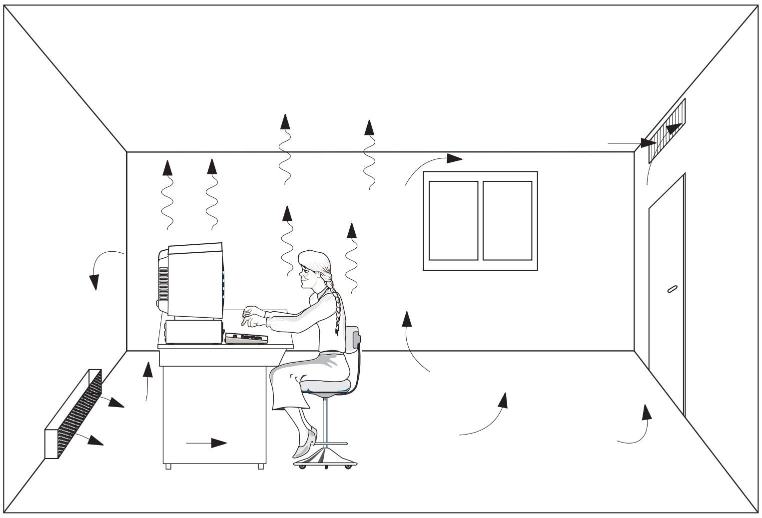
Technical Selection



Displacement ventilation
– General layout specifications

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Applied system solutions

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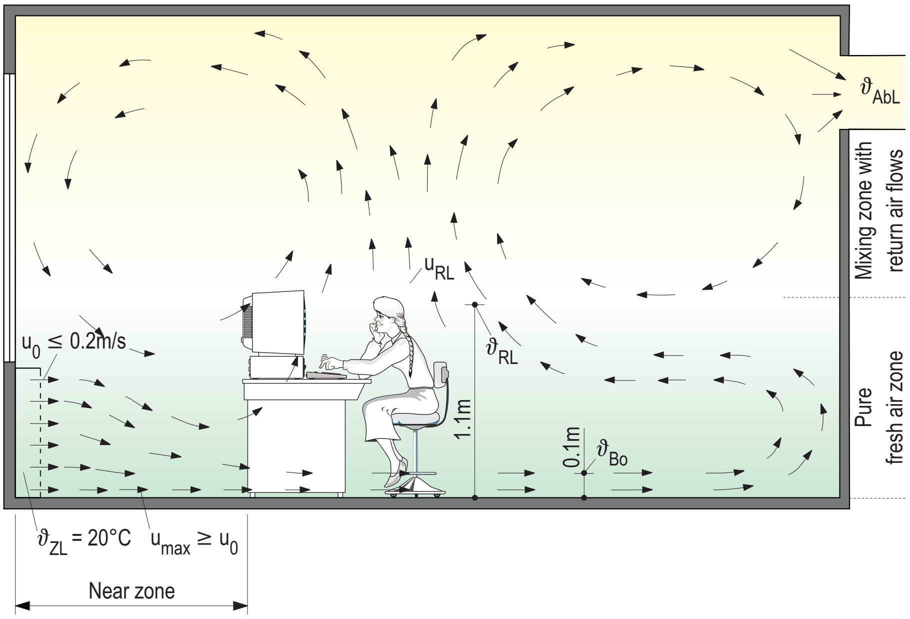
Displacement ventilation principle

The principle of displacement ventilation is based on the supply of low-momentum air and the natural buoyancy in the room caused by heat sources (people, lighting, electrical equipment). Displacement ventilation requires heat sources in the room and is usually applied to ventilate and cool the room. Room heating is possible with specially designed displacement outlets.

The displacement flow pattern is shown in Figure 1. The low-turbulence supply air, which is cooler than the indoor air, is discharged at low momentum and velocity (typically $u_0 \leq 0.2$ m/s) from a large-surface displacement outlet and slides in a thin layer into the room at floor level. Depending on outlet height and temperature difference between supply and indoor air, the supply air flows more or less downward. The air flow velocity can increase and attain a maximum of $u_{max,\ nah}$ in the floor zone at about 0.5 to 1.5 m from the outlet. It can exceed discharge velocity u_0. Flow velocity then declines to make for thermal comfort outside outlet proximity. The size of the near zone generally depends on the kind of outlet, the air volume flow rate and temperature difference between supply and indoor air.

Figure 2 is a sketch of the distribution of possible air contaminants (tobacco smoke) emitted at a heat source for example. These air contaminants are transported by the buoyancy above the heat sources to the ceiling zone and largely removed with the exhaust air. A small percentage only returns downward again with the back air flow into the room. As a result there are hardly any air contaminants in the lower pure fresh air segment



Key:
u_0 = Discharge velocity
u_{RL} = Indoor air velocity in occupied zone
u_{max} = Maximum air velocity
ϑ_{ZL} = Supply air temperature
ϑ_{RL} = Indoor air temperature at a height of 1.1 m
ϑ_{Bo} = Floor air temperature at a height of 0.1 m
ϑ_{AbL} = Exhaust air temperature

Figure 1: Displacement ventilation principle: Example with air supply in lower wall segment

