ACOUSTICS

Basic principles of sound
Before we discuss the connection between the sound power level and the sound pressure level, we must define certain basic concepts such as sound pressure, sound power and frequency.

Sound pressure
Sound pressure is the pressure waves with which the sound moves in a medium, for instance air. The ear interprets these pressure waves as sound. They are measured in Pascal (Pa).

The weakest sound pressure that the ear can interpret is 0.00002 Pa, which is the threshold of hearing. The strongest sound pressure which the ear can tolerate without damage is 20 Pa, referred to as the upper threshold of hearing. The large difference in pressure, as measured in Pa, between the threshold of hearing and the upper threshold of hearing, makes the figures difficult to handle. So a logarithmic scale is used instead, which is based on the difference between the actual sound pressure level and the sound pressure at the threshold of hearing. This scale uses the decibel (dB) unit of measurement, where the threshold of hearing is equal to 0 dB and the upper threshold of hearing is 120 dB.

The sound pressure reduces as the distance from the sound source increases, and is affected by the room's characteristics and the location of the sound source.

Sound power
Sound power is the energy per time unit (Watt) which the sound source emits. The sound power is not measured, but it is calculated from the sound pressure. There is a logarithmic scale for sound power similar to the scale for sound pressure.

The sound power is not dependent on the position of the sound source or the room's sound properties, and it is therefore easier to compare between different objects.

Frequency
Frequency is a measurement of the sound source's periodic oscillations. Frequency is measured as the number of oscillations per second, where one oscillation per second equals 1 Hertz (Hz). More oscillations per second, i.e. a higher frequency, produces a higher tone.

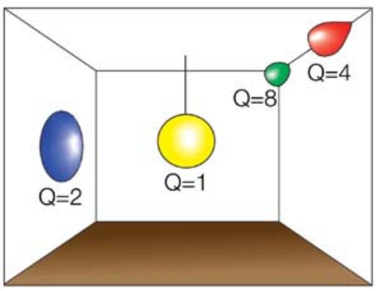
Frequencies are often divided into 8 groups, known as octave bands: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz.

Sound power level and sound pressure level

There is a link between a sound source's sound power level and the sound pressure level. If a sound source emits a certain sound power level, the following factors will affect the sound pressure level:

The position of the sound source in the room, including the direction factor (1), the distance from the sound source (2) and the room's sound-absorbing properties, referred to as the room's equivalent absorption area (3).

1) Direction factor, Q
The direction factor indicates the sound's distribution around the sound source. A distribution in all directions, spherical, is measured as Q = 1. Distribution from a diffuser positioned in the middle of a wall is hespherical, measured as Q = 2.



Q = 1 In centre of room
Q = 2 On wall or ceiling
Q = 4 Between wall or ceiling
Q = 8 In a corner

Figure 1. The distribution of sound around the sound source

Calculation of equivalent absorption area A_{eqv}

$$A_{eqv} = \alpha_1 \cdot S_1 + \alpha_2 \cdot S_2 + \ldots + \alpha_n + S_n$$

where
S = Size of surface (m^2)
a = Absorption factor, depending on the material
n = Number of surfaces

Calculation of sound pressure level
Estimate based on figures 1, 2 and 3 together with table 1.

A normally damped room in a nursing home, measuring 30 m^3, is to be ventilated. According to the information in the catalogue, the directional supply-air terminal device fitted in the ceiling has a sound pressure level (L_{pA}) of 33 dB(A). This applies to a room with a space damping equivalent to 10 m^2 Sabine, or 4 dB(A).

A) What will the sound pressure level be in this room, 1 m from the diffuser?

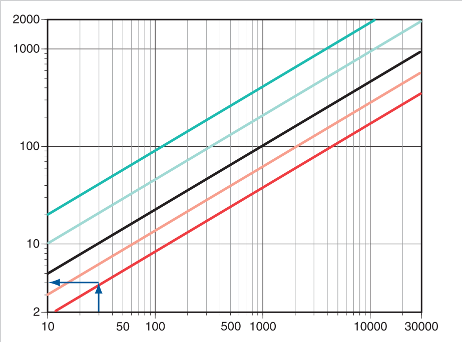
The sound pressure level depends on the room's acoustic properties, so first of all it is necessary to convert the value in the catalogue to a sound power level (L_{WA}).

Fig.3 shows that ΔL (space damping) = $L_{pA} - L_{WA}$

$L_{WA} = L_{pA} + \Delta L$

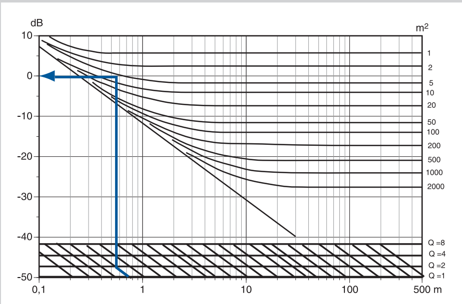
$L_{WA} = 33 + 4 = 37$ dB(A)

With the following values
r = 1
Q = 2 (fig.1)
and information about the room's dimensions, you can calculate the equivalent absorption area with the help of figure 2.



The equivalent absorption area is therefore 4 m².

It is now possible to use figure 3 to establish the difference between the sound pressure and the sound power.



$L_{pA} - L_{WA} = 0$
$L_{pA} = 0 + L_{WA}$

Enter the L_{WA} value which has already been calculated.
$L_{pA} = 0 + 37 = 37$ dB(A)

A) The sound pressure level (L_{pA}) one metre from the diffuser in this particular nursing home room is therefore 37 dB(A).

This calculation has to be made for all rooms not corresponding to the information in the catalogue which assumes a standard 10 m² Sabine.

The less damped (harder) the room is, the higher the actual sound pressure level will be in comparison with the value indicated in the catalogue.

2) Distance from sound source, r
Where r indicates the distance from the sound source in metres.

3) The room's equivalent absorption area, Aeqv
A material's ability to absorb sound is indicated as absorption factor a. The absorption factor can have a value between '0' and '1', where the value '1' corresponds to a fully absorbent surface and the value '0' to a fully reflective surface. The absorption factor depends on the qualities of the material, and tables are available which indicate the value for different materials.

A room's equivalent absorption area is measured in m² and is obtained by adding together all the different surfaces of the room multiplied by their respective absorption factors.

In many instances it can be simpler to use the mean value for sound absorption in different types of rooms, together with an estimate of the equivalent absorption area (see figure 2).

3) Equivalent absorption area based on estimates
If values are not available for the absorption factors of all the surfaces, and a more approximate value of the room's total absorption factor is quite adequate, an estimate can be calculated in accordance with the diagram below. The diagram is valid for rooms with normal proportions, for example 1:1 or 5:2.

