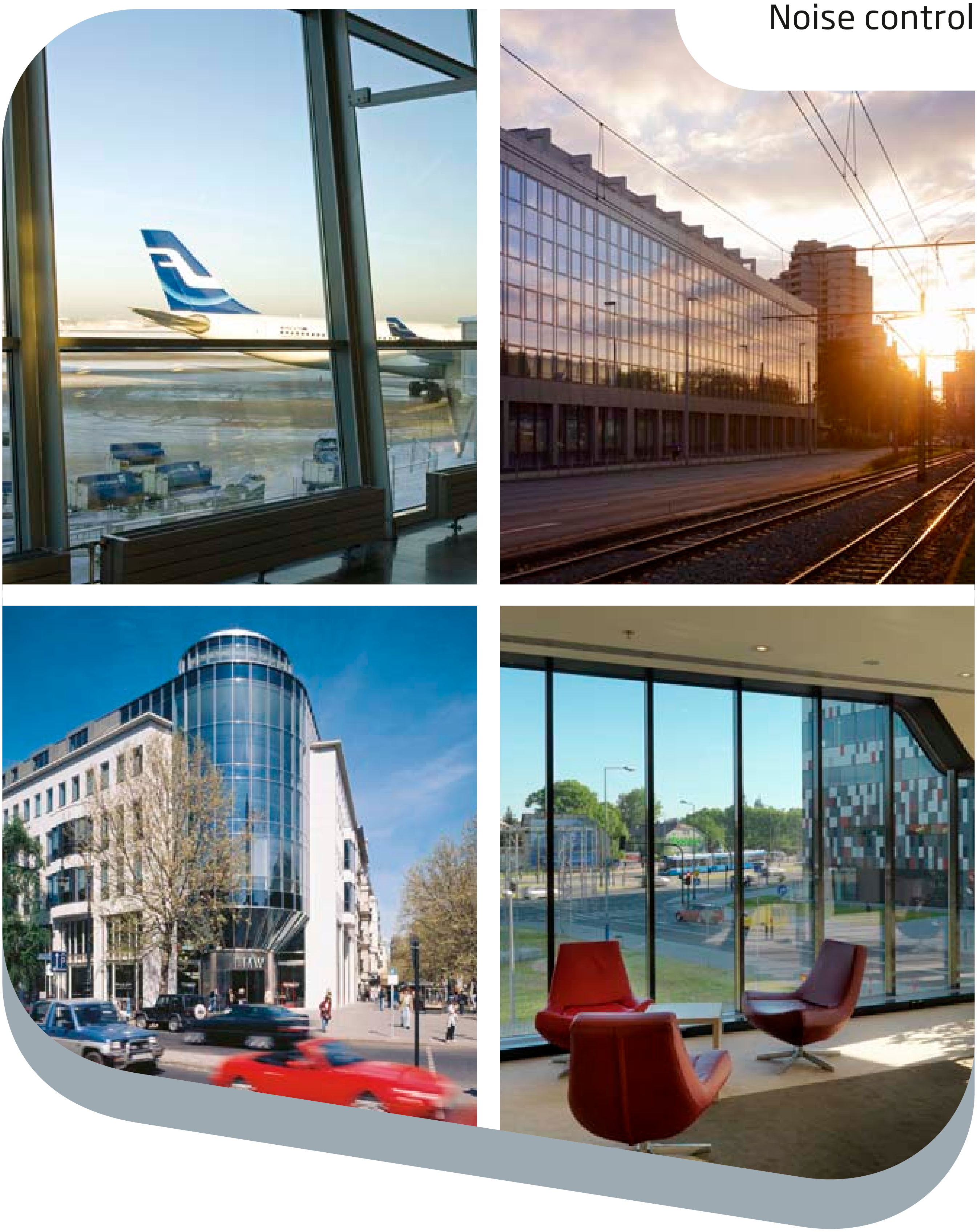
Technical bulletin
Noise control



Noise Control with Glass

Introduction

It could be a Sunday afternoon when you are indoors reading a good book, you could be tucked up in bed at night or seated at work trying to concentrate when you are disturbed by noisy neighbours, traffic or a variety of other unwanted noise. We all suffer from the intrusion of noise at some time or another.

