Introduction

BB93 defines reverberation time (RT) as the time taken for the reverberant sound energy to decay to one millionth of its original intensity (corresponding to a 60 dB reduction in the sound level).

Both Boothroyd and Crandell warn that RT varies with frequency. Boothroyd states that as we are interested in intelligibility, our main concern is with reverberation in the two octaves from 750m to 3000 Hz.

Crandell and Smaldino go further and say, "Generally, because most materials do not absorb low frequencies well, room reverberation is shorter at higher frequencies and longer in low frequency regions. It is recommended that RT be measured at discrete frequencies from 125 to 8000 Hz, whenever excessive reverberation seems to interfere with communication." From Classroom Acoustics for Children by Crandell and Smaldino.

Reverberation time can be calculated using a formula devised by Sabine in 1964. The formula should be used with rooms with volumes less than 200m and a reasonable distribution of sound. The formula is

$T = \frac{0.16V}{A}$ this formula is to be used when the units of measure are metric.

$T = \frac{0.049V}{A}$ this formula is to be used when the units of measure are imperial.

(*V* is the volume of the room and A is the sum of the surface areas of the room multiplied by their respective absorption coefficients at a given frequency.)

Looking at the formula, the way to reduce the reverberation time is to either decrease the volume of the room or increase the amount of absorption in the room. As it is usually difficult to make a room smaller then the most sensible way is to put more absorption in the room.

However, it is generally accepted that RT is represented as one number which is an average of the RTs for frequencies 500, 1000 and 2000 Hz. This is a simple arithmetic sum which involves adding the 3 reverberation times together and dividing them by 3. This gives a value of *T*mf (*T* is the symbol for reverberation time and mf is mid frequency)

A great deal of work has been done to measure reverberation times in a room both using sound level meters and calculation formulae. The most accurate way to find the reverberation times in a room is to use a type 1 sound level meter which uses appropriate software.

Also there are spreadsheets available which can calculate reverberation times. However, these are less accurate. (The BRE spreadsheet is used later in this section).

Combined effects of noise and reverberation

There have been many studies that show the effect of poor acoustics and noise on speech intelligibility in a classroom, mainly from the United States. The Finitzo-Heiber paper produced in 1978 looked at the combined effect of reverberation and background noise levels on both hearing and hearing-impaired children. The table below shows the results.

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

The scores are the percentage of words correctly identified in various conditions.

Yacullo and Hawkins (1987) presented thirty-two hearing 8-9 year olds with words in rooms with reverberation times of 0 seconds and 0.8 seconds plus signal to noise ratios of +2 and +6 dB. They discovered that the reverberation decreased the mean speech discrimination by 41.1% whilst the scores decreased by 27.4% as the signal to noise ratio dropped.

A study in 1997 by Anderson and Towne discussed previous research and presented findings from a new investigation. This report discusses the detrimental effect of speaker to listener distance and the masking effect of speech sounds by high and low frequencies.

The report by MacKenzie and Airey (1999) highlighted many problems related to listening in classrooms, including the problems with dead spots in the room. They also produced speech intelligibility scores in different listening conditions as shown in the table below.

	Word Intelligibility by Picture Identification (WIPI)	
	Untreated	Treated
Control	96.7%	97.5%
Quiet classroom	94.2%	97.5%
Students working	57.2%	67.0%

All of the studies mentioned show the problem with both reverberation time and background noise. Wilson's study (2006) shows similar problems. This study uses the same group of students and the same test procedures but in different rooms with different reverberation times. Comparisons are made between the different reverberation times of the rooms.

The tables below are from Wilson's study and compare the percentage correct score obtained in each room with the reverberation time of the room.

	Average Speech Test Scores		Reverberation Times (averaging 500,1000,2000 Hz)	
Room Numbers	%	Ranking (where 1 is the best score)	Seconds	Ranking (where 1 is the shortest)
1	48	4	1.06s	2
2	56.2	3	1.24	3
3	63.8	2	1.57	4
4	75.9	1	0.55	1

This table also ranks the rooms for best speech intelligibility scores and best reverberation times where the shorter the reverberation time, the better speech intelligibility.

As can be seen, the reverberation time is the mid frequency reverberation time as used in BB93 and the rankings don't match.

Room 4 has the shortest RT and the best speech intelligibility score. Ideally the next best score should be room 1 which has the next shortest RT but room 3 has a better score. These results imply that the shortest RT doesn't always produce the highest SI score.

However, this next table takes into account all the RTs for all the 1/3rd octave bands and not just the mid frequencies.

Now the rankings match.

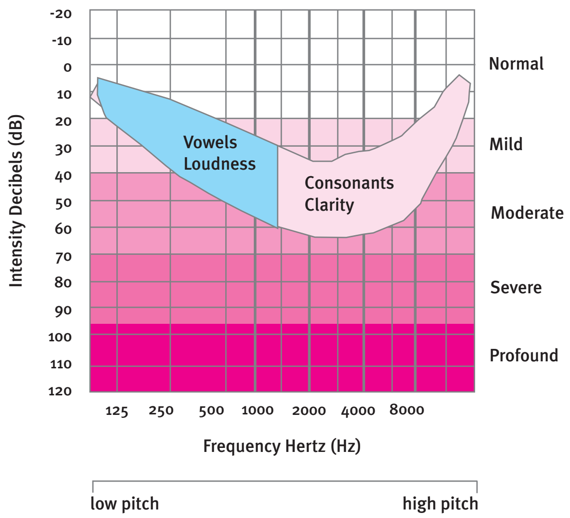
It is important to always take into account low frequency RTs as stated by Crandell an Smaldino earlier, because most materials do not absorb low frequencies well but tend to absorb the high frequencies.

	Average Speech Test Scores		Reverberation Times (averaging all 1/3rd band octaves from 63 Hz to 8 kHz)	
Room Numbers	%	Ranking (where 1 is the best score)	Seconds	Ranking (where 1 is the shortest)
1	48	4	1.17	4
2	56.2	3	1.13	3
3	63.8	2	1.04	2
4	75.9	1	0.59	1

This table shows how the RTs change when all the frequencies are used in any calculation.

Reverberation Times for 1/3rd Octave Band Frequencies, measured in seconds(s)									
Room	63Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	Average RT for all frequencies
1	2.48	1.47	1.3	1.3	1.08	0.8	0.52	0.41	1.17s
				Tmf = 1.06s					
2	0.72	0.5	1.24	1.53	1.67	1.53	1.06	0.81	1.13s
				Tmf = 1.57s					
3	0.92	1.01	1.12	1.47	1.3	1.05	0.81	0.6	1.04s
				Tmf = 1.24s					
4	0.67	0.64	0.69	0.63	0.64	0.54	0.47	0.4	0.59s
				Tmf = 0.55s					

Again if we look at this table we can see that in the case of room 1, the RT is greater in the low frequencies.



Now looking at the speech spectrum opposite, the low frequency sounds in speech are mainly vowels.

This means that in room 1 the reverberating speech noise will be mainly vowel based. As vowels are also the most powerful phonemes in speech, there is a tendency for them to 'mask' the high frequency sounds. This masking effect makes it difficult to hear the consonants for good speech intelligibility.

It is important to reduce low frequency reverberation as much as possible for good speech intelligibility. However, not all reverberation is bad. Boothroyd makes distinctions between early and late reverberations.

He defines early components of reverberation as, "those reflections that arrive soon enough to be integrated with the direct sound, and with each other, so as to enhance perception (less than 1/20th of a second) and these early components of reverberation increase the level of speech at a distance.

The late components of reverberation he describes as ones that, "arrive too late to be integrated with the direct signal or the early components (more than 1/10th of a second). If their level is still high enough, they interfere with the current sound by both physical and perceptual masking."

His visual analogy of these statements is:

Late reverberation

The two sentences are greatly out of phase and make it difficult to read.

The following is a list of Farmers' markets to be held in the surrounding areas

The following is a list of Farmers' markets to be held in the surrounding areas

In this case the sentences are only slightly out of phase and now it is possible to read the sentence. In fact in this situation the words look bolder and in the case of sound would be slightly amplified.

A room with no reverberation is a very uncomfortable room to listen in, so we need to have some reverberant sound but for good speech intelligibility two things need to happen:

1. The room needs to have a short reverberation time.
2. As much low frequency sound needs to be absorbed as possible.

Calculating reverberation times (RT)

As stated in the introduction to this section, there are formulae for calculating RTs based on the Sabine formula.

However, the most accurate way to measure RT is to use a type 1 SLM which has the appropriate software. In the case study in this section you will be shown a comparison between the actual RT (using a type 1 SLM) and the calculated RT using a spreadsheet.

The suggested spreadsheet to calculate RTs is the one produced by the British Research Establishment (BRE). The spreadsheet can be downloaded from the professionals section of the NDCS website www.ndcs.org.uk

Using the BRE spreadsheet

In order to run this spreadsheet your computer will need to have Windows 2000 or XP.

1. Preparing to use the spreadsheet

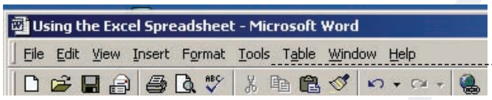
Before using the BRE spreadsheet you need to enable the Macros on your computer.

To use this spreadsheet, macros must be enabled within Microsoft Excel. You will be asked on the start-up screen whether to enable or disable the macros. You will need to choose Enable Macros.

If this option does not appear, but the spreadsheet fails to work, it is possible that Excel is set to disable macros automatically. Where this is set depends on the version of Excel.

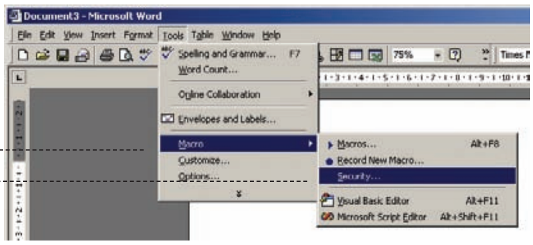
However in Excel 2000 or XP this can be set from the **Tools** menu.

Follow these instructions to enable the Macros by using the **TOOLS** menu.



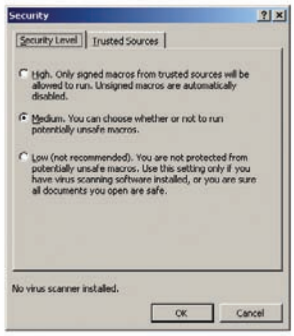
From the drop down menu choose the Macros option

and then the Security option



The Macros should be now set to Medium by choosing clicking the cursor on the circle next to Medium.

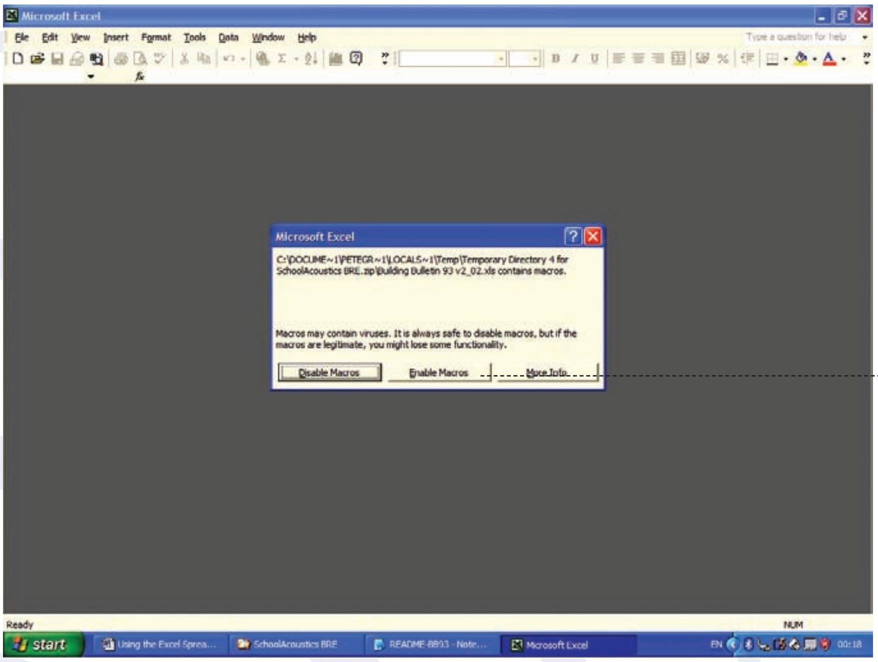
Close down and re-open the spreadsheet.



2. Starting the spreadsheet

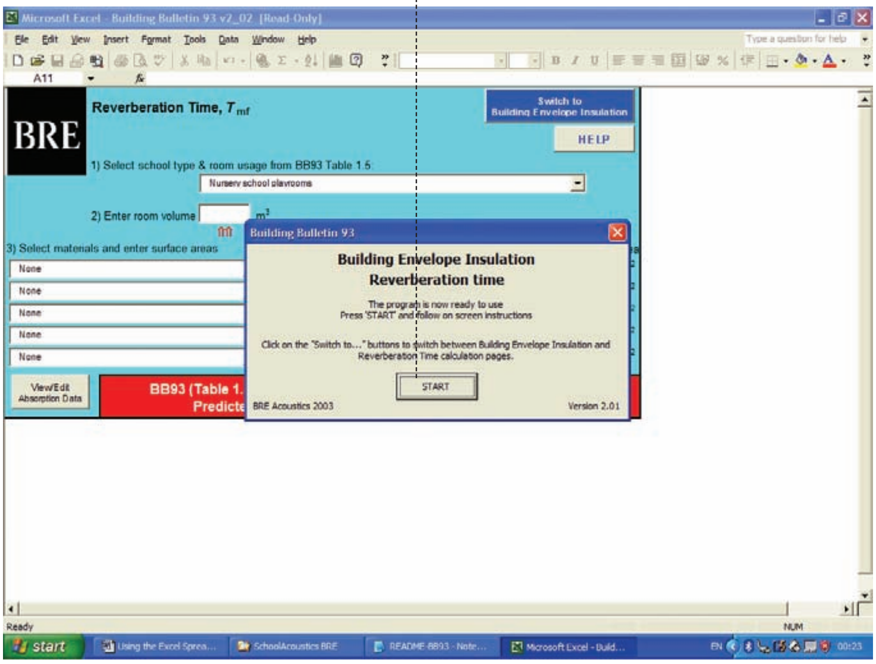
Double click on the icon and the screen below should appear on your computer.

You must choose to 'Enable Macros' before continuing.

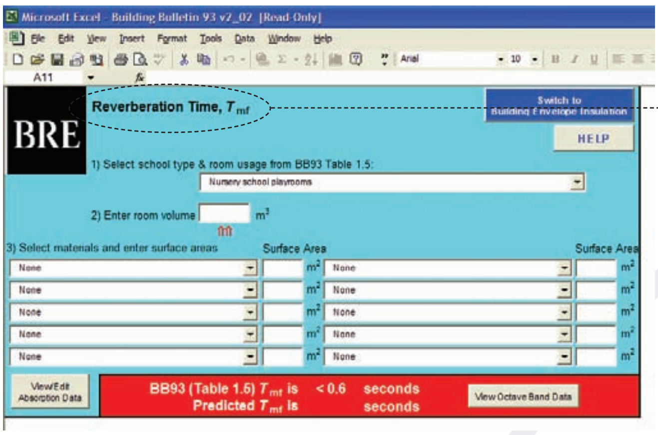


The next screen to appear is the start of the spreadsheet.

