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ACOUSTICS 101

This eBook

This eBook covers relevant acoustic information for New Zealand designers. Our alignment with industry leaders allows us to bring you the most relevant information. Created for all designers, no matter what level.

Also available:
- Case studies and examples showing practical applications.
- Interviews with industry leaders and acoustic experts.
- Helpful checklists and how-to guides.

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Figure 1. Focus 3D tile installed at Everil Orr Healthcare village.

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Figure 2. C Max Abosrb and Eclipse Aluminium Suite installed in Whanganui City Council.

Contents

Introduction

In the field of architecture, design and construction, an understanding of how sound energy behaves in interior spaces, and the ability to measure certain aspects allows designers to create acoustically suitable spaces. Successful acoustic design means the creation of interior spaces that support the activities taking place within it. The scope of things affected by acoustic design is becoming increasingly evident; not only how we hear and perceive our environments but also the effect noise and sound has on our mental and physical well-being.

At the heart of interior acoustics is a fundamental concern for comfort, productivity and health and safety. Accounting for acoustic conditions can greatly increase the overall comfort of a space, leading to increased productivity and well being. Poor acoustics can result in dangerous, unhealthy environments.

Virtually every space demands acoustic attention in order for it to function successfully for its specific purpose. Solutions can be produced for various requirements, such as reducing excessive and distracting noise, creating appropriate reverberation times, reducing echoes and providing clarity where noise is distorted and unclear. Whatever the desired environment is, the successful outcome is reliant on getting the acoustics right.

Health and Safety

Productivity

Comfort

Functionality

How sound energy behaves

Acoustics is the science concerning the physical characteristics of sound. The characteristics of sound mainly concern waves passing through solids, liquids and gasses in the form of vibrations.

The scope of acoustics is ubiquitous in many facets of society, but its influence is especially significant in different disciplines that include music, medicine, industrial production, theatre, art and architecture.

A common thread within these disciplines is the study of production, transmission, reception, control and effect of sound energy. These processes determine how sound waves interact with, and in various environments.

The amplitude, frequency and the complexity of sound waves can be measured and used to determine the generation, propagation and reception of waves and vibrations. In other words, we look at the path of sound from the source to the point where it is perceived by an ear.

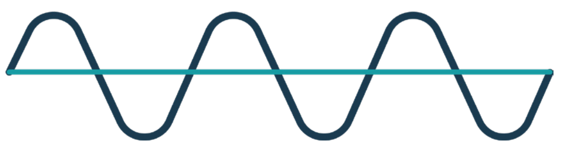

Figure 3. A sound wave of a single frequency.

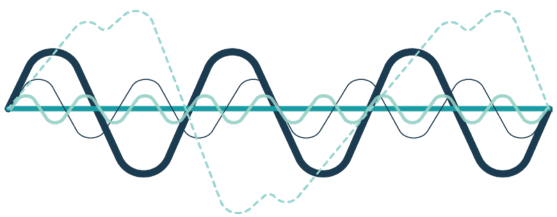

Figure 4. Most interior sound waves consist of many frequencies moving in various directions with hugely differing amplitutes.

There are three main properties to consider;

Direction

Sound is always moving in a direction and through a medium.

Amplitude

The amount of sound energy.
How loud it appears.

Frequency

The amount of waves per second.
How high or low the pitch is.

Interior acoustics is concerned with the way in which sound interacts with materials used in construction. Properties of materials include differing levels of absorption, reflection and diffusion. These qualities are significant in determining how sound energy will behave in an interior space. Interior acoustics looks at these different acoustic phenomena and how we perceive them.

Our perception of a space relates to the paths taken by sound as it travels from the source to the listener. Our brain takes clues from the acoustic signature we receive and can build a very accurate picture of a space (including materiality, size, height, furniture and occupants) even with closed eyes. It does this by constantly evaluating the difference between auditory signals it receives at each ear (stereo).

Figure 5. Ministry of Business and Innovation Office in Wellington.

Sound waves radiate directly outward from the source. Energy can not be created nor destroyed, but as the sound energy sphere gets larger, the percentage of sound that reaches your ears gets smaller, and therefore sound appears to get quieter as it travels futher from the source.

