ‘frequently’ or more often. This is comparable with the findings of a previous large scale study in the US[170, 172] where the reported prevalence was 11% for teachers (compared to 6% for non-teachers).

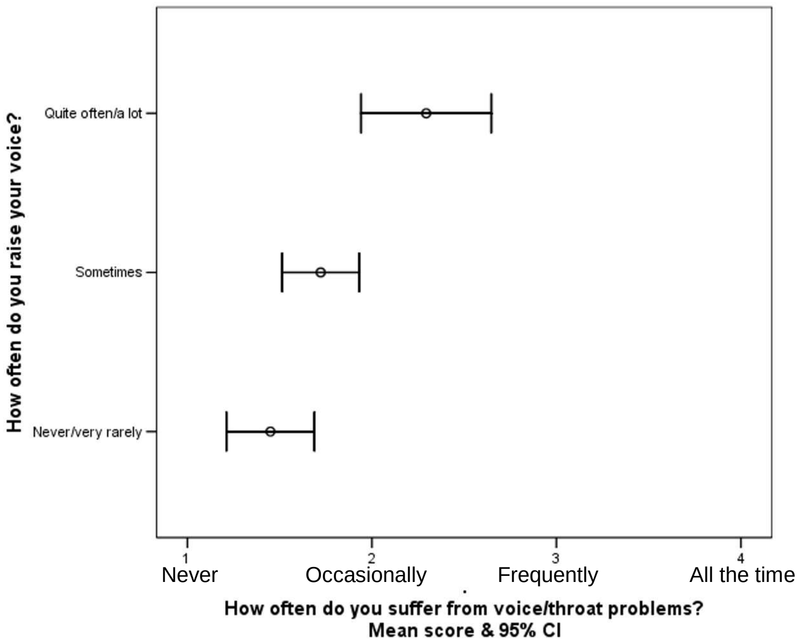
Half of the teachers who reported suffering from voice problems frequently or more often (n=4) were in the age range of 46-60. This is comparable with the US study,[170, 172] where reported prevalence amongst teachers reached a peak in the 50-59 age bracket.

Figure 10.18: How often teachers suffer from voice or throat problems



Teachers who reported having to raise their voice more often during teaching also reported suffering from voice and throat problems more often ($F_{5,72}$ = 3.8, p = 0.005), as shown in Figure 10.19.

Figure 10.19: Frequency of raising voice *vs.* voice/throat problems



10.12 Comparison with objective data

The results of the teacher's survey were compared with the results of the objective survey where possible. The number of questionnaires returned from teachers operating in classbases where objective measurements had been carried out was small (n =35). Responses from teachers in enclosed classrooms (n = 4) and teaching assistants were excluded from the analysis. This resulted in 18 responses from teachers operating in classbases where objective data had been collected.

Reported noise and distraction ratings as perceived by each teacher were compared to the mean occupied intrusive noise level, $L_{Aeq,2min}$, measured in their classbase. Results were grouped into classbases with mean intrusive noise levels of $L_{Aeq.2min} \leq$ 55 dB and > 55 dB, in accordance with recommended limits for background noise level as discussed in Chapter 4. Mean ratings and noise levels are presented in Table 10.27.

Table 10.27: Mean ratings of noise/distraction *vs.* intrusive noise level

	Mean rating (σ)		Sig. p
	$L_{Aeq} \leq$ 55 dB	L_{Aeq} > 55 dB	
Volume of noise in other teaching areas (1 = too quiet; 7 = too noisy)	4.1 (0.7)	5.8 (0.5)	0.002
How distracting is noise in other teacher areas (1 = not at all; 7 = extremely)	3.6 (1.8)	5.2 (0.9)	0.081

A significant difference was found between perceived volume of noise in other teaching areas and measured intrusive noise level ($F_{1,13}$ = 16.5, p = 0.002). Teachers operating in classbases with intrusive noise levels in excess of 55 dB were significantly more likely to report higher perceived noise levels. It was not possible to investigate this in further detail (for example by measurement position and classroom activity) due to the small sample size.

The difference between mean rated distraction from noise in other teaching areas and measured intrusive noise level was not statistically significant ($F_{1,17}$ = 3.5; p = 0.081).

Measured noise levels were also compared with other aspects of the questionnaire such as reported raising of voice and ease of speech communication. However no statistically significant results were found.

Other acoustic parameters such as EDT_{mf}, and T_{mf} were compared with questionnaire responses to noise and distraction, however no significant relationships were found. This is consistent with the comparison of objective data with children's data. Similarly, no significant relationship was found between overall mean STI and perceived noise, distraction or ease of speech communication.

10.13 Discussion

The majority of teachers who took part in the survey employed a combination of independent and cooperative classroom organisation, that is, operating mainly independently but co-operating at certain times or for certain subjects. The slight shift in organisational trends from 1975-1978 (significantly more infant teachers involved in independent instruction, and significantly fewer junior teachers involved in cooperative organisation) is likely to have occurred as a result of the demands of the National Curriculum[264] and National Primary Strategies[53] discussed in Chapter 3.

Solely didactic, whole class teaching methods were reported less frequently than solely child-centred methods (such as project based learning or integrated day methods), although mixed mode methods were most prevalent. Didactic teaching was most prevalent amongst older years, again reflecting the demands of the National Curriculum as discussed in Chapter 3.

Overall, teachers tended to agree that teaching in open plan classrooms rather than enclosed classrooms enabled a wider range of activities to take place, and that children were more independent and responsible and benefited socially. Teachers generally did not feel that discipline was any more of a problem in open plan classrooms, or that work standards were any different. However teachers generally felt that children were more easily distracted, either visually or by noise. These findings were consistent with those of Bennett's 1975-1978 study[20] except that teachers in the 1975 study felt more neutral on the subject of discipline, whereas teachers in the current study actively disagreed that discipline was a problem. This is likely to be due to changes in curriculum and teaching styles over the years.

Both physical and teaching strategy variables appear to influence teachers' opinions of open plan classrooms compared to traditional, cellular classrooms. Teachers were more likely to agree that open plan classrooms provided benefits for children if they planned co-operatively rather than independently, and if teachers used child centred teaching methods rather than whole class teaching. This was also more likely to be the case if teachers operated in limited rather than large open plan units. Whether open plan classrooms provided benefits for teachers was found to depend only on unit size rather than teaching strategies.

Opinions on noise and visual distraction depended on the physical design of the classroom rather than teaching strategy. Teachers were less likely to agree that open plan classrooms caused noise and visual distraction if they operated in limited units with quiet room access. Visual distraction was also linked to the number of children that could see into adjacent classbases, as expected.

The most common source of noise reported in open plan classrooms was children's speech from the main classbase itself, followed by speech interference from children in adjacent classbases, and other teachers' voices. This supports the results of the children's survey where the most frequently perceived source of intrusive noise was children in adjacent classbases, followed by other teachers, see Chapter 9 (note classroom babble from within the main classbase was not investigated in the children's survey). The finding also supports the results of the objective survey in which measured intrusive noise spectra matched that of typical raised speech (Chapter 8).

Conversely, the perceived level of noise was reported to be higher in adjacent classbases than in the main classbase itself, since dissatisfaction levels were considerably higher for 'other' teaching areas. Noise levels in carpet areas and quiet rooms appear to be satisfactory overall.

The perceived level of noise in the various teaching spaces was found to be influenced by the physical design of the classroom rather than teaching strategies. Teachers in larger units and teachers without quiet room access reported significantly higher noise levels in adjacent teaching areas. High levels of dissatisfaction were also found amongst teachers operating in these types of designs. Comparison with Bennett's 1975-1978 study[20] suggests that perceived noise levels were similar for the main teaching space but that the current study suggested an improvement in noise levels in quiet rooms.

In general respondents felt that noise from outside the school was not distracting, with fewer than 4% of teachers reporting high levels of distraction (ratings of 6 or 7). This is supported by only 3% of respondents reporting external noise as a significant noise source, and low levels of measured ambient internal noise levels from the objective survey.

Perceived distraction from noise was influenced by both teaching method and the physical design of the classroom. Teachers using didactic, whole class teaching methods reported that noise from other teaching areas was significantly more distracting than teachers using child centred methods. Additionally, teachers in larger units and teachers without quiet room access reported significantly higher levels of distraction from noise. Higher levels of dissatisfaction were also found amongst teachers operating in these types of designs.

Ease of speech communication was reported to be reasonably easy across all situations. No significant differences were found between perceived ease of speech communication and teaching strategy or basic physical design variables. This is contrary to the results of the children's survey, where unacceptable levels of dissatisfaction were reported for ability to hear the teacher for large layouts and units without quiet rooms. This could suggest that teachers are less aware of speech communication difficulties than children. However the questions on ease of speech communication are fairly generalised and therefore may not be specific enough to compare results between surveys.

