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WHITEPAPER

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ACOUSTIC LUMINAIRES

About sound, noise and acoustically effective lighting

Much Noise About Nothing?

One might ask what are ‚acoustic luminaires', is it actually a word? Before long discussions are led and committees founded: probably not. What should it be, an acoustic luminaire? Is it emitting sound instead of light? Is the luminaire buzzing enervating when switched on? No. They are the result of the intention to combine light with sound absorption and forge it into a single word. As a luminaire producer we focus on the final product, the luminaire, which has an additional acoustic feature. Experts for room acoustics might view it from a different angle and would rather talk about acoustic ceiling sail with integrated lighting.

Architectural trends regarding design or construction physics and hip catchwords like modern workspace, flexible work place or co-working (the urge to use a hashtag is almost unbearable) are often opposing the wish for a quieter work place. So, does the tendency to work in teams instead of as a lone warrior. When people are coming together and communicate more with each other, the noise level increases. This affects concentration, performance and possibly also health in a negative way. Even it we do not talk about a damage to the hearing capacity, it is about the disruptive influences on body and mind, probably also by non-audible effects, like the so-called extra-aural noise effect. Psychoacoustics as a branch of acoustics deals with these topics, on which we are not going into detail.

In this Whitepaper we would like to provide you with a little insight into the world of acoustics, in particular, room acoustics for office work places. We try to implement a holistic approach towards Human Centric Lighting (HCL) and therefore, not only does the quality of light matter to us, but the entire quality of life and work surrounding is in our focus. PLANLICHT acoustic luminaires combine the dynamic-white lighting solutions which can be regulated according to the natural course of daylight with the requirements of room acoustics for an ideal surrounding - a combination of high melanopic and acoustic efficiency levels.
A proper planning, is it for the lighting as well as for the acoustic solution, is the key to success. Not only the single luminaires, the single products, but the entire solution approach provides us with the desired results. Simply HCL.

Sound and Noise

Before we will have a closer look at the vocabulary of acoustics, we should be aware that disturbing sound, the noise, is perceived subjectively. A worker at the airport might define disturbing noises differently that a yoga teacher. The subjective room acoustics is a try to deduce subjective disturbing noise from objective figures. The parameters used for this are a combination of sound pressure level in dB(A), frequency composition, the time period and the duration of the noise. It is generally believed that sounds louder than 30 dB(A) are considered disturbing.
Workplace regulations demand the sound pressure level to be kept as low as possible. The normative definition is about the usual threshold levels, which are just artificial threshold levels - if it is about maximum levels like in our example or about the minimum levels for the illumination intensity.
For office workplaces for tasks of high complexity (creative thinking, decision making, finding solutions for problems, impeccable comprehensibility of speech) an assessment level of maximum 55 dB(A) was established. For tasks of medium complexity (similar repeating tasks, time limits, average comprehensibility of speech) a threshold of 70 dB(A) was defined. Both levels consider noise from outside. However, if the line between the different tasks in the office work routine can always be drawn so clearly remains an unanswered question.

Sound Sources

CONVERSATIONS OF COLLEAGUES
The sound pressure level of an individual speaking is at approximately 63 dB(A). In offices in which people are talking all the time, the normative level of 55 dB(A) can barely be met. Further, we tend to speak louder in loud surroundings and this effect adds up to the sound level. Subjective disturbances depend on the fact, if the content of the conversation is relevant for the listener or if the phone call of the colleague next to them affects the concentration required for their own task. Not only phone calls of the colleagues are distracting, but also ringtones.

COMPUTERS, PRINTERS, COPIERS
Operating noises as well as the permanent frequentation of printers and copy machines might cause noise disturbance.

AIR CONDITIONING
Consistent sound of machines can lead to the so-called sound masking, which means they overlap i.e. conversations acoustically.

Room acoustics **Architectural** acoustics

The discipline of room acoustics is relevant for the approach on the acoustic effect of spaces - if it is a workplace or a private home. This must be differentiated from architectural acoustics.

The **architectural acoustics** addresses the **sound absorption** of construction parts and engages in the question which percentage of the sound reaches the other side of the construction part.

Room acoustics deals further with the **noise reduction** in the room to improve the audibility within the room. And this is also the topic we are approaching in this paper...

