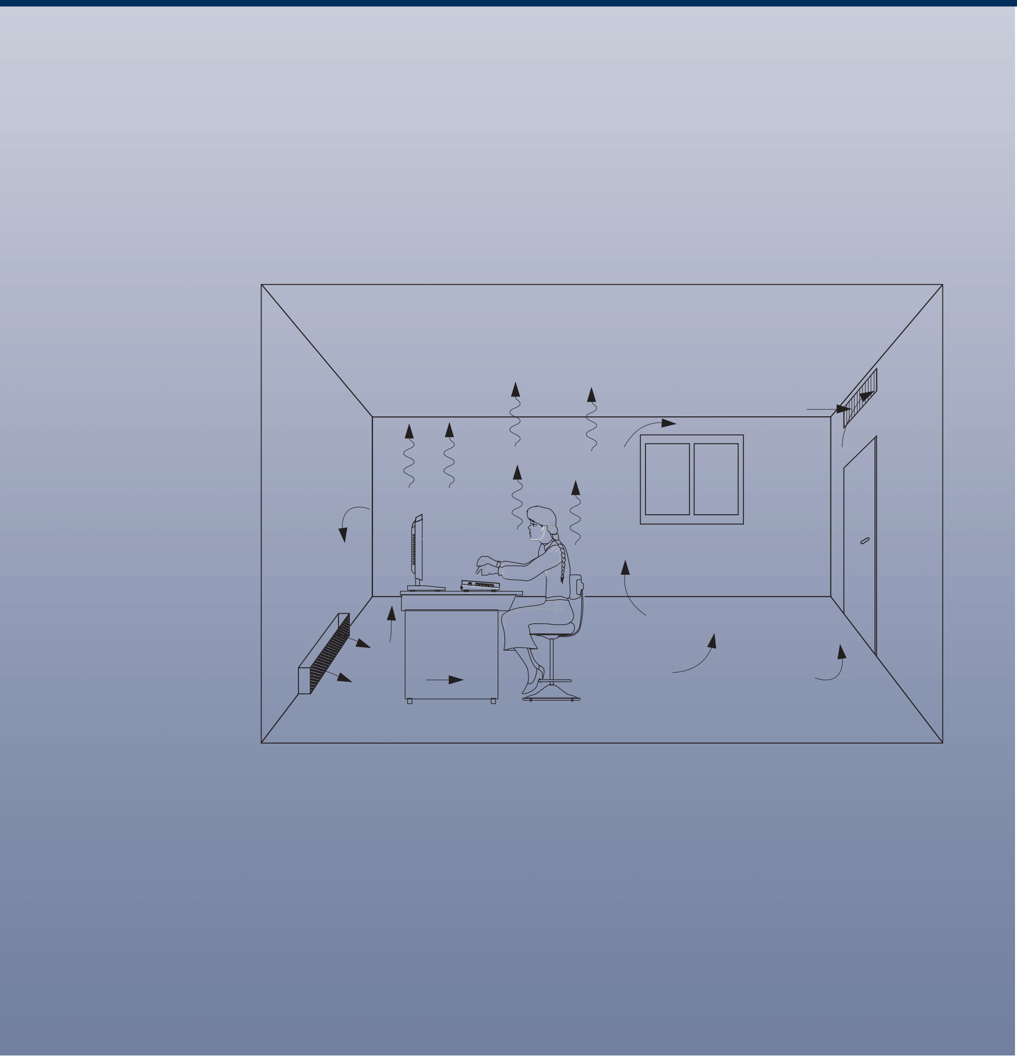
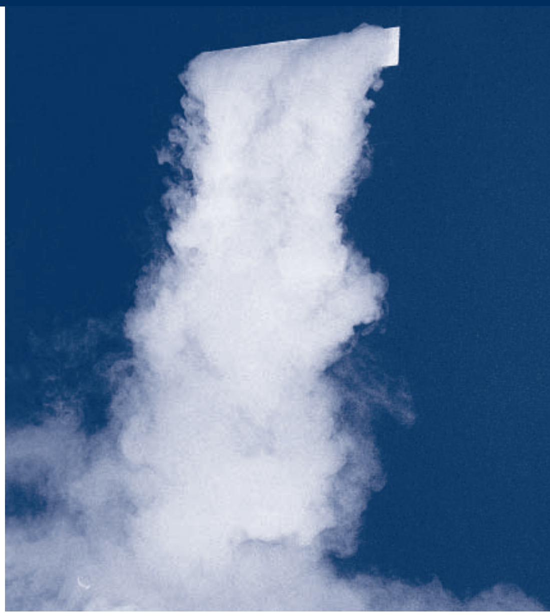
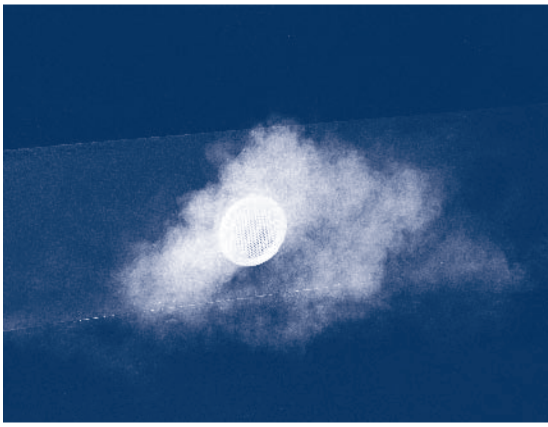
Air distribution systems