Teachers employed a range of coping strategies to control noise and avoid conflicts of use. The most frequently reported strategy was to gather the class closely to reduce communication distance (and hence improve signal-to-nose ratio). This suggests some awareness of the need for coping strategies not to add to existing noise levels in open plan classrooms and to protect the teacher's voice against unnecessary strain.

Reported voice problems are comparable to reported prevalence amongst the general teaching population in the US[170] (a detailed literature review by Williams[171] revealed that there is no similar data available for the UK). This suggests that prevalence of voice disorders amongst teachers in open plan classrooms is similar to that amongst teachers operating in other types of classroom design (although the US survey was conducted by telephone and no information on classroom design was collected). However, further data would be required to confirm this. Teachers who reported having to raise their voice more often also reported suffering from voice and throat problems significantly more often, as expected.

10.14 Conclusions

Although some benefits of teaching and learning in contemporary open plan classrooms have been established, such as enabling a wide range of activities, encouraging independence and responsibility in children, and social benefits, teachers have clearly identified problems with visual distraction, distraction from noise, and overall noise level in some types of open plan classroom design. The results of the teacher's survey and above discussion has illustrated the importance of limiting the size of the open plan unit and providing access to quiet rooms in order to control perceived noise levels and limit perceived distraction, and hence provide improved working conditions and speech intelligibility.

The study also shows that use of co-operative organisation and child-centred teaching methods tend to produce the most successful and positive teaching environments in open plan classrooms, in terms of perceived benefits for children and perceived distraction from noise. The type of strategy used to cope with noise is also important in controlling noise levels and protecting teachers from the long term effects of using elevated vocal levels.

Comparison of results with objectively measured data showed that teachers' perceptions of noise levels in other teaching areas were supported by mean intrusive noise levels measured in each classbase. Further data would be required to investigate relationships between teachers' perceptions and other acoustic parameters (such as reverberation time and STI) since no significant relationships were found for the small valid sample size.

The results of both the subjective surveys and the objective survey are summarised and compared in the concluding chapter.

Chapter 11: Conclusions and further work

In this concluding chapter, the main findings of the literature review (Chapters 2-6) are summarised, and the findings from the objective survey (Chapter 8) are compared with the supporting findings from the subjective surveys (Chapters 9 and 10).

The findings of the study are summarised by acoustic design recommendations and recommended management strategies, and are compared with performance standards and criteria for open plan classrooms, informed by the UK BB93 standard (BB93). From the main findings, key acoustic criteria are identified to aid future open plan classroom design.

Further work, informed from discussions in the conclusions to each previous chapter, has also been summarised.

11.1 Open plan classrooms – past, present and future

The original open plan 'Plowden' classrooms of the 1960s and 1970s symbolised an architectural response to changing educational needs as a result of the post-war educational reform movement (and its associated progressive teaching philosophies and child-centred approach), in addition to cost and area limits placed on school building during this era. Early designs (1966-1967) that developed from careful collaboration between teachers and architects and included a specific pedagogic scheme were deemed successful, but subsequently the open plan model was taken to extremes and open plan schools became associated with problems of noise and distraction.

As a result of the strong reaction that Plowden-style pedagogy faced during the 1970s and early 1980s, the proliferation of open plan classrooms declined in favour of a return to more traditional education, with an emphasis on whole class teaching. This was reinforced by the 1988 National Curriculum and 1998 National Literacy Strategy. As a result, many Plowden designs were converted to enclosed or semi-open classrooms. Nevertheless, open plan classrooms survived in a revised format in the semi-open Post Plowden designs of the late 1980s and early 1990s. These were able to accommodate hybrid teaching methods which are still seen in primary classroom practice today. More informal approaches to whole class teaching (such as being gathered on the carpet rather than at desks) make open plan designs more compatible with this type of practice.

Trends in current and future teaching practices can be seen as ‘coming full circle’, with concepts such as personalised learning and project based learning being encouraged. These practices have much in common with the original brand of progressive education. As a result, open plan and flexible ‘Neo-Plowden’ designs are being seen in new school building, although wide scale adoption of open plan classrooms is unlikely to be repeated. The need for a detailed acoustic assessment of current open plan classrooms in primary schools with respect to current teaching methods was identified in order to ensure that this type of learning environment is acoustically fit for purpose and to avoid a repeat of the circumstances that arose in the 1970s.

11.2 Noise and acoustics in open plan classrooms

The review in Chapter 4 provided evidence that noise has a significant deleterious effect on the learning process. Noise has been cited as one of the most undesirable aspects of open plan schools, although a comparison of data from the literature suggests that average measured noise levels in open plan classrooms are similar to those occurring during active periods in modern enclosed classrooms.

Control of intrusive noise level arising from adjacent activities is the most important aspect of noise in terms of speech intelligibility within open plan classbases. The most effective noise control methods include provision of a limited height acoustically absorbent ceiling, arranging the classbases to maximise attenuation, controlling occupant density and effective classroom management.

Teacher-to-student communication is considered to be the most critical form of speech communication in primary classrooms. The intelligibility of natural speech within open plan classrooms depends on the combination of the speech-to-noise ratio and room acoustic characteristics, generally described by reverberation time.

In open plan classrooms, lower reverberation times are necessary to control the reverberant intrusive noise level from adjacent classbases as well as improving the clarity of the speech signal. This work has shown that the provision of strong early reflections to support the teacher’s speech may be less important given typical organisation and management strategies (such as gathering class together on the carpet for whole class instruction).

Of the various available objective acoustic based parameters, those which combine both speech-to-noise ratio and room acoustics parameters such as STI are the most appropriate for use in open plan classrooms. The current UK standard for acoustic design of schools (BB93) sets out a requirement of STI > 0.6 for open plan classrooms. BB93 also sets out other acoustic standards for open plan classrooms such as reverberation time and ambient noise level. These standards have been used to assess acoustic compliance of existing open plan classrooms, with reference to other relevant international acoustic standards.

Speech privacy is not addressed directly in BB93, however it is important to consider this issue in open plan classrooms. Speech privacy from other teachers' voices in adjacent classbases has been assessed in the current study using an elaborated speech-to-noise parameter (SII), in addition to the sound attenuation between classbases and ambient masking noise level.

Listeners who are more vulnerable to the effects of poor acoustics and noise in primary classrooms include younger children, hearing impaired children, children with EAL, children with learning disorders and children with mild temporary hearing problems. These groups require significantly better acoustic conditions than their 'typical' listening peers or adult listeners.

11.3 Comparison of findings with BB93 criteria

The objective findings from the current study have highlighted some areas where current acoustic performance standards for open plan classrooms may benefit from some revision, as detailed below.

11.3.1 STI

The findings of the objective survey and comparison with recommended speech to noise ratio criteria for children from the literature indicate that whilst the BB93 criterion of STI > 0.6 may be suitable for 'normal' capacity listeners, the standard may not be as appropriate for more vulnerable listeners. Enhanced STI criteria should be considered for younger children as set out in Table 11.1. The proposed enhanced criteria also represent a more suitable criterion for non-native listeners with experienced, daily use of English as an additional language. Very young children (6 year olds or younger) should be gathered closely around the teacher for whole class teaching even when adjacent activities are coordinated in order to achieve the enhanced STI criteria.

Table 11.1: Proposed STI criteria for different ages

Age (years)	Minimum S/N(A) (dB) after Bradley[176]	Minimum corresponding STI under optimum conditions (from equation 10)
11	8	0.60
8	12	0.68
6	15	0.75

Whether it is appropriate to apply the enhanced STI criteria to open plan classrooms would depend on whether it is possible to achieve the criteria in a typical enclosed classroom under realistic occupied noise levels.

11.3.2 Ambient noise level

BB93 requires a maximum ambient noise level of 40 dB L_{Aeq} for open plan teaching areas, which is in line with the findings of this study. In addition, a minimum criterion of 35 dB for ambient noise is also recommended for open plan classbases (although in practice, noise from the presence of occupants is likely to maintain this minimum noise level).

11.3.3 Reverberation time

The maximum BB93 criterion of T_{mf} 0.8 s for open plan teaching spaces is likely to exceed the recommended criterion informed by the current study ($T_{mf,furnished}$ 0.4 seconds), which is in line with other international standards and guidance relating specifically to open plan teaching spaces[216, 239, 240].

It is likely that the recommended criterion for furnished spaces would relate to around T_{mf} 0.5-0.6 seconds for unfurnished spaces, although further measurements would be required to support this. The maximum BB93 criterion of T_{mf} 0.6 seconds for unfurnished, unoccupied primary school classbases could therefore result in an exceedance of the recommended criterion informed by the current study.

