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ACOUSTIS DESIGN GUIDE FOR

METAL ROOF AND WALL CLADDING SYSTEMS

THE METAL CLADDING & ROOFING MANUFACTURERS ASSOCIATION

1.0 Introduction

CONTENTS

Acknowledgement:

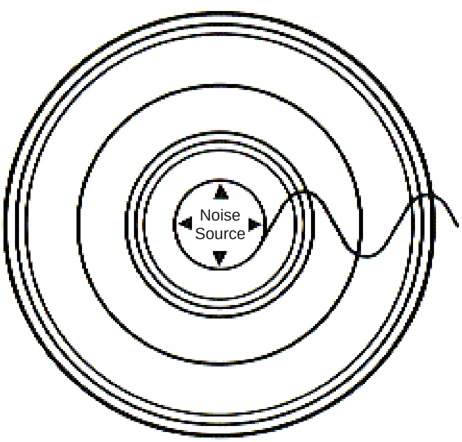
The research was carried out by the Building Acoustics Group, Department of Applied Acoustics, University of Salford, and funded by the Science and Engineering Research Council contract GR/H77088.

Noise and its control is becoming an increasingly important aspect of building design. The purpose of this guide is to explain some of the basic terminology and theory of acoustics, paying particular attention to the performance of profiled metal cladding systems.

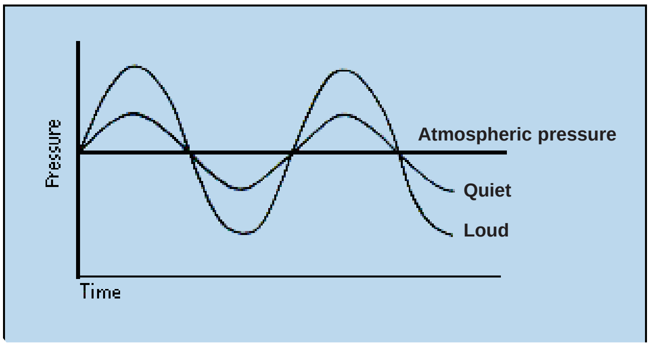
2.0 Basic characteristics of noise

2.1 What is noise?

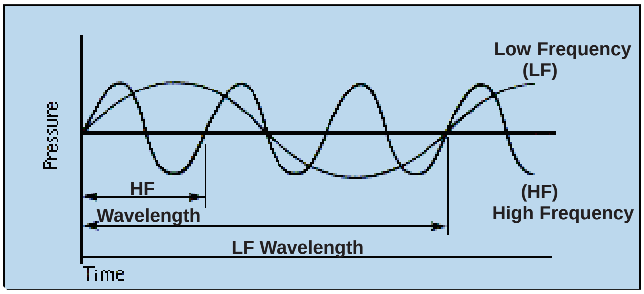
Noise is a sound which can be annoying, can interfere with enjoyment of normal activities, and which can sometimes be harmful. It propagates through the air as a pressure disturbance or wave, superimposed on the atmospheric pressure.



In general terms the greater the variation in pressure, the louder the noise.



The pitch or frequency of the sound is determined by the spacing of the waves (or wavelength)



The human ear drum is set in motion by the incoming sound pressure waves. Through an intricate system in the middle and inner ear these vibrations are converted into impulses in the nervous system which the brain perceives as sound.

The loudness of the sound may be annoying, perhaps because a new sound is introduced into an area and can be heard above the background noise, or the sound may be so loud that it can progressively cause damage to the sensitive hearing system. In either case there is a need for noise control to ensure people are neither annoyed nor harmed by the noise.

2.2 Measurement

Sounds are measured using sophisticated instruments which act approximately in the same way as the human ear, but convert the incoming pressures waves into an electrical signal which can be read on a meter.

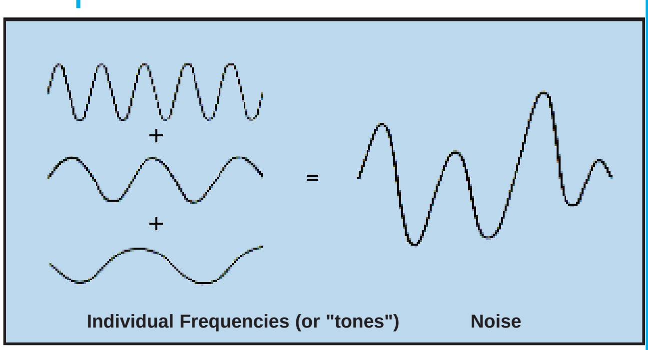
The range of sound pressures is very large, approximately in the ratio 1 to 10,000,000 from the quietest to the loudest sounds. Meters are calibrated to a logarithmic scale, reading in decibels (dB) to give more manageable values.

The scale below shows typical Sound Pressure Levels (SPL) in dB and the corresponding actual pressures for various well known noises.