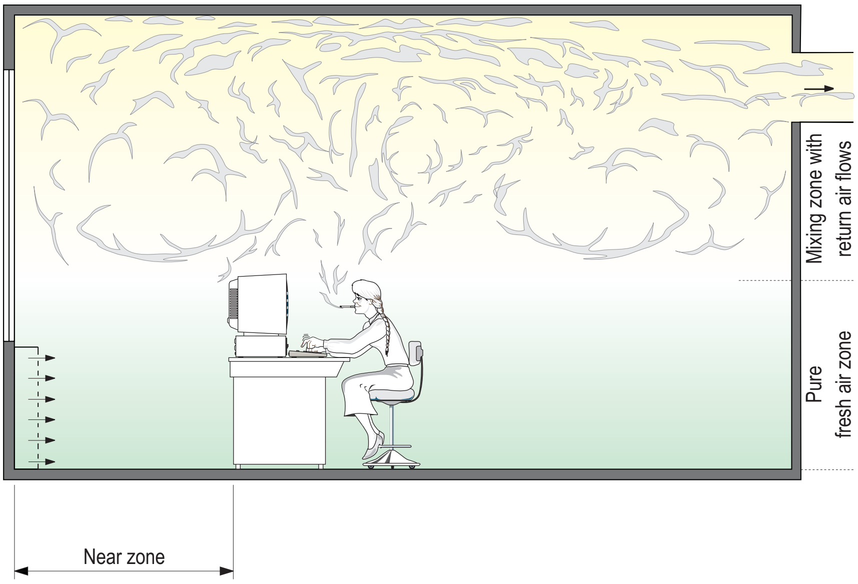


Figure 2: Distribution of air quality: Air contaminants occur caused by heat sources, such as occupants (e.g. smoking), EDP equipment, etc.

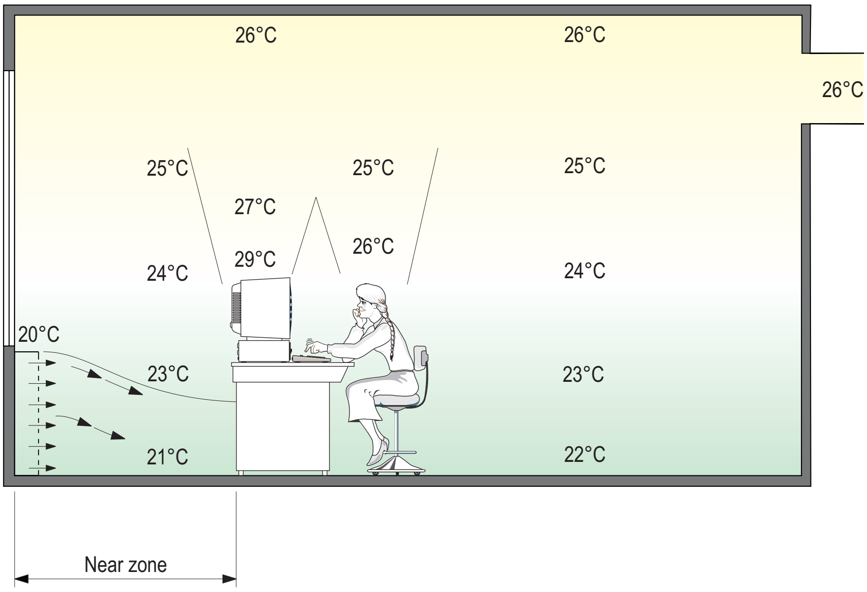


Figure 3: Example of temperature gradient in displacement ventilation

from where the occupants obtain most of the air they inhale, which ensures a high standard of air quality.

In addition to the stratification of possible air contaminants in the room, displacement ventilation produces a pronounced temperature gradient, as shown in Figure 3 for example. In the floor zone the air temperature rises at the warmer floor and due to a slight admixture of warmer indoor air. This is why the air temperature is already slightly higher here than supply air temperature.

Higher air temperatures occur in the buoyancy flow directly above heat sources (occupants, EDP equipment, etc.). Outside this buoyancy flow region, there is a gradual, almost consistently even rise in air temperature towards the ceiling, reaching a maximum at the ceiling in the exhaust air.

The layout requirements of a displacement ventilation system depend in part on the selected and/or admissible temperature gradient in the room. Yardsticks are:

– Temperature difference between head and feet (1) of a seated occupant to gauge comfort,
– Temperature difference between suppy and exhaust air to gauge room cooling load.

Layout specifications for displacement outlets

For a complete layout of displacement outlets, the following data are required or need to be taken into account:

a) General project data

– Room floor area A
– Room height H
– Length of room discharge wall L_W
– Cooling load to be removed $\dot{Q}$
– Supply air volume flow rate $\dot{V}_{ZL}$
– Minimum supply air temperature $\vartheta_{ZL\ min}$ (usually 20°C to 21°C)
– Required room temperature ϑ_{RL}
– Position of displacement outlets in room (window sill, corridor hall wall, floor zone and ceiling)

b) Comfort requirements

– Maximum indoor air velocity u_{RL} in occupied zone
or
– Indoor air velocities to DIN 1946 Part 2, i.e. maximum indoor air velocity correlated to temperature at floor and the degree of turbulence in accordance with the following table:

Air temperature in °C	21	22	23	24	25
Max. perm. indoor air velocity u_{RL} in m/s at degree of turbulence Tu = 20% 2)	0.16	0.17	0.19	0.21	0.23

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1) To DIN 1946, Part 2: max. 2 K/m; also called temperature gradient
2) Typical for displacement ventilation: Tu $\leq$ 20 %

- Max. perm. near zone in front of the displacement outlet where there are no fixed workplaces, as general comfort requirements cannot be met
- Admissible sound pressure level in room

c) Threshold values

- Temperature difference between supply and indoor air $\Delta\vartheta_{ZL-RL} \leq -3$ K
- Air temperature at floor $\vartheta_{Bo} \geq 21°C$[1],
- Temperature difference between indoor air and floor $\Delta\vartheta_{RL-Bo} \leq 2$ K.