Displacement ventilation for commercial applications

General layout specifications

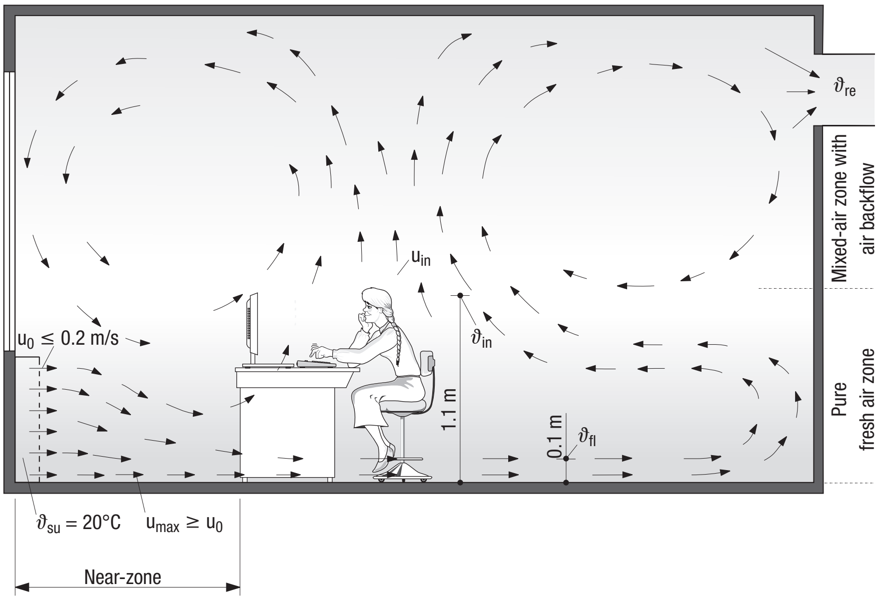
DS 4069 E 04.2014

Displacement ventilation principle

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

The displacement ventilation principle is shown in Fig. 1. The supply air, which is cooler than the indoor air, is discharged at low momentum and velocity (typically $u_0 \leq 0.2$ m/s) and at low turbulence from a large-surface displacement outlet, and slides through the room in a thin layer close to the floor. Depending on outlet height and temperature difference between supply and indoor air, the supply air flows more or less sharply downwards. The air flow velocity may then rise and attain a maximum (u_{max}) at floor level, at about 0.5 to 1.5 m from the outlet, which may exceed the discharge velocity u_0. The flow velocity then decreases, which ensures thermal comfort outside the outlet near-zone. The extent of the near-zone generally depends on the kind of outlet, the air volume flow rate and the temperature difference between supply and indoor air.

Fig. 2 illustrates schematically the distribution of potential air contaminants (tobacco smoke) emitted at a heat source. The air contaminants are conveyed by the warm buoyancy-driven flow above the heat source towards the ceiling where the main part is extracted together with the return air. Only a small percentage returns into the room together with the air backflow. As a result there are hardly any contaminants in the low-level pure fresh air zone from where the occupants obtain most of the air they inhale, which ensures a high standard of air quality.



Key

- u_0 = discharge velocity
- u_{in} = indoor air velocity in the occupied zone
- u_{max} = maximum air velocity
- ϑ_{su} = supply air temperature
- ϑ_{in} = indoor air temperature at 1.1 m height
- ϑ_{fl} = near-floor air temperature at 0.1 m height
- ϑ_{re} = return air temperature

Fig. 1: Displacement ventilation principle: example with air supply from lower wall area

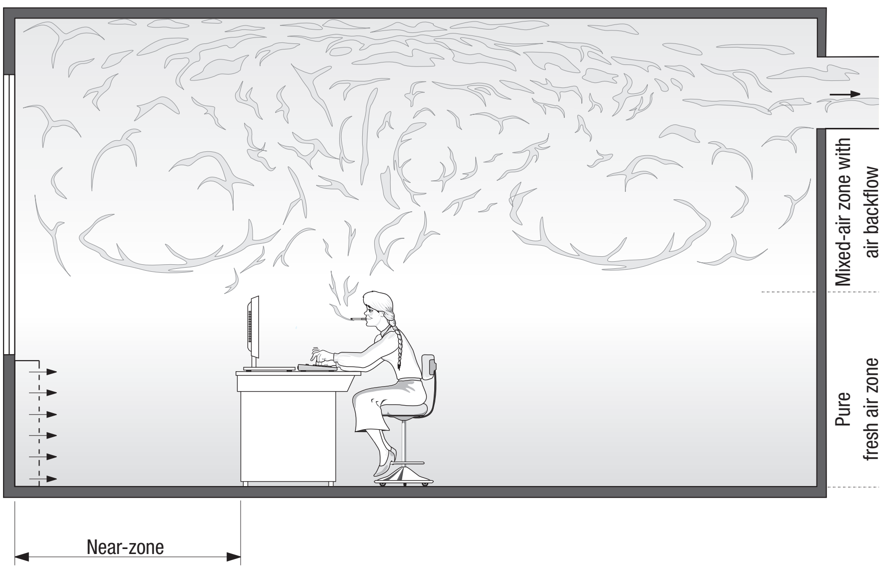


Fig. 2: Spread of contaminated air: air contaminants are mainly generated by heat sources such as occupants (e.g. by smoking), IT equipment, etc.