	Sound pressure level* dB	Pressure P $N/m^2 \times 10^{-6}$
Small jet at take off	120	20,000,000
Sheet metal shop near grinder	110	
Noisy factory with riveting	100	2,000,000
Heavy lorry at 5m	90	
Busy street or workshop	80	200,000
Radio/TV in living room	70	
Restaurant, store, general office	60	20,000
Quiet office	50	
Outside residential area at night	40	2,000
Inside bedroom at night	30	
Recording studio	20	200
Sound proof room	10	
Threshold of hearing	0	20

* Note X dB = 20 log P/P_0, where $P_0 = 20 \times 10^{-6}$ N/m^2

Most noise is made up of many different frequencies added together.



Frequency is normally measured in Hertz (Hz) where 1Hz = 1 cycle per second, i.e. one wave repetition. Each frequency of sound could have a different pressure level, so to produce a more accurate picture of a noise a graph is used showing the sound pressure level at various frequencies.

Groups of frequencies or bands are examined together for simplicity. It is normal to use either full octave (1:1) or the smaller and more detailed one third (1:3) octave bands. An octave is a band of frequencies where the highest frequency is exactly double the lowest. Clearly, use of full octave bandwidths reduces the amount of data to be handled but it also reduces the amount of detail available such that the tonal characteristics of noise can be hidden (see figure 1). Note that the 1:1 values are not averages of the 1:3 figures.

Octave band frequencies							
1:1 Octave bands	125	250	500	1k	2k	4k	8k
1:3 Octave bands	100	200	400	800	1.6k	3.15k	6.3k
	125	250	500	1k	2k	4k	8k
	160	315	630	1.25k	2.5k	5k	10k

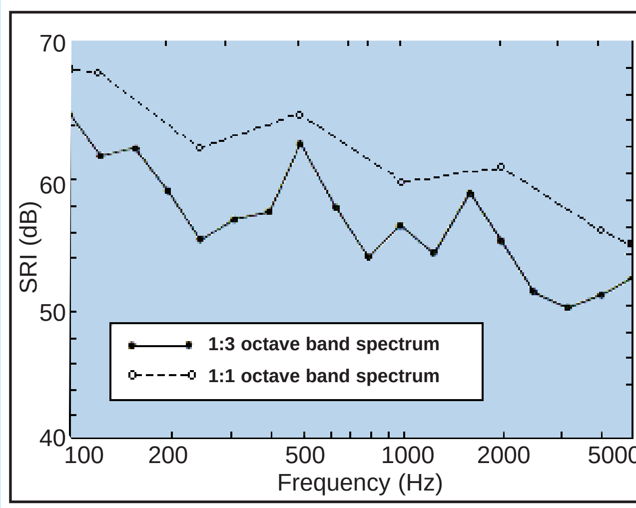


Fig. 1 Typical noise spectrum produced by an air recirculation unit showing the increased detail obtained by using 1:3 octave bands.

With sufficient pressure the frequency range of audible sound is from 20 to 20,000 Hz, although the ear is not equally sensitive at all of these frequencies. At low and high frequencies higher sound pressure levels are required to create the same "loudness" as at mid frequencies.

To accommodate this variation in the ear sensitivity an electronic weighting system is used in measuring equipment. This modifies the Sound Pressure readings so that they approximately equate to the ear's response. The weighting normally used is known as A weighting (see figure 2). Values of Sound Pressure Levels are then quoted in dBA units. Figure 3 shows the effect of A weighting the 1:3 octave band spectrum shown in figure 1.

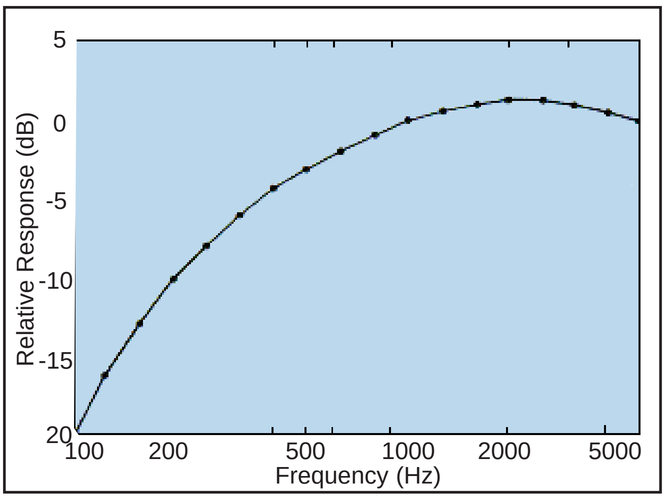


Fig. 2 The A weighting curve

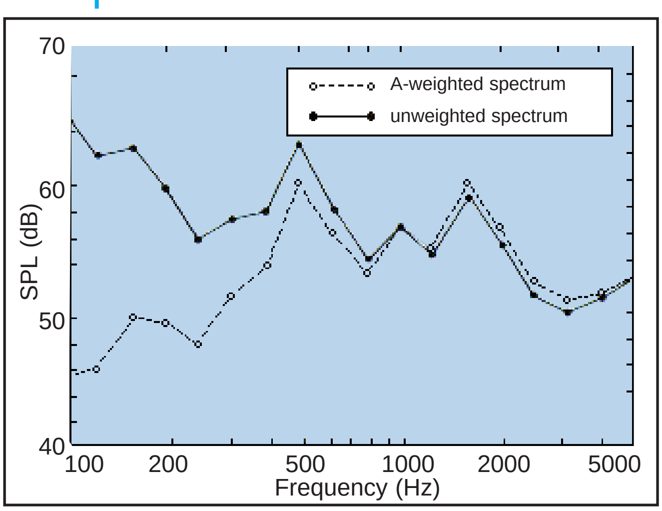


Fig. 3 Typical unweighted and A weighted noise spectra.