Use the diagram as follows to estimate the equivalent absorption area: calculate the room's volume and read off the equivalent absorption area with the correct mean absorption factor, determined by the type of room, see also table 1.

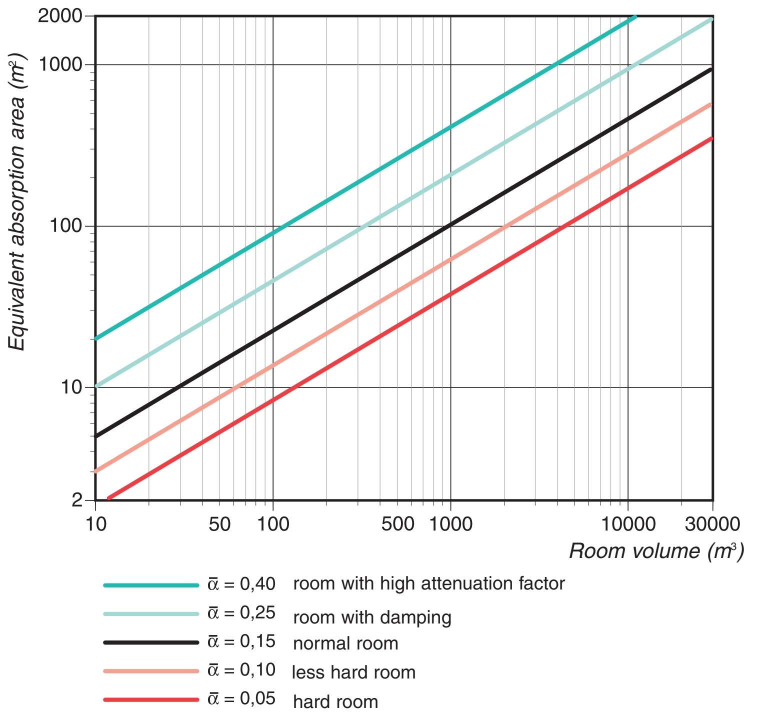


Figure 2. Estimate of equivalent absorption area.

Type of room	Mean absorption factor
Radio studios, music rooms	0.30 - 0.45
TV studios, department stores, reading rooms	0.15 - 0.25
Domestic housing, offices, hotel rooms, conference rooms, theatres	0.10 - 0.15
School halls, nursing homes, small churches	0.05 - 0.10
Industrial premises, swimming pools, large churches	0.03 - 0.05

Table 1. Mean absorption factors for different types of rooms

Calculation of sound pressure level

With the help of the factors previously described, it is now possible to calculate the sound pressure level if the sound power level is known. The sound pressure level can be calculated by means of a formula incorporating these factors, but this equation can also be reproduced in the form of a diagram.

When the diagram is used for calculating the sound pressure level, you must start with the distance in metres from the sound source (r), apply the appropriate directional factor (Q), and then read off the difference between the sound power level and the sound pressure level next to the relevant equivalent absorption area (A_{eqv}). This result is then added to the previously calculated sound power (see also the example on page 509).

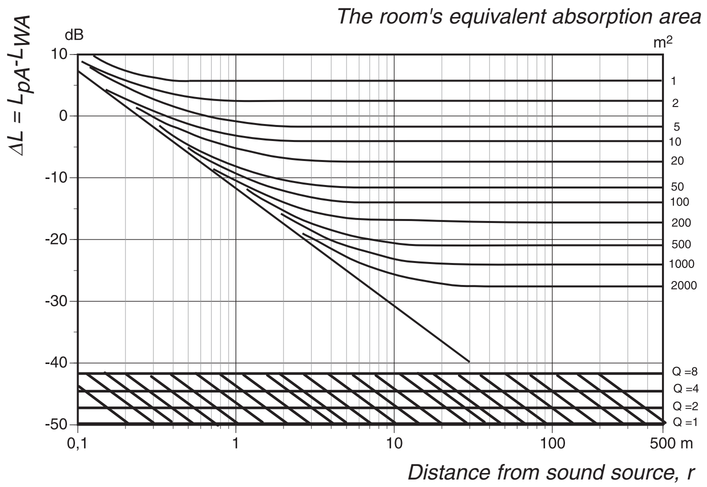


Figure 3. Diagram for estimating the sound pressure level

Calculation of sound pressure level

$$L_{pA} = L_{wA} + 10 \cdot \log\left[\frac{Q}{4\pi r^2} + \frac{4}{A_{eqv}}\right]$$

where

L_{pA} = sound pressure level (dB)

L_{wA}= sound power level (dB)

Q = direction factor

r = distance from sound source (m)

A_{eqv} = equivalent absorption area (m² Sabine)

Near field and reverberation field

Near field is the term used for the area where the sound from the sound source dominates the sound level. The reverberation field is the area where the reflected sound is dominant, and it is no longer possible to determine where the original sound comes from.

The direct sound diminishes as the distance from the sound source increases, while the reflected sound has approximately the same value in all parts of the room.

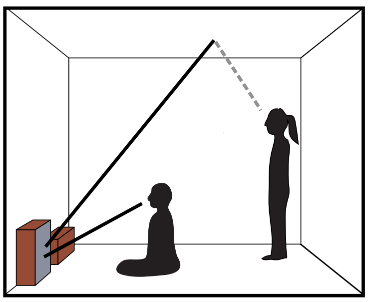


Figure 4. Direct and reflected sound

The reverberation time indicates the time it takes for the sound level to reduce by 60 dB from the initial value. This is the echo effect one hears in a quiet room when a powerful sound source is switched off. If the reverberation time is measured precisely enough, the equivalent absorption area can be calculated.

Calculation of reverberation time

If a room is not too effectively damped (i.e. with a mean absorption factor of less than 0.25), the room's reverberation time can be calculated with the help of Sabine's formula:

$$T = 0{,}163 \cdot \frac{V}{A_{eqv}}$$

where

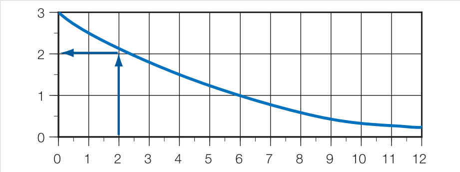
T= Reverberation time (s). Time for a 60 dB reduction of the sound pressure value

V= Room volume (m³)

A_{eqv}=The room's equivalent absorption area, m²

Example of addition
There are two sound sources, 40 dB and 38 dB respectively.

1) What is the value of the total sound level?

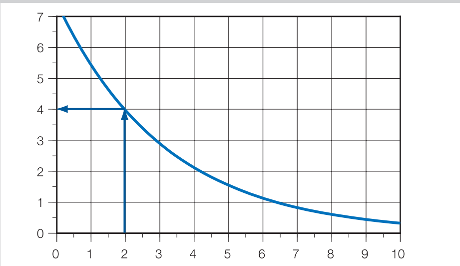


The difference between the sound levels is 2 dB and, according to the diagram, 2 dB must be added to the highest level.