With an increasing population density, factory production and transport the noise seems to get worse with fewer opportunities to escape. Along with the increase in noise is a growing awareness of the effect on health due to the stress caused by everyday sounds intruding into once quiet environments. The trend for the future suggests that traffic and noise in general is going to get worse as living space declines. There is an increasing interest in ways to protect people from noise to avoid the considerable stress that it causes and in some cases serious illness.

A considerable amount of work has been done to control noise intrusion into a building and between adjoining areas and whilst this is valuable we want to concentrate on the contribution that the careful selection of glass has to offer in managing the problem.

What is sound?

From a physical point of view, sound belongs in the field of wave physics / mechanical oscillations. Even 2000 years ago, a Roman architect engaged in the construction of amphitheatres used waves in water to improve his design.

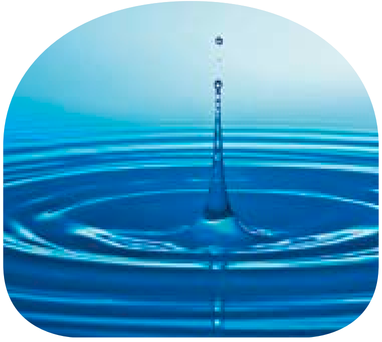


Figure 1: Sound spreads out in a similar manner to waves in water

For example, if we strike a tuning fork, we can hear the oscillations, but we cannot see them. These oscillations of the tuning fork are transmitted to air molecules, which then pass on their oscillations to other air molecules. This behaviour can be demonstrated in water. These oscillations are comparable to a wave in water, with the height of the wave being a measure of the volume of sound and the number of waves in time is the frequency of the sound i.e. the more waves, the higher the frequency. Frequency is defined as cycles per second or Hertz. Hertz is the correct way to describe the frequency or pitch of the sounds and is abbreviated to Hz.

In music, the note A (nearest A above middle C) has a frequency of 440 Hz or oscillations per second in concert tuning. If the frequency is doubled to 880 Hz, the note increases by an octave for equal tempered tuning.

The human ear of a young person can detect frequencies of 20 Hz up to 20,000 Hz and is capable of detecting sound pressures, or to be more precise pressure fluctuations, of between 10^{-5} Pascals (Pa) = 0.00001 (lower limit of hearing) and 10^{2} Pa = 100 Pa (pain threshold) by passing these on to the brain as a sensation of volume. With increased age the range of audible frequency diminishes from both ends of the scale naturally or from hearing damage.

