The thermal effect on the acoustic attenuation of laminated glass

kuraray Trosifol® SentryGlas®

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Introduction

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Based in Oxford and for the past 24 years,
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Content

- introduction
- What is Sound?
- Effects of sound on buildings
- Sound control
- The effect of temperature
- Further research

Introduction

- Modern building designs have culminated into the increased adoption of laminated glass façades. The use of laminated glass in the façade industry mainly adds the benefit of safety, security, structural and sound insulation properties. Sound insulation has been a major consideration for buildings due to the need to maximise comfort for occupants. The sound insulation properties of laminated glass depends on various factors including temperature. Thermal variations determine the optimal performance conditions for laminated glass under different conditions. Most of the acoustic tests are carried out at room temperature which may not reflect the actual scenarios. The presentation will aim to highlight this effect and better understand how it can be compensated in design.

- If you would like a copy of this presentation, please email me at the end Allan.Gibson@kuraray.com

World of interlayers - Trosifol® PVB & SentryGlas® ionoplast interlayers

Delivering your window into the world of advanced interlayers for laminated safety glass, Kuraray's Advanced Interlayer Business is underpinned by decades of innovation, application knowledge, domain experience and market success.

Our advanced interlayer portfolio – comprising Trosifol® PVB and SentryGlas® ionoplast interlayers – has continually revolutionized aesthetic, structural and functional design, fabrication and installation in the architectural and automotive/transportation segments.

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What is sound?

What is sound?

In physics;

sound is a mechanical wave that propagates through a transmission medium such as gas, liquid or solid.

In human psychology and psycho-acoustics;

sound is the reception of sound waves and their perception by the brain

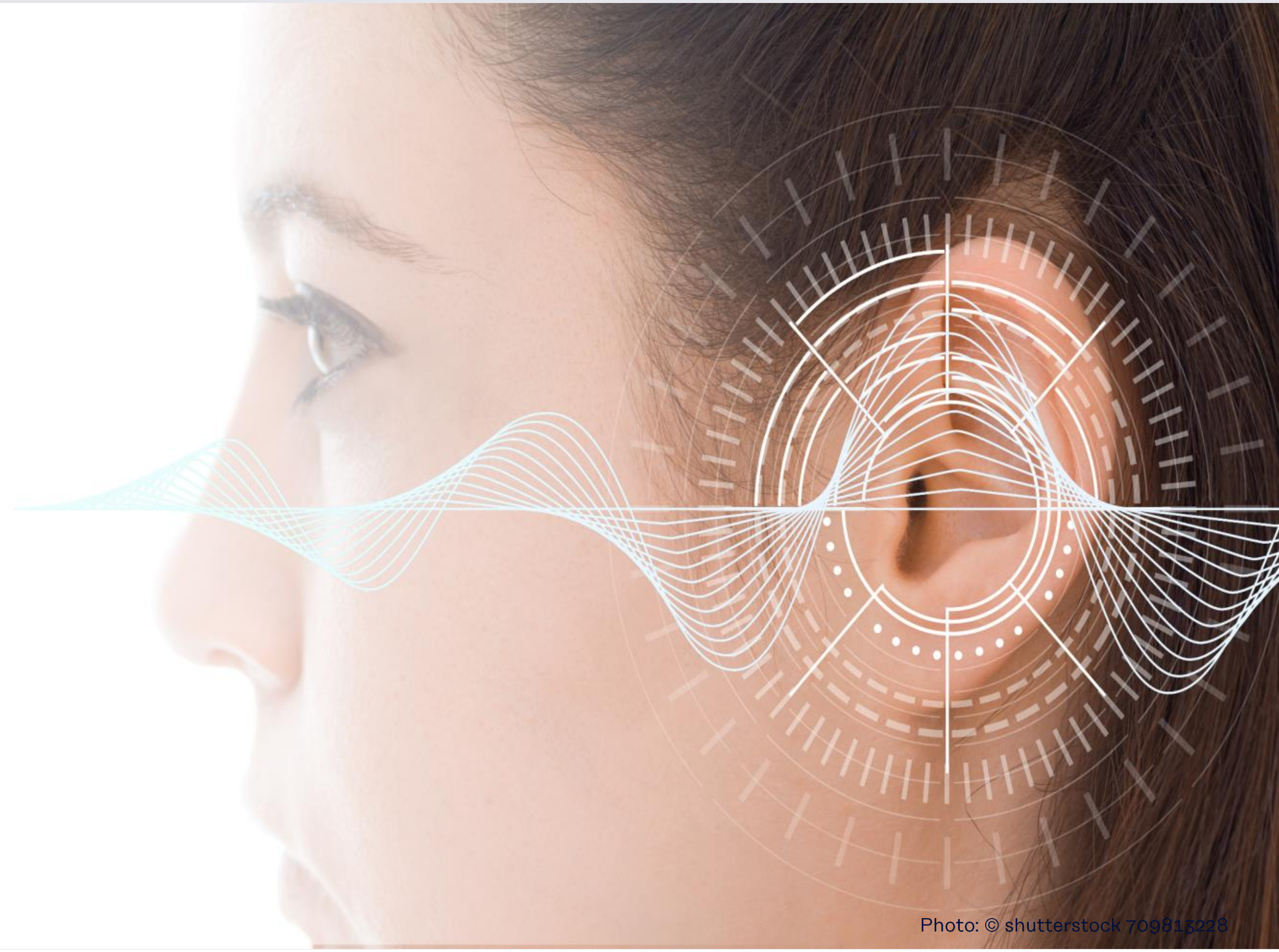


Photo: © shutterstock 709813228

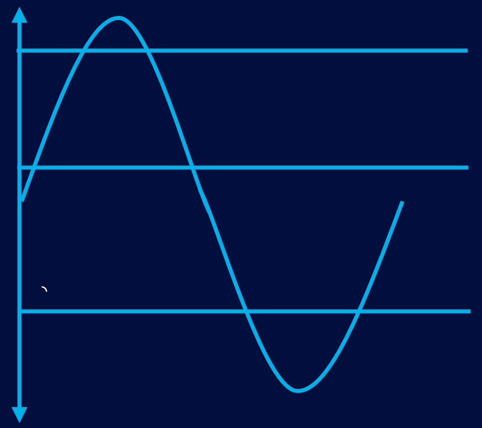
What is noise?

- Noise is unwanted sound
- The perception of ‘noise’ varies from person to person
- Sound may be acceptable in one circumstance but not the other.

*A music CD is ‘**sound**’ when played by the occupant of a house, but ‘**noise**’ when being played loudly by the neighbors at 2 am*