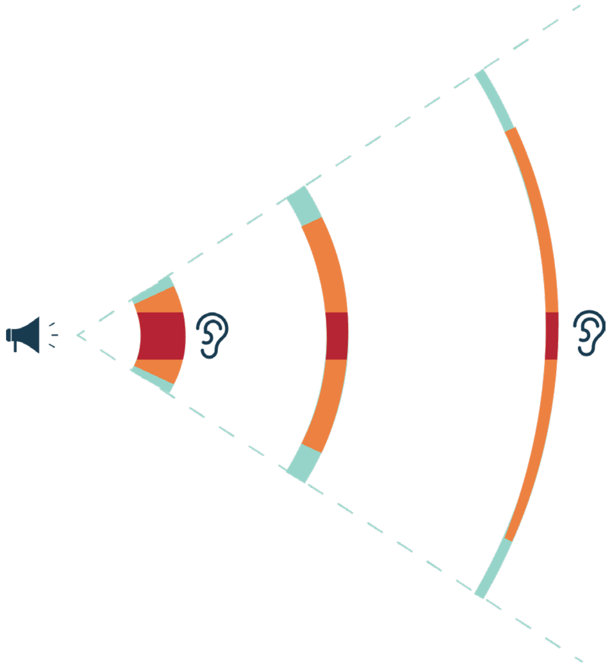

Figure 6. Sound appears to get quieter.

Direct sound:
The shortest path to the listener is called the direct sound path.

Early reflections:
(one reflection off a surface) are equally important to the listener.

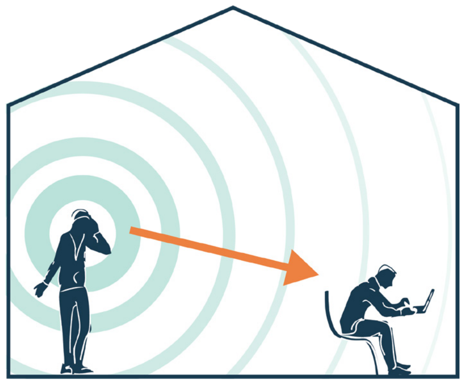

Figure 7. Direct sound.

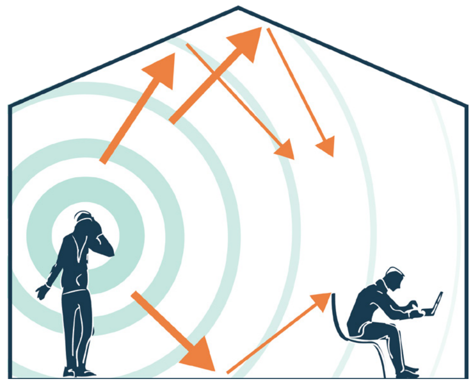

Figure 8. First reflections.

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After early reflections, the sound wave is reflected again by other surfaces in the room. The path length and the efficiency of interior materials in reflecting sounds, determine the amplitude of a particular reflection.

That efficiency is described as the coefficient of absorbtion, and any sound not reflected is absorbed. If the coefficient of absorption is low, a sound may bounce a dozen times before it fades away. This determines the reverberation time, more on this later.

Hard, reflective, non-porous interior building surfaces such as gloss surfaces, plaster and concrete absorb less than 5% of the sound energy and therefore reflect 95% or more back into the space. Soft, less dense materials absorb most of the sound energy.

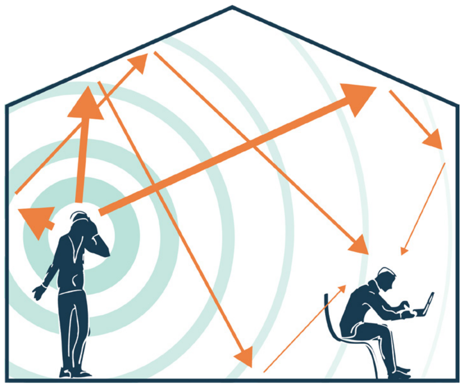

Figure 9. Multiple reflections.

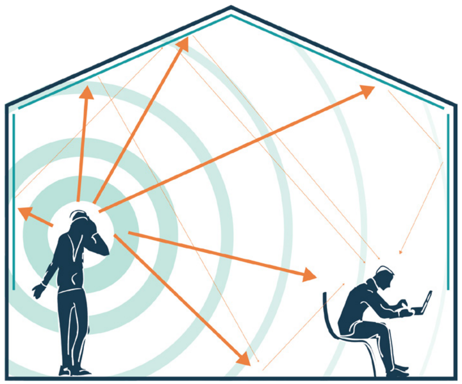

Figure 10. Sound absorbtion.

