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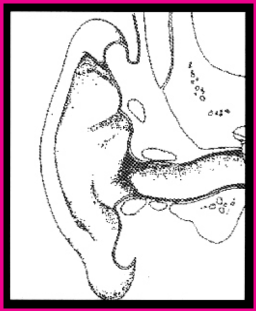

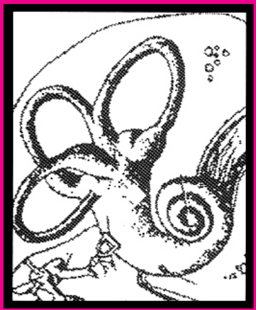

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Noise in open plan classrooms in primary schools: A review

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Abstract
This paper presents a review of research carried out in the past 40 years into various aspects of noise in open plan classrooms. The emergence of open plan classroom design in response to progressive educational reforms is discussed. A limited amount of evidence of the effects of noise in open plan classrooms is presented. Surveys of both background and intrusive noise levels in open plan classrooms are summarized and compared. Differences between noise levels in open plan and enclosed classrooms are also considered. Recommended noise limits and acoustic design criteria for open plan classrooms are discussed, together with some current international standards. The paper concludes with a discussion of appropriate noise control measures to reduce noise and maximize speech intelligibility and speech privacy in open plan classrooms.

Keywords: Acoustics, classrooms, noise, open plan, schools, speech intelligibility

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Introduction

Open plan classroom designs are gaining in popularity in school designs of the 21st century. Having become popular for educational reasons in the 1960s and 1970s, many open plan designs were found to be impractical and difficult to teach in because of problems of noise and visual distraction. For these, and other, reasons, many previously open plan schools have had remedial work to convert them to conventional enclosed classroom designs, or to a "semi-open" plan layout. The majority of new schools built in the latter part of the 20th century opted for the more traditional design with enclosed classrooms.

During the years when open plan schools were popular, research into the acoustic and noise aspects of such teaching spaces was carried out, which aimed to investigate the levels of classroom and intrusive noise, the effects of noise and the ways in which noise could be controlled. Recommendations have been made by researchers concerning optimum levels of noise and suitable acoustic design criteria to provide maximum speech intelligibility and speech privacy. For educational reasons, and also as a result of current architectural fashion, many secondary and primary schools being built in the 21st century include both open plan classrooms and large open atria or teaching spaces in their designs.[1-5] There is thus an urgent need to review the previous research on open plan classrooms in order to apply the knowledge gained previously to the new designs. Previous research has been complemented recently by a large-scale study examining the acoustics of open plan and semi-open classrooms in the UK, alongside surveys of teachers' and children's attitudes to noise.[6,7]

The literature reviewed in this article has been obtained by a search of databases and national and international journals in the acoustics, education and psychology fields, to identify relevant articles, reports and theses published in the past 60 years.

History of Open Plan Classroom Design

Open plan classrooms became popular around 50 years ago following the progressive educational reform movements of the 1950s and 1960s. 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 years following the second world war witnessed a breakdown of this formality, as education began to focus on the individual needs of the pupils rather than the "convenience" of teachers.[8,9] Reflecting the changing political times, the new generation of educationalists was seen to reject anything considered authoritarian.[10] These progressive philosophical changes were apparent in the organization and arrangement of the classroom; didactic teaching was replaced with experiential learning centered on individual assignments and group work.[9,11,12] The new educational methods placed an emphasis and focus on the child rather than the teacher, and were embodied by a "child-centered" pedagogic approach.

