Acoustic Design – Rooms for Speech

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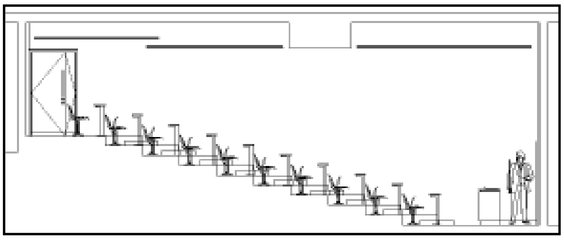

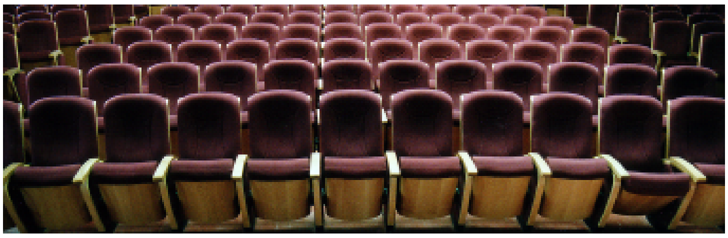

Ever been at a lecture or conference and found it difficult to understand what is being said? Then the chances are it is the room acoustics that are at fault.

The following article provides architects and designers with a structured approach to the acoustic design that will help ensure the room will sound as good as it looks.

At the early design stage of a speech room, it is important to give consideration to how the room will sound in order to optimise speech intelligibility. The obvious room types falling into this category include lecture theatres, auditoria, conference rooms, drama spaces, courts, meeting rooms and classrooms.

The acoustic design should give consideration to the following factors in the order given:

1. Indoor ambient noise levels.
2. Reverberation time and hence, room size and acoustic absorption required.
3. Room geometry – reflections, flutters, focussing and diffusion.
4. Electronic speech reinforcement.

Indoor Ambient Noise Levels

This is one of the most critical elements in room design as the talker's voice needs to be clearly heard above the background noise. This will assist with speech intelligibility but also prevent undue strain to the talker and will minimise distraction. Background noise can come from a number of sources:

- External traffic, planes and trains etc. entering via external walls and windows.
- Noise from circulation corridors, foyers, toilets within the same or adjacent development.
- Air conditioning and mechanical plant serving the room.

There is quite a lot of useful guidance available to assist with this element of the design. For example, *Australian/New Zealand Standard AS/NZS 2107:2000* [i] recommends an "average" indoor noise level in a lecture theatre, from all the above sources, of 30 to 35dB (L_{Aeq}). For drama theatres the recommendation is lower, 25 to 30 dB (L_{Aeq}). The Standard states that these design levels provide "satisfactory" listening conditions and therefore in some cases lower levels will be required. In addition, if the intrusive noise has an unusual character like a rumble (e.g. heavy traffic or plant room) or bass beat (gymnasium music), noise limits 5 to 10dB lower should be specified depending on the situation.

Initially the designer should review the site layout. If possible, position the room away from busy roads or other noisy areas. For instance, allow for a circulation corridor or storeroom between the lecture room and another "noisy" space like a canteen. Appropriate placement on architectural plans during the design phase can provide a significant saving in noise control treatment during construction. Where there is no alternative but to build beside an existing noise source, it is important to objectively quantify existing sound levels and therefore a noise survey (or prediction) should be conducted. The external noise level will determine the extent of noise control required.

A rule-of-thumb estimate for determining internal traffic noise levels is to use the following formula:

Internal sound level = External Traffic Noise level (L_{aeq}) – STC

where *STC* is the *Sound Transmission Class* that is commonly included in manufacturer's product data sheets.

For the purposes of this rough calculation, the other commonly encountered parameter, R_w *(Weighted Sound Reduction Index)*, can be substituted for STC. Strictly the STC/R_w values quoted relate to testing with a broadband noise spectrum in a laboratory, and actual performance values are likely to be lower for traffic noise. It should be remembered that laboratory STC ratings are never achieved on site as a result of flanking transmission and a 3 to 5dB de-rating is normally applicable for well finished constructions.