Photo: © shutterstock 614487812

Elements of sound

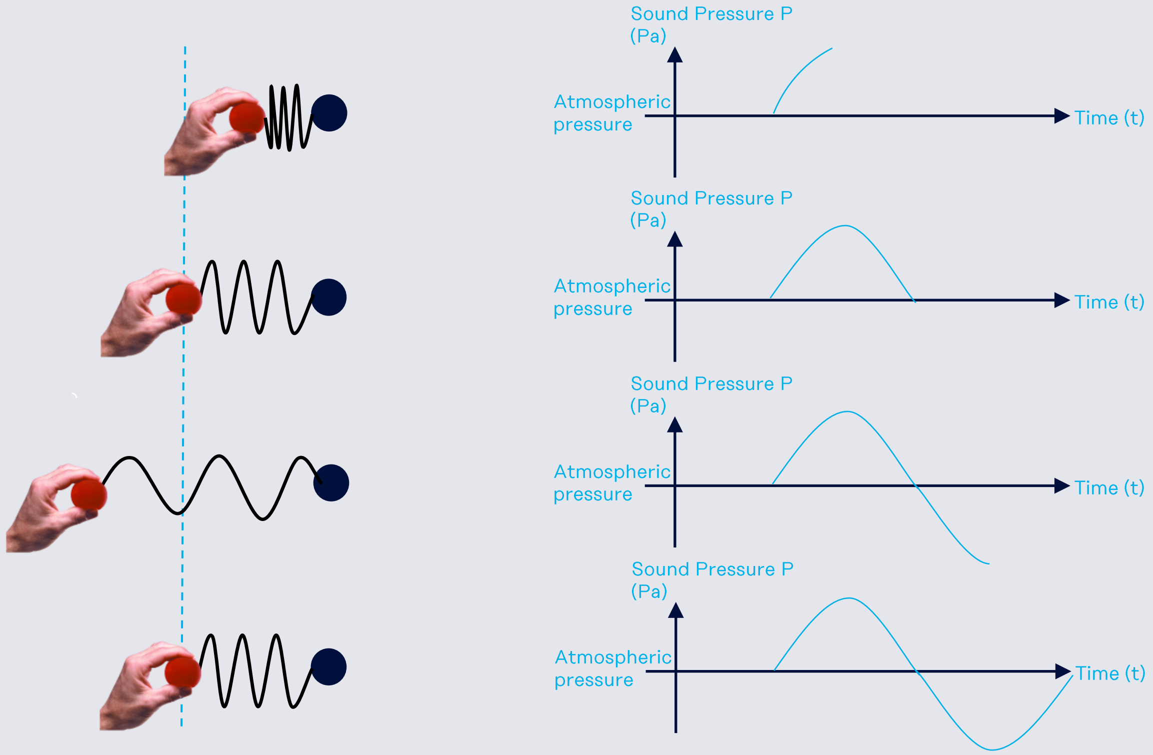


Since sound is a wave, we can relate the properties of sound to that of a wave. The basic properties of sound are:

Amplitude (PA) (The size of the wave)	"Loudness"
Frequency, F (Hz) (Number of cycles per second)	"Pitch"
Wavelength, λ (m) (Wavelength and frequency are inversely proportional; double the wavelength and the Frequency is halved)	"Regularity"

Wavelength (λ) = speed (s) / frequency (f).

Sound pressure



- Sound pressure is the local pressure deviation from the ambient atmospheric pressure, caused by a sound wave.
- Pressure is a force applied per unit area and is therefore given by the unit N/m2 (Pa).

Subjective Perception

SOUND / VOLUME DIFFERENCES: IS MEASURED IN A LOGARITHMIC SCALE

1 dB
is not practically noticeable

3 dB
is just perceptible

5 dB
represents a "clear difference"
(according to VDI 2719)

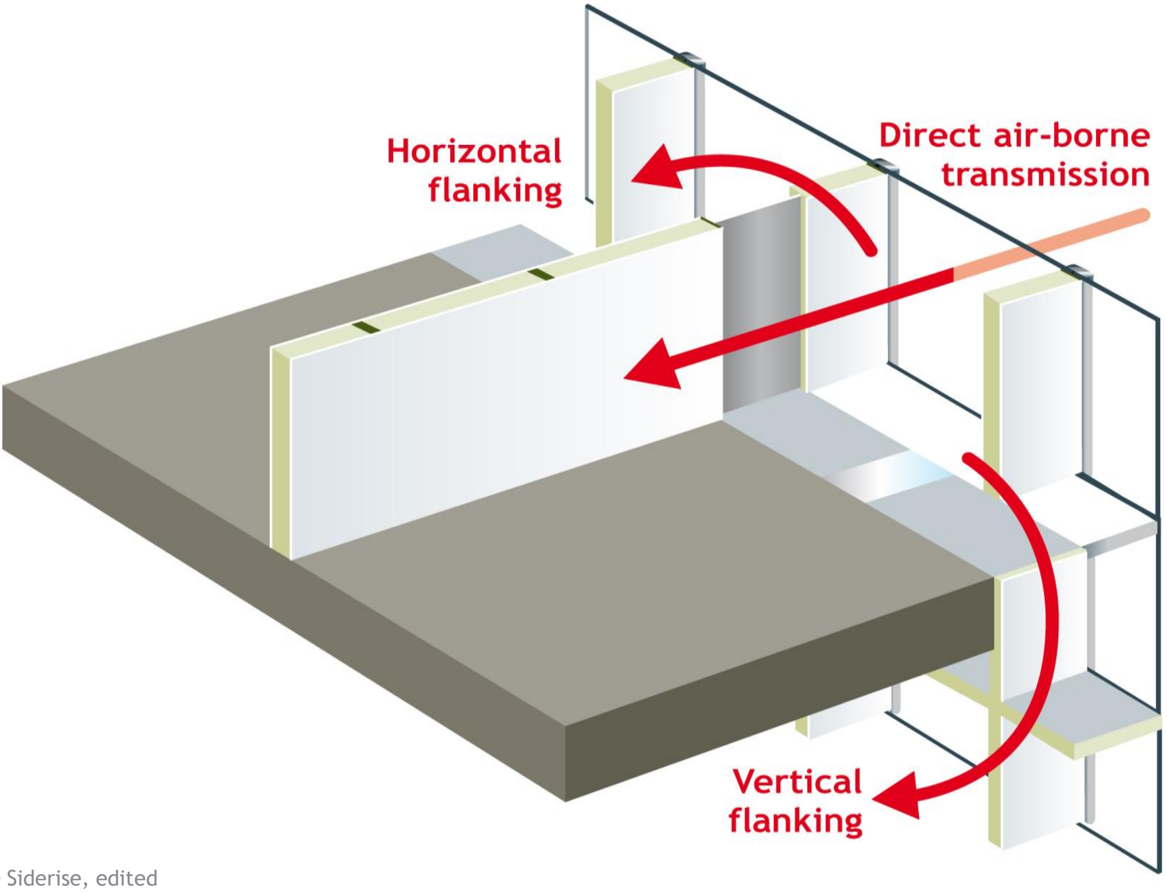
10 dB
are sensed as a doubling or halving

Photo: © One Works

Effect of sound on buildings

- We are mostly worried about the acoustic performance of facades.
  - Noise from the external environment (direct airborne transmission)
  - Noise transmission from adjacent rooms (vertical and horizontal flanking)
- In order to achieve acceptable internal noise levels, the façade will need to achieve a certain acoustic insulation performance.
- This performance is typically specified by acoustic engineers / consultants.

Noise transmission through a glazed facade



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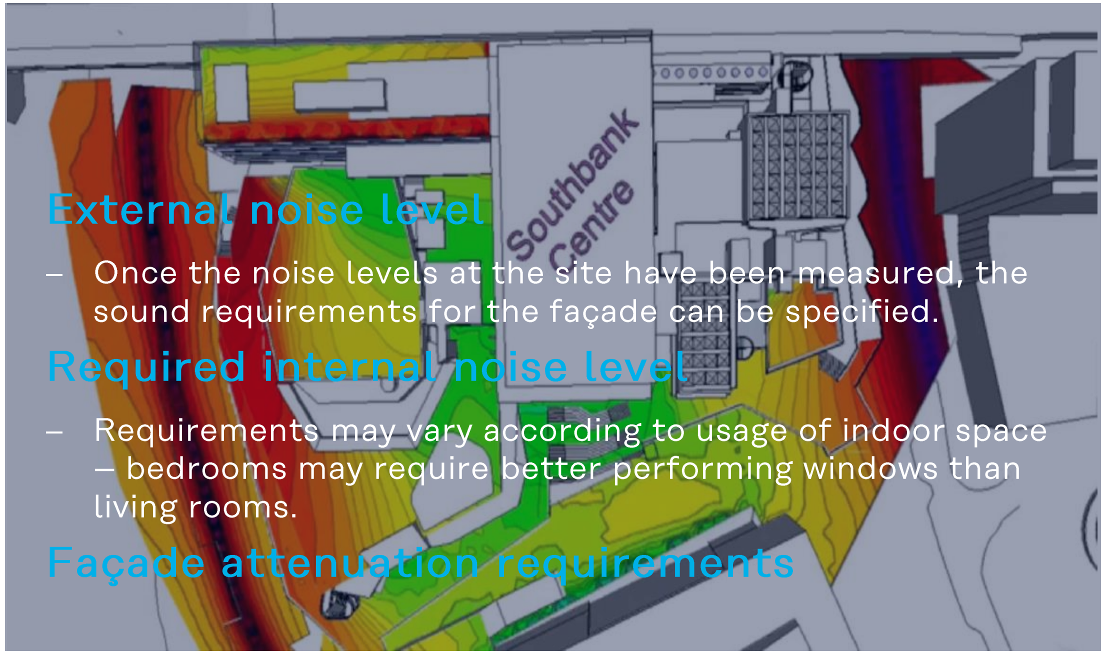
Insulation from the outside environment