For displacement ventilation in offices the maximum supply air volume flow rate is usually limited to 5.5 l/(s · m²) [20 m³/(h · m²)] for reasons of space. Fig. 4 shows the correlation between max. removable specific cooling load and specific volume flow rate.

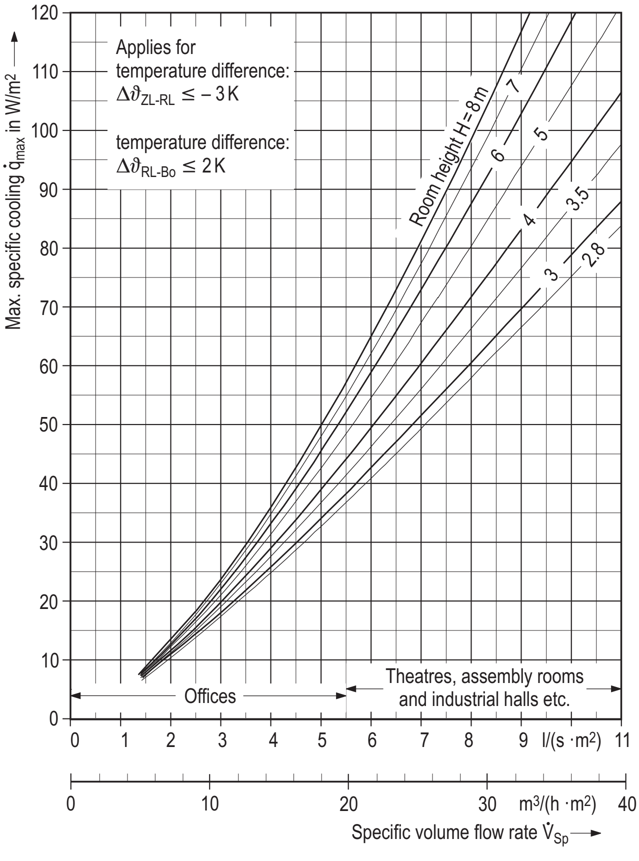

Figure 4: Standard specifications for max. specific cooling load depending on specific supply air volume flow rate

Determining temperature distribution

The vertical room temperature gradient in displacement ventilation can be determined in fair approximation with the aid of the nomogram (Figure 14). With the relevant temperatures needed to gauge comfort we can read off the temperature difference between

- supply air and exhaust air $\Delta\vartheta_{ZL-AbL}$
- indoor air and floor $\Delta\vartheta_{RL-Bo}$ (temperature gradient)

as well as floor air temperature ϑ_{Bo}. We can then calculate the removable specific cooling load.

Where the individual results (e.g. temperature gradient or specific cooling load) do not meet requirements we can take the altered values for the specific volume flow rate or the temperature difference between supply and indoor air and arrive at the necessary values in a second calculation step using the nomogram.

Displacement near zone

As mentioned at the beginnng and shown in Figure 1 higher indoor air velocity can occur in the displacement near zone that fall short of the comfort criteria to DIN 1946, Part 2. These near zones must therefore be accounted for when designing the layout for displacement outlets.

As adjacent displacement outlets influence one another, the near zones of individual displacement outlets or a displacement outlet row must be assessed differently.

The velocity distribution in a displacement near zone depends generally on displacement outlet geometry, discharge velocity, air volume flow rate and the temperature difference between supply and indoor air. Depending on the construction and size of the displacement outlets, the influence of these parameters on velocity distribution differs. The different types of displacement outlet are:

- Circular and semi-circular displacement outlets, single placement
- Rectangular displacement outlets, single placement
- Plinth displacement outlets, height H ≤ 150 mm as displacement outlet band
- Rectangular displacement outlets, height H ≤ 500 mm as displacement outlet band
- Rectangular displacement outlets, height H > 500 mm as displacement outlet band
- Semi-circular displacement outlets in rows
- Floor displacement outlets
- Displacement outlets in ceiling zone

The outlet **near zone $L_{0.2}$** enables a uniform valuation of the indoor air velocity in front of a displacement outlet.

The outlet near zone $L_{0.2}$ means the distance L from the air outlet at which maximum indoor air velocity

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[1] To DIN 1946, Part 2

≤ 0.2 m/s is attained and hence where the comfort requirement to DIN 1946, Part 2 is met at an air temperature of ≥ 23.5°C and a degree of turbulence of < 20 %.

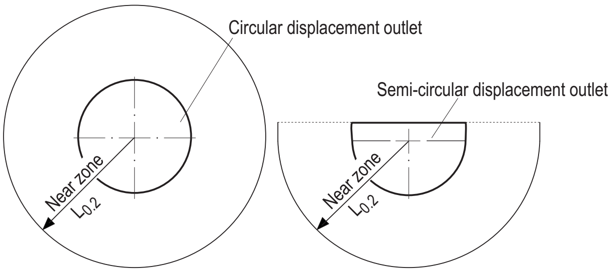
In the following, the **determination** of the **near zone** will be described for the above types.

