Case studies

SECTION 7

This section contains ten case studies which illustrate some of the principles of the acoustic design of schools described in previous sections, and give examples of solutions to problems of poor acoustics in schools.

The school is situated at a considerable distance from the main road running through a large village in a quiet residential area. In the early 1990s, it was extended by adding seven new classbases and a new multi-purpose hall. Activities in the hall include assemblies, singing, concerts and physical education. The hall is of particular interest because it required remedial measures not long after completion to alleviate acoustic problems that were being experienced by teaching staff.

The new hall is adjacent to playing fields and background noise levels around the school are low. Therefore there is little disturbance to occupants of the hall from external noise.

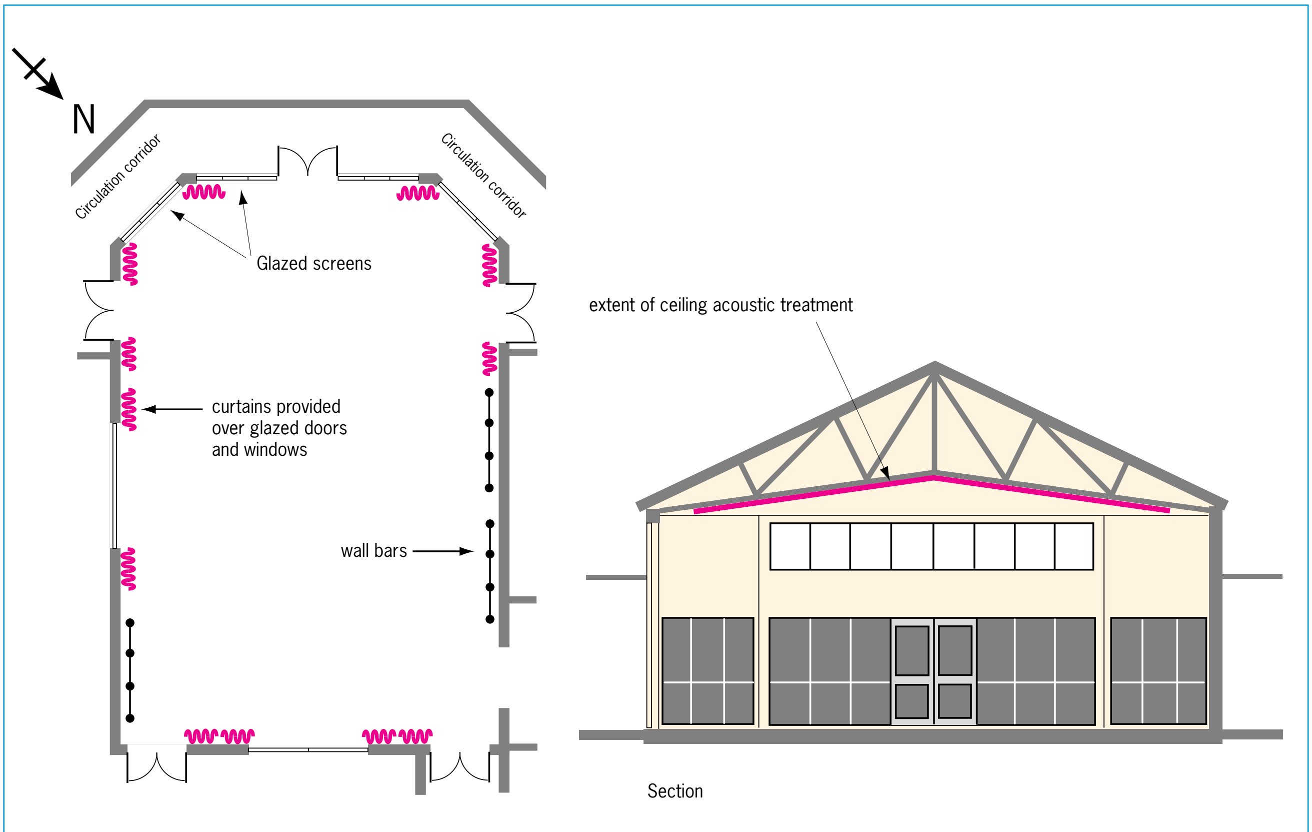
The hall is built of conventional masonry cavity walls comprising 100 mm facing brick outerleaf, 50 mm cavity, and 140 mm blockwork inner leaf with a plaster finish. A plan and section of the hall are shown in Figure 7.1.1.

The roof has a hipped form and is constructed of steel trusses with 100 mm by 50 mm softwood rafters at 600 mm centres. It is covered with slates on battens and felt. The shallow pitched ceiling is formed from tongue and groove timber boards (119 mm by 19 mm), overlain with 150 mm thermally insulating mineral wool batts. The roof void increases from a height of 200 mm at the eaves to 2 m at the ridge.

Large external windows with opening lights are located in the north east and south east walls with a row of smaller high level opening lights located in the external wall to the south west, above the circulation corridor. The circulation corridor connects the hall to the main building at ground floor level via glazed doors in a glazed screen. The corridor also provides a useful acoustic buffer between the hall and the nearby classrooms and offices. External windows and doors are all thermally double glazed. Internal doors and the glazed screen are of 6 mm glass.

Wall bars and similar apparatus are supported off the two long walls. The floor is of sprung timber strip to accommodate physical education, dancing, etc. The hall is naturally ventilated.

Figure 7.1.1: Plan and section of the new hall showing extent of remedial treatment



Case Study: Remedial work to a multi-purpose hall in a county primary school

The new hall suffered from:

- poor speech intelligibility, particularly with small groups of 30 or less
- distortion or colouration of speech
- unusually high background noise noise levels, eg from the shuffling of children's feet.

Teachers found that they could improve speech intelligibility slightly if they slowed down their normal rate of speech or addressed groups of pupils from a sidewall rather than near the centreline. In fact, speech from around the centreline of the hall appeared louder than normal and sounded coloured or distorted.

An acoustical assessment showed that speech was most distorted when both speaker and listener were near the centreline. Flutter echoes and enhanced reverberation were clearly evident and disturbing. When speaker and listener were both near a side wall the conditions were less severe although still poor.

The acoustical faults correlated well with the teachers' complaints. The majority of complaints stemmed from excessive reverberation, attributable to the predominantly hard surfaces in the hall. Both floor and ceiling were hard and acoustically reflective. Excessive reverberation caused consecutive syllables in speech to run into one another, reducing intelligibility.

This problem was compounded by the shape of the ceiling. It has a shallow pitch with hipped ends, similar to an inverted concave dish. Sound focused by the hard reflective ceiling onto the hard floor below and the resulting multiple reflections were detected as a longer reverberation time (RT) near the centreline. This effect caused sounds to appear louder than normal and coloured or distorted.

To rectify these faults, it was proposed that the ceiling should be made acoustically absorbent. This would reduce the RT to a level suitable for primary school uses and reduce the focusing effect.

Although it provided a solution in this case, it is not normally advisable for ceilings to be sound absorbing in rooms where good speech intelligibility is a requirement. If the size, shape and geometry of the space are right in the first place, then the ceiling should be reflective to sound. The reason for the success of the ceiling treatment in this case was the overriding need to make a substantial reduction in RT and the fact that the floor has a timber finish, which provides a useful reflection path in the absence of a comparable reflection from the ceiling.

The school wanted to retain the timber ceiling. Therefore the timber boards were taken down and a series of 20 mm by 200 mm slots were cut into them (see Figure 7.1.2) to give an open area of approximately 25%. A mineral fibre acoustic quilt, 25 mm thick, was laid directly over the slots in the ceiling void. The quilt was faced with an acoustically transparent black scrim on the hall side for aesthetic reasons. The existing layer of thermal insulation was replaced over the acoustic quilt. Figure 7.1.1 indicates the area of the ceiling that was treated. The acoustic treatment to the timber ceiling is considered to be in keeping with the appearance of the hall (see photograph, Figure 7.1.3).

In addition to the ceiling treatment, acoustically diffusing panels were recommended for the walls to distribute sound evenly around the hall and prevent flutter echoes. An example of a diffusing panel is shown in Figure 7.1.4. However, these panels were omitted due to lack of funds. As a result of this omission and the presence of an acoustically absorbent ceiling, there is a tendency for sound to

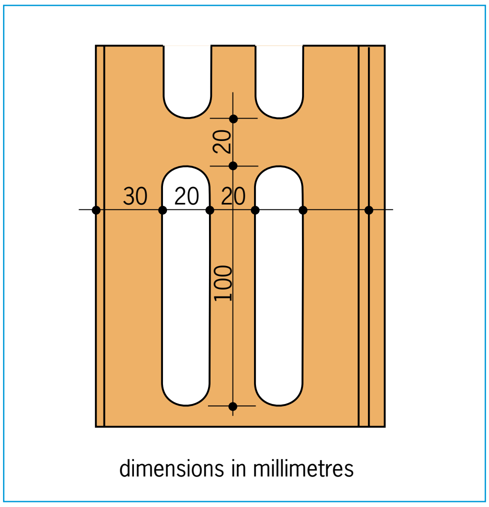


Figure 7.1.2: Detail of timber slats used to line the hall ceiling

Figure 7.1.3: The hall ceiling after acoustic treatment

reverberate around the hall in a horizontal plane, particularly when occupancy is high and the floor is obscured. Under certain conditions, this manifests itself as distracting flutter echoes between the hard parallel side walls. One teacher reported this effect as a disturbing 'ringing' noise whilst rehearsing music and dance with a small group of children at the south west side of the hall.

Following implementation of remedial acoustic treatment to the ceiling, the response from the teachers to the modified acoustics of the hall was very favourable and all reported a very noticeable improvement.

Speech intelligibility was found to be much improved when addressing both small and large groups of children, and noise from physical activities and children shuffling feet during assembly has been reduced to acceptable levels. Communication during physical education and similar noisy activities is easier, and accompanied by lower levels of background noise.

The reverberation time was measured in the same positions before and after the remedial work. Two sets of measurements were made; one with the source and receiver on the centreline of the hall and the other with the receiver positioned 2 m from a side wall. Measurements were made while the space was unoccupied. Curtains were pulled back to their normal bunched positions either side of internal and external doors and windows. This

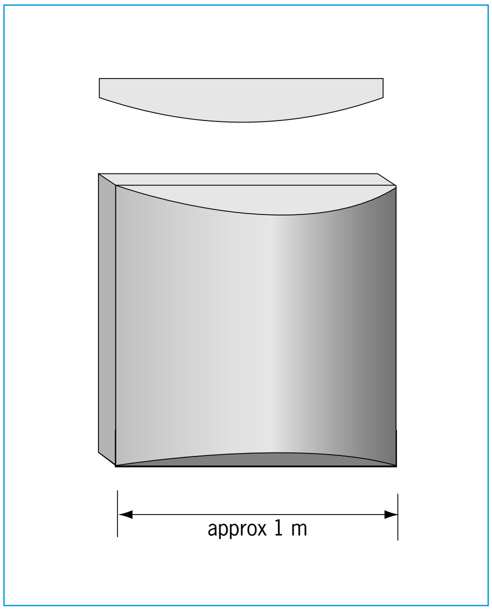


Figure 7.1.4: Example of acoustically diffusing panel

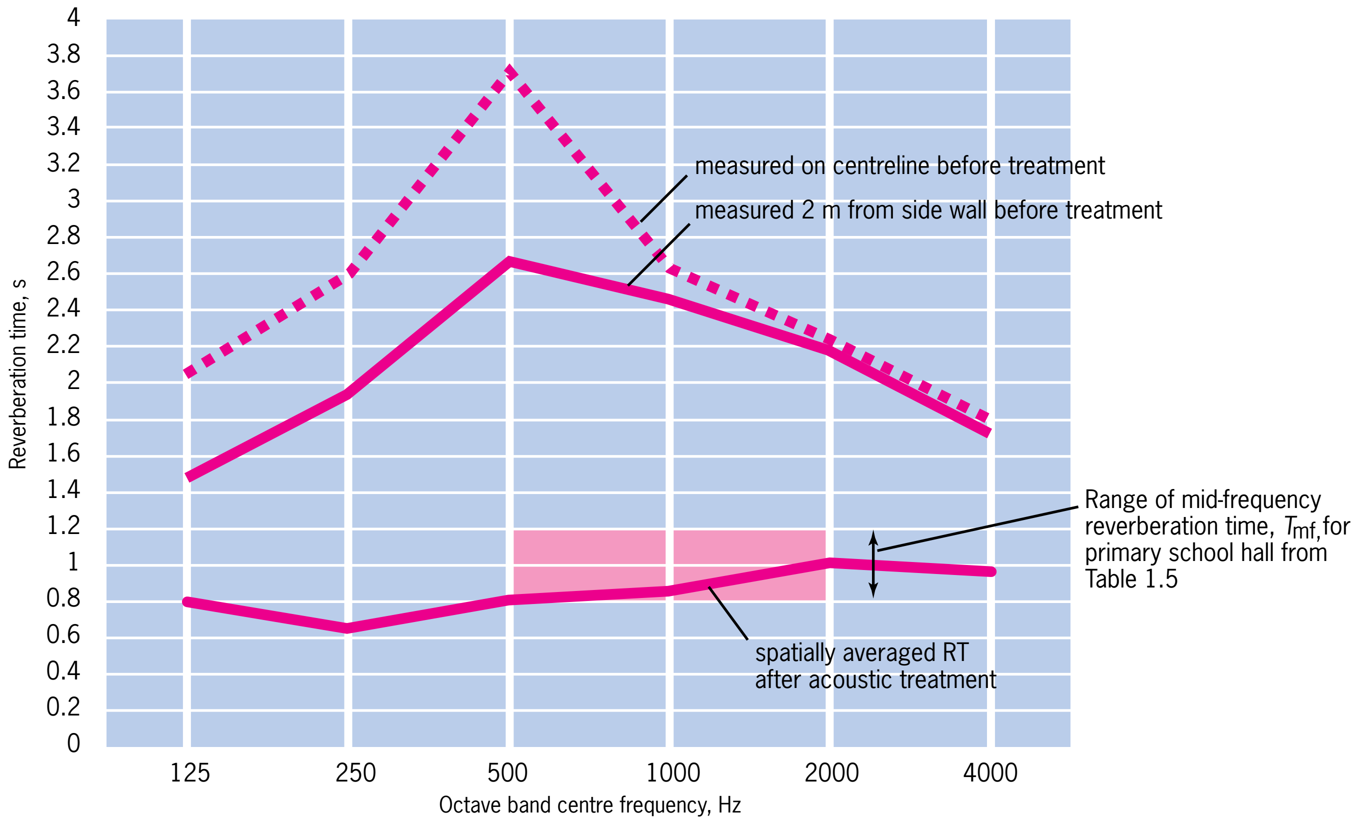


Figure 7.1.5: Measured reverberation time in the new hall before and after implementation of acoustic measures

arrangement was considered to produce the most reverberant condition likely to be encountered during every day small group activities.

Before remedial work, the measured T_{mf} was 2.8 seconds on the centreline but fell to 2.5 seconds along the side of the hall. Figure 7.1.5 shows the measured RT curves as a function of frequency. The T_{mf} after treatment is generally within the range for a primary school hall, which should be between 0.8 and 1.2 seconds.

Concerts and musical activities take place in less reverberant conditions than before, with substantial reductions in colourations and distortions. These conditions have been found to be satisfactory. The introduction of acoustic absorption into the ceiling of the new hall has been successful in providing acoustic conditions which are suited to primary school uses.

It is clear from this study that the acoustics of a hall are of fundamental importance in the effective functioning of this key space in a primary school. In many halls, hard wall and floor finishes will be necessary and the required acoustic absorption will need to be accommodated in the ceiling. Ideally, absorbent and reflective surfaces should be more or less evenly distributed on both walls and ceiling. This case study, where modification of the existing ceiling was complicated and costly, highlights the importance of considering the acoustic requirements at the design stage.

An investigation of the acoustic conditions in three recently built open plan primary schools was carried out. Sound insulation between classrooms and reverberation times and sound levels in unoccupied classrooms were measured.

The effect of noise from adjacent areas on speech intelligibility within the learning bases was assessed. The Speech Transmission Index (STI) was measured in the classrooms using Maximum Length Sequence (MLS) analysis equipment as described in BS EN 60268-16. In each case an artificial mouth, positioned where the teacher usually stood during lessons, was used to produce a reference signal which was received by a microphone at different positions within the room. Speech intelligibility was rated using the measured STI values.

7.2.1 School 1 (pupils aged 5 -11 years)

The layout of the school is shown in Figure 7.2.1(a). The walls are full height between the classrooms and the corridors, with teaching areas accessed via open arches from the corridors The two teaching areas on each side of the corridors are open plan, being separated only by a quiet/IT area. Measurements were conducted in the Yellow and Green team areas indicated. The layout of the Green team area with measurement positions is shown in Figure 7.2.1(b).

Measurement results

The measured classroom mid frequency reverberation times (T_{mf}) are shown in Table 7.2.1.

The sound level ($L_{Aeq,10min}$) was measured in classroom Y1 when occupied during a typical interactive science lesson, and when unoccupied after the school day had finished. The sound level was also measured in the unoccupied Yellow team (Team 4) practical area indicated in Figure 7.2.1. The measured sound levels are shown in Table 7.2.2.

It should be noted that although the level in classroom Y1 was measured after the children had left the school, the corridor adjacent to the room was still occasionally used by those involved in after school activities. The sound level in the unoccupied practical area was measured with lessons being conducted in all the adjacent teaching rooms.

As the school was in use, 10 minutes was the longest practical time period for the measurements of indoor noise levels.

The speech transmission index (STI) was measured at 5 positions in the unoccupied room G3 with and without masking noise being generated in rooms G1 and G2. The position of the artificial mouth and the 5 microphone positions are shown in Figure 7.2.1. The masking noise had the same level as was measured during the science lesson in classroom Y1 and was shaped to give similar levels, in the third octave frequency bands between 50 Hz and 5 kHz, as those measured.

Table 7.2.1: Classroom mid-frequency reverberation times

Room	Mid-frequency reverberation time (s)
Y1	0.4
G1	0.4
G2	0.4

Table 7.2.2: Sound levels in Yellow team area

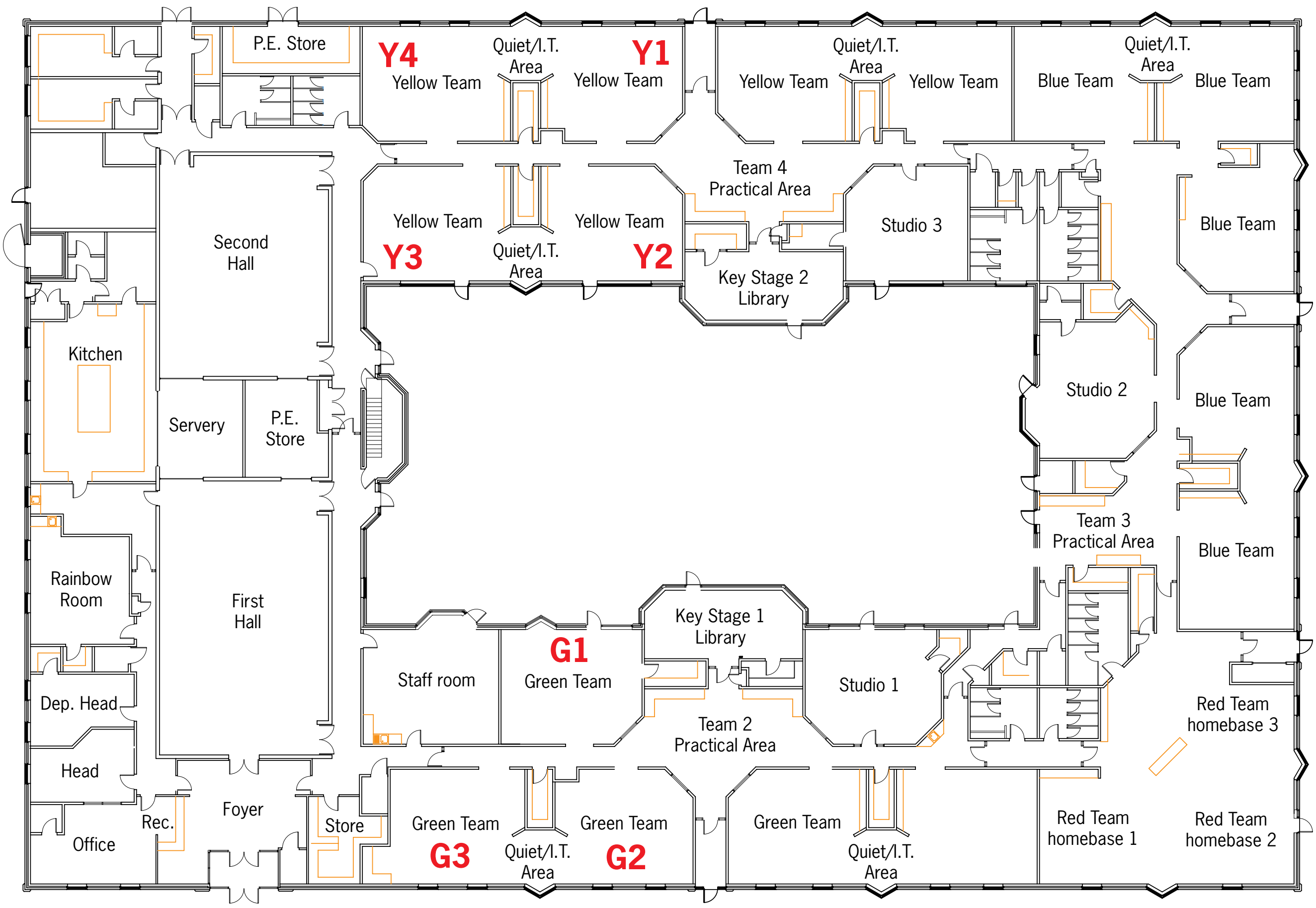
	Classroom Y1 occupied	Classroom Y1 unoccupied	Practical area unoccupied
$L_{Aeq,10min}$ (dB)	62.7	42.4	54.2

Table 7.2.3: Average STI values in unoccupied room G3 with and without masking sound in rooms G1 and G2

Microphone position	No masking		Mask in room G1		Mask in room G2	
	STI	Rating	STI	Rating	STI	Rating
1	0.803	Excellent			0.639	Good
2	0.673	Good	0.654	Good	0.642	Good
3	0.761	Excellent	0.691	Good	0.426	Poor
4	0.739	Good			0.550	Fair
5	0.745	Good			0.555	Fair

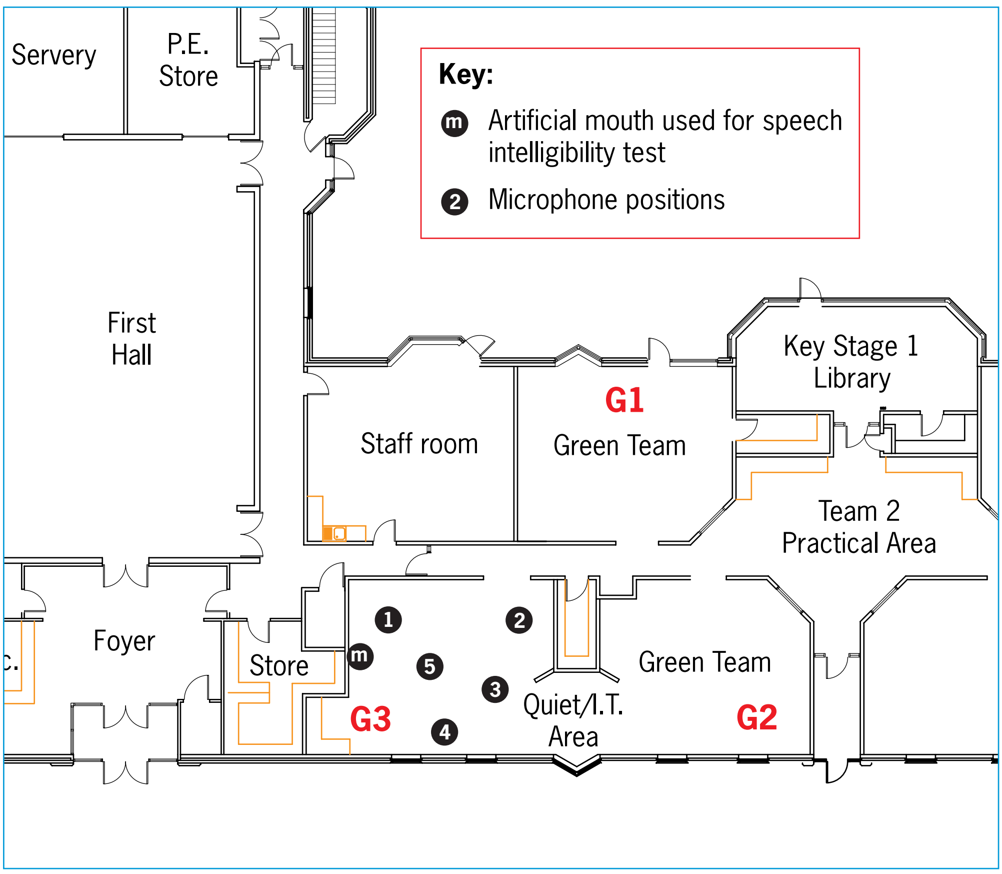
Table 7.2.4: Measured sound insulation between classrooms

Rooms	$D_{nT(0.8s),w}$ (dB)
Y1 to Y4	16
G1 to G2	19
G1 to G3	24
G2 to G3	14



(a)

Figure 7.2.1:
School 1 layout
(a) Whole school
(b) Green Team test area



(b)

The STI measurement results are shown in Table 7.2.3.

The results of sound insulation measurements between classrooms are shown in Table 7.2.4.

Discussion

This school was selected for investigation primarily because it had been reported that the school's open-plan design worked well. The head gave the impression that he strongly favoured the open-plan layout and stated that he had been closely involved with the design process of the new school. However, other members of staff were less enthusiastic.

A team leader in the school stated that the open-plan design suited the teaching practices in the school although it had taken some time to get used to at first. Other teachers were forthright in their disapproval of the school's design and the restrictions that it imposed.

Of the teachers whose opinions were canvassed, the majority stated that they felt the open-plan design led to problems associated with disturbance. Timetabling was organised so that the activities in adjacent teaching areas produced similar levels of noise in order to avoid disturbance to pupils involved in quiet activities.

According to the teachers consulted, usually the arrangement was acceptable but problems could be caused if a teacher unfamiliar to the pupils was taking a class in an adjacent area. In such circumstances the usual strict enforcement of discipline on the children could be subverted leading to disturbance in adjacent areas.

The measured levels in the unoccupied Yellow team practical area and classroom Y1 were greater than those specified in Section 1. In the practical area, it can be assumed that the measured level was affected by sound from adjacent occupied classrooms. For example, it was noted that during measurements in the unoccupied practical area one of the teachers constantly reminded the children to work quietly by uttering the command "Shh" at regular intervals. At a different time, a teacher in classroom Y4 raised her voice sufficiently for her words to be heard clearly in classroom Y1. This was a result of her feeling the need to admonish a pupil for holding a conversation from the open corridor with one of her class members.

The behaviour of the teachers and pupils did not appear to be unusual and the strong impression was given that the day of the investigation was a typical school day.

The measurements of the Speech Transmission Index (STI) showed that speech intelligibility was reduced considerably during an interactive science lesson in classroom Y1. This was due to the increased sound level ($L_{Aeq,10min}$) during the lesson.

The mid-frequency reverberation time in each of the classrooms was 0.4 seconds, which is acceptable for classrooms for hearing impaired pupils. Because of this, in the absence of children and teachers, the measured STI rating varied between good and excellent in unoccupied classroom G3. However, when masking noise was generated in room G2, the STI rating was reduced to poor and fair in positions 3, 4 and 5. This suggests that, when the teacher is speaking to the class from the usual position, pupils sitting closest to room G2 are likely to experience more difficulty understanding the teacher's words than other pupils in the classroom due to noise emanating from room G2. The measurement of STI showed that noise generated in G1 had no significant measurable effect on speech intelligibility in room G3. This is likely to be due to the stagger between the entrances to rooms G1 and G2 on opposite sides of the corridor.

It should be noted that STI is an objective measurement of speech intelligibility, and cannot quantify disturbance to pupils. Disturbance may depend, for example, on whether pupils perceive sound generated in adjacent areas to be interesting or threatening.