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Architectural Acoustics

Defining the space

The time between the direct sound and early reflections is the acoustic phenomenon that gives our brain audio clues to the size, height and materiality of a building. It's the aspect of architecture that is invisible but hugely important to how we perceive a space. Since sound travels at approximately 340 metres per second, the sound of a single event arrives at the listeners ears at several different times, determined by the path lengths. These reflections are different for both ears, this helps our brain to build a '3D picture' of the space.

The ear combines the energy of early reflections with the direct sound and contributes to perceived clarity of sound. Reflections that arrive between 20 and 40 milliseconds after the direct sound can be confusing. These interfere with both clarity and understanding, giving the sound a muddy quality.

Reverberation

When a sound source stops emitting energy in an enclosed space, it takes some time for the sound energy to become inaudible. Most of the sound energy that is reflected twice or more is heard as reverberation, stretching the sound event.

Technically, reverberation is defined as the time required for a sound to decay by 60 decibels after the sound is stopped. The actual amplitude of reverberation is not very important (unless it is strong enough to obscure following sounds) but the time that it persists is. The effects of reverberation time in a given space are crucial to the perception of music and understanding speech.

It is difficult to choose an optimum reverberation time in a multi-function space, as different uses require different reverberation times. A reverberation time that is optimum for music could be disastrous to the intelligibility of the spoken word. Conversely, a reverberation time that is excellent for speech can cause music to sound dry and flat. Music is often preferable when the reverberation time is between 1.7 and 2.1 seconds, whereas the ideal reverberation time for classrooms or lecture spaces is lower than 1 second. In NZ schools, the ideal reverberation time is 0.4 seconds.

The sound at all frequencies should decay at about the same rate (that is, have the same reverberation time). 'Warm Reverb' is also acceptable, where low partials of sounds persist a little longer than the high components. The opposite effect, where high-pitched sounds linger, can be very annoying. This is the situation in many indoor swimming pools. The reverberation decay should ideally be fairly even, with no "lumps" of sound.

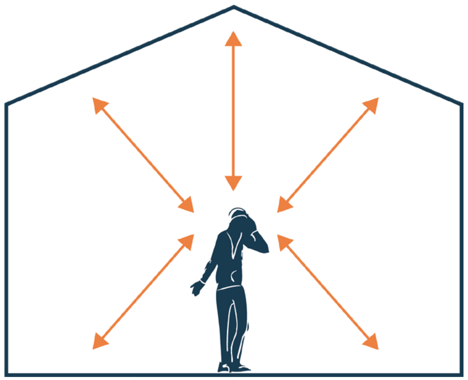

Figure 11. As sound is reflected multiple times in a space it decays.

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Loudness

Loudness is when the original sound source is perceived to be louder than it is, due to early reflections arriving within 20 milliseconds of the direct sound. Outdoors, the sound pressure level decreases 6 dB for each doubling of distance. However, if the sound source is indoors, reflected or reverberant sound will add to the overall sound level within the room to make up for the decreasing direct sound energy.

Loudness of the reflected sound is dependant on how much is absorbed by the materials in the space, while direct sound is dependant only on the distance from the source. For the purpose of clarity, later reflections are detrimental but necessary to create the feeling of being within a room. Any reflections that arrive more than 40 milliseconds after the direct sound may be heard as a distinct echo (generally undesirable), but if they are not too loud, are usually accepted as reverberation.

Figure 12. Sound loudness.

Reverberation Design Times

0.05 seconds	No reverberation, as if outdoors in a field.
0.3 seconds	Dead sound, loss of bass at a distance from sound source. Desirable for recording studio.
<1.0 seconds	Clear articulation of speech. Desirable for lecture halls, classrooms and cafes.
1.5-2.5 seconds	Good for most genres of live music.
3.5 seconds	Loss of articulation. Difficulty understanding speech.
5.5+ seconds	Cannot understand speech at a distance. Cathedrals fall into this category.

Example reverb times for areas of occupancy.

Type of activity	Design reverberation time range
Teaching spaces	0.4 to 0.6
Libraries (general areas)	<0.6
Professional offices	0.6 to 0.8
Board and conference rooms	0.6 to 0.8
Video/audio conference rooms	0.6 to 0.8
Meeting rooms (small)	<0.6
Open plan offices	0.4
Public spaces	0.5 to 1.0
Quiet rooms	<0.6
Reception areas	0.6 to 0.8
Indoor pools	<2.0
Restaurants and cafes	Reverberation time should be minimised for noise control
Shop buildings	Reverberation time should be minimised for noise control

As per reccommendations AS/NZS 2107:2016. Specialised ares require specialised input from an acoustic consultant.