It is also very likely that the BB93 criterion for secondary school classbases (T_{mf} 0.8 seconds) would be considerably in excess of the optimum reverberation time for open plan layouts. Again, further work would be required to support this since measurements were carried out in primary schools only.

11.3.4 Speech privacy

BB93 does not contain a criterion for speech privacy between classbases within an open plan unit, however a design criterion is recommended to ensure that annoyance and distraction from speech in adjacent classbases is adequately controlled during periods of critical listening.

Whilst a criterion of SII ≤ 0.2 (as recommended in the literature and in Danish Guidance[216]) was shown to be acceptable to reduce the risk of reported annoyance from other teacher's voices, a criterion of SII_{raised} ≤ 0.1 is also proposed to achieve 'good' rather than 'acceptable' speech privacy for raised voices, and reduce distraction.

BB93 requirements for sound insulation are not applicable between classbases within an open plan unit. However the current study has identified a need to achieve a performance of at least D_w 25 dB between adjacent classbases, in order to achieve adequate speech privacy. This is equivalent to an overall attenuation, A, of 23 dB). This is practically achievable with a semi-open plan layout provided that layouts are carefully designed as detailed in this study.

11.4 Findings and recommendations from the current study

Provided that speech intelligibility and privacy in open plan classrooms is suitably assessed (based on realistic classroom organisation and practice) and shown to meet the relevant criteria, open plan designs may be given due consideration as an effective learning environment. To this end, a procedure was developed to measure STI for natural teacher-to-student speech communication in critical listening situations within typical open plan classbases, in accordance with the relevant standards (Chapter 7). The measurement procedure was informed by results of pilot studies and validated by experimental laboratory work. The method accounts for the effect of intrusive noise due to different activities in adjacent classbases, and main classbase occupancy noise.

A methodology for the prediction of speech privacy, SII, between classbases (based on measured sound level difference between classbases and measured ambient noise level and in accordance with ANSI 3.5) and measurement of other acoustic parameters (reverberation time, EDT, D_{50}, C_{50} in accordance with ISO 3382) was also developed. This measurement procedure was followed for the objective survey which involved 42 classbases in 12 Plowden and Post-Plowden open plan primary schools. The results of the objective survey detailed in Chapter 8 (and supporting subjective surveys in Chapters 9 and 10) have identified 17 design recommendations to make BB93 compliance (STI ≥ 0.6) feasible, and to achieve satisfactory speech privacy between classbases. The design recommendations are set out in Table 11.2.

Table 11.2: Acoustic design recommendations for open plan classrooms

	Key design recommendation	Reason
1	Limit each unit to 3 classbases	To control intrusive noise level
2	Basic teaching area per pupil ≥ 2.1 m^2*	To control intrusive noise level
3	$T_{mf(furnished)}$ < 0.40 s	Primarily to control reverberant noise
4	EDT $_{mf(furnished)}$ < 0.35 s	Primarily to control reverberant noise
5	Ambient STI** ≥ 0.7	To ensure STI not significantly degraded by noise
6	C_{50} ≥ 10 dB	To maintain speech signal
7	Provide sound absorbent ceiling	To achieve RT requirements as above
8	Provide carpeted floor covering	To control footfall/impact noise
9	SII_{raised} ≤ 0.1	To provide excellent speech privacy and between classbases for raised vocal effort, thus minimising distraction
10	SII_{loud} ≤ 0.2	To provide reasonable speech privacy between classbases for loud voices, thus limiting distraction
11	Ambient 35-40 dB L_{Aeq}	To provide masking of adjacent teachers' speech
12	D_w ≥ 25 dB between classbases	To achieve speech privacy criteria
13	≥ 6.5 m between classbase openings	To achieve speech privacy criteria
14	Stagger classbase openings	To achieve speech privacy criteria
15	Linear layouts preferable to cluster layouts	To achieve speech privacy criteria
16	Provide 'niched' carpet areas	To achieve speech privacy criteria
17	Provide enclosed quiet room to unit	To withdraw for quiet (or noisy) activities

*Although occupant density was found to affect intrusive noise levels for crowded units (< 2.1 m^2 per pupil), it was not a good predictor of noise level for BB99 compliant schools (≥ 2.1 m^2 per pupil). Limiting the number of classbases in a unit and careful design of the layout appears to be a more effective method of controlling the intrusive noise level.

**Excluding noise (SNR > 15 dB)

Supplementary parameters, that may be used as an additional design tool to achieve BB93 compliance (rather than a substitute for STI and RT/EDT criteria) are as follows:

- RASTI ≥ 0.75
- S/N(A) ≥ 8 dB
- SIL ≥ 21 dB
- S/N_w ≥ 6 dB

The design recommendations alone are not sufficient to solve the problem of noise and acoustics in open plan schools and achieve BB93 compliance. Specific classroom management strategies must also be adopted, in order to control intrusive noise levels, ensure adequate conditions for vulnerable listeners and minimise distraction and annoyance. Nine key classroom management strategies have been identified in Table 11.3 to achieve BB93 compliance in acoustically optimised open plan classrooms.

Table 11.3: Classroom management strategies for teachers in open plan classrooms

	Classroom management strategy	Reason
1	Pre-arrange activity plans	To avoid conflicts of use within unit
2	Adopt activity matrix for critical listening (Table 11.4)	To control intrusive noise levels
3	Keep activities involving movement co-ordinated between classbases	To avoid marginal levels of annoyance and distraction and maintain STI > 0.6
4	Try not to exceed a ‘raised’ vocal effort	To maintain good speech privacy and prevent vocal strain
5	Use non-vocal attention gaining strategies such as visual cues	To avoid raising the voice (see above)
6	Repeat children’s answers	To ensure the answer is intelligible by the rest of the class
7	Provide teacher training	To raise awareness of effective management strategies
8	Co-operative organisation	Associated with more positive perceptions of open plan classrooms
9	Child-centred teaching methods	Associated with more positive perceptions of open plan classrooms

Table 11.4: Activity management matrix during critical listening in main classbase

Activity in adjacent classbase(s)				
	Individual work		Group work	
Whole class	at tables	with movement	at tables	with movement
Compatible for all positions	Gather class around teacher	Avoid	Avoid	Avoid

Many of the above management strategies are already commonly used in effective primary school practice, whether in closed or open plan classrooms. Reported coping strategies identified as part of the teacher's survey (Chapter 10) suggest that the majority of teachers were aware of the need for coping strategies not to add to existing noise levels in open plan classrooms and to protect the teacher's voice against unnecessary strain. The frequency with which teachers raised their voice was linked to occurrences of vocal problems.

In a comparison of subjective responses from children operating in the same school with similar design of classbases, younger children (6-7 years) found it significantly more difficult to hear the teacher in quiet than older years (8-11) and this is consistent with studies of enclosed classrooms.

The results of the children's survey (Chapter 9) support and validate the findings of the objective survey. Significant correlations were found between mean reported classroom listening ratings and both mean measured intrusive noise level and STI for certain listening situations (see Chapter 9). These suggest that, whilst children's listening ability in quiet is affected by a number of individual factors specific to the child (such as age and hearing acuity), perceived listening ability is significantly negatively affected by noise when adjacent classbases are active.

Children's reported hearing of other teachers' voices and annoyance from other teachers' voices was supported by objective speech privacy measurements.

There is no significant difference in children's ability to hear peers between open plan and enclosed classrooms. Children in enclosed classrooms are significantly more likely to report annoyance from external noise sources than children in open plan classbases, even though there is no significant difference between both groups' reported hearing of external noise (see Chapter 9 for full discussion).

Results of the children's survey support the objective finding that open plan designs should be limited to three classbases within each unit. For this type of design, reported hearing of teachers and pupils in adjacent classbases is significantly less frequent, and overall listening ratings are significantly more favourable. Similarly, results suggest that all classbases in the unit should have access to a shared quiet room.

Although the survey of teaching staff (Chapter 10) has established some benefits of teaching and learning in today's open plan classrooms, it was found that teachers identified problems with visual distraction, distraction from noise, and overall noise level in some types of open plan classroom design. The most common source of noise reported by teachers in open plan classrooms was children's speech from the main classbase itself, followed by speech interference from children in adjacent classbases, and other teachers' voices. The results of this survey again support the findings of the other surveys, with teachers in limited units and units with quiet room access reporting significantly lower perceived noise levels and perceived distraction.

11.5 Key acoustic design criteria

The work presented in this thesis and the above discussions lead to the following seven key design criteria for the acoustic design of open plan classrooms in primary schools shown in Table 11.5. In addition, the activity plan (described in BB93) should incorporate recommended classroom management strategies.