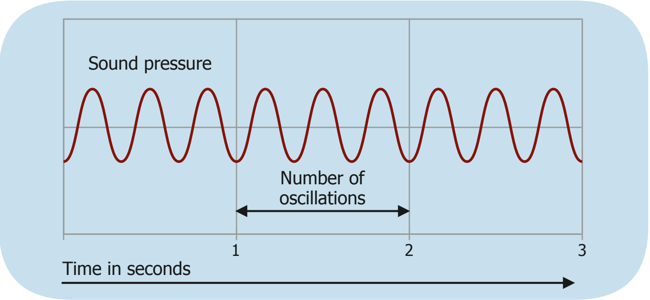


Figure 2: Definition of frequency

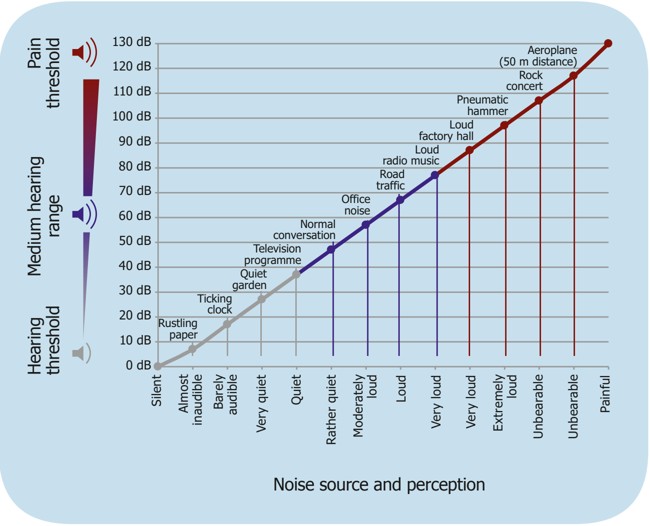


Figure 3: Noise source and perception (source: Kuraray, Troisdorf)

The relationship between the quietest and the loudest noise is a ratio of 1 to 10 million. Since this is very unwieldy, in practice the sound-pressure level, or sound level L for short, is expressed as a logarithmic scale which represents a conversion of the sound pressure into a more convenient measure known as the decibel scale (dB). The normal range extends from 0 dB (hearing threshold) to around 130 dB (pain threshold). Figure 3 shows a few examples.

There are a variety of ways of creating noise and each noise can produce different volumes of sound at different frequencies. If we use aircraft as an example there is a clear difference in the sound made by propeller driven aircraft, modern fan jets and military aircraft. If the volume by frequency is plotted as a graph they would look distinctly different. When trying to defeat noise these variations can be taken into account and different glass types also work better at some frequencies than others. By matching the performance of the glass to the noise we can selectively reduce the most annoying sounds to get the maximum benefit. Anyone living next to a private airstrip with light aircraft has a very different problem to a neighbour of a military base. The solution to the noise problem will be to use a different glass configuration.

Determining the noise level can be done in a number of ways. For large or difficult projects a site noise survey can be commissioned using acoustic consultants who use sensitive equipment to measure and average noise levels by frequency over a period. These surveys give precise data on the volume of noise at each frequency that needs to be attenuated. The information is often provided in reports that break the noise down into a table showing octave frequencies, e.g.:

Frequency [Hz]	125	250	500	1000	2000	4000
Sound pressure [dB]	30	36	42	44	48	50

The sound can be measured at the site, close to the noise source or a distance in between. Where site data is not provided an adjustment can be made to the sound to allow for distance. The further you are away from the source the less impact it has.

Example: Decay of noise with distance

Road traffic noise decreases by approximately 3 dB with doubling of distance at right angles to the road. If, for example, L is the dB noise level at 5 meters, then the decay follows the pattern:

5 m	L dB
10 m	(L-3) dB
20 m	(L-6) dB
40 m	(L-9) dB
80 m	(L-12) dB
160 m	(L-15) dB

The noise level is often measured over a period and averaged to remove the disproportionate effect of isolated loud noise that is exceptional like a car horn sounding. A level of noise energy can be determined that is an A weighted long term average called the day-evening-night level (L_{den}). It is the L_{den} noise level that should be the basis of the design rather than isolated peaks in sound. Therefore the aim of the design should be to control the general noise rather than exceptions otherwise the noise reduction criteria would become extreme. For some applications it may be appropriate to use only part of the three periods or a supplementary noise indicator for noise that only occurs for a short period of time.

There is sometimes an option with noise measuring equipment to record the data with an A weighting. Where interior noise limits are set they are often expressed in dB(A) or L_{Aeq}. The A weighting is an adjustment to the noise at each frequency that follows a standardised curve. The A weighting is a recognition that the human ear does not react to the same volume at each frequency equally i.e. some frequencies seem louder than others even though they are being delivered with the same energy. It is important that the human reaction to noise is considered rather than making decisions based upon the sensitive instruments that measure sound in an absolute way.

Where a survey is not carried out then there are examples of previous surveys that allow designers to assume typical noise levels from common sources of noise e.g. road traffic, music, speech, trains, aircraft etc.