To reflect the new ideas, educators called for a change of thinking in classroom design that would not place limitations on the learning environment. Arrangement of furniture within the classroom became more informal to accommodate the child-centered approach, with desks placed together for group work. School furniture and fittings were redesigned with the ergonomics of the child in mind,[13] to create a home-like atmosphere, and provide children with a greater sense of security.[9] Although the architectural design of the school did not necessarily dictate educational practice, it is fair to say that child-centered learning methods were "exemplified" by early open plan school designs.[10]

An additional factor which influenced school design was economic. The emergence of child-centered teaching methods coincided with the introduction of post war economic restraints which affected the building of primary schools; designs which reduced the amount of non-teaching space while protecting the available teaching space were encouraged. Hence, the open plan school emerged as a combined result of responding to the new needs of the "progressive" educationalists, and to the cost and area limits placed on new schools.[8,9,14-16] Designs included fully open plan "schools without walls" and the more common semi-open plan arrangements consisting of linked "classbases" opening off a common shared area, often with folding screens to separate classes when required. The number of new and converted open plan primary schools increased throughout the 1970s. By 1976, 10% of all primary schools in England and Wales were open plan,[17,18] while in the US at this time, over 50% of new build schools were either fully open or semi-open plan.[19]

During the changing social and political climate of the 1970s and 1980s, there was criticism of this child-centered approach to learning and classroom design, and politicians and educators called for a return to more traditional values. As a result, the proliferation of open plan classrooms (which were synonymous with progressive teaching styles) declined rapidly in favor of a return to more traditional education.

However, in the 21st century, certain aspects of progressive education are once more being encouraged in the UK and elsewhere.[1-5] Today, Britain is undergoing the largest nationwide new school building effort for over 100 years. 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. New school buildings also need to be adaptable to changing trends in classroom practice and future new developments in teaching and learning. Open planning is being used increasingly in high profile and "exemplar" classroom designs in order to respond to this change, and is becoming a major feature of new school buildings. In other countries, new classroom designs have large, flexible, open spaces,[20] in order to accommodate neo-progressive educational philosophies.[1-5,21] However, there are already cases of new open plan designs being enclosed and or additional screening retrofitted to ameliorate problems with noise transmission.[22,23]

Effects of Noise in Open Plan Classrooms

In the early 1970s, a considerable amount of research into open plan schools was conducted.[24] Various aspects of open plan schools were investigated, including pupil and teacher attitudes,[25-29] performance standards,[30] teaching methods and organization,[14,18,25,31-33] and the acoustic environment.[19,32,34-37] While many advantages of open plan schools were identified, higher noise levels were frequently cited as being a major disadvantage. However, opinions were divided on whether this would cause distraction and affect performance.[16,32,34-37] Often, the *type* of noise (for example, interfering speech or environmental sources, continuous or intermittent noise, and spectral characteristics) was considered to be more important than overall noise level in determining the amount of distraction.[19,36,37]

There is a wealth of research examining the effects of noise (mainly from environmental noise external to a school) on all aspects of performance in classrooms. A significant negative relationship has been found between noise levels and learning attainment,[38-44] cognitive processing,[45-47] reading,[16,43,48-55] and to a lesser extent, numeracy tasks.[12,31] Noise has also been found to negatively affect other performance-related aspects such as attention,[56] concentration[40-42] and memory.[45,46] Irrelevant speech has been shown to have a profound detrimental effect on children's literacy tasks.[47]

However, there have been very few rigorous studies which have examined the effects of noise on performance in open plan schools, rather than in enclosed classrooms. Weinstein's carefully designed experiment[30] 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 emphasized that results were not necessarily applicable to schools where background noise levels were higher, and that noise was still likely to affect annoyance and speech communication, and to reduce the number of available teaching options. In another study, Barnett *et al*,[57] compared the performance on an auditory selective attention test of two groups of children, one group who were taught in open plan, and the other in enclosed classrooms, all classrooms having similar average noise levels during lessons and similar densities of pupils. They found that the children in the open plan school performed significantly better than the other children. This suggests that children in open plan classes may habituate to intrusive noise and find it less distracting to their attention than children in enclosed classrooms. However, there is a lack of data on the impact of intrusive noise upon children's cognitive processing in open plan classrooms.