7.2 Case Study: An investigation into the acoustic conditions in three open-plan primary schools

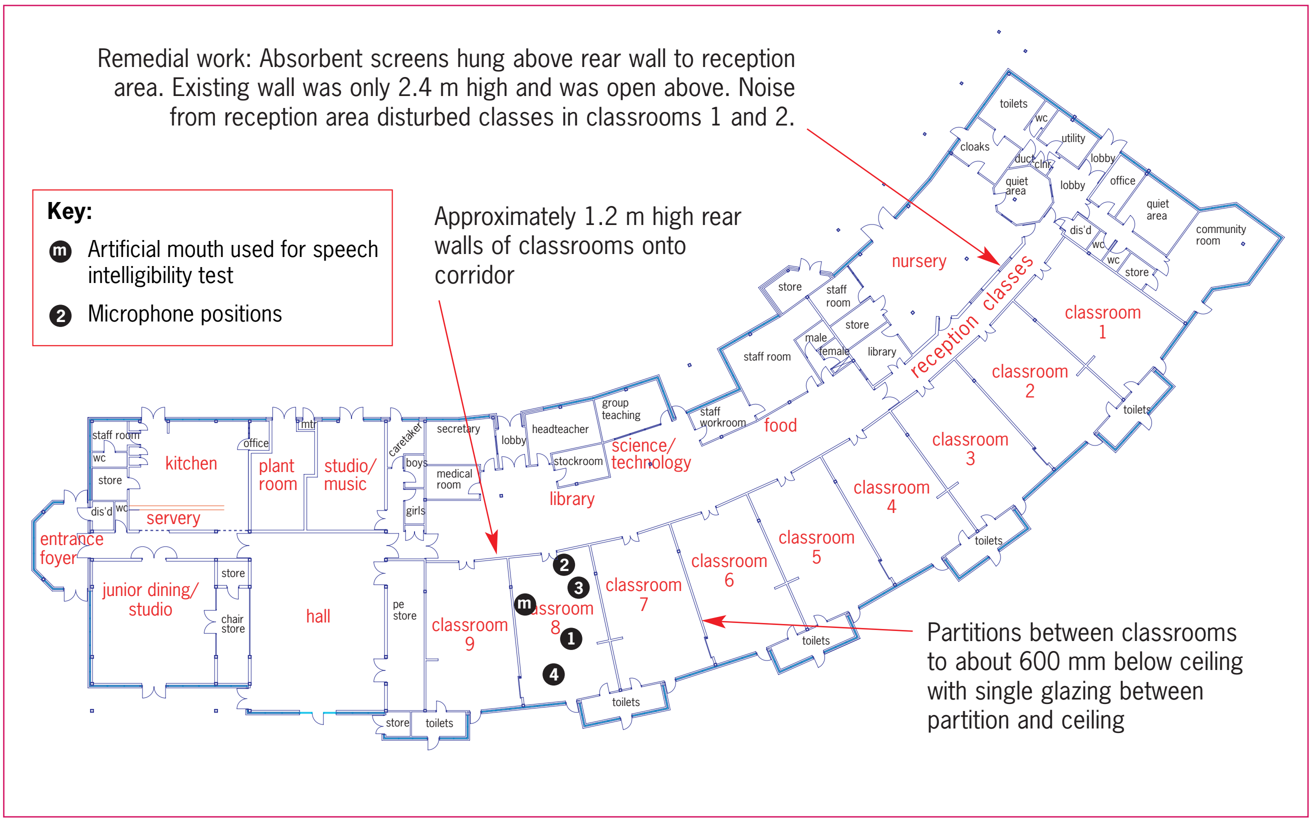


Figure 7.2.2: School 2 layout

7.2.2 School 2 (pupils aged 3 -7 years)

The school layout is shown in Figure 7.2.2. Classrooms 1 to 3 are for reception classes and no measurements were conducted in this area, where some remedial work had been carried out. Originally, the nursery wall onto the corridor was only 2.4 m high with a gap above. However, the disturbance to classrooms 1, 2 and 3 from the high noise levels resulting from normal nursery activities necessitated the closing off of the nursery area using full height acoustic panels above the existing nursery wall.

The walls separating the classrooms from the corridor area are approximately 1.2 m high. Some common resource areas, eg the library and the science/technology area, are located in the corridor space. It is possible to see over the low wall into the corridor and directly from one classroom to another in the vicinity of these walls. Although the height of the walls between classrooms increases towards the external wall of a classroom, at no point is there a continuous barrier from the floor to the ceiling between the classrooms. The gap above the partition wall provides a clear sound path, see Figure 7.2.3, and could with forethought have been easily closed off. However, it is doubtful if this would have made a big difference to the sound transmission given the low walls onto the corridor.

Figure 7.2.3: Partition wall between classrooms. Note the large gap (>300 mm) above the glazed head of the partition.

Measurement results

Measurements were conducted in rooms 4 to 9.

Because the classrooms were identical in appearance, the mid-frequency reverberation time was measured only in unoccupied classroom 8, and was 0.5 seconds.

STI was measured in classroom 8.

First, measurements were conducted at the positions indicated in Figure 7.2.2, without any masking noise in adjacent areas. After this, white noise was generated as masking sound in room 9 to represent noise from an occupied classroom and STI was measured in positions 3 and 4 in room 8. Masking levels of 60 dB(A) and 70 dB(A) were used. White noise was used as masking sound because no pupils were in the school during the measurements. Therefore, a typical classroom sound spectrum could not be recorded and used as the masking signal. The artificial mouth was positioned 1m in front of the white board on the wall between rooms 8 and 9. as shown in Figure 7.2.2.

The average STI values measured are shown in Table 7.2.5.

Table 7.2.6 shows the measured airborne sound insulation between classrooms in terms of the weighted BB93 standardized level difference ($D_{nT(0.8s),w}$). Table 7.2.7 shows the measured sound levels in the classrooms with a sound source in classroom 9.

Discussion

Brief discussions were held with the head of the school and a few other teachers before and after measurements began. The head stated that she liked the open plan design since it meant that pupils were accustomed to seeing her and she could enter classrooms without causing undue disturbance.

When the school was first used, problems with high noise levels had been experienced in the reception class area but these were alleviated by the addition of acoustically absorbent panels on the wall opposite the classrooms. No other adverse comments about the acoustics in the school were made by any of the teachers interviewed although one teacher did describe an unusual situation caused by the lack of acoustic isolation between classrooms.

The same story was being read to pupils in adjacent classrooms at the same time. The teacher said that she became aware that her colleague in the adjacent classroom was one or two words ahead of her in the story. She described the situation as being "like hearing an echo" and attempted to speed up her reading in order to synchronise the delivery to both classes.

The design of the school means that acoustic isolation between classrooms and the area outside the classrooms would be expected to be low. The results of the measurements taken bear this out. 13 dB $D_{nT(0.6s),w}$ between classrooms 7 and 8 is a very low level of sound insulation. Indeed, 28 dB $D_{nT(0.6s),w}$ between classroom 9 and classroom 4 (which are

Microphone position	Masking level (dB(A))	STI	Rating
1		0.656	Good
2		0.616	Good
3		0.640	Good
4		0.588	Fair
3	60	0.459	Fair
3	70	0.263	Bad
4	60	0.541	Fair
4	70	0.430	Poor

Table 7.2.5: Average STI values in classroom 8 with and without different levels of masking noise in classroom 9

Rooms	$D_{nT(0.8s),w}$ (dB)
7 and 8	13
9 and 4	28

Table 7.2.6: Measured sound insulation between classrooms

Table 7.2.7: Sound levels in classrooms 4, 5, 6, 7, 8 and 9 with sound source in classroom 9

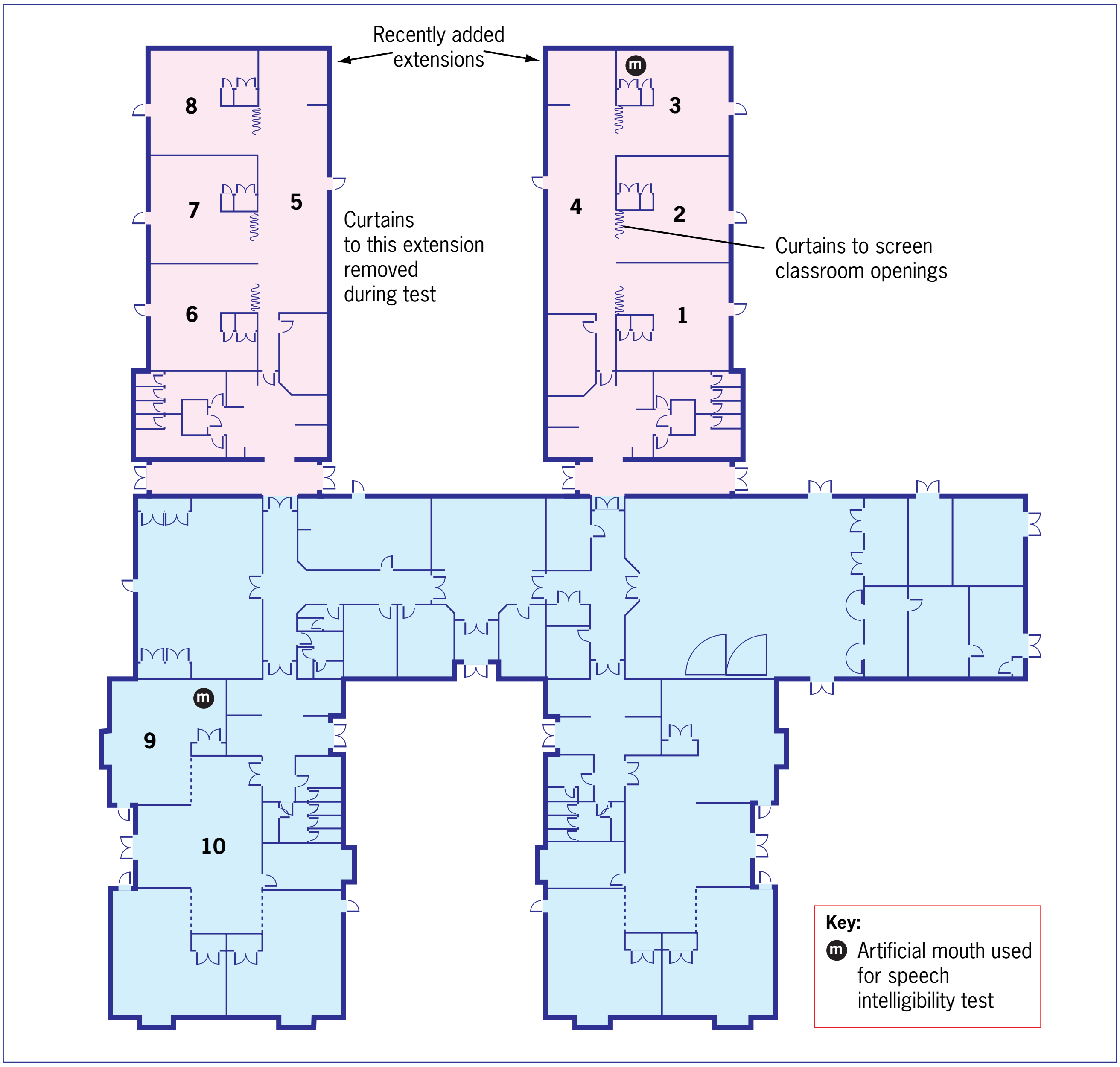
Classroom	4	5	6	7	8	9
$L_{Aeq,2min}$ (dB)	68.2	69.5	72.8	75.8	81.4	96.1

not adjacent, see Figure 7.2.2) is significantly lower than the 45 dB between adjacent classrooms required in Table 1.2 of Section 1.

Comparison of STI values in a classroom with and without masking noise generated in an adjacent classroom demonstrates that there is a significant reduction in speech intelligibility due to the masking noise

The data in Table 7.2.5 show that the STI values and, consequently, speech intelligibility were reduced in the two positions used for the measurements when masking noise was generated in the adjacent classroom and when the level of the noise was increased. Position 4 was better screened from classroom 9 than position 3 where there was an almost uninterrupted path between the two rooms owing to the lower dividing partition at this point. The measurements show that speech intelligibility in position 3 is reduced by masking noise generated in room 9. The masking noise had less effect on STI in position 4 than in position 3. However, position 4 had the lowest STI value of the four measurement positions. This is largely due to the artificial mouth being directed into the classroom perpendicularly from the wall. Directing the artificial mouth towards position 4 would have increased the STI value at this position. Thus, unless the

Figure 7.2.4: School 3 layout showing recently added extensions



teacher is looking directly at a child at this position, the speed intelligibility will only be 'fair'.

Since the mid-frequency reverberation time measured in two of the classrooms was 0.5 seconds problems with speech intelligibility can be attributed to high ambient noise levels in the classrooms. Because the sound insulation between the rooms is so low, it is likely that noise generated in adjacent areas will contribute to the overall sound levels in the rooms.

7.2.3 School 3 (pupils aged 4 -8 years)

This is a recently built school which has been extended. The extensions accommodating rooms 1 to 8 are shown in Figure 7.2.4. Measurements were conducted in the original school building with children present and in the extensions both with and without the children present.

Measurement results

Table 7.2.8 shows mid frequency reverberation times measured in the classrooms. Tables 7.2.9 and 7.2.10 show measured sound levels in occupied and unoccupied classrooms respectively.

The results from the measurements in Schools 1 and 2 demonstrate that STI values are reduced by noise from adjacent areas and that those positions closest to the noise are likely to be most affected. Therefore, STI was measured in only one position in two classrooms. In room 3, STI was measured with the curtains between rooms 3 and 4 open and closed. All measurements were conducted with the artificial mouth positioned where the teacher would usually stand, see Figure 7.2.4, and the receiving microphone was positioned 3 m in front of the artificial mouth. The results are shown in Table 7.2.11.

Discussion

The head in this school was strongly in favour of the open plan design of the school for the following reasons:

- she felt that the staff worked better as a team
- she felt that the children worked better as a group
- she felt that open-plan design allowed more flexibility
- she felt that organising pupils in common teaching areas was "more natural", especially for those joining the reception class.

However, prior to this investigation, the head had contacted her local education authority due to problems encountered in the extensions to the school containing rooms 1 to 4 and 5 to 8. Here, difficulties had been encountered which resulted in 'acoustic curtains' being fitted to separate the classrooms from the communal areas 4 and 5. When the measurements were made, the curtains were temporarily removed from rooms 6 to 8.

The measurement results given in Table 7.2.8 show that the reverberation time in the original building is shorter than in the two extensions. They also show that the reverberation times in the rooms with curtains (rooms 3 and 4) are lower than those in rooms without curtains (rooms 5

Room	Mid-frequency reverberation time (s)
9	0.4
6	0.7
5	0.9
3	0.6
4	0.6

Table 7.2.8: Classroom mid-frequency reverberation times

Room	Lesson type	$L_{Aeq,3min}$ (dB)
5	Project work	74.9
6	Literacy	69.7
4	Project work	69.3
3	Numeracy	69.8
10	Project work	66.2
9	Room empty	56.2

Table 7.2.9: Sound levels in occupied classrooms

Room	$L_{Aeq,3min}$ (dB)
5	35.4
4	32.8
3	31.8

Table 7.2.10: Sound levels in unoccupied classrooms

Table 7.2.11: Average STI values in unoccupied classrooms. Note: adjacent rooms were occupied during the measurements in Room 9.

Room	STI	Rating
9	0.570	Fair
3 (curtains open)	0.689	Good
3 (curtains closed)	0.693	Good

and 6), which exceed the values specified in Table1.5. These results suggest that the acoustic problems experienced by staff in the extensions to the original building can largely be attributed to the lack of sound absorption and the consequent relatively long reverberation times in these areas compared with the original school building. The original building had acoustically absorbent ceilings whereas the extension did not.

The results from the measurement of STI show that in unoccupied classroom 3 speech intelligibility was good with the curtains both closed and open. In room 9, the speech intelligibility rating was fair. Since the reverberation time in room 9 is 0.5 seconds, this lower rating can be attributed to noise generated by children in the adjacent areas at the time of the measurements.

The results shown in Table 7.2.12 show that the curtains reduce the sound transmission between classrooms, in addition to reducing reverberation times, although none of the sound insulation values measured meets the specification of 45 dB in Table 1.2 of Section 1.

Table 7.2.9 shows the sound levels recorded in different rooms whilst lessons were taking place. Pupils were engaged in project work in room 4 while in rooms 3 and 6, more formal literacy and numeracy lessons were being conducted.

Project work meant that the children were working in small groups and noise levels generated by their interaction during these activities were higher than would be expected in a formal lesson. For example, in the numeracy lesson in room 3, the teacher sat in one corner of the classroom with the children seated close to her. In this lesson the teacher spoke and the children responded when it was appropriate.

The level in room 5 was approximately 5 dB higher than the level measured during the literacy lesson in room 6. This part of the extension did not have curtains fitted between the rooms at the time of this investigation. In the other extension, where curtains were fitted, the levels measured in room 4 (project work) and room 3 (numeracy lesson) were virtually the same. The curtains between rooms 3 and 4 were drawn so that only a gap of around 300 mm remained between the curtain and the wall separating room 3 from 4.

A teacher in the school volunteered comments on teaching conditions in rooms 1 to 4. She said that she found it difficult to hear some softly spoken pupils due to the high noise levels in the classroom and that parents would inform her if and when their child had difficulty hearing what was being said in lessons.

The teacher was of the opinion that room 2 was worse to teach in than rooms 1 and 3 because of the low sound insulation of the walls separating the rooms and the consequent noise transmission from rooms 1 and 3. Unprompted she described the difficulties experienced when reading the same story to her class as the teacher in the adjacent room but being a sentence or two behind or in front of her colleague next door.

The teacher felt that the curtains had improved conditions in the classrooms. Cupboards had also been placed in the openings between rooms 1, 2, 3 and 4 in an attempt to improve sound insulation between the different teaching areas. In her opinion, the cupboards had been useful for this purpose.

Table 7.2.12: Measured sound insulation between classrooms

Rooms	Curtains	$D_{nT(0.6s),w}$ (dB)
3 to 4	open	10 dB
3 to 4	closed	15 dB
3 to 2	open	21 dB
3 to 2	closed	28 dB

7.2.4 Summary

In all the schools visited, the head teachers appeared to approve of the open plan design in their school. Some teachers shared their head's enthusiasm for the design but others felt that problems caused by the transmission of sound between rooms were significant.

The measurement of STI in the schools demonstrated that speech intelligibility is reduced by noise generated in adjacent rooms. In all the open-plan schools, high ambient noise level was the most significant cause of low speech intelligibility.

From the few opinions canvassed in the schools it would appear that there are benefits to adopting an open-plan design. These appear to be that the design is favourable for team working, that it engenders a feeling of inclusion in the school and that it allows for a visually attractive environment. However, placing cupboards in spaces between rooms in order to increase isolation between them may detract from the original open-plan design.

From the results of this survey, it is difficult to justify the use of open-plan schools in terms of their acoustic environment. None of the schools met the requirements for sound insulation between classrooms contained in Building Bulletin 93. Although reverberation in classrooms was well controlled (apart from in the extension in School 3), ambient sound levels during teaching periods were too high for the measured STI values to indicate good speech intelligibility. As a consequence of the levels in the classrooms, both teachers and pupils would need to speak more loudly in order to be clearly understood.

In many open plan teaching spaces it is difficult to achieve clear communication of speech between teacher and students.

For this reason, careful consideration should be given as to whether to include open-plan teaching spaces in a school. If open-plan areas are required then rigorous acoustic design is necessary to satisfy the performance standards in Section 1.

The primary school in Case Study 7.1 extended its facilities in the early 1990s by adding seven new classbases and a multi-purpose hall to the existing school. The new classbases were arranged in two open-plan areas, of three and four classbases respectively.

The teaching area with four classbases, numbered 4 to 7 in Figure 7.3.1, is an interesting example of the limitations of an open-plan environment. Acoustic problems were experienced by the teaching staff which subsequently led to the implementation of remedial measures. Visits were made to the school before and after the remedial work.

The new extension to the school is of conventional masonry cavity walls, comprising 100 mm facing brick outerleaf, 50 mm cavity and 140 mm blockwork inner leaf with a plaster finish.

The roof over the teaching area is made up of a combination of pitched sections with a tiled exterior and flat roof constructions with a felt finish. Each pair of adjacent classbases has a roof light located in a flat roof section. Windows are thermally double glazed and openable.

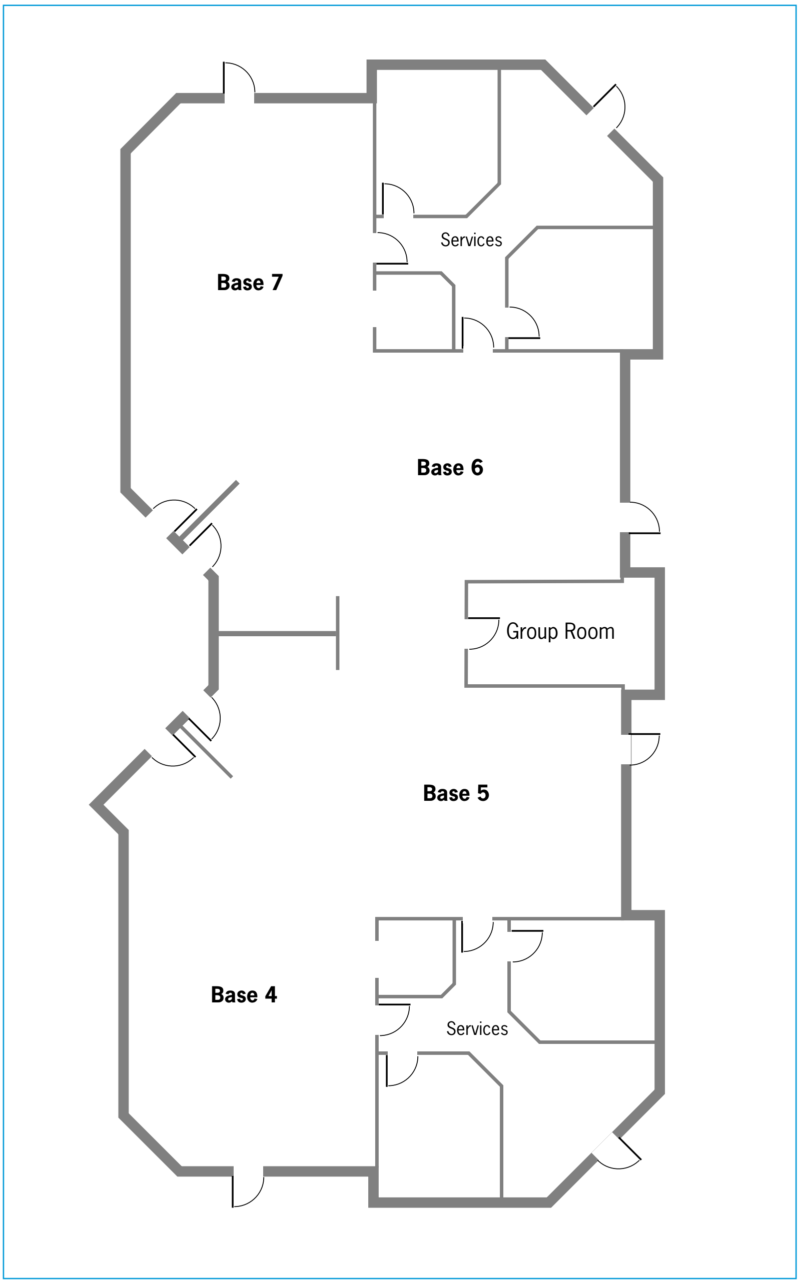
Internal walls are generally constructed of either 100 mm or 140 mm lightweight blockwork. Surface finishes are generally hard and reflective except for the floor which is covered in a short pile carpet. The walls are plastered and have an emulsion paint finish. The ceiling in the open-plan teaching areas is constructed of 12.5 mm plasterboard with a painted skim finish.

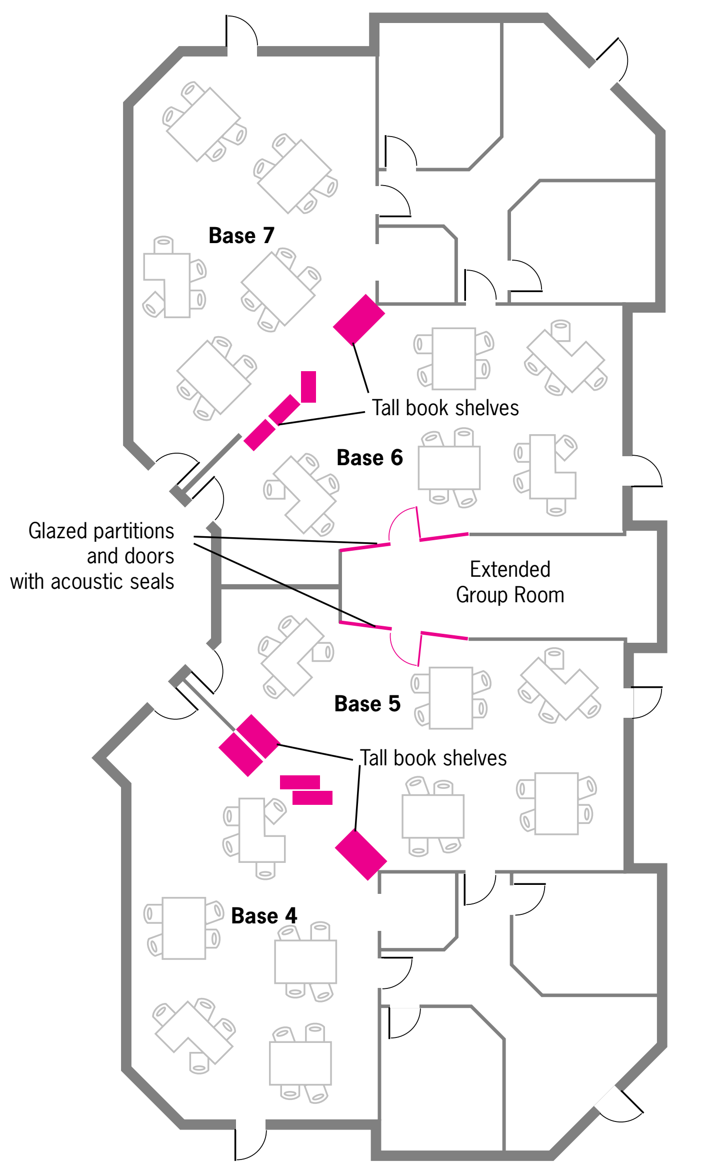
The general features to note about the layout of the open-plan teaching areas are:

- All four teaching spaces are incorporated in an open-plan arrangement.
- The physical separation between classbases 4 and 5, and between classbases 6 and 7 is minimal which implies negligible acoustic separation. A small improvement in acoustic separation may be gained by strategic positioning of tall items of furniture, eg bookcases, between adjacent classbases.
- The physical separation between classbases 5 and 6 is only partial and is formed by the projection of the group room on one side and book shelving on the other.
- The teaching spaces are separated from potentially noise producing and noise sensitive spaces, eg other classrooms and the main hall, by a corridor. This arrangement is advantageous for reducing noise disturbance to or from other parts of the school.
- Toilets and services provided in the corner of each pair of bases are buffered from the teaching spaces by lobbied doors.

Teaching staff perceived the open-plan teaching area to be difficult to work in because of poor acoustics. They had two

Figure 7.3.1: Plan of open-plan teaching spaces before modifications





(a)


(b)

Figure 7.3.2: Arrangement of open-plan teaching spaces following modifications
(a) floor plan
(b) new glazed partition extending the group room

main complaints. Firstly, when teaching in a classbase, they could clearly hear teaching activities in other classbases, even the most distant ones, and they found this very disturbing and disruptive. Some teachers perceived this as a 'funnelling' of sound from one end of the open-plan teaching area to the other. Conditions were worst during normal table activities when a comparatively active and excited class returned to an adjacent classbase from a PE lesson.

Secondly, noise levels within a classbase during teaching activities were excessively high and adversely affected concentration and working ability.

Remedial measures were designed to improve the acoustic separation between classbases in order to reduce difficulties arising from mutual disturbance, and to reduce the build-up of noise levels during classroom activities to promote an improved teaching environment.

The acoustic separation between classbases was increased by installing a full height double-leaf glazed partition between the group room and bookshelves as shown in Figure 7.3.2. The glazing is 6 mm thick and doors have perimeter and threshold acoustic seals. This construction extends the size of the group room and forms an effective acoustic barrier between the two pairs of bases 4 and 5, and 6 and 7.

To provide further acoustic separation between the individual bases 4 and 5, and 6 and 7, several tall bookcases were positioned along the dividing line between these classbases. The acoustical separation provided by this type of partial barrier is, of course, considerably less effective than that provided by a full height partition.

Noise control

Noise levels during class were high because surfaces were hard and acoustically reflective with the exception of the carpeted floor. Acoustic absorption was added to reduce these noise levels. The ceiling was the most suitable area for treatment and acoustic tiles were applied over the whole of the ceiling in the open-plan teaching area. The precise absorption coefficient of the ceiling tiles is not known, but an absorption coefficient of 0.9 over the speech frequency range is normally needed to maximise the benefit of an acoustic ceiling. As well as controlling noise within the classbase, the ceiling treatment helps to reduce the propagation of sound from one classbase to another.

The teachers reported an immediate improvement in aural conditions with the installation of the partitions. They found that they were now only disturbed by the classbase immediately adjacent to them. By strategic location of items of tall furniture they were able to slightly reduce this remaining source of disturbance.

The acoustic ceiling, installed a few months later, was perceived by teachers to produce a small but significant reduction in the noise levels during class activities.

Acoustic measurements

The noise levels during class and the reverberation times of the spaces were measured. Measurements were also made to evaluate how well sound propagates from one classbase to another. The majority of measurements were made after the remedial treatment had been implemented although noise levels during class were also measured before treatment.

Activity noise

The noise levels were measured in the four classbases, before and after the remedial treatment, during typical table activities. Approximately 25 pupils were present with 1 or 2 teachers in each classbase. The octave band frequency spectrum for all measurements was consistent in shape and a typical sound level spectrum for classroom table activity before treatment is given in Table 7.3.1.

For typical table activities, the background noise levels prior to the acoustic modifications ranged from 67 dB(A) to 71 dB(A). Following the installation of the acoustic ceiling and partitions, noise levels ranged from 64 dB(A) to 69 dB(A), a reduction of 2 to 3 dB(A) which appears to be a small but significant subjective decrease.

Reverberation time

The reverberation time was measured in classbases 4 and 5. After remedial treatment, the unoccupied mid-frequency value was 0.4 seconds with a rise to 0.7 seconds at 125 Hz. The mid-frequency reverberation time, which will undoubtedly have dropped with the installation of the acoustically absorbent ceiling, is now generally below 0.6 seconds, as required for primary school classrooms in Table 1.5.

Sound insulation

The sound insulation was measured between classbases 5 and 6. A value for $D_{nT(0.6s),w}$ of 48 dB was obtained which meets the requirements between standard classrooms specified in Section 1.

Sound propagation

Before the partitioning of the room, simple tests showed that speech could easily be understood between extreme ends of the open-plan area even when there was no line of sight. Whilst the partitioning provided by extending the group room gives good sound separation between two pairs of teaching bases, the acoustic ceiling and physical obstructions, such as tall bookshelves, are the only means of achieving a degree of acoustic separation between the other adjacent bases.