Reflected sound

Reflected sound strikes a surface or several surfaces before reaching the receiver. These reflections are one of the defining features of Interior Acoustics. Reflected sound is usually harmless, and adds to the feeling of being 'inside', however, reflected sound can sometimes lead to unwanted consequences, especially in AV rooms with microphones.

Reverberation is due to continued multiple reflections, but simply controlling the Reverberation Time in a space does not ensure the space will be free from problems caused by reflections. When a sound wave strikes a surface such as a floor, wall or ceiling, the direction of travel is changed by the reflection. Reflection of sound waves follows the same physical law as light reflection and the angle of incidence equals the angle or reflection.

Reflective corners or peaked ceilings can create a 'megaphone' effect potentially causing annoying reflections and loud spaces.

Reflective parallel surfaces lend themselves to a unique acoustical problem called standing waves, creating a 'fluttering' of sound between the two surface. Reflections can be attributed to the shape of the space as well as the material on the surfaces.

Domes and concave surfaces cause reflections to be focused rather than dispersed which can cause annoying sound reflections. Absorptive surfaces will help to eliminate both reverberation and reflection problems.

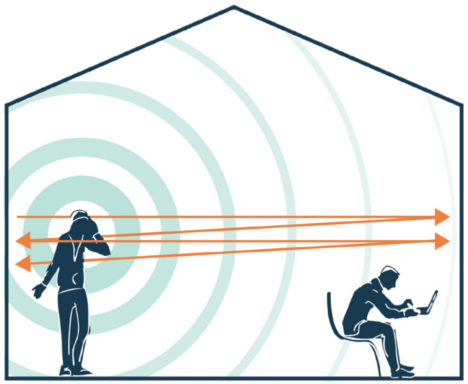

Figure 13. Reverberation and Echo.

In a large space, the listener's ear receives around 8000 reflections in the first second after the direct sound, and each has a delay, a sound level and direction associated with it.

Our brain has become very accustomed to hearing sounds indoors, and is therefore not confused by the multiplicity of sounds arriving from various directions. Our brain almost always computes that the location of the sound source is in the direction of the first arrival.

The characterisation of acoustics involving two ears is usually called spaciousness or spatial impression. A rough measure for this is the portion of sound energy coming from the sides which relates to the difference of the signals entering the listener's ears.

Figure 14. NZ Merino Auditiorium

Acoustic Design Basics

To get the best possible conditions for working and learning, good room acoustics are paramount. To achieve this, it must first be determined which activities will take place in the area and what the human sound preferences for that particular activity is. Optimal acoustics can be achieved by choosing the right amount and correct placement of absorption material.

All materials have acoustic properties which absorb, reflect and transmit all the sound energy that hits the surface.

Sound absorption is defined as the incident sound that strikes a material that is not reflected back. A piece of fabric is an excellent absorber since the sound passing through it is not reflected- but it is a very poor sound barrier because it allows nearly complete sound transmittal. A concrete block on the other hand is a good sound barrier but will reflect about 97% of the incident sound striking it. The ability of a material to prevent sound transmission is called the sound attenuation.

The relative amount of absorption, reflection and transmittal relate to three types of commonly used rating systems for acoustic materials, NRC, CAC and STC. You will find these values on product data sheets.

Please note that due to longer/shorter wavelenghts, different frequencies will react with a material in different ways.