Table 11.5: Key acoustic design criteria

	Acoustic design criterion
1	Limit each unit to 3 classbases
2	$T_{mf(furnished)}$ < 0.40 s
3	Ambient STI** ≥ 0.7
4	SII_{raised} ≤ 0.1
5	SII_{loud} ≤ 0.2
6	Ambient L_{Aeq} 35-40 dB

*Noiseless (SNR > 15 dB)

11.6 Further work

Further work has been discussed in detail in the conclusion to each Chapter and is summarised below:

- Further investigation of group work activity noise
- Extend work to include new-build and fully open plan classrooms
- Extend work to include open plan secondary schools
- Dedicated study investigating perceived differences in children's perception for both open plan and enclosed classrooms
- Dedicated study to investigate perceived conditions in open plan classrooms by further vulnerable listener groups (such as children with EAL and SEN) compared to 'typical' peers
- Further work into teacher's perception of ease of speech communication (current findings inconclusive)
- Computer modelling of measured classbase spaces to verify BB93 recommendations for modelling
- Investigate whether enhanced STI criteria proposed for younger and EAL listeners are possible to achieve in a typical enclosed classroom under realistic occupied noise levels.

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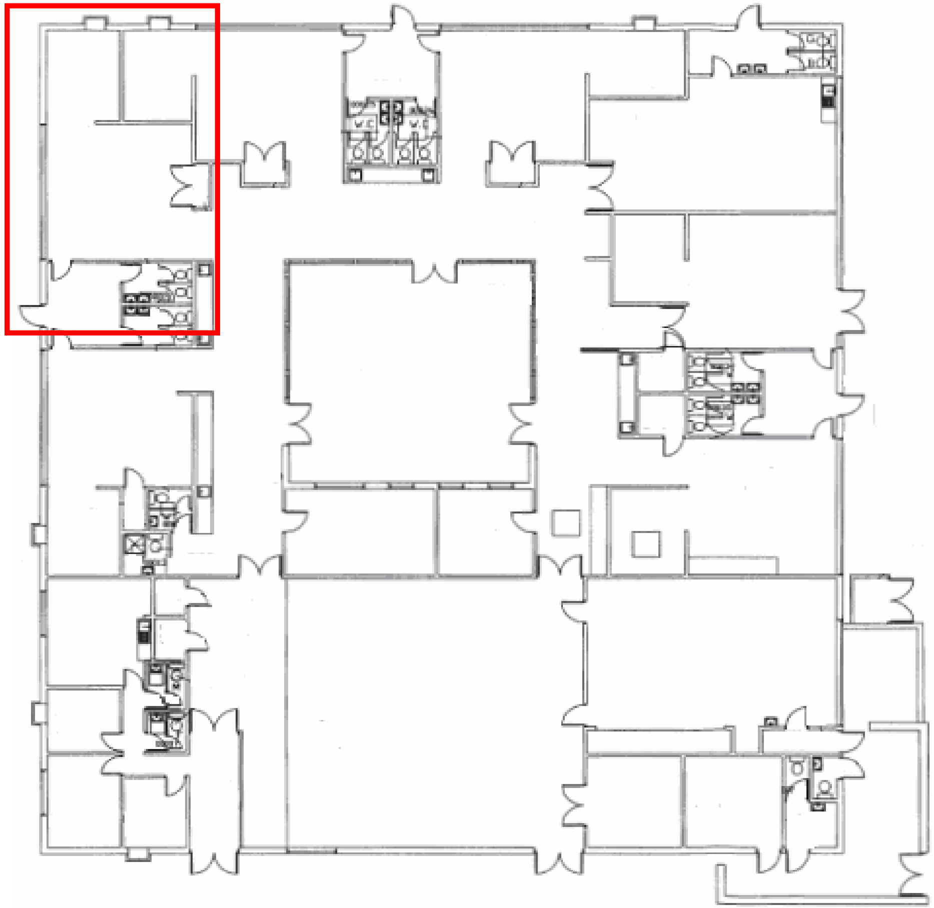
Appendix A

School Plans

School 1



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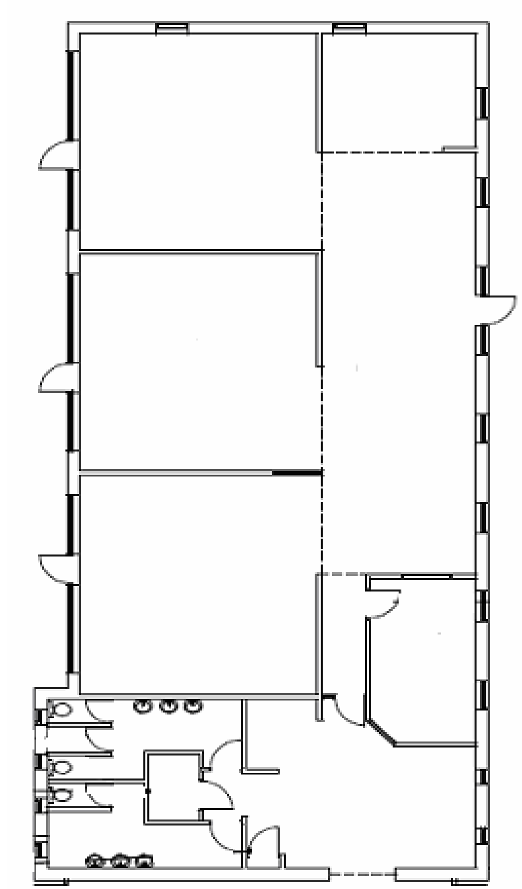
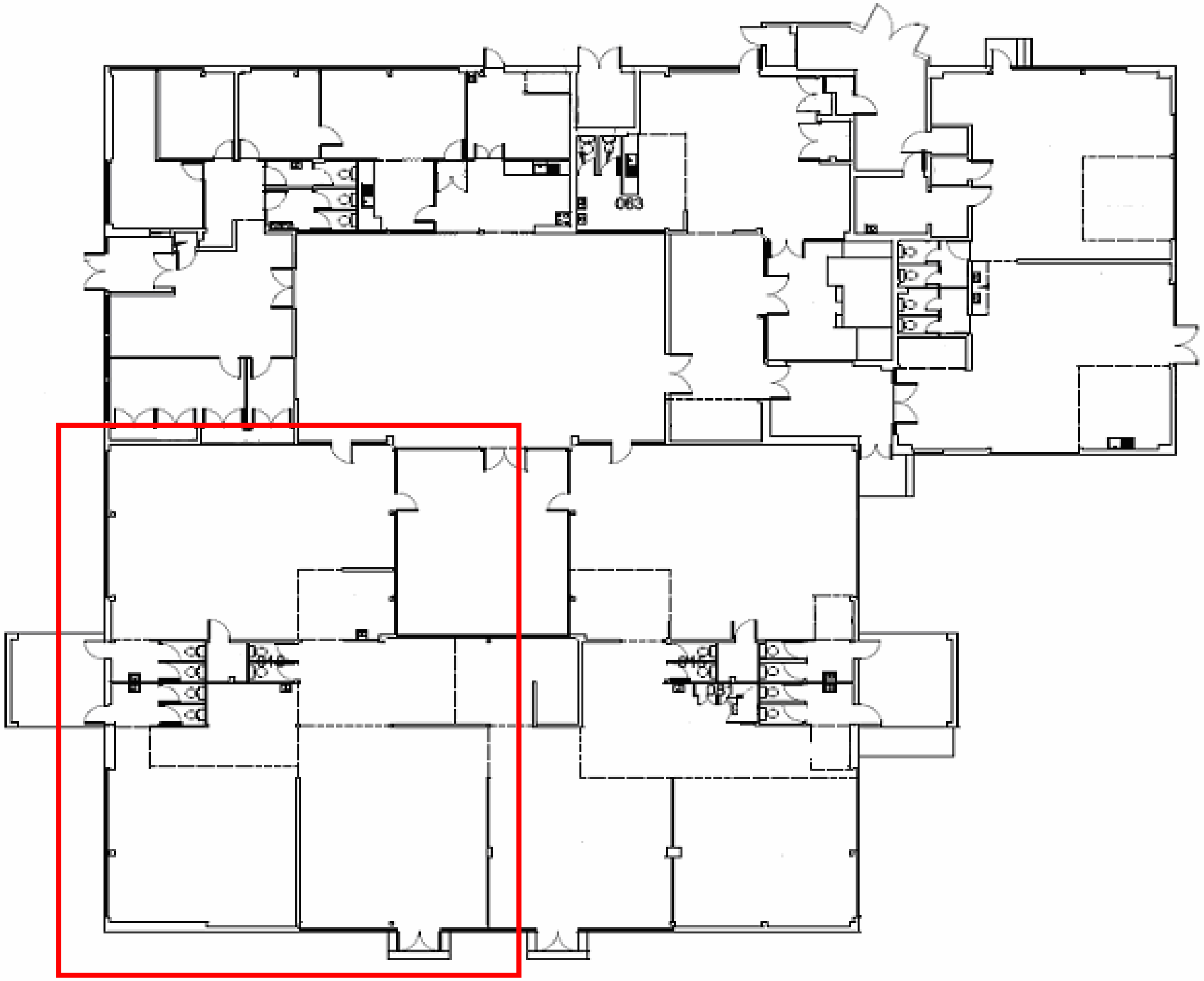