Displacement ventilation

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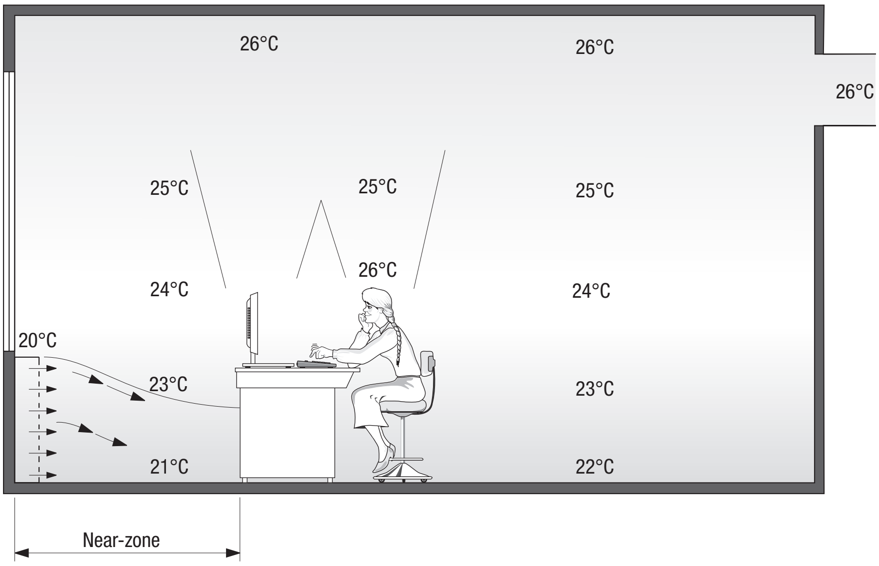


Fig. 3: Example of temperature stratification in displacement ventilation

In addition to the stratification of potential air contaminants in the room, displacement ventilation produces a pronounced temperature stratification as the example in Fig. 3 shows. At floor level the air temperature rises because the floor is warmer and some warmer indoor air mixes with the supply air. This explains why the air temperature here is slightly higher than the supply air temperature.

The air temperatures are higher within the buoyancy-driven flows directly above the heat sources (occupants, IT equipment, etc.). Outside these flows, the air temperature rises gradually and rather evenly towards the ceiling where it reaches a maximum (temperature of return air).

The layout requirements for a displacement ventilation system depend in part on the selected and/or allowable temperature distribution in the room. Yardsticks are:

– temperature difference between feet and head [1] of a seated occupant to evaluate thermal comfort,
– temperature difference between supply and return air to calculate the internal cooling load.

[1] Depending on the category selected for thermal environment to EN ISO 7730
[2] Typical of displacement ventilation: Tu ≤ 25%

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 wall from which the air will be discharged
– Cooling load to be removed $\dot{Q}$
– Supply air volume flow rate $\dot{V}_{su}$
– Minimum supply air temperature $\vartheta_{su\ min}$ (usually 20 to 21 °C)
– Required indoor air temperature ϑ_{in}
– Location of displacement outlets in room (window parapet, corridor wall, floor zone or ceiling).

b) Thermal comfort requirements

– Maximum indoor air velocity u_{in} in the occupied zone
  or
  indoor air velocities to EN ISO 7730 in relation to indoor air temperature and turbulence intensity in line with the following table:

Air temperature in °C	Category	21	22	23	24	25
Local mean indoor air velocity u_{in} in m/s at turbulence intensity Tu = 20% [2]	A	0.13	0.14	0.15	0.16	0.17
	B	0.20	0.22	0.24	0.26	0.28

- Maximum permitted near-zone in front of the displacement outlets with no permanent workplaces (since the comfort requirements cannot be met there)
- Allowable sound pressure level in room.

c) Limit values [1)]

- Temperature difference between supply and indoor air $\Delta\vartheta_{su-in} \leq -3$ K
- Near-floor air temperature $\vartheta_{fl} \geq 21$°C
- Temperature difference between indoor air and near-floor temperature $\Delta\vartheta_{in-fl} \leq 2$ 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 the maximum removable specific cooling load and the specific volume flow rate.

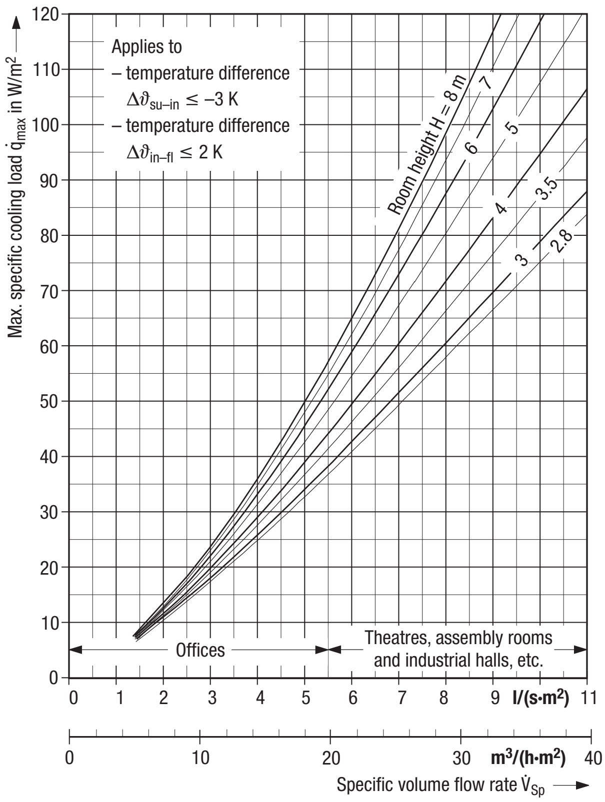


Fig. 4: Guidance values for max. specific cooling load depending on specific supply air volume flow rate

Determining the temperature distribution

The vertical temperature gradient associated with displacement ventilation can be determined in fair approximation using the nomogram in Fig. 13. With the temperatures needed to evaluate comfort you can read off the temperature differences between

- supply air and return air $\Delta\vartheta_{su-re}$
- indoor air and floor $\Delta\vartheta_{in-fl}$ (temperature gradient)

and the near-floor air temperature ϑ_{fl}. Another step enables to calculate the removable specific cooling load.