1) The total sound level is therefore 42 dB.

Example of subtraction
The total sound level is 34 dB in a room fitted with both supply and exhaust ventilation systems. It is known that the supply system produces 32 dB, but the value for the exhaust system is not known.

2) What is the sound level produced by the exhaust system?



The difference between the total sound level and the sound level of the supply system is 2 dB. The diagram indicates that 4 dB must be deducted from the total level.

2) Therefore the exhaust system produces 30 dB.

Several sound sources

To establish the total sound level in a room, all the sound sources must be added together logarithmically. It is, however, often more practicable to use a diagram to calculate the addition or subtraction of two dB values.

Addition
The input value for the diagram is the difference in dB between the two sound levels which are to be added. The dB value to be added to the highest sound level can then be read off they scale.

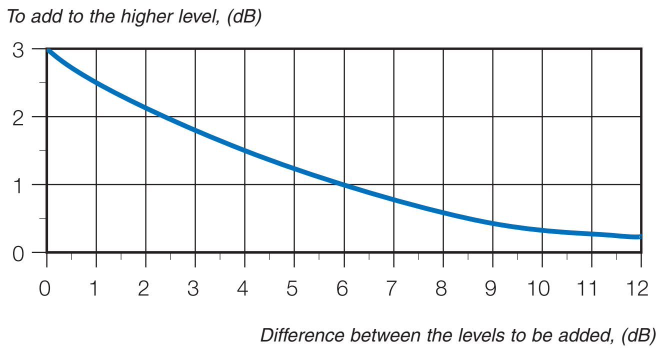


Figure 5. Logarithmic addition

Subtraction
The input value for the diagram is the difference in dB between the total sound level and the known sound source. The y scale then shows the number of dB that have to be deducted from the total sound level to obtain the value for the unknown sound source.

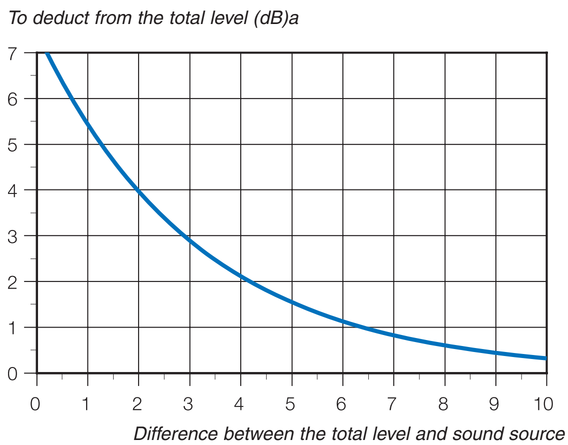


Figure 6. Logarithmic subtraction

Adjustment to the ear

Because of the ear's varying sensitivity at different frequencies, the same sound level in both low and high frequencies can be perceived as two different sound levels. As a rule, we perceive sounds at higher frequencies more easily than at lower frequencies.

A filter

The sensitivity of the ear also varies in response to the sound's strength. A number of so called weighting filters have been introduced to compensate for the ear's variable sensitivity across the octave band. A weighting filter A is used for sound pressure levels below 55 dB. Filter B is used for levels between 55 and 85 dB, and filter C is used for levels above 85 dB.

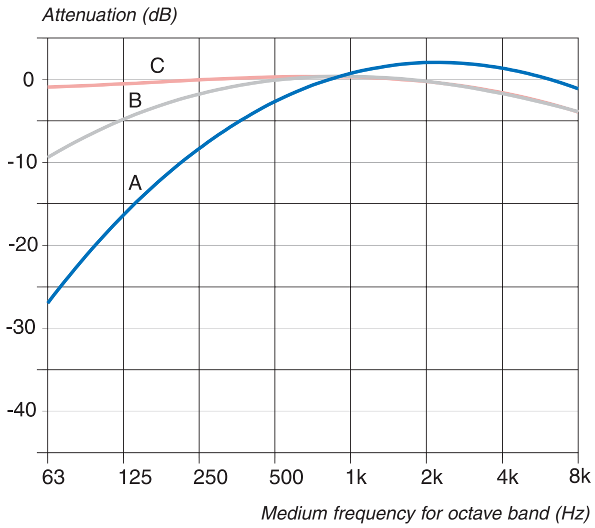


Figure 7. Damping with different filters

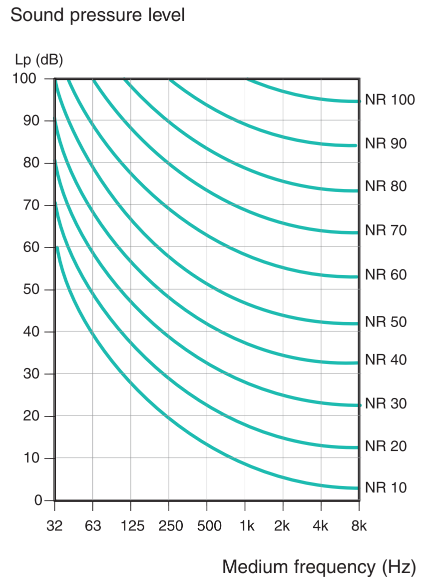
The A filter, which is commonly used in connection with ventilation systems, has a damping effect on each octave band as shown in table 2. The resultant value is measured in dB(A) units.

Hz	63	125	250	500	1k	2k	4k	8k
dB	-26,2	-16.1	-8.6	-3.2	0	+1.2	+1.2	-1.1

Table 2. Damping with the A filter

There are also other ways of compensating for the ear's sensitivity to different sound levels, apart from these filters. A diagram with NR curves (Noise Rating) shows sound pressure and frequency (per octave band). Points on the same NR curve are perceived as having the same sound levels, meaning that 43 dB at 4000 Hz is perceived as being as loud as 65 dB at 125 Hz.

NR curves



Sound attenuation

Sound attenuation is principally achieved in two ways: either by absorption or by reflection of the sound.

Attenuation by absorption is achieved by internal insulation in ducts, by special silencers or by means of the room's own sound absorption. Attenuation by reflection is achieved by forking or bending, or when the sound bounces back from a supply-air device into the duct, which is referred to as end reflection.

The degree of sound attenuation can be calculated by using tables and diagrams presented in the relevant suppliers technical documentation.

Air terminal devices

There are essentially two ways of ventilating a building: ventilation by displacement and ventilation by diffusion.

Ventilation by diffusion is the preferable method for supplying air in situations requiring what is known as comfort ventilation. This is based on the principle of supplying air outside the occupied zone which then circulates the air in the entire room. The ventilation system must be dimensioned so that the air which circulates in the occupied zone is comfortable enough, in other words the velocity must not be too high and the temperature must be more or less the same throughout the zone.