School 3

School 4

School 5



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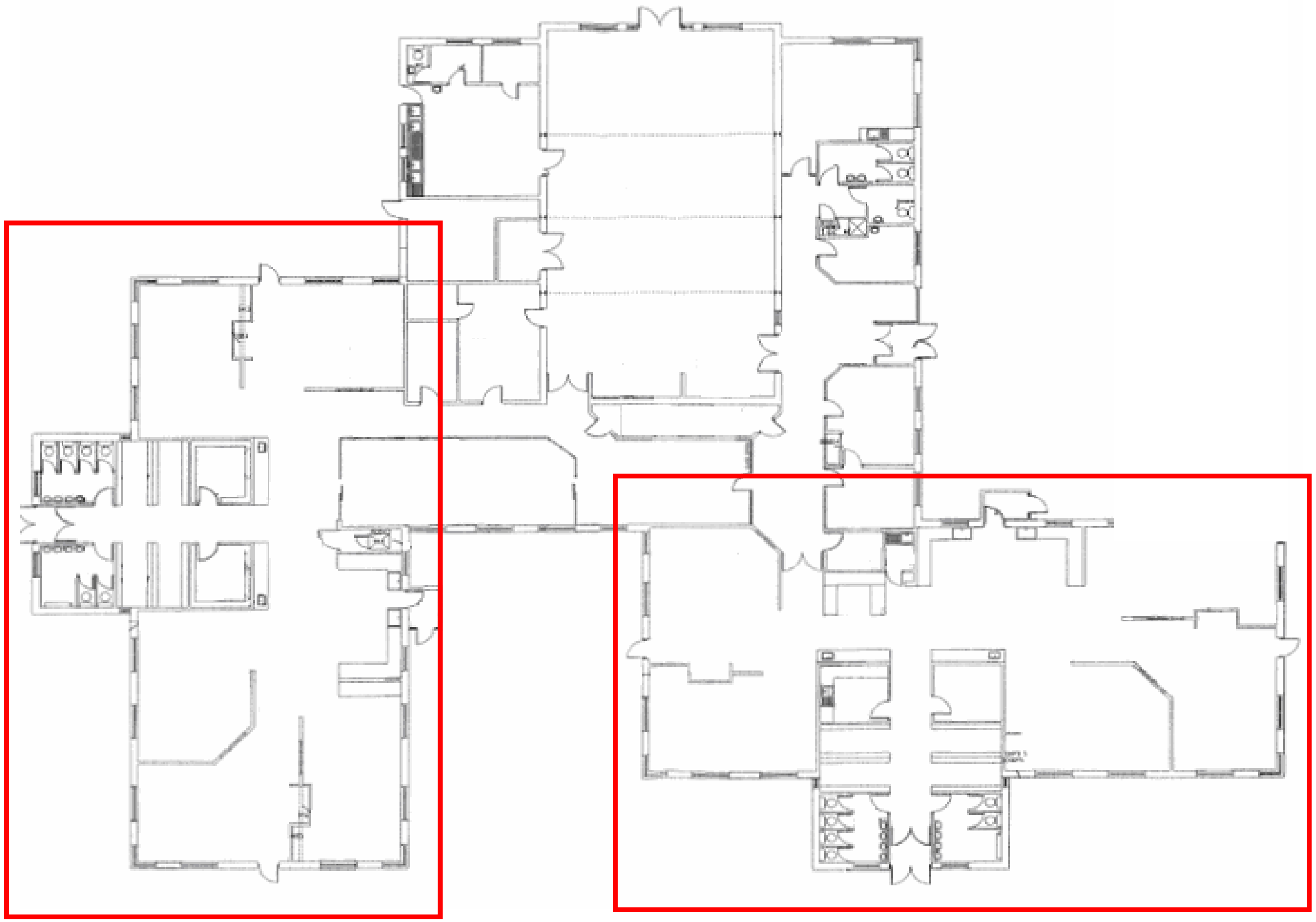

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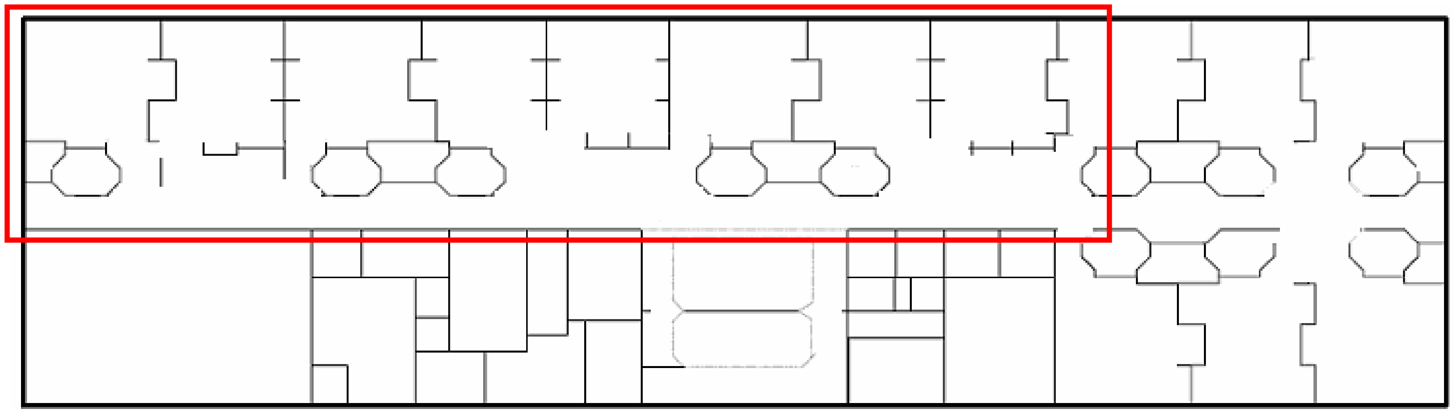

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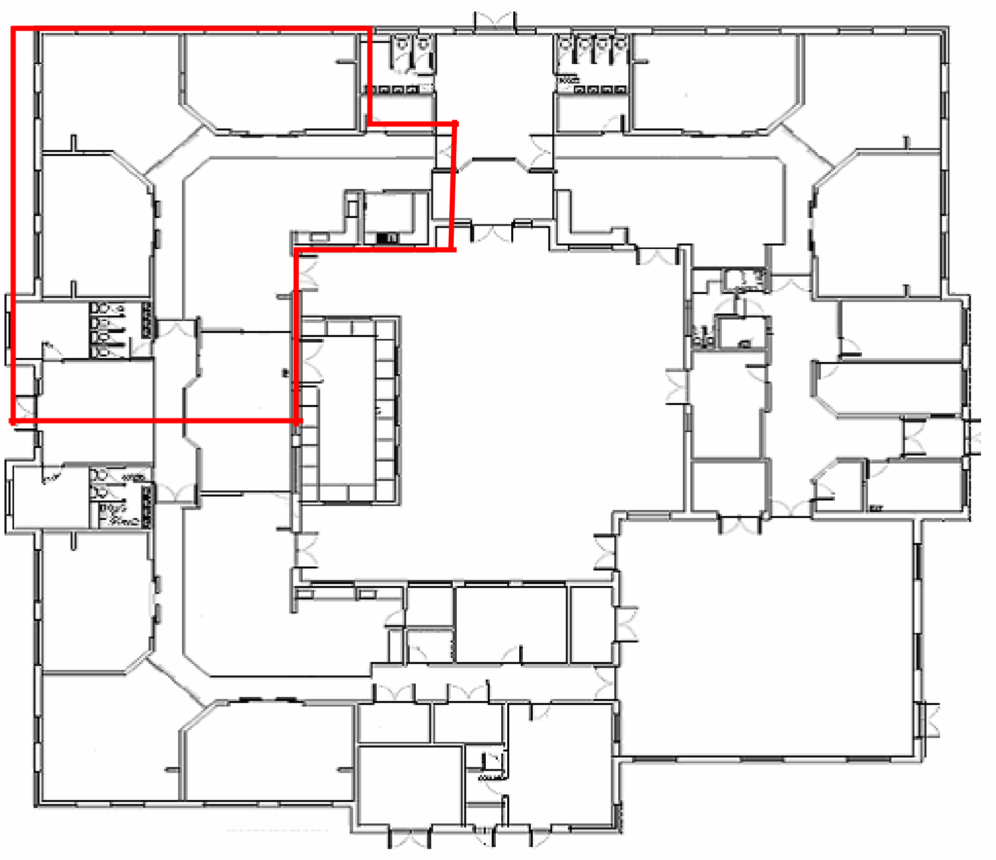