Similarly, there have been few detailed studies of non-auditory effects of noise in open plan classrooms. Reported non-auditory effects of noise in general classrooms include stress,[39,58] raised blood pressure[59] and motivational effects such as learned helplessness.[59] Different groups of children have been found to be affected differentially by noise. For example, whilst older children were found to be more aware of external noise, younger children were more annoyed by it.[60] Children with sensory hypersensitivity, for example those with Autistic Spectrum Disorders (ASD), may be more easily distracted by noise.[61] Other groups of listeners who are particularly vulnerable to the specific effects of noise on speech perception include children who are hearing impaired,[42,62] non-native speakers,[63-68] children with language, learning and reading disorders,[26-28,69-71] and also children with mild hearing loss[65] and middle ear problems.[72]

In Shield and Dockrell's study on children's perceptions of noise in UK primary schools,[60] 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[6,34,35,73,74] and perceived by both teachers and pupils to be a problem.[6,16,30] The level of distraction in open plan schools is attributed to "individual perception, social conversation, movement and noise".[16] Irrelevant meaningful speech has been shown to be a particularly distracting source of noise compared to other sources at equivalent levels[75] due to the associated meaning in speech;[76] thus open plan schools are particularly vulnerable to this effect. A recent, large-scale survey of children in semi-open plan primary schools in the UK[7] found that children perceive themselves to be significantly affected by intrusive speech from pupils and teachers in adjacent classbases, in terms of noise annoyance and their ability to hear the teacher in critical listening situations. Children's perceived ability to hear their teacher decreases as activity in adjacent classbases increases to include movement.

Noise Levels in Open Plan Classrooms

Excessive noise levels and lack of acoustic privacy have been frequently identified as the most undesirable aspects of open plan schools.[16,19,34,35,77-81] 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. While there have been several surveys of noise in enclosed classrooms published over the past 20 years,[42,82-87] there is a paucity of data relating to the more recent open plan designs.

The surveys of noise in enclosed classrooms have shown that, as would be expected, the noise level depends on the classroom activity; typical levels for primary schools are 44 dB L_{Aeq} when pupils are silent,[88] 56 dB L_{Aeq} when pupils are engaged in quiet activities (for example, silent reading),[82,84] 65 dB L_{Aeq} for individual work (for example, working at tables where some talking is allowed),[82] and 70–77 dB L_{Aeq} for group work.[82-85]

Table 1 summarizes the surveys of noise in open plan classrooms, which have been carried out since the 1960s.

Table 1: Surveys of occupied noise levels in open plan classrooms

Reference	Number of classrooms	Average noise level (range) dB	Comments
Charlton-Smith[89] 2005		66 (64–69)	Semi-open with large openings, full height partitions, carpeted floors, u ntreated ceilings
		63	Sliding partitions, carpeted floors and absorbent ceilings
		64 (60–68)	Semi-open, partial height partitions, carpeted floors and absorbent ceilings
Charlton-Smith[90] 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 2003[91]	1	(66–75)	Primary classroom – project work, literacy and numeracy sessions
Airey[85] 1995 and	14	57 (49–70)	Primary classrooms – pupils silent
MacKenzie 1999[92]		72 (60–84)	Primary classrooms – pupils working
		64 (49–74)	Primary classrooms – teacher talking
School Sound Level	36	63 (52–69)	Fully open plan elementary schools, very active periods (at least four class groups)
Study[37] 1986		62 (54–73)	Fully open plan secondary grade schools, very active periods (at least four class groups)
Barnett[57] 1982	1	60 (58–62)	Two classes of 30 children moving freely between classrooms, but same pupil density as enclosed classroom
Finitzo-Hieber[76] 1981		66–73	Fully open plan, 100 students, 10 teachers
Yerges 1976	5	55 (54–71)	Fully open plan schools, "normal classroom activities"
Walsh[19]		47–62	Fully open plan high schools, carpeted absorbent ceiling
		54–67	Carpeted, reflective ceiling
Kyzar[32] 1971	4	61* (57–65)*	Fully open plan schools
Fitzroy and Reid[94] 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[83]

It can be seen that the levels measured during classroom activities in these studies are comparable with those measured in enclosed classrooms. Thus, despite the common perception that noise levels are higher in open plan than in enclosed classrooms, they appear to be very similar in the two cases.