Although it is preferable to show the whole spectrum of a noise it is sometimes more convenient to compare noise levels using a single figure value, often called the "broadband level". This is obtained by adding (logarithmically) the individual Sound Pressure Levels to give either a dB or a weighted dBA value.

For the cases in figure 3 the single figure values are:-

Overall	69.1 dB
A weighted	64.2 dBA

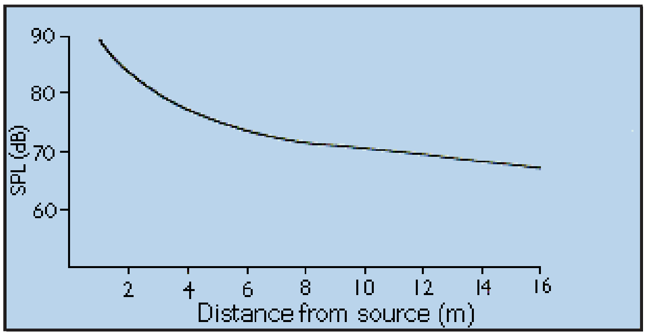
3.0 Noise control

3.1 Noise reduction methods

There are four generally accepted ways to reduce the noise heard by a receiver.

1 Reduce the noise at source
This might be by modifying or simply maintaining noisy equipment so that it does not make as much noise. If this can be done it is likely to be the best solution.

2 Increase distance from source
As sound waves spread out from a source, provided there are no reflections, they gradually decay. For small outside sources the sound pressure level reduces by up to 6dB as the distance doubles.



3 Use sound absorption
Sound pressure waves can be absorbed by many materials such as carpets, soft furnishings, and any open structured, textured, or fibrous material including grass and vegetation. Hard smooth surfaces will reflect sound rather than absorb it, which will have an adverse effect on the acoustics inside a building because multiple reflections increase the internal sound level. Sound which is reflected back into a room or enclosure is often referred to as Reverberant Sound. Therefore sound absorption is used to reduce noise levels inside a building.

A material's ability to absorb sound can be measured and expressed as a sound absorption coefficient. A coefficient of 1 means a surface absorbs all incident sound, whilst a coefficient of 0 means total reflection. Sound absorption also varies with frequency and can be shown in graphical form (See figure 4).

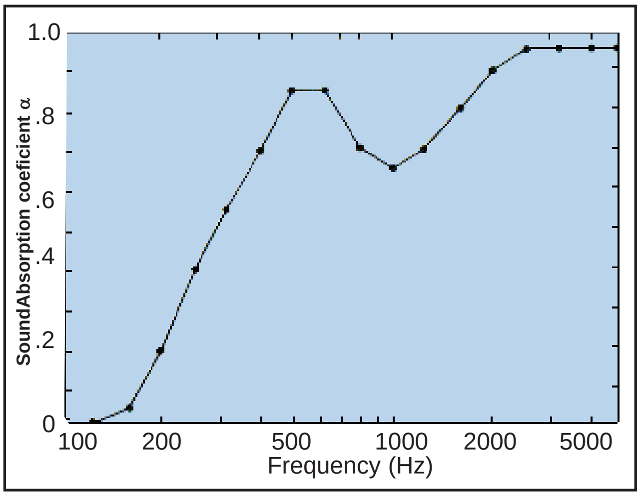


Fig. 4 Acoustic absorption coefficient for a typical fibrous material.

4 Use of sound insulation
If a machine is placed in an acoustic enclosure or is inside a building, the only way noise escapes outside is by transmission through the structure (assuming no windows or doors are open). In the same way sounds outside the building such as aircraft or traffic noise can be transmitted to the inside. The reduction in noise levels provided by walls, windows, roofs etc. is variously referred to as sound reduction or sound insulation. In general, the heavier the structure the more sound insulation it provides.

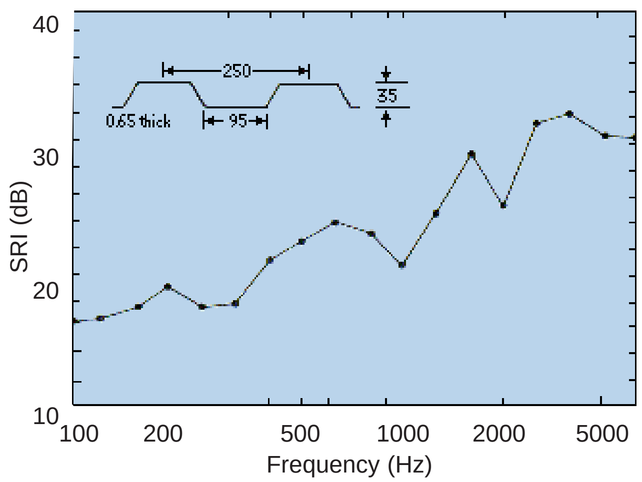
It is important to understand that for sound to transmit through the wall itself requires a relationship between sound and vibrations. In other words, the changing air pressure (sound) inside a building will cause the internal surface of the walls and roof to move (vibration). The vibrations can then pass along structural links such as screws, spacer rails, bricks, or by causing air movement in the air cavity, to the external surface of the building. Here the reverse process occurs and the wall vibrations cause small changes in the outdoor air pressure. Consequently the sound has been "transmitted" from one side of the structure to the other.