Where third octave or octave band information is not provided there are a range of shorthand expressions used for the noise, typically the R_w and R_{tra} figures may be used to abbreviate the information. For glass performance the abbreviations are determined by taking plots on a graph of the sound attenuation by frequency and mathematically comparing standard curves to them until they are a good fit. The noise reduction at a fixed frequency on the standard curves provides the R_w and R_{tra} figures.

When the noise level is known the performance of the glass can be matched to get the required level of residual noise. It is important that the indices of measurement are matched or in the same scale to ensure that the calculation is correct.

For those who like to dig a little deeper

The measured values for 10 mm Pilkington **Optifloat**™ – 16 mm air space – 9.1 mm Pilkington **Optiphon**™* are shown in blue. The reference curve specified in EN ISO 717-2 is shown in red. This reference curve is now moved downwards in whole dB increments, until the sum of the deviation of the measured values from the shifted reference curve is maximised and less than 32 dB. Only those measured values that are less than the reference values are taken into account. The y-value of this shifted reference curve (green curve in Fig. 4) at a frequency of 500 Hz is the sought R_W-value, in this example 45 dB. Unfortunately, the above-mentioned relationship between the sound-pressure amplitude and the perceived volume is not as simple as scientists would like it to be because nature has made our hearing more sensitive to certain ranges than to others. This means that we perceive a thousand Hz tone as louder than a hundred Hz tone, even though the volume is the same. This property of the human ear is taken into account in the shape of the reference curve.

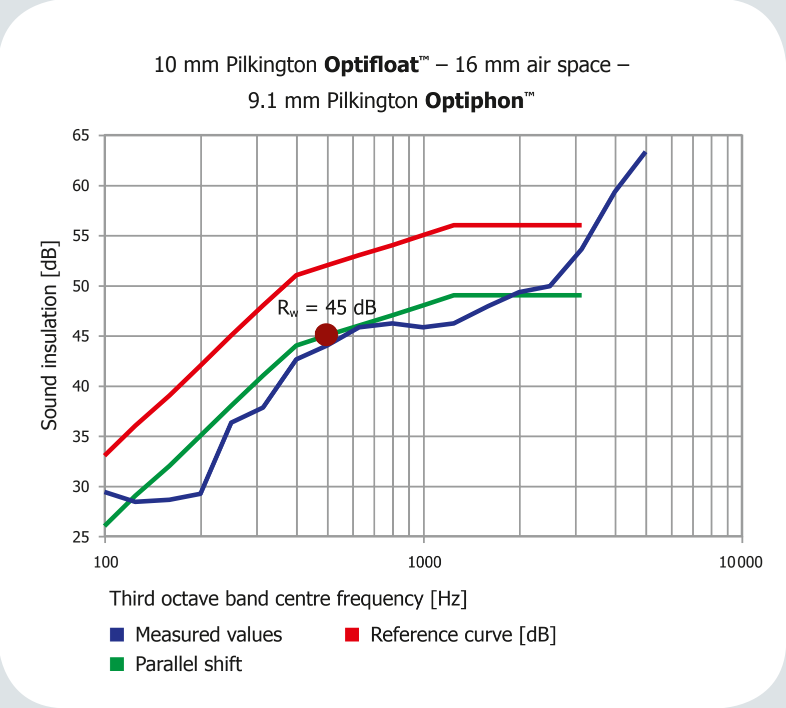


Figure 4: Determining the sound insulation value R_W

* previously known as Pilkington **Optilam**™ Phon

Determining the sound insulation of types of glass

Since it would be time consuming and costly to measure every system on site, all sound insulation spectra are recorded under standardised conditions. As we see, sound insulation is very frequency- dependent. To avoid having to work with the complete data set this diagram can be reduced to a single value. The standardised procedure is described in Figure 4. The result is a single number – in this case $R_W = 45$ dB – which can be used in further calculations.

The disadvantage of such a single-value specification is that we can arrive at the same result with completely different curve shapes, as shown in Figure 5.

We achieve more expressive single-value specifications if we use "custom-made" reference curves for specific requirements.