Sound and Sound Propagation

Sound is defined in generally by the mechanical vibration within and elastic medium (gas, liquids, solid bodies).
This vibration expands in the form of sound waves. Depending on the medium we differentiate between airborne sound, waterborne sound and structure-borne sound. Within a room the airborne sound, which can be perceived with hearing, is relevant. Sound waves are changes of pressure and density in the air. Sounds expands in general in every direction within the room, although some sound sources show a higher sound emission in one direction depending which way they are pointing. In the planning process an approximately spherical sound emission is taken into consideration. The sound pressure level of sound sources reduces by 6 dB each time the distance doubling.

Influencing the Room Acoustics

CEILING

In most cases the ceiling is the biggest free space in a room. With an acoustic ceiling or also - and here we come in - an acoustic luminaire can produce significant results.

WALL

Walls are tendentially non-absorbent, which means they reflect the sound and it might build up the sound level depending on the layout of the room. Sound-absorbing wall elements like pictures or picture-absorber reduce the problem.

FLOOR

Other than parquet floor, carpets absorb the impact sound (structure-borne sound) and therefore reduce to pass on disturbing sounds. Carpets take in the sound in higher frequencies and lead in this way to a subjectively more pleasant room acoustics.

FURNITURE

The surfaces of cupboards or other furniture without acoustic tuning reflect sound. Acoustically effective furniture surfaces like cupboard doors have a positive effect on the room acoustics.

WINDOWS

Window surfaces reflect the sound very strongly. Sound absorbing vertical blinds or curtains provide a good sound absorption.

PEOPLE

The human body acts like an absorber and takes in as much sound as 0,5 m^2 of highly absorbing material.

PLANTS

Against common believe plants do not improve the room acoustics. They do look pretty, though.

Frequency and wavelength

The frequency range perceptible by human beings lies between 16 and 20.000 hertz (Hz). Sensibility of hearing depends strongly on the frequency - the one we are most sensitive to is the frequency range of the human speech between 250 and 2.000 Hz. It helps us to listen to each other, but it is exactly this range which is most vulnerable to disturbances.
With the so-called isophones, waves of the same acoustic perception are displayed. A sound with 100 Hz must have 25 dB to be heard, 5 dB are already enough at 1.000 Hz.

RELEVANT FREQUENCE RANGES FOR ROOM PLANNING

In the planning of room acoustics, the internationally normed test procedure for sound absorption of materials (DIN EN ISO 11654) is referring to the frequency range between 100 and 5.000 Hz.

WAVELENGTH λ

For each frequency, there is an accordingly matching wavelength λ. Within the frequency range we are talking about, the wavelength is between 7 centimetres at 5,000 Hz and 3,4 metres at 100 Hz.

FOR MATHS GEEKS

The expansion of sound waves in the air follows the rule: The product of the wave length λ and the frequency f equals the speed of sound.

$\lambda \cdot f = c$

The wave length λ is stated in metres (m), the frequency f (the number of oscillations per second) are given in hertz (Hz).

The speed of sound depends on temperature and air pressure.

THIRDS AND OCTAVES

It is all about the frequency. So far, so good. Since many values which play an important role in room acoustics (reverberation time, sound absorption, sound pressure level, etc.) depend on the frequency, they differ naturally if the frequency changes. According to DIN 18041 the planning of bandwidths should be carried out within a single octave. Additionally, there are third and octave centre frequencies. The step from one octave to the next derives from the doubling of the frequency. One octave has three thirds. Within the relevant frequency range of room acoustics this results in six octave steps and eighteen third steps.

FREQUENCY RANGES

Hearing range	16 Hz	20.000 Hz
Music	16 Hz	16.000 Hz
Speech	63 Hz	8.000 Hz
Communication	200 Hz	2.000 Hz
Infra ound	< 16 Hz	
Ultrasound		> 20.000 Hz

Third steps

Third steps	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Octave steps		125			250			500			1000			2000			4000	

Octave steps

Sound Pressure, Sound Pressure Level and Assessment Level

The **sound pressure p** describes the sound impact on individuals. We have already learnt that oscillations in the air form the airborne sound and they are caused by a chance in the air pressure. The louder a sound event is, the stronger are the pressure changes. The sound pressure is indicated in pascal (Pa) or micropascal (µPa).

The **sound pressure level L_p** describes the logarithmic ratio of the efficiency value of the sound pressure of a sound event to the reference value p_0 (hearing threshold). The result is indicated in the measuring unit decibels (dB).