Ventilation by displacement is chiefly used to ventilate large industrial premises, as it can remove large volumes of impurities and heat if properly dimensioned. The air is supplied at low velocity directly into the occupied zone. This method provides excellent air quality, but is less suitable for offices and other smaller premises because the directional supply-air terminal device takes up a considerable space and it is often difficult to avoid some amount of draught in occupied areas.

The theory section which follows will discuss what happens to the air in rooms ventilated by diffusion, how to calculate air velocity and displacement in the room, and also how to select and position a directional supply-air terminal device correctly in the premises.

Ventilation by diffusion
An air stream which is injected into a room will attract, and mix together with, large volumes of ambient air. As a result, the air stream's volume increases while at the same time the air velocity is reduced the further into the room it travels. The mixing of the surrounding air into the air stream is termed 'induction'.

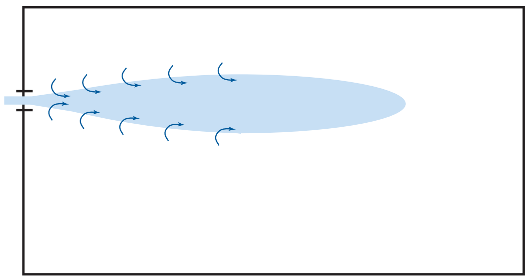
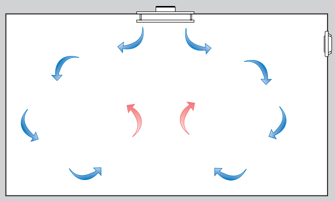


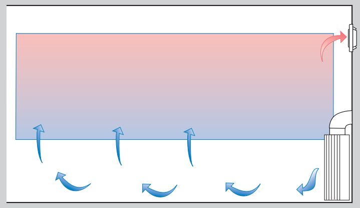
Figure 8. Induction of the surrounding air into the air stream.

The air movements caused by the air stream very soon mix all the air in the room thoroughly. Impurities in the air are not only attenuated but also evenly distributed. The temperatures in the different parts of the room are also evened out.

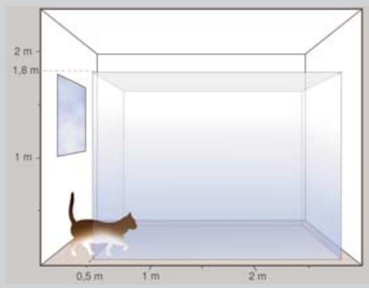
When dimensioning for ventilation by diffusion, the most important consideration is to ensure that the air velocity in the occupied zone will not be too high, as this will be experienced as a draught.



Ventilation by diffusion
The air is blown in from one or more air streams outside the occupied zone.



Ventilation by displacement
Air which is somewhat cooler than the ambient air flows at low velocity into the occupied zone.



Occupied zone
The occupied zone is that part of the room normally occupied by people. This is usually defined as being a space 50 cm from an outer wall with windows, 20 cm from other walls, and up to 180 cm above the floor.

α = the discharge angle

The discharge angle
According to ASHRAE's Handbook (AHRAE [The American Society of Heating, Refrigerating and Air-Conditioning Engineers], 1996) the distribution of an air stream has a constant angle of 20-24° (22° on average).

The shape of the vent, the geometry of the room and also the number of vents all have an effect on the discharge angle. Diffusers and valves with plates or other details which spread the air can produce a wider discharge angle, but even after a relatively short distance from the valve opening, these air streams have a distribution of between 20 and 24°.

Calculation of air velocity
For a conical or radial air stream:

$$\frac{v_x}{v_0} = K \cdot \frac{\sqrt{A_{eff}}}{x} \qquad A_{eff} = \frac{q}{v_0}$$

x = distance from the diffuser or valve (m)
v_x = centre velocity at distance x (m/s)
v_0 =velocity at the diffuser/valve outlet (m/s)
K = the diffuser coefficient
A_{eff} = the diffuser/valve's effective outlet area (m^2)
q = air volume through the vent (m^3/s)

For a flat air stream

$$\frac{v_x}{v_0} = \sqrt{K \cdot \frac{h}{x}}$$

x = distance from the diffuser/valve (m)
v_x = velocity at distance x (m/s)
v_0 = velocity at the diffuser/valve outlet (m/s)
K = the diffuser coefficient
h = the height of the slot (m)

The velocity at the cross section of the air stream will be:

$$\frac{v}{v_x} = \left[1 - \left(\frac{y}{0,3 \cdot x}\right)^{1,5}\right]^2$$

y = vertical distance from the central axis (m)
x = distance from the diffuser/valve (m)
v = velocity at distance y (m)
vx = centre velocity at distance x (m/s)

Air stream theory

The figure below shows an air stream that is formed when air is forced into a room through an opening in the wall. The result is a free air stream. If it also has the same temperature as the rest of the room, it is referred to as a free isotherm stream. To begin with, this section will only deal with streams of this type.

Distribution and shape
The air stream actually consists of several zones with different flow conditions and air velocities. The area which is of most practical interest is the main section. The centre velocity, the velocity around the centre axis, is in inverse proportion to the distance from the diffuser or valve, i.e. the further away from the diffuser the slower the air velocity.

The air stream is fully developed in the main section, and the prevailing conditions here are the ones that will principally affect the flow conditions in the room as a whole.

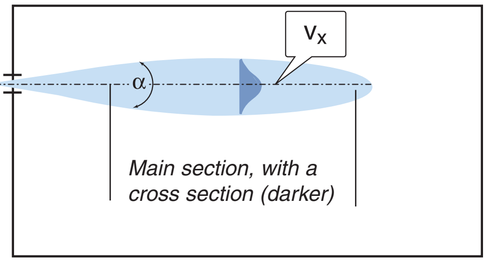


Figure 9. The main section of the air stream, the centre velocity vx and discharge angle.

The shape of the diffuser or valve opening determines the shape of the air stream. Circular or rectangular openings produce a conic (axial) stream, and this also applies to very long and narrow openings.

To produce a completely flat air stream, the opening must be more than ten times as wide as it is high, or nearly as wide as the room so that the walls prevent the stream widening out laterally.

Radial air streams are produced by completely circular openings where the air can spread in all directions, as is the case with a supply-air diffuser.

