Air distribution systems
Cooling and heating systems

Kranz KOMPONENTEN ®
Applied system solutions

Layout specifications
for thermal comfort

TB 69 E 2013

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Categories of thermal comfort

With regard to thermal comfort in **commercial buildings** the European standard EN ISO 7730 defines three categories of thermal environment where the percentage of dissatisfied is expected to be under the PPD index (Predicted Percentage of Dissatisfied). Dissatisfaction may be the result of too high indoor air velocities (Draught Rating DR in %), too high vertical temperature gradient, too high radiant temperature asymmetry and uncomfortable floor temperatures. The three categories are shown in Table 1.

Category	PPD %	DR %	Percentage of Dissatisfied because of		
			vertical temperature gradient	radiant temperature asymmetry	floor temperature
A	< 6	< 10	< 3	< 5	< 10
B	< 10	< 20	< 5	< 5	< 10
C	< 15	< 30	< 10	< 10	< 15

Table 1: Three categories of thermal environment

In category A, for instance, one expects that less than 6% of the people are not satisfied with their thermal environment. This is the case when the Draught Rating DR is < 10% and dissatisfaction is as follows: < 3% with regard to vertical temperature gradient, < 5% with regard to radiant temperature asymmetry and < 10% with regard to floor temperature. These 4 criteria should be met simultaneously for each of the three categories. Which category is to be complied with will be agreed upon between the consultant and the client. Each criterion can be specified as follows:

Indoor air velocities and draught rating

The maximum allowable indoor air velocities to meet the corresponding category A, B or C are shown in Figures 1 to 3.
Category A corresponds to DR = 10% (DR = Draught Rating), category B to 20% and category C to 30%.

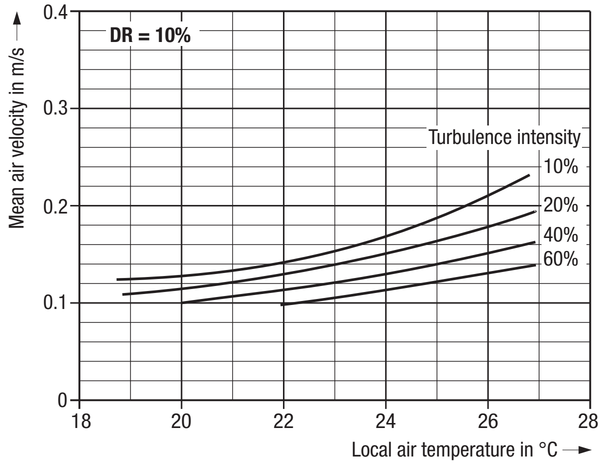

Fig. 1: Allowable mean air velocities complying with category A according to EN ISO 7730, corresponding to DR = 10%

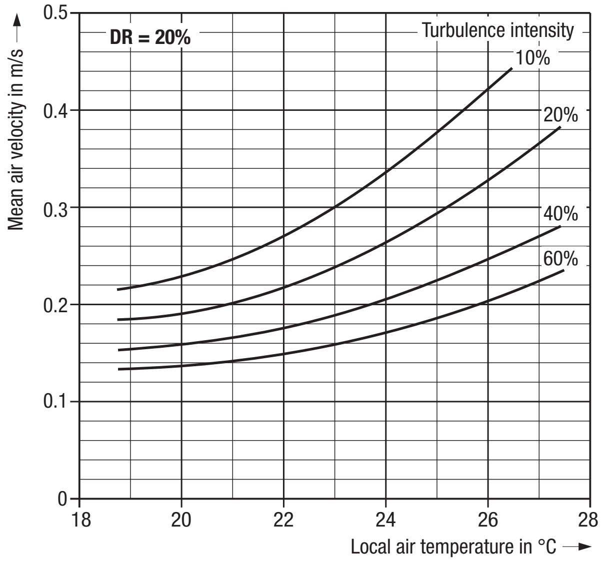

Fig. 2: Allowable mean air velocities complying with category B according to EN ISO 7730, corresponding to DR = 20%