Semi-circular and circular displacement outlets in single placement

With semi-circular displacement outlets especially at great heights and high volume flow rates the velocity increases substantially in the first metre after discharge due to the downward flow of the colder supply air. Flow velocity of up to 0.35 m/s can occur in this area. Due to the radial discharge flow caused by the circular outlet jacket the velocity however declines rapidly so that comfort conditions are achieved at a greater distance.

The indoor air velocites that determine the near zone are largely independent of discharge velocity, provided these are ≤ 0.25 m/s.

If a discharge velocity of ≤ 0.25 m/s is selected, the near zone $L_{0.2}$ at which maximum indoor air velocities amount to ≤ 0.2 m/s can be read off the chart in Figure 5 with adequate precision. The near zone $L_{0.2}$ for circular and semi-circular displacement outlets is measured from the air outlet axis.



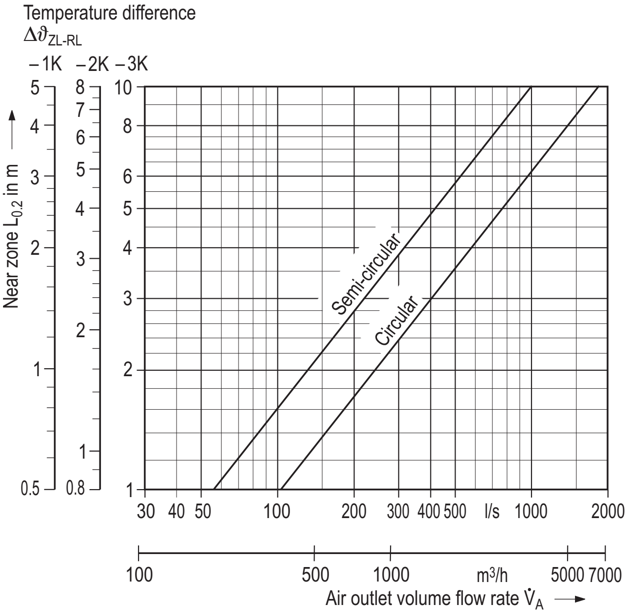
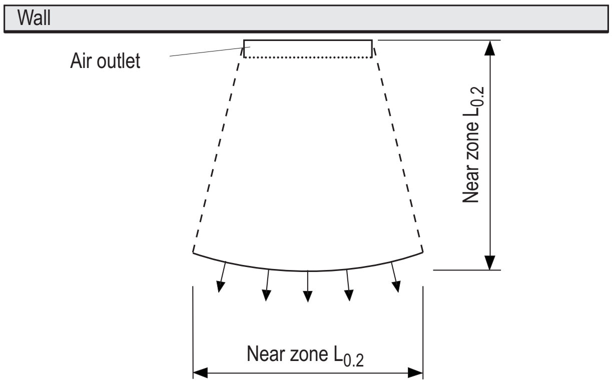


Figure 5: Near zone $L_{0.2}$ for circular and semi-circular displacement outlets, single placement

Rectangular displacement outlets, single placement

Due to the straight discharge the air tends to flow perpendicular into the room and spreads less radially than with the semi-circular displacement outlets. The near zone $L_{0.2}$ is shown in Figure 6.

Discharge velocity should be ≤ 0.25 m/s.



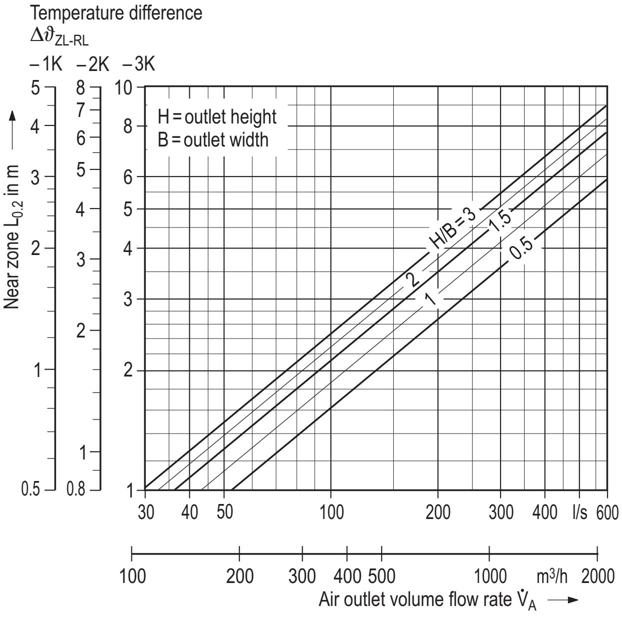


Figure 6: Near zone $L_{0.2}$ for rectangular displacement outlets, single placement

Plinth displacement outlet, height H ≤ 150 mm

These displacement outlets at a maximum height of 150 mm are best installed in offices under windows or cupboards. They are often placed at a short distance from one another or very close to each other forming a more or less continuous outlet band.

Due to the low discharge height there is no significant constriction of the discharge air flow so that maximum indoor air velocities correspond more or less to discharge velocities. When the occupied zone extends to directly in front of the displacement outlets, the discharge velocity should be ≤ 0.15 m/s. If there is a minimum distance to the outlet of 800 mm, a higher discharge velocity can be selected (Figure 7).

Occupied zone:	Max. discharge velocity u_0 in m/s	Air outlet height H in mm	Max. specific volume flow rate $\dot{V}_{Sp}$ in l/(s · m)
Up to the plinth displacement outlet	0.15	150	22
About 800 mm from the plinth displacement outlet	0.2	100	21
	0.18	150	28

Figure 7: Maximum specific volume flow rate depending on discharge velocity for plinth displacement outlets

Rectangular displacement outlets, height H ≤ 500 mm, as displacement outlet band

In this type of outlet the near zone depends on the discharge velocity and outlet height. It can be read off the chart in Figure 8.