Hearing threshold
(sound pressure p_0)
$p_0 = 2 \cdot 10^{-5}$ Pa
(= 20 µPa)

Pain threshold
(sound pressure p_s)
$p_s = 20$ Pa
(= 20.000.000 µPa)

For the visualisation of this big range (from hearing threshold to pain threshold is multiplied by the factor 10 million) a logarithmically defined value is used - the decibel (dB).

FOR MATHS GEEKS

The **sound pressure level L_p** is calculated and indicate in decibel (dB) as follows:

$$L_p = 10 \log_{10} \left(\frac{p^2}{p_0^2}\right) \text{ dB}$$

Sound pressure level **L_p**
p = measured sound pressure (Pa)

p_0 = Reference sound level (hearing threshold)

According to this the sound pressure level at the hearing threshold is 0 dB, at the pain threshold it is 120 dB.

FREQUENCY WEIGHTING

Since the human hearing experiences the same sound pressure as differently loud depending on the tone pitch, so-called frequency valuation curves are used to display this. For this purpose, filters with empirically adapted transfer functions are used (this is now for hard-core maths geeks only).
The for us relevant **A-weighting dB(A)** corresponds to the curve of same volume levels of approximately 20-40 phon.

SOUND PRESSURE LEVEL OF SPEECH

In rooms inhabited by people, the prediction of the sound level is relevant, but non the matter quite difficult. The volume of speech is different and adapts to the sound level of the surrounding. The sound pressure level is an A-weighted sound pressure level of speech which is measured at a distance of 1 metre from the mouth.

SPEECH PRESSURE LEVEL

WAY OF SPEAKING	LEVEL
relaxed	54 dB(A)
normal	60 dB(A)
slightly raised	66 dB(A)
loud	72 dB(A)
very loud	78 dB(A)

FOR MATHS GEEKS

The **weighting level** L_r according to DIN 45645-2 is calculated as follows:

$L_r = L_{pAeq} + K_I + K_T$

Weighting level $\mathbf{L_r}$
$\mathbf{L_{pAeq}}$ = A-weighted equivalent constand sound level
$\mathbf{K_I}$ = addition for impulses
$\mathbf{K_T}$ = addition for sound- & content amount

The addition for impulses K_I can be deduced with measuring equipment, but not the addition K_T, which is established on the base of experience values. Sounds with informative content are those which attract attention in a very particular way or which encourage eavesdropping. The addition K_I can be 0 or 3-6 dB , the addition K_T 0, 3 or 6 dB.

WEIGHTING LEVEL

The weighting level L_r is used to measure the sound pollution in a room. It is an average accumulated over a specific time (i.e. a work day) of the A-weighted sound pressure level of a task including possible additions from returning, short, loud sounds.
The maximum levels are:
$L_r \leq 55$ dB(A) for creative tasks
$L_r \leq 70$ dB(A) for simple or mainly mechanical tasks

BACKGROUND SOUND LEVEL

The acoustic equipment of rooms, architectural structures of the building and sounds from outside like traffic noise define the background sound level which - if it is too high - affects the performance capacity of office rooms negatively.

BACKGROUND SOUND LEVEL

TYPE OF ROOM	max. LEVEL
Conference rooms	30-35 dB(A)
Single offices	30-40 dB(A)
Open-plan offices	35-45 dB(A)
Industrial work places	65-70 dB(A)

Recommended maximum level for background sound level according to DIN EN ISO 11690-1.

Reverberation Time

Jubilate deo! When the well-trained organ player strikes the keys and the praising opus rings out in the gothic arches, the impressive sound gives the curious audience goose bumps. However, the tingling sensation of the reverberation in a church is not something we want in an open-plan office.

For the acoustic quality of a room the reverberation time is the measuring criteria per se. Further, the reverberation time influences the sound of speech significantly.

Like so many other values, also the reverberation time depends on the frequency, why it is often displayed in a table or as a function curve. Therefore, the indication of the reverberation time is usually only for a frequency range between 500 - 1,000 Hz.

The reverberation time is mainly influenced by:
- the volume of the room
- the surface of the room
- the furnishing objects

As a thumb-rule we could summarize it as follows:
- The bigger the room, the longer the reverberation time. With growing room height increases the reverberation.
- The more absorbing surface, like carpets, curtains, people, other absorbing materials, there is in a room, the shorter is the reverberation time.

The **reverberation time** T is the time in seconds until the sound pressure level drops by 60 dB after a sound event.