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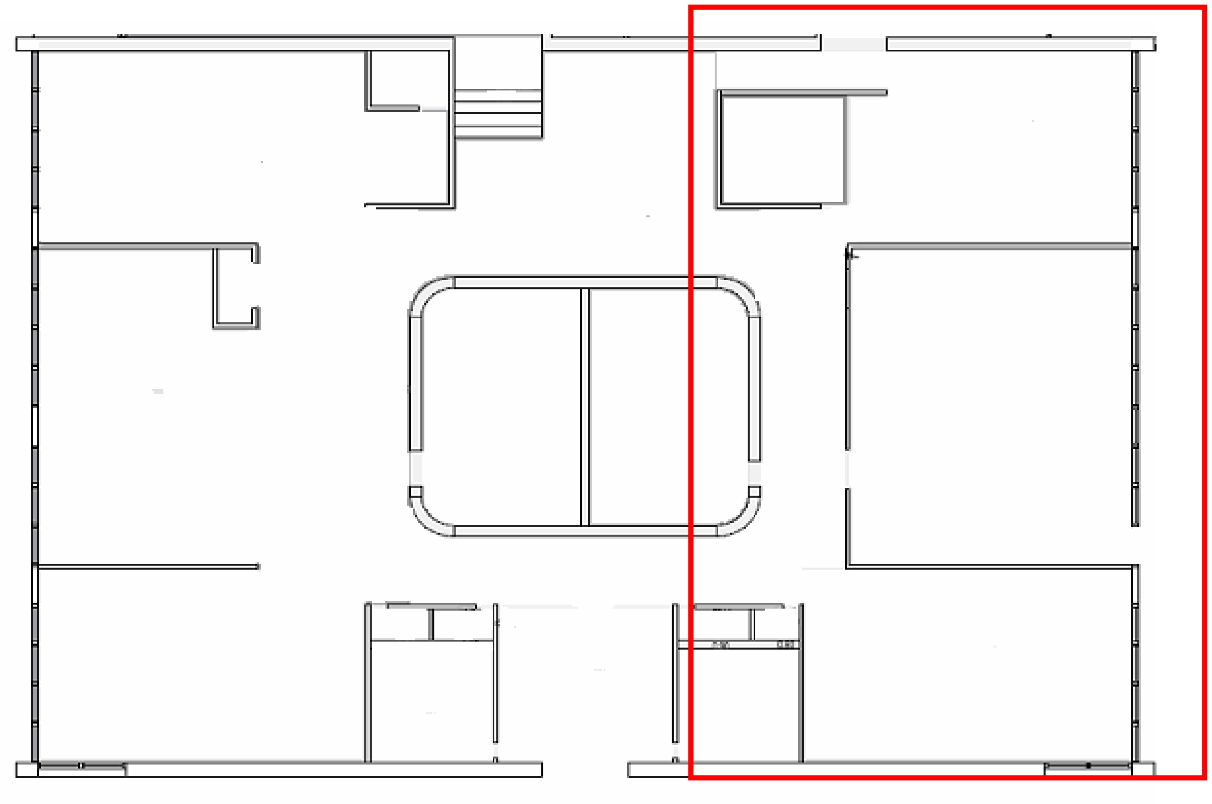
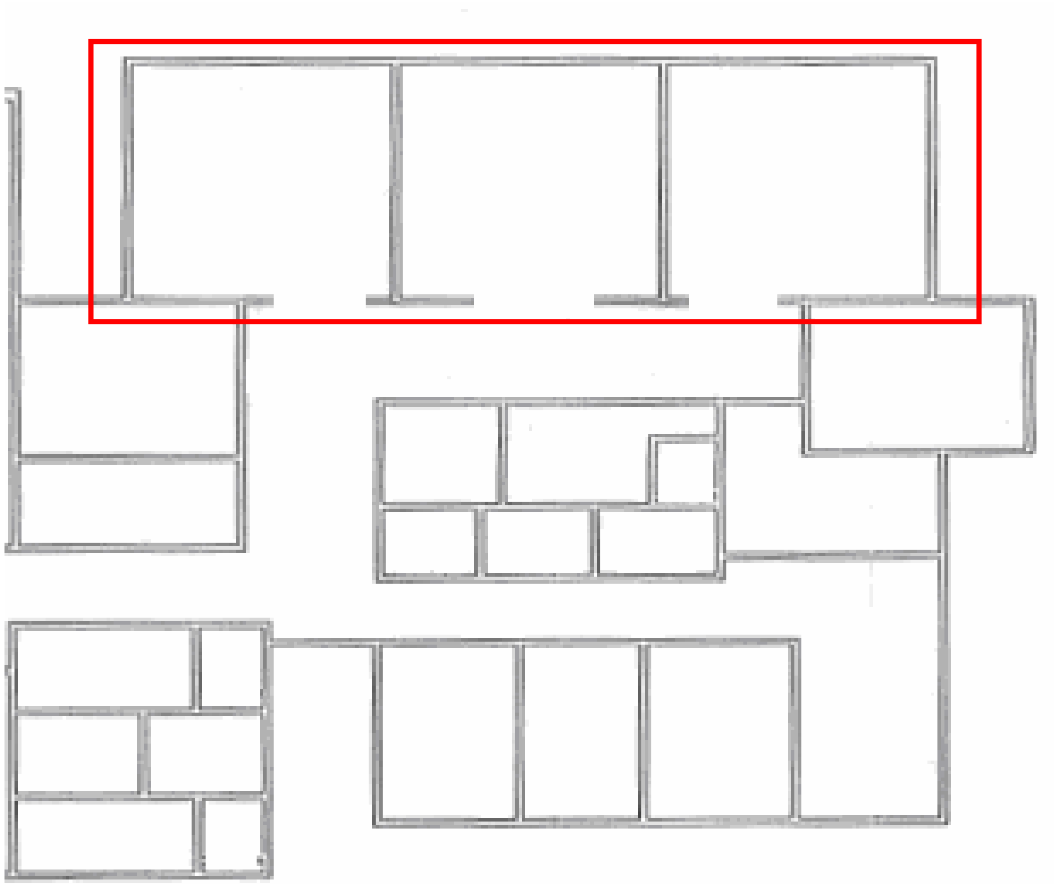


School 10



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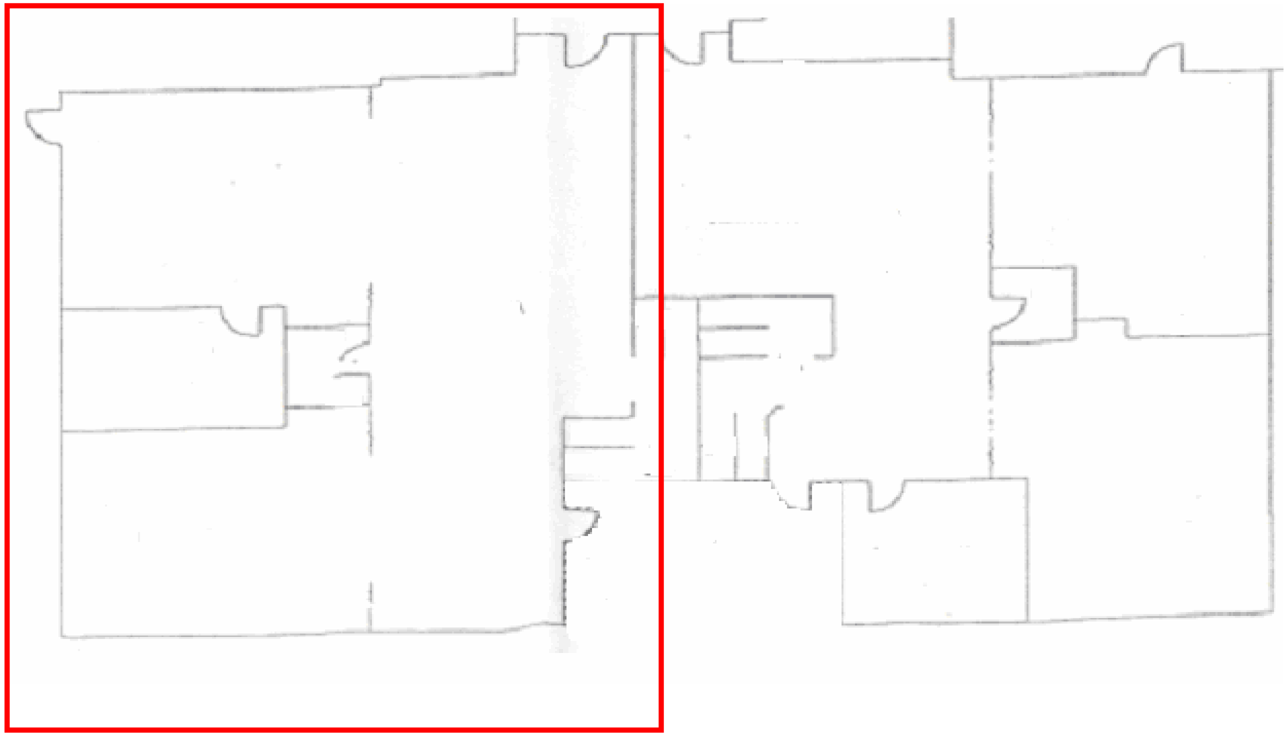