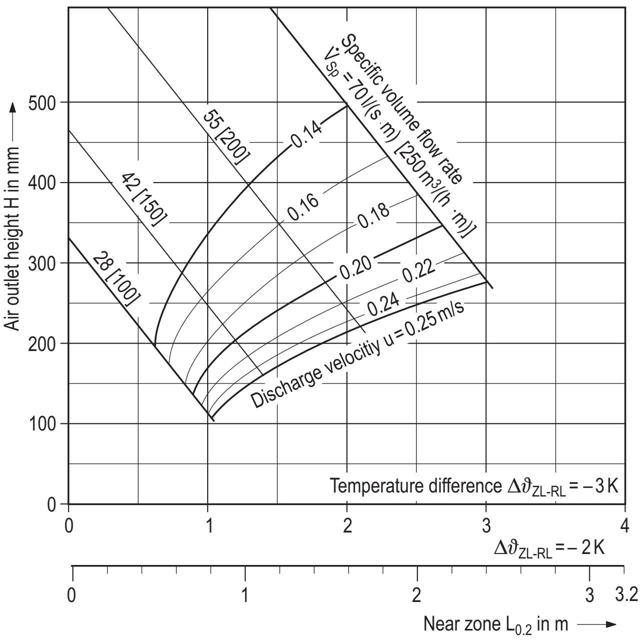


Figure 8: Near zone $L_{0.2}$ for rectangular displacement outlets with a height H ≤ 500 mm as displacement outlet band

If the occupied zone already begins at a distance of 800 mm from the air outlet the maximum specific volume flow rate can be read off the chart in Figure 9 as a function of the oulet height.

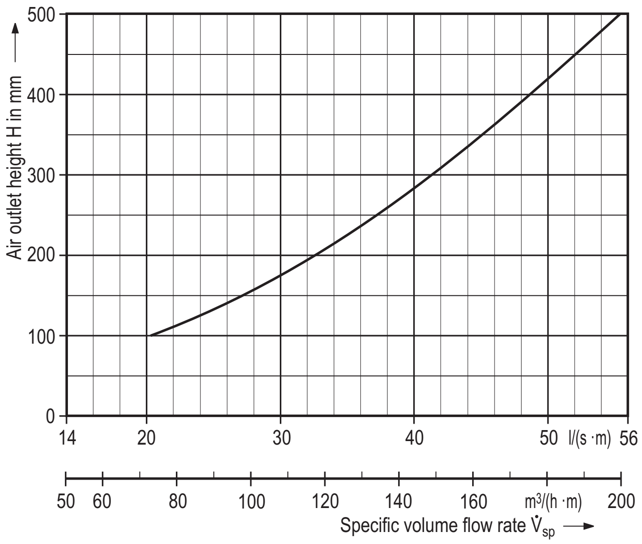


Figure 9: Maximum specific volume flow rate depending on outlet height for a near zone of 800 mm for rectangular displacement outlets with a height of H ≤ 500 mm as displacement outlet band

Rectangular displacement outlets with a height of H > 500 mm as displacement outlet band

In displacement outlets with a height of H > 500 mm the discharge velocity has very little influence on indoor air velocity from a distance of about 2 m and more. It is largely influenced by volume flow rate and the temperature difference between supply and indoor air.

If the supply air is discharged along the whole wall and if there are only a few heat sources near the wall the air flows in a straight line at almost constant velocity into the room until it encounters obstacles or heat sources.

At a distance of about 2 m to 4 m from the room wall maximum indoor air velocities in response to temperature difference and volume flow rate as shown in Figure 10 can occur.

The air velocities at a distance of up to about 2 m from the displacement outlets depend mainly on discharge velocity. This should not exceed 0.25 m/s. At low discharge velocities and larger outlet heights the air descends more sharply at a resultant higher velocity. The area of up to 2 m distance should therefore not be occupied.

Because the decline in velocity at larger distances (> 4 m) depends on room use (obstacles, heat sources) it cannot be determined in advance.

Figure 10 for example shows that at a temperature difference of $\Delta\vartheta_{ZL-RL} = -3$ K, maximum specific volume flow rate is 72 l/(s ·m) [260 m³/(h ·m)] for indoor air velocities under 0.2 m/s at a distance of > 2 m.

For larger volume flow rates higher indoor air velocities must be expected depending on furniture.