This means: If there is a loud bang of 110 dB in a room, the reverberation time is the duration until the sound pressure level drops to 50 dB.

REVERBERATION TIMES

TYPE OF ROOM	REVERBERATION TIME (s)
Office room	0,5 - 0,8 s
Conference room	0,8 - 1,2 s
Class room	0,6 s
Concert hall	1,5 s
Swimming pool	≤ 1,7 s
Church	4 - 8 s

ROOM GROUP according to DIN 18041

To distinguish the audibility on various distances, the DIN 18041 groups the different types of rooms. Rooms of group A should provide a good audibility on medium and long distances, rooms of group B on short distances. Fundamental is the inclusion of people with hearing impairment.

In details this means the office rooms are to be categorized in group B4, conference rooms in A3, break rooms and cantinas in B3.

Recommendations for offices and call centres are additionally described in detail in the VDI Guideline 2569

regarding„sound protection and acoustic design of offices".

TYPES OF USAGE GROUP A - DIN 18041

A1	Music
A2	Speech/Presentations
A3	Classes/Communication, Speech/Presentation inclusive
A4	Classes/Communication inclusive
A5	Sports

TYPES OF USAGE GROUP B - DIN 18041

B1	Rooms without quality of staying
B2	Rooms to remain for a short time
B3	Rooms to remain longer
B4	Rooms with the requirement to reduce noise & increase comfort
B5	Rooms with special requirement to reduce noise & increase comfort

Understanding Speech

To understand speech or audibility is influenced by different parameters. A main factor is reverberation time. In general, the understanding of speech is better if the reverberation time is lower.
Furthermore, the volume of the room, the basic sound level and the position of sound absorbing materials define the audibility.
The requirements may differ - during a presentation or in class rooms as well as conference rooms a high level of understanding of speech on long distances is required, while in a office audibility should be good over a short distance, since hearing everything in an open-plan office might be distracting. A sound screen might be a solution for this problem.

The OPEN-PLAN OFFICE and DIN EN ISO 3382-3

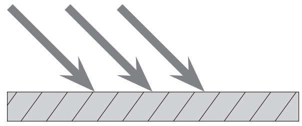
The regulation DIN EN ISO 3382-3 defines the main values for an objective weighting of acoustic circumstances in an open-plan office. A high acoustic decay rate can be reduced with this to minimize the expansion of sound.
The sound pressure level is measured at a distance of 4 m as well as distances of the diversion and the discretion zone.
These values combined provide us a standardised speech spectrum as an average of male and female voices of an accumulated level of 57,4 dB(A) at a normal speaking effort.

Sound Absorption

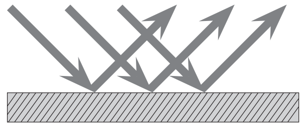
Sound absorption is the removal of sound energy. In this process, the sound energy is either converted into other energy forms (heat or kinetic energy) as it hits a surface, or it can escape out of the room through sound-permeable design components.

The **sound absorption coefficient α** is used to evaluate the sound absorption efficiency of materials. It is defined as the proportion of the total sound energy hitting a material that is "swallowed up" (i.e. absorbed) by the material. The α-value lies between 0 (no absorption) and 1 (complete absorption). For example, a sound absorption coefficient of α = 0,85 means 85% of the total sound energy is absorbed.
In practice, sound absorption coefficients are determined using a standardised measurement procedure. Although mathematically nonsensical, this can give sound absorption coefficient values of greater than 1. The maximum is approximately 1.2.

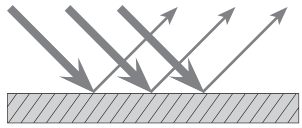
And here we are once again: it comes as no surprise that the sound absorption coefficient also depends on frequency



Sound absorption coefficient α = 1
Complete sound absorption
100%



Sound absorption coefficient α = 0
No sound absorption
0%



Sound absorption coefficient
0 < α < 1
Partial sound absorption

SOUND ABSORPTION CLASSES

Class	α_w-value
A	0,90 - 1,00
B	0,80 - 0,85
C	0,60 - 0,75
D	0,30 - 0,55
E	0,15 - 0,25
not classified	0,00 - 0,10