Furthermore, this quick method does not take account of the acoustic absorption (i.e. furnishings) within the room and collectively, this rough calculation may underestimate the level in the room by up to 5dB L_{Aeq}. Hence, if the estimate is within 5dB of the design criteria, a more rigorous assessment should be conducted using octave band spectra, for example using the method set out in BS8233[ii].

As an example, let's take a proposed lecture theatre to be located directly adjacent to a busy city arterial road where the existing traffic noise level is in the order of 80dB L_{Aeq}. Assume an external façade construction of 100mm thick concrete with an internal wall lining of 1 layer of 13mm plasterboard on 60mm metal studs fixed to the concrete, and insulation in the cavity. This construction has a laboratory performance of 64dB STC. This will result in an internal noise level of 16dB (i.e. 80dB L_{Aeq} – 64dB STC). This value lies well below our deign criteria of 30 to 35dB L_{Aeq} and is therefore satisfactory. However, it is important to remember that the sound reduction of any construction is only as good as it's weakest element. If this wall was made entirely of 6mm thick glass in a sealed frame with a sound insulation performance of 33dB STC, the corresponding internal sound level would be roughly 47dB L_{Aeq} which significantly exceeds our design criterion. Therefore, to provide adequate performance, the glazing would have to be upgraded to a 6mm glass/200mm cavity with absorptive lining in the reveals/10mm laminate with both elements mounted in independent frames. The performance of the glazing system would then be in the order of 49dB STC. The internal noise level using the quick method is calculated as being 31dB (i.e. 80dB L_{Aeq} – 49dB STC) which suggests that the internal noise environment will be satisfactory. As this is within 5 dB of the upper limit, a more rigorous assessment would be required in this instance.

In practical situations where the external façade includes both wall and windows, the resulting internal noise level will be somewhere between the two rough values calculated above.

In relation to other sources of noise, the mechanical services engineer should be made aware of the noise design criterion right from the outset so that their mechanical plant and duct sizes can be appropriately selected.

If it is established that the corridor or circulation area outside the lecture theatre doors will be noisy perhaps due to a high

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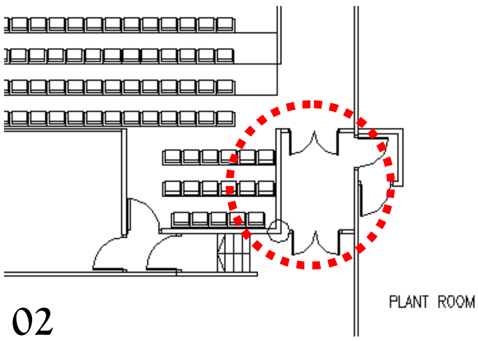

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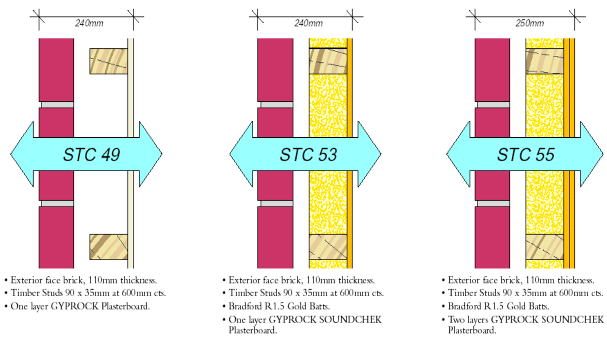
EXTERIOR WALL SYSTEMS