To measure the sound propagation with distance across an adjacent pair of classbases, a broadband sound source was used to simulate the radiation of sound from a nominal teaching position and sound level measurements were made across the classbase and into the adjacent classbase. Figure 7.3.3 illustrates the three

	Octave band centre frequency (Hz)							
	63	125	250	500	1 k	2 k	4 k	8 k
Sound pressure level (dB)	56	60	65	69	68	62	57	54

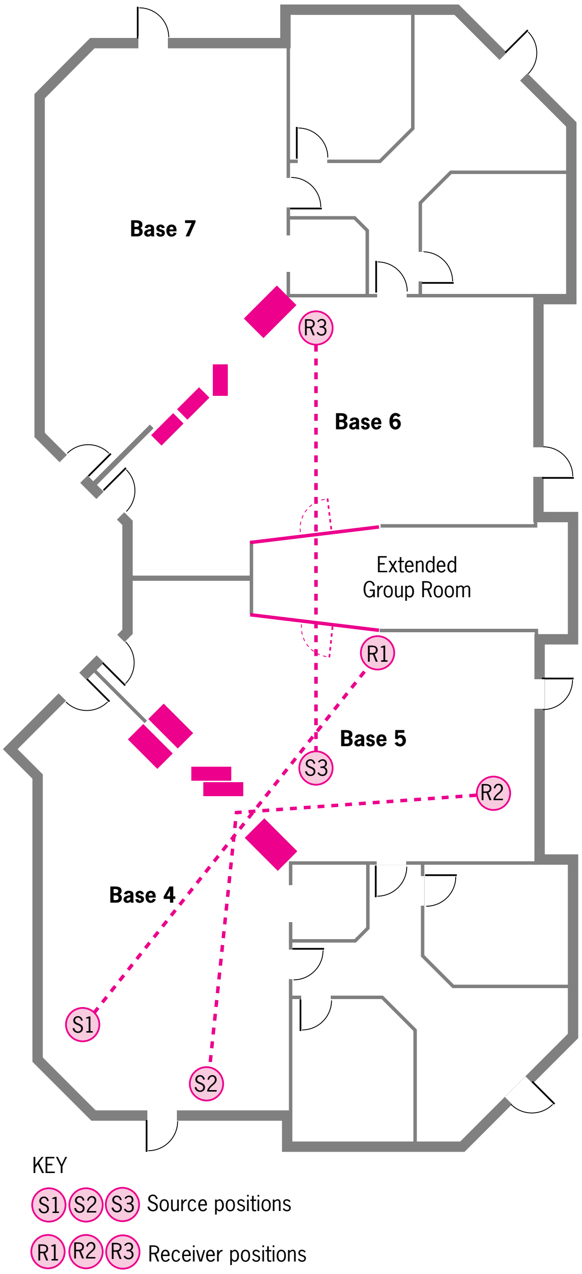
Table 7.3.1: Typical measured activity noise levels in an open-plan classbase before remedial treatment

propagation paths that were investigated:

- from base 4 to base 5 with line of sight
- from base 4 to base 5 via an indirect path
- from base 5 to base 6 via the partitioning formed by extending the group room.

The results for the three paths are shown in Figures 7.3.4 (a) and (b).

Figure 7.3.3: Sound propagation paths investigated



By comparing the two figures, it is evident that the reduction in sound level with distance between bases 4 and 5 is very modest compared with the large reduction between bases 5 and 6 (ie across the partition). This is clearly reflected by the subjective impressions of teachers who are disturbed by noise from an adjacent classbase on the same side of the partition but are not disturbed by classbases beyond the partition.

The erection of a physical barrier across the middle of the open-plan teaching area was clearly effective in improving conditions. It is important to note the constructional simplicity of this barrier and its acoustical effectiveness in reducing sound transmission. This was achieved by using two partitions with a large air cavity in between (the extended group room). A single partition would have needed to be substantially heavier with more elaborate acoustical detailing.

The new partition did not solve all the problems of sound transmission since classbases 4 and 5, and classbases 6 and 7 were still open to each other and some mutual disturbance is still occurring. This has been reduced by partial barriers but can not be effectively eliminated without a complete barrier.

The acoustic ceiling treatment is beneficial in reducing noise levels but did not result in a dramatic effect since the classbases were already carpeted and furnished.

Conclusions

The effect of mutual disturbance in open-plan teaching areas is clearly illustrated in this case study and relatively simple remedial measures have been shown to work moderately well.

Before embarking on the design of an open-plan teaching area, serious consideration should be given as to whether the advantages of the open-plan arrangement outweigh the serious inherent acoustic disadvantages.

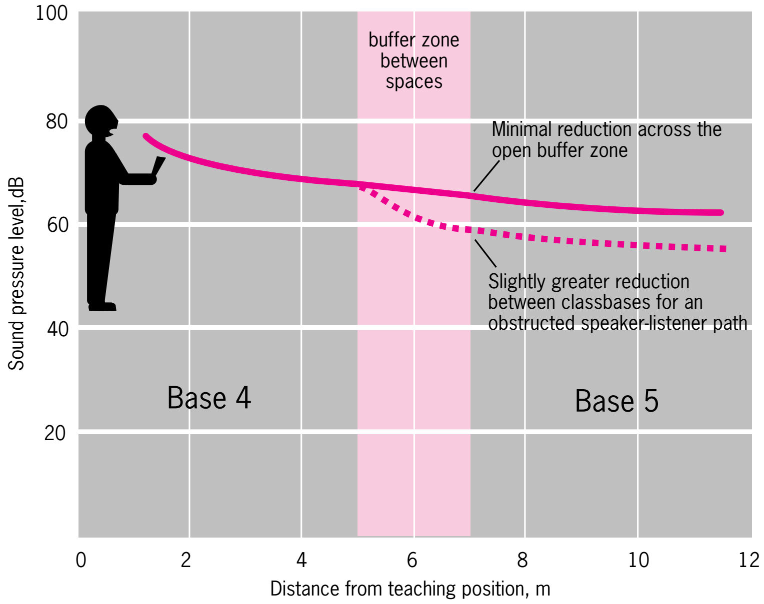
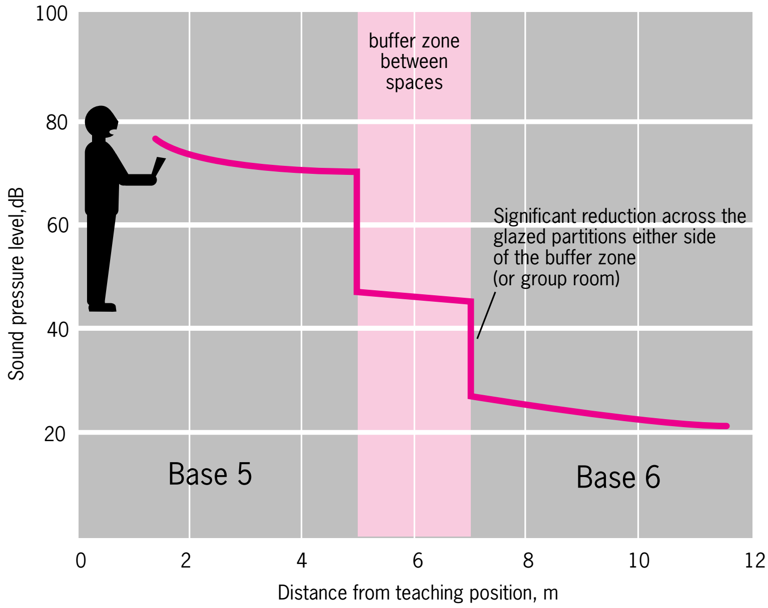


Figure 7.3.4: Sound propagation from one classbase to another

(a) without full height partition



(b) with full height double partition

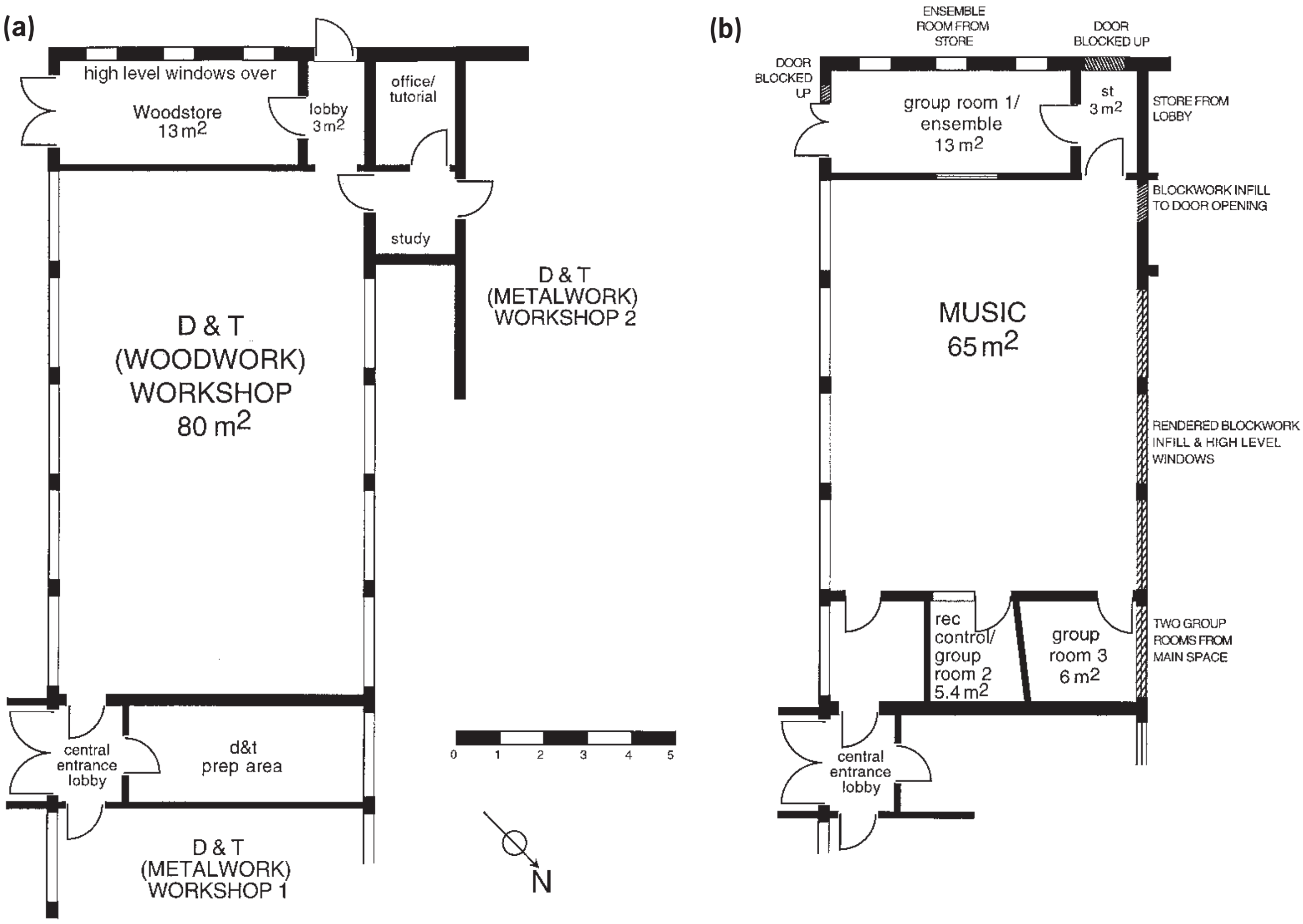
Existing school buildings may have spaces that are less than ideal and compromises have to be made during remodelling. A design and technology (D&T) workshop was converted into music accommodation for an 11–16 comprehensive school with 600 pupils on its roll. Figure 7.4.1 shows plans of the original workshop and the conversion.

The floor area of the conversion is 96 m², including an adjacent 13 m² space with independent access.

The original workshop was built in 1954 using a prefabricated, reinforced concrete system of modular design having concrete roof panels and double skin walls; there is a wood block floor. The south-east and north-west facades of the building were fully glazed from a sill height of about 1.0 m. The ceiling height in the main space was 3.3 m. The size of the main space was suitable for a music room but there were some disadvantages with the accommodation:

- Existing floor and ceiling surfaces were hard, resulting in an unacceptably long reverberation time of 2 seconds. Standing waves and flutter echoes were likely due to parallel walls and hard surfaces.
- The north-west wall abutted the

Figure 7.4.1:
(a) Plan of the original workshop
(b) Plan showing conversion to music accommodation



school playing field. The extent of glazing was excessive and considered undesirable from a security point of view on a side with potential for intrusion.

- The school playground, a potential source of noise, is adjacent to the south-east wall.
- A second design and technology workshop is adjacent to the space (although an entrance lobby and store provide a buffer between the teaching spaces).
- The building is free-standing and circulation is external which results in an excessive number of entrances.
- The reverberation time of the space was too long for a music room.

The adaptation

Structural alterations were kept to a minimum in order to constrain costs and maximise available funds for acoustic treatments and finishes. Within the existing area, it was possible to provide a music room of 65 m^2, three group rooms and a store, see Figure 7.4.1(b). Performances to an audience or large scale rehearsals take place in the school hall. The largest group room (or ensemble room) is converted from the existing store and can be accessed separately, if necessary, to avoid disturbing classes. The dimensions of this space are not ideal as proportions are long and narrow but compromise has been accepted and the wall treatment is designed to optimise room responses. An entrance lobby houses coats and bags and provides additional sound insulation between the main space and the adjacent D&T room.

The sound insulation of the music room was a priority. The key aspects of the acoustic treatment are shown in Figure 7.4.2, and described below.

Construction

In order to improve security, glazing to the north-west wall was removed and the opening was infilled up to two thirds of its height with rendered blockwork. Medium density block (1500 kg/m^3) was used to give appropriate sound insulation. The top third of each panel was thermally and acoustically double glazed with bottom-hung openable fanlights.

Angled panels of medium density particle board were fixed to studding on the inside face of the north-west wall of the main space. These help to prevent standing waves between parallel side walls and can provide much needed display space. The panels are without fabric covering since this would compromise the high frequency response. Panels are omitted where there are shelves as these have an equivalent acoustic effect. Angled panels are also used in the group rooms.

Secondary acoustic glazing was added to the windows to the south-east (playground) side, as two sliding panels. This allows access for maintenance and to open casements or fanlights. Solar reflective film was added to the outside of the existing fenestration to reduce solar

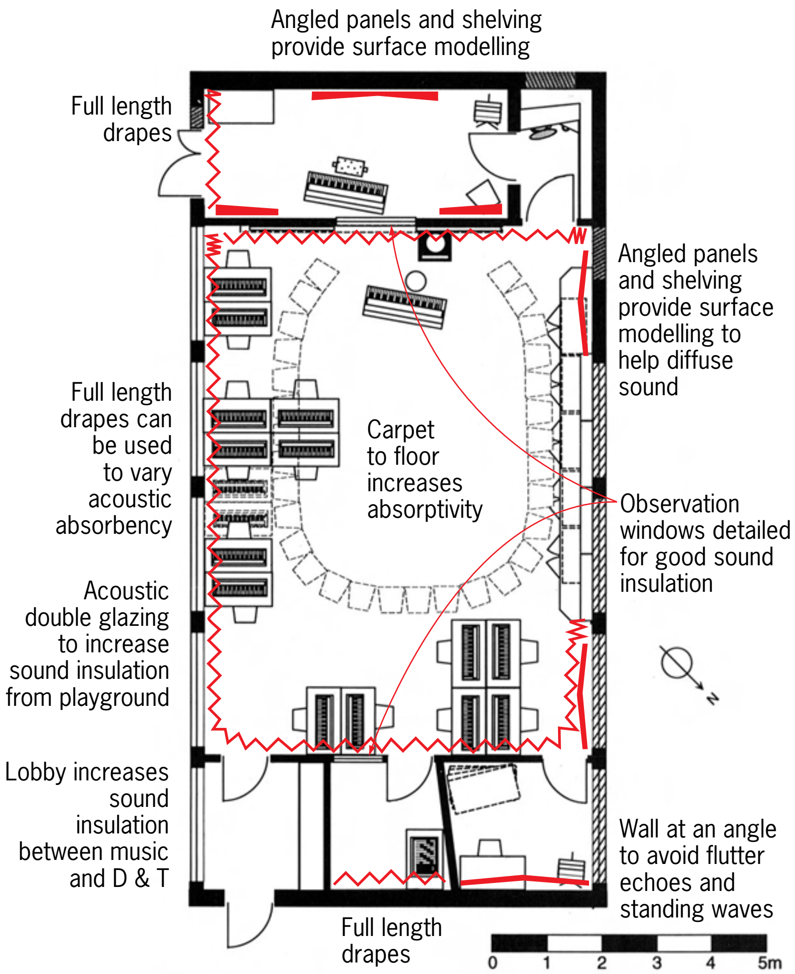


Figure 7.4.2: Plan showing acoustic treatments

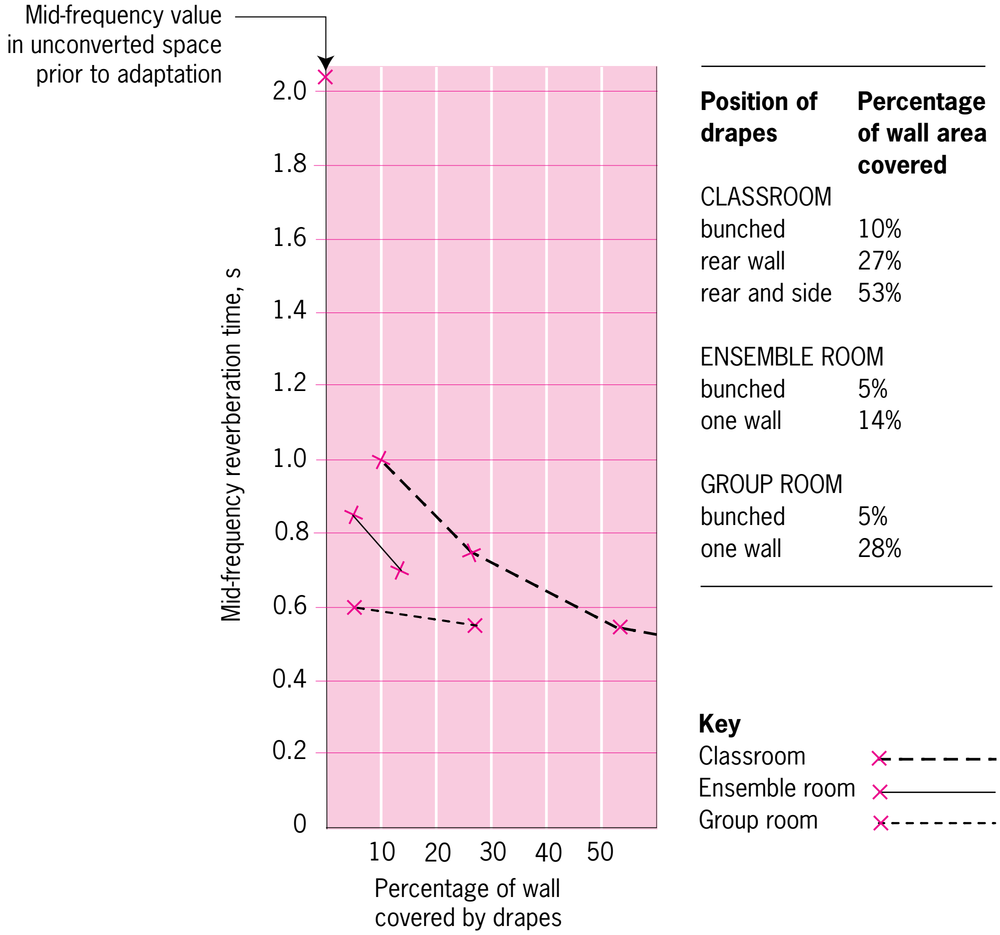


Figure 7.4.3: Graph showing effects of drapes on reverberation times in classroom, ensemble room and group room

gain. In a new building, an alternative solution may be to incorporate a fixed sunshade or 'brise soleil' at the eaves soffit.

Internal doors into the music classroom, the adjacent D&T space and the ensemble room were upgraded to heavy solid core doors with double seals all round including threshold seals. Doors to the two group rooms have vision panels for supervision with 10 mm glass. Acoustically double-glazed observation windows are formed in the partition walls to the ensemble room and one of the group rooms.

Fixtures and finishes

The existing plasterboard ceiling finish was retained; the existing wood block floor to the main space was also retained and carpeted for acoustic reasons. The ensemble room floor has a basic underlay and corded carpet, so that the finish is not too acoustically absorptive.

Wall finishes in the main space are supplemented by heavy drapes of at least 0.5 kg/m^2 at 200% gather, providing acoustic variability and control. The curtain track is ceiling mounted along three sides of the room providing maximum flexibility allowing curtains to be positioned to suit the configuration of the musical activity. This is useful in a school where one classroom serves a number of functions.

Curtains are also provided in group rooms. In the ensemble room, they are positioned at the south-east end of the space, screening the doorway or bunched in the corner as required.

On completion, acoustic measurements were taken in the music classroom, ensemble room and a group room (all when unoccupied). Resulting mid-frequency reverberation times are depicted in Figure 7.4.3. This graph shows that measured values are in accordance with Table 1.5 of Section 1, and demonstrates the potential of providing acoustic variability using drapes.

In the 65 m^2 classroom it can be seen

that curtains can be very effective in reducing mid-frequency reverberation time. Because of the number of variables combining to affect the reverberation time in a room including volume, the weight and location of curtains, surface finishes and furniture, the results shown here are indicative only. The graph shows that the ensemble room at 13 m^2 has a measured RT of 0.7 to 0.8 seconds, within the range given in Table 1.5 of 0.6 to 1.2 seconds for an ensemble room.

The background noise level in the unoccupied music classroom measured whilst adjacent classes were in session was 29 dB $L_{Aeq,\ 1hr}$. This suggests that the indoor ambient noise level is less than the required level of 35 dB $L_{Aeq,\ 30min}$ given in Table 1.1 of Section 1.

The music department at a school with 650 pupils between the ages of 11 and 18 was replaced. The new self-contained suite comprises a large music room, three music practice rooms, an ensemble room and ancillary accommodation.

The school is located in a quiet rural district with low ambient outdoor noise levels. The music block is several metres away from other buildings, which ensures that noise egress to other parts of the school is minimised.

The building is constructed of masonry with an external leaf of brickwork, an insulated cavity and internal leaf and walls of blockwork, some of which are plastered. The density of the blockwork is not known but ideally it should be the highest available, ie 2000 kg/m^3. The tiled roof has an internal sheathing of plywood which benefits sound insulation.

A full height blockwork crosswall, up to the roof soffit, separates the large music room from the rest of the building. The music practice rooms also have full height walls.

Windows are double-glazed and can be opened. Doors are generally hollow core with basic seals giving around 20 dB R_w for the doorsets.

The music suite is a good example of how to control noise transmission between rooms, and thus reduce disturbance, by careful planning of the room layout, see Figure 7.5.1. The key features are:

- The large music room is separated from other music rooms by a corridor and storage areas.
- The ensemble room with its associated recording/control room is also separated from other rooms by a corridor.

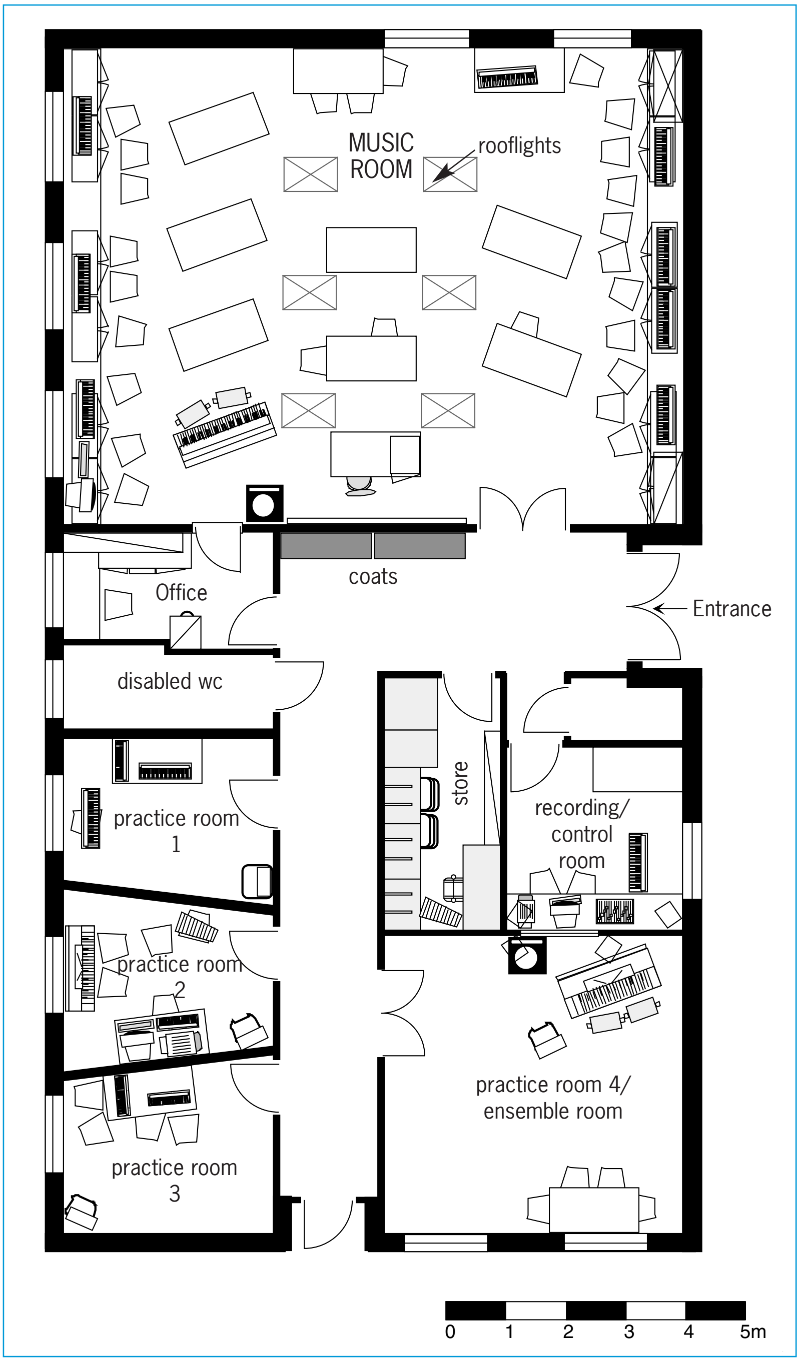
Music classroom

The geometry of the large music room is good, with a rectangular plan shape and a fairly steeply pitched ceiling, see Figure 7.5.2. The light fittings and recessed roof lights provide some useful modelling to break up and diffuse the sound.

Two large encased purlins, projecting down from the plane of the ceiling cause a minor localised problem. Small sound colourations occur when musicians play in the area underneath the main roof beams. It is possible that these are caused by strong reflections from the junction between the roof beam and ceiling as shown in Figure 7.5.2. Additional localised measurements would be necessary to investigate this effect. A solution in this particular case would be to treat one side of the beam with absorbent material, as indicated.

As a general principle, it is useful to incorporate elements into a ceiling to provide diffusion and hence uniformity in

Figure 7.5.1: Plan of music department (furnished)



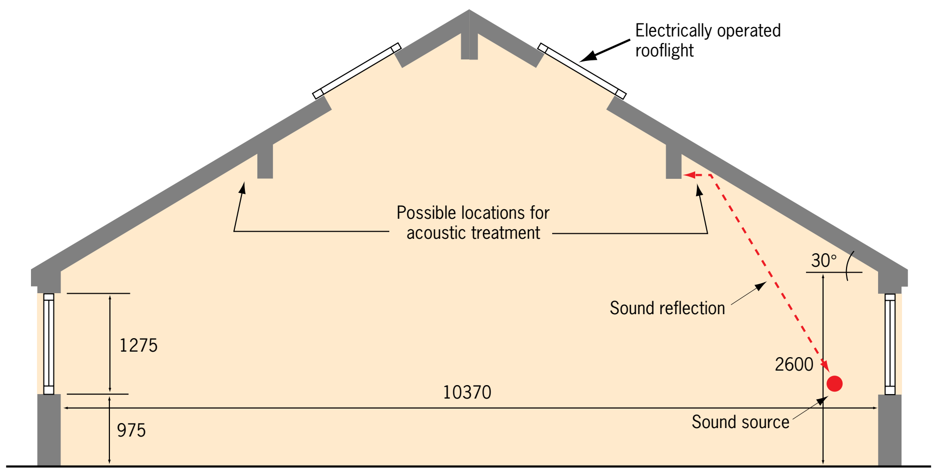


Figure 7.5.2: Section through music room

the sound field. For effective diffusion, projections of 0.3 m to 0.5 m are necessary. However, such projections should be distributed over the whole ceiling area; a single large projection can lead to a prominent and potentially disturbing reflection, as in this case.

Surface finishes are generally hard and reflective except for the floor which is covered with a short pile carpet. In detail, the walls are of plastered blockwork with an emulsion paint finish and the ceiling is of plasterboard with a plaster skim finish. This combination of hard and soft finishes ensures that the reverberation is sufficiently long for music performance and adequate for teaching.

No provision has been made for varying the acoustics, eg by use of heavy curtains. This would be desirable but not essential.

The measured mid-frequency reverberation time (RT), with 25 children and 4 adults present, was 1.0 seconds with a rise to 1.5 seconds at 125 Hz. The full RT curve as a function of frequency is shown in Figure 7.5.3.

This RT is within the range for ensemble rooms specified in Table 1.5 of Section 1.