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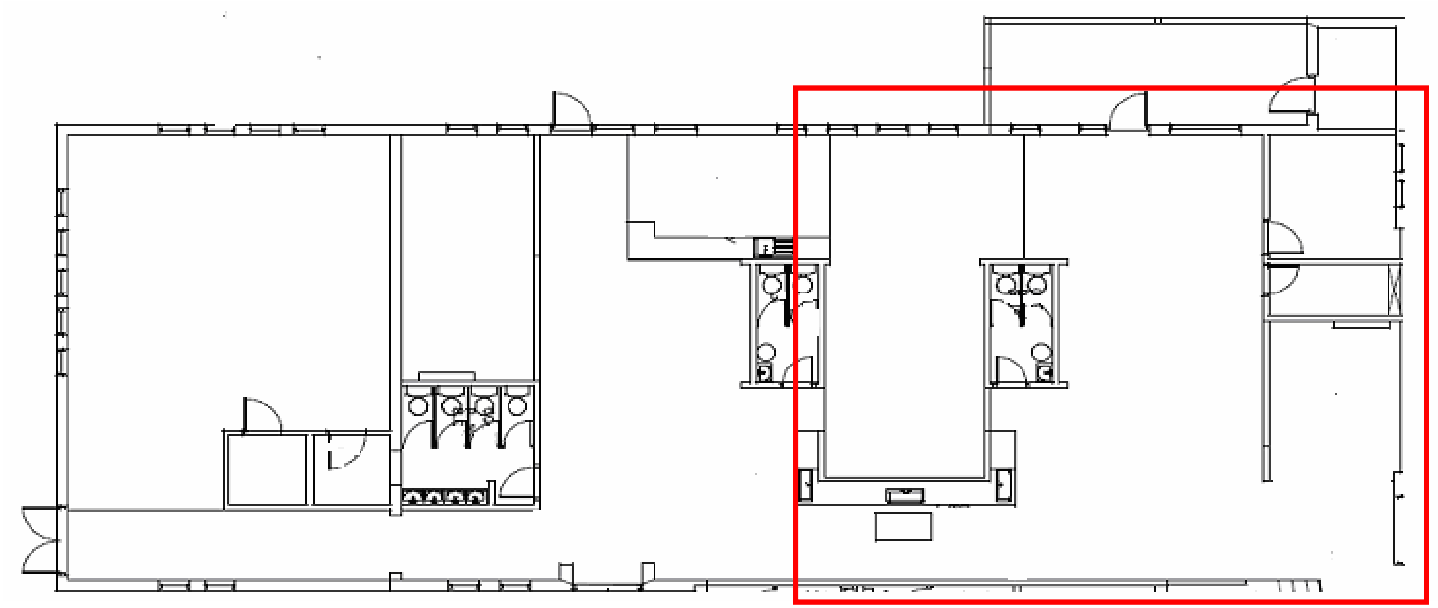


Appendix B

Children’s questionnaire

School Code:
Year :
School Type:

Noise Project

Our project is about the difference between noise and quiet. We would like you to help by filling in this worksheet for us.

Your school: ……………………………………

Your class: ……………………………………

What is your first name? ………………………………

Are you a boy or a girl?

Boy ☐ Girl ☐

How old are you? …………………………

Is English your first language?

Yes ☐
No ☐

If no, what is your first language? ………………………………

Do you have problems hearing?

Yes ☐ No ☐

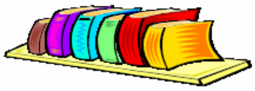
Do you wear a hearing aid?

Yes ☐ No ☐

The development of the "*How well do you hear your teacher*" section of the scale was informed by "*Listening Inventories for Education*" (Canning, D., 1999)

School Code:
Year :
School Type:

What do you hear in the classroom?

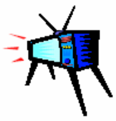


Read the question and put a tick √ under the box to show your answer. Here's an example:

When you are in the classroom do you ever hear noise from traffic? Yes √ No ☐
If yes, does it ever annoy you? Yes ☐ No√

1a) When you are in the classroom do you ever hear noise from outside the school? Yes ☐ No ☐
1b) If yes, does it ever annoy you? Yes ☐ No ☐

2a) When you are in the classroom do you ever hear musical instruments? Yes ☐ No ☐
2b) If yes, does it ever annoy you? Yes ☐ No ☐



3a) When you are in the classroom do you ever hear noise from televisions? Yes ☐ No ☐
3b) If yes, does it ever annoy you? Yes ☐ No ☐

4a) When you are in the classroom do you ever hear noise from fans and other machines? Yes ☐ No ☐
4b) If yes, does it ever annoy you? Yes ☐ No ☐

5a) When you are in the classroom do you ever hear noise from computers? Yes ☐ No ☐
5b) If yes, does it ever annoy you? Yes ☐ No ☐

6a) When you are in the classroom do you ever hear noise from pupils in other class groups? Yes ☐ No ☐
6b) If yes, does it ever annoy you? Yes ☐ No ☐

7a) When you are in the classroom do you ever hear noise from other teachers voices? Yes ☐ No ☐
7b) If yes, does it ever annoy you? Yes ☐ No ☐

The development of the "*How well do you hear your teacher*" section of the scale was informed by "*Listening Inventories for Education*" (Canning, D., 1999)

School Code:
Year :
School Type:

How well do you hear your teacher?

Read the question and put a tick √ in the box to show your answer.

---

1. Your class is quiet and you are listening to your teacher. The class(es) next to you are doing a test. How well can you hear your teacher?

				
very well	well	ok	not very well	not at all

---

2. Your class is quiet and you are listening to your teacher. The class(es) next to you are working at their tables. How well can you hear your teacher?

				
very well	well	ok	not very well	not at all

---

3. Your class is quiet and you are listening to your teacher. The class(es) next to you are working *and* moving around the classroom. How well can you hear your teacher?

				
very well	well	ok	not very well	not at all

The development of the "*How well do you hear your teacher*" section of the scale was informed by "*Listening Inventories for Education*" (Canning, D., 1999)

School Code:
Year :
School Type:

How well do you hear your classmates?

Read the question and put a tick √ in the box to show your answer.

4. The teacher is asking a question and one of your classmates is giving an answer. In general how well can you hear what your classmate is saying?

very well	well	ok	not very well	not at all

5. You are working in groups. How well can you hear what the people in your group are saying?

very well	well	ok	not very well	not at all

Thankyou for helping us with our project!

The development of the "*How well do you hear your teacher*" section of the scale was informed by "*Listening Inventories for Education*" (Canning, D., 1999)

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Appendix C

Teacher Questionnaire

School Code: ☐☐

Teaching Staff Questionnaire

To be completed by teaching staff (please provide additional photocopies if necessary):

PERSONAL DETAILS:

Your name:……………………………………………………………………………………..

School:………………………………………………………………………………………..

Your year group, class name and/or subject:………………………………………………

Number of pupils in you class:……………….

1.0 EDUCATIONAL & TEACHING BACKGROUND:

1.1 What is your age?

21-25	☐	46-55	☐
26-35	☐	56-60	☐
36-45	☐	60+	☐

1.2 How long have you been a qualified teacher?

Less than two years	☐	Between five and 10 years	☐
Between two and five years	☐	10 years or more	☐

1.3 How long have you been teaching at this school?

Less than one year	☐	Between five and 10 years	☐
Between one and five years	☐	10 years or more	☐

1.4 Approximately how many years teaching experience do you have in the following:

Open plan classrooms	☐
Traditional (enclosed) classrooms	☐

2.0 YOUR CLASSROOM:

2.2 Which of the following best describes the planning and organisation in your class?

- ☐ Independent instruction (i.e. teaching on your own)
- ☐ Mainly independent instruction but plan co-operatively with other teachers sometimes
- Independent operation for basic subjects but co-operation on project work
- ☐ Independent operation for project work but co-operation on basic subjects
- ☐ Co-operative team teaching between classes with teacher specialist subjects
- ☐ Team teaching between classes with no teacher specialist subjects
- ☐ Other

If other, please specify:…………………………………………………………………..