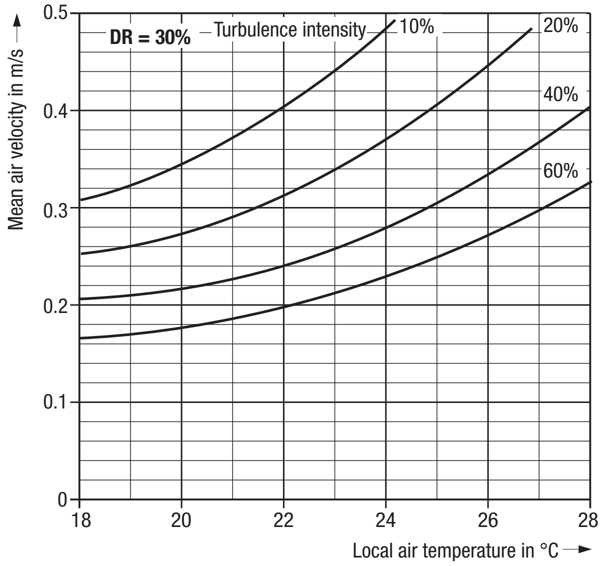

Fig. 3: Allowable mean air velocities complying with category C according to EN ISO 7730, corresponding to DR = 30%

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Category A can be achieved at cooling loads > 50 W/m² only when chilled ceiling systems such as radiant cooling ceilings are combined with an air distribution system which ensures the required hygienic air change rate.

The percentage of turbulence intensity can be chosen empirically to 20% for displacement ventilation systems and 40% for turbulent mixing systems.
The maximum indoor air velocities which are mentioned in Table 2 can be considered at the layout indoor air temperature of 26 °C (according to EN 15251).

Category	Turbulent mixing system m/s	Displacement ventilation system m/s
A	0.15	0.18
B	0.25	0.32
C	0.33	0.45

Table 2: Maximum allowable indoor air velocities in relation to the air distribution system

Both EN ISO 7730 and EN 15251 declare that higher indoor air velocities are acceptable when indoor air temperatures are higher than 26 °C, but only if the occupant has the option to adapt the air movement in the room (e.g. with fan coil units or decentralised facade units).

Temperatures

Indoor air temperature

In the occupied zone one should consider the interaction of air temperature and radiant temperature of the enclosing surfaces, particularly when rooms are fitted with chilled ceilings or buildings have large glass facades. The local temperature ϑ_o is called operative temperature and is determined from the following approximate equation:

$$\vartheta_o = \frac{1}{2}(\vartheta_a + \vartheta_r)$$

ϑ_o = operative temperature
ϑ_a = indoor air temperature
ϑ_r = mean radiant temperature

ϑ_r is calculated from the surface temperatures of the room enclosing surfaces and their angles of radiation to the point of reference (normally the workplace). For instance, the closer the workplace is located to the facade, the greater is the influence of the facade surface temperature on the operative temperature and sensed temperature respectively.

The operative temperature is also classified in relation to the three categories of thermal environment. Table 3 is valid for office rooms, conference rooms, auditoria, restaurants and classrooms.

Category	Operative temperature in °C	
	Summer (Cooling period)	Winter (Heating period)
A	24.5 ± 1.0	22.0 ± 1.0
B	24.5 ± 1.5	22.0 ± 2.0
C	24.5 ± 2.5	22.0 ± 3.0

Table 3: Range of acceptable operative temperatures

Unless otherwise agreed, the operative temperature stated above applies to the area in the middle of the room at 0.6 m above the floor.

Radiant temperature asymmetry

Thermal comfort is also affected by the radiant temperature asymmetry. Discomfort occurs when the surface temperatures of the room enclosing surfaces differ too widely. These are influenced by active cooling and heating surfaces which can be used to compensate too big differences, e.g. to a facade. One should also take into consideration that people have different perceptions of the same values of radiant temperature asymmetry in different situations. To an individual a warm ceiling is much more unpleasant than a cold one.

The acceptable limits for radiant temperature asymmetry have been derived from this experience and are specified in EN ISO 7730 as follows (Table 4):

Category	Radiant temperature asymmetry in K			
	Warm ceiling	Cold wall	Cold ceiling	Warm wall
A	< 5	< 10	< 14	< 23
B	< 5	< 10	< 14	< 23
C	< 7	< 13	< 18	< 35

Table 4: Limits of radiant temperature asymmetry according to EN ISO 7730

If these values are not exceeded, the acceptable percentage of dissatisfied with radiant temperature asymmetry as per Table 1 is kept to.

In practice, where chilled ceilings are installed, the limit of 14 K or 18 K will never be reached in cooling mode, simply because water condensation would occur much earlier.