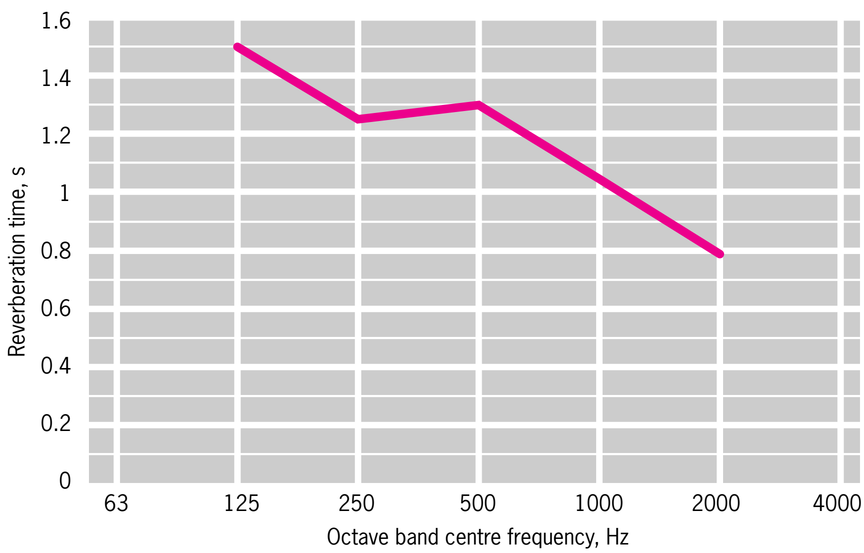


Figure 7.5.3: Measured reverberation time in the music room

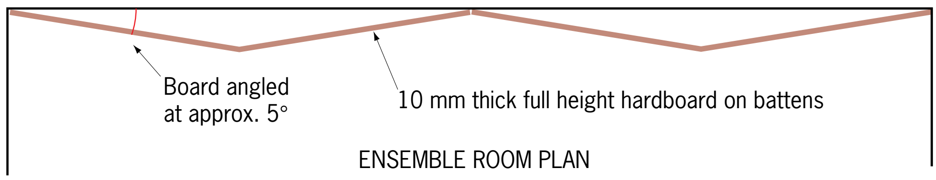


Figure 7.5.4: Simple acoustically diffusing elements

Practice rooms

All practice rooms include one pair of non-parallel walls which reduces the possibility of sound colouration from standing waves.

The practice room volumes are of the order of 20 m^3 and can accommodate up to 5 pupils working on composition. Ceiling heights are 2.6 m which is lower than desirable but acceptable.

The measured mid-frequency RT in one of the practice rooms was 0.4 seconds with a rise to 0.9 seconds at 125 Hz. This is at the lower limit recommended for practice rooms which results in a 'dry' sound but is nevertheless satisfactory. The moderate rise in bass frequencies is generally a welcome feature giving fullness of tone to certain instruments.

A combination of acoustically reflective and absorbent finishes has been used. The walls are of blockwork with a paint finish, the floor is carpeted with short pile carpet and the ceiling is treated with acoustic tiles. Although the selection of materials has resulted in acceptable reverberation times, the distribution of absorption is concentrated on the ceiling and floor which tends to emphasize sound reflections in the horizontal plane; an undesirable effect that has been noted by users. This problem could be overcome by redistributing a proportion of the absorption onto the walls, eg by installing absorbent wall panels and replacing some absorbent ceiling tiles with reflective ones.

Ensemble room

The ensemble room is square which could give rise to strong standing waves and hence possible colouration. However, one wall has simple angled reflective panels acting as diffusing elements which work effectively to counteract this. Surface finishes in this room are the same as in the practice rooms. Again the distribution of absorption is uneven although the sound field is rendered more diffuse by the installation of the angled panels on one wall, see Figure 7.5.4. Treatment of these panels with hessian is not desirable since it could reduce 'brilliance' of the sound as there is already sufficient high frequency absorption in the carpet and ceiling.

The measured mid-frequency RT was 0.4 seconds with a rise to 0.6 seconds at 125 Hz. This is lower than the range given in Table 1.5. A longer mid-frequency RT could have been achieved by reducing the ceiling absorption. There would then have been scope for having acoustic variability using curtains.

Recording/control room

The control room is also square but without the benefit of diffusing elements. This could give rise to standing waves although these were not evident. The shelving and equipment probably provide sufficient diffusion to avoid sound colouration. A facing wall could be treated with absorbing material to assist in preventing this.

This room has the same surface finishes as the practice rooms and is generally suitable for music practice and composing as well as monitoring and recording sound from the ensemble room. (Monitoring is normally done in a very dead acoustic although a suitable compromise has been struck here between practicing and monitoring).

There is good visual communication with the ensemble room through an acoustic double-glazed window.

Sound insulation

The measured sound level difference between two practice rooms in octave

Table 7.5.1: Measured level difference between two practice rooms

	Octave band centre frequency (Hz)						
	63	125	250	500	1 k	2 k	4 k
Level difference *D* (dB)	22	27	34	46	50	52	58

Table 7.5.2: Measured indoor ambient noise levels in practice room

	Octave band centre frequency (Hz)				
	125	250	500	1 k	2 k
Measured sound pressure level (dB)	38	33	26	21	25

bands is shown in Table 7.5.1. This equates to a weighted BB93 standardized level difference of 44 dB $D_{nT(0.8s),w}$.

The sound insulation between practice room 2 and the adjacent corridor was limited by the poor sound insulation of the doorset between them. The weighted BB93 standardized level difference between the ensemble room (practice room 4) and practice room 2 was 47 dB $D_{nT(0.8s),w}$.

Indoor ambient noise

The indoor ambient noise level was measured in practice room 3 during a period when people were moving around the building but no significant musical activity was taking place. The results are shown in Table 7.5.2. This equates to a single figure value of approximately 30 dB(A). It means that there is little masking of intrusive noise from adjoining spaces. Therefore, separation of sensitive spaces by storerooms and corridors is particularly important.

Table 7.5.3 compares the subjective assessments of the acoustic quality of the spaces with the acoustic measurements.

Discussion

One of the key issues relating to acoustics in music accommodation is sound transmission between different rooms which may cause disturbance to music practice and teaching.

Clearly, the layout of the building provides good separation between main rooms or groups of rooms. The measured $D_{nT(0.8s),w}$ from the ensemble room to practice room 2 was 47 dB.

However, the situation is more complicated because disturbance to a musician or teacher is also a function of the indoor ambient noise in the room they are playing/teaching in: the higher the indoor ambient noise (if relatively steady) the more masking of external sounds occurs and hence the lower the disturbance from external noise.

The sound insulation was significantly reduced by transmission through doorsets. The installed doors are hollow core with poor seals around the perimeter and threshold. The two sets of double doors in the music suite do not have effective seals at the meeting stiles. This is a common problem with double doors but can be overcome by careful detailing with rigid fixings at the meeting stiles. It might have been better to use unequal paired doors instead of double doors. The small leaf can then usually be bolted shut making the seal much more effective than on a normal double door. A wide single door is also a possibility.

Upgrading seals to proper acoustic seals and replacing doors by the solid core type would improve performance close to that required. (Preventing doors from squeaking would also be beneficial in reducing disturbance.)

A second key issue is the acoustic characteristics of each of the different types of space.

The large music room has a very good geometry for providing a diffuse sound field. The 1.0 seconds T_{mf} is sufficiently long to provide fullness of tone but short enough to maintain clarity which is an important quality in music teaching. The rise in RT at bass frequencies is beneficial in terms of adding 'warmth' to the acoustic characteristic.

The music practice rooms also have an

Table 7.5.3: Comparison of subjective and objective assessments

	Subjective impressions of the acoustic character of the space	Acoustic measurements		
		Mid-frequency reverberation time, T_{mf} (s)	Airborne sound insulation $D_{nT(T_{mf,max}),w}$ (dB)	Indoor ambient noise level L_{Aeq} (dB)
Music room	Moderately reverberant. Diffuse sound field. Adequate loudness	1.0		
Practice room (Tutorial 2)	Modest reverberation. Non diffuse sound field. Reverberation concentrated in horizontal plane. Can hear instruments playing in adjacent rooms but just tolerable.	0.4	44 between practice rooms 2 and 3	29
Ensemble room	Modest reverberation. Adequate loudness. Disturbance from practice rooms only during quiet moments.		47 between the ensemble room and practice rooms	
Corridor	Can clearly hear piano from practice room and clarinet from ensemble room.			

appropriate geometry in plan, namely two non-parallel walls. However, absorption is not evenly distributed on the room surfaces which prevents a sufficiently diffuse sound field.

The ensemble room appears to be much favoured by teachers and musicians alike who feel comfortable with its size. A square plan shape is always problematic in terms of standing waves although this has been mitigated by using simple and effective diffusing panels.

The associated control room includes a well designed acoustic double-glazed viewing window and the two spaces together form a good quality recording suite. The window consists of 2 x 6 mm glass panes with a 100 mm air space.

Conclusions

The music block is exemplary in most respects in terms of its fitness for teaching and practicing music at secondary school level. The acoustic design is generally good but there are some minor shortcomings such as inappropriate selection of doorsets and door seals, and poor distribution of absorption in practice rooms.

In summary, the main points to note about the acoustic design of the music block are:

- location of the building at a distance from other buildings
- separation of large music room and groups of rooms by full height walls, corridors and buffer zones
- selection of a simple rectangular plan shape for the large music room
- selection of non-parallel walls for practice rooms
- use of simple angled wall panels to provide sound diffusion in the ensemble room
- use of solid, acoustically reflective materials for walls and ceilings in the large music room to ensure sufficiently long reverberation.

This case study describes a junior school and hearing impaired unit which provide an inclusive environment for hearing impaired children who are educated through a natural aural approach. The children attached to the unit all have a 'significant' hearing loss and abilities that fall within the 'average' range. The guiding principle that underlies their placement within the school is that they should be allowed to make best use of their residual hearing. The children have full access to the national curriculum and are members of a mainstream class. Children also have the use of a specialist teaching resource facility as described below.

Characteristics of the school

The junior school is of average size with about 230 children aged between 7 and 11. Sixteen children are included specifically within the resource provision for deaf pupils, although this number includes children currently attending the infants' school and is liable to fluctuation depending on the unpredictable changes in the size of the hearing impaired population.

Accommodation

The school was built in the late 1950s and is set away from the road in a quiet location. The school has been pleasantly decorated throughout. Some attention has been given to reducing internal noise by carpeting classrooms and some corridors. Most of the ceilings have some degree of acoustic treatment. There are no open-plan classrooms within the junior school. It is the intention of the school to further improve the acoustics of the classrooms and a report on sound treatment has been commissioned.

There are 8 classrooms of similar size. In addition there is a dedicated ICT space, a drama room, music room and a large hall. A library has been established in one of the larger corridors.

Attached to the main building by a covered walkway is a building formerly called the hearing impaired unit, but now renamed as the RPD (resource provision for the deaf). This has extensive sound treatment and the main teaching room is situated so that it does not face the playground.

This case study focuses on two rooms: the main teaching space in the RPD (marked as RPD on the plan) and a

Figure 7.6.1: School room layout

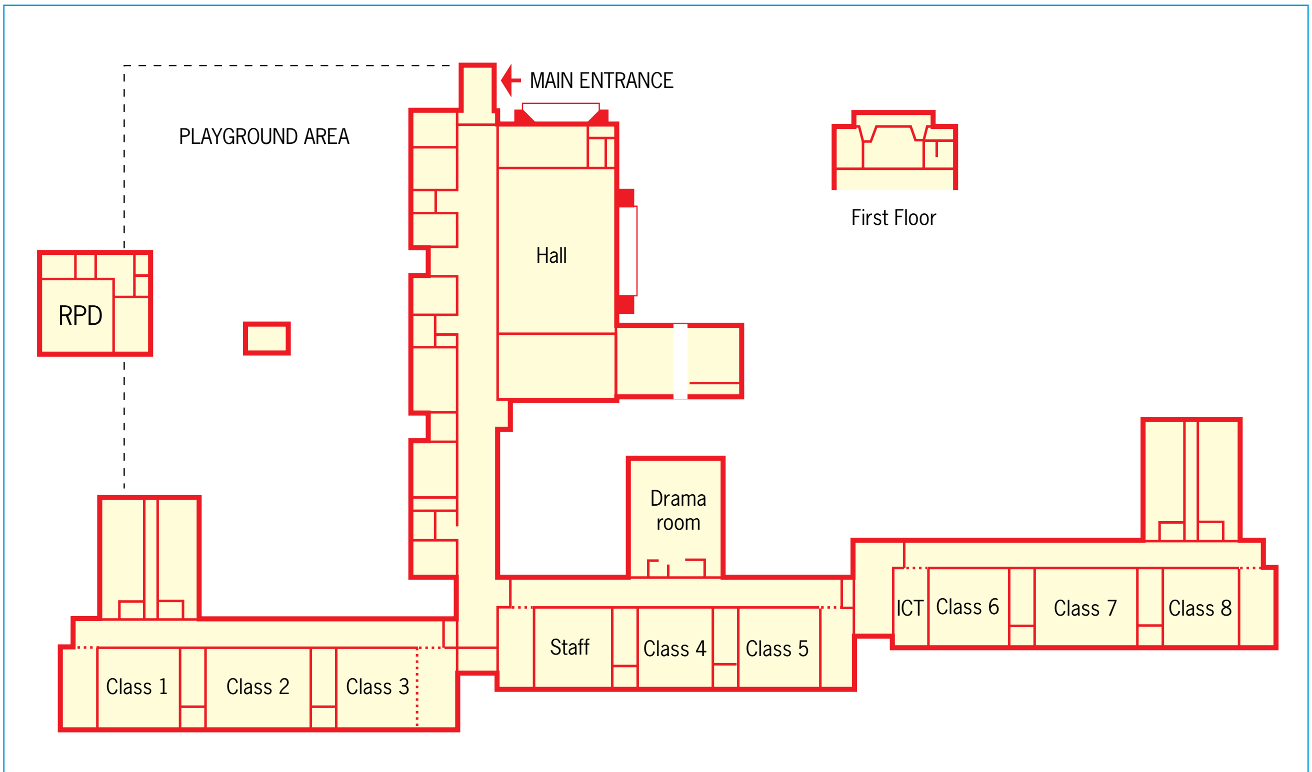


Figure 7.6.2: 'Circle time' in Class 4

typical classroom within the school (Class 4 on the plan).

Figure 7.6.2 shows the children all facing each other during circle time. The hearing impaired child has been placed next to the teacher to ensure that she can hear the teacher well and see all contributions. Figure 7.6.3 shows the layout of the room and the positions of the children during circle time. The teacher is wearing a radio transmitter that transmits her voice directly to the child's hearing aids and to a classroom soundfield amplification system. This will ensure that the teacher does not have to raise her voice and distort her speech unhelpfully. All children benefit and as a consequence are better able to participate.

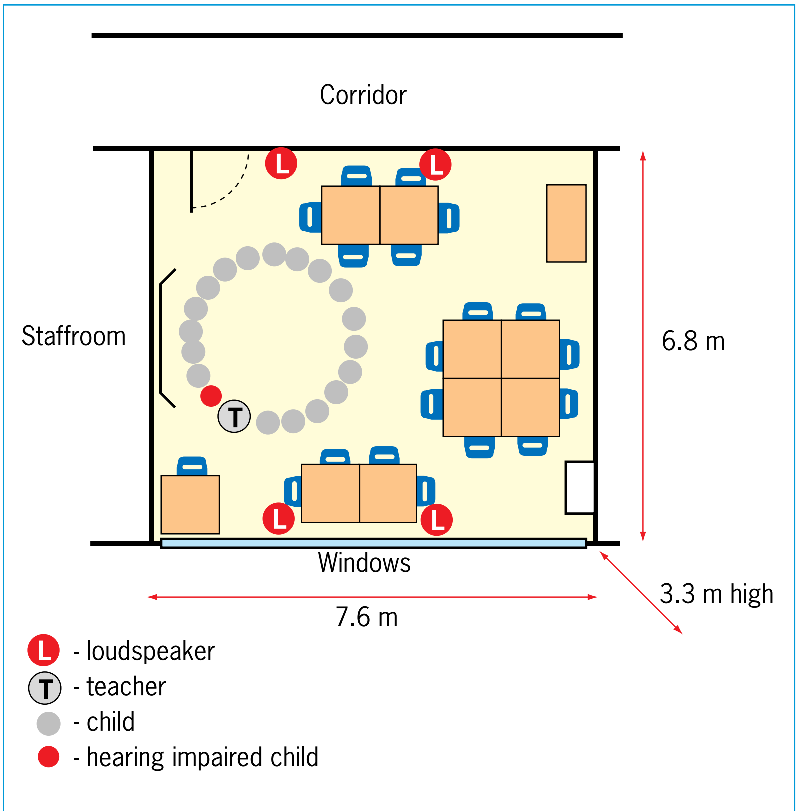


Figure 7.6.3: Class 4 layout

Acoustic and behavioural measures

A number of acoustic and behavioural measures have been obtained in order to present an account of the acoustic environment of the classroom. These measures include:

- listening inventories for education (LIFE UK, see Section 6.5)
- sound level during school day (1 minute average dB(A))
- short term sound level measurements (2 minute runs at 6 time intervals)
- room acoustic measures.

LIFE UK is a protocol for evaluating listening abilities of children. Application of the protocol indicates that the class are able to hear the teacher and each other well most of the time, see Figure 7.6.4. The hearing impaired child has a similar profile with the exception of several

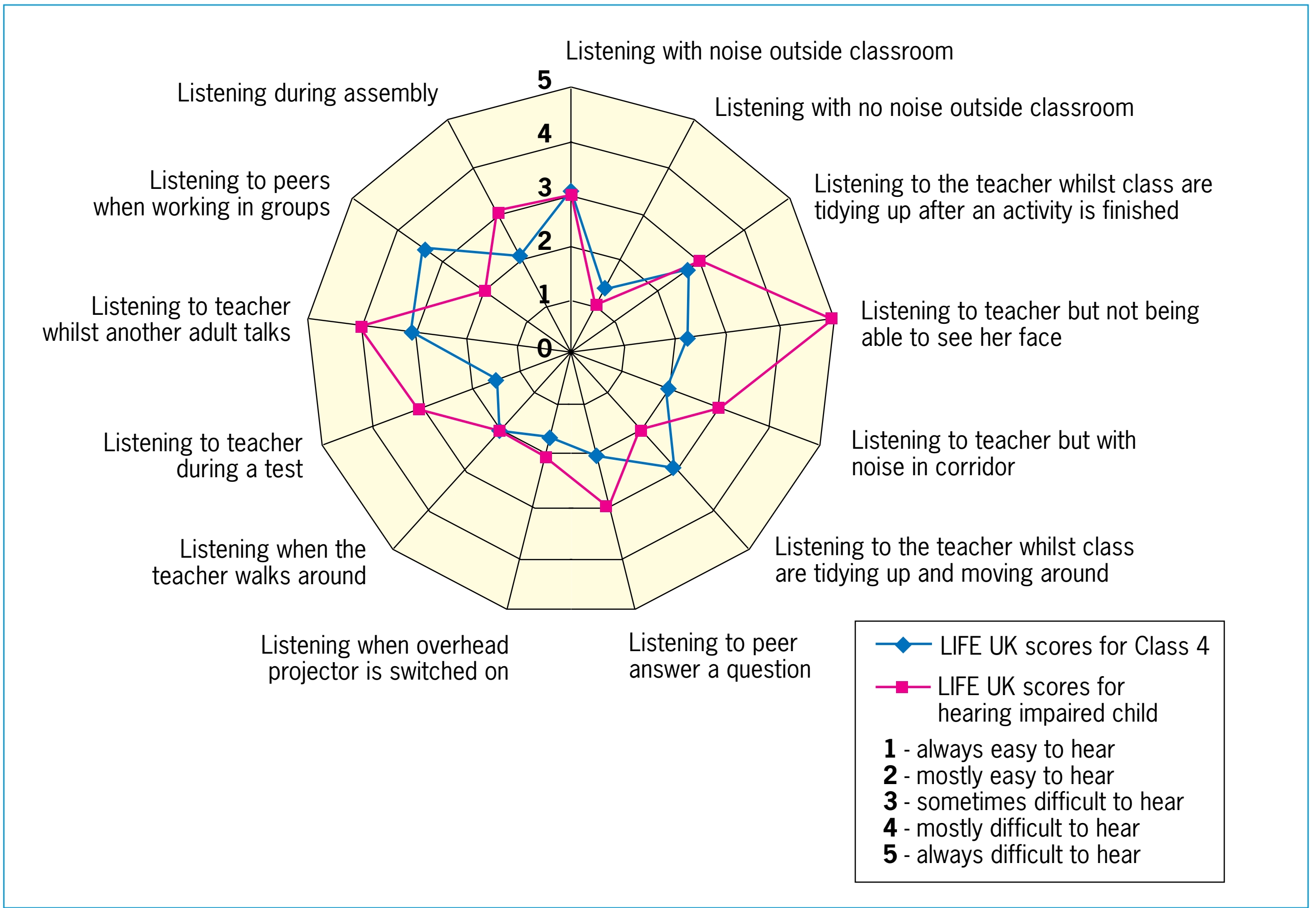


Figure 7.6.4: LIFE UK scores for Class 4

critical areas, primarily the child indicates that she needs to be able to see the teacher's face in order to understand what is being said. This is consistent with the benefits offered by lip-reading in less than ideal listening conditions. This can be addressed through the teacher modifying her teaching style. Other areas where the hearing impaired child finds greater difficulty include listening to her peers answer questions; listening when there is another adult talking; and listening when there is intrusive noise, for example from the corridor. The child indicates that she is making satisfactory use of the personal radio system and classroom amplification system to overcome many of the potential obstacles to hearing effectively.

Figure 7.6.5 shows a chart obtained using a noise logging dosimeter placed at the front of the classroom and out of the reach of the children. The chart presents the one minute history of the sound level obtained between 11.30 am and 15.28 pm during a typical school day. 'A' represents the class quietly engaged in group work.

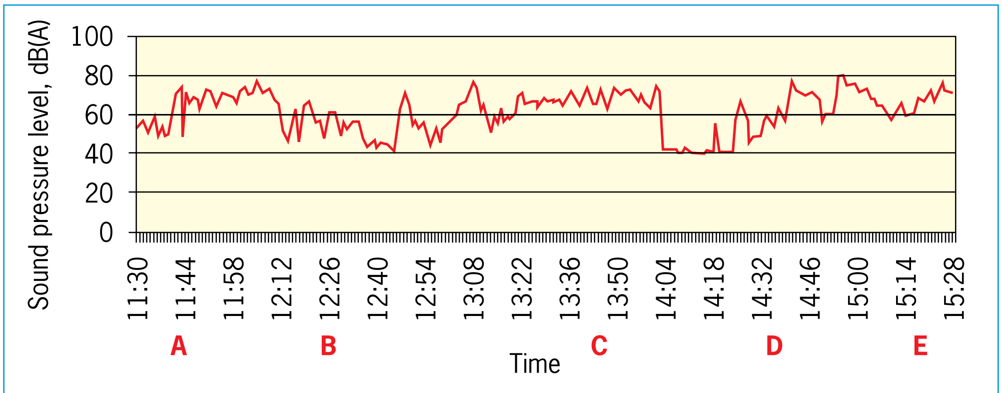


Figure 7.6.5: Sound levels in Class 4 during the day

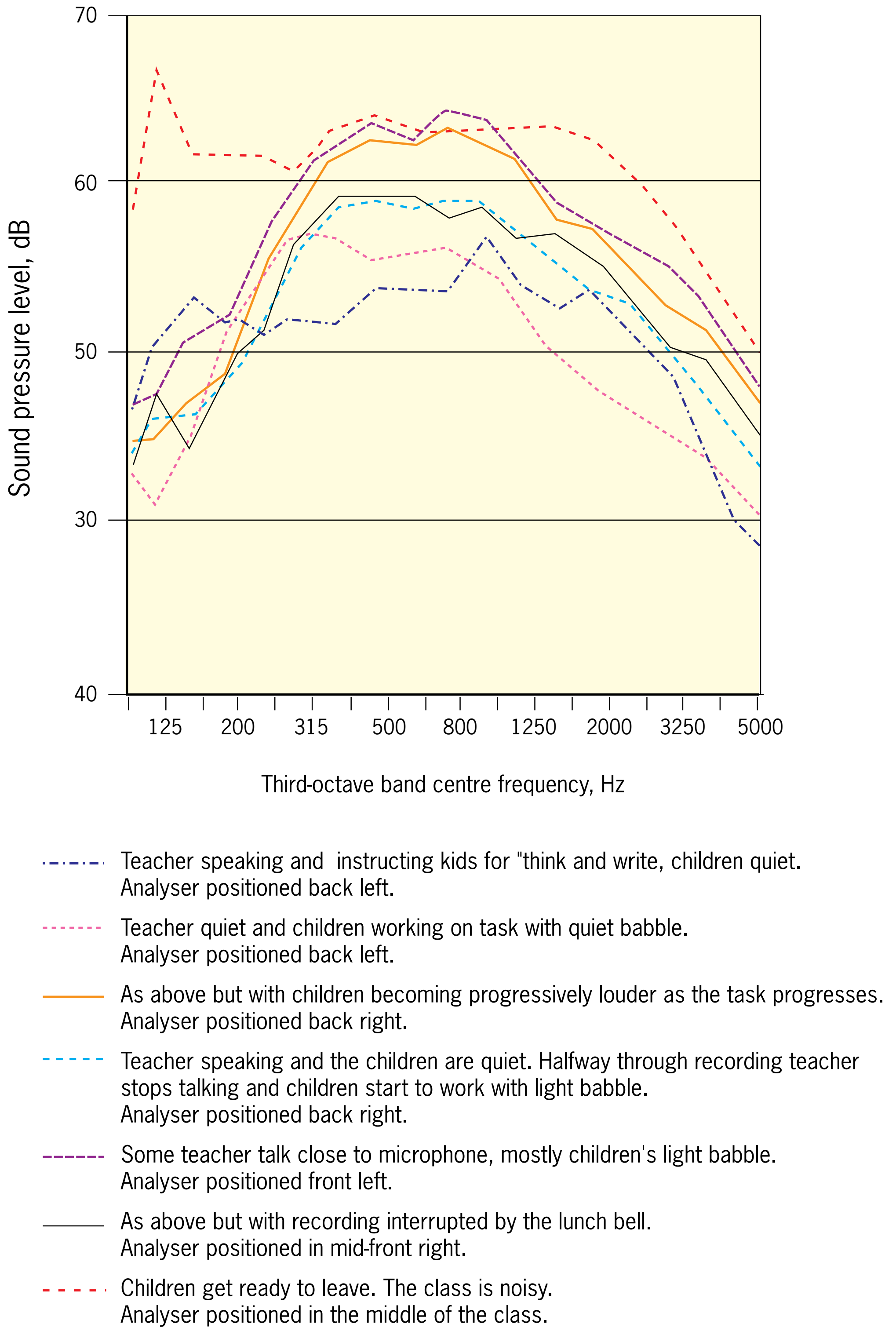


Figure 7.6.6: Frequency spectra for various classroom activities

'B' is the lunch break. During the period marked 'C' the class are again engaged in quiet group work; the end of period 'C' coincides with a break. During the period marked 'D' the sound level gradually rises while the children take part in a carefully controlled circle time discussion. A classroom soundfield system is used by the class teacher and a personal radio FM system is used by the one hearing impaired child who uses a hearing aid. Period **'E'** represents the end of the school day and the sound level rises as children and adults use the room informally.

Figure 7.6.6 shows the third-octave band frequency analysis for some of the classroom activities.

Room acoustic measures

Ambient noise level

Measured levels with the classroom empty were in the range 32-36 dB L_{Aeq}, but this was after the end of school so did not include noise from other areas of the school. Noise from other areas was not perceived by the teachers as a problem.

Sound level changes due to use of soundfield system

Measurements of the sound pressure level and L_{Aeq} did not show changes that could be definitely attributed to the use of the system. The teacher being measured had, as judged subjectively, an exceptionally powerful voice, and it is quite possible that she was able to monitor the acoustic impact on the class and adjust her speaking level accordingly.

It is worth noting that the system is not purely an amplification system, it exists to distribute the sound from the teacher's voice evenly about the classroom. Simultaneous acoustic measures would have been useful to indicate the extent to which this was achieved.

Subjectively, there was an increase in clarity at mid and high frequencies. The increase in clarity does not imply a pleasant quality of sound and it was felt that the sound from the speakers was rather harsh. This could be a function of the frequency response of the speakers or the adjustment of the system.

Room acoustics assessment, Class 4

The measured reverberation times (RTs) are shown in Figure 7.6.7. The T_{mf} is above the value specified in Table 1.5. In addition, detailed analysis of the measured impulse responses showed flutter echoes between the parallel, reflective walls. These were not at such a level as to be annoying but they probably reduce speech clarity in the room. The room has predominantly reflective wall surfaces and although the ceiling and the carpets provide some absorption, more absorption on the walls would reduce or eliminate the flutter echoes as well as reducing the RTs to acceptable levels.