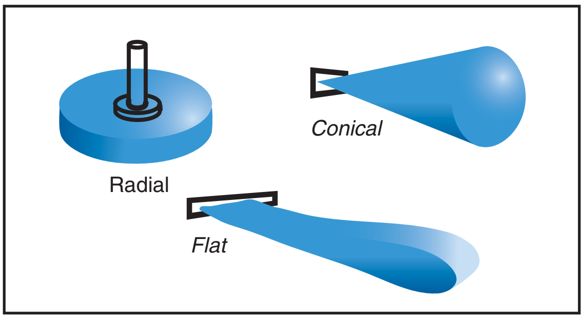


Figure 10. Different kinds of air stream

Velocity profile
It is possible to calculate mathematically the air velocity in each part of the stream. To calculate the velocity at a particular distance from the diffuser or valve, it is necessary to know the air velocity at the diffuser/valve outlet, the shape of the diffuser/valve and the type of air stream produced by it. In the same way, it is also possible to see how the velocities vary in every cross section of the stream.

Using these calculations as the starting point, velocity curves for the entire stream can be drawn up. This enables one to determine the areas which have the same velocity. These areas are called isovels. By checking that the isovel corresponding to 0.2 m/s is outside the occupied zone, one can ensure that the air velocity will not exceed this level in the normally occupied areas.

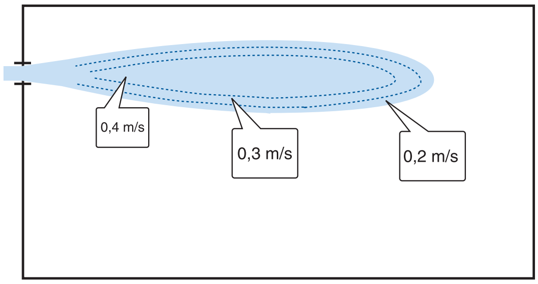


Figure 11. The different isovels of an air stream

The diffuser coefficient
The diffuser coefficient is a constant which depends on how the diffuser or valve is shaped. It can be calculated theoretically by using the following factors: the impulse dissipation and contraction of the air stream at the point where it is blown into the room, together with the degree of turbulence created by the diffuser or valve.

In practice, the constant is simply determined by taking measurements on each type of diffuser or valve. The air velocity is measured at a minimum of eight different distances from the diffuser/valve, with at least 30 cm between each measuring point. These values are then plotted into a logarithmic diagram, which indicates the measurement value for the main section of the air stream, and this in turn provides a value for the constant.

The diffuser coefficient enables one to calculate air velocities and to predict an air stream's distribution and path. It must not be confused with the K-factor which is used for such tasks as entering the correct air volume from a directional supply-air terminal device or iris damper.

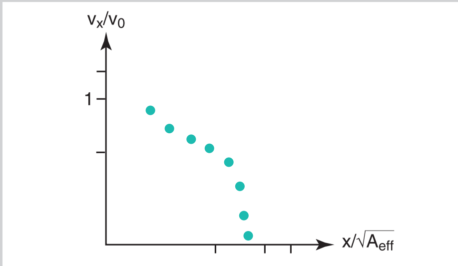
The K factor is described on page 389.

Theoretical calculation of the diffuser coefficient

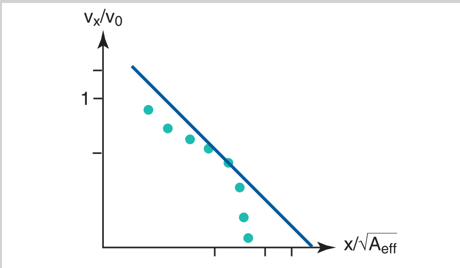
$$K = \sqrt{\frac{i}{\varepsilon}} \cdot \frac{1{,}5}{C_b}$$

i = impulse factor indicating impulse dissipation at point where air is blown in (i<1)
e = contraction factor
C_b = turbulence constant (0.2-0.3 depending on type of diffuser or valve)

Practical calculation of the diffuser coefficient
The measurement values (v_x/v_0) and (x/Ö A_{eff}) are plotted into the diagram.



Using the values obtained from the main section of the air stream, a tangent (angle coefficient) is drawn at an angle of -1 (45°).



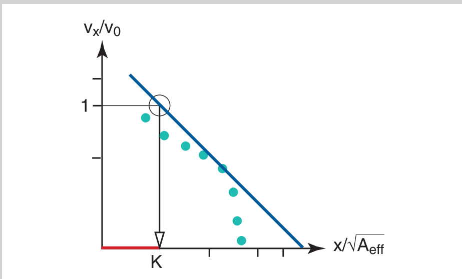
The formula for the velocity profile

$$\frac{v_x}{v_0} = K \cdot \frac{\sqrt{A_{eff}}}{x}$$

shows that

$$K = \frac{x}{\sqrt{A_{eff}}} \quad \text{when} \quad \frac{v_x}{v_0} = 1$$

A line should now be drawn from the intersection of the angle coefficient and 1 on the y scale to produce a value for the diffuser coefficient K.



The diffuser coefficient when the Coanda effect is influencing the air stream:

$$K_{corrected} = \sqrt{2} \cdot K_{free\ flow}$$

The horizontal discharge angle also increases to 30° when the stream is sucked towards the ceiling, while the vertical angle remains unchanged (20-24°).

Deflection
The deflection from the ceiling to the central axis of the air stream (Y) can be calculated using

$$Y = \sqrt{A_{eff}} \cdot 0{,}0014 \cdot \frac{\Delta t_0 \cdot \sqrt{A_{eff}}}{K \cdot v_0^2} \cdot \left[\frac{x}{\sqrt{A_{eff}}}\right]^3$$

where
Δt_0 = the temperature difference between the air stream and the ambient air
x = distance from the diffuser/valve (m)
v_x = centre velocity at distance x (m/s)
v_0 = velocity at the diffuser/valve outlet (m/s)
K = the diffuser coefficient
A_{eff} = the diffuser or valve's effective outlet area (m^2)

Point of separation
The point where a conical air stream leaves the ceiling (xm) will be:

$$x_m = \frac{1{,}6 \cdot K \cdot v_0 \cdot A_{eff}}{(A_{eff})^{0,75} \cdot \sqrt{\Delta t_0}}$$

and for a radial air stream will be

$$x_m = \frac{3{,}5 \cdot K^{1,5} \cdot v_0 \cdot A_{eff}}{(A_{eff})^{0,75} \cdot \sqrt{\Delta t_0}}$$

where
Δt_0 = the temperature difference between the air stream and the ambient air
v_0 = velocity at the diffuser/valve outlet (m/s)
K = the diffuser coefficient
A_{eff} = the diffuser or valve's effective outlet area (m^2)

After the stream has left the ceiling, a new path can be calculated with the aid of the formula for deflection (above). The distance x is then calculated as the distance from the point of separation.

Coanda effect
If a directional supply-air terminal device is fitted close enough to a flat surface, usually the ceiling, the air stream will cling to the surface. This is due to the fact that the ambient air will be drawn into the stream, but close to the flat surface, where no new air can flow from above, an underpressure forms instead, and this causes the stream to be sucked to the surface. This is known as the Coanda effect.