Select the **START** icon



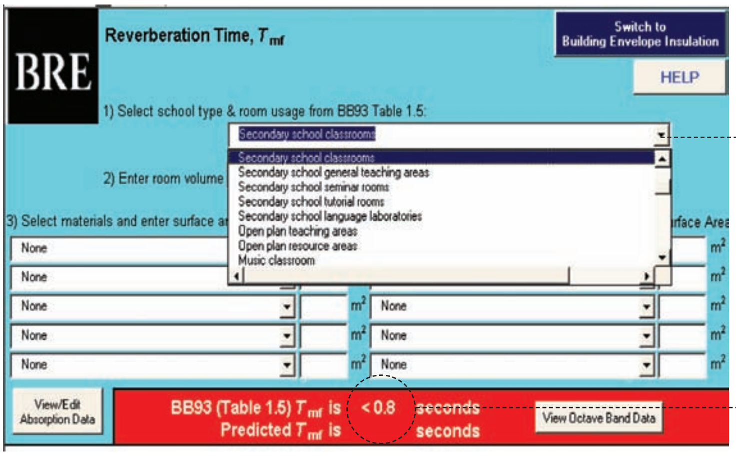
Before moving on, make sure that the screen on your computer matches the one below. There are potentially two screens and they can be changed using the icon.



Click on this icon and toggle between the two screens.

Before continuing, make sure you have the reverberation time screen in front of you.

3. Choosing the classroom type



The classroom types listed in BB93 can be accessed by using the arrow symbol which produces a drop down menu as shown on the screen above.

Use this to find the type of classroom you are assessing.

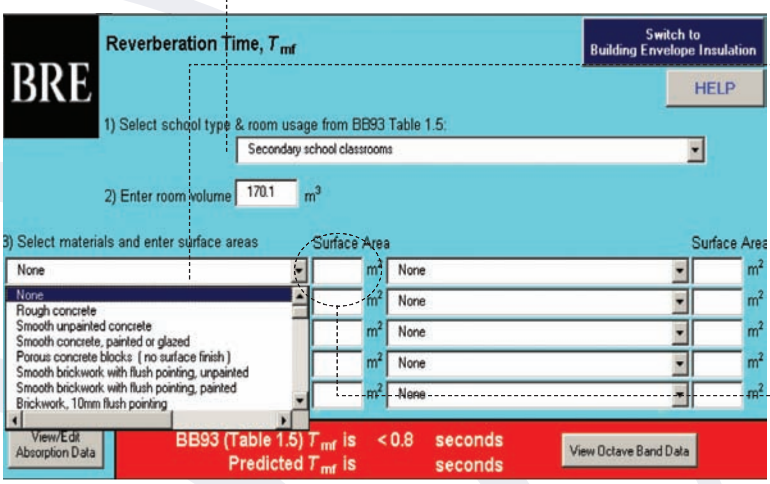
Changing the classroom type will change the required reverberation time (Tmf).

Try choosing a different room type and the Tmf should change.

4. Entering and changing the data

The first piece of information to enter on the spreadsheet is the volume.

After it has been calculated in cubic metres m³, it should be put in the designated box.

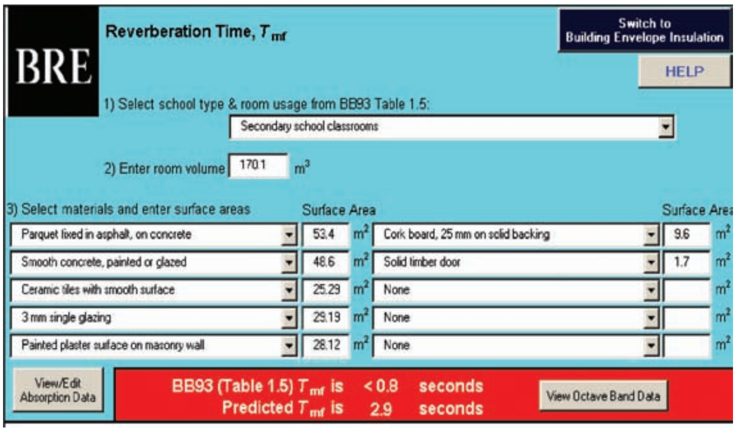


Now use the drop down menu to highlight the materials and choose from this list the material you wish to enter.

Enter the area for the chosen material in the box beside it.

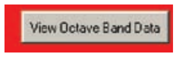
Appendix A has sheets which can be used to collect all the details for the spreadsheet. The case study has an example of how to use the sheets.

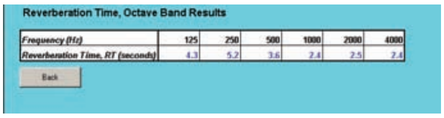
Appendix C has a list of the absorption coefficients of the materials in the spreadsheet. You may find it easier to use if you have it near you when entering the data.



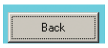
Once all the data has been entered a predicted Tmf will be displayed on the bottom of the screen.

This is an average of frequencies 500, 1000 & 2000 Hz.

To see what is predicted in the other 1/3rd octave bands select the icon  on the bottom of the screen and this will display the information below.



Record this data as you will be able to enter it into an Excel spreadsheet later.

Return to the previous screen using the  Back icon and make changes to the materials to see how to improve the reverberation time for the room.

An example of how to use this facility is in the section, Using the Spreadsheet and Data Collection Sheets.

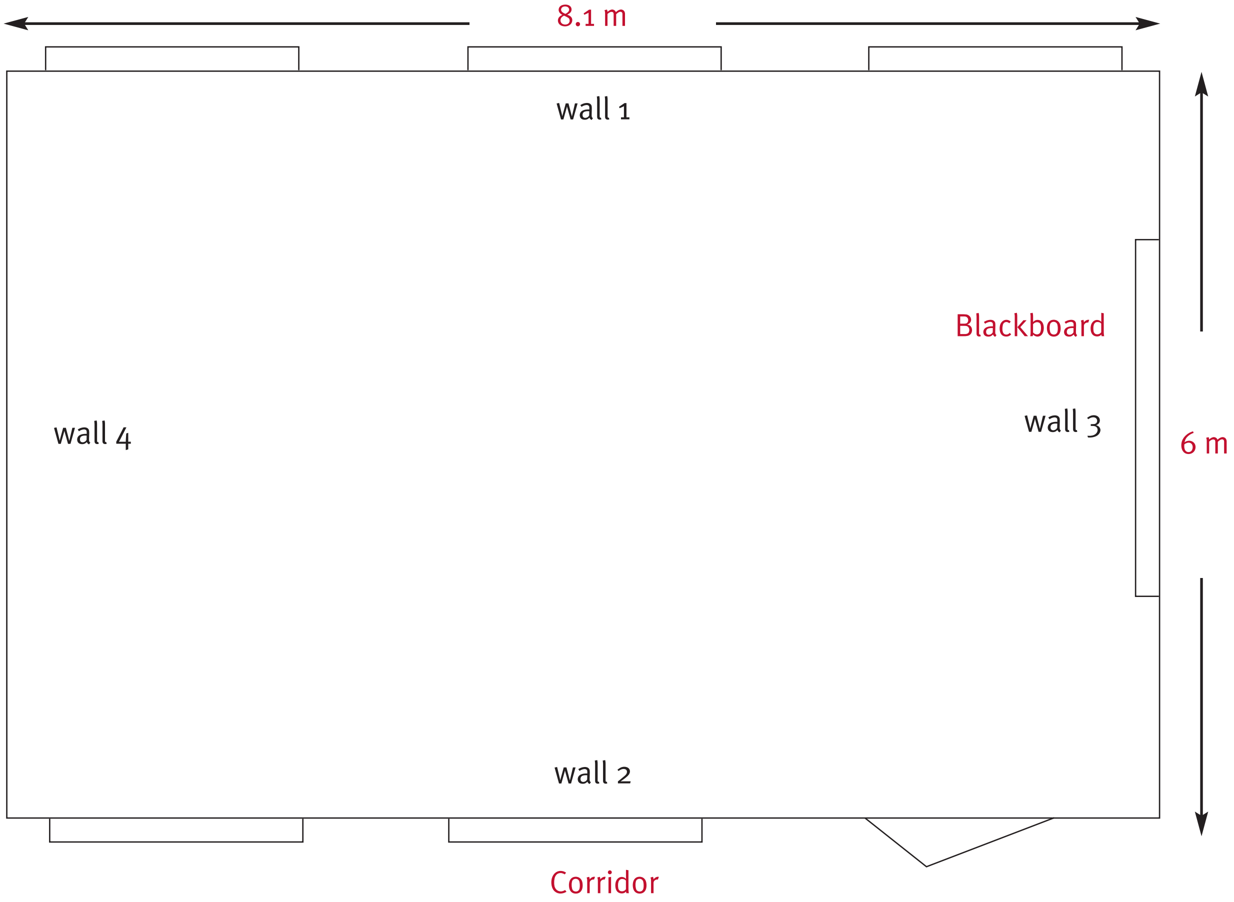
Using the spreadsheet and data collection sheets

The next few pages show the measurements and calculations needed to arrive at figures to enter into the spreadsheet which will then give you an approximate RT for the room.

Data Collection sheets examples

Name of School .... Date ....

Plan View



NB mark on the plan the following

- Black/Whiteboard
- Main Teaching Position
- Direction of South
- Tables/desks
- Outside, corridors, adjoining classrooms

Materials

Floor (Wood) .... 48.6 m^2

.... m^2

.... m^2

.... m^2

Ceiling

Dimensions 6 m x 8.1 m = ... m^2

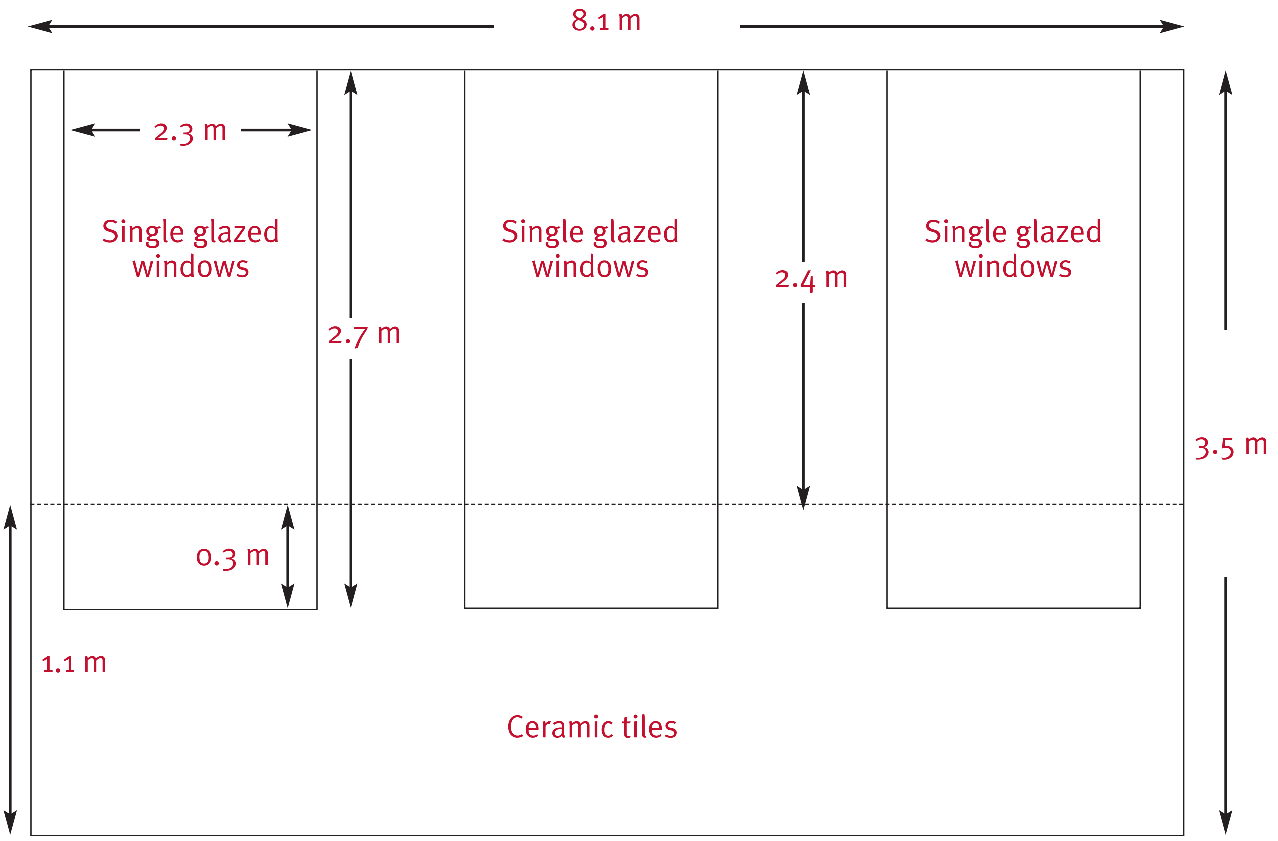
Material Concrete

Volume of the Room

Dimensions

6 m x 8.1 m x 3.5 m= 170.1 m^2

Wall 1



Calculations

Material Glass (single)

2.3 x 2.7 x 3 = **18.63 m²**

Material Ceramic tiles

1.1 x 8.1 – (3 x 2.3 x 0.3)
= 8.91 – 2.07
= **6.84 m²**

Material Plaster

8.1 x 2.4 – (3 x 2.3 x 2.4)
= 19.44 – 16.56
= **2.88 m²**

Material

Material

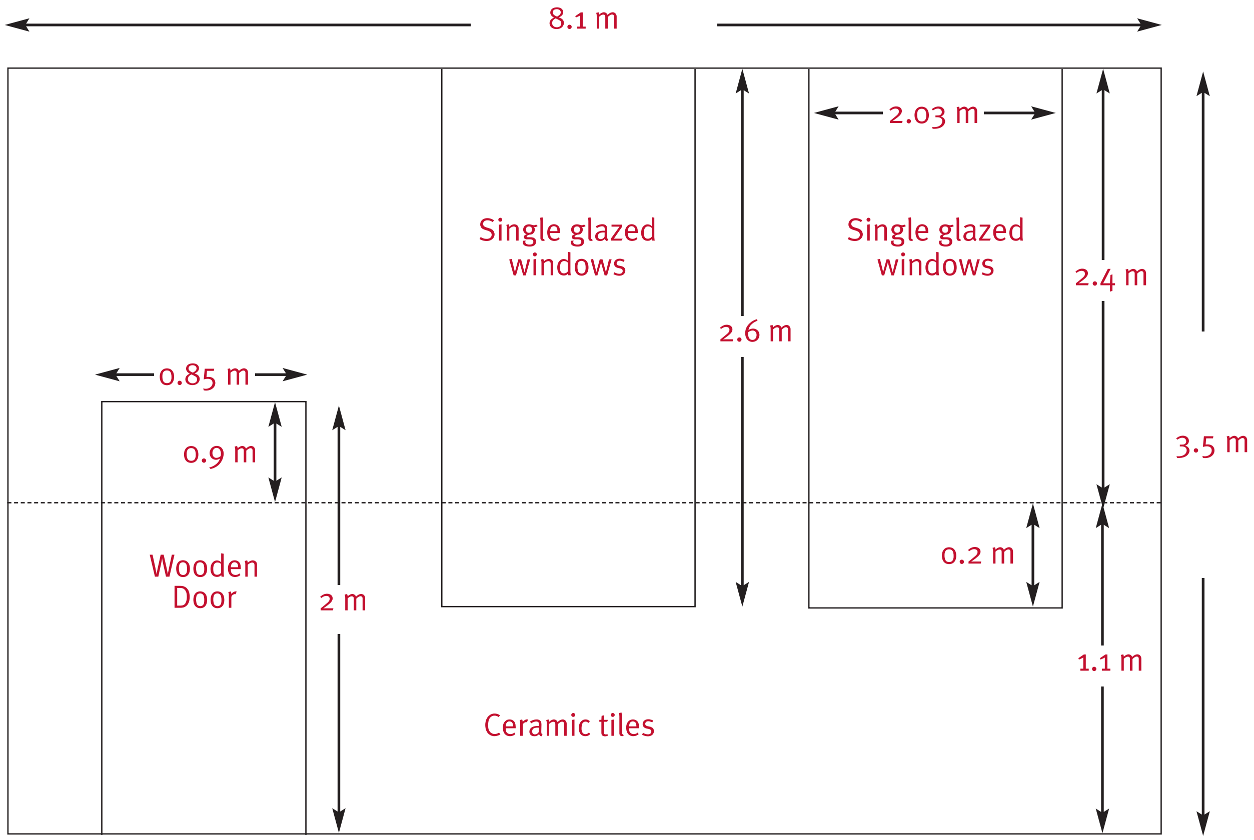
Materials (Total Surface Areas for this Wall)