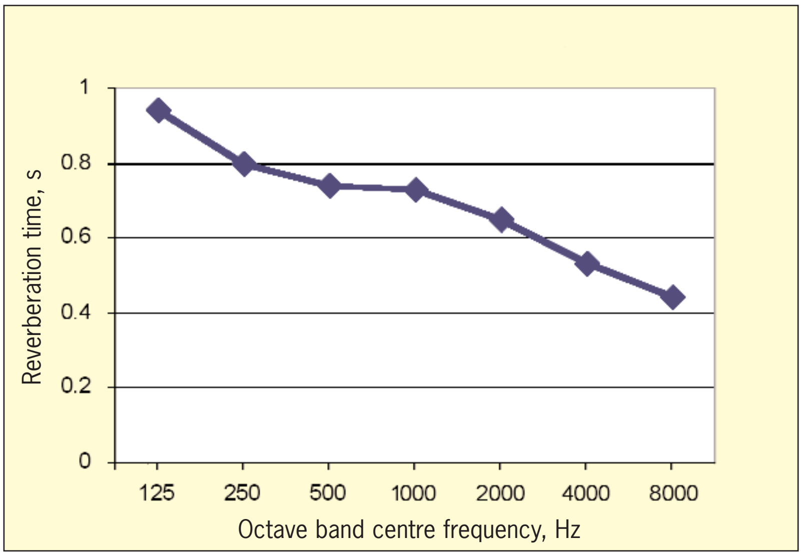


Figure 7.6.7: Reverberation times in unoccupied Class 4

Room acoustics assessment, RPD room

The measured RTs are shown in Figure 7.6.8. As expected for an RPD room, the T_{mf} is lower than the value of 0.4 seconds given in Table 1.5 for classrooms designed specifically for use by hearing impaired pupils. Furthermore, the RT across the frequency range is lower than 0.4 seconds as recommended in Table 6.1. There are no apparent flutter echoes or other problems and no complaints of acoustic problems in this room, which would be

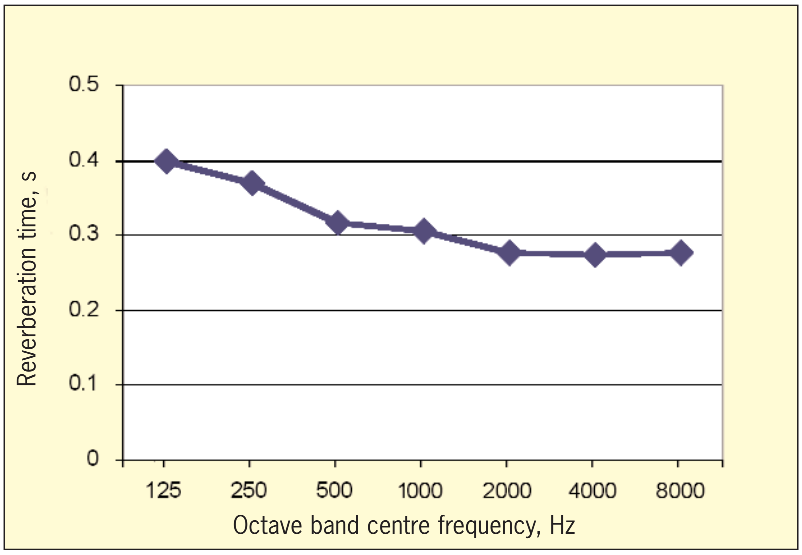


Figure 7.6.8: Reverberation times in unoccupied RPD room

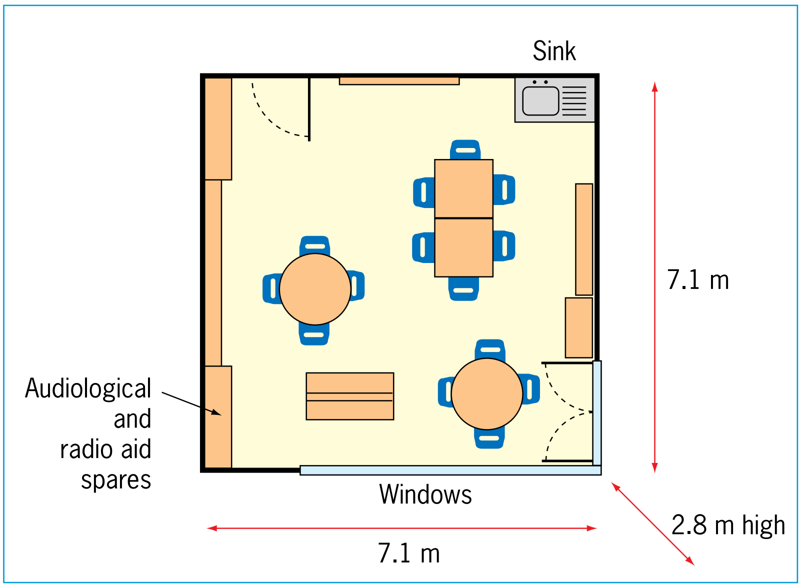
considered to be very well designed acoustically.

Teaching resource base

The RPD is separated from the main school by a short covered walkway. There are two rooms and the entrance lobby outside the rooms is large enough to provide a space for small group work. The larger room shown in Figures 7.6.9 and 7.6.10 is used for teaching larger groups. The whole building has extensive sound treatment, ensuring that the environment has little reverberation. The building is set in the playground, but is only used for teaching purposes outside playtime. The largest space faces away from the playground. The windows are not double-glazed and there is no air conditioning, however the setting is very quiet and the rooms are large.

Figure 7.6.9: Teaching resource base

Figure 7.6.10: Teaching resource base room layout



Strengths of the school

A review of the school shows that there has been considerable investment in ensuring that the school is one that reduces acoustical barriers to learning for hearing and hearing impaired children alike. The key features are:

- carpeting to reduce noise in corridors and classroom noise caused by movement
- attaching rubber ends to chairs and tables to reduce movement noise
- maximising lighting, and where appropriate using blinds, so that children and teachers are visible but not silhouetted against the light, thereby ensuring that lip-reading is effective
- using personal radio systems for the hearing impaired children to limit the effects of distance from the teacher
- using a soundfield system, which provides benefit to the hearing impaired child directly by increasing the strength and naturalness of the speech signal, and indirectly by modifying classroom behaviour in a positive manner
- making use of expertise in the in-service training of staff throughout the school
- providing an acoustically well-specified area for supporting those special needs of hearing impaired children that cannot be met within the mainstream classroom.

Future developments at the school

The school is about to undergo major roof repairs. As part of the process the school will take the opportunity to upgrade the acoustic treatment within the classrooms, seeking to lower the reverberation times. This will assist in reducing noise build up during critical learning times of group work and class discussion. The lower reverberation times will enable the soundfield system to work more effectively, and possibly enable the school to use ceiling mounted speaker systems for future installations.

This case study describes the acoustics of an all-age special school for hearing impaired pupils. The school is located on two sites. The primary aged pupils attend a primary special school for hearing impaired children and the secondary age pupils attend a special unit within a mainstream secondary school about one mile away from the primary school.

The primary school, the secondary special unit and the audiology room in the primary school are described separately.

The primary special school

The primary school is a school in which only severely hearing impaired pupils are taught. It was founded in 1975 and caters for up to 115 children between the ages of 3 and 11. The school consists of nine teaching classrooms and a nursery as well as a hall, a dining room and more informal open areas which are used for activities such as art and cookery. There is also an audiology room which is discussed in more detail later.

Pupils are taught in small groups by a teacher aided by a classroom assistant. The teachers wear radio transmitters and all pupils wear radio hearing aids so that they can make use of their residual hearing. Sign language (accompanied by speech) is used for teaching.

Classes were observed to gain an insight into the use of the school and measurements of background noise, reverberation time and sound insulation were carried out.

Location

The school is located on the outskirts of a city, a considerable distance away from the main road, in a residential area.

Layout and construction

A part plan of the school showing the classrooms for Year 2 and Year 3W is shown in Figure 7.7.1. Good internal space planning has generally ensured that noise sensitive areas have not been placed immediately adjacent to noise producing areas, thus avoiding the need for high performance sound insulating constructions. The dining room and main hall are separated from the nearest teaching rooms by an area which is used for activities such as art. Where there are two adjacent classrooms, storage areas have been created between them to act as a buffer zone. The school is single storey, so impact noise from footfalls and chairs being moved above is not an issue. The partitions are blockwork; the doors are timber hollowcore doors with no seals. The roof construction is not known, but the quiet location means that ingress of external noise is not problematic. All classrooms are naturally ventilated.

The classrooms for Year 2 and Year 3W are adjacent but are separated by store rooms. Both rooms are entered through a common area which is used for art and craft work, for storing teaching aids and as an area in which the classroom assistants can prepare teaching material. This common area is a useful acoustic buffer

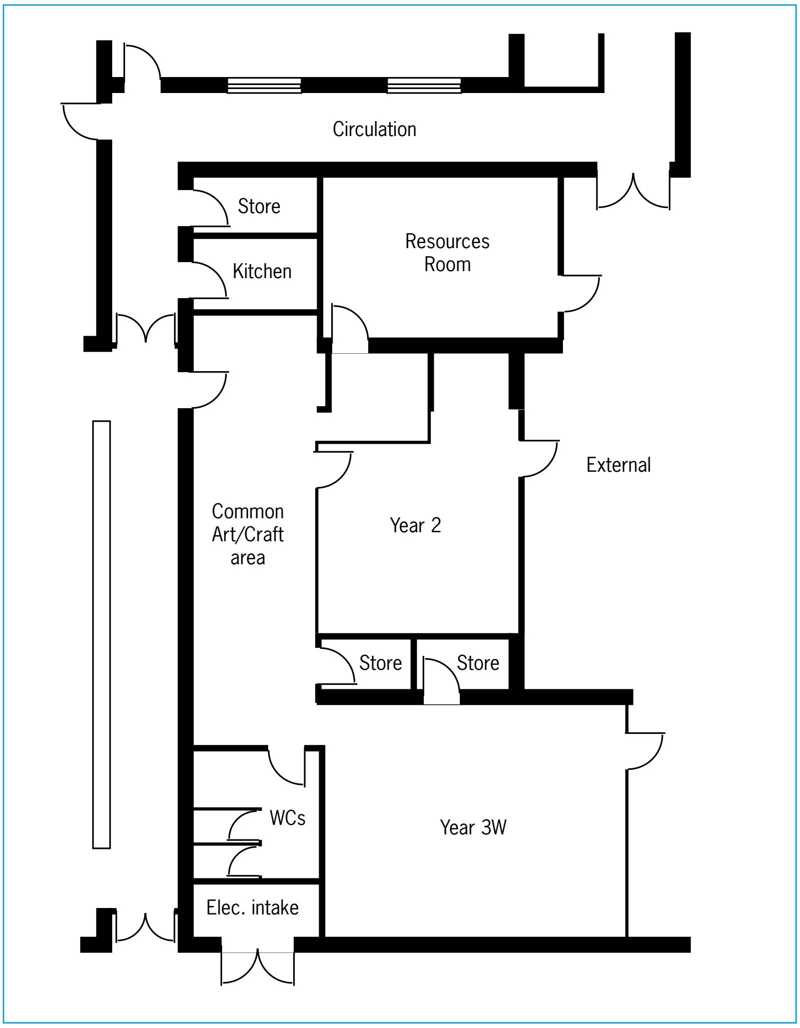


Figure 7.7.1: Part plan of primary school showing Year 2 and Year 3W classrooms

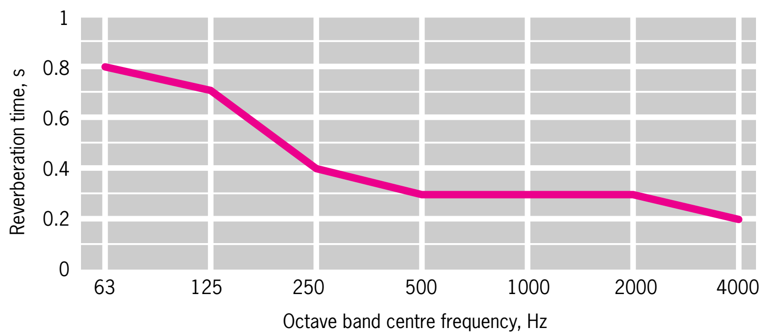


Figure 7.7.2: Measured reverberation time in Year 3W classroom

zone separating the classrooms from the corridor. Despite the fact that the two classrooms have been designed so that noise from one does not disturb teaching in the other, classes were being taught with the doors open between each classroom and the common area. Noise from one classroom was thus clearly audible in the classroom next door.

Surface finishes

In classrooms, surface finishes have been used to control reverberation times. All classrooms have thin carpet on the floors. The pitched classroom ceilings are covered in mineral fibre tiles; these extend down to cover the walls at high level (from the ceiling down to the height of the tops of the doors). The walls have a painted plaster finish with hardboard pinboards dispersed around them.

The amount of absorption provided ensures that the reverberation time is sufficiently short to provide good conditions for speech.

The measured unoccupied mid-frequency RT in the classroom for Year 3W was 0.3 seconds with a rise to 0.7 seconds at 125 Hz. The full spectrum is shown in Figure 7.7.2.

Sound insulation

Sound insulation measurements were carried out between the Year 2 and Year 3W classrooms because these represented a 'worst case' sound transmission configuration, no two other classrooms being located so close together.

The sound insulation between the Year 2 classroom and the common art/craft area via the Year 2 classroom door, which was closed, was also measured.

The BB93 standardized weighted sound level differences, $D_{nT(0.4s),w}$ between Year 2 and Year 3W classrooms and between Year 2 classroom and the common art/craft area were as follows:

Year 2 classroom to Year 3W classroom:

$$D_{nT(0.4s),w} = 53 \text{ dB}$$

Year 2 classroom to common area:

$$D_{nT(0.4s),w} = 18 \text{ dB}$$

Ambient noise levels during lessons

Measurements of ambient noise were made during a desk-based lesson in the Year 2 classroom. A teacher, two classroom assistants and five children were present. Maximum sound levels of 85 dB L_{Amax} were measured. The equivalent continuous sound level was 65 dB L_{Aeq}. Although there was some noise made by the pupils trying to talk, the dominant noise source was due to the teacher talking to the classroom assistants. Noise from the Year 3W classroom was also audible.

Measurements of ambient noise were also made during a physical education lesson in the main hall. The class consisted of a teacher, two assistants and approximately 10 children. Noise levels were very similar to those measured in the Year 2 class; namely a maximum sound level of 84 dB L_{Amax} and an equivalent continuous sound level of 65 dB L_{Aeq}.

Unocupied noise levels

Noise levels were measured in the Year 2 and Year 3W classrooms during a time when the rooms were unoccupied. These results are shown in Table 7.7.1.

The measured values were 40 dB L_{Aeq} in the Year 2 classroom and 29 dB L_{Aeq} in the Year 3W classroom. The dominant noise source in the Year 2 classroom was from the fan on a computer. In Year 3W there was no computer on, but at high frequencies noise from a fluorescent light fitting was dominant.

Discussion

A fundamental issue in the design of rooms for teaching hearing impaired children is the level of background noise which should be allowed. Background noise is amplified by hearing aids and reduces the signal to noise ratio of speech, reducing the effectiveness of the pupils' residual hearing.

The quiet location of the primary school and the absence of mechanical ventilation in the building ensures that indoor ambient noise levels in classrooms (29 dB L_{Aeq} in classrooms without computers) are low. This is lower than the recommended maximum indoor ambient noise level for classrooms for teaching severely hearing impaired pupils (see Table 6.1 of Section 6).

A potential disadvantage of low background noise levels is that there is little masking of intrusive noise, so good sound insulation is essential. The layout of the school has been designed to tackle this by not locating noise-sensitive rooms adjacent to noise-producing rooms.

The sound insulation between the Year 2 and Year 3W classrooms of 53 dB $D_{nT(0.4s),w}$ meets the performance standard in Table 1.2. This would be exceeded between other classrooms in the school which are further apart than the Year 2 and Year 3W classrooms. If teaching were to be carried out with the doors between rooms shut, there would be little risk of noise from one classroom disturbing the class in the adjacent room.

The measured sound insulation of 18 dB $D_{nT(0.4s),w}$ between the Year 2 classroom and the common area is poor and implies that the door is a weak sound insulating element. If a class was being taught in the Year 2 or Year 3W classroom while a separate teaching activity was going on in the common area, then it is highly likely that noise from one would disturb the other. This was not perceived to be a problem by the teaching staff, as the classes were being taught with the doors open. Effective frame and perimeter seals would improve the performance of the doors slightly, but the door constructions would need to be changed to incorporate solid cores in order to significantly improve the sound insulation.

The control of reverberation time is vital, firstly to ensure that speech is intelligible and secondly to prevent an excessive build up of reverberant noise which can impair speech discrimination. The measured classroom mid-frequency reverberation time of 0.3 seconds meets the performance standards in Table 1.5.

It is often recommended that classroom ceilings are sound absorptive around the perimeter but reflective in the centre to aid propagation of the teacher's speech to the rear of the classroom. In this school, the classrooms were very small and pupils sit near the teacher because of the small numbers in each class, so sound propagation to the back of a large classroom is not an issue. In larger classrooms for teaching hearing impaired children, however, a central sound reflective ceiling zone may be advantageous.

Key design points to note are:

- quiet site location, away from any major noise sources such as roads, railways and industrial premises
- separation of classrooms by buffer zones such as store rooms, corridors and lobbies
- use of carpet and sound absorptive ceiling tiles in all classrooms to control reverberation times.

	Octave band centre frequency (Hz)							
	63	125	250	500	1 k	2 k	4 k	8 k
Year 2 L_{Aeq} (dB)	38	33	44	37	33	29	23	20
Year 3W L_{Aeq} (dB)	39	28	22	17	17	17	25	25

Table 7.7.1: Measured unoccupied noise levels in classrooms

7.7 Case Study: An all-age special school for hearing impaired children

A special unit in a mainstream secondary school

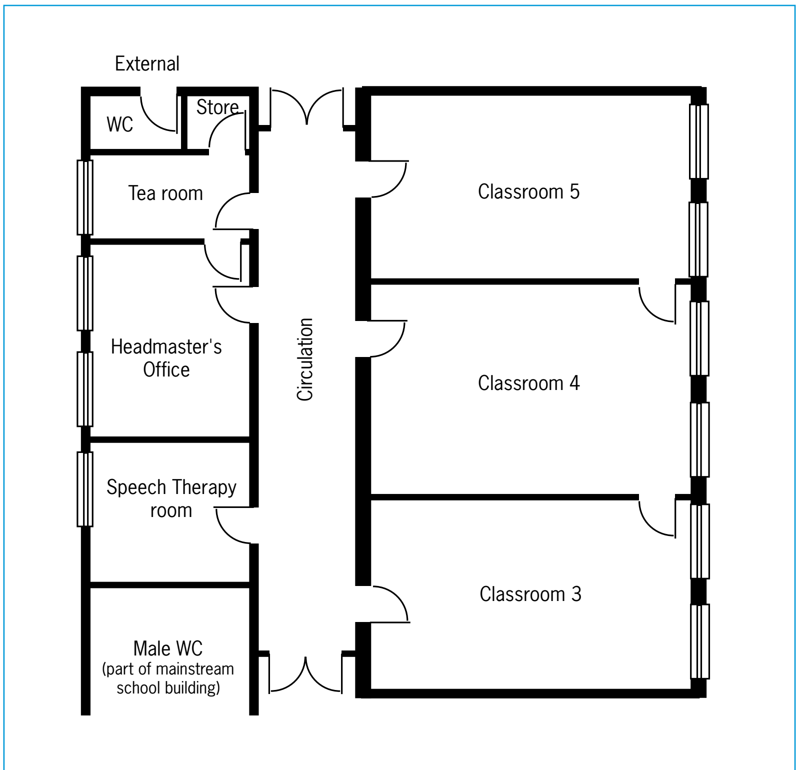
The special unit for hearing impaired pupils is located in a refurbished block of the mainstream secondary school and consists of six teaching classrooms, the resources area, a speech therapy room and an office for the headteacher of the unit.

When in the special school unit, pupils are taught in small class groups. Pupils are encouraged to communicate using sign language, lip-reading, speech and residual hearing with the help of hearing aids. For 30% of the time, hearing impaired pupils are taught in integrated classes in the mainstream school.

The special school unit forms an interesting comparison with the primary age part of the same school which is located in a nearby primary school, and is some 20 years older.

The unit was visited only four months after it was opened. During the visit, discussions were held with the headmaster of the hearing impaired unit to obtain his opinions on its acoustics. Measurements of background noise, reverberation time and sound insulation were carried out.

Figure 7.7.3: Ground floor plan of secondary school unit for hearing impaired pupils



Location

The secondary unit is surrounded on three sides by open countryside, and is far from any main roads. The unit is at one end of the school, so that the potential for noise break-out from other classrooms is minimised. Background noise levels on the site are low.

Layout and construction

The special school accommodation is divided between the ground and second floors, with mainstream accommodation in between on the first floor. Figure 7.7.3 shows the plan of the ground floor.

Unlike the primary school, classrooms are located immediately adjacent to each other with no non-sensitive buffer zones in between. Partitions between adjacent classrooms are studwork and consist of one layer of 12.5 mm plasterboard and one layer of 19 mm plasterboard on each side of a 48 mm stud. The partition between the headmaster's office and the speech therapy room is built of staggered 70 mm studs with two layers of 15 mm plasterboard on each side and mineral wool in the cavity. The partitions have been built to full height up to structural slab level. The headmaster complained, however, that there were gaps at the partition heads which reduced the sound insulation of the partitions, meaning that sound from one classroom could often be heard in the adjacent room. Examination of the partition heads revealed that pipe penetrations of the partitions had not always been properly sealed.

In many cases adjacent classrooms have connecting doors. All the doors in the special school are single solid core timber doors of 40 - 50 mm thickness with wiper seals acting on a raised timber threshold and compression frame seals. External windows are double-glazed with a deep cavity (approximately 200 mm) and are openable via a sliding casement mechanism.

The party walls between the specialist school and the adjoining mainstream school accommodation are masonry.

The first floor mainstream classrooms have been carpeted to reduce impact noise transmission to the ground floor classrooms, although the carpet has only a thin pile and does not appear to have underlay beneath it. Floor slabs are of concrete. No mechanical ventilation is provided.

Surface finishes

All the classrooms have thin pile carpets and mineral fibre suspended ceilings. The plasterboard walls have a sound reflective finish. Pinboards on the walls are timber, backed by an airspace and provide some control of low frequency reverberation times. The speech therapy room also has a thin carpet and a suspended mineral fibre tile ceiling. The amount of absorption provided ensures that the reverberation time is sufficiently short to provide good conditions for speech.

Reverberation time

The measured unoccupied mid-frequency RT of classroom 4 was 0.4 seconds with a small rise to 0.5 seconds at 125 Hz.

The measured unoccupied mid-frequency RT of the speech therapy room was 0.3 seconds with a flat spectrum down to 125 Hz.

Sound insulation

Sound insulation measurements were carried out between classrooms 4 and 5 which are horizontally adjacent.

The weighted BB93 standardized level difference between classrooms 4 and 5 was 34 dB $D_{nT(0.4s),w}$.

The sound insulation between several other areas was also measured and the following weighted BB93 standardized level differences obtained:

- classroom 5 to mainstream classroom directly above: $D_{nT(0.8s),w}$ = 48 dB
- headmaster's office to speech therapy room: $D_{nT(0.4s),w}$ = 47 dB
- male toilets to speech therapy room: $D_{nT(0.4s),w}$ = 52 dB

Unoccupied noise levels

Noise levels were measured in classroom 4 and the speech therapy room during a time when the rooms were unoccupied, but when there were staff elsewhere in the building. The noise spectra are shown in Table 7.7.2.

The corresponding indoor ambient noise levels are 26 dB L_{Aeq} in classroom 4 and 19 dB L_{Aeq} in the speech therapy room. The dominant noise sources in classroom 4 were a faint buzzing noise from the radiator and from fluorescent light fittings. Talking in other classrooms in the unit was just audible. The main noise sources in the speech therapy room were a clock ticking and a fluorescent light fitting buzzing. The headmaster's voice as he talked on the telephone in his office next door was clearly audible although the words were not intelligible. It should be noted that at high frequencies the reported octave band noise levels in the speech therapy room were actually due to electrical noise in the sound level meter; actual noise levels were probably lower.

Discussion

Measured noise levels in a typical classroom and the speech therapy room were very low (26 dB L_{Aeq} and 19 dB L_{Aeq} respectively) and are lower than the recommended noise levels in Table 6.1. This is appropriate in rooms in which hearing impaired pupils are taught, to ensure good speech signal to noise levels. There was no unpleasant tonal content in the frequency spectra.

Very low unoccupied ambient noise levels mean that any extraneous noise intrusion will be especially audible. The site location and high performance external windows ensure that noise ingress from outside does not cause problems. The teaching staff have, however,

	Octave band centre frequency (Hz)							
L_{eq} (dB)	63	125	250	500	1 k	2 k	4 k	8 k
Classroom 4	34	30	29	18	22	13	12	13
Speech therapy room	28	23	15	12	12	11	11	12

Table 7.7.2: Measured unoccupied noise levels in Classroom 4 and the speech therapy room

complained about the sound transmission between horizontally adjacent rooms. The sound insulation appears to be of a lower standard than they had expected in a new purpose-built unit. These subjective comments are borne out by the results of the objective sound insulation measurements. The $D_{nT(0.4s),w}$ of 34 dB measured between classrooms 4 and 5 is lower than that required for classrooms in mainstream schools. Where background noise levels are low, hearing impaired pupils cannot discriminate between intrusive noise and speech as easily as pupils with full hearing, and a higher standard of sound insulation is needed. A minimum $D_{nT(0.4s),w}$ value of 50 dB is required, see Table 1.2.

Measurements showed that the sound insulation performance of the partition did not rise at high frequencies as would normally be expected. This confirms the existence of small gaps which were found at the partition heads. Notwithstanding this, the mid frequency level difference across the partition is poor (between 30 dB and 35 dB). This indicates that the studwork partition selected was not of a sufficiently high performance. A partition with staggered studs, increased plasterboard thicknesses and mineral wool in the cavity would provide a higher standard of sound insulation. The overall sound insulation performance between adjacent classrooms is, however, ultimately limited by the communicating door. Although the doors are of a very high standard (this is discussed further below) they are still a weak sound insulation element. Whilst this may not be a serious problem between classrooms and the corridor, the presence of doors between classrooms is inconsistent with the requirement for a high standard of sound insulation. Connecting doors are not recommended.

The sound insulation measured between the headmaster's office and the speech therapy room was 47 dB $D_{nT(0.4s),w}$. This is below the performance standard in Table 1.2 for sound insulation between an office and a speech therapy room. The headmaster had complained that he was sometimes disturbed by noise from the speech therapy room and whilst in the unoccupied room the headmaster's voice was audible but not intelligible. This level of privacy means that although the headmaster's conversations would remain confidential, intrusive noise may disturb the concentration of both the headmaster and of users of the speech therapy room. A higher standard of studwork wall construction between rooms may have been considered to be impracticable in the special school design. An alternative solution would have been to locate non-sensitive acoustic buffer zones, such as storage areas, between the headmaster's office and other noise producing rooms.

A value of 48 dB $D_{nT(0.4s),w}$ was measured from one of the ground floor classrooms for hearing impaired pupils to the mainstream classroom directly above it on the first floor. This is an appropriate standard of sound insulation for the mainstream classroom and no complaints have been made by the teaching staff.

Visual inspection of the doorsets confirmed that they were of suitable quality and likely to meet the 30 dB R_w sound insulation specification for doorsets in Table 1.3.

Reverberation times in the classrooms are well controlled due to the provision of acoustic absorption on the floors and ceilings. The mid-frequency RT of 0.4 seconds meets the performance standards in Table 1.5. The wooden wall panels help to control the RT at low frequencies, on which hearing impaired people often rely for information. The teaching staff judged the classroom acoustics to be satisfactory.

The RT in the speech therapy room is also well controlled due to the carpet and mineral fibre suspended ceiling. The mid-frequency value of 0.3 seconds meets the performance standards in Table 1.5.

Conclusions

The acoustic design of the special school unit is good, in terms of room acoustics and unoccupied noise levels, although there are some deficiencies in the sound insulation provided by the party wall constructions.

Key points to note are:

- The site is in a quiet location, away from any major noise sources such as roads, railways and industrial premises.
- Communicating doors between adjacent classrooms limit the sound insulation that can be achieved and are inconsistent with the need for low levels of intrusive noise.
- Partitions are full height, but poor workmanship has resulted in small gaps at partition heads.
- Sound transmission problems between the headmaster's office and the speech therapy room could have been avoided by better space planning.
- Use of carpet and sound absorptive ceiling tiles in all classrooms and the speech therapy room helps to control mid-frequency reverberation times.
- Wooden pinboards backed by an airspace help to control low frequency reverberation times.
- First floor classrooms are carpeted which reduces impact noise transmission. However, there was no underlay which would have reduced the impact transmission further.

Audiology room

In the primary school for hearing impaired children there is an audiology facility, which consists of a technician's room and an audiometric test room.

The tests carried out in the audiometric test room are generally carried out in the ambient acoustic field rather than using headphones. Activities range from testing hearing saturation levels and hearing aid discomfort (during which high noise levels of up to 90 dB(A) are generated in the room) to testing for speech discrimination against background noise, which requires low ambient noise levels.

Measurements were carried out of indoor ambient noise, sound insulation and reverberation time in the audiology suite. In addition, a discussion was held with the audiologist who uses the suite to obtain his opinion of the suitability of the acoustics.

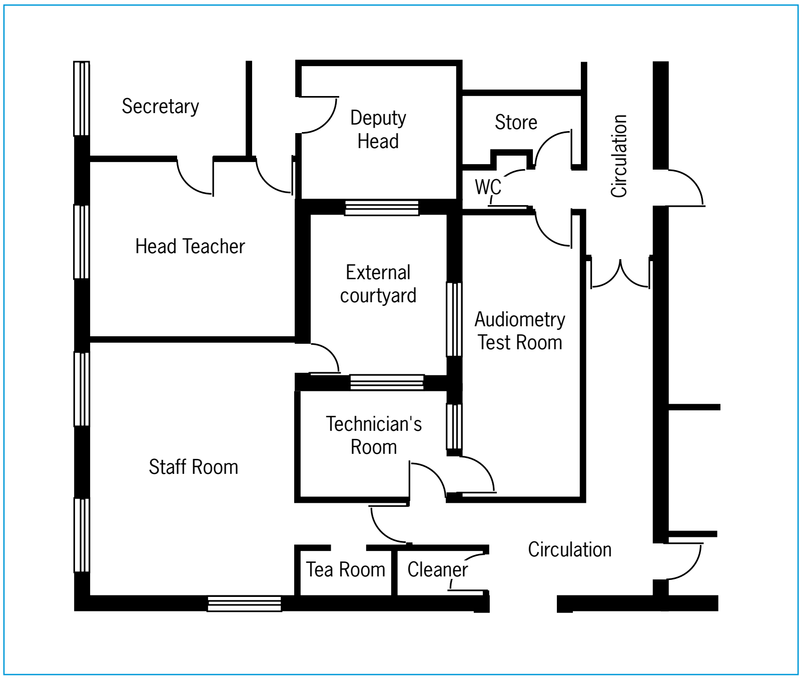
Layout and construction

The location of the audiology suite within the primary school is shown in Figure 7.7.4. The audiometric test room is entered directly from the corridor. The test room also has an external wall and a window onto an enclosed courtyard.