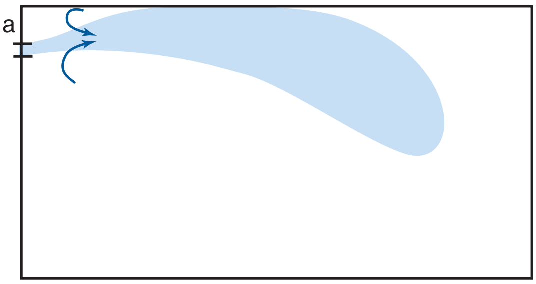


Figure 12. The Coanda effect

Practical experiments have shown that the distance between the diffuser or valve's upper edge and the ceiling ('a' in figure12) must not be greater than 30 cm if there is to be any suction effect.
The Coanda effect can be used to make a cold air stream stick to the ceiling and travel further into the room before it reaches the occupied zone.
The diffuser coefficient will be somewhat greater in conjunction with the suction effect than for a free air stream. It is also important to know how the diffuser or valve is mounted when using the diffuser coefficient for different calculations.

Non-isothermal air
The flow picture becomes more complex when the air that is blown in is non-isothermal air, in other words warmer or colder than the ambient air. A thermal energy, caused by differences in the air's density at different temperatures, will force a cooler air stream downwards and a warmer air stream upwards.
This means that two different forces affect a cooler stream that is sticking close to the ceiling: both the Coanda effect which attempts to adhere it to the ceiling and the thermal energy which attempts to force it towards the floor. At a given distance from the diffuser or valve's outlet, the thermal energy will dominate and the air stream will eventually be dragged down from the ceiling.
The stream's deflection and point of separation can be calculated using formulae which are based on the temperature differentials, the type of diffuser or valve and the size of its outlet, together with air velocities etc.

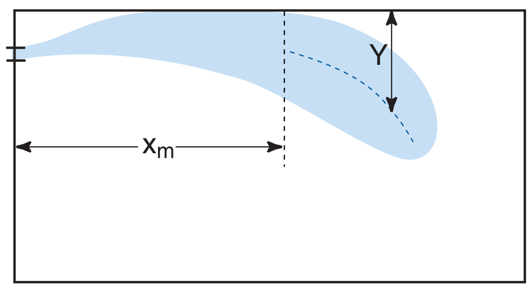


Figure 13. The air stream's point of separation (Xm) and deflection (Y)

Important considerations when dimensioning air supply

It is important to select and position the directional supply-air terminal device correctly. It is also important that the air temperature and velocity are as required for producing acceptable conditions in the occupied zone.

Correct air velocity in the occupied zone

A specification called 'throw' is indicated for most supply-air equipment in the manufacturer's product catalogue. 'Throw' is defined as the distance from the diffuser or valve opening to the point in the air stream where the centre velocity has been reduced to a particular value, generally 0.2 m/s. A throw of this type is designated by $l_{0.2}$ and is measured in metres.

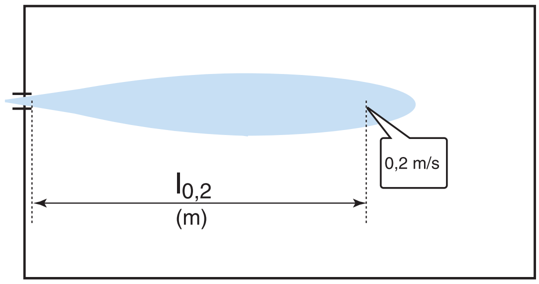


Figure 14. The 'throw' concept

One of the first considerations when dimensioning an air supply system is usually to avoid velocities in the occupied zone that are too high, but as a rule it is not the air stream itself that reaches us there.

In the occupied zone we are more likely to be exposed to high velocities in the return air stream: see the figure below.

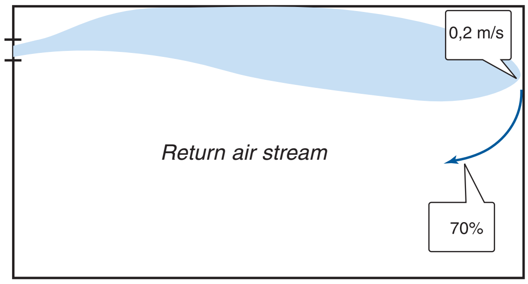


Figure 15. Return air stream with a wall-mounted diffuser

It has been shown that the velocity of the return air stream is approximately 70% of the velocity it had when it reached the wall. This means that a diffuser or valve fitted on the rear wall, with an end velocity of 0.2 m/s, will cause an air velocity of 0.14 m/s in the return air stream. This is within the limits for comfort ventilation, which is understood to mean that the velocity should not exceed 0.15 m/s in the occupied zone.

The throw for the diffuser or valve described above is the same as the length of the room, and in this instance is an excellent choice. A suitable throw for wall-mounted ventilation is somewhere between 70% and 100% of the room's length.

Effective penetration

The most common method for selecting the correct directional supply-air terminal device is to consider the throw $l_{0,2}$. But since the desired end velocity in the air stream depends on both the room's geometry and the required air velocity in the occupied zone, this can sometimes be rather misleading. Therefore the concept of the air stream's effective penetration has been introduced instead.

The effective penetration is the distance to the point where an end velocity is to be calculated. This can be the distance along the centre of the air stream from the diffuser itself to the furthest point in the room where the supply air is required. For wall-mounted diffusers, this means that the effective penetration is the same as the room's depth, while for ceiling diffusers the penetration is half the room's depth.

The velocity of the return air stream is approximately 30% slower than the air stream's velocity when it meets the wall. If the maximum air velocity in the occupied zone is to be 0.18 m/s, this means that the air stream must have a maximum velocity of 0.26 m/s when it meets the wall.

Effective penetration – calculation

The velocity at the effective penetration depth of a diffuser can be calculated theoretically by using the formula for calculating air velocity.

$$v_x = v_0 \cdot K \cdot \frac{\sqrt{A_{eff}}}{x_v}$$

where

v_x = velocity at the effective penetration (m/s)

v_0 = velocity at the diffuser outlet (m/s)

K = the diffuser coefficient

A_{eff} = the vent's effective outlet area (m²)

x_v = the effective penetration (m)

This method enables one to dimension the ventilation system more precisely than is possible when only using the throw data, and is therefore frequently used in different diffuser selection programmes.

Throw data for isothermal air

Rear-wall diffuser and wall-mounted diffuser:
0.7 to 1.0 x room depth.

Ceiling diffuser (supply air blown horizontally):
0.5 x room depth
(with rectangular rooms, the distance is calculated to the nearest wall).

The penetration of the air stream
The shape of the room can affect the flow picture. If the cross section of the air stream is more than 40% of the cross section of the room, all induction of air in the room will stop. As a result, the air stream will deflect and start to suck in the induction air itself. In such a situation it does not help to increase the velocity of the supply air, as the penetration will remain the same while the velocity of both the air stream and the ambient air will increase.