Single Glazing	**18.63**	m²
Ceramic Tiles with smooth surfaces	**6.84**	m²
Painted Plaster on Masonry walls	**2.88**	m²
		m²
		m²

Total Area of the Wall

8.1 x 3.5 = **28.35** m²

Wall 2



Calculations

Material Glass (single)

2.03 x 2.6 x 2 = **10.56 m²**

Material Ceramic tiles

1.1 x 8.1 – (2 x 0.2 x 2.03)– (1.1 x 0.85)
= 8.91 – 0.812 – 0.935
= **7.163 m²**

Material Plaster

8.1 x 2.4 – (2 x 2.03 x 2.4) – (0.9 x 0.85)
= 19.44 – 9.744 – 0.765
= **8.931 m²**

Material Wooden Door

2 x 0.85 = **1.7 m²**

Material

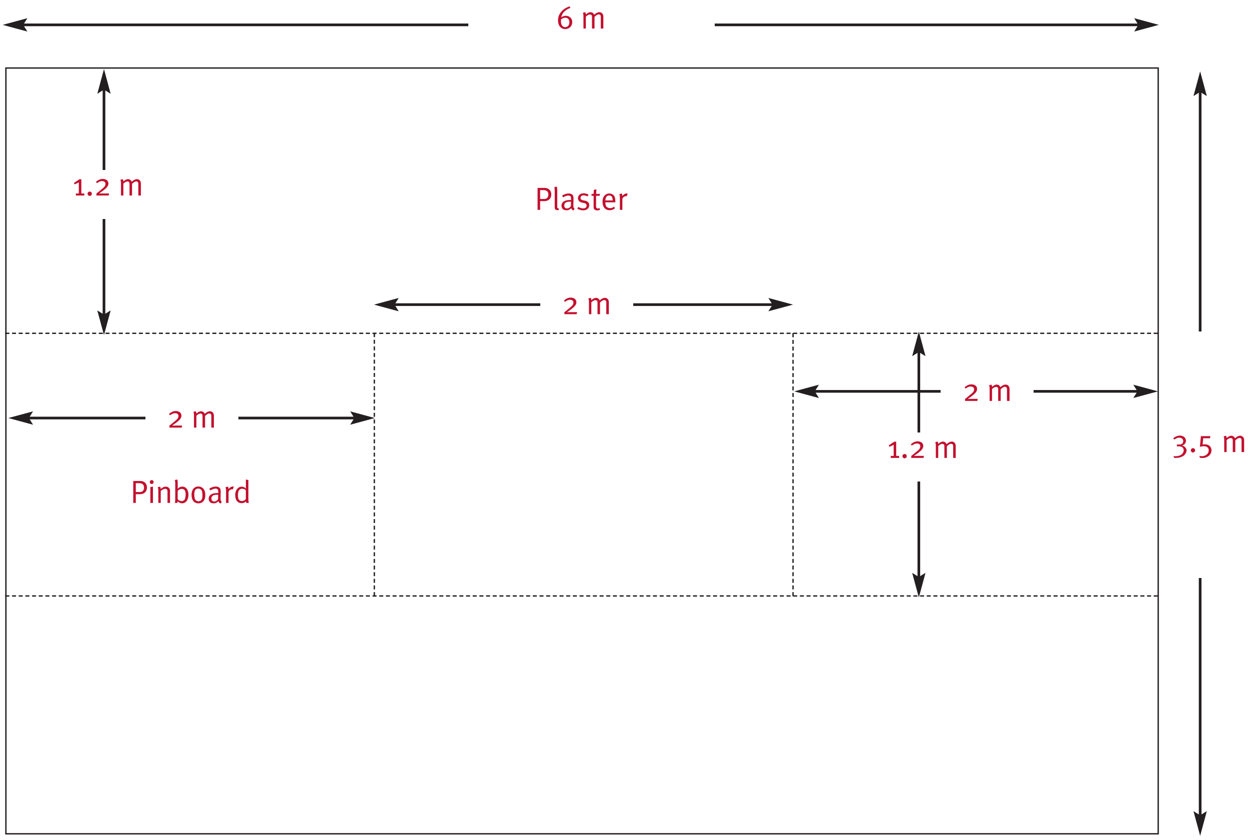
Materials (Total Surface Areas for this Wall)

Single Glazing	**10.56**	m²
Ceramic Tiles with smooth surfaces	**7.163**	m²
Painted Plaster on Masonry walls	**8.931**	m²
Solid Wood	**1.7**	m²
		m²

Total Area of the Wall

8.1 x 3.5 = **28.35** m²

Wall 3



Calculations

Material Ceramic tiles

1.1 x 6 = **6.6 m²**

Material Plaster

1.2 x 6 = **7.2 m²**

Material Pinboard

2 x 2 x 1.2 = **4.8 m²**

Material Wood (blackboard)

2 x 1.2 = **2.4 m²**

Material

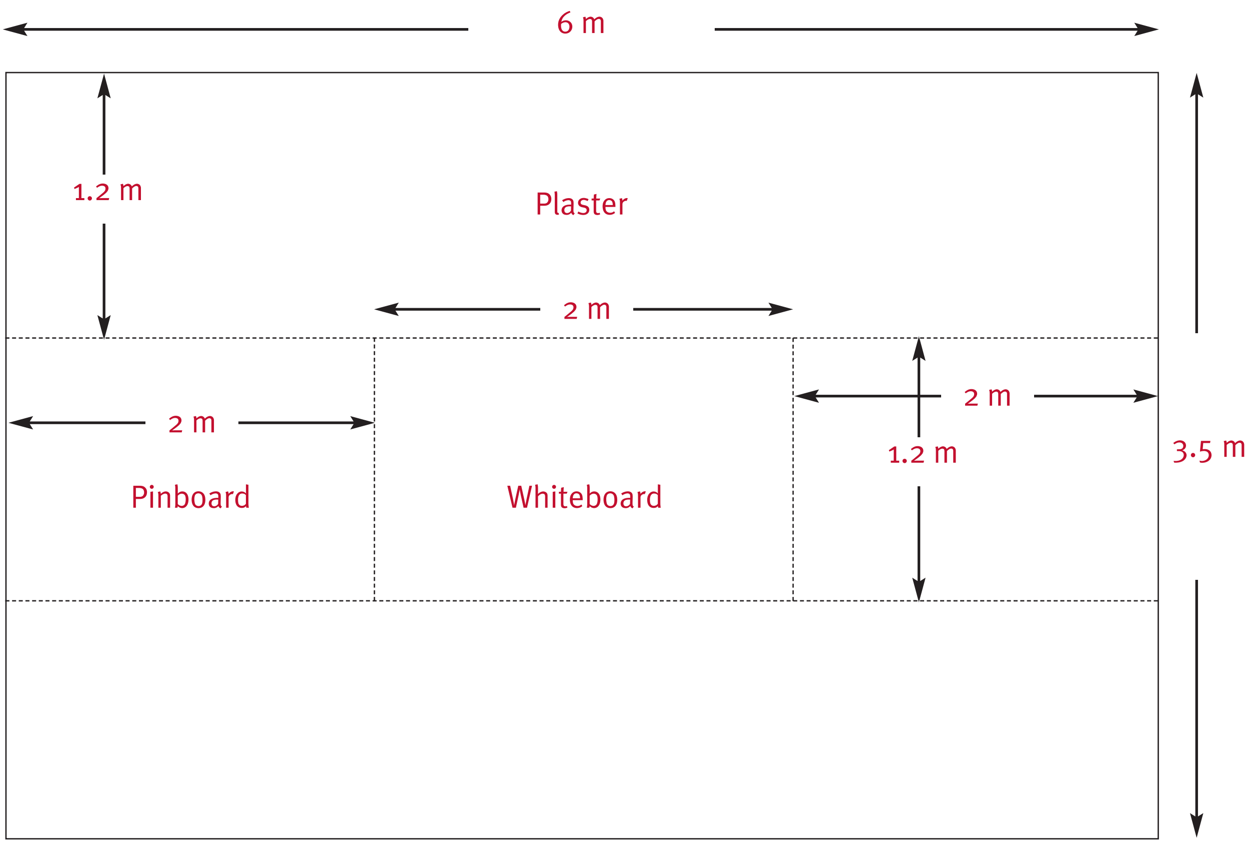
Materials (Total Surface Areas for this Wall)

Pinboard	**4.8**	m²
Ceramic Tiles with smooth surfaces	**6.6**	m²
Painted Plaster on Masonry walls	**7.2**	m²
Solid Wood	**2.4**	m²
		m²

Total Area of the Wall

6 x 3.5 = **21** m²

Wall 4



Calculations

Material Ceramic tiles

1.1 x 6 = **6.6 m²**

Material Plaster

1.2 x 6 = **7.2 m²**

Material Pinboard

2 x 2 x 1.2 = **4.8 m²**

Material Wood (whiteboard)

2 x 1.2 = **2.4 m²**

Material

Materials (Total Surface Areas for this Wall)

Pinboard	**4.8**	m²
Ceramic Tiles with smooth surfaces	**6.6**	m²
Painted Plaster on Masonry walls	**7.2**	m²
Solid Wood	**2.4**	m²
		m²

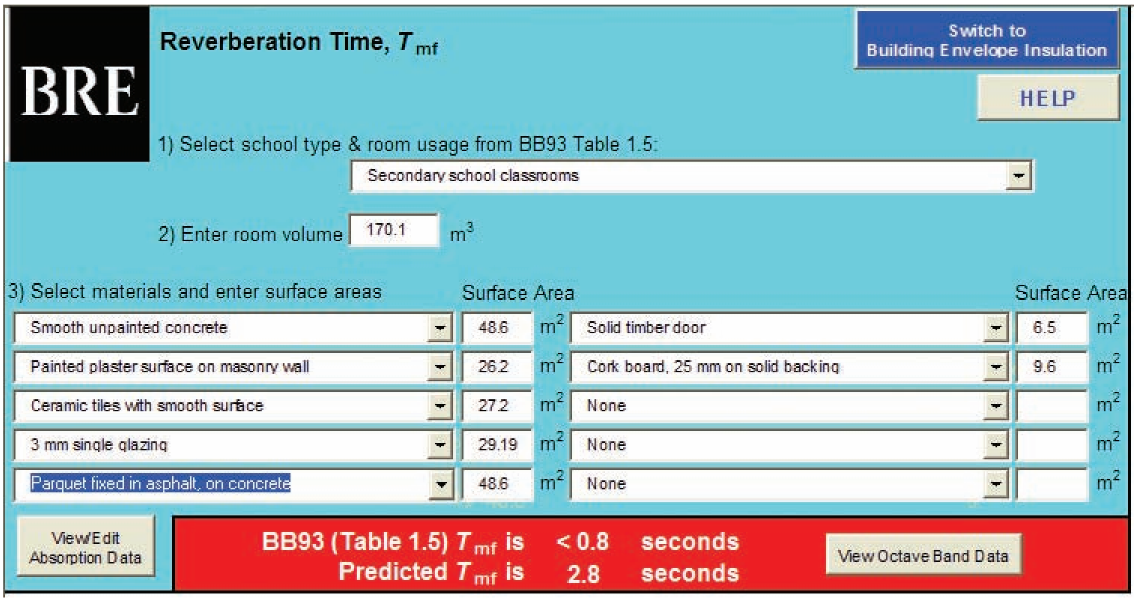
Total Area of the Wall

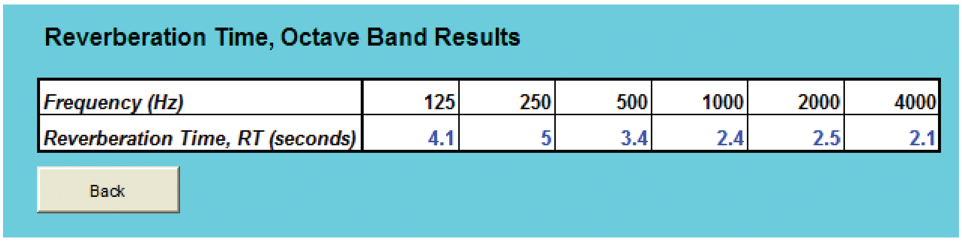
6 x 3.5 = **21** m²

TOTAL SURFACE AREAS

Material	Floor	Ceiling	Wall1	Wall2	Wall3	Wall4	TOTAL
Concrete (Smooth unpainted)	XXX	48.6	XXX	XXX	XXX	XXX	48.6 m²
Wood (Parquet flooring)	48.6	XXX	XXX	XXX	XXX	XXX	48.6 m²
Glass (single glazing)	XXX	XXX	18.63	10.56	XXX	XXX	29.19 m²
Ceramic Tiles with Smooth Surface	XXX	XXX	6.84	7.163	6.6	6.6	27.2 m²
Painted Plaster in Masonry wall	XXX	XXX	2.88	8.931	7.2	7.2	26.2 m²
Pinboard – corkboard on solid backing	XXX	XXX	XXX	XXX	4.8	4.8	9.6 m²
Solid Wood	XXX	XXX	XXX	1.70	2.4	2.4	6.5 m²

After all the calculations are complete, they can be entered into the BRE spreadsheet to produce estimated RTs for the room.