Such "special cases" are C and C_{tr}. They take into account the different frequency spectra of residential and traffic noises and thus make it possible to find adequate solutions to the problems in question in a simple manner.

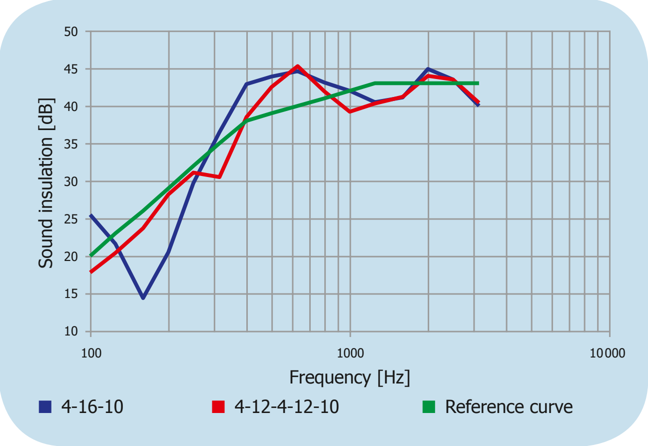


Figure 5: Comparison between two insulating glass structures where $R_W = 39$ dB

The C-value takes into account the noise sources:

- Residential activities (talking, music, radio, TV)
- Children playing
- Rail traffic at average and high speed
- Motorway traffic > 80 km/h (50 mph)
- Jet aeroplanes a short distance away
- Businesses that emit primarily medium- and high-frequency noise

The C_{tr}-value takes into account noise sources such as:

- Urban road traffic
- Low speed rail traffic
- Propeller aeroplanes
- Jet aeroplanes a long distance away
- Disco music
- Businesses that emit primarily low- and medium-frequency noise

Thus, if the planned building is located in a city, right by a main road, the C_{tr} value is the most suitable. If a building is planned right next to a motorway, the C value is more appropriate.

Calculation rules

Although the use of the dB scale facilitates nice convenient numbers, it also gives rise to somewhat unusual "calculation rules". If a noise source is duplicated then the overall dB value rises by only 3 dB. A ten-fold increase i.e. ten electric fans instead of one, leads to an increase of only twice as much noise i.e.10 dB.

To complete the explanation, we should also mention that a halving of the noise level at the ear is not recognised as a halving of the volume. In general it is true that:

- A difference of 1 dB is not practically noticeable
- A difference of 3 dB is just perceptible
- A difference of 5 dB represents a clear difference
- A difference of 10 dB halves / doubles the noise.

The different types of sound insulation

Mass

As mentioned above, sound spreads in waves by exciting the molecules of the medium in question so that they oscillate. Due to this means of transmission, the noise is subject to a natural damping – depending upon the mass in question. Expressed simply: the more mass put between transmitter and receiver, the greater the damping.

The simplest way of increasing the sound insulation of glass is therefore to use a lot of glass. Thus a 12 mm single pane has an R_W value of 34 dB, whereas the corresponding value for a 4 mm pane is only 29 dB.

Coincident frequency and asymmetry

If we compare the spectra of 4 mm, 8 mm and 12 mm float glass, we see that each of these spectra has a downturn in the right-hand section.

This fall off in performance at certain frequencies or coincident frequencies occurs at the frequency that matches the natural resonant frequency for the product. The so-called coincident frequency is material specific and dependent upon thickness for glass. As a rule of thumb:

$$f_g = \frac{12000\ \text{Hz}}{d}$$

(where d = thickness of material)

According to this formula, f_g is 3000 Hz for 4 mm float glass, 1500 Hz for 8 mm float glass and 1000 Hz for 12 mm float glass, which corresponds very well with the spectra in Figure 6.

To overcome this we can mix the thicknesses of glass panes in an insulating unit structure so that when one pane is at its coincident frequency the other is not and continues to defeat the sound. Such asymmetric structures can thus significantly reduce the downturn in the coincidence range, as shown in Figure 7. A 30% difference in thickness is desirable. Not only does this reduce the dip but it also shifts it up the scale which is beneficial as the higher the frequency, the more effective the glass becomes at reducing the overall noise level.