Other air streams, secondary vortices, will start to appear further into the room where the main air stream does not reach. However, if the room is less than three times as long as it is high, it can be assumed that the air stream will reach all the way in.

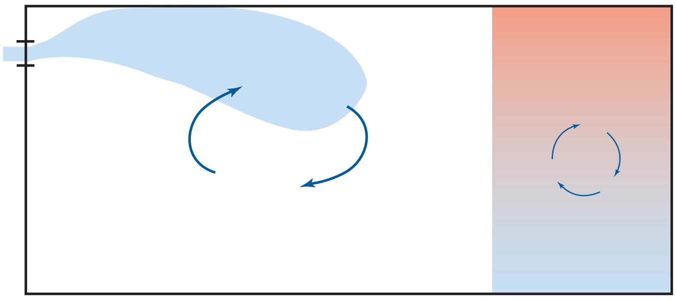


Figure 16. Secondary vortices are formed at the furthest point in the room, where the air stream does not reach.

Avoid obstacles
Unfortunately, it is very common for the air stream to be obstructed by light fittings on a ceiling. If these are too close to the diffuser and hang down too far, the air stream will deflect and descend into the occupied zone. It is therefore necessary to know what distance (A in the diagram) is required between an air supply device and an obstacle for the air stream to remain unimpeded.

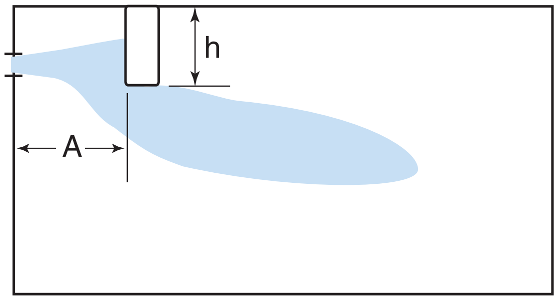
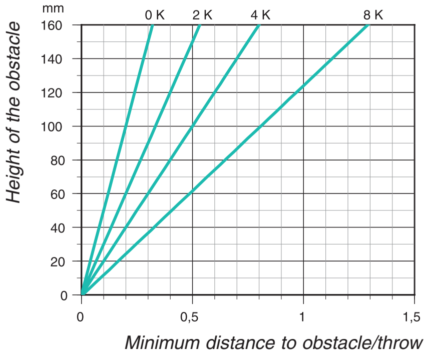


Figure 17. Minimum distance to an obstacle

Distance to an obstacle (estimate)
The diagram shows the minimum distance to the obstacle as a function of the obstacle's height (h in figure 17) and the air stream's temperature at the lowest point.



Installing several directional supply-air terminal devices
If a single ceiling diffuser is intended to service an entire room, it should be positioned as close to the centre of the ceiling as possible, and the total surface should not exceed the dimensions indicated in Figure 18 below.

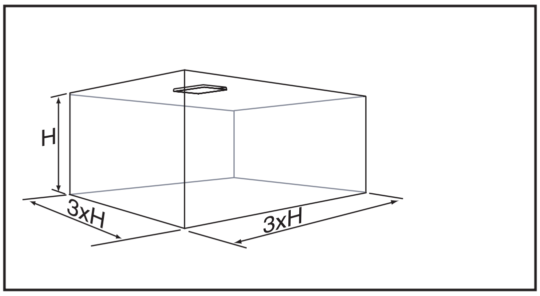


Figure 18. A small room ventilated by a single ceiling diffuser

If the room is larger than this, it usually has to be divided into several zones, with each zone ventilated by its own diffuser.

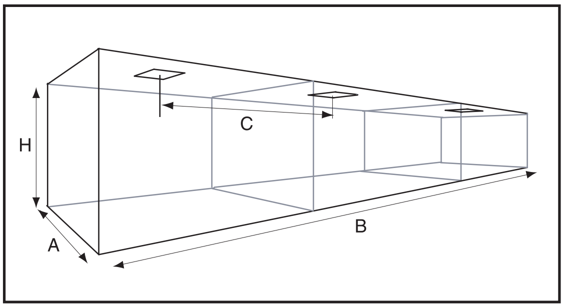


Figure 19. A large room ventilated by several ceiling diffusers

A room which is ventilated by several wall-mounted diffusers must also be divided into several zones. The number of zones is determined by the requirement to ensure sufficient distance between the diffusers to prevent the air streams affecting each other. If two air streams mix together, the result will be one stream with a longer throw.

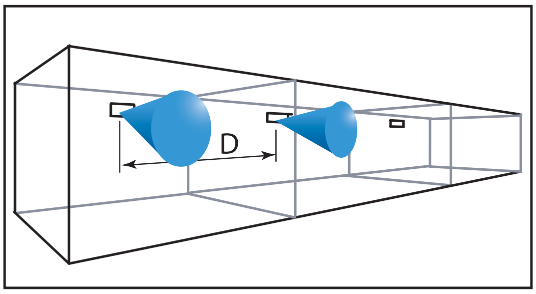


Figure 20. A large room ventilated by several wall diffusers

Dimensioning with several ceiling diffusers
A large room has to be divided into several zones. The maximum dimension for each zone is 1.5 x the room's length (A), as long as this does not exceed 3xH (see figure 18).

The appropriate throw is 0.5 x C, where C = the distance between two diffusers, (see figure 19).

Example
A large room (see figure 19) has the following dimensions:
H = 3 m
A = 4 m
B = 16 m

1) *How many zones should the room be divided into?*
2) *What will be distance be between the diffusers?*

1) The maximum size for each zone is 1.5 x A = 6 m, which means that the room should be divided into three zones, each 5.33 m long.
2) If the diffuser is placed in the centre of each zone, the distance (C) will be 5.33 m.

Dimensioning with several wall diffusers
The smallest distance between two wall-mounted valves or diffusers (D in figure 20) is 0.2 x $l_{0.2}$.

The appropriate throw is between 0.7 and 1.0 x A, where A = the depth of the room.

Example
A room which is 5 m deep is ventilated from the rear wall by means of diffusers with a throw of 4 m.

1) *What distance should there be between two diffusers?*

$0.2 \times l_{0.2} = 0.2 \times 4 = 0.8$ m

1) There should be 80 cm between two diffusers.

Blowing in warm air

Blowing supply air horizontally from the ceiling works excellently for most rooms, including those with very high ceilings. If the supply air is above ambient temperature and also used to heat the premises, practical experiments have shown that this works well in rooms with ceiling heights of no more than 3.5 metres. This assumes that the maximum temperature difference is 10-15°C.