The walls of the audiometric test room are a single skin of 100 mm thick blockwork of an unknown density. The single leaf doors into the technician's room and the corridor are a hollowcore timber construction with no frame or threshold seals. Noise from the corridor was clearly audible in the test room. There is a fixed double glazed window between the test room and the technician's room which incorporates a deep acoustic cavity between the panes of glass. The external window which looks onto the courtyard is single glazed and is openable.

The roof construction is not known, but the quiet site location means that ingress of external noise is not problematic. There is no mechanical ventilation system.

Figure 7.7.4: Plan of audiology facility



Surface finishes

The audiometric test room is carpeted and has a mineral fibre suspended ceiling. Apart from where there are windows or doors, the entire wall area is also lined with mineral fibre tiles. Subjectively, the room is very dead acoustically.

Audiologist's opinion

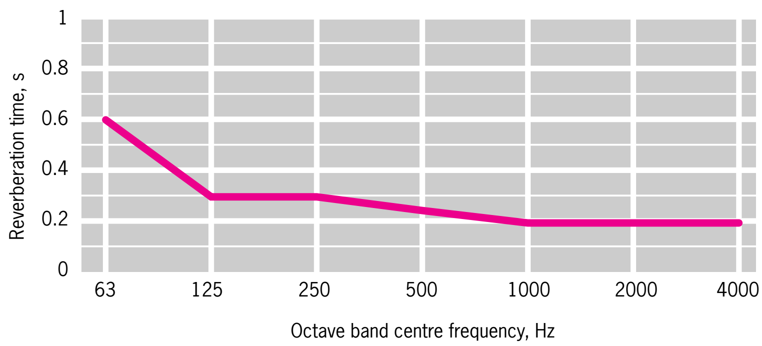
The audiologist finds intrusive noise very disturbing to his work, particularly when he is carrying out tests of speech discrimination against background noise. This means that the times when he can carry out certain measurements are determined by possible activity in the corridor. When there is no activity in the corridor, the background noise levels in the room are sufficiently low for his tests.

Conversely, when loud noises are generated in the audiometric test room (for example when hearing aid discomfort is being tested), these can clearly be heard in the corridor, although this does not cause disturbance to teaching.

The audiologist did not express any dissatisfaction with the internal room acoustics, but noted that achieving low ambient noise levels should be a first priority when designing audiology facilities and that good room acoustics were worthless without sufficiently low background noise levels or good enough sound insulation.

[1] 'Acoustics: Audiology', Health Technical Memorandom 2045, HMSO, 1996.

Figure 7.7.5: Measured reverberation time in audiometry test room



Acoustic measurements

Reverberation time

The unoccupied mid frequency reverberation time, T_{mf}, in the audiometric test room was 0.2 seconds with a small rise to 0.3 seconds at 125 Hz. The RT across the frequency spectrum is shown in Figure 7.7.5.

Sound insulation

The sound insulation measured between the technician's room and the audiometry test room was 36 dB $D_{nT(0.4s),w}$.

Unoccupied noise levels

Noise levels were measured in the audiometry test room when the room was unoccupied. The results are shown in Table 7.7.3.

The noise level corresponds to an A-weighted sound pressure level of 21 dB L_{Aeq}. The dominant noise source was water running through the radiator. Voices in the corridor outside were audible. It should be noted that at high frequencies the reported octave band noise levels in the audiometry test room were due to electrical noise in the measurement system; actual noise levels would have been lower.

Discussion

Guidance for the acoustic design of audiology facilities in hospital audiology departments is given in Health Technical Memorandum 2045 "Acoustics: Audiology"[1], but the suite in the school is used for educational audiology and as such is provided by the County in which the school is situated rather than by the Health Service.The guidance includes maximum permissible ambient sound pressure levels in third octave bands and reverberation times for audiometric test rooms, depending on the audiometric tests which will be carried out in the rooms. Because the use of each audiometric facility is specialised, the end users of any facility should be consulted and reference made to HTM 2045[1] before the acoustic design of a facility is undertaken.

In this test room the background noise

	Octave band centre frequency (Hz)							
L_{eq} (dB)	63	125	250	500	1 k	2 k	4 k	8 k
Audiometry test room	35	24	21	17	12	10	11	13

Table 7.7.3: Measured noise levels in audiometry test room, unoccupied

levels are sufficiently low for the audiologist to carry out his tests. The background noise spectrum does not contain any unpleasant tones, due to the quiet nature of the school site.

The limited sound insulation afforded by the single leaf masonry wall and the poor quality single door mean that intrusive noise levels in the test room are high when there is activity in the corridor. The high intrusive noise levels disrupt the audiologist's work. An appropriate sound insulation performance for the wall between the test room and the corridor would be very dependent on the specific requirements of the audiologist and the school, but it is likely that a double leaf masonry wall construction plastered on both sides (each leaf at least 415 kg/m^2 including plaster) would be the minimum required. The door from the corridor into the test room is a weak sound insulation element and would limit the performance of any upgraded wall construction. The best solution would be to allow entry to the test room only via the staff room and technician's room. Failing this, a lobbied door arrangement would be required.

HTM 2045 recommends that reverberation times at all frequencies between 125 Hz and 4 kHz are between 0.2 seconds and 0.25 seconds in audiology test rooms. The measured reverberation times are generally within this range, given the accuracy of the on-site measurements. Thus the reverberation time in the test room has been well controlled by the selection of surface finishes. Recommendations are also made for reverberation times in third octave bands from 31.5 Hz to 100 Hz. Due to the small size of the test room, reverberation times could not be measured accurately at these low frequencies.

Conclusions

Although background noise levels are low and the reverberation time is well controlled, the poor sound insulation means that the test room is unsatisfactory for its purpose.

Key points to note are:

- The site is in a quiet location, away from any major noise sources such as roads, railways and industrial premises, so background noise levels are low.
- The audiometric test room is poorly located adjacent to a noisy corridor.
- The 100 mm blockwork wall between the test room and the corridor is insufficient in controlling noise intrusion.
- The single door between the test room and the corridor is a weak sound insulation element.
- The reverberation time is well controlled by the use of carpet, a mineral fibre tile suspended ceiling system and mineral fibre tiles on all the walls.

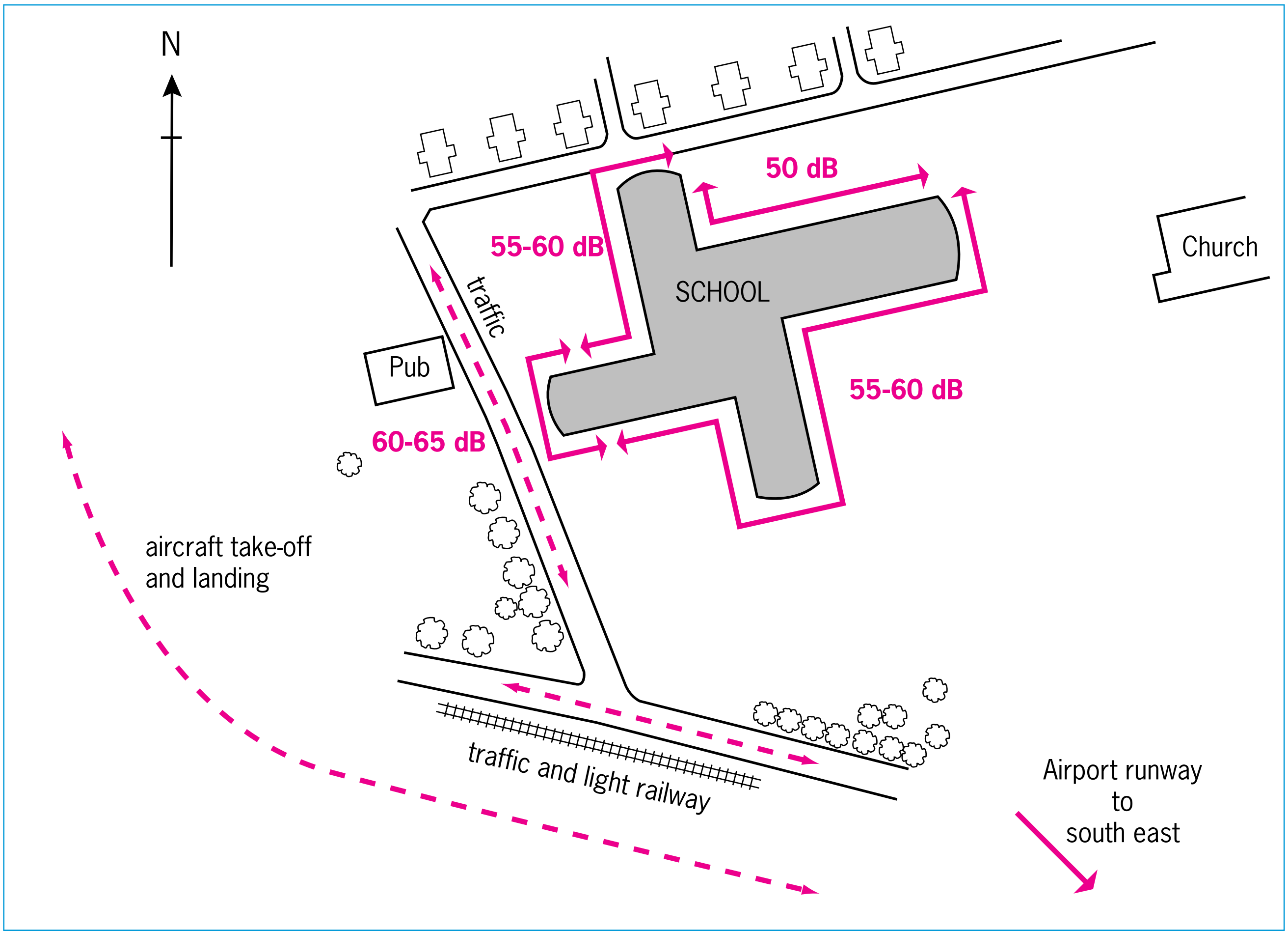


Figure 7.8.1: Site plan showing external noise levels, L_{Aeq}

Figure 7.8.1 shows a site plan, based on the site survey carried out at the start of the project. The high external noise levels are generated by low-flying aircraft and traffic on nearby busy roads. One option would have been to acoustically seal the building envelope and mechanically ventilate the building. However, this was too expensive for the available budget. The design team also wished to reduce lifetime costs and opted for a naturally ventilated building which would maintain the same internal noise levels.

Being an inclusive school, the design had to accommodate pupils and other members of the community with hearing problems. The target for background noise was set at 35 dB(A). At the same time the design had to provide fresh air at a rate of up to 8 litres per second for each of the usual number of occupants. This equates to approximately 4.5 air changes per hour in both ground and first floor classrooms.

Standard products such as attenuated trickle ventilators inserted into window openings, as are often used in housing, would not have achieved the required air flow rates. Alternative purpose designed systems were therefore required.

Classrooms are naturally ventilated by means of inlet vents under the external windows and passive stacks located at high level at the rear of the rooms, adjacent to the central corridors. The inlet louvres duct air into the classrooms via grilles just inside the perimeter convector grilles. These inlet grilles are controlled by classroom users by easy to operate openable flaps covering the grilles.

Both inlets and outlets are acoustically insulated to prevent the entry of external noise.

Depending on the prevailing weather, wind driven or temperature driven ventilation provides sufficient fresh air.

- The more windy the weather, the greater the pressure difference across the building envelope and the greater the air

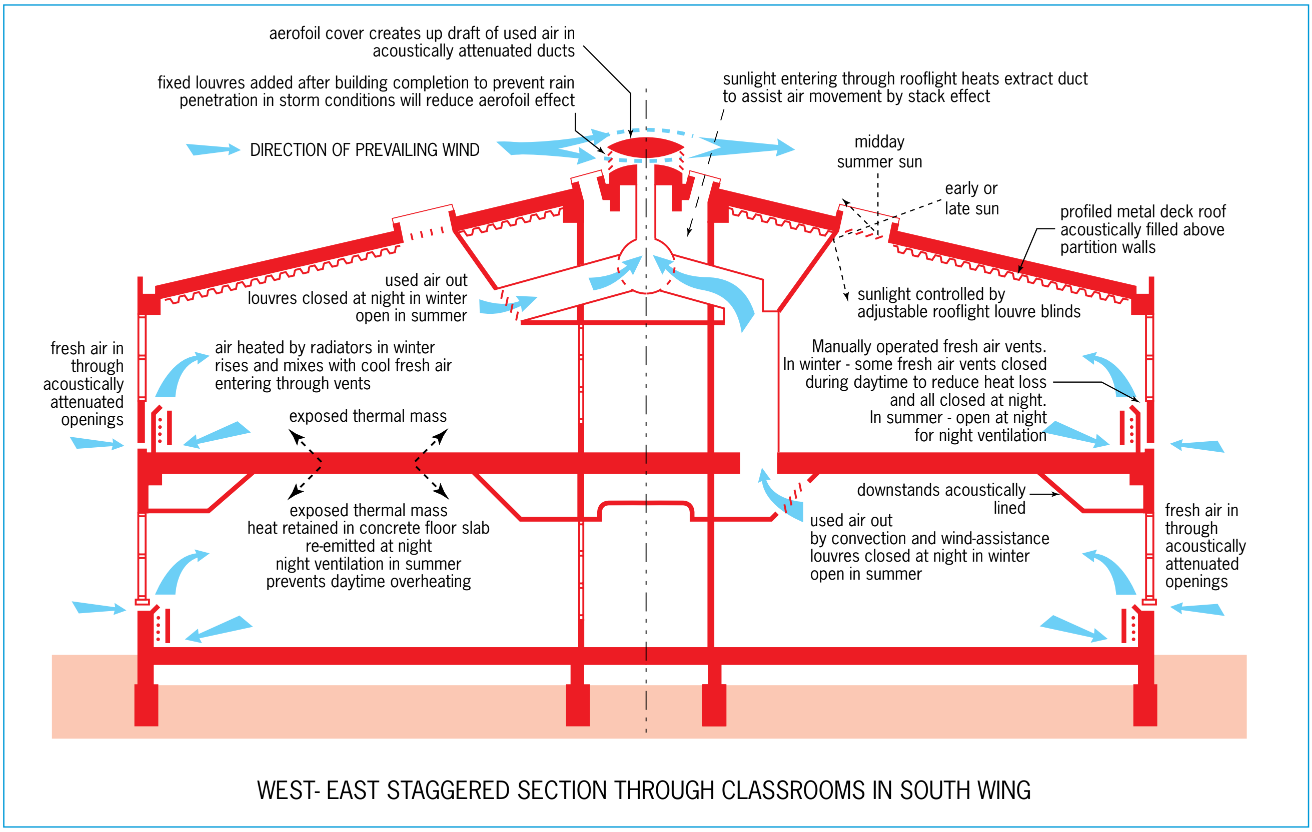


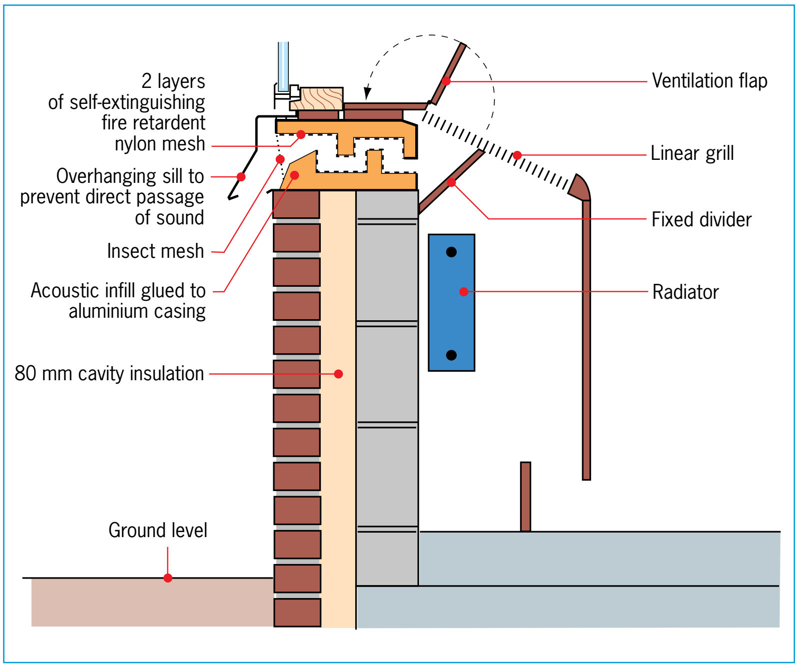
Figure 7.8.2: Schematic diagram of ventilation paths through two storey section of building

movement in the ducts.

- The temperature difference when the internal spaces are warmer than outside, as in winter, drives the stack effect ventilation causing air to rise up the central ducts.
- The central ducts which leave the back of the classrooms join into a combined duct over the first floor corridor which then rises to the outlet at roof level. The passive stack effect is enhanced by providing roof glazing over the combined section of duct which is painted black and encased over a drop ceiling area in the corridor. Solar gain raises the air temperatures in the top section of ductwork causing the air to rise. This is particularly effective in hot weather.
- An aerofoil is positioned at the duct outlet to enhance the wind driven stack effect. The problem of wind blown rain in storm conditions led to modification of the aerofoils to incorporate louvres beneath the aerofoil sections. This will probably have made the aerofoils on their own considerably less effective.
- The windows are openable and are designed to increase the maximum possible ventilation rate so that when the wind and stack driving forces are small there will still be adequate ventilation, although this will obviously let in some ambient noise.

The ventilation system is completely under the control of the occupants in individual spaces, who can open and close flaps over the inlets below the windows

Figure 7.8.3: Ground floor air vents



and high level adjustable louvres at the back of the classrooms, controlled by a short pole.

Ground floor vents (Figure 7.8.3) and first floor vents (Figure 7.8.4) are of different design. These proprietary/purpose designed external vents on the window walls are acoustically insulated.

The airborne sound insulation of prototype ground floor and first floor ventilators was tested in the laboratory. The resulting element-normalized level differences in octave bands and the resulting $D_{n,e,w}$ values are shown in Table 7.8.1. As a result of these tests, the ground floor vent design was modified to improve its performance. This included the addition of an overhanging sill and extended internal nibs of sound absorbing material. The final design, shown in Figure 7.8.3, appears as effective acoustically after installation as the first floor vents.

The passive stacks are acoustically lined which prevents cross-talk between classrooms which share the same discharge ductwork. Four classrooms are ventilated via one final extract duct.

Air flow tests were carried out in typical classrooms. These showed that on a typical spring day, with a moderate wind (10-15 kph), with all the vent flaps and louvres open, air entered at between 0.8 and 1.6 m/s depending on location within the building, and left through the high level louvres at between 0.3 and 0.7 m/s, again depending on location. This corresponds to a fresh air rate of 5.3 air changes per hour.

Metal deck roof

The roof structure, from outside in, is as follows:

- 0.9 mm gauge stucco embossed aluminium external covering
- 120 mm (compressed to 110 mm) thermal insulation
- 30 mm acoustic insulation
- vapour control layer
- 0.9 mm gauge polyester powder coated steel (internal support decking).

There is no void within the roof except between the profiles of the support decking. The profile voids are filled at partition lines with inserts of acoustically absorbent material.

There is some flanking transmission through the continuous profiled steel roof construction, which reduces the sound insulation between rooms.

Concrete floor

At first floor level, the floor finish on the precast concrete floor is a steel mesh reinforced sand/cement screed on 50 mm thick acoustic mineral wool board, which prevents the transmission of impact sound to the ground floor rooms below.

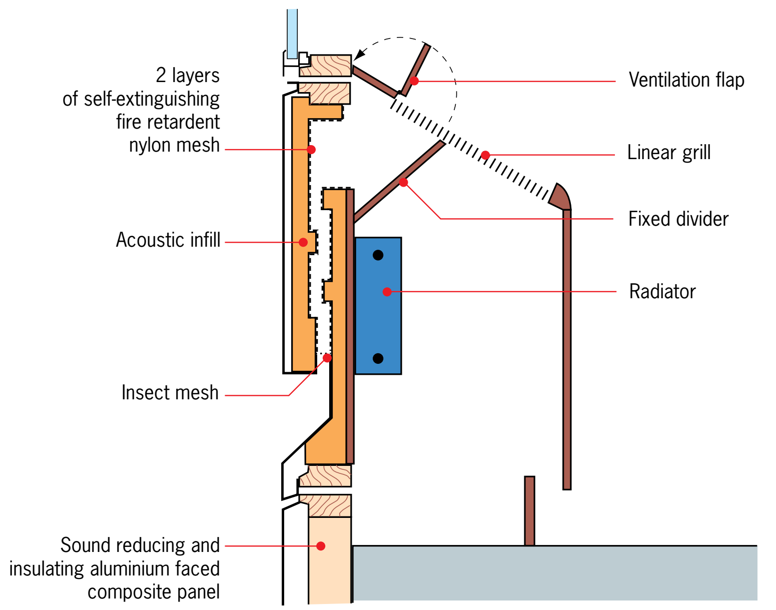


Figure 7.8.4: First floor air vents

Table 7.8.1: Element-normalized level differences for prototype ground floor and first floor vents

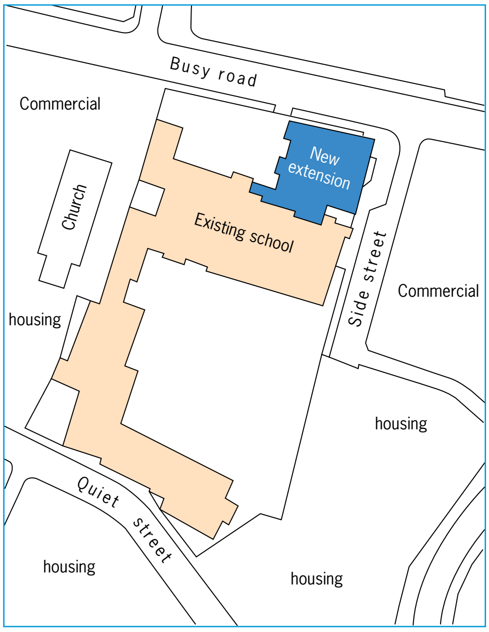
	Octave band centre frequency (Hz)								
$D_{n,e}$ (dB)	63	125	250	500	1 k	2 k	4 k	8 k	$D_{n,e,w}$ (dB)
Ground floor vent	28.0	21.6	22.5	25.8	40.8	57.9	54.0	53.9	33
First floor vent	24.5	19.6	22.2	28.4	42.2	50.8	53.4	53.0	34

Internal partitions

Internal partitioning generally uses two layers of 12.5 mm plasterboard each side of metal studs, with quilt in the cavity, giving a construction width of 200 mm. Laboratory test results for this form of construction indicate a sound reduction index of 52 dB R_w. Performance on site is usually at least 5 dB less than this. Tests carried out on site show a considerable variation in performance, from 44 dB to 38 dB D_w. The walls therefore meet the standard of 38 dB for classrooms given in Building Bulletin 87, that was required at the time of the design. However some fail to meet the 43 dB D_w design target for the project, which is lower than the present standard given in Table 1.2. There are a number of causes of the performance loss. On the first floor, flanking sound carried through the lightweight roof was seen to be a contributory factor, despite the use of fillers in the profile voids. However, the best performance was also recorded in one of the first floor rooms. A reduction in insulation was found in some ground floor rooms where partitions directly abut the precast concrete first floor. The conclusion was that variability in construction standards, rather than detailing, was the key factor.

Generally, staff and pupils at the school do not consider noise between spaces to be a problem, and are happy with the acoustics.

Classrooms are provided with acoustic treatment in specific ceiling areas to bring the mid-frequency reverberation times below 0.8 seconds. At first floor level, this is provided at the rear of the rooms, over the sloping soffit which encloses services and also helps to reflect daylight from the rooflights into the back of the room. On the ground floor, suspended ceilings run along both sides of classrooms to enclose services and cut off indirect sound paths. In the centre, the first floor precast concrete floor slab is exposed to absorb re-radiated solar radiation and to reinforce direct speech sound paths.



The site plan shows that the new extension is adjacent to a heavily polluted inner city road. The road is a very busy two lane highway and is the main source of noise in the area.

Acoustic design

The acoustic design was based on the noise limits recommended in Building Bulletin 87(BB87) of 40 dB $L_{Aeq,1h}$ in classrooms and not more than 50 dB $L_{Aeq,1h}$ in a gymnasium. These values are now superseded by the performance standards in Section 1 of Building Bulletin 93.

Noise survey

Noise surveys were carried out on site before and after the completion of the new extension. The aim was to establish the external noise levels and use these data to calculate the required sound insulation for the building envelope.

The measured free-field external noise level was 70 dB L_{Aeq}. The major source of noise was road traffic on the very busy main road.

The rooms with most exposure to road traffic noise are:

Ground Floor: Gymnasium

First Floor: Language classrooms 1, 2 and 3

Second Floor: Mathematics classrooms 2, 3, 4 and 5 and ICT rooms 1 and 2.

Sound insulation of the building envelope

The noise levels to which various parts of the building envelope would be exposed were calculated by extrapolation from the baseline noise measurements according to the Calculation of Road Traffic Noise. Design calculations of internal noise levels were made on an iterative basis to determine required acoustic specification of the windows, the roof and the wind scoop system so that background noise levels given as guidance in BB87 would not be exceeded.

The building envelope comprised:

- walls: part brick/block cavity, part blockwork with a terracotta tile rain screen and mineral fibre in the cavity
- windows: double glazing incorporating 10 mm and 6.4 mm laminated glass
- main roof: proprietary double skin steel roofing system (38 dB R_w)
- mansard roof: proprietary roofing system, supplemented by an internal plasterboard lining with mineral fibre infill
- roof lights: double glazing incorporating 4 mm glass.

Recommendations were given for the attenuation of external noise through the wind scoop system. It was recognised that new measures to attenuate external noise might affect the airflow characteristics and therefore any suggestions would need to be confirmed by the manufacturer.

The manufacturer of the wind scoop system arranged for acoustic tests to be undertaken in a UKAS test laboratory. A number of different internal lining treatments were tested. The results are summarised in Table 7.9.1.

Initial calculations for the classrooms indicated that a 5 m length of lined duct would provide sufficient attenuation to reduce the internal noise to approximately 40 dB L_{Aeq}. For classrooms on the second floor, the wind scoop ducts were not long enough and it was necessary to increase the attenuation by fitting an additional attenuator. For classrooms on the lower floors the length of the wind scoop duct was sufficient and no additional attenuator was required. The proposed duct details are summarised in Table 7.9.2.

7.9 Case Study: Acoustically attenuated passive stack ventilation of an extension to an inner city secondary school

Table 7.9.1: Laboratory measurement data for the airborne sound insulation of the wind scoop system

Test element	$D_{n,e,w}$ (C;C_{tr}) (dB)
620 mm x 620 mm square hole	13 (0;0)
Vent, unlined with dampers open	16 (0;0)
Vent, unlined with dampers closed	26 (0;-1)
Vent lined with acoustic tile, dampers open	26 (0;-3)
Vent lined with acoustic tile, dampers closed	35 (-1;-5)
Vent lined with open cell foam, dampers open	26 (0;-3)
Vent lined with open cell foam, dampers closed	35 (-1;-4)
Vent lined with open cell foam, linear ceiling grille fitted	27 (-1;-4)

Table 7.9.2: BB87 background noise levels and proposed duct details

Classroom	Floor	BB87 background noise levels $L_{Aeq,1hr}$ (dB)	Treatment
Mathematics 2, 3, 4 and 5	2	40	Internal acoustic lining plus 500 mm attenuator
ICT 1 and 2	2	40	Internal acoustic lining plus 1800 mm attenuator
Languages 1, 2 and 3	1	40	Internal acoustic lining
Gymnasium	Ground	50	Thermal insulation only to blockwork ducts

Post-completion measurements of indoor ambient noise levels

Following completion of the building, measurements of the indoor ambient noise levels were carried out at a number of different locations in each room and averaged. Simultaneous measurements were taken of the free-field external noise level which was 70.6 dB $L_{Aeq,5h}$ and within 1 dB of the level measured prior to development. The measurement results are summarised in Table 7.9.3 where they are compared with the design targets and predicted values.

The measured results in the Gymnasium, Languages 1, Mathematics 2 and Mathematics 3 were found to meet the design limits. The failure to meet the internal noise limit in Languages 3, ICT 1 and ICT 2 can be explained by the factors noted in the comments column, that is, excessive noise transmission via unsealed window frames and the noise from computer fans in the operational ICT rooms.