One way to reduce the level of noise passing through a wall at certain frequencies is to minimise the structural linkage between its internal and external surfaces. Naturally it will be impossible totally to isolate layers of a wall. Even partitions consisting of two separate layers and an empty cavity cannot stop sound transmission because vibrations will pass through the adjacent floor and ceiling. This is known as "flanking".

The sound which is transmitted through any construction can be accurately measured in a special laboratory.

The insulation provided is then referred to as the Sound Reduction Index (SRI). This varies with frequency and can be illustrated graphically (see figure 5).

For convenience the SRI can be expressed as a single figure. Examples of single figure ratings are the Weighted Sound Reduction Index Rw which accounts for subjective perception and is calculated by reference to a set of standard curves, and the Average Sound Reduction R_{ave} which is an arithmetic average of SRI values from 100 Hz to 3150Hz.

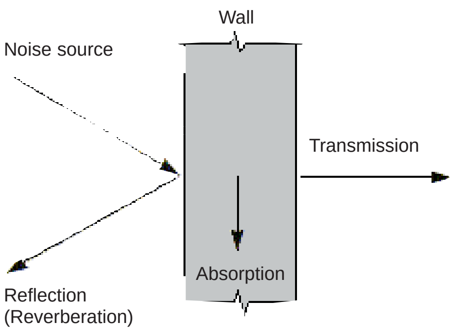


Weighted sound reduction index Rw = 24 dB

Average sound reduction index R_{ave} = 22 dB

Fig 5 Sound reduction of a profiled metal sheet

The various aspects of noise control can therefore be shown diagrammatically as follows:

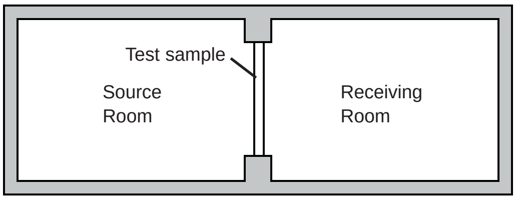


3.2 Test methods

To determine the Sound Reduction Index for a material or construction a test has to be carried out to BS2750: 1980 (equivalent to ISO 140) in a transmission suite. This is a large purpose made facility comprising two adjacent reverberant rooms which are isolated from each other and from all external noise sources.

The test sample is fixed in an aperture of typically 10m² between the two rooms and is carefully sealed. Noise (usually in 1:3 octave bands from 100 to 5000 Hz) is generated in the source room, and the noise levels are measured in both rooms. The difference in Sound Pressure Levels is adjusted for the absorption of the receiving room and the area of the test sample in order to calculate the Sound Reduction Index.

The Absorption Coefficient of walls and roofs is measured in a reverberation room in accordance with BS3638:1987 (ISO 354) by measuring the rate of decay of sound with and without a known area of the sample present. This is carried out in one half of the transmission suite with the sample fixed in the aperture, as in the Sound Reduction Index test.



Transmission suite

These laboratory tests provide the basic acoustic performance data for a material or construction. They generally indicate the best that can be achieved on a real building. Sound insulation measurements on a completed building may be lower because of flanking, features of the building, and poor workmanship on site.

Testing is the only way the basic acoustic performance of a proposed construction can be determined accurately. Estimated values based on comparisons with apparently similar systems or based on the simple mass law will not be reliable.

4.0 Regulations and enforcement

4.1 Assessment

"When designing a new building, or converting an existing building, likely sources of noise should be considered and an assessment made of the possible effects on neighbours of noise generated within the building. Where there is a risk of disturbance from noise it will usually be possible to control the noise, as perceived by the listener, by careful attention to various factors of the design."
(Clause 4.1 BS 8233: 1987)

It is equally important to consider the effects of external noise, such as aircraft or road traffic, on the occupants of a building.

4.2 Regulations

A maximum exposure limit of 90 dBA averaged over an eight hour day in the workplace is specified in the Noise at Work Regulations 1989, and monitored by the Health and Safety Executive. Other environmental requirements are determined by the appropriate local authority, using Department of the Environment and local structure plans for guidance. This is because every situation is likely to be unique.

The following local authority/regional officials could be involved in any noise control work:

- Planning Officer
- Environmental Health Officer
- Building Control Officer
- Factories Inspector (HSE)

It is advisable to discuss any proposed plans and requirements with these people at an early stage.

If planning permission is requested the local planners may:

1 Refuse if the site is too noisy for the proposed use

2 Refuse if the proposed use is likely to cause a noise nuisance

3 Accept, but impose conditions regarding noise levels. These will probably define levels which must be achieved at the site boundary, which will be similar to the existing background sound level.