Comparison of Noise Levels in Open Plan and Enclosed Classrooms

Four of the studies cited in Table 1 have made a direct comparison between noise levels in open plan and enclosed classrooms (Kyzar,[93] Barnett *et al,*[57] Finitzo-Hieber *et al,*[76] Mackenzie and Airey[85,92] and Fitzroy and Reid[94]). Of these, only the study by Finitzo-Hieber *et al,*[76] 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 necessarily typical of today's open plan designs. Barnett *et al,*[57] 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[32] and Fitzroy and Reid,[94] who found a difference of less than 2 dB between average results for open plan and enclosed classrooms.

Airey *et al,*[95] 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 in open plan classrooms due to increased use of acoustic absorption, in addition to anecdotal evidence that teachers in open plan classrooms spend more time and effort controlling pupils and "restricting lessons to quieter activities to avoid disturbing other classes"[95] The reduction in noise levels due to absorbent ceilings (3–5 dBA) is apparent from the data shown in Table 1 and is investigated further by Charlton-Smith[90] and Walsh.[19]

However, the standard deviation of the results of Barnett *et al,*[57] indicate that there was more fluctuation in open plan noise levels, attributed to the fact that pupils moved in and out of the open 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,[32] Fitzroy and Reid[94] and Yerges.[74]

Conversely, Airey *et al,*[95] 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 during normal lesson time is less likely to occur. This effect was observed in a recent case study[91] which showed 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 has been identified in several studies as being important to avoid distraction.[36,37,96] 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.[97]

Whilst observing that noise was a problem in open plan schools of the 1970s, Durlak and Lehman[98] 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 Heppell *et al*.[20] Bennett *et al,*[17] draw attention to Brunetti's argument[99] 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" [17]

Weinstein[30] 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 arising from activities in adjacent classbases.

Intrusive Noise Levels

The above discussion demonstrates that when children are engaged in classroom activities, the overall noise levels in open plan and enclosed classrooms are similar. Nevertheless, perceptions of higher noise levels, distraction and disturbance by noise in open plan classrooms are consistently reported.[6,16,32,34-37] Therefore, it is likely that it is the intrusive noise arising from activities in neighboring classbases, rather than the overall noise in the main classbase, which is critical in causing disturbance and distraction, and interfering with children's ability to hear their teacher in an open plan classroom.

Measurement of the intrusive noise level when the main classbase is occupied is 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. Therefore, the intrusive noise level is more commonly measured with the main classbase unoccupied.

Table 2 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 and Taylor's[34] survey had an acoustic ceiling installed. Although no specific description

Table 2: Surveys of measured intrusive noise levels in open plan classrooms

Reference	Number of classbases in unit	Average L_{Aeq} (range) dB	Comments
Weinstein[30]	5	60 (55–66) 47 (45–49)	Adjacent spaces active Adjacent classes quiet
Kingsbury and Taylor[34]	6	47–49	"Normal" activities

of the adjacent activity is given, Kingsbury and Taylor's data agree very closely with Weinstein's[30] data for when adjacent spaces were quiet. The data support the suggestion that when the main classbase is involved in active periods such as group work (around 70–77 dBA), the additional intrusive noise level from adjacent classbases (around 60 dBA from Table 1) 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; this emphasizes the need for careful coordination of activities by teachers in different classbases.

A more detailed survey of intrusive noise levels in open plan classrooms has recently been undertaken.[100] Noise measurements were carried out in 42 open plan classbases in 12 primary schools across southern England. These schools were selected following a survey of all local authorities in England, which identified 122 schools that feature open plan classrooms. The 12 schools surveyed were chosen to represent the full range of classroom sizes, layouts (from 2 to 14 classbases) and designs built between 1973 and 1997. All classrooms included in the survey were of semi-open plan or flexible open plan design as most of the fully open plan schools of the 1970s have had remedial works to modify the open plan design; hence fully open plan classrooms rarely feature in current UK building stock. The intrusive noise was measured with the main classbase unoccupied and with normal activities being carried out in adjacent classbases.