If any of the results (e.g. temperature gradient or specific cooling load) do not meet the requirements, the values for the specific volume flow rate or temperature difference between supply and indoor air can be altered and the corresponding results derived from the nomogram so as to fulfil the comfort criteria.

Near-zone around displacement outlets

As mentioned at the beginning and shown in Fig. 1, increased indoor air velocities may occur in the outlet near-zone that do not fulfil the comfort criteria to EN ISO 7730. The near-zones must therefore be considered when selecting displacement outlets.

As adjacent displacement outlets influence one another, the near-zone of a single displacement outlet or a row of outlets must be assessed in a different manner.

The velocity distribution in the near-zone of a displacement outlet generally depends on the outlet geometry, discharge velocity, air volume flow rate and temperature difference between supply and indoor air. These parameters have a more or less great influence on velocity distribution, depending on outlet type and size. The different types of displacement outlets available are:

- Circular and semi-circular displacement outlets, in single placement
- Rectangular displacement outlets, in single placement
- 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 a row
- Floor displacement outlets
- Displacement outlets in the ceiling area.

A consistent method of assessment of indoor air velocities in front of a displacement outlet is provided by the layout value '**near-zone $L_{0.2}$**'.

The near-zone $L_{0.2}$ refers to the distance L from the outlet at which the maximum indoor air velocity is ≤ 0.2 m/s.

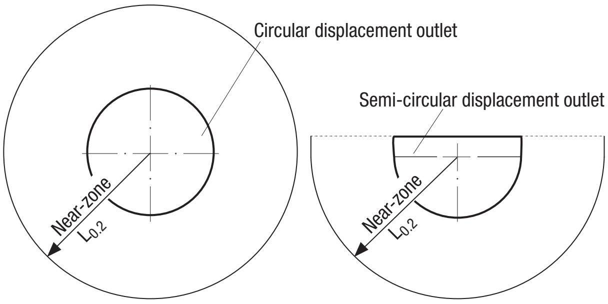
The following subsections describe how to determine the near-zone for the above-mentioned outlet types.

[1)] For compliance with category A to EN ISO 7730

Circular and semi-circular displacement outlets in single placement

With circular and semi-circular displacement outlets, especially for great outlet heights and high volume flow rates, the air velocity increases substantially within the first metre upon discharge of the colder supply air flowing downwards. In this zone the air velocities can reach up to 0.35 m/s. Yet the radial supply air flow generated by the outlet casing causes the velocity to decrease rapidly so that comfort conditions are achieved at a greater distance.

The indoor air velocities that determine the near-zone are largely independent of the discharge velocity provided this is ≤ 0.25 m/s.



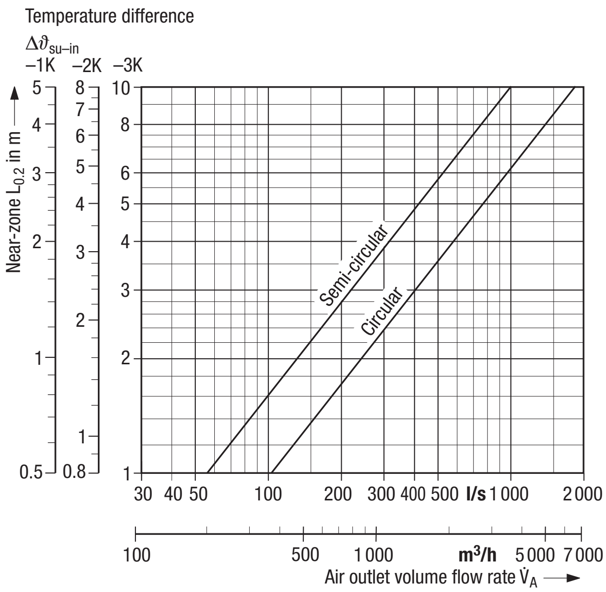


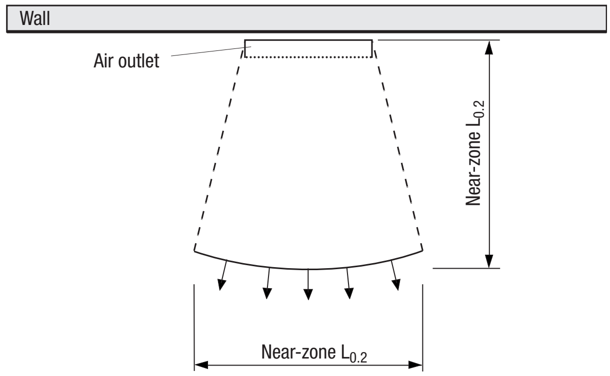
Fig. 5: Near-zone $L_{0.2}$ for circular and semi-circular displacement outlets in single placement

If a discharge velocity ≤ 0.25 m/s is selected, the near-zone $L_{0.2}$ at which the maximum indoor air velocities u_{max} are ≤ 0.2 m/s can be read off the chart in Fig. 5 with enough accuracy. The near-zone $L_{0.2}$ for these displacement outlets is measured from their axis.