If chilled ceilings are also used for heating, normally thermal comfort is not restricted as long as the heating capacity does not exceed 55 – 65 W/m² (Fig. 4). More details are contained in our report ref. TB 87.

One should note that the radiant temperature asymmetry is calculated under consideration of the surface temperatures of the enclosing walls, ceiling and floor and their angles of radiation. The latter depend on the location of the workplace. As a rule, it has to be checked whether the nearest workplace to the facade complies with the criteria.

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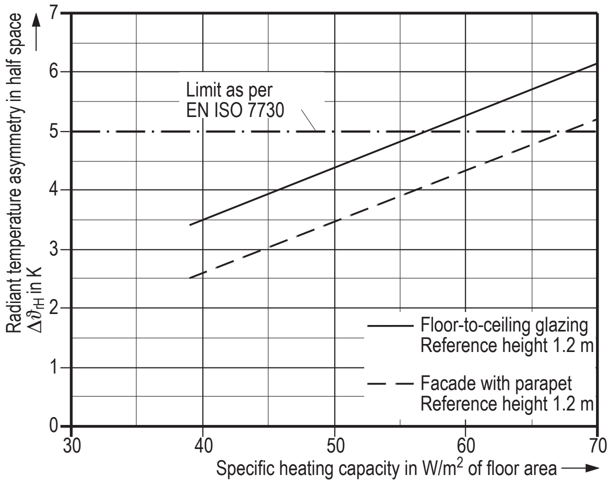

Fig. 4: Radiant temperature asymmetry in half space $\Delta\vartheta_{rH}$ (ceiling to floor) at 1 m from facade when using chilled ceilings for heating

Vertical temperature gradient

According to EN ISO 7730 the following maximum vertical temperature gradients are acceptable at a height between 1.1 m and 0.1 m above the floor, depending on the category of thermal comfort (Table 5).

This corresponds approximately to the distance between head and feet of a seated person.

Category	Vertical temperature gradient in K
A	< 2
B	< 3
C	< 4

Table 5: Acceptable vertical temperature gradients as per EN ISO 7730

If this is complied with, the acceptable percentage of dissatisfied with the vertical temperature gradient as per Table 1 is kept to.

With turbulent mixing ventilation and a chilled ceiling operating in cooling mode, the limits for vertical temperature gradient are of no significance as the related values are always far below these limits.

With displacement ventilation and a chilled ceiling operating in heating mode, however, one should take care that the limits for vertical temperature gradient are not exceeded. The following empirical values are applicable in this regard:

With displacement ventilation, the specific cooling load should not exceed 45 W/m^2 for category A and 55 W/m^2 for category B.

For a chilled ceiling operating in heating mode, the specific heating capacity per m^2 of floor area should not exceed 50 W/m^2 for category A and 70 W/m^2 for category B. If a turbulent mixing ventilation system from the ceiling or alternatively underfloor ventilation is in operation along with a chilled ceiling, then the acceptable heating capacity will be raised to 100 W/m^2 of floor area.

Floor temperature

Table 6 shows the acceptable values for the surface temperature of the floor, depending on the category of thermal comfort according to EN ISO 7730.

Category	Acceptable surface temperature of the floor in °C
A	19 – 29
B	19 – 29
C	17 – 31

Table 6: Acceptable surface temperature of the floor as per EN ISO 7730

The surface temperature of the floor can be influenced only a little using HVAC systems.

Cold air drop at facades

There is a risk of discomfort as a result of cold air drop at glass facades being very high or having a too high heat transmission coefficient U > 1.6 to 2 W/(m^2•K). The cold air flow is deflected at floor level and penetrates the occupied zone.

Fig. 5 illustrates the indoor air velocities u in relation to the window/facade height.