The intrusive noise level was measured using a hand held sound level meter (Larson Davis Type 824) 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). Short samples of 2 minutes duration were measured and averaged to give the level due to activity in adjacent classbases. This measurement period has been found to give a good indication of fluctuations of noise within a classroom and does not interfere with teaching or children's concentration.[82] The dominant activity occurring in adjacent classbases during each measurement sample was recorded.

The average $L_{Aeq,2min}$ levels for each activity are shown in Table 3.[6] It can be seen that the results are consistent with those measured by Weinstein.[30] The measured average level for "one person talking" falls within the range of Weinstein's[30] measured intrusive noise level data for a six classbase unit when adjacent spaces were "quiet" (45–49 dBA). Similarly, the measured data for activities involving movement fall within the range of Weinstein's data for "active" adjacent classbases (55–66 dBA).

Table 3: Average intrusive noise levels

Adjacent activity	Mean $L_{Aeq,2min}$ (dB)	*n*	σ (dB)
One person talking	47	140	4.8
Individual work at tables	54	316	5.4
Individual work with movement	57	83	4.4
Group work at tables	53	7	5.6
Group work with movement	62	15	6.7

Recommended Limits for Noise in Open Plan Classrooms

Criteria for background noise levels in open plan classrooms need to consider distraction and annoyance, speech intelligibility within the classbase and 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 have not taken into account the difference between overall background noise level (including main classbase activities) and intrusive noise level, or considered the role of classroom management and organization in controlling noise levels.

An occupied noise level between 50 and 70 dBA was recommended for classbases engaged in similar activity to avoid interference[37] and to avoid impairment of language development.[101] An alternative study recommended a maximum average noise level of 60 dBA.[97] Although not apparent from the article, it is assumed that this refers to an intrusive noise level, as clearly a maximum overall level of 60 dBA, would preclude all but the quietest classroom activities from being carried out in the main classbase.

Walsh[19] measured background noise levels in open plan schools and related these to teachers' subjective dissatisfaction levels. He concluded that to ensure a satisfactory level for teachers, the maximum acceptable background noise level in open plan classrooms should be between 55 and 65 dBA.

Walsh[19] also investigated the fluctuation of measured noise levels throughout the day and related percentile levels (L_{A10}, L_{A50} and L_{A90}) to teacher dissatisfaction in order to derive limits of acceptability. He defined three regions of acceptability: "acceptable" "marginal" and "unacceptable". The acceptable region corresponds to levels below 55 dB L_{A50}; the unacceptable region occurs at levels above 65 L_{A50}; while levels between 55 and 65 dB L_{A50} are marginal.

Acoustic Design Criteria for Speech Communication in Open Plan Classrooms

As discussed above, various researchers have attempted to define maximum acceptable noise levels for open plan classrooms. However, most classroom design criteria aim to provide adequate conditions for speaking and listening, and are thus usually expressed in terms of combinations of noise levels and reverberation times to provide good speech intelligibility. Alternatively, a single parameter such as the Speech Transmission Index (STI) or useful-to-detrimental speech ratio, U_{50}, both of which combine speech to noise ratio and reverberation time, is specified. In open plan classrooms, the issue of speech privacy also needs to be considered to control for intrusive noise from neighboring classbases.

The literature generally recommends providing at least 15 dB speech-to-noise ratio throughout the classroom (with reverberation time controlled to 0.5 seconds) to ensure that all participating listeners are able to receive the signal without degradation.[65,83,102,103] This is supported by the studies of Houtgast[102] and Bradley,[104] which showed that in 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 dBA, before reaching a plateau. However, Bradley and Sato[105] have recently demonstrated that 15 dBA is only suitable for the older (11-year old) primary school children and that the youngest classes require a speech-to-noise ratio of 20 dBA.

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 is 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 generally agrees a maximum occupied mid-frequency reverberation time of 0.4–0.5 seconds[65,103,104] for a speech-to-noise ratio of +15 dB. In their survey of elementary school classrooms, Sato and Bradley[88] conclude that 0.3 seconds is an optimum reverberation time for occupied classrooms, although near ideal conditions can be achieved over the range 0.2–0.5 seconds (assuming a teacher's voice level of 65 dBA at 1 m). However, using speech intelligibility tests of children aged 6–11 years, Yang and Bradley[106] found that the effect of varying reverberation is much less than the effect of varying speech-to-noise ratio.