SPECIFICATIONS OF REQUIREMENTS



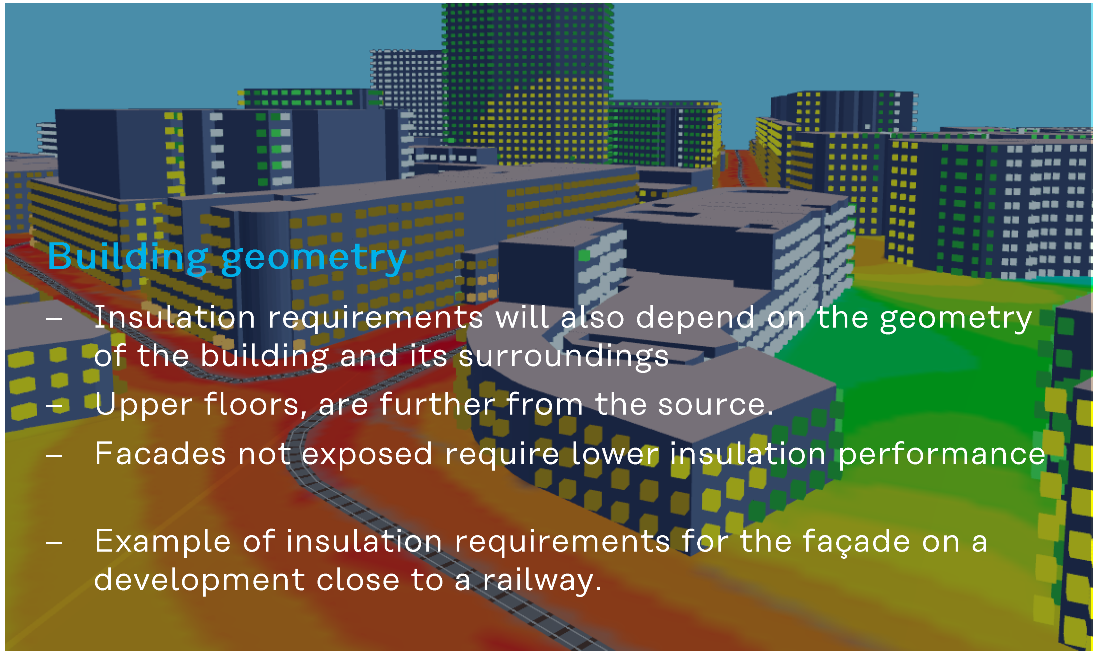
External noise level

- Once the noise levels at the site have been measured, the sound requirements for the façade can be specified.

Required internal noise level

- Requirements may vary according to usage of indoor space – bedrooms may require better performing windows than living rooms.

Façade attenuation requirements



Building geometry

- Insulation requirements will also depend on the geometry of the building and its surroundings
- Upper floors, are further from the source.
- Facades not exposed require lower insulation performance

- Example of insulation requirements for the façade on a development close to a railway.

Measuring sound

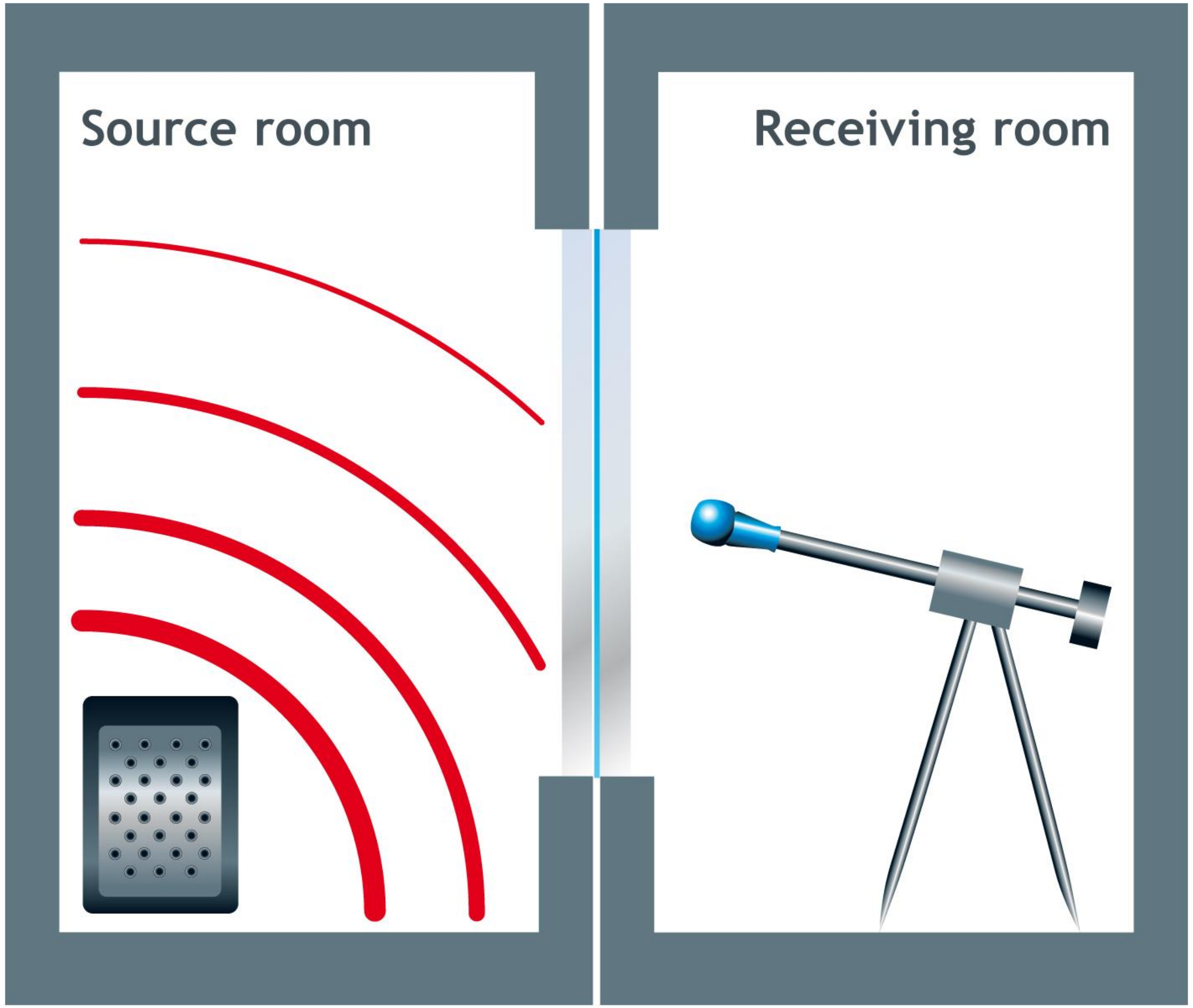
LABARATORY MEASUREMENTS

- The basic method is to create a uniform sound (equal energy at all frequencies is best) on one side of a specimen and measure the sound coming through on the other.

- Constructed carefully to minimize flanking transmission.