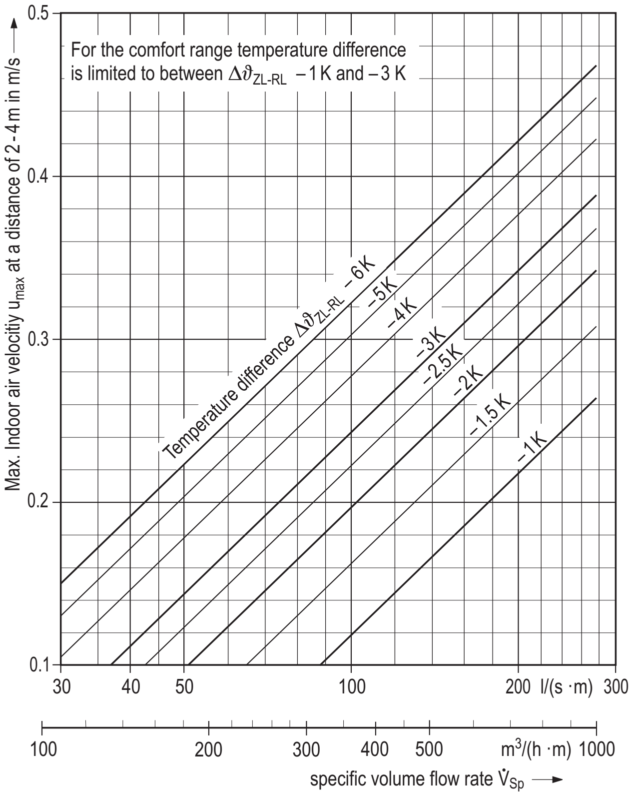


Figure 10: Specific volume flow rate depending on indoor air velocity for rectangular displacement outlets with a height of H > 500 mm as displacement outlet band

Semicircular displacement outlets in a row at a wall

If several semi-circular displacement outlets are placed in a row at a wall a similar flow pattern will emerge at about 3 m distance as with a rectangular displacement outlet band (see Pages 6 and 7). The indoor air velocities at about 3 m distance can be read off Figure 10. The specific volume flow rate equals the total volume flow rate divided by total width.

In the near zone of up to about 3 m distance from the wall the indoor air flow is comparable with that for individual semi-circular and circular displacement outlets. The indoor air velocity however declines with increasing distance due to reciprocal influence only to the values in line with Figure 10.

Near zones for other velocities

The near zones $L_{0.2}$ shown in Figures 5 and 6 apply for a maximum indoor air velocity of 0.2 m/s. For rectangular circular and semi-circular displacement outlets the near zones for other permissible indoor air velocities (0.15 to 0.3 m/s) can be calculated using the following equations:

$$Lu_X = L_{0.2} \cdot 0.2/u_X$$

Lu_X = near zone for a maximum indoor air velocity of u_X
u_X = maximum permissible indoor air velocity outside the near zone in m/s

Example:
For a semi-circular displacement outlet with a volume flow rate of 150 l/s and temperature difference between indoor and supply air of $\Delta\vartheta_{ZL-RL} = -3$ K, the near zone according to Figure 5 is ⇒ $L_{0.2}$ = 2.2 m. Converting this gives us for a permissible indoor air velocity of $u_X = 0.25$ m/s:

$$L_{0.25} = L_{0.2} \cdot 0.2/u_X = 2.5\text{ m} \cdot 0.2/0.25 = 2\text{ m}$$

This means that from a distance of about 2 m maximum indoor air velocity equals ≤ 0.25 m/s.

Penetration depth

A factor that needs to be determined when designing the layout of displacement ventilation systems is the penetration depth of air into the room. A permanent requirement is that the supply air temperature does not exceed room temperature since this prevents an adequate penetration depth.

The supply air flows outside the near zone in a very thin layer along the floor (normally at a height of H < 200 mm). Customary heat sources have minimum or no buoyancy at this height so that only a small percentage of supply air volume flow rate ascends directly. The major part of the supply air slides along the floor throughout the whole room up to the opposite wall (or up to the counterflow from displacement outlets on the opposite wall), ascends and flows at a height of about 0.3 to 1 m back to the heat sources in the room (cf. Figure 1). In this standard case flow pattern, penetration depth equals room depth.

Displacement ventilation

General layout specification

Where the ratio of supply air volume flow rate to heat sources is very low (< 7 l/s [25 m^3/h] per 100 W), penetration depth can drop to 4 m to 5 m. Penetration depths of 7 to 10 m are possible where there are no obstructions (such as closely arranged seating in assembly rooms) or heated surfaces (e.g. intensive solar gain) on the floor. If the penetration depth is not sufficient, additional displacement outlets must be placed in the room (e.g. floor displacement outlets, displacement outlets at pillars or at opposite walls). The radial penetration depth of the supply air flow or its coverage with floor displacement outlets amounts to about 4 to 5 m.

For the layout of pure displacement ventilation systems, penetration depth does not usually pose a constraint on layout design.

Floor displacement outlets

Floor displacement outlets are designed for rooms with raised or cavity floors. The supply air is discharged at an upward incline and at 0.5 m from the outlet it spreads at horizontal in radial mode in a layer near the floor into the room.

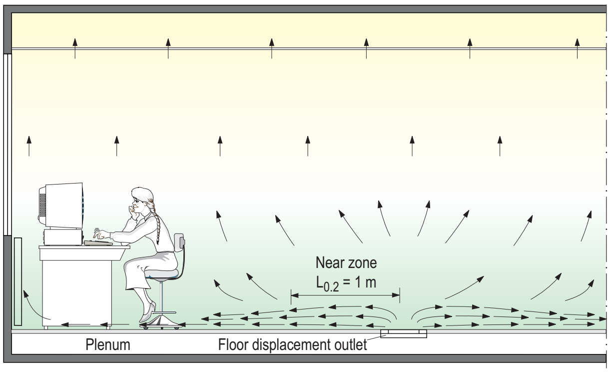


Figure 11: Air flow pattern of floor displacement outlet

The requisite near zone $L_{0.2}$ is about 1 m (distance from the outlet). The temperature gradient (distribution) in the room can be read off the nomogram in Figure 14.

Displacement outlets in ceiling zone

Displacement outlets can also be installed in the corridor wall under the ceiling or directly in the ceiling. Discharge velocity should not exceed 0.25 m/s.