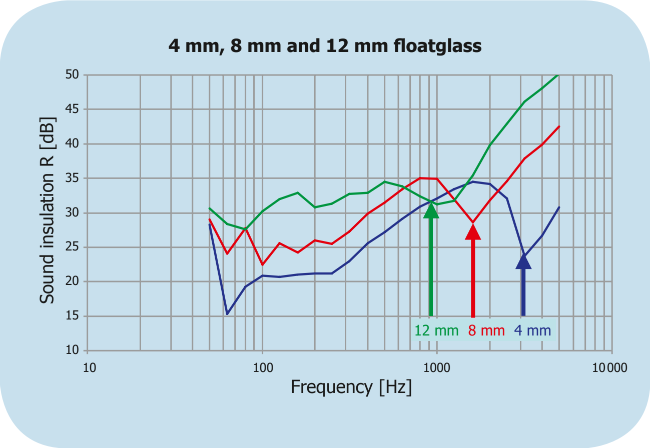


Figure 6: Influence of the pane thickness on the coincidence frequency

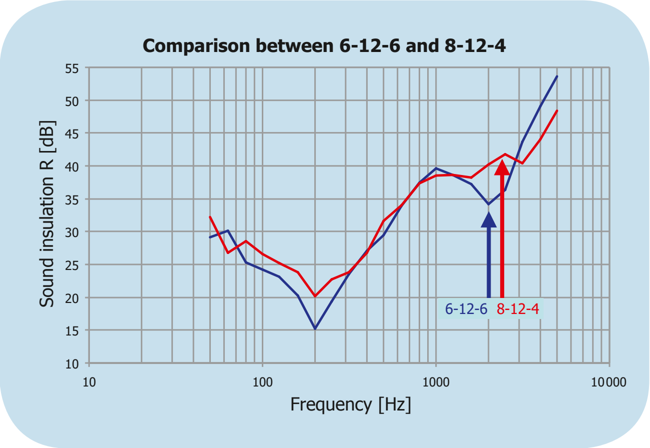
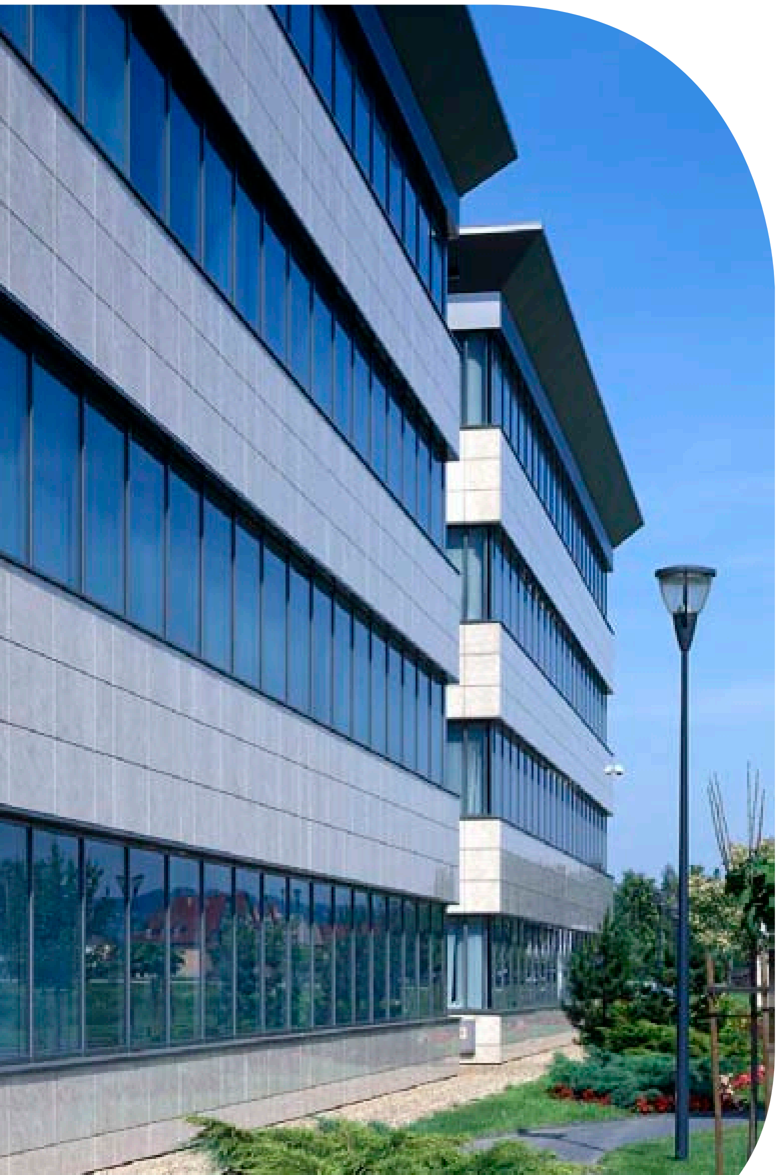