In open plan design, control of reverberant noise from adjacent classbases is of critical importance. Petersen[107] recommends a maximum reverberation time of 0.3–0.4 seconds for open plan classrooms. This is consistent with the findings of Greenland *et al,*[6,108,109] that in order to control reverberant noise, the (furnished, unoccupied) reverberation time should be less than 0.4 seconds and the early decay time less than 0.35 seconds.

For open plan classrooms with dynamic learning activities and varying intrusive noise levels, it is more appropriate to use a design criterion such as STI which combines both speech-to-noise ratio and reverberation in a single parameter. Petersen[107] recommends STI $\geq$ 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.[105,108,109]

Only two studies, those of Petersen[107] and Greenland,[6] have considered a suitable criterion to provide sufficient speech privacy in open plan classrooms. Petersen[107] recommends a maximum criterion for speech privacy between classbases of STI $\leq$ 0.2, in order to avoid speech from adjacent classbases becoming intelligible and hence impacting on information processing. An attenuation of at least 15–20 dB between classbases is recommended to achieve this criterion, or 5–8 dB per doubling of distance.[110] Greenland,[6] however, found that a minimum attenuation of 23 dB between classbases is preferable to allow for high speech levels in neighboring classbases and the needs of vulnerable listeners such as children with hearing difficulties.

In recent years, many countries have introduced standards or guidelines on noise in schools. However, only those in Denmark,[111] Sweden[112] and the UK[91] contain criteria specifically for open plan classrooms [Table 4].

It can be seen from Table 4 that only the Danish and UK standards specify a criterion in terms of STI. It is worth noting that the US standard on classroom acoustics, ANSI 12.60,[113] actively discourages the use of open plan classrooms:
"*...open-plan classroom design should be strongly discouraged since the resulting background noise levels in a core learning space as a result of activities by students in other core learning spaces within an open classroom setting are highly likely to exceed the background noise limits. The poor acoustical performance of open-plan systems has a negative impact on the learning process and tends to defeat any teaching methodology advantages that may accrue from their use*". [113]

Noise Control Measures for Open Plan Classrooms

In order to achieve the recommended attenuation of noise from neighboring classbases, it is important to maximize the

Table 4: International standards/guidance for open plan classrooms/teaching areas

Country	Room type	RT (s)	Maximum ambient noise level L_{Aeq} (dB)	STI
Denmark[111]	Open plan classrooms	<0.3–0.4*	30	Within groups: >0.6 Between groups: <0.2
Sweden[112]	Open plan (landscaped) lecture space	0.4**	30 (building services) 30 (traffic)	
England and Wales[91]	Open plan classrooms	<0.8***	40 dB	> 0.6

*RTs in 500, 1000 and 2000 Hz bands for unoccupied, furnished spaces, **RTs in 500 and 1000 Hz bands for unoccupied spaces, ***RTs in 500, 1000 and 2000 Hz bands for unoccupied, unfurnished spaces

sound absorption of the ceiling and ensure that the height of the ceiling maintains sound absorption effectiveness. Petersen[107] recommends ceiling absorption of at least 90%, with a maximum ceiling height of 3.5 m. This is consistent with earlier studies of fully open plan classbases.[19,37,114] Several studies[85,89,100] have found that a fully sound absorbent ceiling is highly beneficial since it not only shortens reverberation time, thus increasing speech intelligibility, but also helps to control reverberant noise build up and noise transmission from adjacent spaces. It should be noted that the recommended sound attenuation cannot be achieved by means of absorptive surfaces alone. Kingsbury[81] measured around 4.5 dB per doubling of distance in a typically highly absorptive fully open plan classroom. Kyzar[32] measured 6–9 dB attenuation between teaching spaces in classrooms with only temporary or moveable divisions (cabinets, bookcases or other furniture). Similarly, Yerges[74] measured less than 10 dB attenuation between groups in fully open plan classrooms. Some form of partitioning (i.e., semi-open plan arrangement) is therefore necessary to achieve the recommended attenuation between classbases.