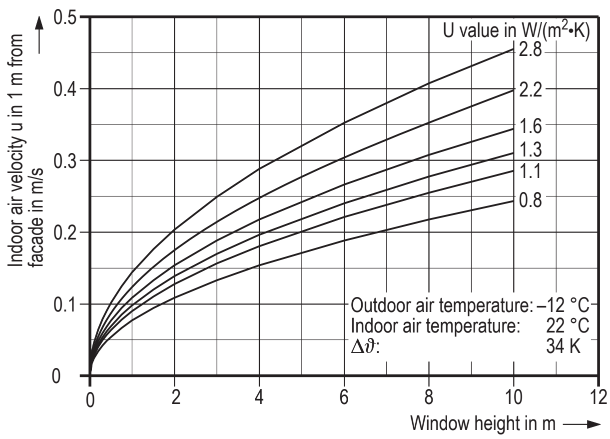

Fig. 5: Indoor air velocities u above the floor as a result of cold air drop at glass facades

To efficiently prevent cold air drop at high facades, one can use window air curtain units or facade heating systems; for floor-to-ceiling glazing one can also use heaters or parapet air supply units.

Compliance with allowable indoor air velocities

Turbulent mixing ventilation

Compliance with allowable indoor air velocities as per Fig. 1 to 3 mainly depends on the following physical variables:

1. Maximum temperature difference $\Delta\vartheta_{max}$ between supply air and indoor air in the cooling mode.
2. Specific cooling load per m^2 of floor area.

For air diffusers for turbulent mixing ventilation manufactured by KRANTZ KOMPONENTEN the following limit criteria apply:

1. Maximum temperature difference

Ceiling twist outlet Radial outlet Radial slot outlet Multiplex outlet	$\Delta\vartheta_{max}$ = –12 K
Induction outlet Opticlean Swivel jet outlet Floor twist outlet	$\Delta\vartheta_{max}$ = –10 K

Table 7: For air outlets generating three-dimensional diffuse air flow without tangential patterns

Broad multiplex outlet Parapet outlet Wall slot diffuser	$\Delta\vartheta_{max}$ = –10 K
Linear whirl outlet Jet nozzle	$\Delta\vartheta_{max}$ = –8 K

Table 8: For air outlets generating two-dimensional diffuse air flow with tangential patterns

Active chilled beams also create a two-dimensional air flow and therefore can be handled as mentioned under $\Delta\vartheta_{max}$ = –8 K.

Fig. 6 shows the conversion of the specific cooling capacity to the specific volume flow rate in relation to the temperature difference between supply and return air.

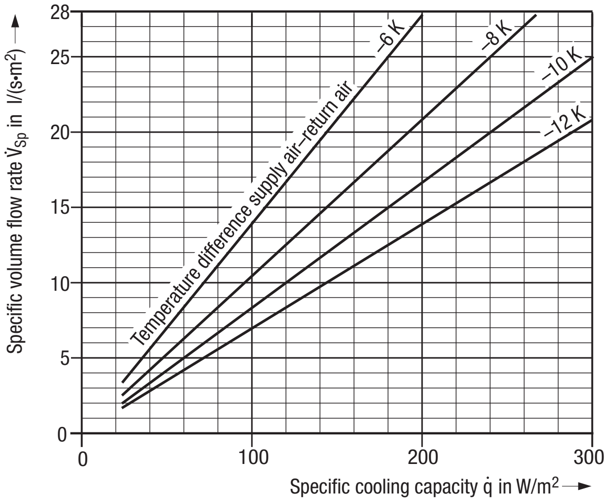

Fig. 6: Relation between specific cooling capacity, temperature difference and specific volume flow rate

2. Maximum specific cooling capacity

The maximum specific cooling capacity depends on the selected ventilation system (two- or three-dimensional air flow – referred to preceding section), the allowable indoor air velocity and the discharge height. The allowable indoor air velocity can be chosen as follows:

- from Fig. 1 to 3 for commercial applications,
- or from Fig. 9 for industrial applications,
- or from a particular agreement between consultant and client.

The relations between indoor air velocities, discharge height and specific cooling capacity are shown in Fig. 7 for three-dimensional air flow and in Fig. 8 for two-dimensional air flow.

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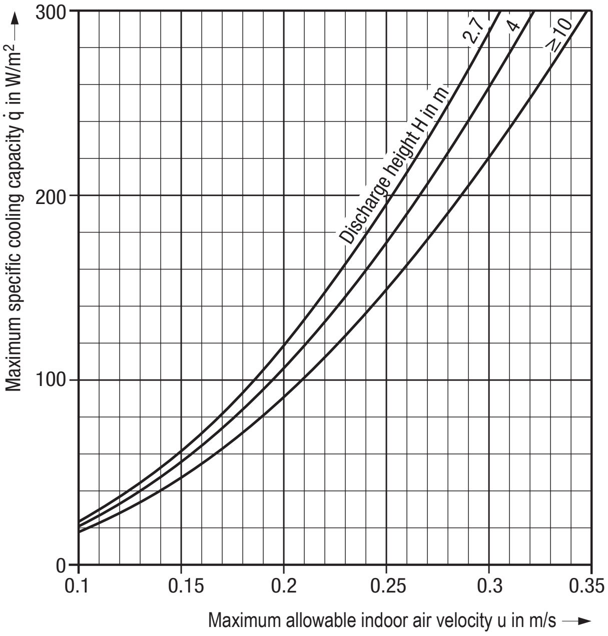