- Large scale testing - up to 4 x 3 m in the UK; story height specimens for bespoke facades.

- Standard tests - for component testing;
  - Window or glazing unit;
  - standard sample 'size' 1250mm x 1500mm



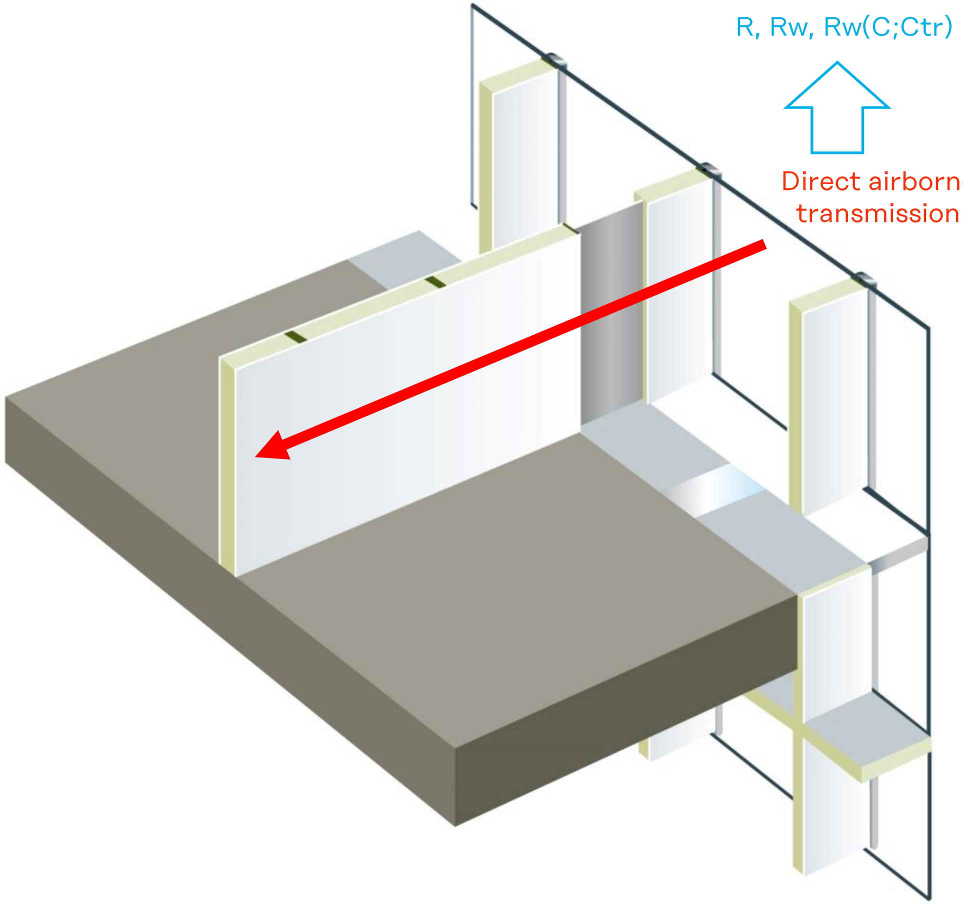
Understanding acoustic readings

Abbreviation	Description	Explanation
SRI (R)	is expressed as a spectrum of frequencies. However, for most practical purposes, it is better to use a single number rating.	Sound Reduction Index, For most practical purposes, it is better to use a single number rating.
Rw	Rw is derived from comparing the obtained sound insulation/frequency curve with a family of reference curves and selecting one to obtain the 'best fit'.	Weighted Sound Reduction Index Rw takes into account the response of the human ear.
C	Correction for sound from; • living activities railway traffic at medium and high speed; • road traffic >80 km/h; • jet aircraft, short distance; • Factories omitting medium/high frequency noise	Spectrum adaption term for weighted Pink Noise (medium and high frequency noise)
Ctr	Correction for sound from; • railway traffic at low speed • urban road traffic • aircraft, propeller driven, or jet aircraft, long distance • disco music; • factories emitting low/medium frequency noise.	Spectrum adaptation term for a weighted urban traffic noise (low medium frequency noise)

- The acoustic performance of glass can be improved in several ways:
  - Make the glass thicker (mass law).
  - Use two layers of glass with a gap between them (combination of more mass and decoupling).
  - Very large gaps are best; relative thickness of panes is a factor because of potential resonance issues.
  - Incorporate damping within the glass (laminated glass interlayers).

Acoustic properties of glass

CAN BE IMPROVED



So we can express The insulation of a Façade from external noise with:

- R Performance as spectrum at different frequencies.
- Rw Single number
- rating (weighted).
- Rw (C;Ctr) Compensated single number rating.

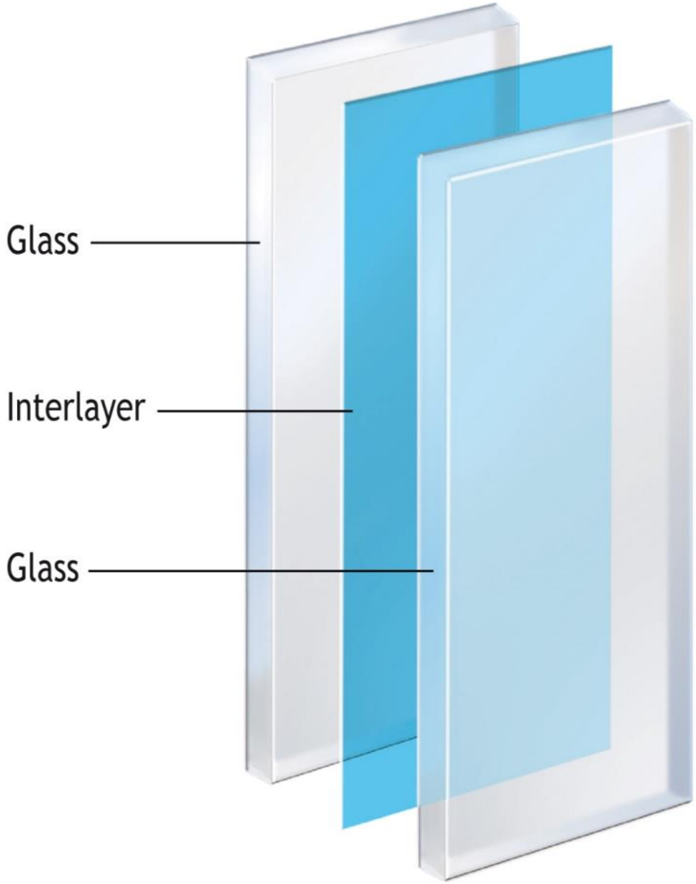

Photo: © Eckersley O'Callaghan

Sound control

What is laminated glass?