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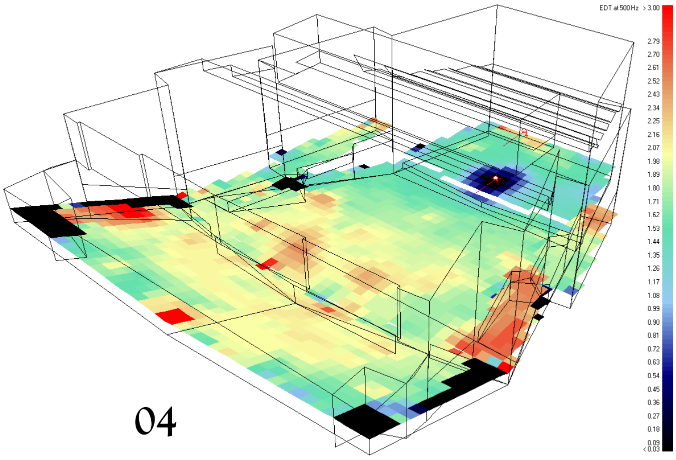
01 Glazing in an external façade can significantly increase the noise level within a room designed for speech and therefore should be appropriately specified.

02 Lobbied doors should be used to separate the room if a busy circulation space and other noise sources are nearby.

03 Manufacturers' technical data commonly expresses sound insulation performance in terms of STC or R_w values which can be used to provide a "rough" estimate of the internal noise level . (Source CSR Gyprock)



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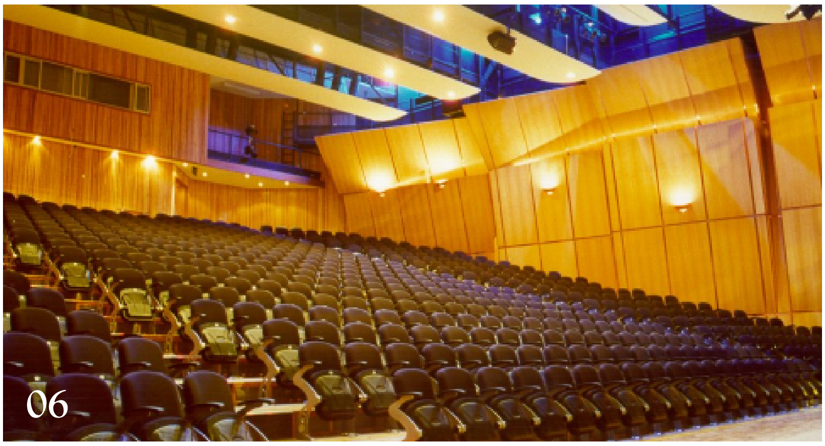

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04 Proprietary acoustics software can be a very powerful tool for larger projects and show how the reverberation time and many other parameters vary throughout the space. (Illustration from ODEON)

05 The mechanical services engineer should be made aware of the design noise criterion for the room as early as possible. For critical spaces, the acoustic consultant should perform a review of the design.

06 In this medium sized performance space, a computer model was developed to assist with the side wall reflector panels.

concentration of people, it would be prudent to allow for a double door in a lobby arrangement. The specification for the doors and their requirement for perimeter seals should be determined by calculation.

Reverberation Time

Speech intelligibility is also a function of the Reverberation Time (RT) of a room. RT is a parameter that objectively describes the echoic quality of a room. A cathedral can have a RT in the range 4 to 10 seconds and a bedroom an RT of 0.4 seconds on average. A long RT of several seconds in a room will cause syllables to be prolonged so that they overlap and degrade speech intelligibility.