Reverberation Time, Octave Band Results

Frequency (Hz)	125	250	500	1000	2000	4000
Reverberation Time, RT (seconds)	4.1	5	3.4	2.4	2.5	2.1

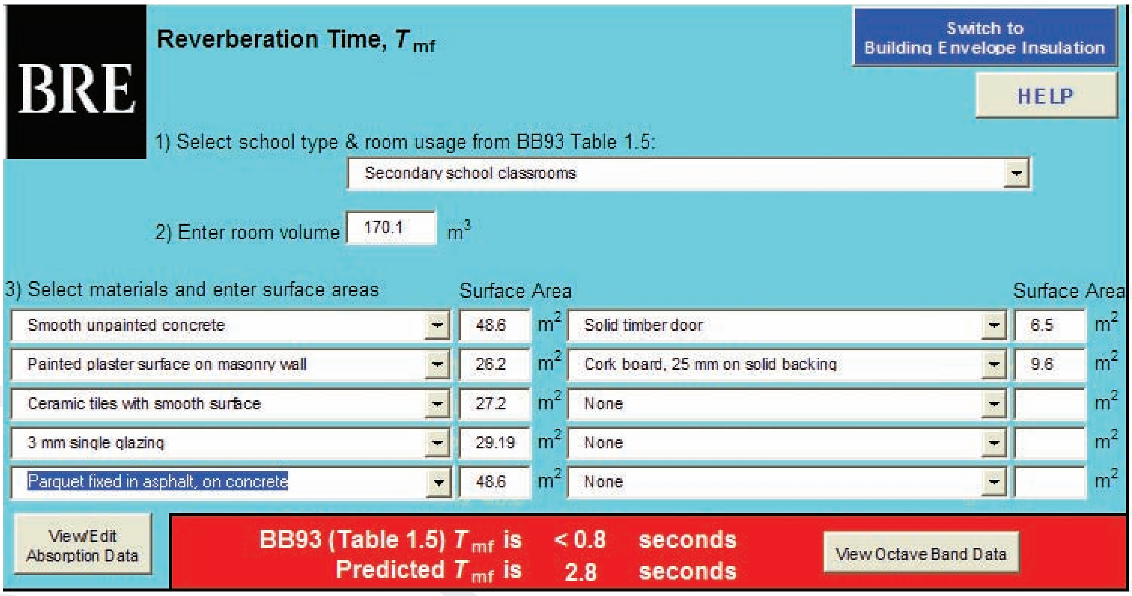
Back

Once the data has been entered, it is now possible to change some of the materials in the room and then see what happens to the RT.

In this example, the first change to make is to the ceiling – to cover the concrete with a suspended ceiling. Again using the BRE absorption coefficient sheet (Appendix C) will help you decide which would be the most suitable material. In this example, the low frequency reverberation needs to be reduced. The sheet shows that the '13mm mineral wool tile 500mm below ceiling' will greatly reduce the RTs.

Mineral wool/fibre	0.10	0.25	0.70	0.85	0.70	0.60
Perforated metal, 31mm thick absorbent infill	0.10	0.30	0.65	0.75	0.65	0.45
13mm mineral tile	0.10	0.25	0.70	0.85	0.70	0.60
Perforated metal 33mm thick absorbent infill	0.25	0.55	0.85	0.85	0.75	0.75
13mm mineral tile 500mm below ceiling	0.75	0.70	0.65	0.85	0.85	0.80
Seats unoccupied, leather upholstery, per m²	0.40	0.50	0.58	0.61	0.58	0.50
Seats unoccupied, cloth upholstery, per m²	0.44	0.60	0.77	0.89	0.82	0.70
Floor with cloth upholstered seats, per m²	0.49	0.66	0.80	0.88	0.82	0.70
Seating, slightly upholstered, unoccupied	0.07	0.12	0.26	0.42	0.50	0.55

When the concrete is replaced with the suspended ceiling, the following is produced.

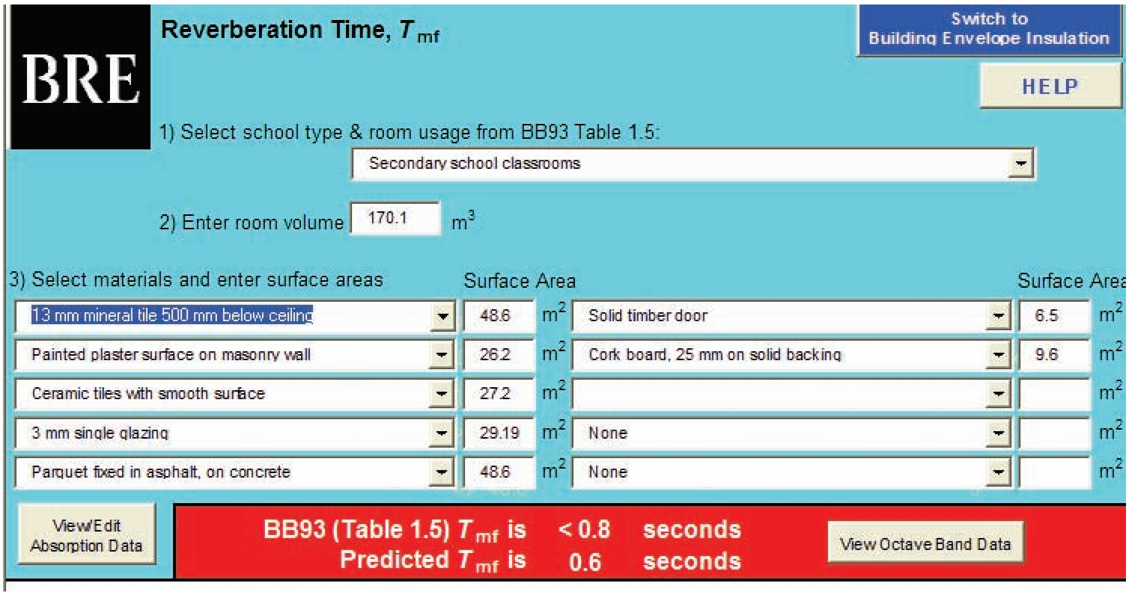


The RTs have now been significantly reduced.

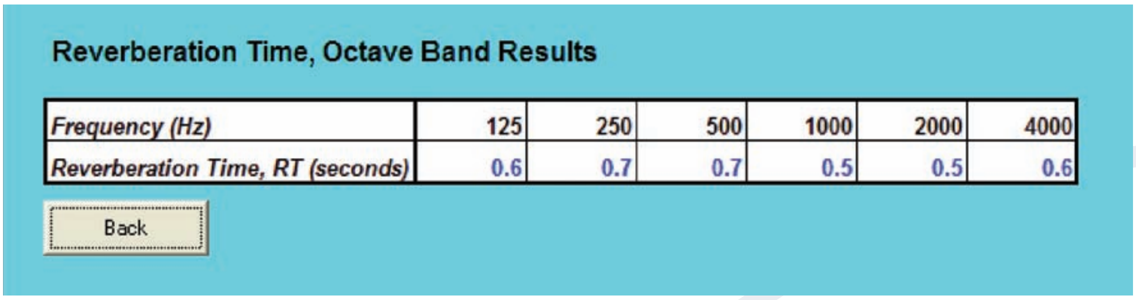
However, it may be decided that the installation of a suspended ceiling is too costly and all that can be afforded is a carpet and possibly some curtains.

Again, these can be entered into the spreadsheet. (Make sure you replace the old ceiling information first.)

If in this example the floor was covered with a carpet the following would happen to the RT.



The spreadsheet now shows a reduction in the mid frequency RT from 2.9s to 1.3s. However, when you look at the other 1/3rd octave bands, the low bands are still too long.

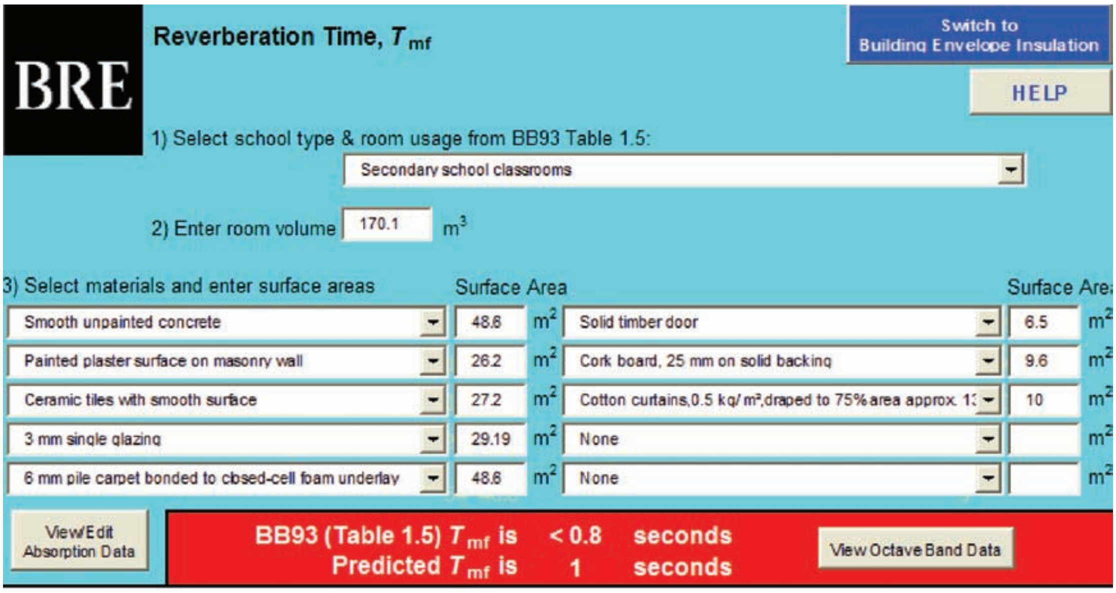

Reverberation Time, Octave Band Results

Frequency (Hz)	125	250	500	1000	2000	4000
Reverberation Time, RT (seconds)	0.6	0.7	0.7	0.5	0.5	0.6

Back

Fitting carpets will not reduce the low frequency reverberation, they will only help to reduce impact noise in any room below.

Curtains have now been added to the room. They are usually fitted over windows but are usually open. In this example the window area has been reduced and replaced with some carpets.



This has helped to reduce the mid frequency RT to 1s, (still too long for speech) but the low frequencies still reverberate too much.

Reverberation Time, Octave Band Results

Frequency (Hz)	125	250	500	1000	2000	4000
Reverberation Time, RT (seconds)	3	2.2	1.2	0.9	0.9	0.7

Back

It is worthwhile mentioning at this point the order in which materials should be changed to reduce RT.

1. Ceiling

2. Furthest wall from the speaker

3. Side walls

4. Floor

This spreadsheet should help you to decide the appropriate course of action in a room.

Reverberation times survey worked example

Case study

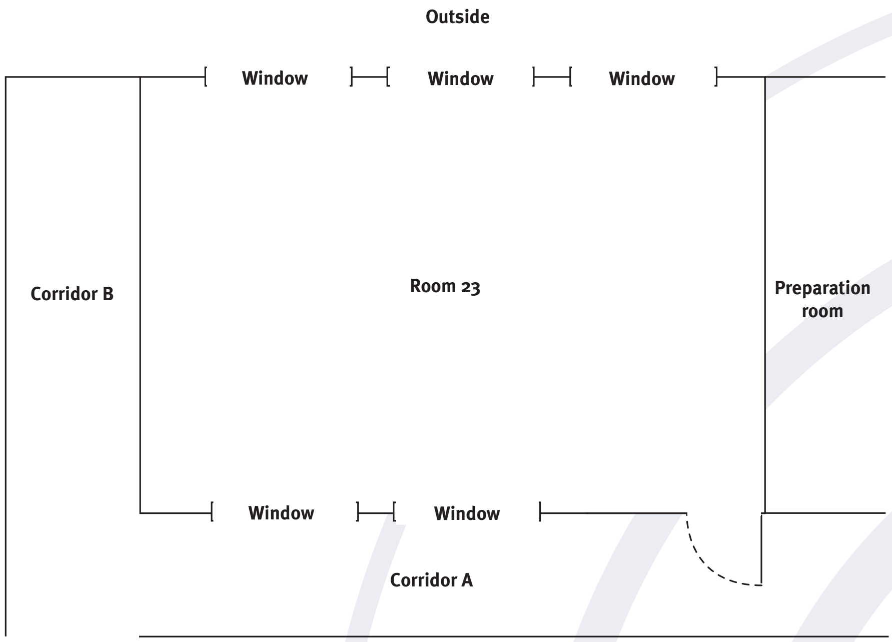
An English teacher in a Secondary school was continually having headaches and sore throats. She reported that her classes also complained of having difficulty hearing not only her but also the replies from other students.

After a preliminary noise survey, which showed that the noise wasn't excessive, it was decided to measure the reverberation time of the room.

Report

The room

This is a ground floor room with corridor on two sides, a preparation room next to it and the other wall has windows to the outside. There are two further windows leading on to corridor A. There is a classroom above but it was unoccupied at the time of the test. The teacher reported that there was little noise from the room above as it had recently been carpeted.



This room was tested twice, before and after any remedial work was done.

Test equipment used:
Norsonic Type 1 sound level meter - serial number 28930

Norsonic calibrator type 1251

First visit

On the first visit the RT for the room was measured using the Norsonic SLM.

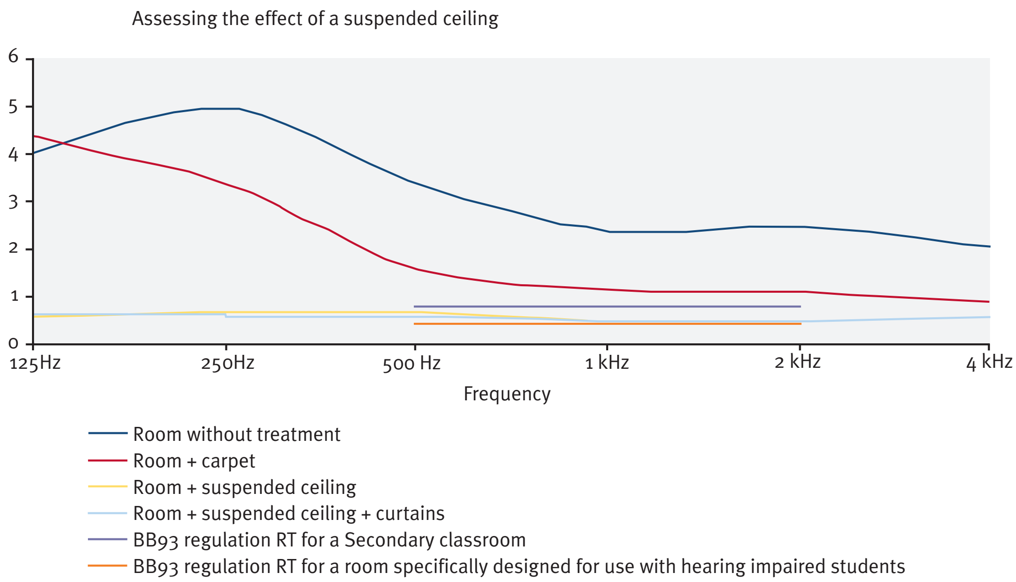
Also the room was measured so that calculations could be performed to assess the effect of some acoustic treatment.

The following table shows the calculations for the RTs before and after various treatments to the room.

Reverberation times for 1/3rd Octave Band Frequencies, measured in seconds

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	Average RT for all frequencies
Room without any changes	4.1	5	3.4	2.4	2.5	2.1	3.25s
			Average RT = 2.8s				
Change made Carpet fitted	4.4	3.4	1.6	1.2	1.1	0.9	2.1s
			Average RT = 1.3s				
Change made Suspended ceiling fitted	0.6	0.7	0.7	0.5	0.5	0.6	0.6s
			Average RT = 0.6s				
Change made Suspended ceiling + curtains	0.6	0.6	0.6	0.5	0.5	0.5	0.55s
			Average RT = 0.5s				

The table shows that only fitting a carpet to the room will reduce the RT for the room but on closer inspection, it tends to improve the mid and high frequencies more than the low frequencies.



These scores were then put into Excel to create a graph.