It will be the designer's responsibility, using the noise control measures above, to ensure the conditions are met.

A common way to achieve the target is by cladding the building with a construction which has a particular Sound Reduction Index. This is commonly specified in the design at the tender stage.

As noted earlier, values achieved on site may be less than laboratory measurements because of sound leaks through windows, doors, etc., and because of detail variations in the construction. This should be taken into account at the specification stage to ensure the acoustic targets are achieved.

4.3 Specification

The specification for the cladding on a building might include a section on acoustic performance. This might say, for example, "The weighted sound reduction index for the cladding should be Rw = 36 dB."

Whilst this gives an indication of the performance required, a cladding system with an Rw of 36 dB will not reduce the noise by 36 dB at all frequencies, even if it is correctly assembled (see figure 5). The actual noise level outside the building depends on the complete construction, the internal acoustics of the space enclosed by the cladding and the frequency content of the noise source (e.g. figure 1).

It is therefore always best to work with a full SRI frequency spectrum to ensure the cladding will attenuate the noise as planned.

4.4 Practical details

The effectiveness of a wall or roof to attenuate sound depends on weight, airtightness, and isolation of the layers of construction.

On a real building it is important to recognise that sound will bypass acoustic walls (flanking) through bridging elements such as walls and floors, and through windows and doors which may have a lower performance than the wall, especially if they are left open.

Similarly sound can escape through poorly sealed junctions in the construction, or if there are relatively rigid connections between the inside and outside faces of the wall.

Noise control measures often fail to perform adequately on site because the building details are not constructed as the designer intended. Relatively minor variations by the contractor can have a significant effect on the acoustic performance. The designer should recognise this and provide sufficient construction details.

Noise control is only one part of environmental control in a building, and designers should be aware that the solution to a noise problem might produce difficulties in other aspects of the building's performance, for example condensation.

Clearly, acoustics is a complex subject and the building designer should not rely solely on the cladding manufacturer or installer for expert advice on the overall acoustic performance of the building. If acoustics is an important issue it is essential to have an acoustic consultant on the design team.

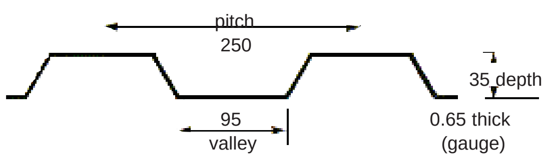
5.0 Performance of profiled metal cladding

5.1 Single skin constructions

The Sound Reduction Index spectra for various single and double skin constructions are shown below.

It should be noted that changing the specification, even slightly, can have a significant effect on the acoustic performance. "Typical" results **will not** apply to a construction where the individual components and/or assembly differs from the sample which was tested.

Figures 6 to 10 show how the acoustic performance of a single skin profiled sheet can change by making small alterations to its specification.