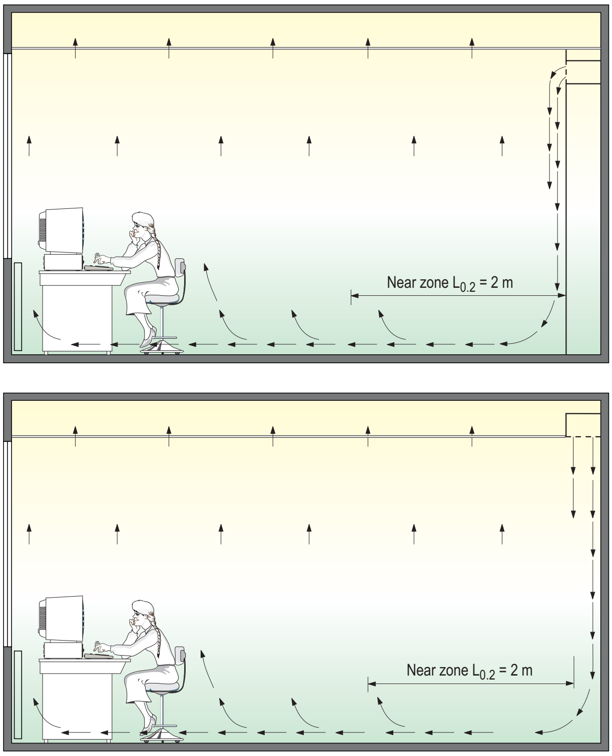


Figure 12: Air flow pattern of displacement outlets in ceiling zone
Above: positioned above the cupboard wall
Below: positioned in the ceiling

In its descent, the supply air flows along the wall or furniture surfaces and heats up by the time it reaches the floor to 1 to 1.5 K under room temperature. Near the floor a normal displacement ventilation is generated.

Maximum temperature difference between supply and indoor air can amount to as much as – 6 K and temperature difference between supply and exhaust air to about – 8 K. On discharge, supply air can therefore have a minimum temperature of 16°C.

The vertical temperature gradient in the occupied zone is always < 2 K/m so it does not need checking in Figure 14.

As the air flow under the air outlet accelerates, no permanent workplace should be installed here. The indoor air velocities in this area are > 0.25 m/s.

The near zone $L_{0.2}$ from the wall or from vertical to the air outlet in the ceiling amounts to about 2 m.

Plinth displacement outlet with built-in heating coil

Due to a built-in warm water heating coil, this special displacement outlet enables room heating in addition to cooling with cooled supply air. By installing the outlet under the window the room can be effectively heated and a cold air drop can be avoided. The mode of operation for heating is explained in the publication DS 4050.

Otherwise, the layout is the same as for the plinth displacement outlet.

Induction unit

Low rectangular displacement outlets and plinth displacement outlets can be fitted with an induction unit to mix secondary air (indoor air) with supply air before discharge into the room. A secondary air percentage of up to 50% of total volume flow rate is possible, depending on outlet dimensions. Instead of the usual 2 K to 3 K, the primary air temperature can be about 5 K to 6 K lower than room temperature. A larger room cooling load can therefore be removed while maintaining comfort conditions.

Technical layout documents

Further details on displacement outlets, such as construction specifications, sizes, sound power level and pressure loss, are available in the product layout documents. The following publications are available for displacement outlets:

Rectangular displacement outlets	DS 4021
Circular and semi-circular displacement outlets	DS 4022
Plinth displacement outlet	DS 4008, 4050
Combined displacement outlets	DS 4055
Floor displacement outlets	DS 4007, 4047, 4062

Layout example

The dimensions of rectangular displacement outlets need to be determined (see publication DS 4021) for an office room with a layout as depicted in Figure 13 and the given project data specifications.

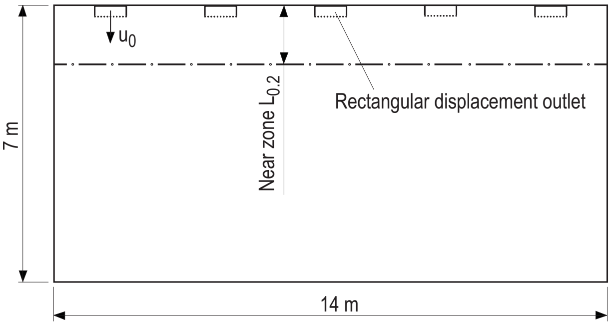


Figure 13: Layout of an office room as a layout example

Project data:

1	Floor area	A	=	70 m^2	
2	Room height	H	=	3.5 m	
3	Supply air temperature	ϑ_{ZL}	=	20°C	
4	Temperature difference between supply and indoor air	$\Delta\vartheta_{ZL-RL}$	=	– 3K	
5	Indoor air temperature	ϑ_{RL}	=	23°C	[**3** + **4**]
6	Room cooling load	$\dot{Q}$	=	2570 W	
7	Maximum specific room cooling load	$\dot{q}_{max}$	≈	37 W/m^2	[**6** : **1**]
8	Maximum specific volume flow rate	$\dot{V}_{Sp}$	=	5 l/(s · m^2) [18 m^3/(h · m^2)]	[**Fig. 4**]
9	Supply air volume flow rate	$\dot{V}_{ges}$	=	350 l/s [1260 m^3/h]	[**1** · **8**]

From nomogram (Figure 14):