Internal noise measurements were also

Table 7.9.3: Comparison between the BB87 background noise levels, calculated and measured indoor ambient noise levels

Room	BB87 background noise levels $L_{Aeq,1h}$ (dB)	Calculated $L_{Aeq,1h}$ (dB)	Measured $L_{Aeq,1h}$ (dB)	Comments
Gym	50	45	42	Significant flanking transmission around escape door
Languages 1	40	37	38	
Languages 3	40	40	43	Some window frames not yet sealed
Mathematics 2	40	39	38	
Mathematics 3	40	40	38	
Mathematics 4	40	41	41	
ICT 1	40	42	44	Computer noise present
ICT 2	40	33	42	Computer noise present

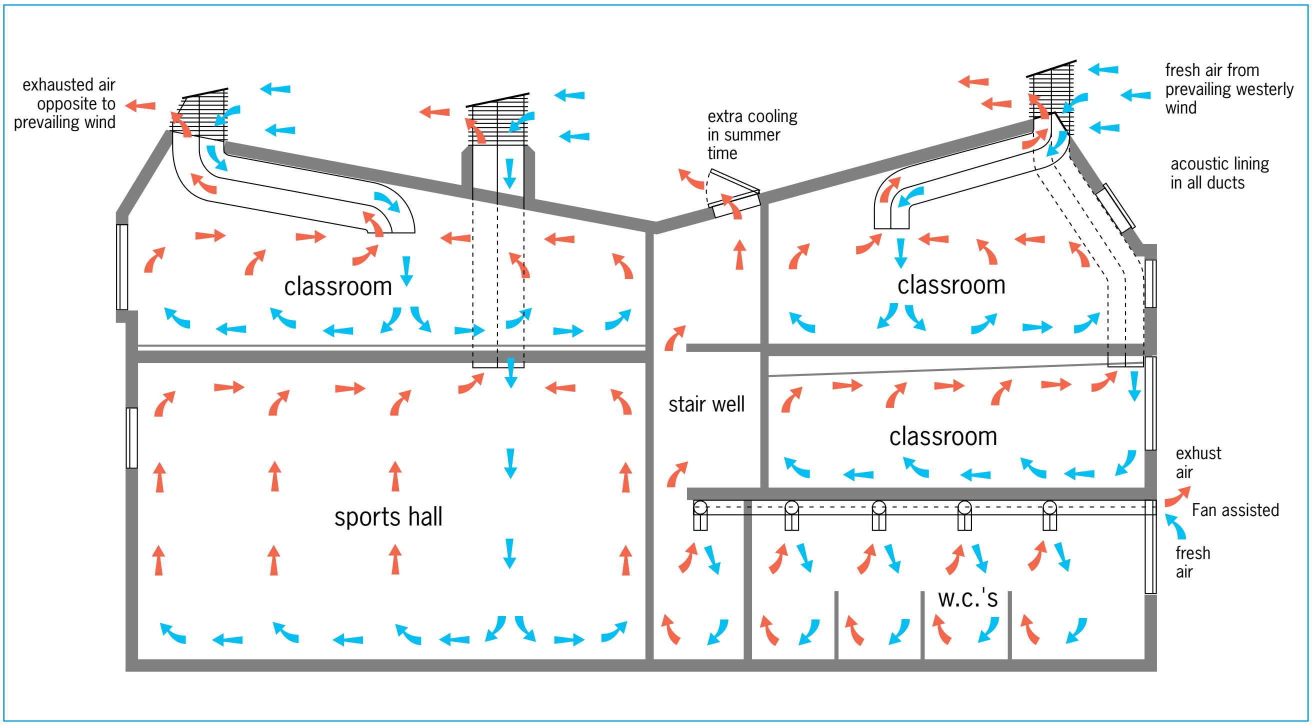


Figure 7.9.1: Section through new extension shows stack ventilation in operation

carried out with the ventilation system open and closed. The results did not display any significant change in level nor was there any significant variation in the sound pressure level around the room.

Ventilation design

The close proximity of the road meant that open windows could not be used for ventilation because road traffic noise would cause problems and airborne pollutants emitted by the heavy road traffic could be carried into the building through low level open windows.

The rooms exposed to traffic noise are therefore ventilated using a wind scoop system with the exception of a manager's office which is provided with a noise-attenuated ventilator unit. This type of unit was originally developed to comply with the requirements of the Noise Insulation Regulations 1975. The unit either comprises a variable speed powered ventilator which is designed to be installed in the building façade and a permanent air vent, or it may be a single unit which combines both. There are normally two speed settings and the Regulations set limits on noise transmission through the units and the self noise of the fan.

The acoustic consultant suggested that attenuated ventilators should also be fitted in Mathematics classroom 1, the Mathematics office and the staff room as opening the windows in these rooms would result in noise levels exceeding the BB87 guidance of 40 dB $L_{Aeq,1hr}$.

Taking into account the characteristics of the new building and site conditions, adequate ventilation has been achieved as described below.

(i) Teaching areas (Classrooms, ICT Rooms, Science Laboratory and Gymnasium)

All new teaching spaces are naturally ventilated by a wind scoop type system through terminals mounted at roof level. The roof terminals are designed to be omni-directional allowing the intake of fresh air regardless of the prevailing wind direction. Each terminal is divided into equal quadrants; two are positively pressurized by the wind to create a fresh air intake, the remaining two on the leeward side are negatively pressured allowing stale air to be exhausted.

Air is ducted from the terminals either directly into the second floor rooms or down to the ceiling of the first floor classrooms and gymnasium. Each terminal

Fugure 7.9.2: The roof terminals, viewed from inside during construction

7.9 Case Study: Acoustically attenuated passive stack ventilation of an extension to an inner city secondary school

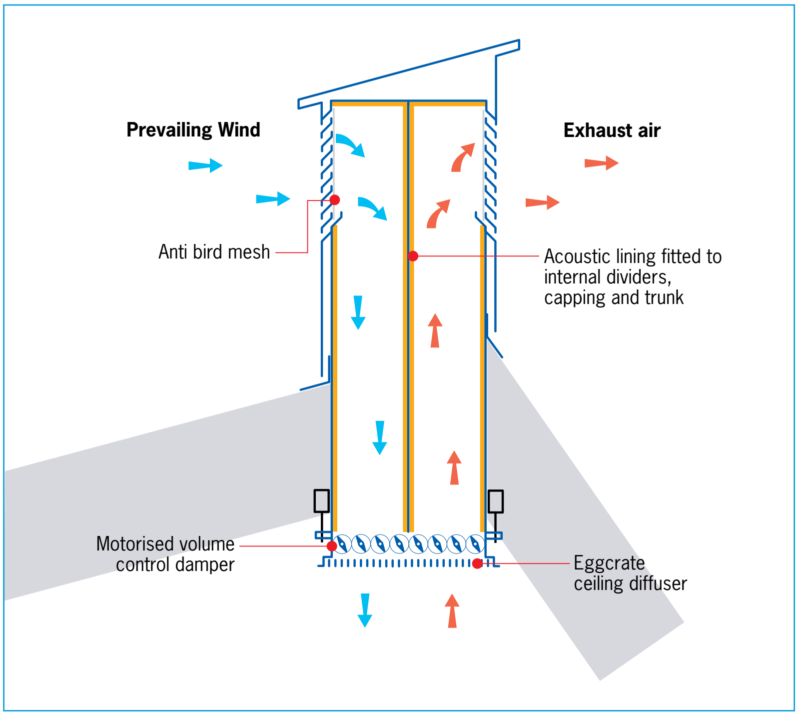


Figure 7.9.3: Section through ventilation stack shows stack operation and acoustic treatment

Figure 7.9.4: Three of the roof teminals, during construction

has been carefully sized according to the volume of the space to be ventilated, the number of people who will normally occupy each space and any potential source of additional heat, for example solar gain or computers. The performance of each terminal has been modelled for a variety of wind speeds to ensure that adequate fresh air can be provided.

Each terminal is individually controlled by dampers set in the ends of the duct to modify the ventilation rate according to the actual conditions in each room. During summer time the control is based on room temperature because higher ventilation rates are required to keep the rooms within acceptable comfort levels. With passive stacks, temperature differences within the room and the length of the ducts will result in improved extract. During the winter the quantity of fresh air needs to be minimized, reducing heat losses via exhaust air, hence there is control by an air quality sensor.

A manual override allows users to have control of the system depending on their experience of room conditions. All windows are openable to allow additional fresh air to be introduced, for example, during changeover of lessons when indoor ambient noise levels are less critical.

The proposed system takes full advantage of the prevailing site conditions. Fresh air is both drawn in and exhausted at the highest level. Wind speeds at 15 m above the ground will be higher than at street level due to fewer obstructions by surrounding buildings. The quality of the air also generally improves with increasing distance from the source of pollution, which in this case is road traffic. Heavy pollutants from vehicle exhausts tend to remain at street level particularly in conditions of high atmospheric pressure.

The ventilation strategy also allows for night time cooling of the building. Studies have shown that air quality by main roads improves at night due to lower traffic flows. At the end of each day stale air left in the building can be fully replaced and then warmed, depending on the season, ready for the next morning.

(ii) Rooms for specialist activities (Changing rooms, toilets, shower areas and science laboratories)

Natural ventilation is not suitable for certain parts of the building. Therefore limited mechanical intake and extract are used in areas which require a high rate of ventilation, for example in changing rooms where high levels of water vapour and body odours need to be removed. The mechanical system extracts air at low level, with a simple heat recovery apparatus used to reclaim heat, and replacement air is filtered to remove airborne particles.

The science laboratory requires specific extract ventilation to fume cupboards. This is achieved by mechanical extract ventilation systems that exhaust away from the other roof terminals, with make-up air being naturally induced via a wind scoop and opening window lights.

This case study demonstrates that free-field external noise levels can be reduced by approximately 30 dB inside naturally ventilated classrooms using a sound attenuated passive stack ventilation system.

An investigation was carried out into the acoustic conditions in open plan learning spaces in a secondary school, construction of which was completed in 1991. Figure 7.10.1 shows the site. The ground and first floor plans can be seen in Figure 7.10.3.

The curriculum model divides the day into 3 hour subject modules. Team teaching is fundamental to the curriculum and to facilitate this, there are several relatively large open plan learning bases, as shown in Figure 7.10.2, that typically hold around seventy students.

Some of the learning bases are used for teaching particular subjects such as Mathematics or English. All the learning bases are subdivided into smaller areas so that different lessons or activities can take

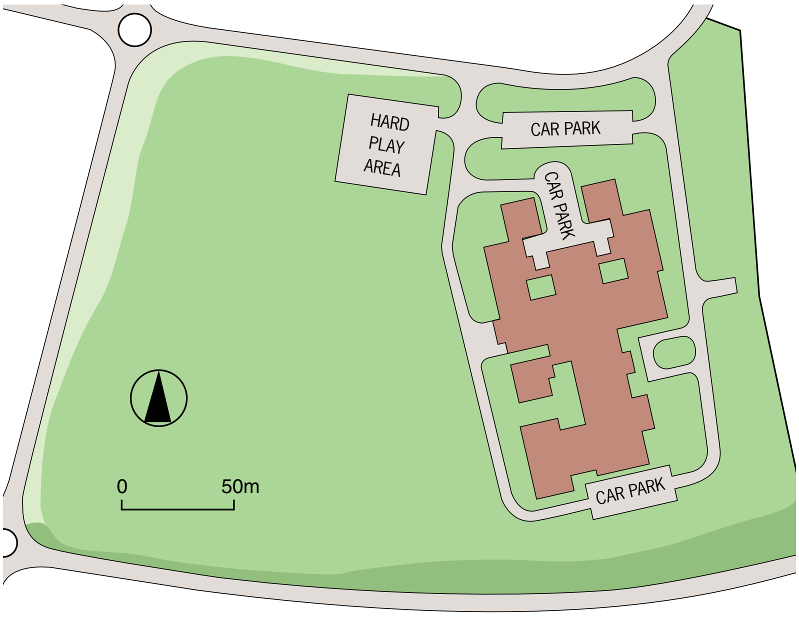


Figure 7.10.1: Site layout

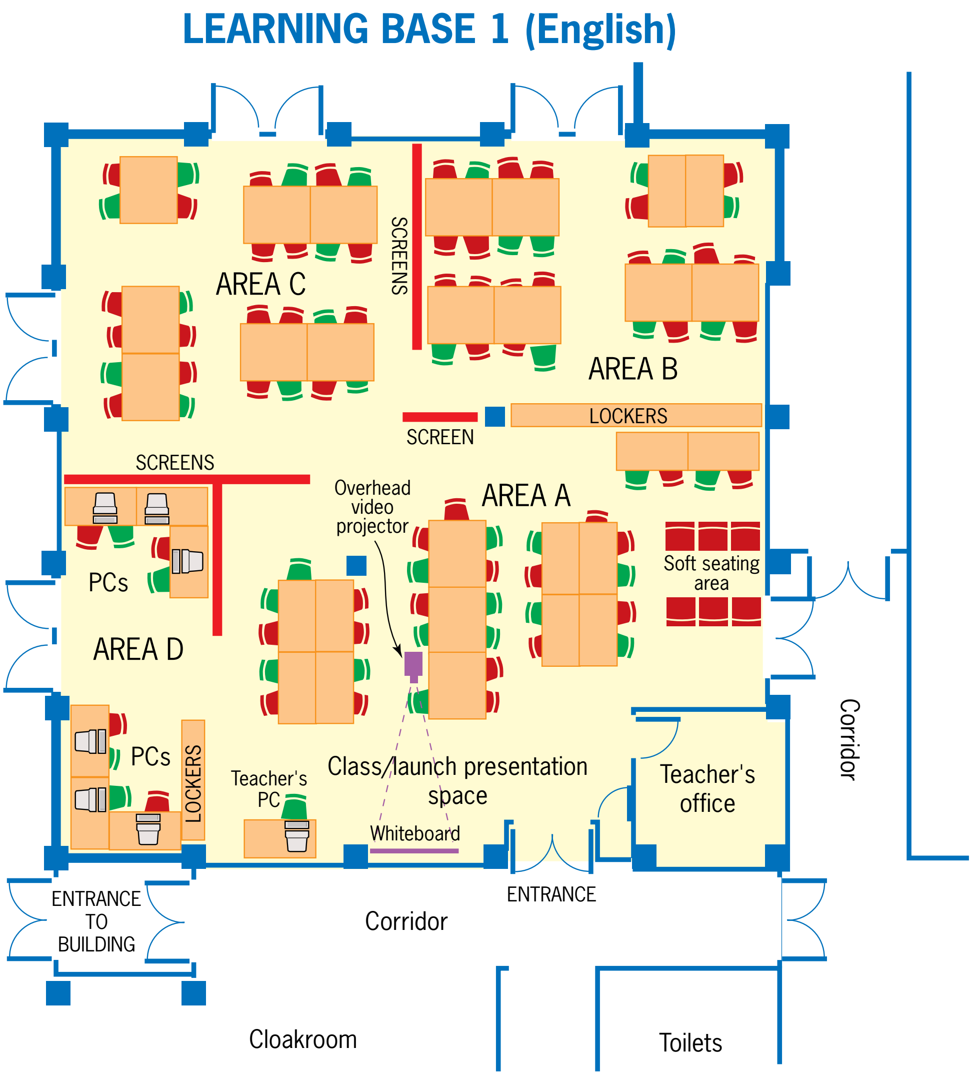


Figure 7.10.2: Open plan learning base 1

7.10 Case Study: An investigation into the acoustic conditions in open-plan learning spaces in a secondary school

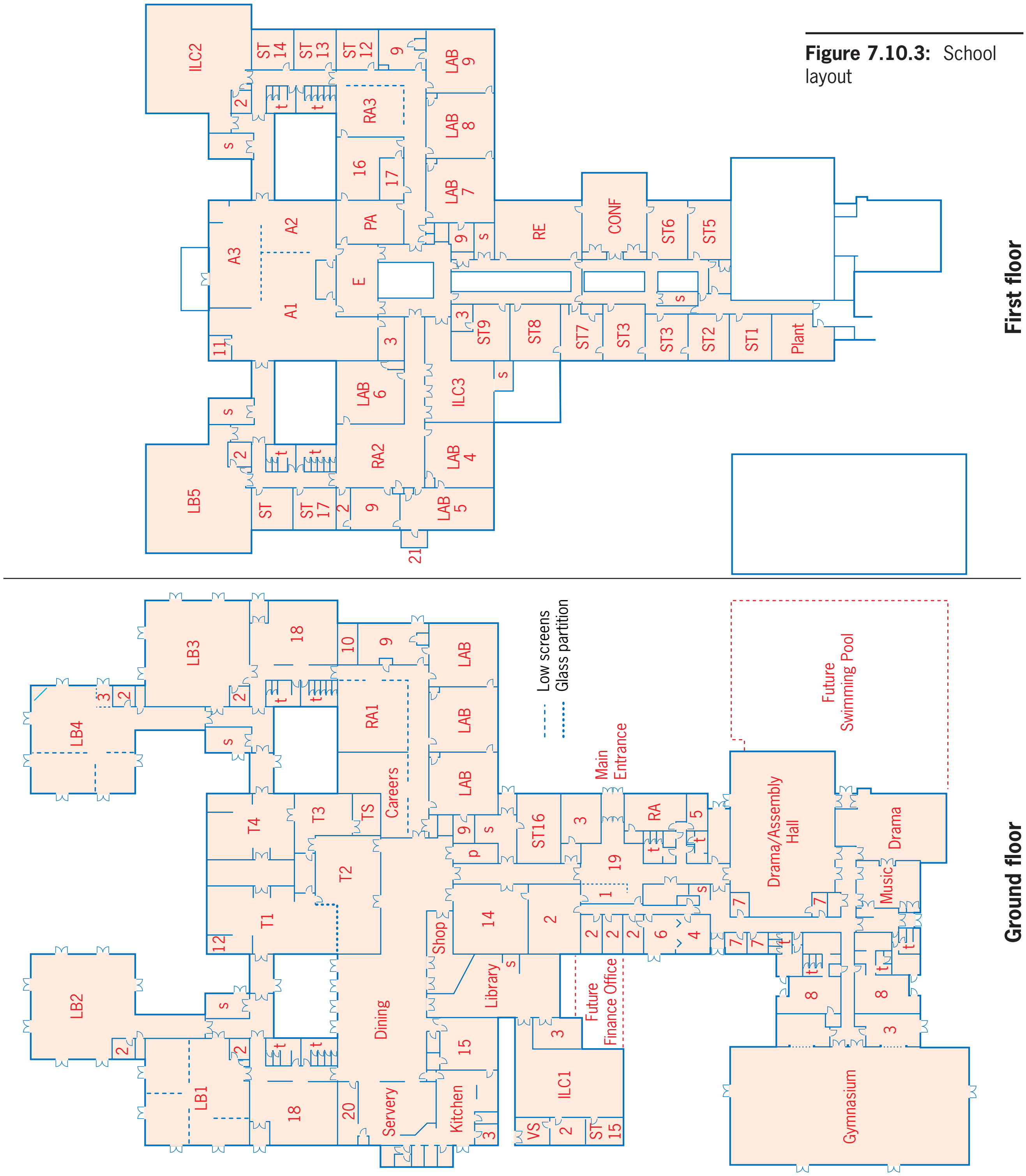


Figure 7.10.3: School layout

Key

- 1 Reception
- 2 Office
- 3 Store
- 4 Meeting room
- 5 Medical inspection
- 6 Principal
- 7 Music practice
- 8 Changing room
- 9 Science prep.
- 10 Darkroom
- 11 Kiln
- 12 Heat bay
- 13 Technicians base/materials
- 14 Hospitality suite
- 15 Training kitchen
- 16 Sound Laboratory
- 17 Music Tech.
- 18 Cloakroom
- 19 Foyer
- 20 Wash-up
- 21 Greenhouse

(LB - Learning Bases)

- LB1 English
- LB2
- LB3 Business Studies
- LB4 Humanities
- LB5 Mathematics

- ILC Independent Learning Centre
- TS Technology Store
- A1–3 Art
- T1–4 Technology
- E Electronics
- RA Resource Area
- RA1 Sixth Form ICT Resource
- Conf Conference Room
- ST Study Room/Genral Teaching
- RE Religious Education
- PA Performing Arts
- LAB Science Laboratory
- VS Video Studio

- s Stairs
- t Toilets

place at the same time. Typically, moveable screens or lockers are used to separate the different areas within a learning base.

Acoustic measurements

Measurements of sound pressure level, reverberation time, speech intelligibility and airborne sound insulation were made in the school to assess the acoustic environment. These measurements were made in learning base 1 (English learning base), the art area, the workshop and technology areas, and language teaching rooms (study area 1 and study area 5).

Sound pressure levels were measured over 30 minute periods (starting on the hour or half-hour) during the school day to determine $L_{Aeq,30min}$, $L_{A90,30min}$, $L_{A10,30min}$, L_{AFmax} and L_{AFmin}. Observations of classroom activity were noted in order to attribute measured levels to specific activities and events.

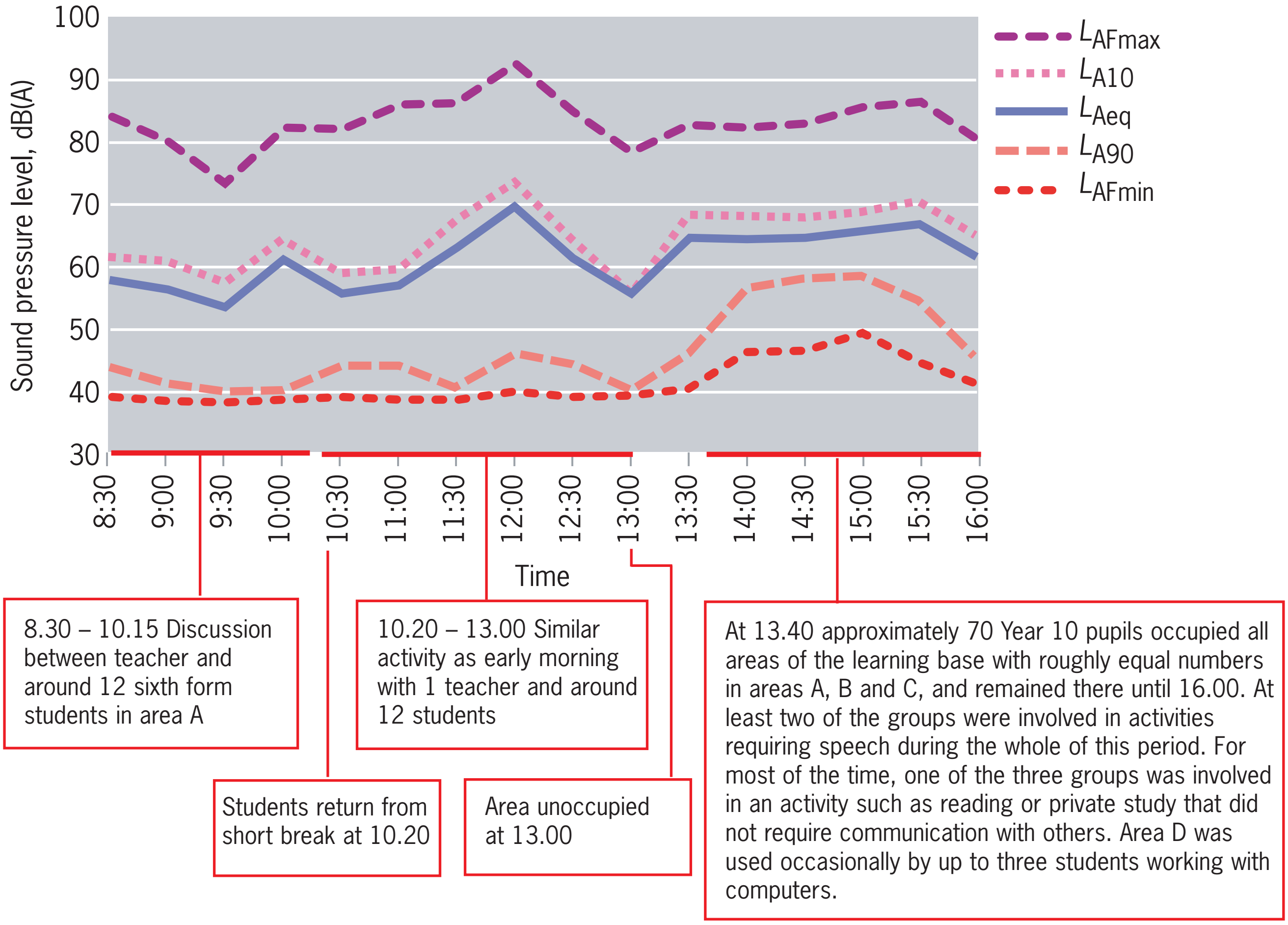
In the open plan area of learning base 1, the Speech Transmission Index (STI) was measured according to BS EN 60268-16 to assess speech intelligibility.

Airborne sound insulation was measured between adjacent language teaching classrooms. These classrooms were enclosed rooms and did not form part of the open plan teaching space.

In addition to the acoustic measurements, teaching staff completed a questionnaire about the effect of the school layout on their work.

Figure 7.10.4: Students in area A of learning base 1

Figure 7.10.5: Learning base 1 – sound pressure levels in area A



7.10 Case Study: An investigation into the acoustic conditions in open-plan learning spaces in a secondary school

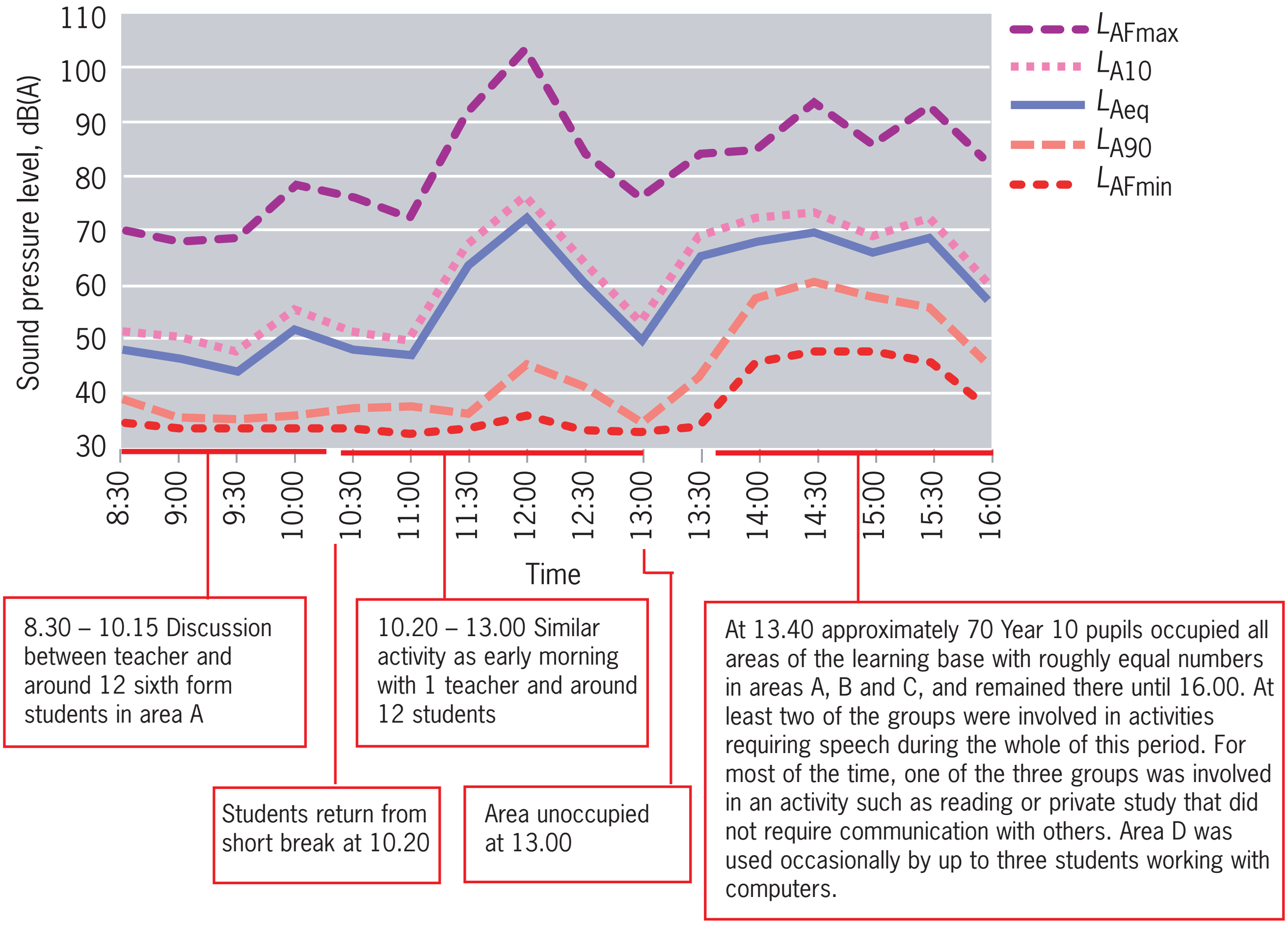


Figure 7.10.6: Learning base 1 – sound pressure levels in area C

Learning base 1

The open plan layout of learning base 1 is shown in Figure 7.10.2. Figure 7.10.4 shows students working in area A of learning base 1.

Sound pressure levels

Figures 7.10.5 and 7.10.6 show graphs of the continuous sound pressure levels measured in areas A and C. Figure 7.10.7 shows the difference in $L_{Aeq,30min}$ between area A and area C of learning base 1 (area A – area C).

It was intended that observations made during the measurements would allow analysis of individual events that cause disturbance. This aim proved not to be possible. For example, when a telephone rang in learning base 1 there was no observed reaction from the students. The telephone in the room was used to inform teachers that the students could go for lunch and appeared to be viewed as nothing unusual by the students.

Between 08.30 and 11.00 the teacher and students occupied area A. During this time the difference between $L_{Aeq,30min}$ in areas A and C was between 7 and 10 dB (see Figure 7.10.7). The measurements thus demonstrate that there is a maximum of 10 dB attenuation of airborne sound between areas A and C. Therefore, if another class were present in area C carrying out a quiet activity such as private reading, the students in area C would be able to clearly hear the activity noise emanating from area A. These measurements indicate that if the airborne sound insulation were measured between areas A and C then it would not meet the minimum performance standard for airborne sound insulation of 45 dB $D_{nT(0.8s),w}$ required between general teaching areas.

Between 11.00 and 13.00 the level in area C was sometimes higher than in area A. The reason for this is not known because area C was unoccupied, but

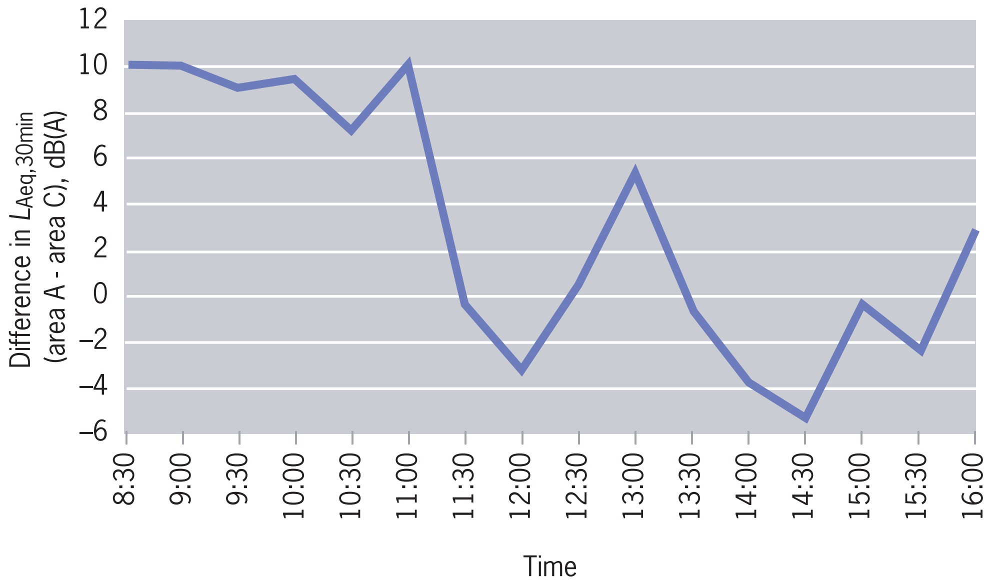


Figure 7.10.7: Learning base 1 – difference in sound pressure levels between area A and area C

could be due to sound generated from the playground outside.