Figure 7: Asymmetric glass structure to reduce coincidence

Gap between panes / gas fillings

Another method for controlling the transmission of noise is to vary the distance between the panes of glass. With conventional insulating glass units the gap between the panes is limited to maintain the optimal thermal performance and the size of the gap is not large enough to significantly improve the acoustic performance. With secondary glazing there is an opportunity to have relatively large gaps and an airspace of over 60 mm starts to provide real improvements in performance. The space between the panes can also be lined with acoustic tiles to enhance the benefit.

Gas filling the space between panes of an IGU has a marginal effect and there is no practical improvement in using argon gas. Due to the density of krypton a small benefit can be gained in acoustic performance of up to 1 dB. Sulphur hexafluoride (SF_6) could be used for sound insulation simply because it is so heavy, however, this gas has two disadvantages. Firstly it worsens the thermal insulation value and secondly this gas has a CO_2 equivalent of 22 800 and thus makes an extremely large contribution to the greenhouse effect. For these two reasons, SF_6 gas fillings are banned throughout large parts of Europe.



Decoupling / damping

We have said that the thickness of glass helps and varying the glass thicknesses in an insulating unit is a useful method of improving noise reduction. Adding mass to the product or having large air gaps may also be undesirable for reasons of weight and space. Fortunately there are ways of improving the noise reduction of relatively thin panes of glass by introducing a damping effect within the glass. By laminating the glass with ordinary PVB interlayer we can reduce the fall off in performance due to the coincident frequency and shift the frequency at which the downturn occurs. Adding a Pilkington **Optilam**™ product to the construction can have a marked improvement particularly where the noise level would be high at the coincident frequency for a monolithic glass. Insulating glass units can provide very good results with a mixture of monolithic (Pilkington **Optifloat**™) and Pilkington **Optilam**™ glass types.

For higher specification requirements there is Pilkington **Optiphon**™. These products use special interlayers in a laminate that further decouple the two panes of glass whilst still providing the impact safety of laminated glass. If you look at the curve profile for Pilkington **Optiphon**™ you will see that the fall off in performance at what would have been a coincident frequency is almost eliminated. The correct grade of product can be chosen to match the sound profile to allow superior performance without dramatically increasing the glass thickness. This allows for greater flexibility in design without compromising other glazing functions.

In the left-hand part of the spectra we see a further downturn. This is the so-called resonant frequency. This is the frequency at which the component as a whole oscillates in resonance and thus transports the sound oscillations particularly well and insulates poorly.

The sound insulation can be improved by moving the resonant frequency of the component to another frequency (away from the nuisance frequency or to where the human ear can hear less well). This is achieved by "decoupling" the insulating glass, by making a pane of glass at the same time dense and soft. This can be achieved by joining two panes of glass either with special (soft) casting resins or with modern PVB interlayers developed specially for this application.