10	Temperature difference between indoor air and floor	$\Delta\vartheta_{RL-Bo}$	=	1.4 K 1)
11	Floor temperature	ϑ_{Bo}	=	21.6°C
12	Temperature difference between supply and exhaust air	$\Delta\vartheta_{ZL-AbL}$	=	– 6 K
13	Actual removable specific cooling load	$\dot{q}_{tats}$	≈	37 W/m^2 1)

From publication DS 4021, Rectangular displacement outlet:

14	Size	H x B x T	=	500 x 880 x 200	in mm
		b x t	=	250 x 100	in mm
15	Number	n	=	5 units	
16	Outlet volume flow rate	$\dot{V}_A$	=	70 l/s [252 m^3/h]	[**9** : **15**]
17	Discharge velocity	u_0	=	0.18 m/s	
18	Sound power level	L_{WA}	≈	23 dB(A)	ref. 10^{-12} W
19	Total pressure loss	Δp_t	=	12 Pa	

From available publication (Figure 6):

20 Near zone $L_{0.2}$ ≈ 1.2 m
(for $\dot{V}_A$ = 70 l/s [252 m^3/h], H/B = 0.5 and $\Delta\vartheta_{ZL-RL}$ = – 3 K)

Subject to technical alterations!

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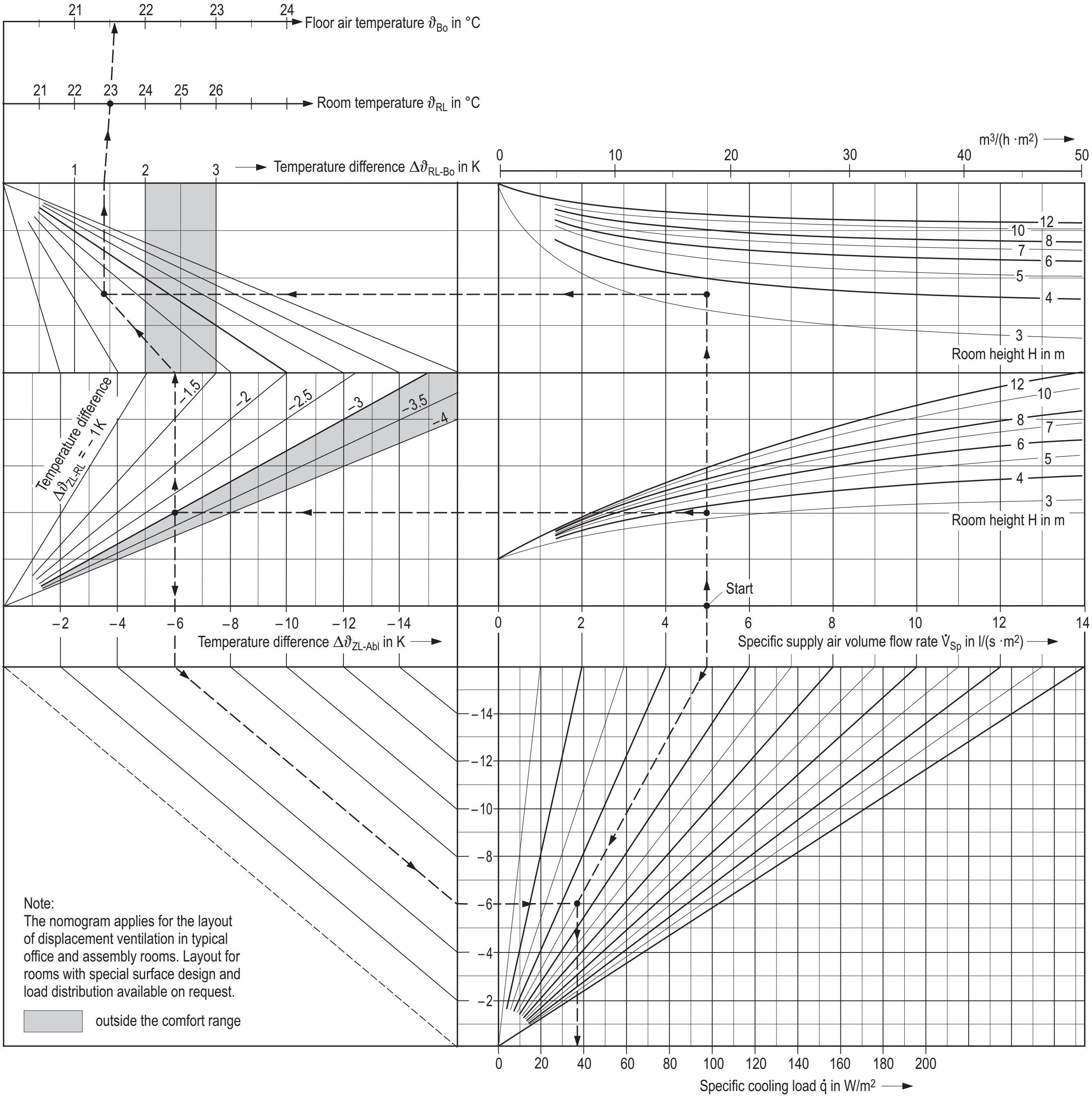
1) Where the value determined does not meet requirements, the selected specific volume flow rate or the temperature difference $\Delta\vartheta_{ZL-RL}$ can be altered to obtain the desired result.



Note:
The nomogram applies for the layout of displacement ventilation in typical office and assembly rooms. Layout for rooms with special surface design and load distribution available on request.

▨ outside the comfort range

Figure 14: Nomogram to determine temperature gradient and removable cooling load

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