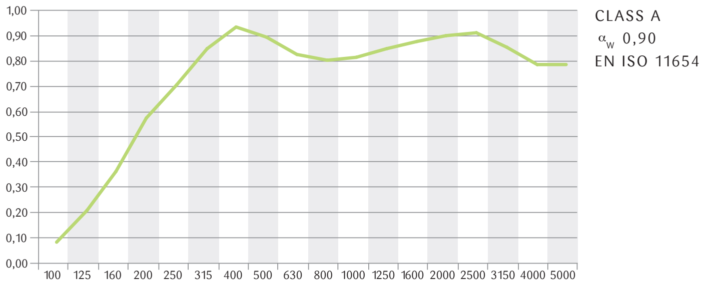
EUROPÄISCHE EINZAHLANGABE DIN ESN ISO 11654

Für die Ermittlung des **bewerteten Schallabsorptionsgrades α_w** wird zuerst ein Mittelwert aus drei Terzwerten (α_s) für die Oktavmittlenfrequenzen (100 - 4.000 Hz) ermittelt. Die Mittelwerte der Oktaven (α_p) werden mit der Bezugskurve aus der DIN EN ISO 11654 verglichen und somit der bewertete Schallabsorptionsgrad α_w als Einzahlwert abgelesen.
Mit diesem Einzahlwert lassen sich Schallabsorber grob klassifizieren und vergleichen. Nachteil dabei ist, dass mit der starken Vereinfachung das Absorptionsspektrum nicht abgelesen werden kann.

EQUIVALENT SOUND ABSORPTION AREA

After all, size matters. The surface area of the absorbing material is key, and its equivalent sound absorption area A_{eq} (in m²) is defined as the product of the surface area S of an absorber and its sound absorption coefficient α, so $A_{eq} = S \cdot \alpha$. This means that, for instance, 10 m² of a sound absorber with α = 0.80 has an equivalent absorption area of 8 m², so has the same effect in a room as a 20 m² absorber with α = 0.40 or a 40 m² absorber with α = 0.20.

Example: sound absorption coefficient for PLANLICHT p.quiet with Organoid® absorber in the one-third bands and octave middle frequencies



100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
0,09	0,22	0,37	0,58	0,71	0,85	0,94	0,90	0,83	0,81	0,82	0,85	0,88	0,90	0,91	0,86	0,79	0,79
0,25			0,70			0,90			0,85			0,90			0,80		

Sound Absorbers

We only want one thing from a sound absorber: for it to absorb sound. The challenge is dealing with different frequencies. Low frequencies with long wavelengths require bulky sound absorbers made from porous materials, or a resonance mechanism (an enclosed air volume or a vibrating surface). The aim is to optimise absorption capacity over a wide range of frequencies to absorb various wavelengths effectively. The different types of absorbers are often used in combination to achieve this.

POROUS SOUND ABSORBERS

When sound hits a porous material, the displaced air particles create friction as they move inside the pores of the absorber, which converts the sound energy into heat energy. The air-filled pores must be exposed to the surrounding air, interconnected and deep enough that sound can enter them and create friction. Suitable materials would be mineral fibres or porous foam. Insulating materials with closed pores such as polystyrene are not suitable. Closing these pores, for example by painting over the material, also reduces the absorption effect.

Porous absorbers are characterised by their increasing sound absorption coefficient at higher frequencies; their absorption ability at lower and mid-range frequencies depends heavily on the thickness of the material.