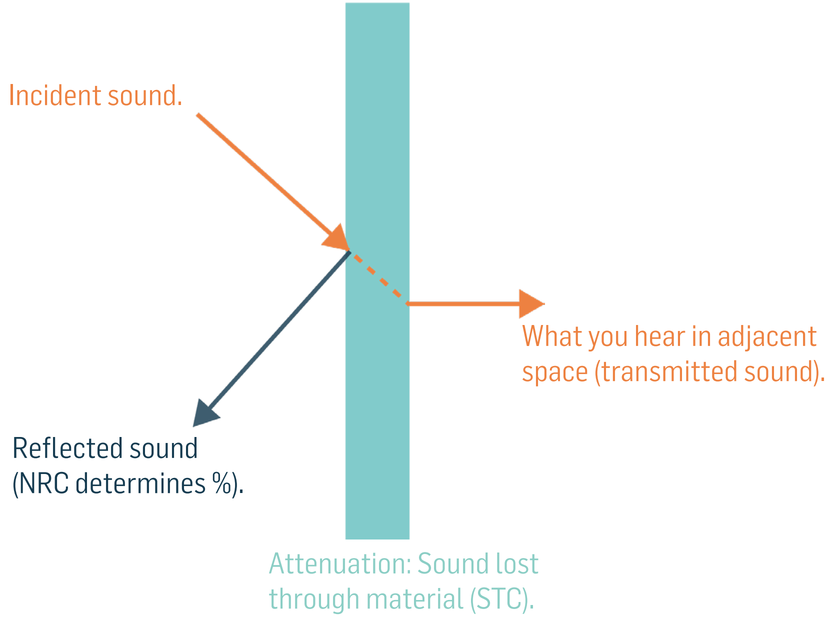

Figure 15. Showing sound energy interacting with a material.

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NRC- Noise Reduction Coefficient

NRC (Noise Reduction Coefficient) is a number between 0 and 1, with higher values representing higher levels of sound absorption. It is the mean value of the sound absorbtion in four frequency bands ranging from 250 Hz to 2000 Hz (a sample range of audible sound energy).

An NRC of 0.85 indicates that the material absorbs 85% of the sound that reaches it and therefore only reflects 15% back into the room. This does not mean that it will reduce the sound level by 85%. The sound absorbing characteristics of acoustical materials vary significantly with frequency. Low frequency sounds are very difficult to absorb because of their long wavelength.

Ceilings are often used to increase the amount of absorptive materials in a space because it is a large, often uninterrupted surface area, that is often close to the sources of noise.

NRCs for most acoustic ceiling materials (mineral fibre, glasswool or polyester) range from NRC 0.50 to 0.99 compared to values below NRC 0.10 for plasterboard, concrete and smooth timber ceilings.

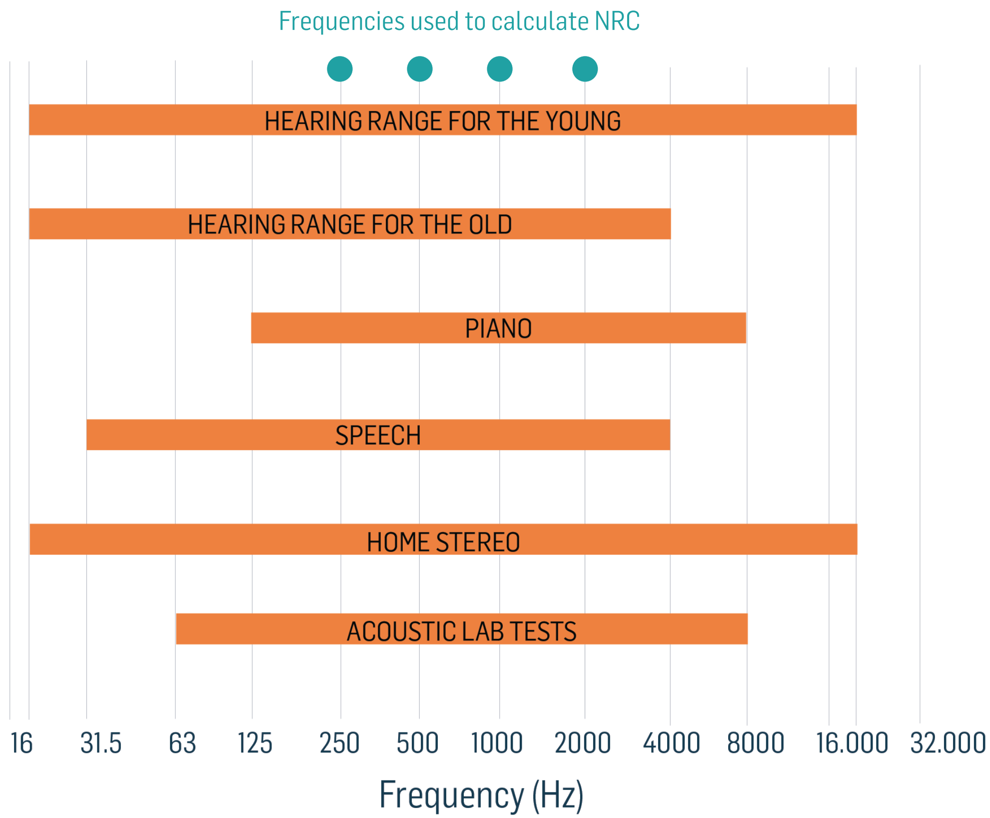

Figure 16. Frequency range of audible sound.