Greenland[6] also found that a distance of at least 6.5 m between classbase openings would minimize noise transmission between classbases to achieve adequate speech privacy. A buffer space such as an enclosed classroom or quiet room may be used to maximize spaces between openings and hence enhance speech privacy.

Arranging the classbases in a linear rather than square or cluster arrangement has been shown to achieve maximum attenuation.[6,90,115,116] Use of barriers with a height of at least 1.6[35]–2.0[97]m and a mass of at least 10 kg/m^2 has been recommended to cut off the line of sight between source and receiver. However, it was noted in one study that use of partitioning might actually encourage noise, with individuals behaving “as though they were in totally enclosed areas”.[117]

Carpeted flooring is recommended in most studies[19,37,118] but this is mainly to control footfalls and other impact noise (e.g., from furniture movement) rather than to absorb airborne sound.[19] A resilient floor covering or rubber stops on furniture legs are also recommended as alternative solutions.[107] Whilst curtains to classbase openings may be used to provide visual separation, they provide negligible acoustic attenuation.

Occupant density has been identified as a major factor in the control of distraction from noise, rather than the total amount of space provided or type of acoustic treatment or partitioning used in a space.[12,14,119,120] Walsh[19] demonstrated reductions in classroom noise level of 3–5 dBA due to the presence of an acoustically absorbent ceiling, whilst more significant reductions of 6–10 dBA were achieved following reductions in the number of students in the class, as would be expected. Walsh[19] 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. Greenland *et al,*[100] found that limiting the number of classbases in the unit (and hence number of children) to three or fewer significantly reduces noise levels.

Significantly more floor area is required for open plan classrooms than for enclosed classrooms, with 4–5m^2 per child recommended in the literature.[19,35,49] However, surveys of open plan classrooms built in the 1970s showed that the average floor area per child in UK schools reduced over the years to 3.0 m^2[17] while current UK guidance[121] recommends 2.1 m^2 basic teaching area per primary school child. It is interesting to note that 9m^2 floor area per child is provided in Hellerup School in Denmark[2]. However, noise transmission issues have still been experienced in this school and some remedial partitioning had to be retrofitted recently.[23]

Noise in the classroom may be controlled by approaches to classroom organization and management[122] as well as alterations to the physical environment and building fabric. For example, Crandell and Smaldino[123] recommended that children should be situated within approximately 6 feet (2 m) of the teacher to benefit from maximum speech intelligibility. 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 and Taylor[34] and Choudhury[97] recommended keeping all students within about 20 feet (7m) of their teacher. In a survey of enclosed primary classrooms,[124] 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%). A recent survey of teachers in open plan classrooms[6] found that they cope with intrusive noise by gathering the class around them (49%), changing the characteristic of their voice (43%) and coordinating teaching activities with colleagues in neighboring classbases (39%).

Conclusions

It is important that all teaching spaces are appropriate and inclusive learning environments. Studies of open plan classrooms over the past 40 years have shown that intrusive noise from adjacent classbases is a major problem, reducing speech intelligibility and privacy and causing distraction and dissatisfaction to both pupils and teachers. Measurements of noise levels have remained remarkably consistent over the years and show that noise control measures are required to minimize distraction and annoyance caused by noise, whilst ensuring adequate speech intelligibility and speech privacy. Effective techniques include installation of an absorbent ceiling at a height of 3.5 m or less, linear layout of classbases, partitioning between classbases to achieve sufficient distance between openings and sound attenuation between classbases (i.e., semi-open plan layout), limiting the number of classbases to three or fewer and providing sufficient floor space per child. Such physical measures, while reducing the likelihood of noise problems, allow open plan classrooms to become flexible learning environments, maintaining their advantages to provide for a range of activities. In addition, classroom management strategies may be employed to overcome potential problems caused by noise from neighboring classbases. Compliance with these physical and teaching approaches would minimize the detrimental impacts of noise on learning outcomes in open plan classrooms.

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