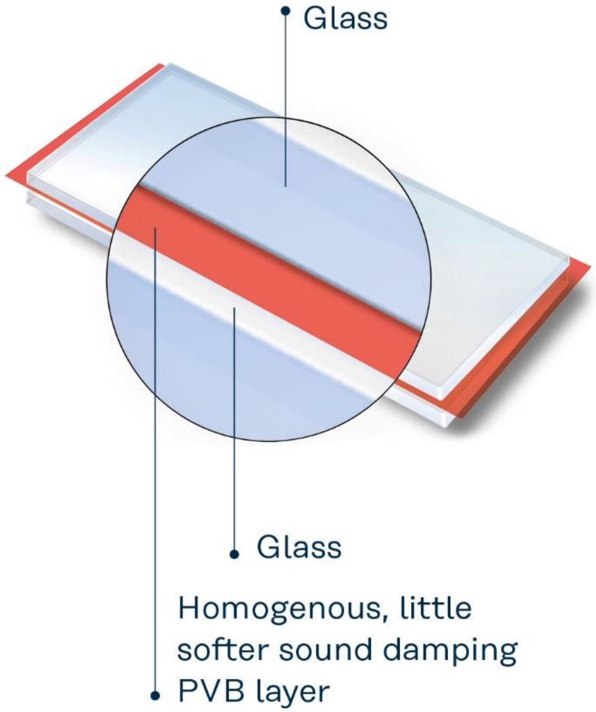
- A laminated safety glass is a sandwich of glass – PVB - glass

- Glass retention if breakage occurs
- Types of Interlayers:
  - Polyvinyl Butyral (PVB)
  - Ionoplast
  - Others:
    - EVA
    - PC + PU
    - PMMA(CIP)



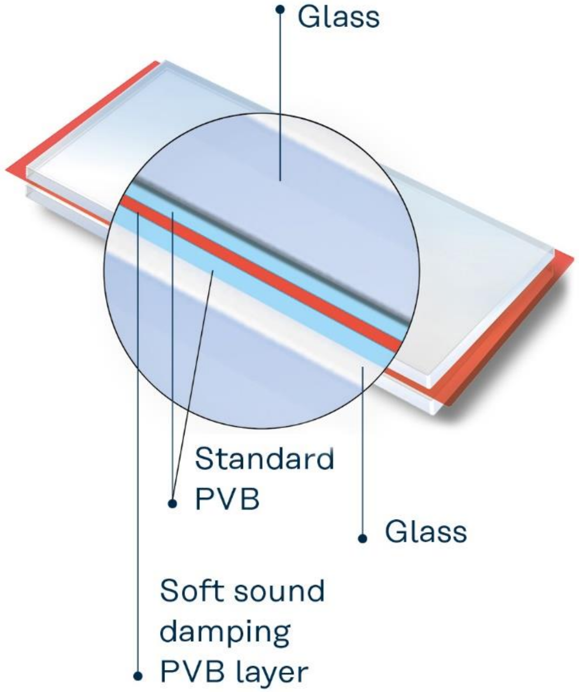
Sound Control Interlayers

SC Monolayer



- Outstanding sound protection properties
- Globally successful application since 2000

SC Multilayer



- Extremely high production efficiency, above all with jumbo sizes
- Processing identical to that of Trosifol® UltraClear standard products
- Security/safety classes conforming to EN 356 and EN 12600

Coincidence dip

What is it?

The frequency at which the glass panel vibrates in unison with the frequency of the incident sound pressure waves.

Why is it important?

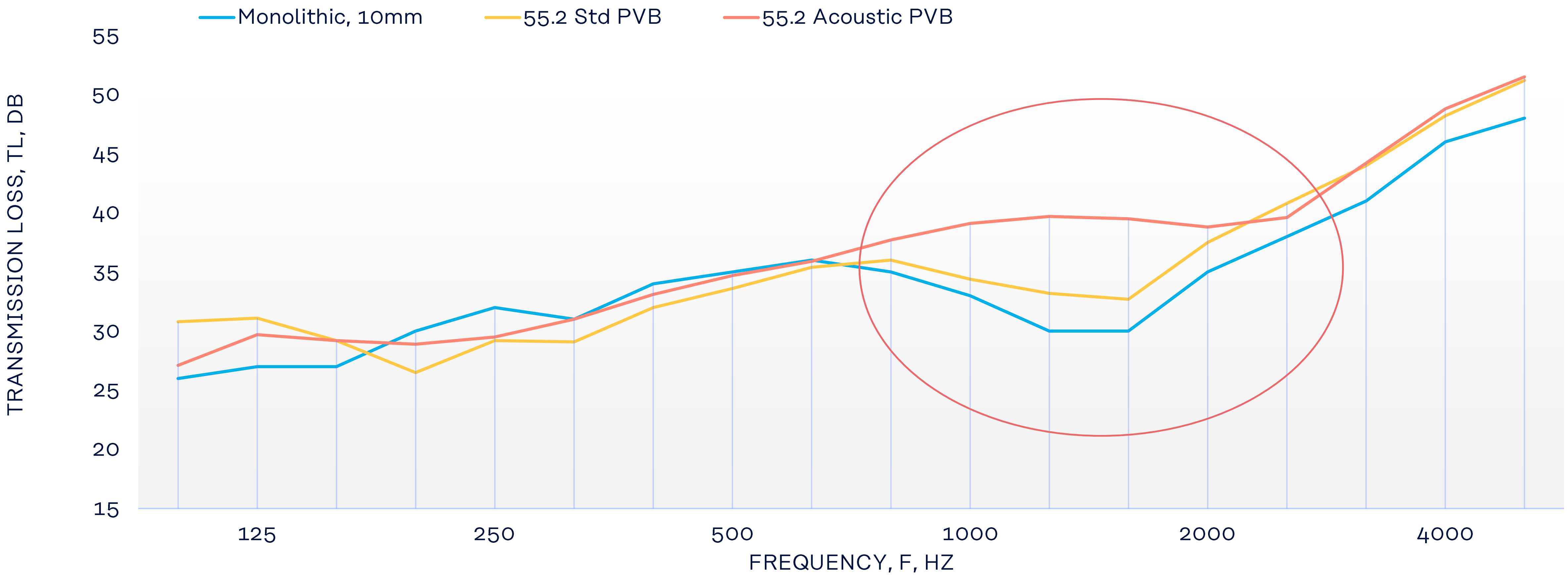
Sound insulation properties of glass are strongly reduced at this specific frequency.

How is the specific frequency determined

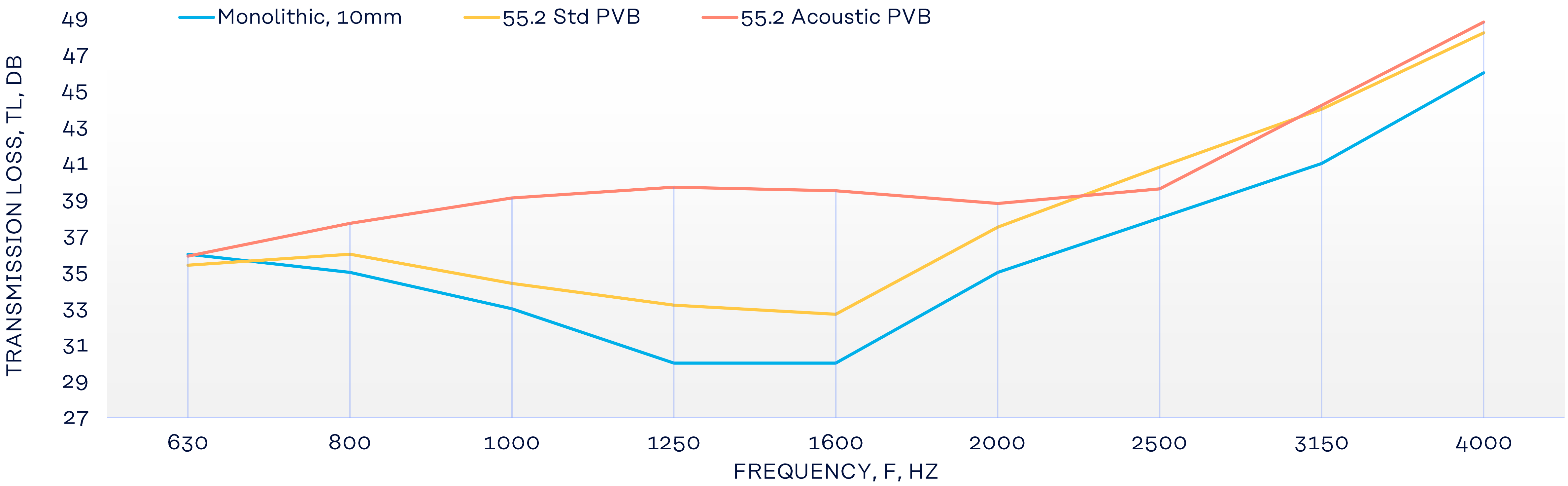
The frequency at which the glass panel vibrates in unison with the frequency of the incident sound pressure waves.