When all areas in the learning base were occupied between 14.00 and 16.00, $L_{Aeq,30min}$ increased to levels between 65 and 70 dB. To gauge the effect of this increase in $L_{Aeq,30min}$ on speech intelligibility, it is instructive to consider the required signal to noise ratio in a classroom which is generally taken to be a minimum of 15 dB, or, ideally, 20 to 25 dB when hearing impaired children are being taught. In these noise levels, a teacher's voice would have to be raised to a level of at least 80 to 85 dB in order to be heard by the students. It is unlikely that a teacher would be able to shout at a sufficiently high level to communicate with hearing impaired students. Thus, based upon measured sound pressure levels, the open-plan space is inadequate in terms of speech intelligibility.

The measurements that indicate inadequate signal to noise ratios were corroborated by the fact that staff reported difficulties in listening to students in the open-plan setting. In addition, some students also reported that it was difficult to hear the teachers when they spoke quietly.

Reverberation time

The mid-frequency reverberation time in learning base 1 was 0.6 seconds, which meets the performance standards in Table 1.5.

Speech intelligibility

For the speech intelligibility measurements, the STI was measured in area C of learning base 1.

STI was measured at two microphone positions with an artificial mouth used to transmit the measurement signal. Six measurements were made at each microphone position. The artificial mouth was sited by the white board in a position that was used by the teacher when addressing the class and referring to information on the white board. The signal level at a point 1 m in front of the artificial mouth was adjusted until a level of 68 dB(A) was measured. The positions of the artificial mouth and the microphones are shown on Figure 7.10.8.

STI measurements were made when the space was empty. Masking sound from a loudspeaker was used to simulate occupied conditions with groups of approximately 12 students in each class base. In the afternoon when all the areas of learning base 1 were occupied, measured levels in the learning base were between 65 and 70 dB $L_{Aeq,30min}$ (see Figures 7.10.5 and 7.10.6). Case Study 7.2 indicates that there is little point in measuring speech intelligibility at such high masking sound levels because the speech intelligibility is likely to be 'Bad', 'Poor' or 'Fair' with low signal to noise ratios where the signal (speech) level is similar to the noise level.

To assess the effect of sound

7.10 Case Study: An investigation into the acoustic conditions in open-plan learning spaces in a secondary school

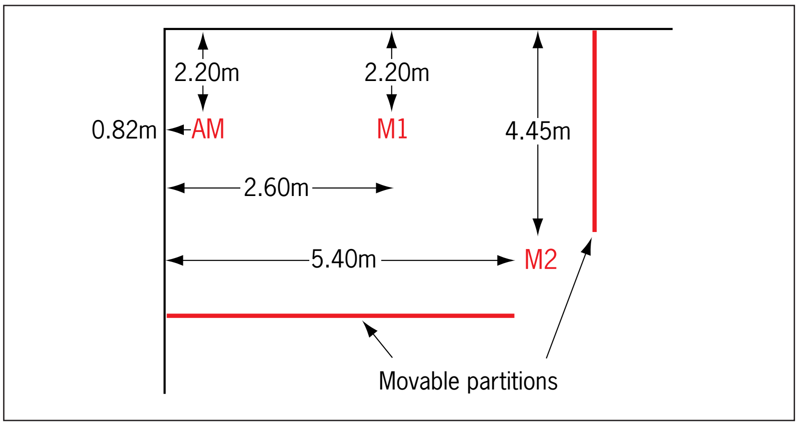


Figure 7.10.8: Learning base 1 – artificial mouth position (AM) and microphone positions M1 and M2 in area C

transmission from adjacent areas on speech intelligibility in area C, measurements were conducted with and without masking sound generated in the learning base. Two masking conditions were used: 1) masking sound in area A; 2) masking sound simultaneously in areas A and B. The masking sound was produced from a loudspeaker using a white noise signal shaped to the sound spectrum recorded whilst the teacher addressed her students during a tutorial session with the sixth form students. The spectrum was measured at a distance of approximately 5 m from the teacher, the level at that point being 54 dB $L_{Aeq,30min}$. When masking sound was generated in area A only, the masking sound level was adjusted until 54 dB L_{Aeq} was measured in the same position as that used to measure the level of the teacher speaking. When masking sound was generated simultaneously in areas A and B, the same shaped sound signal was fed to the loudspeakers in each area and the level adjusted until 57 dB L_{Aeq} was measured at a position midway between areas A and B.

Measured STI data are shown in Tables 7.10.1 and 7.10.2.

From the tables it can be seen that the speech intelligibility was 'Good' at microphone positions M1 and M2 when there was no masking sound. Hence, when the other areas in the learning base are not occupied, the speech intelligibility is acceptable. When there was masking sound in area A or areas A and B (ie with either one or two of the other teaching areas simulated as being occupied), speech intelligibility was 'Good' at microphone position M1 but 'Fair' at microphone position M2. The reason for the reduction in speech intelligibility at microphone position M2 is because it is closer than position M1 to the other teaching areas, where masking sound was generated. Therefore, when other areas in the learning base are occupied, the speech intelligibility between the teacher and

Table 7.10.1: Learning base 1 – measured STI values at microphone position M1, with and without masking sound

	No masking sound	Masking sound in area A	Masking sound in areas A and B
	STI	STI	STI
Average	0.702	0.666	0.644
Standard deviation	0.041	0.054	0.048
Rating	Good	Good	Good

Table 7.10.2: Learning base 1 – measured STI values at microphone position M2, with and without masking sound

	No masking sound	Masking sound in area A	Masking sound in areas A and B
	STI	STI	STI
Average	0.655	0.569	0.571
Standard deviation	0.037	0.031	0.084
Rating	Good	Fair	Fair

students sitting near microphone position M2 is not acceptable. In the afternoon, when all the areas of learning base 1 were occupied, measured levels in the learning base were between 65 and 70 dB $L_{Aeq,30min}$ (see Figures 7.10.5 and 7.10.6). STI measurements were not made with this masking sound condition as the speech intelligibility would be expected to be 'Bad', 'Poor' or 'Fair' due to the low signal (speech) to noise ratio as in Case Study 2.

The teachers in this school adopted strategies to make the best use of their surroundings, for example, gathering students more closely around them (see Figure 7.10.15) to help overcome problems with speech intelligibility and to reduce disturbance to those involved in other activities within the room. It appeared that co-operation between staff working in the same open-plan area and careful planning of lessons was an important aspect in coping with the speech intelligibility problems in these areas. For example, a teacher in area C notified her colleague in area A that her class would be engaged in quiet reading after they had finished a more noisy activity. This was to reduce disturbance to the reading of a play in area A.

The school has tried to teach languages in the open-plan learning bases, however, it had been decided that such lessons can only be taught effectively in enclosed classrooms. It is not known whether this was due to ambient levels being too high for good speech intelligibility in open-plan areas or whether it was due to disturbance from adjacent areas in a learning base. It is to be expected that conditions for language teaching need to be more closely controlled than for teaching some other subjects. Measuring STI enables speech intelligibility in rooms to be objectively assessed. However it does not enable disturbance to be quantified since this could depend on how distracting the activities are in adjacent areas.

Workshop and technology areas

Sound pressure levels

Figures 7.10.9 and 7.10.10 show graphs of the continuous sound pressure levels recorded in the workshop and technology

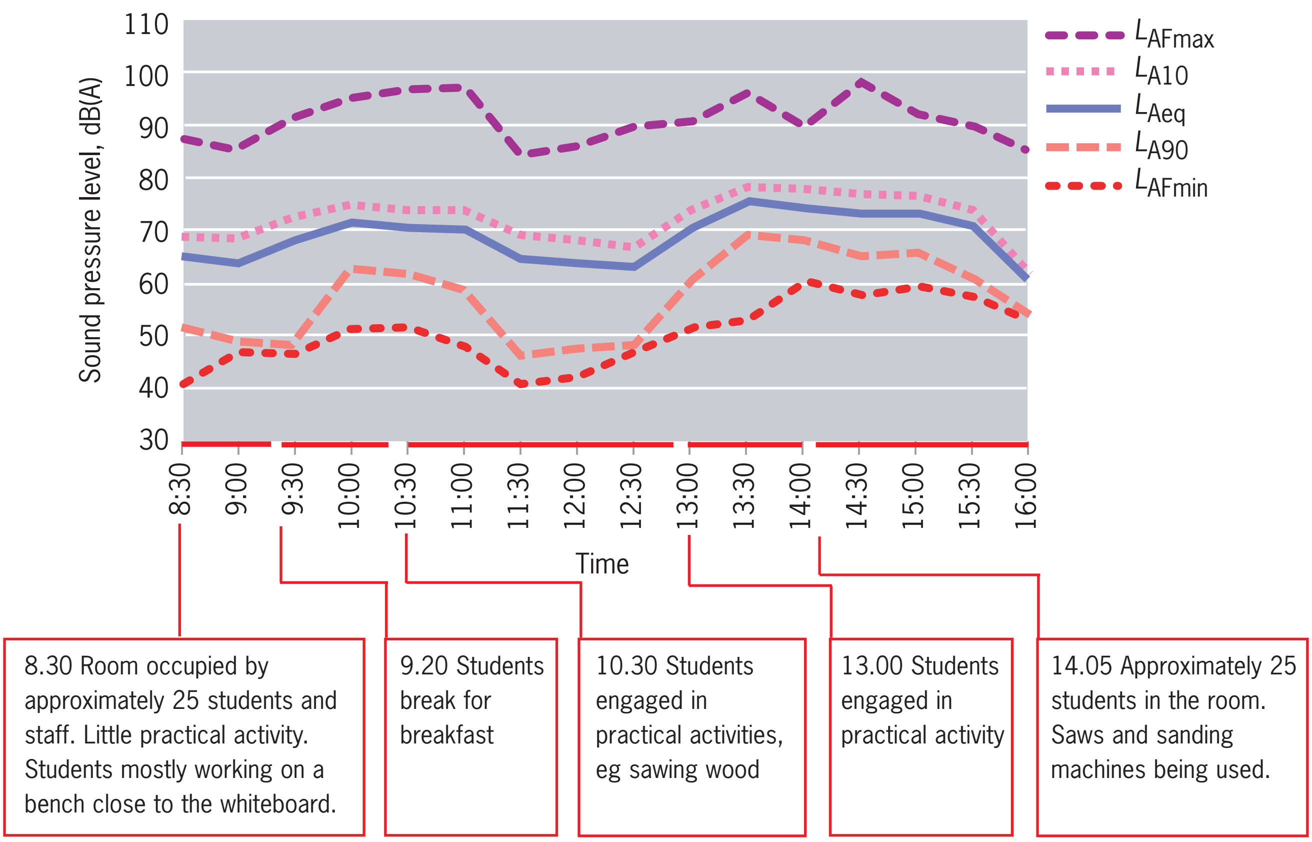


Figure 7.10.9: Workshop area sound pressure levels

areas. The levels in these areas are significantly higher than would be expected in classrooms due to the machinery noise. During the period of highest noise, 76 dB $L_{Aeq,30min}$, the signal to noise ratio would result in inadequate speech intelligibility for a teacher talking to a group of students.

Reverberation times

The mid-frequency reverberation time in the workshop was 1.2 seconds, which does not meet the performance standards in Table 1.5.

The mid-frequency reverberation time in the technology area was 0.8 seconds, which does not meet the performance standards in Table 1.5.

A mid-frequency reverberation time of 1.2 seconds in the workshop combined with levels greater than 70 dB $L_{Aeq,30min}$ will provide inadequate speech intelligibility. However, in rooms where students use machine tools such as lathes, good speech intelligibility is essential for safety.

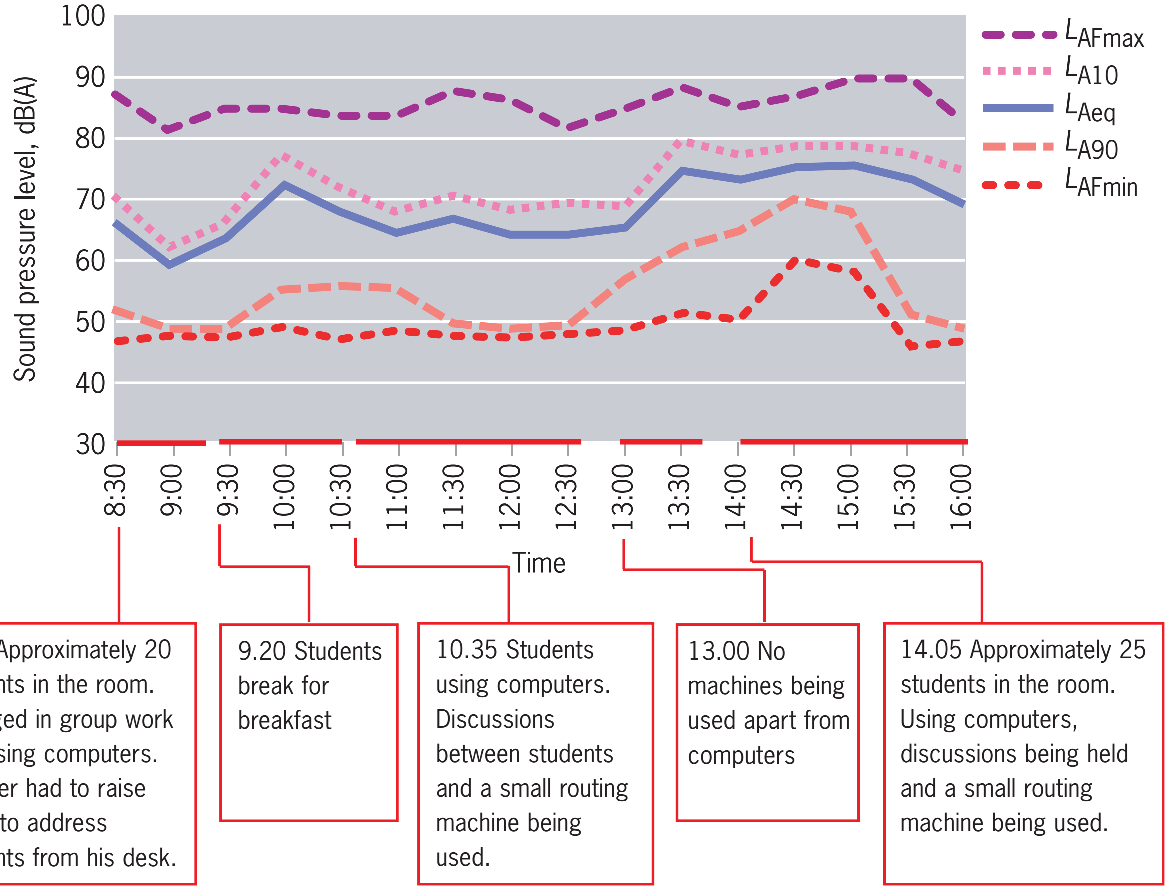
Art area

Sound pressure levels

The art area on the first floor is shown in Figure 7.10.3. During the measurements it was occupied by Year 7 students and teaching staff. The room was divided by partitions into three areas, indicated as A1, A2 and A3.

Measurements were taken in areas A1 and A2, which held between 20 and 25 students. Throughout the day, activities undertaken in the art area did not appear to change significantly. Noise sources included hairdryers which were used to dry items of art work. Figures 7.10.11 and 7.10.12 show graphs of the sound pressure levels recorded in areas A1 and A2 respectively. For most of the day the noise level varies from 65 to 75 dB $L_{Aeq,30min}$. Thus, for a teacher talking to a group of students in the art area, the signal to noise ratio would be inadequate for good speech intelligibility.

Figure 7.10.10: Technology area sound pressure levels



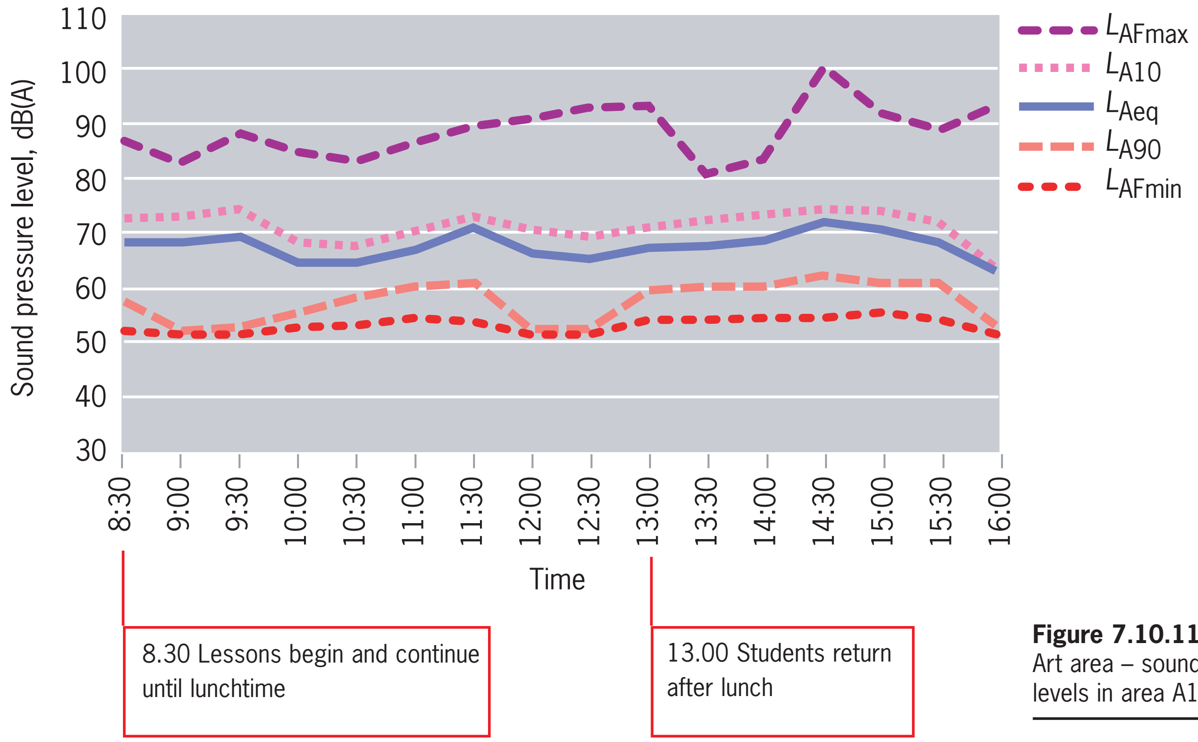


Figure 7.10.11:
Art area – sound pressure levels in area A1

Reverberation time

The mid-frequency reverberation time in the art area was 0.9 seconds, which does not meet the performance standards in Table 1.5 for an art room.

Language teaching rooms (study areas 1 and 5)

These rooms were enclosed classrooms that were originally intended to be sixth form study rooms. However, they were subsequently designated as language teaching rooms owing to the difficulties

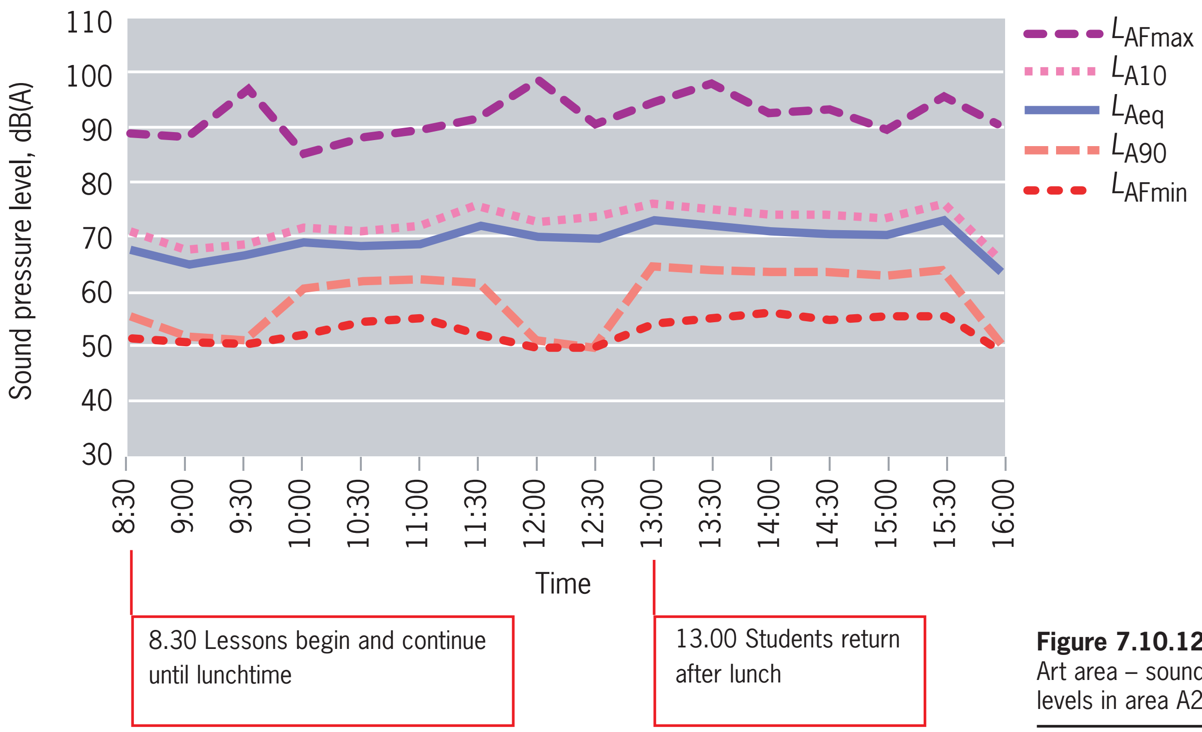


Figure 7.10.12:
Art area – sound pressure levels in area A2

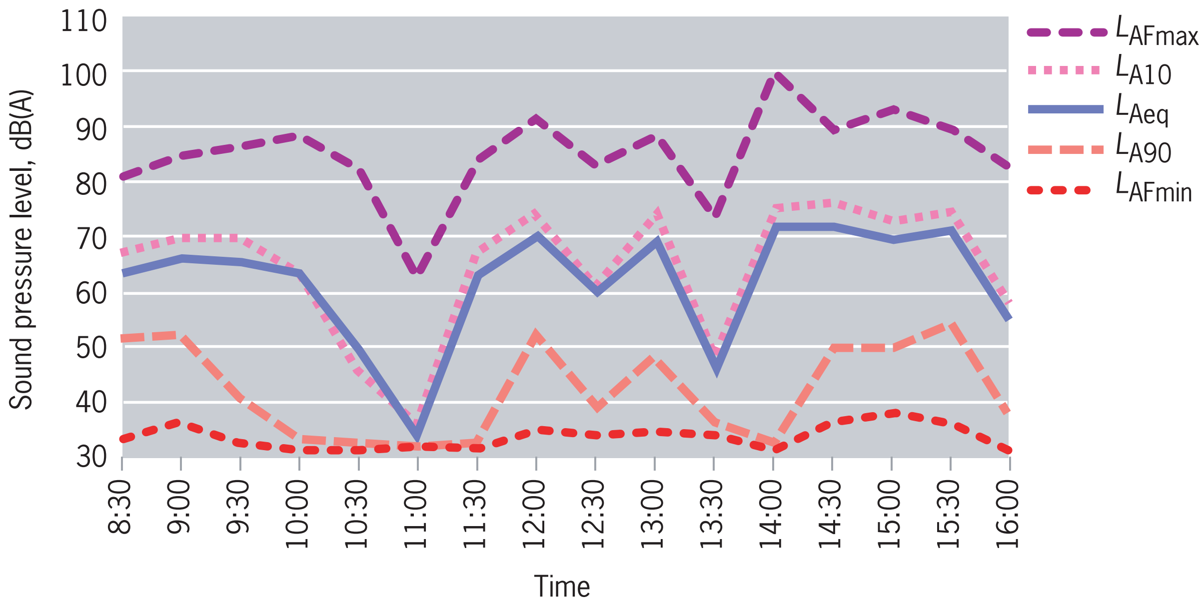


Figure 7.10.13: Language study area 1 sound pressure levels

experienced in teaching two different languages (eg German and French) simultaneously in different areas of the open plan space.

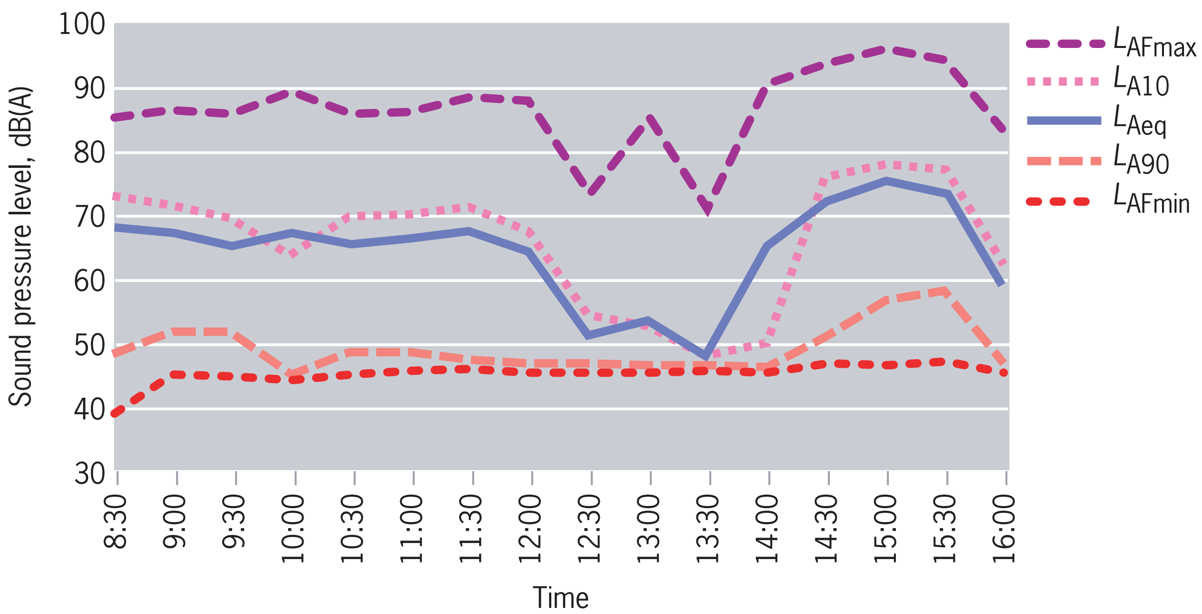
Sound pressure levels

Figures 7.10.13 and 7.10.14 show the sound pressure levels recorded in study areas 1 and 5 respectively. When the classrooms were unoccupied the measured levels were less than 50 dB $L_{Aeq,30min}$. When there was speech in the room, $L_{Aeq,30min}$ was typically between 65 and 75 dB. In general, $L_{Aeq,30min}$ was between 15 dB and 20 dB higher than $L_{A90,30min}$, indicating that the signal to noise ratio could potentially provide reasonable speech intelligibility. When the spaces were occupied and students and/or staff were speaking, there was a greater difference between $L_{Aeq,30min}$ and $L_{A90,30min}$ in the enclosed classrooms than in the fully occupied open-plan spaces. This indicates that the signal to noise ratios are likely to be higher in the enclosed classrooms than in the open-plan spaces.

Reverberation time

The mid-frequency reverberation time in

Figure 7.10.14: Language study area 5 sound pressure levels



each study area was 0.5 seconds, which meets the performance standards in Table 1.5.

Airborne sound insulation

The measured airborne sound insulation between study area 1 and study area 2 is 40 dB $D_{nT(0.8s),w}$, which does not meet the performance standards in Table 1.2.

Summary

Teaching in an open-plan area in a secondary school requires a different type of working from teaching in traditional enclosed classrooms. This is due in part to the noise levels in open-plan teaching areas. In this school, both students and teachers in the open-plan areas reported being disturbed by noise, whilst in enclosed classrooms very little disturbance was reported. Some of the techniques observed in primary schools in Case Study 9.2 were used when it was important to ensure that students could hear the teacher during noisy periods. For example, students were gathered more closely around their teacher. Also, teaching staff in the area co-operated with each other to minimise disturbance to classes in adjacent areas.

It is concluded that it is difficult to justify the use of open-plan areas in secondary schools in terms of their acoustic environment. This is a similar conclusion to that in Case Study 7.2 for open-plan primary schools. High noise levels in occupied open-plan areas are the primary cause of inadequate speech intelligibility, especially for those students furthest from the teacher. STI measurements demonstrated that for these students, the performance standards in Table 1.6 of Section 1 were not met.

Fugure 7.10.15: Students in learning base 1 gathered around the teacher in area A

When all areas of the learning base were occupied, measured sound pressure levels were between 65 and 70 dB $L_{Aeq,30min}$. At these levels, the signal to noise ratios are likely to be less than 10 dB and speech intelligibility will be inadequate. When the teaching areas were occupied and students and/or teachers were speaking, there was a greater difference between $L_{Aeq,30min}$ and $L_{A90,30min}$ in the enclosed classrooms than in the open-plan spaces. This suggests that the signal to noise ratios are generally higher in enclosed classrooms than in open-plan areas. Hence, speech intelligibility is likely to be better in enclosed classrooms than in fully occupied open-plan areas.

In many open-plan teaching spaces it is difficult to achieve clear communication of speech between teacher and student, and between students. For this reason, careful consideration should be given as to whether to include open-plan teaching spaces in a secondary school. If open-plan areas are required then rigorous acoustic design is necessary to meet the required performance standards in Section 1.