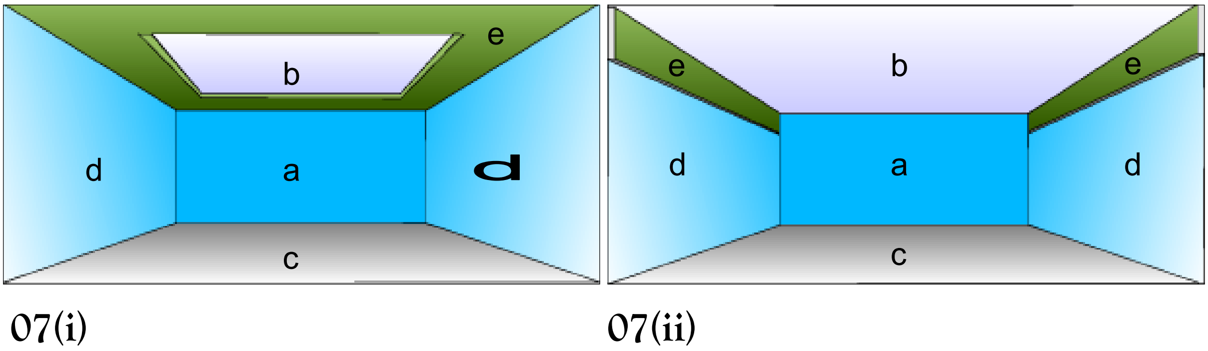
Furthermore, in reverberant rooms people tend to increase the volume of their voice to compensate for the increased noise level, so that they will be heard over the reverberant noise - this further exacerbates the situation.

Long RT's are commonly encountered in large rooms, typically with a high ceiling, which have hard wall and ceiling surfaces. For guidance on appropriate RT's on different room types we can again reference AS/NZS 2107 which provides a range of performance criteria depending on the room type and size. In most cases, the reverberation time should be in the range 0.6 to 0.9 seconds. There are of course special cases, for example, classrooms for children with hearing difficulties should have a RT of less than 0.4 seconds[iv] and in large auditoria, a RT of 1.2 seconds might be satisfactory.

For any given room, the RT can be varied by changing the amount of acoustic absorption on the rooms surfaces. Different materials absorb sound by different amounts at each sound frequency measured in *Hertz (Hz)*. The amount of

absorption is quantified by the *Absorption Coefficient* (α). An α of 1.0 means that all the sound is absorbed (i.e. an open window). An α of 0.05 means that 99.5% of the sound energy is reflected at that frequency indicating that the material is hard e.g. painted concrete. Manufacturers usually present this data in octave bands from 125Hz to 4kHz.

In rooms used for music, experience shows that often relatively little acoustic absorption is required in addition to the audience, however the orientation of the room's surfaces is critical.



07 Options for the location of surface finishes in classrooms or lecture theatres[iv]

Option (i)– predominantly absorptive ceiling

- a REAR WALL– if greater than 8.5m from the speaker, and has a direct reflection path, this wall should be either sound absorbing or diffusing.
- b CEILING (CENTRE) - sound reflective e.g. plasterboard.
- c FLOOR– sound absorbing e.g. carpet
- d WALLS– sound reflective
- e CEILING (PERIMETER) - sound absorbing

Option (ii)– reflective ceiling

- a REAR WALL– if greater than 8.5m from the speaker, and has a direct reflection path, this wall should be either sound absorbing or diffusing.
- b CEILING - sound reflective e.g. plasterboard.
- c FLOOR– sound absorbing e.g. carpet
- d WALLS– sound reflective
- e TOP OF WALLS - sound absorbing or diffusing

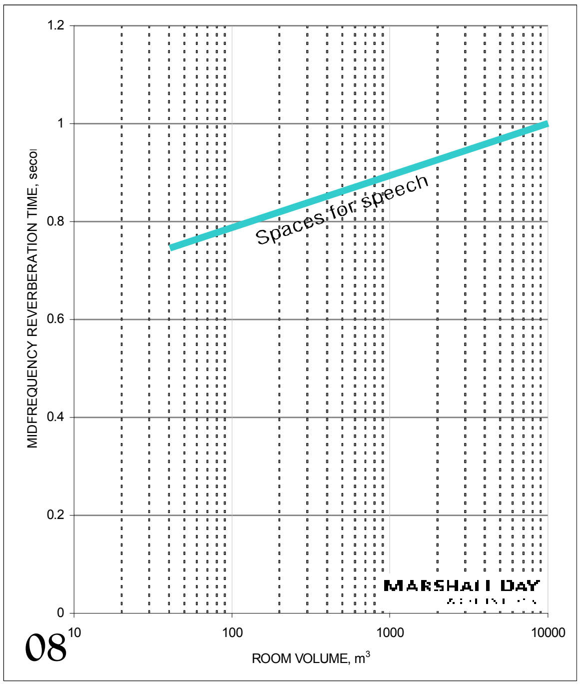
www.acoustics.org.nz

The New Zealand Acoustical Society website offers information on society activities and details of the elected officers of the Society.