- $F = \frac{12500}{e}$
- where F = frequency and e = thickness of the glass
- So the frequency for 4mm glass is 3125 Hz and the frequency for
- 6mm glass is 2083 Hz

Coincidence dip for 10 mm glass



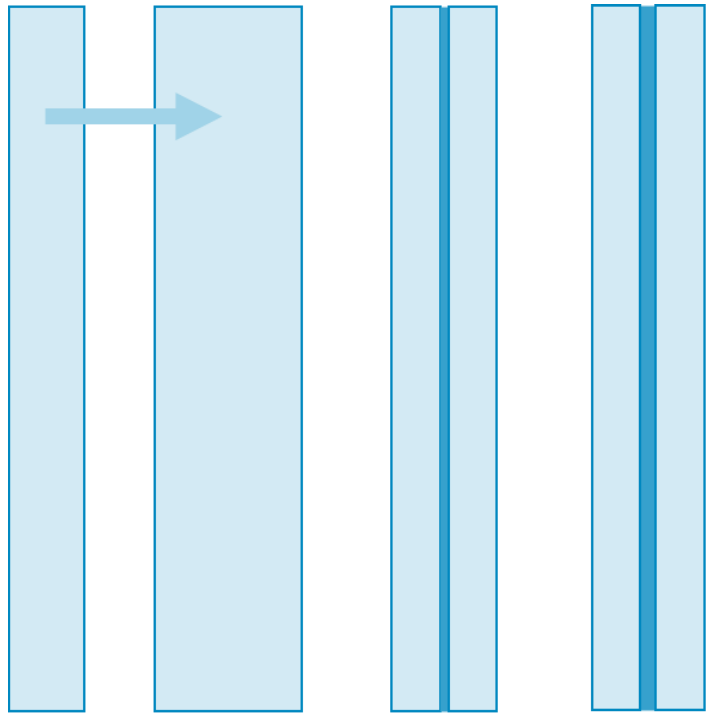
Coincidence dip comparison



Acoustic PVB delivers up to 10 dB improvement in sound reduction in this frequency range over monolithic glass.

How can I achieve noise insulation with monolithic glass?

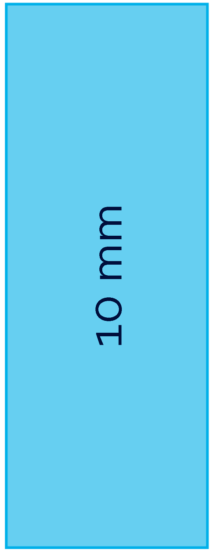
- Glass thickness (=mass)
- Laminated glass
- Acoustic laminated glass



How can I achieve noise insulation, reduce weight of the construction and save costs?

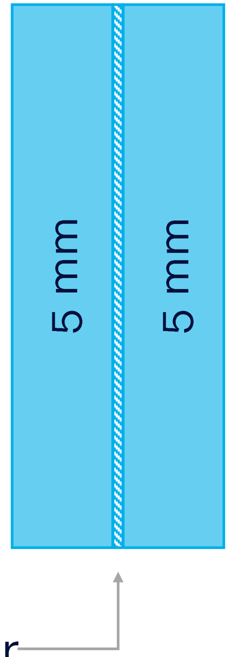
MONOLITHIC GLASS

R_w = 33 dB



LAMINATED GLASS 0.76 mm / 30 mil

R_w = 35 dB

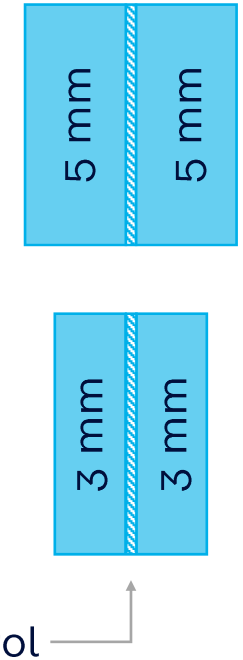


Trosifol® Clear

ACOUSTIC LAMINATED GLASS 0.76 mm / 30 mil

R_w = 38 dB

R_w = 36 dB



Trosifol®
Sound Control

Acoustic PVB test results

Glass [mm]	Cavity air or argon [mm]	Glass [mm]	Cavity [mm]	Glass [mm]	R_w [dB]	C, C_{tr} [dB]	STC	OITC
3 SC Mono* 0.76 3					35	(-1/-4)	35	30
4 SC Mono 0.76 4					37	(-1/-3)	37	32
5 SC Mono 0.76 5					38	(0/-2)	38	34
6 SC Mono 0.76 6					39	(0/-2)	39	35
8 SC Mono 0.76 8					41	(-1/-3)	41	37
10 SC Mono 0.76 10					42	(0/-3)	42	38
12 SC Mono 0.76 12					43	(0/-3)	43	39
4 SC Mono 0.76 4	16	4			39	(-1/-5)	39	31
4 SC Mono 0.76 4	16	6			41	(-2/-6)	41	33
4 SC Mono 0.76 4	16	8			42	(-3/-8)	42	31
6 SC Mono 0.76 6	16	8			43	(-2/-6)	43	34
4 SC Mono 0.76 4	16	10			44	(-2/-6)	44	35
4 SC Mono 0.76 4	16	6 SC Mono 0.76 6			47	(-2/-6)	48	37
4 SC Mono 0.76 4	20	6 SC Mono 0.76 6			49	(-2/-7)	49	38
4 SC Mono 0.76 4	12	4	12	6	41	(-2/-6)	41	32
4 SC Mono 0.76 4	12	4	12	8	42	(-2/-6)	42	33
4 SC Mono 0.76 4	12	6	12	4 SC Mono 0.76 6	47	(-2/-7)	47	38

Photo: © Eckersley O'Callaghan

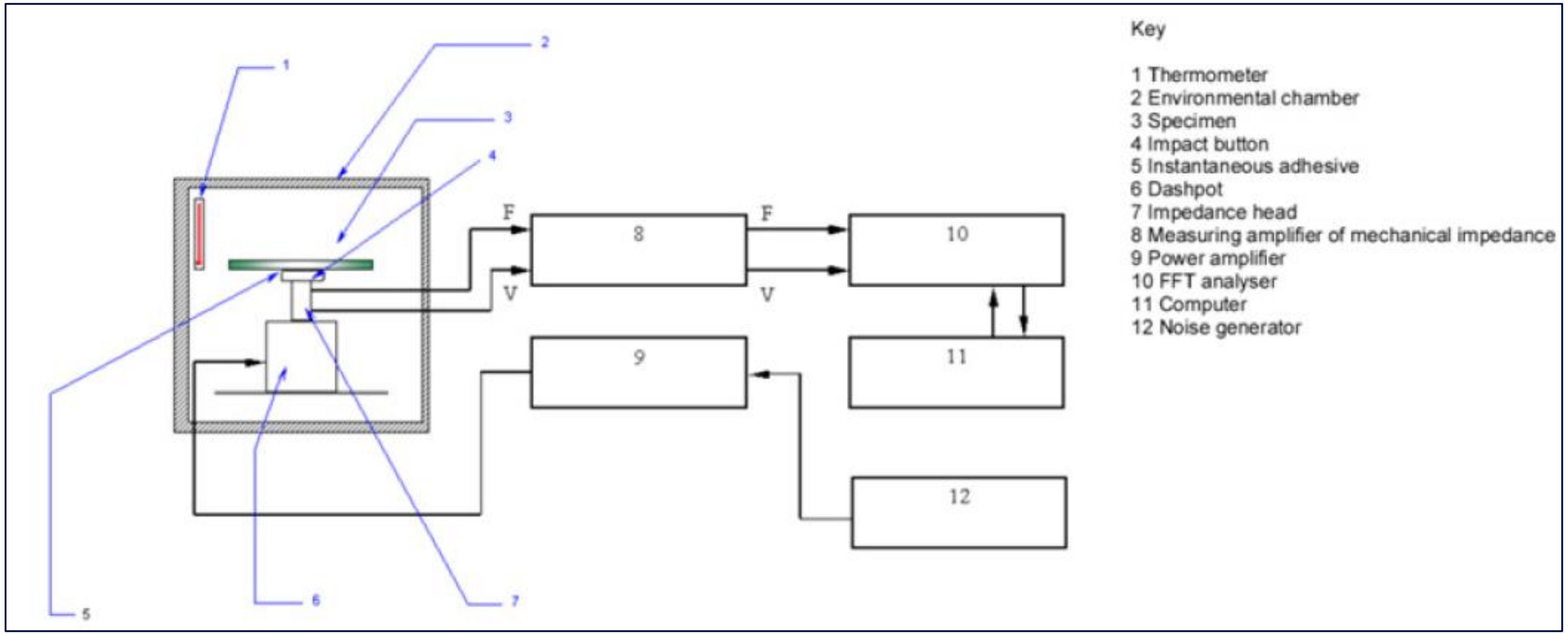
The effect of temperature.