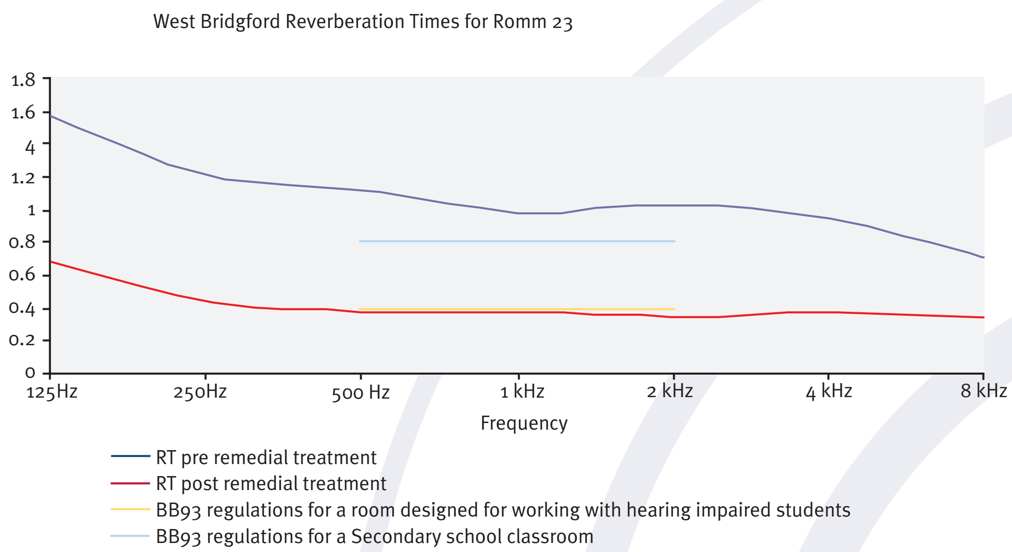
The graph again shows that the reverberation is mainly in the low frequencies.

Second visit

Between the two visits the room had a suspended ceiling fitted along with a carpet and some blinds to the windows. On the day of the visit the blinds on the outside wall were open and the blinds on the corridor side were closed.

The RT was again measured using the Norsonic SLM

The graph below shows the two sets of results from the two test days. The blue line is pre remedial treatment and the pink line is the most recent test, after the treatment to the room.



Comments

The shortening in the length of the reverberation time (RT) in this room is significant and will allow speech to be more intelligible. The RT is shorter in all frequencies and more importantly in the low frequencies. Noise tends to be low frequency in nature and when it reverberates 'masks out' the high frequency sounds which we need for speech to be intelligible.

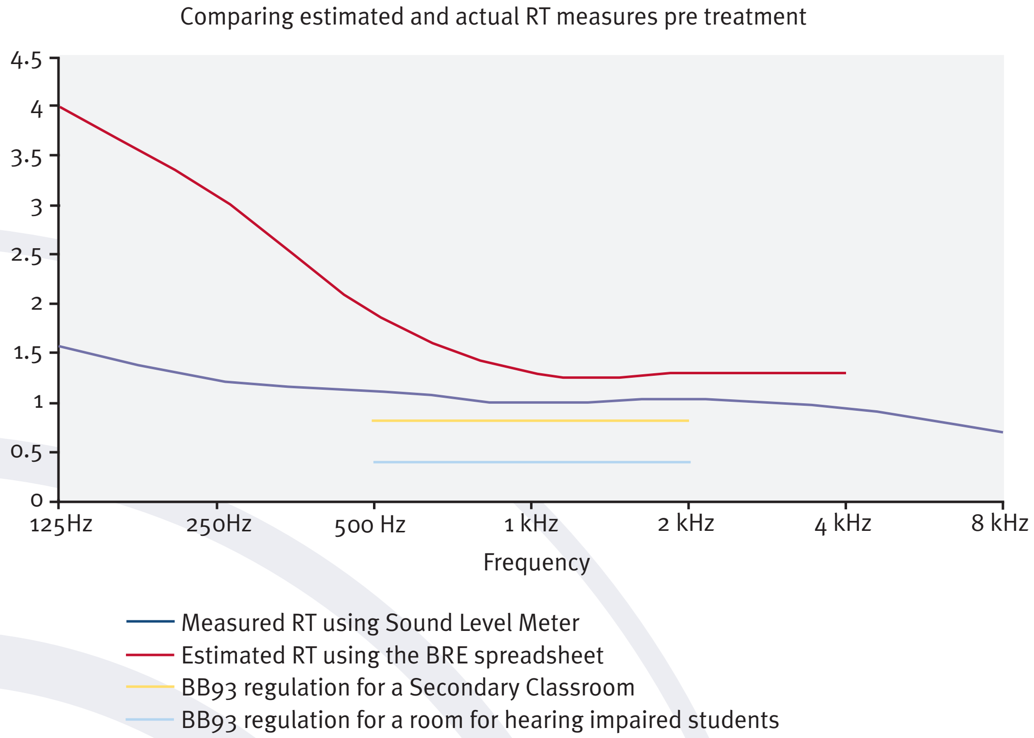
The retest shows that this room is more comfortable for listening to speech and one of the teachers who uses the room commented that it is much better to work in.

The RT for this room easily satisfies the BB93 regulations for a secondary school classroom and also complies with a room which is designed for use with deaf students.

The spreadsheet is an invaluable tool to demonstrate the effect of altering some materials in a room.

However, it is not as accurate a measure as would be gained using a type 1 SLM.

To demonstrate this, a comparison can be made between the calculated RT, using the spreadsheet, and the actual RT as measured using the SLM.



The graph above shows the estimated RT to be much longer than the actual RT, especially in the low frequencies.

For this reason, the estimated RT should only be used for comparison purposes and not as a true representation.

Data Collection sheets

Name of School .... Date ....

Plan View

wall 1

wall 4

wall 3

wall 2

NB mark on the plan the following

- Black/Whiteboard
- Main Teaching Position
- Direction of South
- Tables/desks
- Outside, corridors, adjoining classrooms

Materials

.... m

.... m

.... m

.... m

Ceiling

Dimensions ....m x ....m = ...m..........

Material ....

Volume of the Room

Dimensions

..........m x ....m x ....m= ....m..........

Wall..................

Calculations

Material ....

Material ....

Material ....

Material ....

Material ....

Materials (Total Surface Areas for this Wall)

.... m ....

.... m ....

.... m ....

.... m ....

Total Area of the Wall

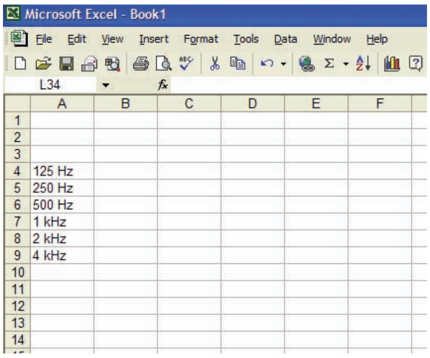
.... x .... = ... m ....

Producing graphs

For a report you may wish to produce your calculations in a graph form.

You will need to put your calculations in an Excel spreadsheet and the following instructions should guide you through the process.

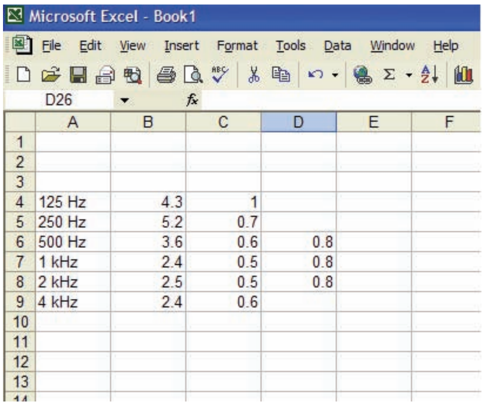
Open the spreadsheet and type in column A the frequencies you have calculated. It is important to remember to put Hz or kHz after the numbers in this column.



You are now going to enter your calculations in the next columns.

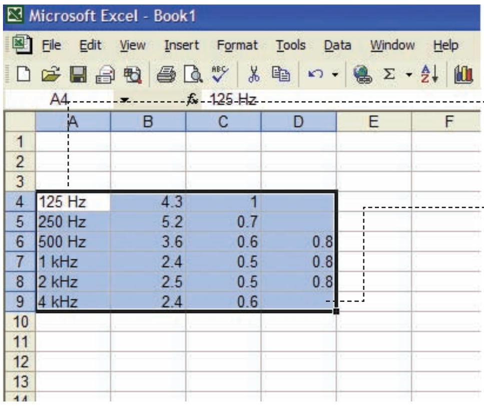
Take your information from the table with the recordings of your calculations and place them in the spreadsheet.

	Reverberation Times for 1/3rd Octave Band Frequencies, measured in seconds (s)								
	63Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	Average RT for all frequencies
Room without any changes		4.3	5.2	3.6	2.4	2.5	2.4		3.4s
				Average RT = 2.9s					
Change made Suspended ceiling added.		1	0.7	0.6	0.5	0.5	0.6		0.65s
				Average RT = 0.5s					
Change made									
				Average RT =					
Change made									
				Average RT =					



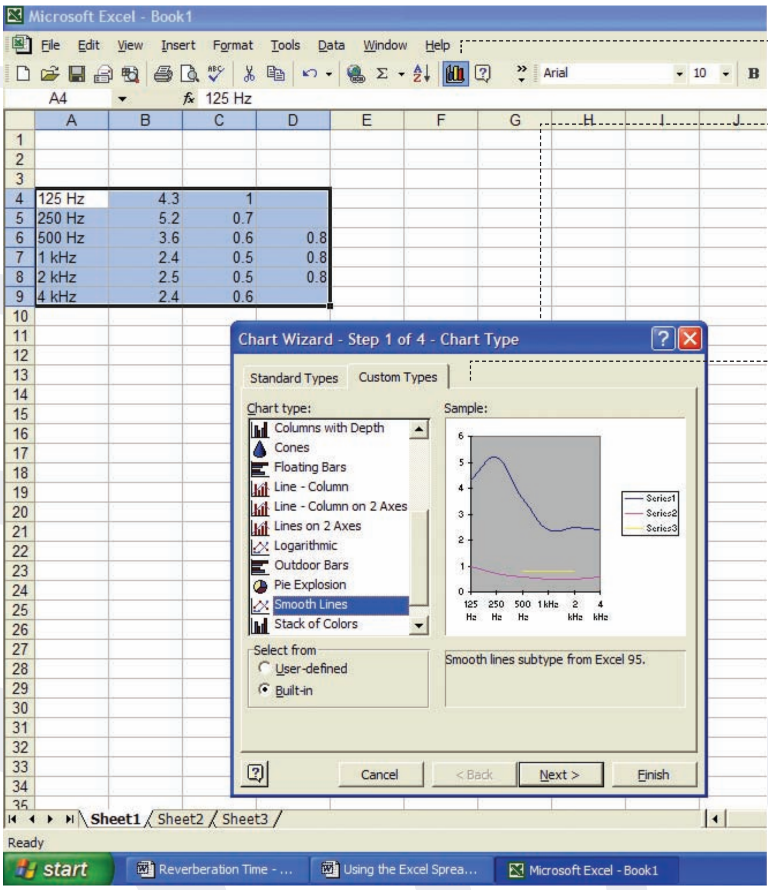
In this case columns B and C have been used.

You may also want to put in the RTs from BB93 for this particular room.



The next stage is to highlight your data by placing the cursor on the first piece of data A4, hold down the left mouse button and drag to your last piece of data, D9, and then release the mouse button.

All your data should now be highlighted.



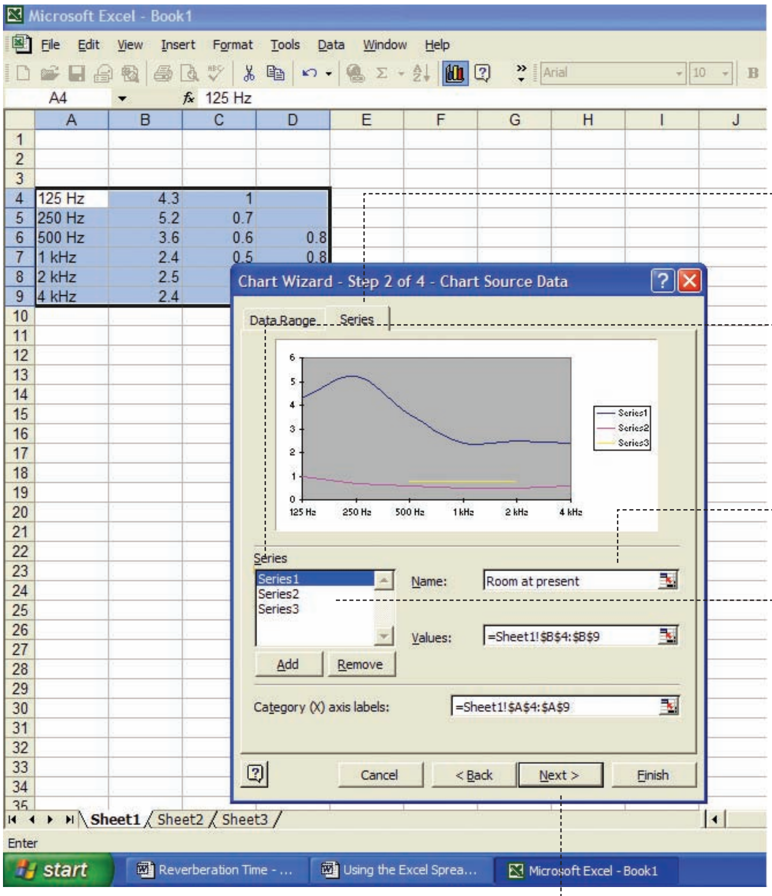
Next choose the Chart Wizard.

A box will appear.

If you wish to produce a graph of smooth lines you will find it in Custom Types

If you wish to present you data in a different way then experiment with other choices.

Highlight your chosen chart type and then choose Next.



This screen allows you to start labelling your graph.

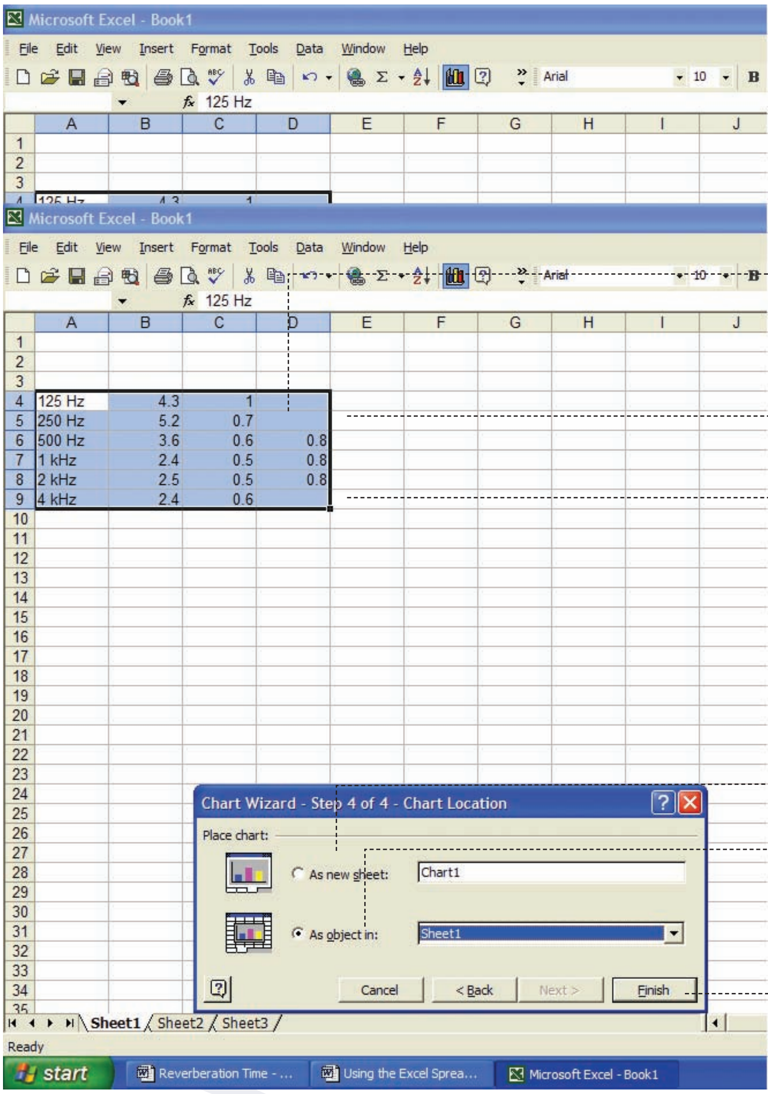
Choose the Series icon.