Other ideas which are being developed are:

- Adding a search engine for archives of *New Zealand Acoustics*,
- Providing a list of members of the Society,
- Publishing reviews of the 16th Biennial Conference.

Please send further suggestions and feedback to Thomas Scelo (t.scelo@auckland.ac.nz) or follow the instructions on the home page of the web site



08 Reverberation Time "curve" from Appendix A1, AS/NZS 2107

The situation is somewhat different for rooms for speech where larger amounts of fixed absorption can be required.

The first stage in determining just how much absorption is required is to perform a calculation using one of the establish methods. These make use of equations developed by Eyring, Fitroy or, most commonly, Sabine. The Sabine formula is:

$$RT = \left(\frac{0.161 \times V}{S \times \alpha} \right)$$

where:

V is the room volume in m^3

S is the surface area of product being used in m^2

α is the absorption coefficient

This calculation should be conducted at each octave band centre frequency of interest and is relatively straightforward to perform in a spreadsheet. There are several on-line resources[iii] to do this calculation, however, they are somewhat limited in their flexibility.

When calculating the required RT, one should first model the bare room, allowing for the audience occupancy and the type of seats in use (ie. plain or upholstered). If the RT exceeds the design criterion for the room type, absorption should be added. This traditional method of calculating reverberation times assumes that the absorptive surfaces are evenly distributed about the room's surfaces. If this is not the case, the equation is not valid and undesirable variations in the acoustics can occur. Furthermore, if large areas of reflective materials are present, other acoustic phenomena such as echoes, standing waves and focussing are likely.

For larger projects, it is common practice to construct a 3D computer model using proprietary room acoustics software (e.g. ODEON). These very powerful tools can greatly assist with many aspects of the acoustic design.

Room Geometry

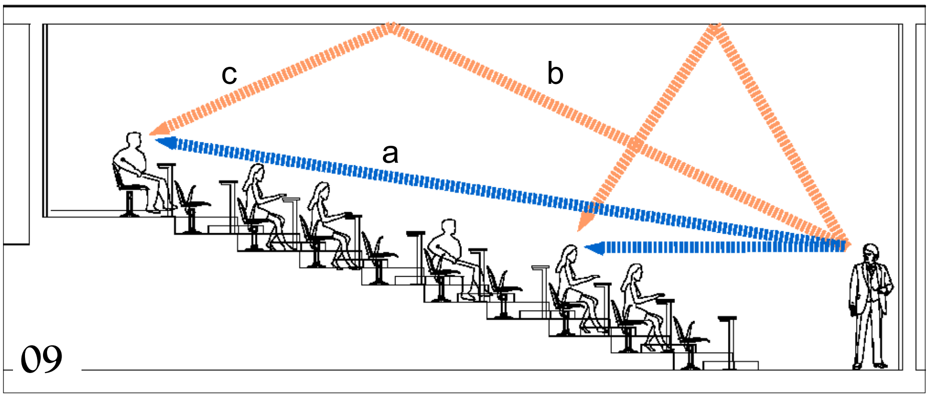
The shape of the room, the location of its surfaces and whether these surfaces are absorptive or reflective, all determine the loudness of the speech signal and contribute to its intelligibility. In the previous section we discovered how to determine how much acoustic absorption will be required. Next we have to determine where to locate the absorption.

The direct sound from the talker's voice to the listeners' ears must have a clear unobstructed path. The loudness of the direct sound can be supported by strong reflected sound that arrives a short time after the direct sound. Supportive reflections for speech should arrive within 50 milliseconds (ms) of the direct sound. Sound arriving after 50ms can be detrimental to the speech intelligibility and can, if long enough, be heard as a "late reflection" also known as a "slap echo".