Rectangular displacement outlets in single placement

As air discharge is linear, the supply air tends to flow perpendicularly to the discharge surface and spreads less radially than is the case with semi-circular displacement outlets. The near-zone $L_{0.2}$ is shown in Fig. 6.

The discharge velocity should be ≤ 0.25 m/s.



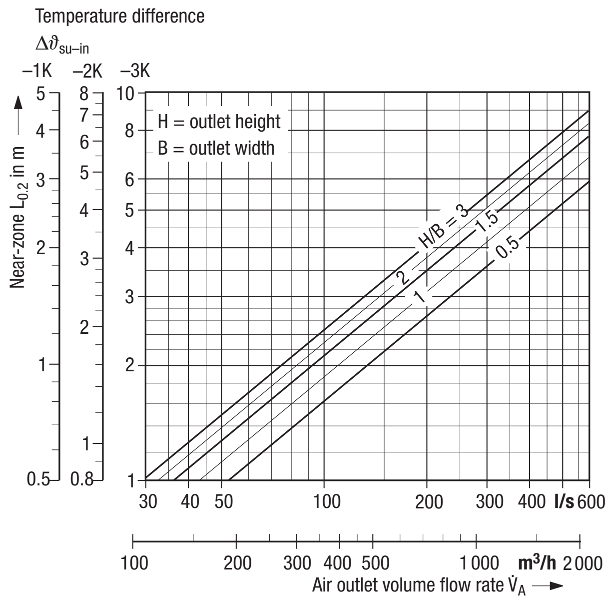


Fig. 6: Near-zone $L_{0.2}$ for rectangular displacement outlets in single placement

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

With this type of outlet, the near-zone depends on discharge velocity and outlet height. It can be read off the chart in Fig. 7.

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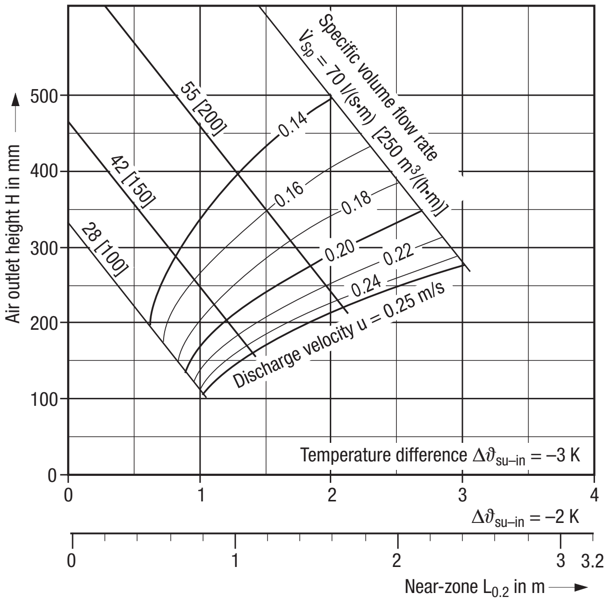

Fig. 7: Near-zone $L_{0.2}$ for rectangular displacement outlets, with H ≤ 500 mm, as displacement outlet band

If the occupied zone already begins at 800 mm from the air outlet, the maximum specific volume flow rate can be read off the chart in Fig. 8 as a function of the outlet height.

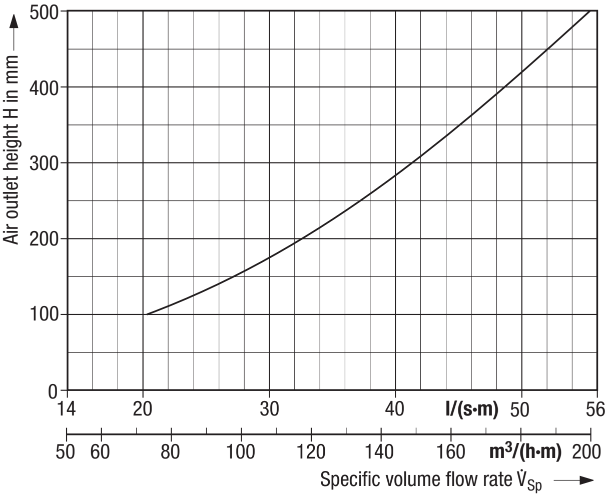

Fig. 8: Maximum specific volume flow rate depending on outlet height, for a near-zone of 800 mm, for rectangular displacement outlets with H ≤ 500 mm as displacement outlet band

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

With rectangular displacement outlets with a height H > 500 mm, the discharge velocity has less influence on the indoor air velocity at a distance of about 2 m and over. This is mainly influenced by the volume flow rate and the temperature difference between supply and indoor air.

If the supply air is discharged along the entire wall and if there are only few heat sources near the wall, the air flows in a linear pattern at almost constant velocity until it encounters obstacles or heat sources.

At about 2 to 4 m from the room wall, the maximum indoor air velocities can be as shown in Fig. 9 depending on temperature difference and volume flow rate.