On this screen, Series 1 will automatically be highlighted.

You will now need to type a short description of this data in the Name box

The other lines on the graph can be labelled by first highlighting the Series number and then typing the description in the Name box.

When all this has been completed, choose Next



This screen allows you to label the chart and choose the position of the Legend box.

The title of the graph can be put in the Chart title box.

The (X) axis should be the 1/3rd octave bands you have calculated.

The (Y) axis should be the reverberation times.

When complete choose Next

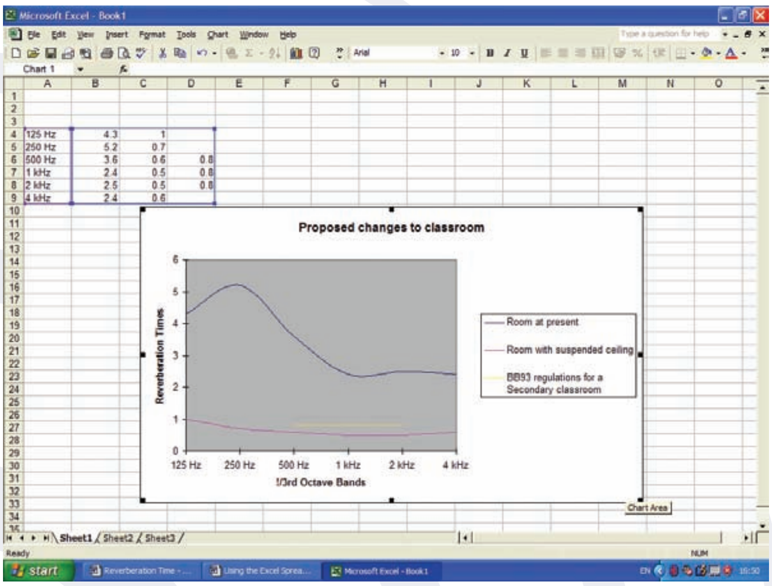
In this screen you can choose from either

‘As new sheet’

or ‘As object in’.

Either of these will produce a graph.

Now choose Finish to produce the graph.



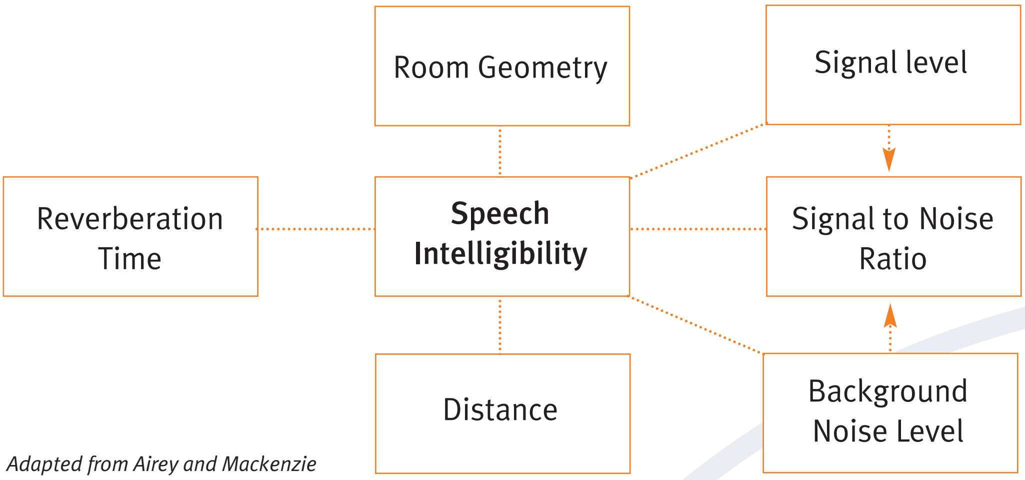
The chart can be highlighted and copied into a Word document.

Introduction

The main aim of the Acoustic Toolkit is to provide you with the tools to identify and remedy the problems in the school listening environment and improve speech intelligibility for the pupils and the teaching staff.

Airey and Mackenzie (1) defined speech intelligibility as, "the process whereby a person can clearly hear what is being said and fully understand the context of the spoken word." They also stated that, "In a classroom situation, children should not only clearly hear what the teacher is saying but also the teacher must hear what the pupil is saying in reply."

The factors which can affect speech intelligibility are shown below



Adapted from Airey and Mackenzie

Building Bulletin 93 (BB93), The Acoustic Design of Schools produced by the Department for Education and Skills (2), states that "The intelligibility of speech depends upon its audibility as well as clarity. Audibility is affected by the loudness of the speech relative to the background noise level. An increase in the background noise will cause greater masking of speech and hence will decrease intelligibility.

BS 7827:1996; Code of practice for designing, specifying, maintaining and operating emergency sound systems at sport venues, (3) provided definitions for the following terms

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

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

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

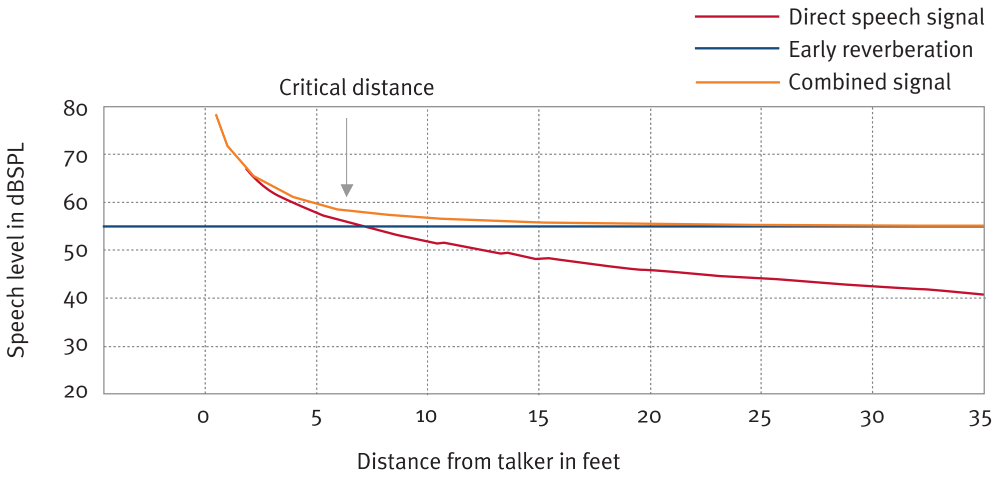
Clarity + Audibility = Intelligibility

Room geometry

In the open air, sound will follow the inverse square law and not be influenced by any distortion of the signal.

In a room the direct sound will also follow the inverse square law but will be affected by late and early reverberation.

The graph below shows what happens to sound in a room.



The red line on the graph shows how the direct signal follows the inverse square law which means, in the open air, the sound level falls by 6dB for every doubling of distance.

The blue line shows that the level of the early reverberation is fairly constant throughout the room.

The green line is the Effective Signal which is a combination of the direct speech signal and the early components of reverberation (otherwise known as early reflections).

The effective signal level, expressed in dB, is the higher of the two levels at most points in the room.

Critical distance (Dc) is the distance from the talker at which the levels of the direct speech and the early components of reverberation are equal. Before the critical distance, the effective signal is the direct signal. Beyond the critical distance, the effective signal is dominated by reverberation and, at three times the critical distance; the direct speech makes negligible contribution.

At the critical distance the combined level of direct signal and early reverberation is 3dB higher than either one.

Critical distance depends on both room size and reverberation time.

The formula for calculating critical distance (using metric measurements) is:

$$DC = 0.2\sqrt{\frac{V}{\pi \times RT}}$$

(DC – Critical Distance, V – Volume, RT – Reverberation Time)

As the formula shows, the critical distance is dependant on the volume of the room (V) and the reverberation time (RT).

Example

A classroom with a volume of 170.1 m^{3}has been acoustically treated and the RT has changed from 2.9s to 0.6s. How does the critical distance (CD) change?

RT = 2.9s

$$DC = 0.2\sqrt{\frac{170.1}{3.14 \times 2.9}}$$

DC = 0.86 m

RT = 0.6s

$$DC = 0.2\sqrt{\frac{170.1}{3.14 \times 0.6}}$$

DC = 1.9 m

By lowering the RT in a room, the critical distance is increased. This means that with an RT of 0.6s a student needs to be less than 1.9m away from the teacher if reverberation is not to affect speech intelligibility.

There have been many studies that show the effect of poor acoustics and noise on speech intelligibility in a classroom, mainly from the United States. The Finitzo-Heiber paper produced in 1978 looked at the combined effect of reverberation and background noise levels on both normally hearing and hearing-impaired children. The table below shows the results.

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

The scores are the percentage of words correctly identified in various conditions.

Yacullo and Hawkins (1987) presented thirty-two normally hearing 8-9 year olds with words in rooms with reverberation times of 0 seconds and 0.8 seconds plus signal to noise ratios of +2 and +6 dB. They discovered that the reverberation decreased the mean speech discrimination by 41.1% whilst the scores decreased by 27.4% as the signal to noise ratio dropped.

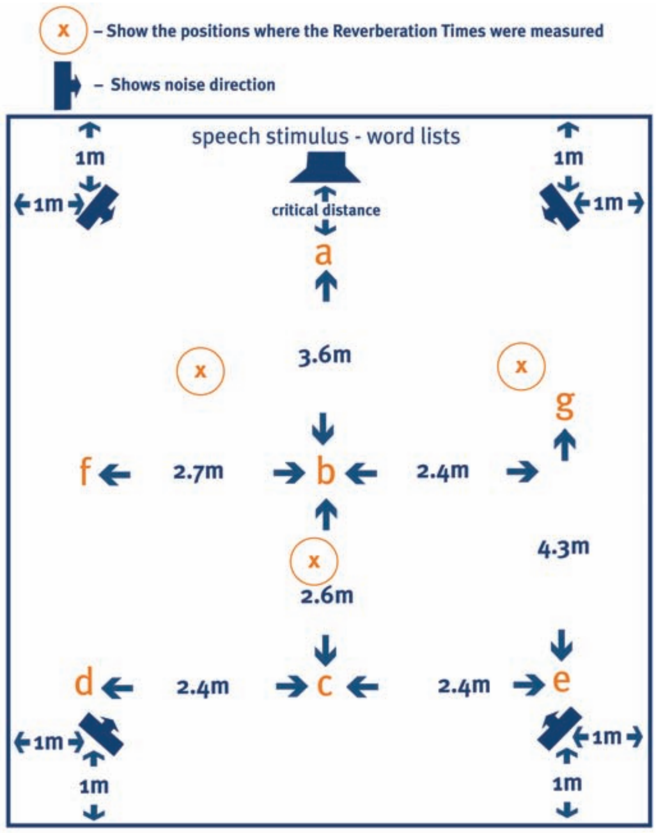
A study in 1997 by Anderson and Towne discussed previous research and presented findings from a new investigation. This report discusses the detrimental effect of speaker to listener distance and the masking effect of speech sounds by high and low frequencies.

The report by MacKenzie and Airey (1999) highlighted many problems related to listening in classrooms, including the problems with dead spots in the room. They also produced speech intelligibility scores in different listening conditions as shown in the table below.

Word Intelligibility by Picture Identification (WIPI)

	Untreated	Treated
Control	96.7%	97.5%
Quiet classroom	94.2%	97.5%
Students working	57.2%	67.0%

All of the studies mentioned show the problem with both reverberation time and background noise. Wilson's study (2006) shows similar problems but they are obtained using the same group of Y7 students and the same test procedures but in different rooms with different reverberation times. Comparisons are made between the different reverberation times of the rooms.



Opposite is the set up for the rooms.

The same distances were used in each room.

All 14 students were tested in all the positions.

The noise was classroom babble played through a portable soundfield system.

All 14 students had a hearing test before every test to ensure their hearing was normal.

The results table below shows that the higher the reverberation time, the poorer the speech intelligibility scores.

The results also show that the lowest scores are the furthest points from the speaker, (C,D & E)

	Speech Intelligibility Scores / %								
	Quiet	Student Positions							Reverberation Times
Room		A	B	C	D	E	F	G	(averaging all 1/3rd band octaves from 63 Hz to 8 kHz)
1	80.5	67.8	43.2	45.1	40.2	39.7	48.8	51.1	1.17s
2	86.1	75.3	49.6	45.9	42.9	50.1	50.8	49.1	1.13s
3	93.2	87.5	58	64.5	56.7	56.7	62	61.1	1.04s
4	95.2	91.9	79.6	74.9	70.4	62.2	73.1	79	0.59s

This type of testing is an accurate measure of how students perform in a classroom but it is very time consuming. The test used in this study (AB Word Lists) has limitations with the vocabulary and will discriminate against younger students and students where English is their second language. If the test can be done, it will provide some good information about the room.

Measures of speech intelligibility

Phonemically balanced tests using normally hearing people are by far the most accurate and reliable methods for intelligibility testing. However, the tests are complicated to set up and time consuming and so speech intelligibility in a room can be measured in 2 ways:

1. Machine measures
2. Speech discrimination testing

1. Machine measures

These are some of the measures which can be obtained using a type 1 sound level meter.

%Alcons

AI - Articulation Index

STI - Speech Transmission Index

RASTI - Rapid Speech Transmission Index

SII - Speech Intelligibility Index

%Alcons

This is a measure of the percentage articulation loss of consonants. Since %Alcons expresses loss of consonant definition, lower values are associated with greater intelligibility. For learning environments the desired value is 5% or less. The %Alcons method is widely used by acoustical consultants, particularly in the United States, but it has significant drawbacks. First, it is based on measurements in a single one-third octave band centred on 2 kHz, all other frequencies are ignored. Also this method does not account for many factors that can dramatically affect intelligibility, including signal to noise ratio, background noise, distortion, late reflections etc.

Articulation Index (AI)

This is one of the earliest attempts to measure intelligibility using a machine. The AI is based on the idea that the response of a speech communication system can be divided into twenty frequency bands, each of which carries an independent contribution to the intelligibility of the system, and that the total contribution of all the bands is the sum of the contributions of the individual bands. The AI varies in value from 0 (completely unintelligible) to 1 (perfect intelligibility). An Ai of 0.3 or below is considered unsatisfactory, 0.3 to 0.5 satisfactory, 0.5 to 0.7 good, and greater than 0.7 very good to excellent.

Speech Transmission Index (STI)

Developed in the early 1970's, the STI is a machine measure of intelligibility whose value varies from 0 (completely unintelligible) to 1 (perfect intelligibility)

In STI testing, speech is modelled by a special test signal with speech like characteristics. This is based on the concept that speech can be described as a fundamental waveform that is modulated by low frequency signals; STI employs a complex amplitude modulation system to generate its test signal. At the receiving end of the communication system, the depth of modulation of the received signal is compared with that of the test signal in each of the frequency bands. Reductions in the modulation depth are associated with loss of intelligibility.