Basic single skin profile used in the tests

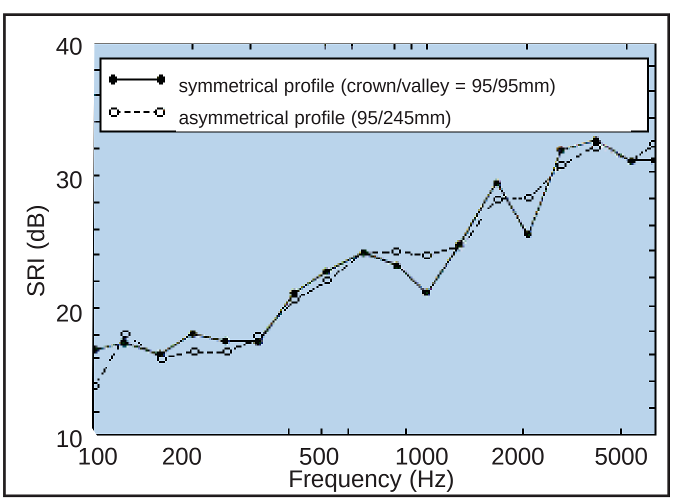


Fig. 6 Effect of profile shape or symmetry

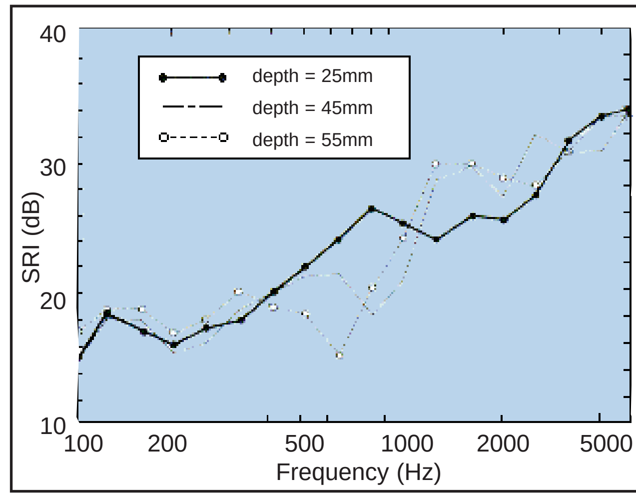


Fig. 7 Effect of profile depth

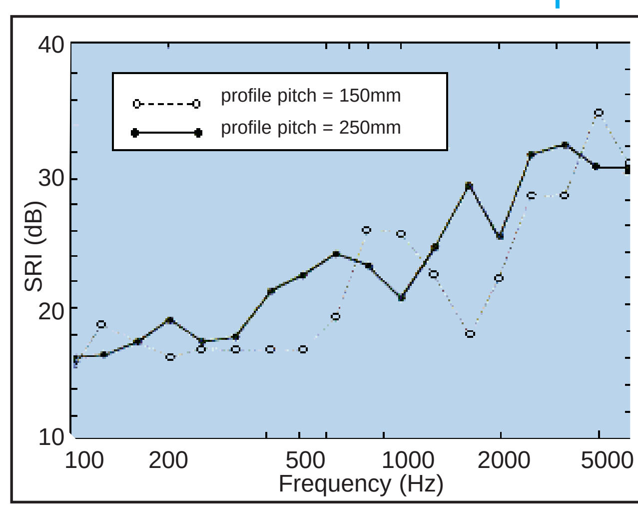
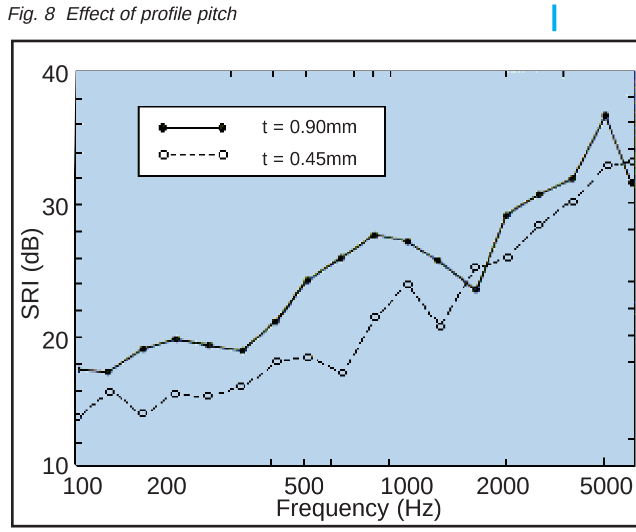


Fig. 8 Effect of profile pitch

Fig. 9 Effect of profile gauge



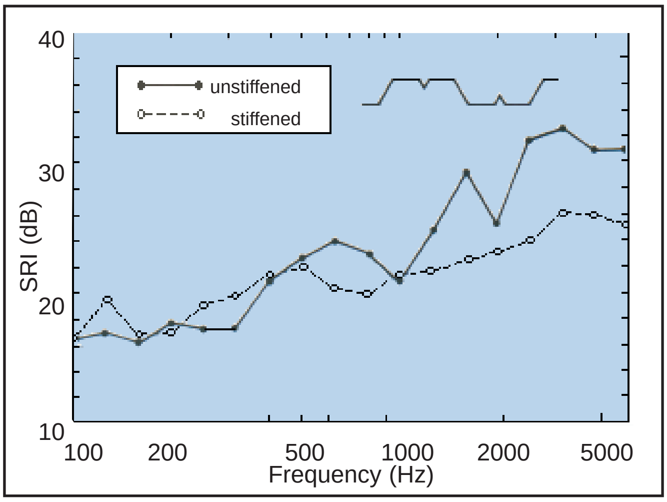
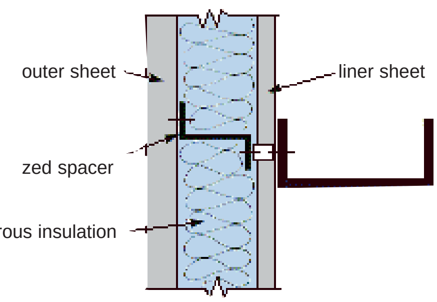


Fig. 10 Effect of stiffeners

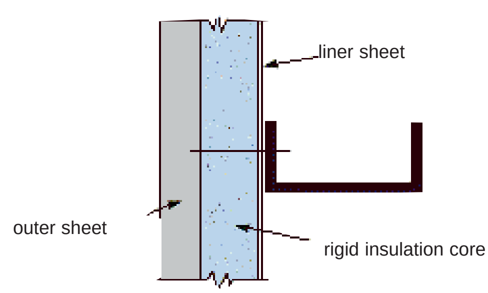
Note that in each case there are several "dips" or drops in performance in the critical mid frequency area. Changing the profile depth, shape or thickness alters the frequency at which the dip occurs and its relative magnitude. The significance of this is that a noise which happened to coincide with the dip frequency would not be adequately reduced.

5.2 Double skin constructions

Most metal cladding is now either built up on site to form an insulated double skin system, or it may be supplied as a factory made composite panel. The acoustic performance of these constructions is affected not only by the performance of the individual metal sheets but also by the insulation material and the construction details (see figures 11 to 13).