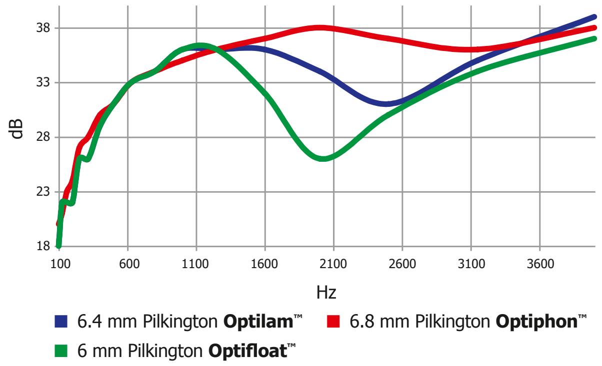


Figure 8: Sound reduction illustration

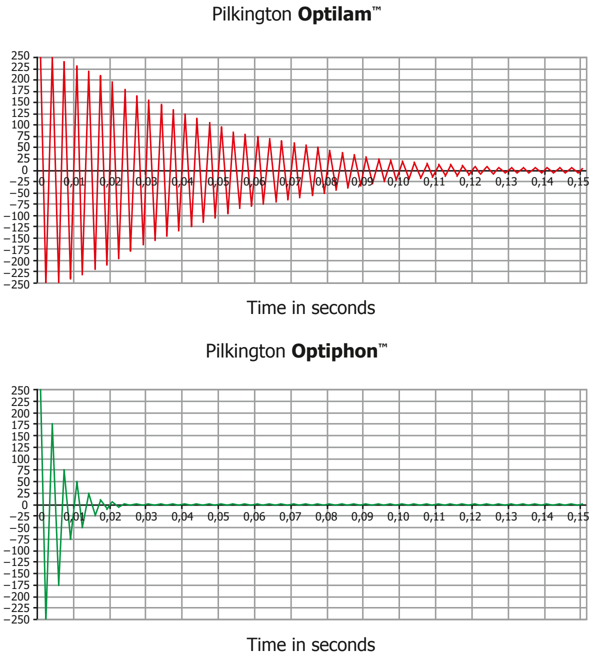


Figure 9: The illustration shows the impressive damping differences between Pilkington **Optilam**™ and Pilkington **Optiphon**™ from the sound engineering point of view.

Important reminder

The object of selecting the right acoustic product is to make the internal environment comfortable and free from the stress associated with noise intrusion. The level of residual noise is not the same for all locations and national guidelines are produced for most environments. For instance in a library the background noise should be around 30 dB and a bedroom is different from a lounge area. Zero noise is undesirable and tends only to be found in anechoic chambers usually reserved for testing. Zero noise can be an eerie experience as the ear tunes to other sounds that become distracting. The equation as a first guide becomes:

Noise Source – building attenuation = residual noise

Note that the whole building needs to work and that glass alone will not solve all acoustic problems. Sound only needs a small entry way to get into a building unlike heat loss or gain, which tends to be proportional to the surface area. For glass noise reductions up to around 35 dB normal windows without ventilators will achieve similar performance. Above this level, windows developed for noise reduction need to keep pace with the glass performance to ensure the combined product is functioning.

To sum up

There are five factors that can be combined, which can positively influence the sound insulation of insulating glass.

1. Glass mass
2. Asymmetric structure
3. Large gap between panes
4. Use of alternative gases
5. Use of **Optiphon**™ special laminated safety glasses or Cast In Place (CIP) products.

For the higher sound insulation requirements, modern sound insulating laminated safety glass products such as Pilkington **Optiphon**™, are becoming increasingly prevalent in comparison to the cast resin products because R_W values of even more than 50 dB can be achieved and they can be supplied in large sizes. The compatibility of PVB with other materials is well understood and safety benefits such as impact protection / safer overhead glazing can also be achieved.

CE marking confirms that a product complies with its relevant harmonised European Norm.
The CE marking label for each product, including declared values, can be found at www.pilkington.com/CE

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