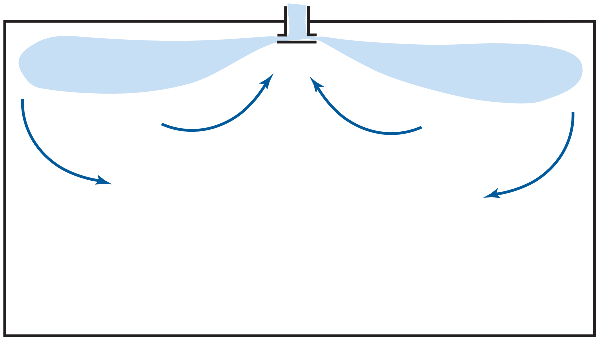


Figure 21. Blowing supply air horizontally from a ceiling diffuser

In very high rooms, however, the supply air has to be jetted vertically if it is also used for heating. If the temperature difference is no more than 10°C, the air stream should flow down to approximately 1 metre above the floor in order to produce a satisfactory evenness of temperature in the occupied zone.

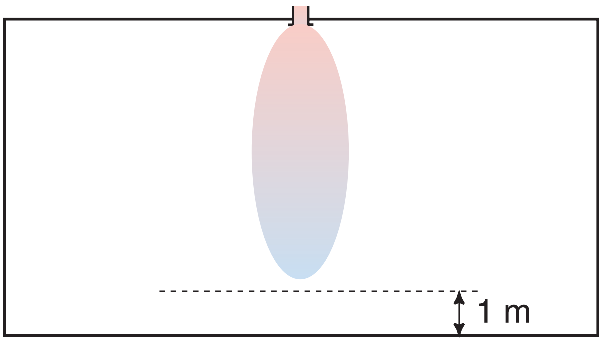


Figure 22. Supply air blowing vertically from a ceiling diffuser

Blowing in cold air
When supplying air that is colder than the ambient air, it is particularly important to make use of the Coanda effect to prevent the air stream from falling down into the occupied zone too early. The ambient air will then be sucked in and mixed more effectively, and the temperature of the air stream will have a better chance to increase before it reaches the occupied zone.

If the sub-ambient-temperature air is directed along the ceiling in this way, it is also important that the air stream velocity is high enough to ensure that there is sufficient adherence to the ceiling. If the velocity is too low there is also a risk that the thermal energy will push the air stream down towards the floor too early.

At a certain distance from the supply-air diffuser, the air stream will in any case separate from the ceiling and deflect downwards. This deflection occurs more rapidly in an air stream that is below the ambient temperature, and therefore in such cases the throw will be shorter.

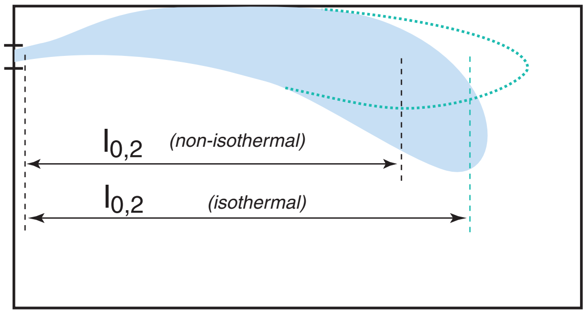


Figure 23. The difference between the throws of isothermal and non-isothermal air streams.

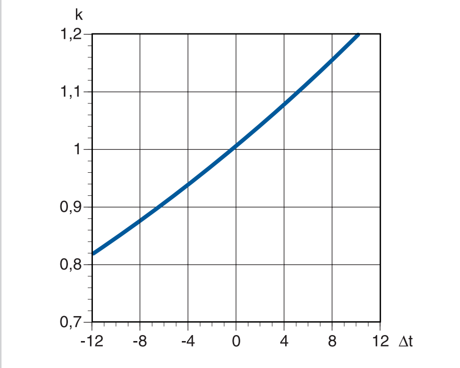
The air stream should have flowed through at least 60% of the room's depth before separating from the ceiling. The maximum velocity of the air in the occupied zone will thus be almost the same as when the air supply is isothermal.

The method for calculating where the air stream will separate from the ceiling is explained in the paragraph headed 'Non-isothermal air' on page 518.

When the supply air is below ambient temperature, the ambient air in the room will be cooled to some extent. The acceptable degree of cooling (known as the maximal cooling effect) depends on the air velocity requirements in the occupied zone, the distance from the diffuser at which the air stream separates from the ceiling, and also on the type of diffuser and its location.

In general a greater degree of cooling is accepted from a ceiling diffuser than a wall-mounted diffuser. This is because the air from a ceiling diffuser spreads in all directions, and therefore takes less time to mix together with the ambient air and to even out the temperature.

Correction of throw (estimate)
This diagram can be used to obtain an approximate value for the throw of non-isothermal air.

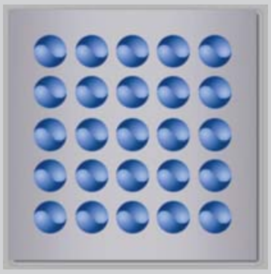


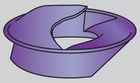
$l_{0.2}$ (corrected) = k · $l_{0.2}$ (isothermal air)

Maximum acceptable cooling effect
A rule of thumb for the maximum acceptable cooling effect (Q_{max}) is:

Supply air blown from rear wall
Q_{max} = 20-40 W per m² floor surface at Δt 8K

Supply air blown from ceiling
Q_{max} = 60-100 W per m² floor surface at Δt 12K





The nozzles on the new Sinus series have been specially designed to provide the fastest possible mixing of supply air with ambient.

Selecting the correct supply-air terminal device

A supply-air terminal device for ventilation by diffusion can be fitted on either the ceiling or the wall. Diffusers are often equipped with nozzles or perforations which facilitate the admixture of ambient air in the air stream.

Nozzle diffusers are the most flexible devices because they allow individual fitting of each nozzle. They are ideal for supplying air that is well below ambient temperature, particularly if they are fitted in the ceiling. The throw pattern can be altered by turning the nozzles in different directions.

Perforated diffusers have a positive effect where the air stream temperature is significantly below that of the ambient air. They are not as flexible as nozzle diffusers, but by shielding off the air supply in different directions it is still possible to change the distribution pattern.

Wall-mounted grilles have a long throw. They have limited possibilities for altering the distribution pattern, and they are not particularly suitable for the supply of air that is below ambient air temperature.

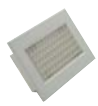
	Ceiling			**Wall**		
	 Nozzle diffuser	 Perforated diffuser	 Conical air distributor	 Nozzle diffuser	 Perforated diffuser	 Grille
Short throw	x	x	(x)	x	x	
Long throw	x			x		x
Flexible distribution pattern	x	(x)	(x)	x		
Sub ambient temperature air	x	(x)		x	(x)	

Table 3. Comparison of the different types of directional supply-air terminal device.