Rapid Speech Transmission Index (RASTI)

This was developed as a simpler alternative to the more complex STI. In contrast to STI, RASTI measures only two octave bands centred at 500 Hz and 2 kHz, respectively. It uses a speech like excitation signal and like STI, correlates reductions in modulation depth to loss of intelligibility. It is possible for RASTI to give an overly optimistic rating because it only uses these octave bands and doesn't take into account the low frequencies.

Speech Intelligibility Index (SII)

This is very similar to STI. The value of SII varies from 0 (completely unintelligible) to 1 (perfect intelligibility). This test shows good correlation to speech discrimination testing. SII covers bandwidth from 150 Hz to 8.5 kHz and far greater resolution than any other method. SII properly includes reverberation, noise and distortion, all of which are accounted for in the modulation transfer function. Under certain conditions SII can yield misleading results. In particular, late arriving reflections and echoes can distort the measurement significantly.

2. Speech discrimination testing

There are many speech discrimination tests available and the one you choose will depend on factors like age and ability.

The two lists below show some of the tests and have been split into two categories. The 'pointing' list only requires the student to point to a picture or object, and the other list requires the student to repeat either words or sentences.

Pointing	Repeating
Minimal pairs	AB Word Lists
Toy Tests – Mc Cormack	Manchester Junior Word Lists
English as a Second Language	
Consonant Confusion Task Response Cards	BKB Sentence Lists
Manchester Picture Test	HARPA
FAAF	
BKB Picture Related Tests	

Pointing

Most of these tests are normally used with the tester and student close together probably 1 metre apart. Unfortunately this distance would be inside the critical distance of most rooms meaning that reverberation would not affect the speech signal.

Previous studies have used picture tests, like the WIPI test. This test involved a word being presented and the pupil choosing from a set of pictures in front of them. The research by MacKenzie and Airey used the WIPI test. However, this particular test only provides a minimum choice and consequently a student could obtain a good score by guessing only.

The MacKenzie and Airey study had the students sat in their normal seating position in the classroom. This implies that all the 'pointing' tests could be used over a distance but caution should be used as these tests are usually used with younger students and they may not have the linguistic skills or confidence to complete the tests.

Repeating

The main reason for using these tests is to assess a room for speech intelligibility and the most appropriate tests are phonemically balance word lists. Of the lists above, only the AB word lists and the Manchester Junior word lists are appropriate.

Wilson's study used a pre-recorded CD of the AB word lists as the speech signal and classroom babble for the noise. In this study, Y7 students were required to write the words they thought were spoken by the speaker. In other smaller studies by Grayson, Y6 students in primary schools were also asked to write the words spoken. Y6 and Y7 students were chosen as they were similar in age and were able to complete the task asked of them.

The CD used in both studies presented each word individually but Boothroyd argues that they should be preceded by a carrier phrase e.g 'Write the word'. He has devised a computer programme, called CASPA, which has several different carrier phrases which can be played before each word. He has used this programme to assess room acoustics in the United States. Unfortunately it is not easy to understand because the speaker on the programme has a strong American accent.

AB Word Lists

This test consists of several lists of phonemically balanced consonant-vowel-consonant words (CVC), see appendix 1.

Arthur Boothroyd devised the test in the 1970's as a means of assessing a hearing impaired child's ability to hear the phonemes of speech. Originally the whole test comprised of nearly 20 lists, and there should be no one list harder than the other. However, Southampton University discovered that some of the lists proved to be more difficult than others. They produced a modified version comprising of fewer lists of which this project will use the first eight. Southampton University also produced a CD of the lists, which has been used as the speech source for the project.

Using this test is not without its problems. Looking at the vocabulary of the lists, it is important to choose appropriate students for the assessment. Students who have English as a second language may find the vocabulary difficult as well as the accent of the speaker on the CD. Also students who have problems with spelling and auditory processing disorders would find the test difficult.

Below are the lists of words.

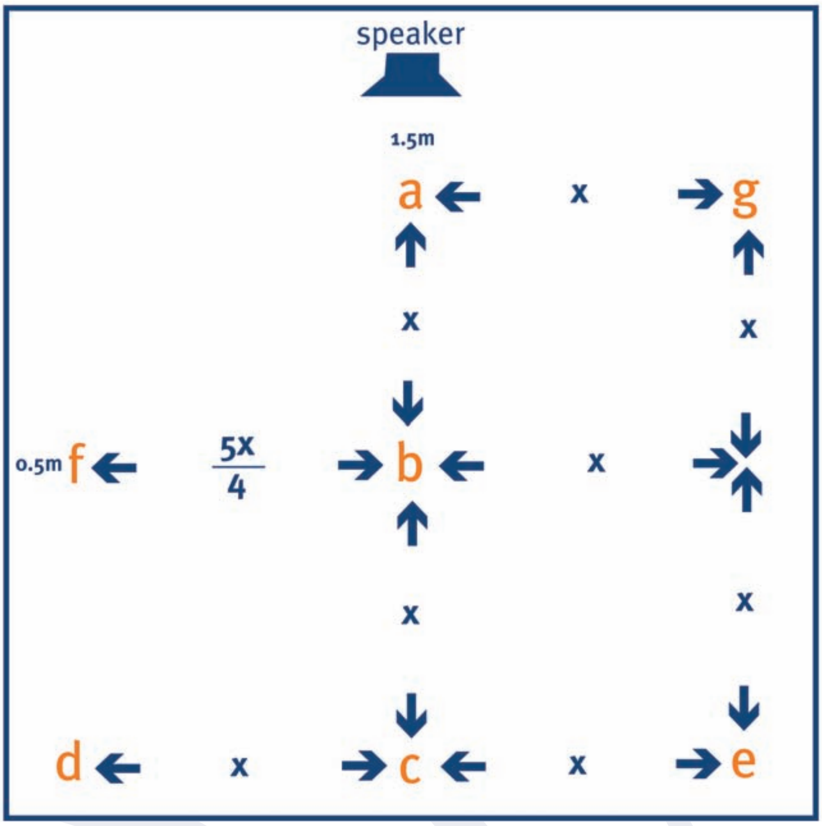
List 1	List 2	List 3	List 4	List 5	List 6	List 7	List 8	List 9	List 10
ship	fish	thug	fun	fib	fill	badge	bath	hush	jug
rug	duck	witch	will	thatch	catch	hutch	hum	gas	latch
fan	path	teak	vat	sum	thumb	kill	dig	thin	wick
cheek	cheese	wrap	shape	heel	heap	thighs	five	fake	faith
haze	race	vice	wreath	wide	wise	wave	ways	chime	sign
dice	hive	jail	hide	rake	rave	reap	reach	weave	beep
both	bone	hen	guess	goes	got	foam	joke	jet	hem
well	wedge	shows	comb	shop	shown	goose	noose	rob	rod
jot	log	food	choose	vet	bed	not	pot	dope	vote
move	tomb	bomb	job	June	juice	shed	shell	lose	shoes

List 11	List 12	List 13	List 14	List 15	List 16	List 17	List 18	List 19	List 20
math	have	kiss	wish	hug	wage	jade	shave	vase	cave
hip	wig	buzz	Dutch	dish	rag	cash	jazz	cab	rash
gun	buff	hash	jam	ban	beach	thief	theme	teach	tease
ride	mice	thieve	heath	rage	chef	set	fetch	death	jell
siege	teeth	gate	laze	chief	dime	wine	height	nice	guide
veil	jays	wife	bike	pies	thick	give	win	fig	pin
chose	poach	pole	rove	wet	love	rub	suck	rush	fuss
shoot	rule	wretch	pet	cove	zone	hole	robe	hope	home
web	den	dodge	fog	loose	hop	chop	dog	lodge	watch
cough	shock	moon	soon	moth	suit	zoom	pool	womb	booth

Setting up a room for speech testing and using the AB word list

The seven different positions in the diagram below can be used for assessing speech intelligibility. The positions can be used with students and SLM measuring STI.

The positions could be used with a group of students or some of the positions could be used with an individual student to see how they function within the room.



Setting up the room –

1. Find position B, the centre of the room
2. Position F, 0.5 metres from the wall
3. Measure the distance from F to B
4. Divide this figure by 5 and the multiply by 4
5. This is x
6. All the other positions can be found using the distance x

The diagram is an adaptation from the Wilson study as it was found that the grid used in the study was too big for a Primary classroom.

This plan was chosen as it covers most of the possible seating positions where a student may sit in a room.

Using the AB Word Lists

Lipreading should not be used with this test, as it is not a test of lip-reading. However, you may decide to use live voice so that the student can have eye contact. If live voice is used then you need to cover your mouth, but a piece of paper held in front of the mouth will stop some high frequency sounds and make it more difficult for the student. You need to hold some dark loosely woven fabric in front of your mouth to obscure your mouth movements. You will need to ensure that you use a consistent sound level throughout one test e.g. if you test at 65db you will to ensure that every word is spoken at 65db.

1. For a group of students

Seven students can be placed in the seven positions in the classroom.

Lists 1 to 8 will be used for the test. Firstly, list 1 is played to the students when the listening conditions are quiet. This list is used to educate the students as to how to do the test. They are then instructed to listen to each word and then write down, on a score sheet, what they thought the speaker said. The second list will then be played with the students remaining in the same position but this time noise is present. For the next list the students were required to move to the next position alphabetically. This continues until all the students have been in all the different positions.

The test is scored on a phoneme correct basis i.e. as each word is a consonant-vowel-consonant word, the phoneme/s correct are given a mark.

e.g. if the word presented is 'ship' and the pupil writes 'chip', the pupil has got two parts of the word correct and one part wrong. The scoring system is –

word totally correct	10
two parts correct	7
one part correct	3
word totally wrong	0

This is used for each word in a list of 10 and will produce a percentage score for each list.

2. Individual student

You may wish to test an individual student in the room to assess their most effective seating position. The results could also be shown to the teacher as a means of demonstrating the difficulties the student has in the class.

The student may find the task of doing seven lists in one go quite arduous and so it may be you decide that the test can be performed in two sessions.

As only one student is doing the test, they could repeat the answers rather than writing them down.

The scoring of the test is the same as above.

Some results using the test

This plan and the test procedure has also been used in another small-scale study that produced the results below.

Like Wilson's study, the AB word lists were used as the speech signal and classroom babble used as noise.

Results

Positions	Pupil Scores / %													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quiet	87	88	76	80	88	64	70	37	77	87	97	70	80	87
A	80	65	91	67	81	71	54	29	64	72	78	67	83	91
B	36	28	72	74	51	36	47	17	77	68	50	50	42	33
C	64	26	63	49	54	17	36	7	36	71	46	44	53	0
D	34	33	50	44	26	12	30	10	51	53	29	19	34	13
E	30	33	39	36	26	50	42	3	42	46	36	38	49	33
F	60	34	50	44	64	43	49	0	57	56	17	33	50	34
G	41	3	46	43	67	54	26	0	56	55	26	44	66	16

These results highlight the problems hearing impaired students have when listening in a classroom.

Student 8 has a moderate hearing loss but refuses to wear hearing aids.

Student 2 has a left sided unilateral loss and position G is on the right side of the room which means that his good ear was near the wall.

Student 14 had a heavy cold on the day and, when tested, had a mild hearing loss sufficient to cause listening problems.

These results were shown to the teaching staff, the audiology clinic and the education authority.

As a consequence of this testing, the teacher changed her teaching style completely and was more aware of the needs of the students in the class. All three hearing impaired students were tested and the girl with the moderate hearing loss is now wearing hearing aids after sympathetic pressure from the school and is doing well. The education authority has fitted a suspended ceiling and is contemplating fitting a sound field system.

Worked example

An education authority has fitted two newly built primary schools with soundfield systems. They are questioning whether soundfield systems are cost effective and should be fitted to all future new builds.

The authority asked for a report to show benefit to the pupils and teachers.

The Report

The testing for the report is split into two parts

a. Room acoustics

b. Pupil responses

Machine measures of speech intelligibility were used to measure room acoustics and a phonemically balanced set of word lists were used for the pupil responses.

a. Room acoustics

The measurements to be taken for this part of the project are –

Reverberation times (RT)

Signal to noise ratios (S/N ratio)

Speech transmission index (STI)

All the above measures were achieved using a Norsonic Sound Level Meter.

Sound level meter details Norsonic Type 118

Serial no. – 28930

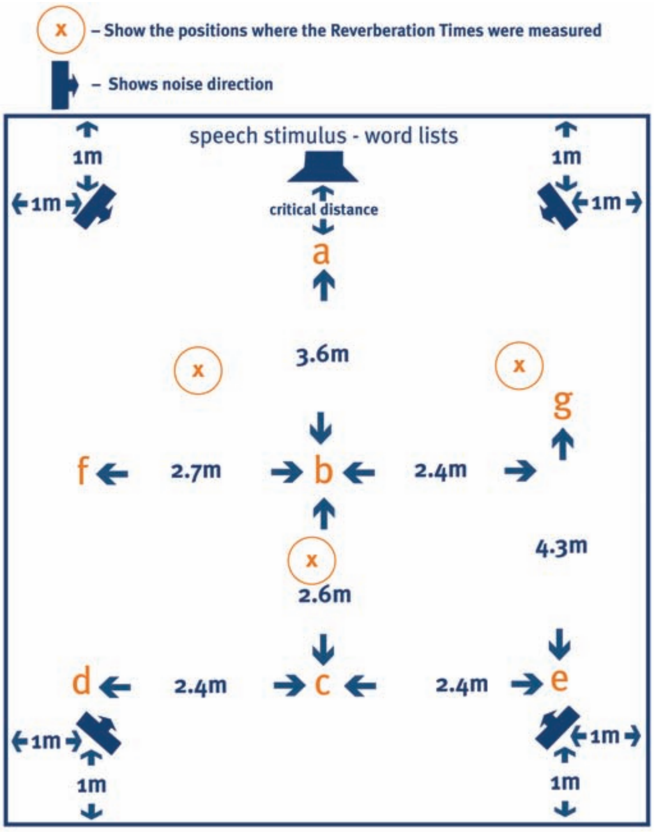
Next calibration due April 2005

The meter was calibrated using Calibrator type 1251

Serial no. – 28930

Next calibration due April 2005

Test room layout

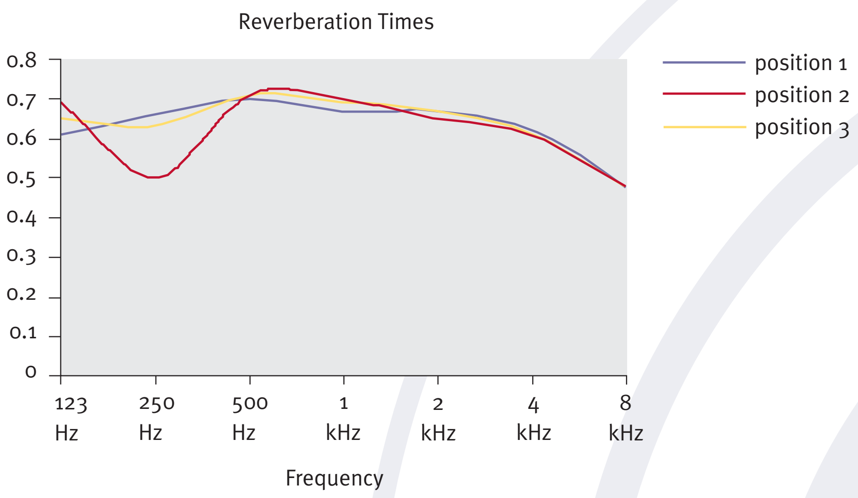


The diagram opposite shows the positions used for STIPA, S/N ratio and the word discrimination test. (Points A – G)

The distances used are all measured from the centre of the room, B. These are the same distances used in the Wilson study in Secondary rooms.