Double skin system



Composite panel

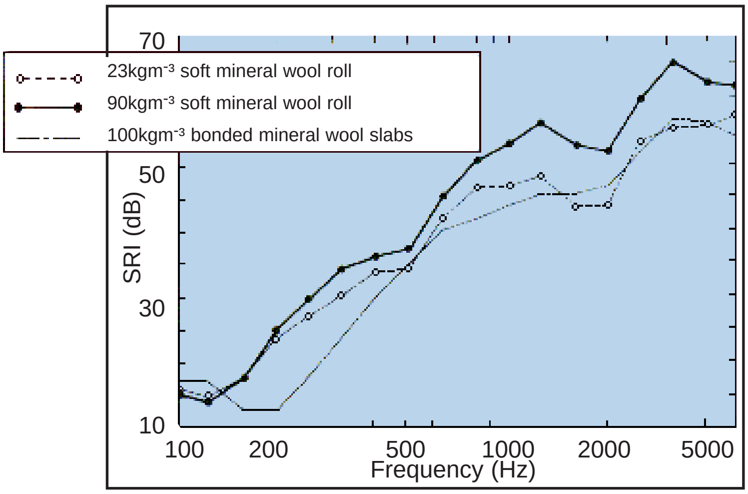


Fig. 11 Comparing the effect of density and softness of mineral fibre insulation

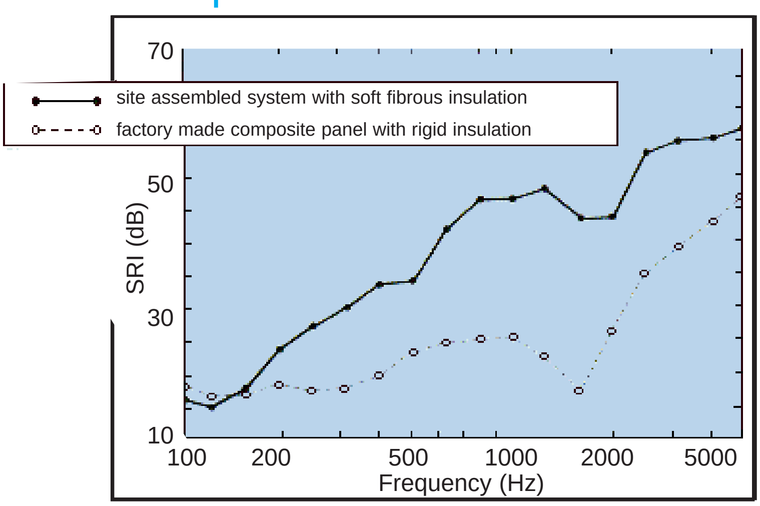


Fig. 12 Comparing a site assembled system and a composite panel.

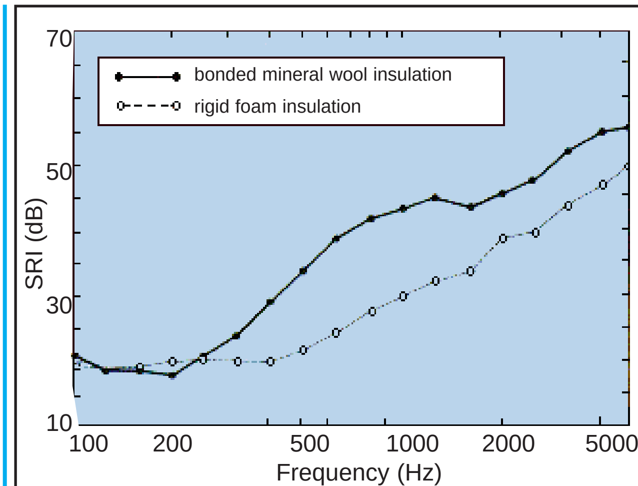


Fig. 13 Comparing site assembled systems with profiled mineral fibre and profiled rigid foam insulation.

Soft insulation such as mineral wool can act to dampen out vibration in the panel, but it should not be packed too tightly or it will provide "bridging" to other components. Rigid foam insulation, such as in factory made or site assembled composite panels, has the same acoustic bridging effect so, although it provides excellent thermal performance, its acoustic insulation value is low (typically Rw = 26 dB). Filling the profile completely with densely bonded mineral wool slabs can also adversely affect the acoustic insulation of the construction, as will fixing details and cladding span.

Ideally the less the mechanical linkage or bridging between the individual layers of the construction, and between the cladding and the support structure, the higher the acoustic insulation. Any fixing is therefore detrimental to the acoustic performance but clearly essential for the structure. Point fixing, such as widely spaced screws, is better acoustically than a line of closely spaced rivets. However, if there is any distortion of the edge of the sheets between fixings, creating gaps, the high frequency noise insulation can be reduced.

Varying the cladding span has a similar effect. In general the greater the span the less the mechanical linkage, and the better the acoustic performance. However, altering the span can also change the effect of low frequency noise on the panel, which could alter the insulation performance.

The examples above illustrate the way in which the acoustic insulation performance of the cladding can be affected by materials and design. In some situations it is necessary to influence the internal acoustics of the building by reducing reverberation, either to control the build up of noise, or to make the space more acceptable for a particular activity. This can be achieved by perforating the liner to allow the noise to be absorbed by the fibrous insulation. Generally to achieve absorption across the widest possible frequency range a minimum perforation ratio (hole area/sheet area) of approximately 30% should be used, spread evenly across the whole surface. If the ratio is less the high frequency absorption is reduced significantly. Note that this amount of perforation will reduce the strength of the liner and the use of thicker material such as 0.7mm should be considered.