At a distance of up to about 2 m from the displacement outlets, the air velocities depend mainly on the discharge velocity which should not exceed 0.25 m/s. At low discharge velocities and with greater outlet heights, the air flows more sharply downwards and, as a result, at higher velocity. The zone up to 2 m from the outlet should therefore not be occupied.

At a greater distance (> 4 m) the decrease in velocity depends on the room use (heat sources, obstacles) so it cannot be determined in advance.

Fig. 9 shows, for instance, that at a temperature difference $\Delta\vartheta_{su-in}$ = –3 K the maximum specific volume flow rate is 72 l/(s•m) [260 m³/(h•m)] with indoor air velocities under 0.2 m/s at a distance > 2 m.

For larger volume flow rates higher indoor air velocities are to be expected depending on room furniture.

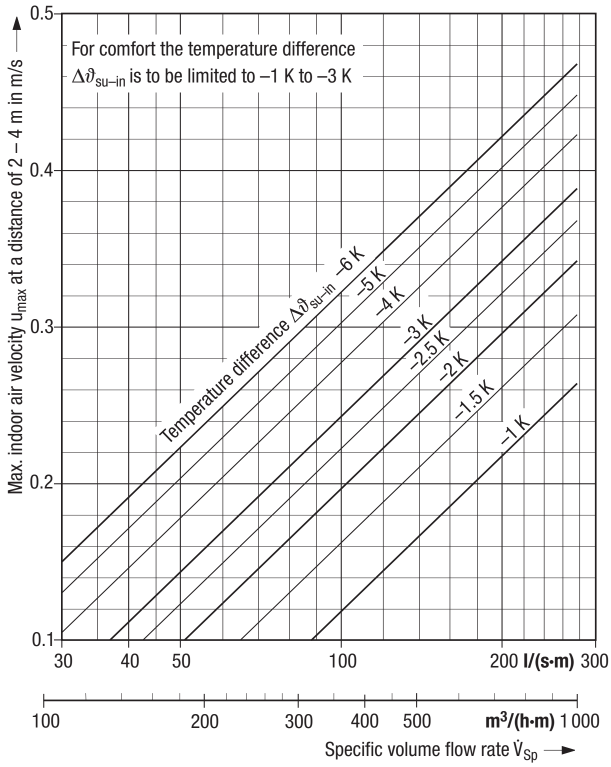

Fig. 9: Specific volume flow rate depending on indoor air velocity for rectangular displacement outlets with H > 500 mm as displacement outlet band

Semi-circular displacement outlets in a row along a wall

If several semi-circular displacement outlets are placed in a row along a wall, at about 3 m and more the flow pattern will be similar to that obtained with a rectangular displacement outlet band (see page 6). The indoor air velocities at this distance can be read off Fig. 9. The specific volume flow rate is equal to the total volume flow rate divided by the total outlet width.

In the near-zone up to about 3 m from the wall, the indoor air flow is comparable with that of single semi-circular and circular displacement outlets. Yet, with increasing distance, the indoor air velocity decreases only up to the values given in Fig. 9 owing to reciprocal influence.

Floor displacement outlets

Floor displacement outlets are designed for rooms with raised floors or floor plenums. The supply air is discharged at an upward incline, and at 0.5 m from the outlet it spreads within the room horizontally and radially in a layer close to the floor.

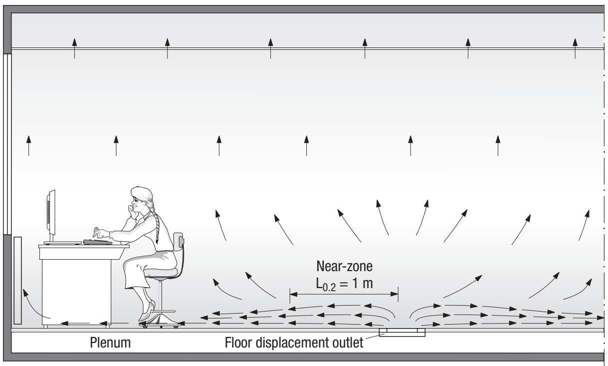

Fig. 10: Air flow pattern of floor displacement outlet

Here the near-zone $L_{0.2}$ is about 1 m (from the outlet). The temperature distribution within the room can be determined with the nomogram in Fig. 13.

Displacement outlets in ceiling area

Displacement outlets can also be installed in the corridor wall, below the ceiling, or inside the ceiling. The discharge velocity should not exceed 0.25 m/s.

Upon discharge the supply air flows downwards along the wall or wall furniture, if any, and heats up to 1 to 1.5 K under the room temperature by the time it reaches the floor. Near the floor the air flow is a normal displacement flow.

The maximum temperature difference between supply and indoor air can amount to –6 K and that between supply and return air to about –8 K. The supply air may therefore be discharged at a minimum temperature of 16°C.

The vertical temperature gradient in the occupied zone is always < 2 K/m so it does not need to be checked in Fig. 13.

No permanent workplace should be installed under the air outlet as the air flow accelerates in this area, with indoor air velocities being > 0.25 m/s.