RESONANCE ABSORBERS

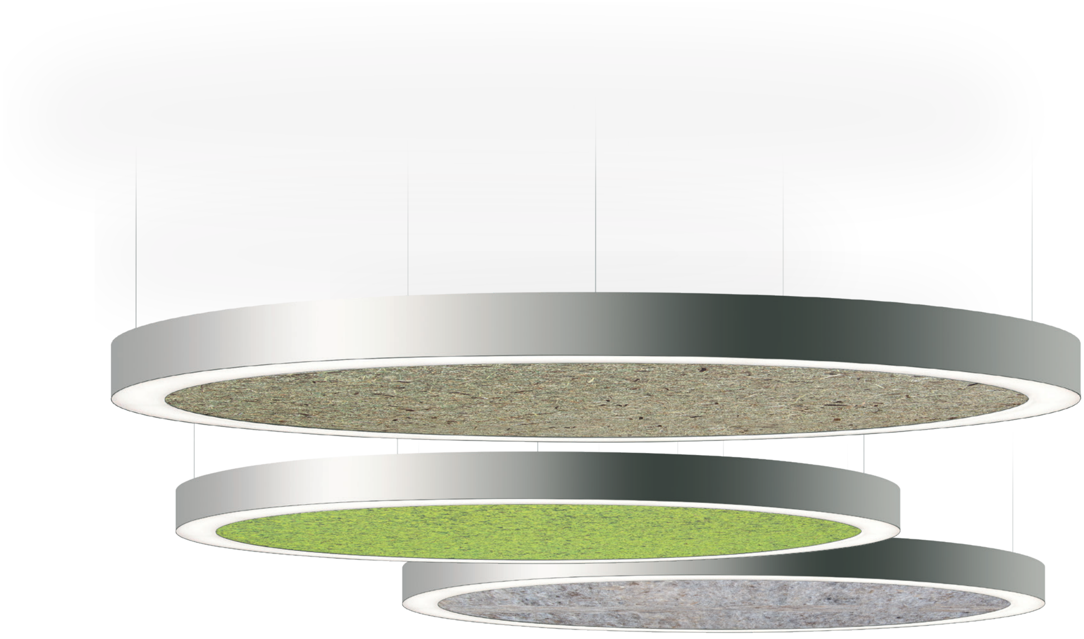
A resonance absorber is a physical spring-mass system, in which a panel or sheet is set into oscillation. The air in between acts as a spring and the sound energy that hits it is converted into kinetic energy. This system has a resonant frequency (a natural frequency) which is especially effective at absorbing nearby sound. We can distinguish between hole and slit resonators according to the Helmholtz principle of resonators and panel/ sheet absorbers.

Both systems absorb sound within a narrow frequency range (the natural frequency). This effective frequency range can be increased significantly through combination with porous absorption materials on fixed surfaces.

MICRO PERFORATED ABSORBER

Like porous absorbers, micro perforated absorbers convert sound energy into heat energy through friction inside tiny holes. These absorbers are made of a thin, very finely perforated material (hole diameter < 1 mm), of which the perforations make up only around 1% of the total surface area. The frequency range at which maximum absorption occurs is determined by the distance between the panel or sheet and the reflecting surface (a wall or window). For the absorption of mid-range to high frequencies, this distance is approximately 30 – 200mm.

RULE OF THUMB
High frequencies are dampened by shorter sound absorbers, low frequencies require taller or larger absorbers.



Sound Absorption by Ceilings

Since ceilings are the largest open surface in a room, they play a key role in sound absorption.

ACOUSTIC CEILINGS

Acoustic ceilings are particularly effective due to their large surface area. The acoustic effect can be further enhanced with acoustic plaster as well as by installing acoustically effective recessed lighting.

BAFFLE CEILINGS

Baffle ceilings come in handy when cladding a ceiling entirely isn't possible. The vertically-hung panels are also suitable for thermo-active ceilings.

CEILINGS SAILS

Ceiling sails hang freely in the room and so can also be easily retrofitted to improve room acoustics. Where acoustic absorption is required, light is also of utmost importance (think: office), so acoustic lighting is particularly recommended here.

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Acoustic Planning

In acoustic planning, we begin by assessing the basic acoustic properties of a room. After this, suitable acoustic measures can be taken (and adequate absorbers incorporated) to stop echo and reduce noise levels.

For concrete and thorough acoustic planning, it is important for us to consider some relevant parameters to achieve optimum results:

ROOM LAYOUT/ VOLUME

The length, width and height of the room. The shape/ layout and the volume or size of the room have a significant effect on reverberation time.