Therefore the required acoustic absorption should be located where unwanted reflections could occur. The ceiling and side walls are the surfaces normally employed to provide appropriate reflections and should be acoustically hard surfaces such as plaster or solid timber panels. Absorptive treatment should be located around the perimeter of the ceiling and at the upper portion of the side walls. Special attention to the rear wall will be required if it is greater than 8.5 metres away from the talker, and has the potential to reflect sound directly back at them which will be perceived as a discrete "echo". The rear wall in this instance should be either absorptive or should provide diffusion.

As the room size increases, the greater the reliance on the room geometry to provide an appropriate environment. Special consideration should be given to lecture theatres and auditoria:

- Provide as strong a direct sound as possible by keeping the average talker-listener distance as short as possible.
- Minimise the loss of direct sound energy as it passes over the audience at grazing incidence – use raked seating or elevate the talker. With a rake, a clearance of around 100mm should be provided between the sight line from one row and the sight line from the next row.
- Because speech is directional at higher frequencies that contain a lot of intelligibility



09 In order to provide supportive reflections to the talker's voice, the additional distance travelled by the reflected path must be less than 17m $(b + c) - a < 17$m

information, the seating plan should be arranged to fall within an angle of around 140° subtended at the talker position.

- Provide as many early reflections (i.e. within 50ms) as possible by maintaining reflective walls and ceilings. High ceilings may require the use of suspended reflector panels in order to shorten the reflected path. The difference in distance between the direct and reflected sound paths must be less than 17m.
- Rear walls (or other surfaces) that promote reflection directly back to the talker after 50ms should be rendered sound diffusing or absorptive.
- Attention should be given to rooms with parallel or near parallel walls as flutter echoes can occur. This effect can also occur between a reflective shallow pitched roof and flat floor and in rooms with concave surfaces.
- Concave surfaces, as with light, reflect sound back to their focal point and this focussing effect is undesirable for both talker and listener alike.

Speech Reinforcement

It is widely accepted that an acoustically well designed room can allow a trained talker to achieve good speech intelligibility for large audiences. Quieter and untrained talkers may, however, require speech reinforcement on some occasions. The challenge in designing such a system is to increase the loudness of the direct sound particularly to distance listeners while keeping the sound as natural as possible. The location and directional characteristics of both microphones and loudspeakers is the key in maximising speech intelligibility. In larger rooms it is typical for loudspeakers to be located in a central cluster above the talker, or to use a distributed system of loudspeakers in the ceiling or along the walls at high elevation. The most important note to remember is that sound system design is a specialist field and professional advice should be sought.

Summary

This design guide, whilst not exhaustive, has been intended to give architects and designers a step-by-step approach to achieving the best possible acoustic environment in a rooms designed for speech. The design process should flow in the following order:

- Determine what the internal noise levels should be and select constructions for the building envelope based on the external noise sources affecting the space.
- Arrive at an appropriate reverberation time design criterion and determine how much absorptive treatment will be required in addition to the audience.
- In conjunction with an assessment of the room geometry, determine where the absorption should be located in order to promote supportive sound reflections whilst eliminating late relations, flutter echoes and focussing.
- A speech reinforcement system should only be considered when the natural acoustic environment of the room has been optimised.

References

i AS/NZS 2107: 2000 Acoustics-Recommended design sound levels and reverberation times for building interiors

ii BS8233: 1999 Sound insulation and noise reduction for buildings – Code of Practice

iii www.mcsquared.com
www.rockfon.co.uk/ba.slrp?ID=26
www.grooveschmiede.de/rt60.htm

iv Building Bulletin 93 (UK) – Acoustic Design of Schools

Glossary

L_{eq} is essentially the "average" noise level over a measurement period.

Reverberation Time is defined as the time taken for sound in a room to decay to 60dB below its original value ❑