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

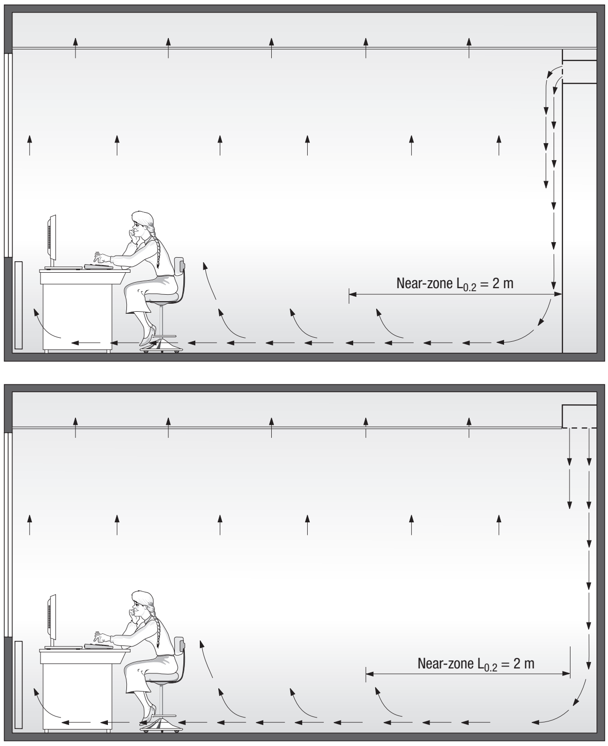

Fig. 11: Air flow pattern with displacement outlets mounted in the ceiling area

top: in the corridor wall

bottom: in the ceiling

Near-zones for other indoor air velocities

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

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

where

Lu_X = near-zone for a maximum indoor air velocity u_X

u_X = maximum allowable 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 [500 m³/h] and a temperature difference between supply and indoor air $\Delta\vartheta_{su-in}$ = –3 K, the near-zone according to Fig. 5 is: $L_{0.2}$ = 2.1 m. By conversion, the near-zone for a maximum allowable indoor air velocity u_X = 0.25 m/s is:

$L_{0.25} = L_{0.2} \cdot 0.2/u_X = 2.1\ \text{m} \cdot 0.2/0.25 \approx 1.7\ \text{m}$.

This means that at about 1.7 m and over from the outlet the maximum indoor air velocity u is ≤ 0.25 m/s.

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Penetration depth

A parameter that needs to be considered when designing displacement ventilation systems is the depth of air penetration into the room. A basic requirement is that the supply air temperature does not exceed the room temperature since this would prevent the air from penetrating deep enough into the room.

Outside the near-zone the supply air flows in a very thin layer above the floor (normally at a height H < 200 mm). As common heat sources have very little or no buoyancy at this height, only a small percentage of the supply air volume flow rate moves directly upwards. The major part of the supply air slides above the floor throughout the room up to the opposite wall (or up to the counterflow from displacement outlets, if any, on the opposite wall), moves upwards and, at a height of about 0.3 to 1 m, flows back to the heat sources in the room (cf. Fig. 1). In this standard-case flow pattern, penetration depth equals room depth.

Where the supply air volume flow rate is very low in relation to heat sources (< 7 l/s [25 m^3/h] per 100 W), the penetration depth may drop to 4 to 5 m. Penetration depths of 7 to 10 m are achievable where there are no obstructions (such as closely arranged seating in assembly rooms) or heated surfaces (due to intensive solar gain, for instance) 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 against pillars or along the opposite wall). The penetration depth of the supply air flow, or rather its coverage radius with floor displacement outlets, amounts to about 4 to 5 m.

When designing pure displacement ventilation systems, the penetration depth is normally not a limiting design criterion.

Induction unit

Low-height rectangular 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 the total supply air volume flow rate is possible depending on outlet dimensions. Thus, instead of the usual 2 to 3 K, the primary air temperature can be about 5 to 6 K lower than the room temperature. This makes it possible to remove a higher internal cooling load while maintaining comfort conditions.

[1] Where the value determined does not meet the requirements, the selected specific volume flow rate or the temperature difference $\Delta\vartheta_{su-in}$ can be altered in order to fulfil the comfort criteria

Technical layout documents

Further details on displacement outlets (such as design features, sizes available, sound power level and pressure drop) are contained in the relevant product brochures listed below:

Rectangular displacement outlets	DS 4021
Circular and semi-circular displacement outlets	DS 4022
Wall displacement outlets	DS 4055
Ceiling displacement outlets	DS 4079
Floor displacement outlets	DS 4007, 4047, 4062
Seat displacement outlets	DS 4028
Step displacement outlets	DS 4054

Layout example

Rectangular displacement outlets (cf. brochure ref. DS 4021) for an office space with a ground plan as in Fig. 12 and the project data mentioned below.

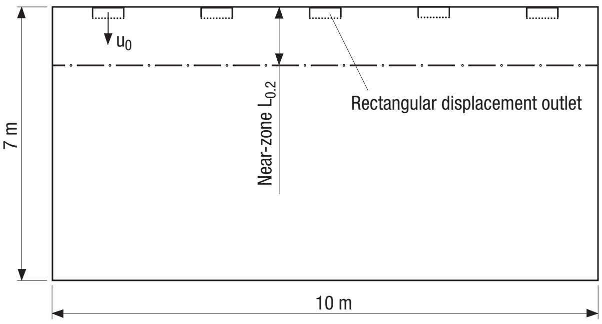

Fig. 12: Ground plan of an office space

Project data:

1	Floor area	A	=	70 m^2	
2	Room height	H	=	3.5 m	
3	Supply air temperature	ϑ_{su}	=	20 °C	
4	Temperature difference supply to indoor air	$\Delta\vartheta_{su-in}$	=	–3 K	
5	Indoor air temperature	ϑ_{in}	=	23 °C	[**3** + **4**]
6	Internal cooling load	$\dot{Q}$	=	2 570 W	
7	Max. specific internal cooling load	$\dot{q}_{max}$	≈	37 W/m^2	[**6** : **1**]
8	Specific volume flow rate	$\dot{V}_{Sp}$	=	5 l/(s·m^2) [18 m^3/(h·m^2)]	[Fig. 4]
9	Total supply air volume flow rate	$\dot{V}_{tot}$	=	350 l/s [1 260 m^3/h]	[**1** · **8**]

From nomogram (Fig. 13):

10	Temperature difference indoor air to near-floor temp.	$\Delta\vartheta_{in-fl}$	=	1.4 K	[1]
11	Near-floor temperature	ϑ_{fl}	=	21.6 °C	
12	Temperature difference supply to return air	$\Delta\vartheta_{su-re}$	=	–6 K	
13	Actually removable specific cooling load	$\dot{q}_{act}$	≈	37 W/m^2	[1]

Displacement ventilation

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From brochure DS 4021, rectangular displacement outlet:

14 Outlet size	H x B x T	=	500 x 880 x 200	in mm
	b x t	=	250 x 100	in mm
15 Number of outlets	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)	
19 Total pressure drop	Δp_t	=	12 Pa	

From this publication (Fig. 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 $\Delta\vartheta_{su-in}$ = –3 K)

Subject to technical alterations.

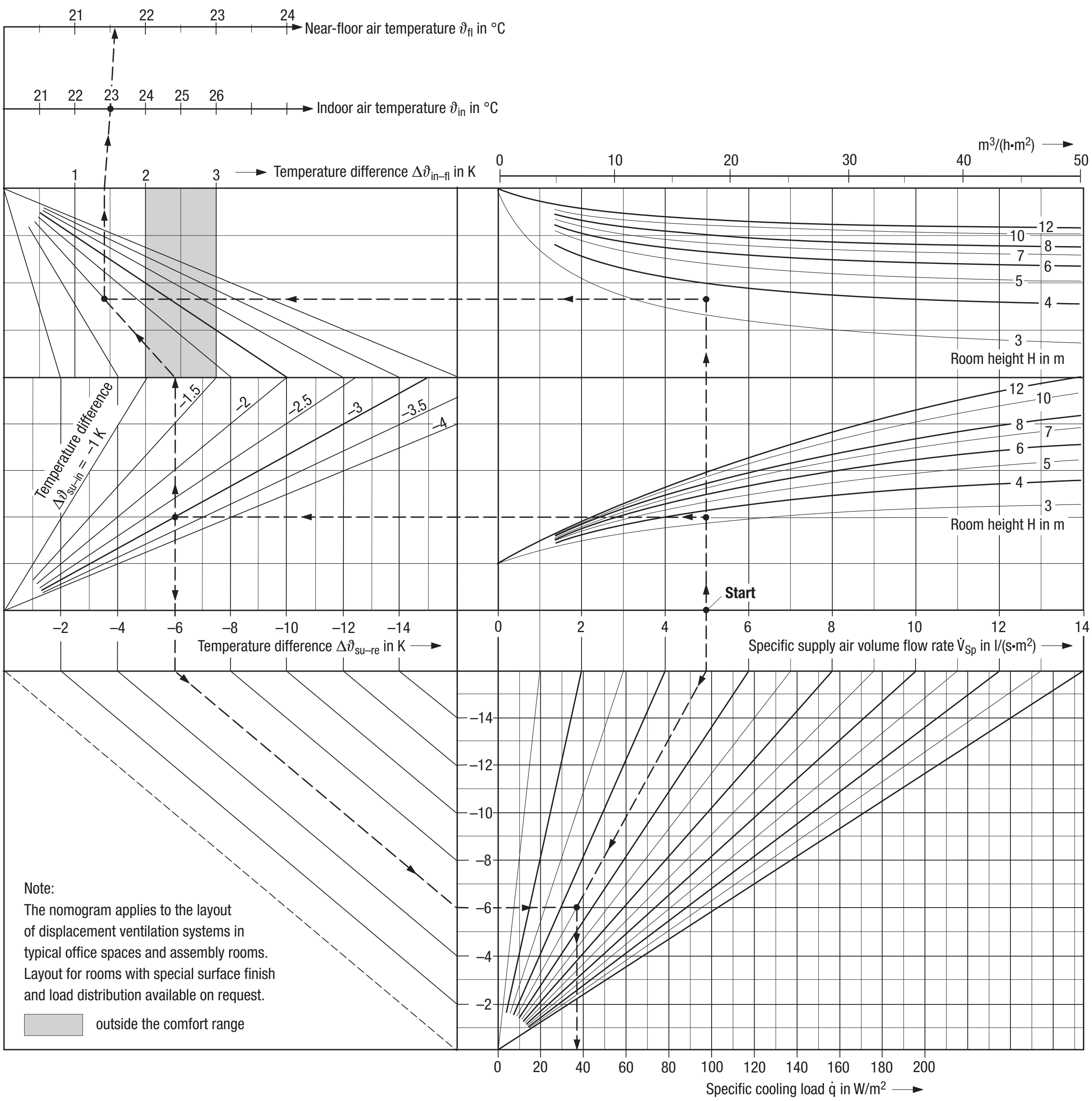

Fig. 13: Nomogram to determine temperature gradient and removable cooling load

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