Reverberation times (RT)

The reverberation times were measured in three positions in the room. The graphs below show an octave band analysis of the reverberation times in this room. The RT was measured using a starting pistol as the noise stimulus. It is appreciated that a starting pistol may give odd results in the low frequencies and this may account for the discrepancies between the traces at 250 Hz.



Most texts recommend a RT of below one second for listening to speech in large room. The graphs above show that the RT goes no higher than 0.7 seconds across the frequency range.

This is longer than the reverberation time BB93 recommends for a Primary classroom.

Signal to noise (S/N) ratios

The speech stimulus (Signal) used in this project is the AB word lists. This is a set of lists containing ten consonant-vowel-consonant (CVC) words. All of the lists are phonemically balanced in that all the lists contain the same vowels and consonants.

The speech stimulus and noise field will be set to give a (S/N) ratio of 0 in the centre of the room (position B).

In order to obtain this figure, the speech stimulus will be set to give an average of 70 dBA at point B, using list 1 of the speech lists.

The noise stimulus will also be set to produce a value to match the speech signal at B. This will give an average S/N ratio of 0 at B but as there will be some variation in the speech signal output, there will also be a range of S/N ratios at this point.

Measurements will be made at all the other points with no alteration to the speech or noise signals.

The table below gives the levels of the speech signal measured at all the seven positions. When analysing the levels it is always the same words in the list which produce the greatest and quietest levels.

Position	Mean Speech Level (dBA)	Range (dBA)
A	74	4
B	70	7
C	69	7
D	69	7
E	68	7
F	69	9
G	68	5

Despite using the same words, the range changes at different points.

Point F has the highest range and other testing shows that this point stands out as not providing expected values.

Four speakers at four positions in the room produce the noise. From a previous study, this set-up produced a uniform noise field. It is impossible to predict where noise will come from and so a uniform field is produced in the room. The noise is created using ‘classroom babble’, which is recorded speech. The babble has been adapted so it produces a constant output and nothing can be understood of the speech.

The noise levels were measured in each position and taken away from the signal level producing a S/N ratio as shown in the table below. These scores were produced with the soundfield switched OFF.

Position	Mean Speech Level (dBA)	Noise level (dBA)	S/N Ratio (dBA)
A	76	69	+7
B	72	70	+2
C	71	69	+2
D	71	70	+1
E	69	70	-2
F	71	69	+2
G	71	69	+2

The procedure was repeated with the soundfield system switched ON.

Position	Mean Speech Level (dBA)	Noise level (dBA)	S/N Ratio (dBA)
A	78	69	+9
B	75	70	+5
C	74	69	+5
D	74	70	+4
E	64	70	+4
F	73	69	+4
G	72	69	+3

When comparing the S/N ratios between the two scenarios, other than in position A, the sound field produces a more uniform spread over the room.

Speech transmission index (STI)

The STI methods can be used to compare speech transmission quality at various positions and under various conditions within the same listening space, in particular it is useful for assessing the effect of changes in acoustic properties.

The STIPA program was recently purchased for the sound level meter from Campbell Associates. This is the first time this program has been used and a protocol for its use has been drawn up. This protocol will be continually updated as STIPA is used more, until it meets the needs of the Service.

The STI is measured by placing a sound source at the speaker's position. The sound source used is an excitation signal of male speech. This is recorded on a CD and lasts for 70 minutes. The protocol states the method for the calibrating the sound level meter (SLM) when used to obtain STI figures.

The SLM is then placed in each of the seven positions and a recording made of the STI and the rating.

The table below shows the STI measurements for each of the seven positions and in four different listening scenarios.

STIPA Measurements

	1. In Quiet No S/Field		2. In Quiet + S/Field		4. In Noise No S/Field		3. In Noise + S/Field	
Seating Position	Value	Rating	Value	Rating	Value	Rating	Value	Rating
A	0.67	Good	0.59	Fair	0.59	Fair	0.59	Fair
B	0.59	Fair	0.37	Poor	0.37	Poor	0.52	Fair
C	0.59	Fair	0.33	Poor	0.33	Poor	0.54	Fair
D	0.58	Fair	0.36	Poor	0.36	Poor	0.53	Fair
E	0.61	Good	0.37	Poor	0.37	Poor	0.61	Good
F	0.6	Good	0.39	Poor	0.39	Poor	0.53	Fair
G	0.63	Good	0.35	Poor	0.35	Poor	0.54	Fair

b. Pupil responses

Speech intelligibility testing is to be used to assess the students' responses to speech in the classroom.

The fourteen students were divided into two groups of seven and the first group was placed in the seven positions in the classroom. Firstly, list one of the eight lists used was spoken to the students when the listening conditions were quiet. This list was used to educate the students as to how to do the test. They were required to listen to each word and then write down, on a score sheet, what they thought the speaker said. The second list was then presented with the students in the same position but this time noise was present. For the next list the students were required to move to the next position alphabetically. This continued until all the students had been in all the different positions.

The test is scored on a phoneme correct basis i.e. as each word is a consonant-vowel-consonant word, the phoneme/s correct are given a mark.

e.g. if the word presented is 'ship' and the pupil writes 'chip', the pupil has got two parts of the word correct and one part wrong. The scoring system is:
word totally correct 10

two parts correct 7

one part correct 3

word totally wrong 0

This is used for each word in a list of ten and will produce a percentage score for each list.

It was originally intended that alternate lists would be presented with the sound field ON and then OFF, and only present seven lists in noise on two separate visits. This was planned to stop any problems with boredom. However, on the second visit it was discovered that the sound field system wasn't working properly and that there was no differences in the S/N ratios between the sound field being ON and OFF.

It was then decided to use the responses from the second visit the results with the Sound Field OFF and have a third visit when the sound field was ON all the time.

This problem meant that there wasn't enough time to use the second group of children and all the scores are from using the same group of seven children.

On the third visit, the sound field had been checked and set up by the supplier.

Before the test started the S/N ratios were checked in all seven positions to ensure that they matched with the previous test, when the sound field was OFF. They were found to be within +/- 1 dB(A). The microphone attached to the transmitter was placed at an appropriate distance in front of the signal speaker and orientated correctly as a directional microphone.

The table below gives the results the students produced in all the different positions on the second visit with the Sound Field OFF.

	Percentage Scores for each list in each position									
Position	Quiet / 1	2	3	4	5	6	7	8	Mean Score	Ranking	S/N Ratio
A	97	97	74	94	87	82	79	90	87	1	+7
B	100	84	74	57	71	83	74	74	74	3	+2
C	100	74	84	57	60	73	77	64	70	=5	+2
D	90	70	64	84	72	74	64	67	71	4	+1
E	93	63	67	67	72	64	81	61	69	7	-1
F	100	71	63	80	77	66	67	68	70	=5	+2
G	97	80	87	78	84	90	59	67	78	2	+2

The table below gives the results the students produced in all the different positions on the second visit with the Sound Field ON.

	Percentage Scores for each list in each position									
Position	Quiet / 1	2	3	4	5	6	7	8	Mean Score	Ranking	S/N Ratio
A	94	97	83	83	97	90	94	97	92	1	+9
B	100	83	87	84	87	87	94	94	88	2	+5
C	100	63	71	74	88	91	87	97	82	4	+5
D	93	83	74	90	75	83	77	81	80	=6	+4
E	94	71	78	77	91	74	83	94	81	5	+4
F	97	77	60	81	84	88	81	87	80	=6	+4
G	100	77	87	81	87	80	87	84	83	3	+3

The tables also show rankings of the best to worst positions (1 the best) to illustrate where in the room the best positions are for listening.

Analysis of the results

The mid frequency reverberation standards from BB93 for a Primary classroom are that the reverberation time should be below 0.6 seconds. This room has an RT of 0.7s which is just longer than it should be to meet the standards. However, this school was planned and built before the regulations came into force and does not need to comply with the regulations. General opinion is that if the RT is below 1s then speech should be understood.

The true test of being able to listen in this room is provided by the students themselves. The worst listening conditions in any room are when noise is present and the listener is as far away from the speaker as the room will allow. The word discrimination scores provide an indication of the difficulties the students will have in the room. Most audiological speech discrimination tests have a score of 80% or better as being a pass for the test and showing that the listener has sufficient information to understand the speaker.

Mean Score	Ranking	S/N Ratio
87	1	+7
74	3	+2
70	=5	+2
71	4	+1
69	7	-1
70	=5	+2
78	2	+2

It is difficult to compare the results from this project with other studies as the assessment criteria are different. However, if a comparison is made between the mean scores, when the Sound Field is OFF, with those produced by Finitzo-Heiber for a reverberation time of 0.4s.

S/N ratio	+6 dB	0 dB
Scores	71%	48%

Remembering that the RT for this room is 0.7s and there is no indication of distance away from the speaker with the Finitzo study, then a score of 87% compares well but the lowest score of 69% would be expected to be lower.

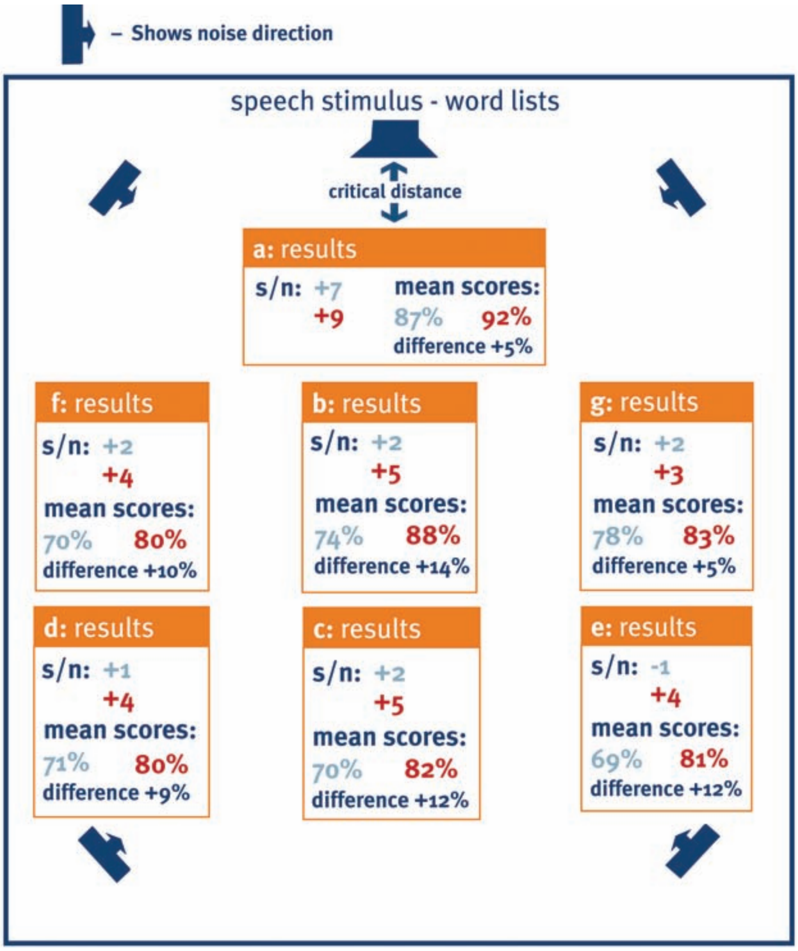
The table below shows a comparison between the Sound Field ON and OFF. The difference column gives an indication of any improvement when using the Sound Field. (A + score shows an improvement when using the Sound Field)

Position	Sound Field OFF	Sound Field ON	Difference
A	87%	92%	+ 5%
B	74%	88%	+14%
C	70%	82%	+12%
D	71%	80%	+9%
E	69%	81%	+12%
F	70%	80%	+10%
G	78%	83%	+5%

The scores in the column Sound Field OFF are mainly below 80%, except for position A which is inside the critical distance for the room. The other column has all the scores above 80% indicating that the students have a greater opportunity to hear the speaker, when noise is present in the room. The 3 positions across the back of the room are particularly low scores showing that distance from the speaker is also a problem in the room. The nearer the listener is to the speaker, the higher the score. However, position F is in the middle of the room and yet has a poor score. This may be due to the high range of output from the speech signal as discussed earlier. Also, in this particular room, F had to be close to a wall in order to maintain the dimensions for the test layout. The close proximity to the wall may be the reason for the relatively low score.

The scores in the column Sound Field ON are all 80% or above. Again the lowest scores are either at the back or position F but with a score of 80% the students will be able to understand more of what the teacher is saying.

The Difference column shows the improvement in each position when the sound field is switched ON. The greatest improvements are in the poorer positions. After the test was completed (Sound Field ON), the students were asked what they thought of listening to the words with the Sound Field being both ON and OFF. All of them preferred listening when the Sound Field was ON.



This diagram shows the mean scores for each position and the differences between the scores as in the table above.

Also included on the diagram are the S/N ratios for each position.

As stated above, the differences improve the further away from the speaker.

This table shows comparisons between the S/N ratios in each position and then score differences from the previous table.

Position	Sound Field OFF	Sound Field ON	Difference	Score Differences
A	+7	+9	+2	+ 5%
B	+2	+5	+3	+14%
C	+2	+5	+3	+12%
D	+1	+4	+3	+9%
E	-1	+4	+5	+12%
F	+2	+4	+2	+10%
G	+2	+3	+1	+5%

There appears to be little correlation between the improvement in the S/N ratio and the improvement in word discrimination scores.

The greatest improvement in S/N ratio is at position (+5 dB) and the improvement in word discrimination is +12%. The biggest improvement in word discrimination is at position B and yet the S/N ratio is only improved by 2 dB.

The following table makes comparisons between the STIPA values and the mean scores for each position in the room.

	Sound Field OFF			Sound Field ON		
	STIPA		Word Discrimination	STIPA		Word Discrimination
Position	Value	Rating	Mean Score	Value	Rating	Mean Score
A	0.59	Fair	87%	0.59	Fair	92%
B	0.37	Poor	74%	0.52	Fair	88%
C	0.33	Poor	70%	0.54	Fair	82%
D	0.36	Poor	71%	0.53	Fair	80%
E	0.37	Poor	69%	0.61	Good	81%
F	0.39	Poor	70%	0.53	Fair	80%
G	0.35	Poor	78%	0.54	Fair	83%

The STIPA scores show that when the noise is present and the soundfield is OFF, the only position in the room where there would be a reasonable chance of hearing speech well would be at position A (inside the critical distance). However, a score of 0.59 is close to being a good value. When the Sound Field is ON all the positions are rated as being at the top end of fair or in the good section.

The values and rating from STIPA match well with the improved word discrimination scores when the Sound Field is ON.

There will be times when the test used to obtain the word discrimination scores would be difficult to use. It may be that the majority of students in the Y6 group have English as a second language and would find the vocabulary of the test too difficult, or the rooms being tested may be in an Infant or Nursery school where the children are too young to do the test. It would be useful to find a correlation between the STIPA scores and the word discrimination scores so that STIPA could be relied on to predict accurately the best and worst seating positions in the room when listening to speech in noisy conditions.

Overall, the results obtained show that the students will benefit by the use of the Sound Field system.