STC- Sound Transmission Class

STC (Sound Transmission Class) is an integer rating of how well a building partition attenuates airborne sound. The STC number is derived from sound attenuation values measured in sixteen frequency bands from 125 Hz to 4000 Hz. STC is roughly the decibel reduction in noise a partition can provide. When designing an interior space, the CAC rating of the ceiling should be close to the STC rating of the wall for optimal performance of the system.

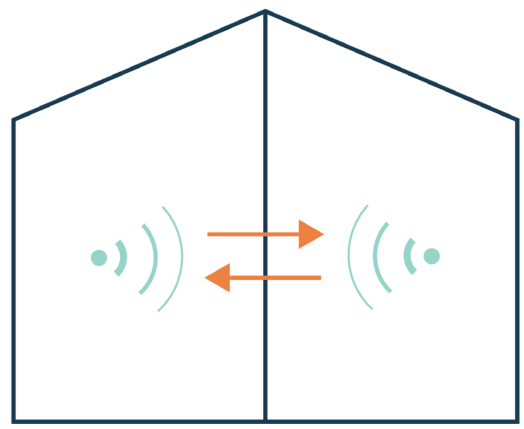

Figure 17. Sound transmission.

CAC- Ceiling Attenuation Class

The ability of a ceiling system to attenuate sound from one space to another through a shared plenum is measured by its CAC (Ceiling Attenuation Class).

Dense, non-porous ceiling materials tend to have higher CACs than lighter, more porous materials. Lightweight, porous materials that produce high NRC ratings will often allow most sound energy to be transmitted. In other words, a ceiling made of porous materials will not give very good acoustic privacy between adjacent rooms unless a suitable full-height wall separates the rooms and blocks the ceiling plenum.

For closed offices with shared ceiling plenums, a ceiling system with a CAC of not less than 35 to 40 is recommended. The CAC performance should always match the STC of the partition.

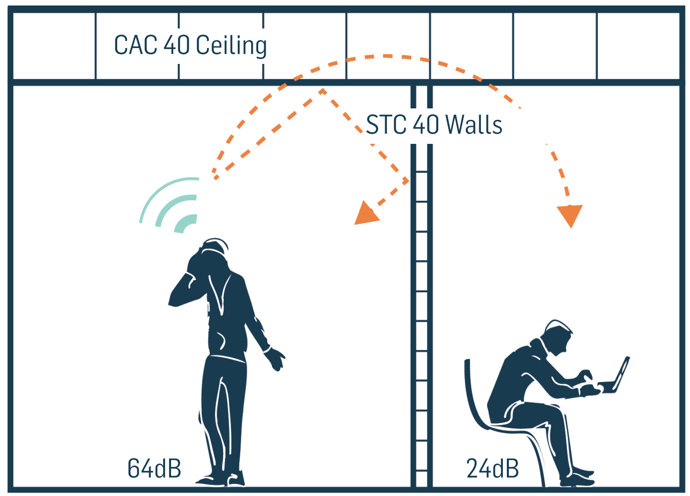

Figure 18. STC/CAC 40 reduces sound transmission by roughly 40dB across the system.

Acoustic comfort

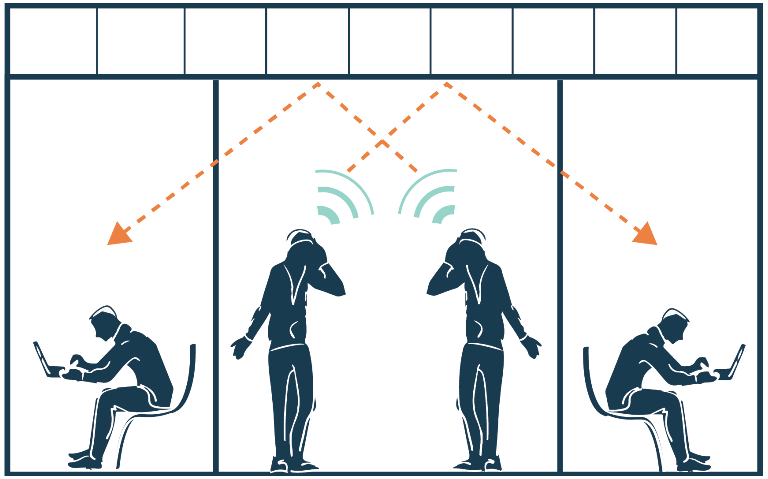

Figure 19. Controlling noise is a mix of correct absorbion and attenuation performance.