An example of the absorption coefficients for a construction with a perforated liner is shown in figure 14.

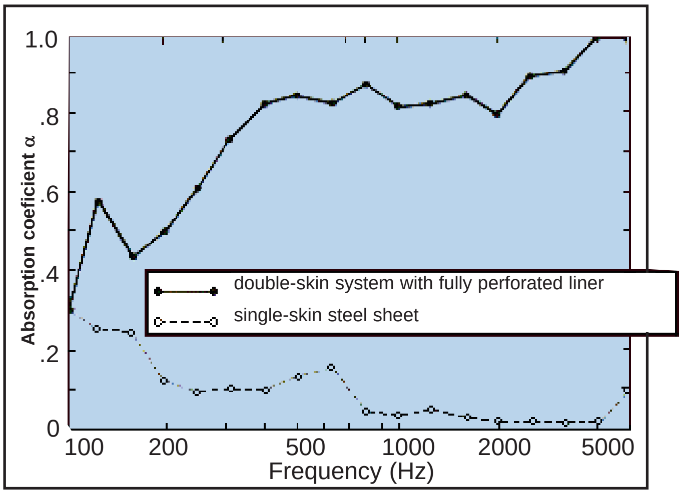


Fig. 14 Comparing sound absorption coefficients of a single skin cladding and a double skin system with perforated liner.

Note that covering the absorbent material, or using a vapour barrier between the perforated liner and the acoustic insulation can adversely affect the absorption characteristics. Perforating the liner may also reduce the acoustic insulation value for the construction, as shown in figure 15.

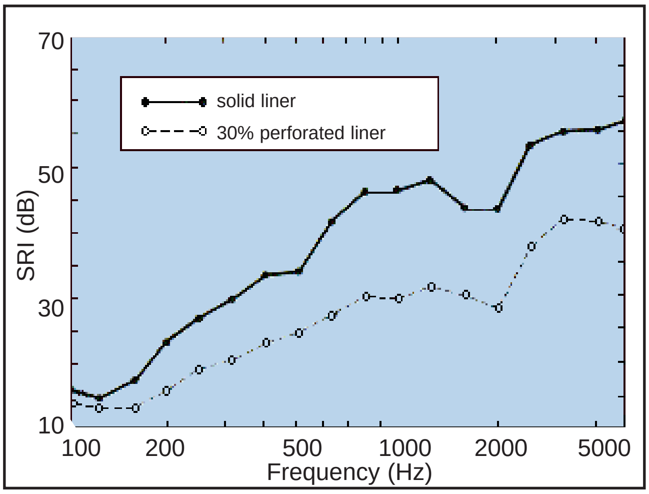


Fig. 15 Effect of perforated liner on sound insulation of a double skin system.

The sound insulation can be improved by using a higher density infill material. It is therefore possible to optimise the Sound Reduction Index and acoustic absorption by careful selection of materials.

It is important to provide a vapour barrier on the warm side of the thermal insulation in double skin constructions to reduce the potential for interstitial condensation. This must therefore be considered very carefully when introducing a perforated liner. Using other types of absorbent materials inside the building may sometimes be a more appropriate alternative solution.

5.3 Enhanced performance systems

It is possible to modify double skin systems in a number of ways in order to improve their acoustic performance. These methods are based on optimising the parameters outlined above: e.g. a thicker gauge of metal increases mass; improving the methods of fixing by isolating the skins from the support structure; or by adding more layers.

The final acoustic performance depends on the total configuration. It is difficult to predict with certainty the effect of changing one parameter in a complex construction, and it is still essential to carry out laboratory tests to determine the performance accurately.

In practice, as the acoustic insulation of the basic cladding is improved the effect of the other building components becomes more significant and must be considered. Doors and windows are often acoustically weak and can significantly reduce the insulation of a facade. When reductions of approximately 30 dB or more are required it is important that doors, windows and other apertures are selected and designed with the overall acoustic performance of the building in mind.

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No 1 Recommended good practice for daylighting in metal clad buildings (Revised edition)

No 2 Curved sheeting manual

No 3 Secret fix roofing design guide

No 4 Fire and external steel-clad walls: guidance notes to the revised Building Regulations 1992

No 5 Metal wall cladding design guide

No 6 Profiled metal roofing design guide (Revised edition)

No 7 Fire design of steel sheet clad external walls for building: construction performance standards and design

No 8 Acoustic design guide for metal roof and wall cladding

No 9 Composite roof and wall cladding panel design guide

No 10 Profiled metal cladding for roofs and walls: guidance notes on revised Building Regulations 1995 parts L & F

No 11 Flashings for metal roof and wall cladding: design, detailing and installation guide

Leaflets:

Manufacturing tolerances for profiled metal roof and wall cladding

Built up metal roof and wall cladding systems tables of insulation

Latent defects insurance scheme: basic guide

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The diagrams of typical constructions in this publication are for illustration only.

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