MATERIALITIES

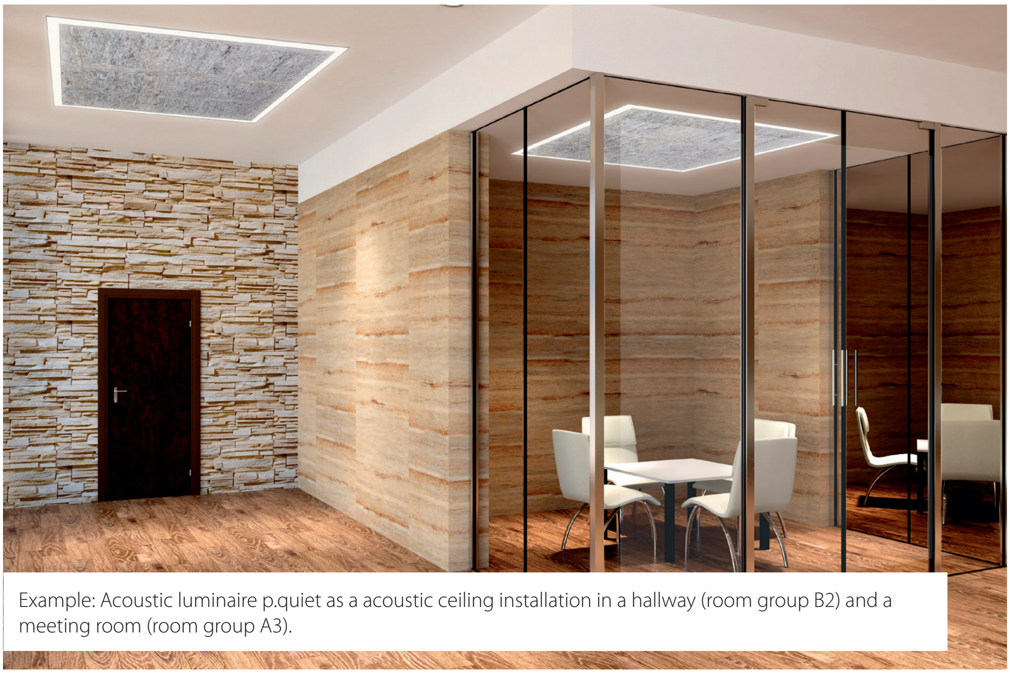
Different materials have different reflectance values. Walls, ceilings, floors and window surfaces have a significant influence on the acoustics of a room.

ROOM USE

How is the room used? Different purposes have different acoustic requirements (see room groups).

OCCUPANCY

People are useful absorbers. One person absorbs as much sound as a 0.5 m2 highly absorbent surface. Therefore, the number of people in the room should also be taken into account.



Example: Acoustic luminaire p.quiet as a acoustic ceiling installation in a hallway (room group B2) and a meeting room (room group A3).

Example: Acoustic luminaire p.quiet as a ceiling sail installation in a chemistry laboratory (room group B4)

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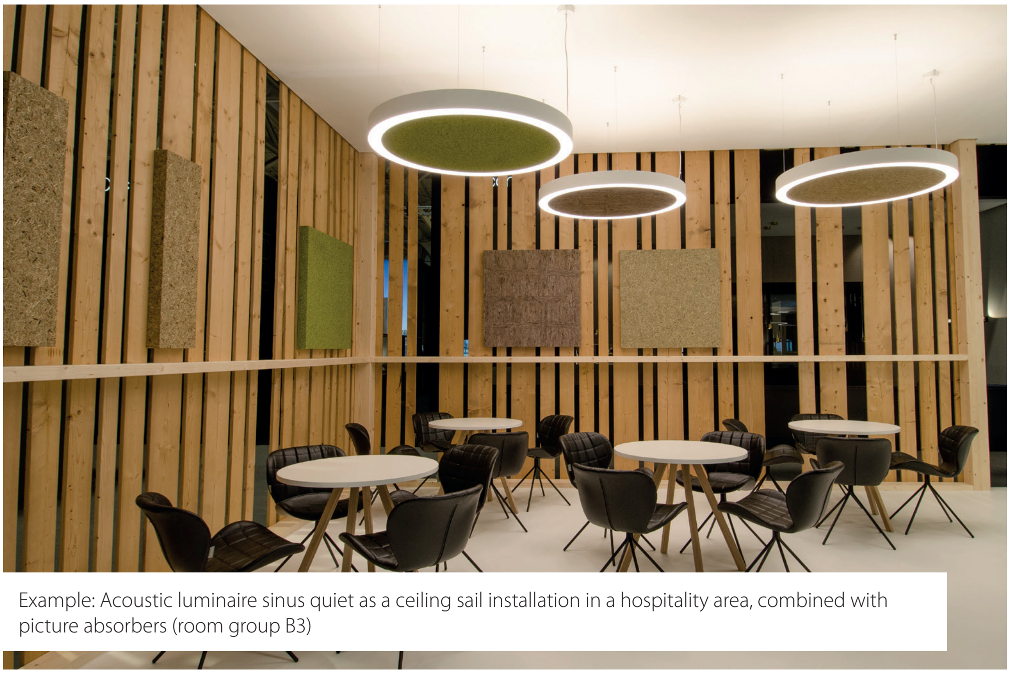

Example: Acoustic luminaire sinus quiet as a ceiling sail installation in a hospitality area, combined with picture absorbers (room group B3)

Literature

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