Control of the noise within an interior space requires consideration of the sound sources in the space, the sound absorbtion within the space and the attenuation of the noise provided by the walls, floor and roof to control noise entering the space.

Sound Transmission Class (STC/CAC)

30+	Loud speech can be understood fairly well. Normal speech cannot be easily understood.
40+	Loud speech can be heard, but is hardly intelligible. Normal speech can be heard only faintly, if at all.
46+	Loud speech can be faintly heard but not understood. Normal speech is inaudible.
50+	Loud speech cannot be heard through the wall.
60+	Very loud sounds(such as loud singing, brass musical instruments or a radio at full volume) can be faintly heard (complete privacy).
65+	Most noise

Sound Control

Very few products are able to obtain sound absorption and sound attenuation. When specifying products, one needs to identify what purpose a product is intended for. This is often a choice between absorption (lowering reverb time) or attenuation (achieving a certain level of privacy). Products can be combined if required, such as mounting acoustic absorbent materials on denser materials such as plasterboard or timber (which has typically has a good STC rating).

MATERIAL	ABSORPTION	ATTENUATION
Timber	-	+
Plaster	-	+
Plaster board	-	+
Polystyrene	-	-
Perforated metal /wood	+	-
Non-perforated metal	-	+
Glass wool or polyester fibre	+	-
Mineral Fibre	+	+

Figure 20. Sound control using a range of materials.

Acoustic surfaces

Potential acoustic surfaces can be divided into three areas; ceilings, walls and floor.

Ceilings:
The most common types of absorptive acoustic ceiling materials are glasswool and mineral fibre tiles. Glasswool tiles have a high NRC rating, but low CAC performance, making it a great tile for open plan spaces. It can be direct fixed to a denser material to provide sound absorbtion and attenuation. Mineral fibre tiles are slightly heavier and have a decent NRC and decent CAC rating.

Walls:
Most partition walls will need to provide a level of privacy, meaning that the STC performance is important. However, smaller rooms with parallel walls can suffer from parallel echo/flutter and often need sound absorption on the walls to prevent this.

Floors:
Floors cause a lot of noise. Footfall, objects falling, office equipment moving etc, are all exacerbated by hard, reflective flooring. Carpet (although it has a low NRC) is able to mitigate a lot of this noise energy.

Figure 21. Reverberation Room at JSK Acoustic Testing Facility

Specifying for Acoustics

1. **Analyse the space.**

   Gather information about the space; including the functionality and usage, privacy requirements, and if it's an existing space, the current acoustic environment.

2. **Identify STC performance and amount of absorption required.**

   Using the tables, select a desired reverberation time. This will determine the amount of absorbing materials required (determine absorption area by using the Sabine formula). If a certain level of privacy is needed across partition walls, identify the STC/CAC performance for the system.

3. **Manage expectations.**

   When it comes to privacy, the weakest link determines overall performance, and there is no such thing as sound proof.

4. **Specify materials to meet absorption and privacy requirements.**

   Zoning, space allocation and realistic expectations can all lead to better outcomes.

- Sound will travel through the weakest structural elements, which often are doors, windows and electrical outlets.
- When the mass of a barrier is doubled, the STC rating increases by approximately 5 dB, which is clearly noticeable.
- Installing insulation within a wall or floor/ceiling cavity will improve the STC rating by about 4-6 dB, which is clearly noticeable.
- Staggering the studs or using dual studs can provide a substantial increase in attenuation.
- Increasing air space in a wall or window assembly will improve attenuation.
- Walls extending to a suspended ceiling will result in inadequate attenuation between rooms, unless a ceiling with a decent CAC performance is used.
- Correct construction methods are vital when trying to achieve acoustic attenuation.
- For the vast majority of conventional acoustic absorption materials, the material thickness has the greatest impact on the material's acoustic performance, however, other factors can make a large difference in acoustic effectiveness. Incorporating an air space behind an acoustic ceiling or wall panel can often improve performance.

Figure 22. C Max Absorb and GridLux Lights installed in Koha Gym.

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