2.3 On the whole, which of the following best describes teaching methods used in your class?

(Tick more than one box if necessary)

- ☐ Mainly didactic instruction with whole class
- ☐ Teacher directed project based learning
- ☐ Pupil centred project based learning
- ☐ Teacher directed integrated day
- ☐ Pupil centred integrated day ('High Scope')
- ☐ Other (please specify)……………………………………………………………

2.4 In the main, how are pupils assigned to your class/teaching group?

☐ Age ☐ Ability
☐ Friendship ☐ Random

2.5 Do you use a sound field (electronic amplification) system in you class area?

☐ Yes ☐ No

2.6 If yes, how often do you use it?

☐ Never ☐ Occasionally
☐ Most of the time

2.7 How many of the class can see other teaching groups easily from their seats?

All	Most	Some	A few	None

2.8 Do you have the use of a quiet room?

☐ Yes ☐ No

2.9 If yes, how often do you use it?

Never	Very occasionally	Once a week	Several times a week	Every day

2.10 Please read each of the following statements (a-m) about *open-plan classrooms as compared with enclosed classrooms*. Please indicate how strongly you agree or disagree by placing a tick in the appropriate box

Statement: In your open plan school	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
a. The environment provides for a wide range of activities					
b. The children are more independent and responsible					
c. Standards of work tend to be higher					
d. Children are more easily distracted by noise					
e. Children are more easily visually distracted					
f. Children benefit socially					
g. There are discipline problems					
h. There is greater continuity for pupils					
i. There is better pastoral care for students					
j. Teachers feel more confident					
k. The environment helps NQTs to make better progress					
l. The environment facilitates better pupil supervision					
m. The environment makes pupils feel more secure					

3.0 YOUR CLASS ENVIRONMENT:

3.1 During a typical lesson, what is the dominant source(s) of background noise in your class? (Tick more than one box if necessary)

- [ ] External noise (e.g. traffic)
- [ ] Plant (e.g. air conditioning)
- [ ] Classroom equipment (OHP, computers, etc.)
- [ ] Classroom 'babble' within your own class
- [ ] Classroom 'babble' from other classes
- [ ] Other teachers' voices
- [ ] Other (please state)………………………………………………………………………..

Please answer each the following questions by circling a score from 1-7, indicating the strength of your response.

3.2 In your opinion, is the volume of noise in the following areas:

	Too quiet						Too noisy	
a. General classroom	1	2	3	4	5	6	7	
b. Carpet	1	2	3	4	5	6	7	N/A
c. Enclosed quiet room	1	2	3	4	5	6	7	N/A
d. Other teaching areas	1	2	3	4	5	6	7	N/A

3.3 How distracting is noise intruding from:

	Not at all						Extremely
a. Other teaching groups	1	2	3	4	5	6	7
b. Outside the school?	1	2	3	4	5	6	7

3.4 How easy do you find speech communication with children in the following situations?

	Not at all						Extremely
a. Talking individually:	1	2	3	4	5	6	7
b. Addressing small groups	1	2	3	4	5	6	7
c. Addressing the whole class:	1	2	3	4	5	6	7

4.0 HEARING IMPAIRED STUDENTS:

If you do not have any hearing impaired students in your class, please go on to section 5.

4.1 How many hearing-impaired students do you have in your class? ☐☐

4.2 How easy is it for hearing-impaired students to hear you in the open plan environment?

Not at all						Extremely
1	2	3	4	5	6	7

4.3 Do hearing impaired pupils use an FM system?

☐ Yes ☐ No

5.0. COPING WITH NOISE:

5.1. During the teaching day how frequently do you have to raise your voice above a comfortable speaking level?

- ☐ Never
- ☐ Very Rarely
- ☐ Sometimes
- ☐ Quite Often
- ☐ A Lot
- ☐ All the time

5.2. When the adjacent class activity conflicts with yours (in terms of noise), what do you do? (Tick any that apply)

- ☐ Raise your voice
- ☐ Change your voice (e.g. lower it or speak quietly)
- ☐ Gather class closely around you
- ☐ Arrange a compatible activity schedule with other teachers
- ☐ Change the seating arrangement
- ☐ Stop/change teaching activity
- ☐ Use visual cues for attention
- ☐ No particular action
- ☐ Other (please state)………………………………………………………

5.3 Do you ever suffer from voice or throat problems?

- ☐ Never
- ☐ Occasionally
- ☐ Frequently
- ☐ All the time

6.0 FURTHER INFORMATION:

Please continue with any further comments or information you wish to include on the following pages.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE

Please return to:

Emma Tate-Harte
Faculty of Engineering, Science and the Built Environment (FESBE)
London South Bank University
103 Borough Road
London SE1 0AA

Further information:

7.0 OFFICE USE ONLY

7.1 Classroom age:

- Pre-Victorian ☐
- Victorian ☐
- 1900-1959 ☐
- 1960-1979 ☐
- 1980-1989 ☐
- 1990-1999 ☐
- 2000-present ☐

7.2 Design:

- ☐ Fully open plan
- ☐ Fully open plan with quiet rooms
- ☐ Semi open plan (teaching spaces defined by walls with openings in them)
  - with ☐ full height walls
  - ☐ partial height walls
- ☐ Semi open plan with enclosed rooms off main space
- ☐ Flexible open plan (use of sliding partitions)
- ☐ Other (please state): ……………………………………………………………

7.3 Number of classes in unit:

- ☐ One
- ☐ Two
- ☐ Three
- ☐ Four
- ☐ Five or More

Appendix D

Factor analysis on teachers' opinion scores

A high degree of correlation was found between some of the thirteen opinion statements, a-m, included in the teachers' survey (see Chapter 10 and Appendix C). In order to reduce the data for analysis, a principal components factor analysis was carried out on the statements to identify underlying variables for further analysis

In order to carry out the factor analysis, the scoring scale for statements d, e and g, ('more easily distracted by noise', 'more easily visually distracted', 'more discipline problems',) was reversed, in order to provide a consistent direction of meaning (negative to positive) for comparison with other statements. The transformed questions therefore became 'there are fewer discipline problems', 'children are less easily distracted by noise', and 'less easily visually distracted, for the purposes of the initial analysis.

Three factors were initially extracted with Eigenvalues of at least 1, accounting for 71% of the variance in total. An Eigenvalue represents the amount of variance in the data that is explained by the factor. The orthogonal rotated loading on the factors (similar in principle to correlation coefficients) is shown in Table D (N.B. loadings of less than 0.3 are not shown for clarity).

Considering the factor loadings of 0.7 and above (highlighted in Table D1), the first factor appears to be related to benefits for teachers and teacher-pupil relationship. The second is related to distraction (both visual and noise). The third appears to be related to benefits for children.

A repeated measures ANOVA was carried out on the groups of variables highlighted below (loadings of 0.7 or more), to investigate if the means of the variable groups were significantly different.

Table D1: Rotated factor loadings on variables (% of variance)

	Factor 1 (27%)	Factor 2 (22%)	Factor 3 (22%)
i) Better pastoral care	.785		
l) Better pupil supervision	.752	.456	
h) Greater continuity	.733		
m) Pupils more secure	.732	.407	
j) Teachers more confident	.705		.492
k) NQTs make better progress	.549		.524
e) Less visually distracted		.846	
d) Less distracted by noise		.803	
g) Less discipline problems		.654	
c) Work standards are higher	.317	.603	.386
b) Children are more independent, responsible			.838
f) Children benefit socially	.350		.789
a) There is a wider range of activities	.305	.407	.709

For the factor 1 variables, no significant difference was found between the means of the groups ($F_{4,288}$ = 2.00, p = 0.10). Therefore it was considered valid to group the 5 variables into a single factor attributed to benefits for teachers and teacher-pupil relationship as per the factor analysis. This factor is referred to as 'benefits for teachers' for simplicity.

For the factor 2 variables (visual and noise distraction), a significant difference was found between the two variables ($F_{1, 77}$ = 6.30, p = 0.01), therefore it was not considered appropriate to group these two variables together as indicated by the factor analysis. Each variable was considered separately in further analysis.

For the factor 3 variables, no significant difference was found ($F_{2,150}$ = 2.04, p = 0.13), therefore it was considered valid to group these three variables under a single factor 'benefits for children' as per the factor analysis.

Statements relating to discipline and work standards were considered separately.

The statement 'NQTs make better progress' was excluded from further analysis as this was not considered pertinent to the main research questions.