MIM Apparatus

ISO 16940:2008(E)

For the pupose of study MIM was chosen for its;

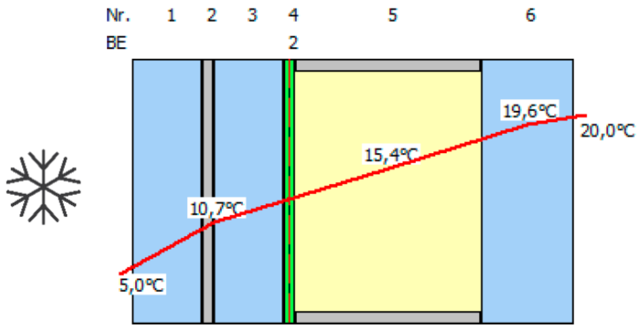
- Simplicity
- Availability
- Ease of temperature manipulation.



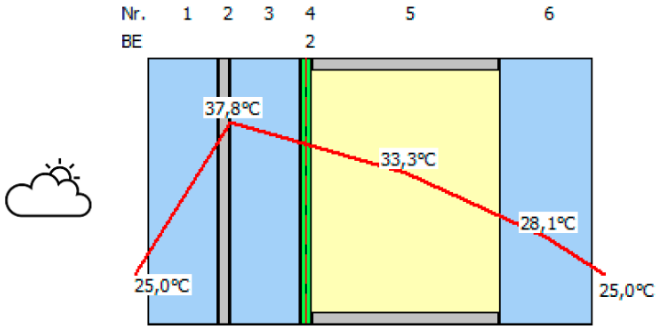
ISO 16940-2008

IGU Heat Transference

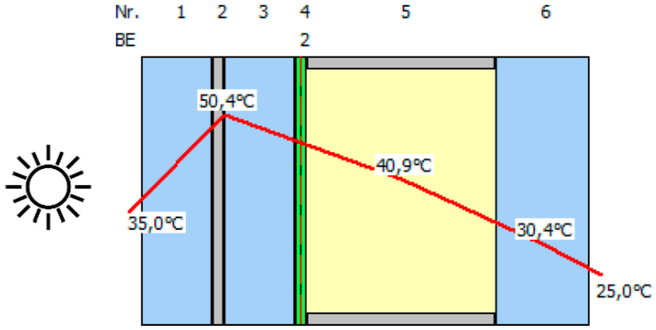
INFLUENCE OF TEMPERATURE



Winter with external T= 5 °C, internal T=20 °C, and radiation of 300W (the interlayer temperature at 10.7 °C)



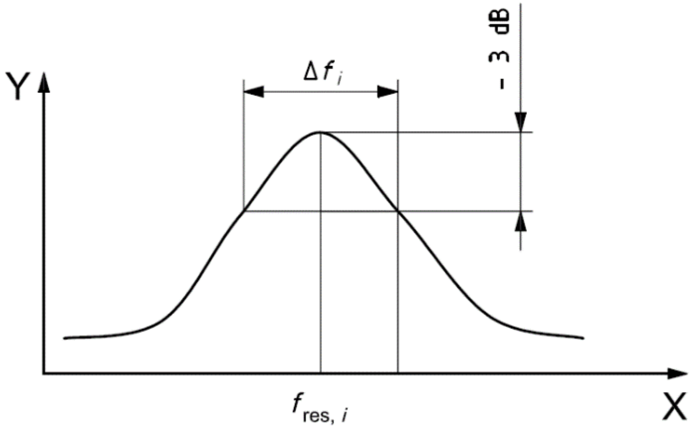
Summer with external T= 25 °C, internal T= 25 °C, and radiation of 500W (the interlayer temperature at 37.8 °C)



Customized hot summer with external T= 35 °C, internal T= 25 °C, and radiation of 750W/ reduced wind speed (the interlayer temperature at 50.4 °C)

Loss Factor

SOUND TRANSMISSION LOSS



Key

X - Frequency, f (Hz)

Y – impedance, f/v

The STL, R, shall be calculated using the following equations;

$$\tau(\theta)=\frac{I_{\text{trans}}}{I_{\text{inc}}}=\frac{|P_t^2|}{|P_i^2|}=\left\{\left[1+\eta\left(\frac{\omega\rho_s}{2\rho c}\cos\theta\right)\left(\frac{\omega^2 B}{c^4\rho_s}\sin^4\theta\right)\right]^2+\left[\left(\frac{\omega\rho_s}{2\rho c}\cos\theta\right)\left(1-\frac{\omega^2 B}{c^4\rho s}\sin^4\theta\right)\right]^2\right\}^{-1}$$

where

I	is the bound intensity, in W/m^2;
P	is the sound pressure, in N/m^2;
η	is the composite glass loss factor (dimensionless);
$\rho_s=\rho_m t$	is the plate surface density in kg/m^2;
τ	is the thickness of the plate in m;
ρ	is the density of the air, in m/s;
θ	is the angle of incidence;
B	is the plate bending rigidity per unit width, in N m;

$\omega=2\pi f$

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Loss Factor

SOUND TRANSMISSION LOSS FORMULA

Where

f is the frequency, in Hz

$$\overline{\tau} = \frac{\int_0^{\mathrm{lim}} \tau(\theta)\mathrm{cos}\theta\mathrm{sin}\theta\mathrm{d}\theta}{\int_0^{lim} cos\theta sin\theta d\theta} \text{ [dB]}$$

After determining the sound transmission loss coefficient, the sound transmission loss is calculated in dB as follows:

$$STL = 10lg\frac{1}{\tau}dB \left(with\ \theta_{lim} = 75^{o}\right.$$

Temperature effect

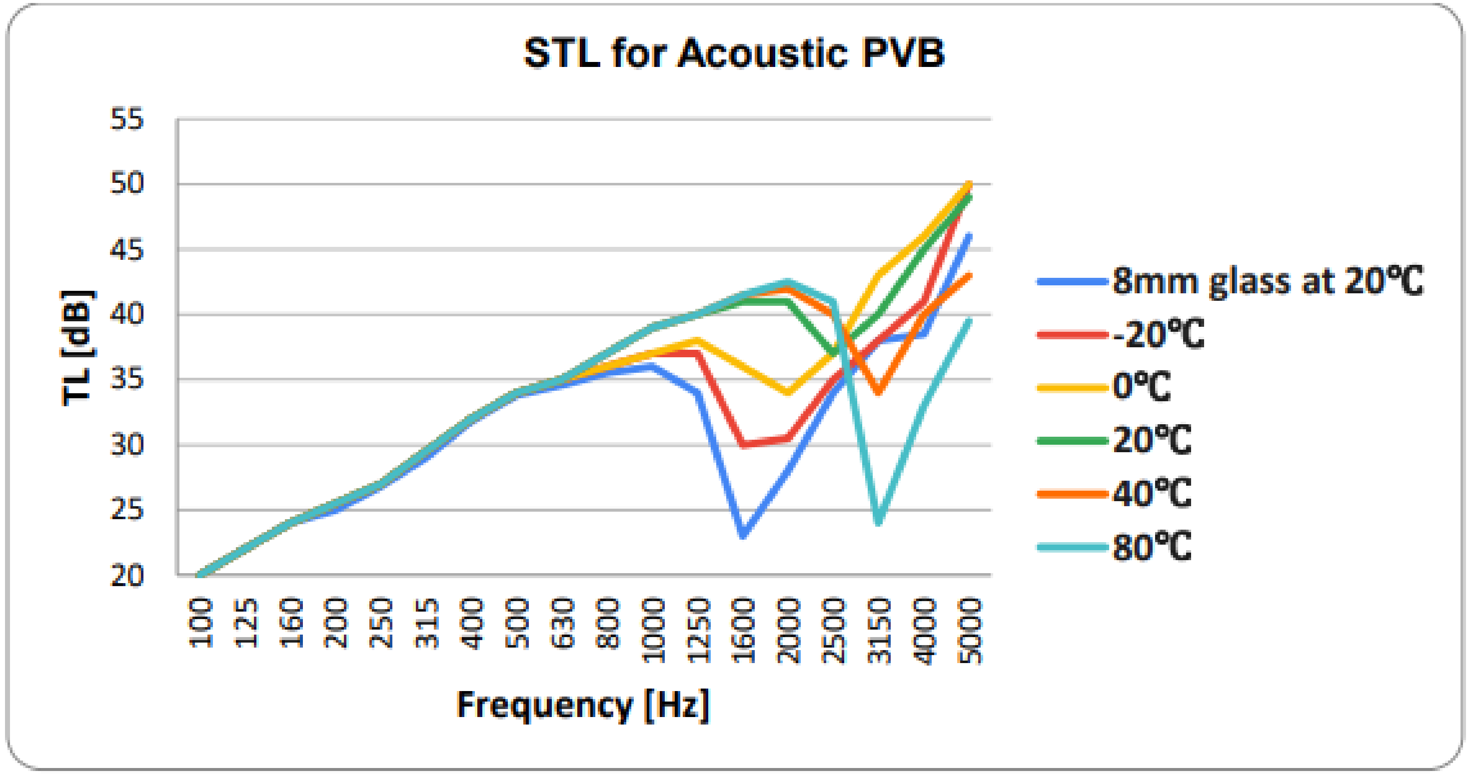
INTERLAYER

The effect of temperature on the acoustic performance of an acoustic interlayer.

Coincidence change
2500Hz – Room Temp
1600 – 2000Hz Lower °C
3150Hz Higher °C

Temperature alters the performance

MIM Results



Conclusion

INTERLAYER LOCATION

To maintain ambient temperatures.

Recommendation;

Install the acoustic Laminate on the internal panel, influences from heating or aircon will Influence the interlayer Temperature and optimal performance

LAMINATED GLASS 0.76 mm / 30 mil

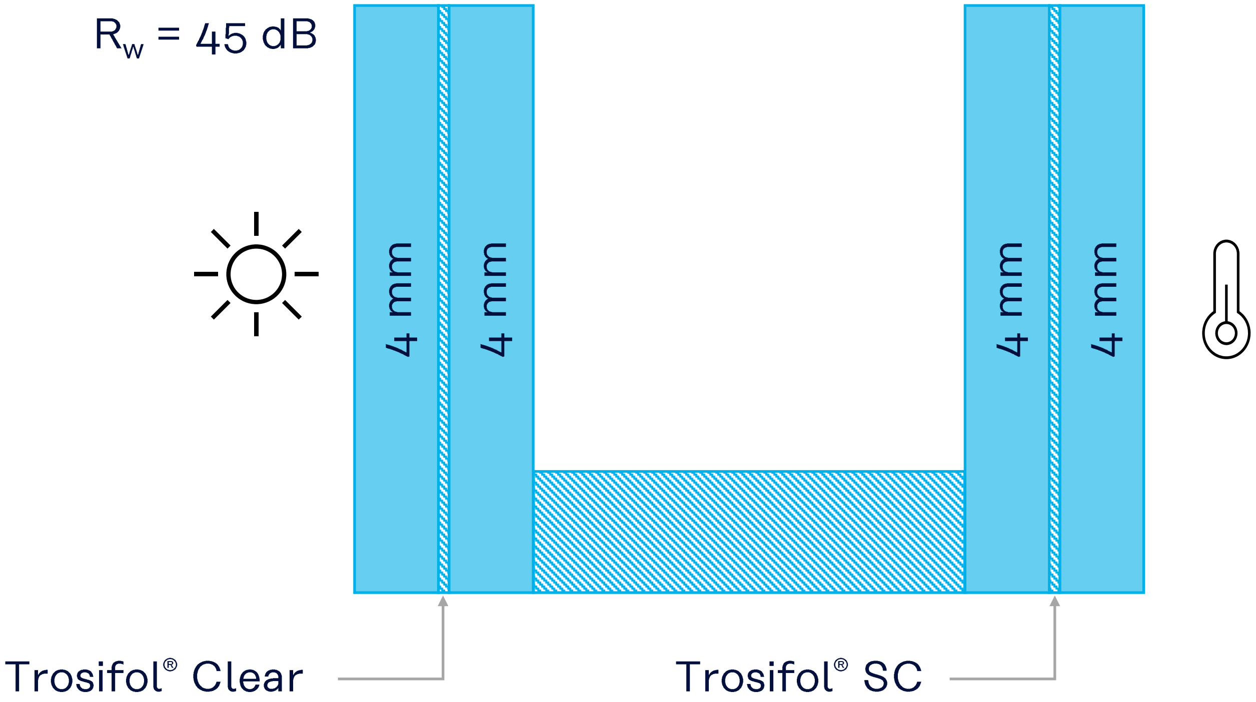



Photo: © Eckersley O'Callaghan

Further Research.

Further research

Here's an example of how temperature dependence can be incorporated into the Kelvin-Voigt model for viscoelastic behavior

$$\sigma(t) = E(T)\varepsilon(t) + \eta(T)(d\varepsilon(t)/dt)$$

If we assume that the temperature dependence of the elastic modulus (E) and viscosity coefficient (η) can be represented by simple linear relationships with temperature (T):

$$E(T) = E_0 + \alpha E(T - T_0)$$
$$\eta(T) = \eta_0 + \alpha\eta(T - T_0)$$

By incorporating these temperature-dependent relationships, the modified Kelvin-Voigt equation become this:

$$\sigma(t) = (E_0 + \alpha E(T - T_0))\varepsilon(t) + (\eta_0 + \alpha\eta(T - T_0))(d\varepsilon(t)/dt)$$

Further research

A modified version of the equation that incorporates the temperature-dependent acoustic absorption coefficient could be:

$$\sigma(t) = \alpha(T)E(T)\varepsilon(t) + \eta(T)(d\varepsilon(t)/dt)$$

In this equation, $\alpha(T)$ represents the temperature-dependent acoustic absorption coefficient.
It will need to be obtained from experimental data that identifies how the absorption coefficient changes with temperature.

Conclusion

Variations in the loading at different temperatures portray performance-related disparities attributable to the frequency. According to the research, increasing the frequency significantly affects the performance of laminated glass at different temperatures. Long-term loading at lower temperatures results in poor acoustic performance since the high viscosity limits sound dampening properties. Similarly, laminated glass materials can withstand higher frequencies or long-term loading at elevated temperatures. Thus, the acoustic performance of laminated glass materials has a direct relationship with temperature and an inverse relationship with the Elastic modulus.

Thank you!

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