Fig. 7: Three-dimensional diffuse air flow, e.g. ceiling twist outlet, radial outlet, radial slot outlet, multiplex outlet, induction outlet, Opticlean, swivel jet outlet

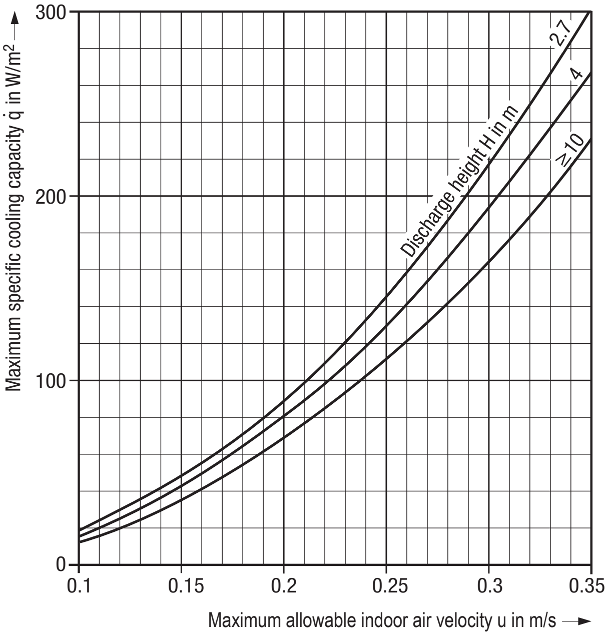

Fig. 8: Two-dimensional air flow for wall diffusers such as linear whirl outlet, wall slot diffuser, broad multiplex outlet, jet nozzle, parapet outlet, as well as for active chilled beam

Layout example:

The required cooling load for an office building with a room height of 2.7 m amounts to 90 W/m². The recommended diffuser type is a linear whirl outlet. The thermal comfort criterion shall comply with category B according to EN ISO 7730. The maximum allowable indoor air velocity amounts to 0.21 m/s under consideration of a layout indoor air temperature of 24 °C and 40% turbulence intensity (Fig. 2).

With regard to Fig. 8 the limit for two-dimensional indoor air flow amounts to 100 W/m² in order to meet category B concerning indoor air velocities.

The maximum temperature difference is limited to –8 K for linear whirl outlets (referring to Table 8). This results under consideration of Fig. 6 and the required cooling load of 90 W/m² to a specific volume flow rate of 9.4 l/(s•m²) [34 m³/(h•m²)].

If the linear whirl outlet is replaced by a broad multiplex outlet, the maximum temperature difference can be increased from –8 K to –10 K (Table 8). Consequently the required specific volume flow rate drops from 9.4 to 7.5 l/(s•m²) [34 to 27 m³/(h•m²)].

Low-turbulence displacement ventilation

For low-turbulence displacement flow (generated by displacement outlets for commercial or industrial applications), other layout criteria are relevant; they are described in the technical brochures relating to the different types of KRANTZ KOMPONENTEN displacement outlets. In particular the near-zone is defined, where higher air velocities occur due to physical conditions.

An exception, however, is our circular displacement outlet VA-ZD when placed above the occupied zone. In this case and for horizontal discharge, the criteria indicated in Fig. 7 can be roughly taken as a basis for layout.

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Allowable indoor air velocities in **industrial plants** are specified for instance in the German standard VDI 3802 (Air-conditioning systems for factories). As shown in Fig. 9, this standard defines the allowable mean indoor air velocities in relation to activity level and clothing, yet independently of turbulence intensity. The type of clothing or rather the clothing insulation value is expressed in **clo** units.

The following values refer to:
0.6 clo: light work clothing (shirt)
0.9 clo: standard work clothing
1.3 clo: heavy work clothing (protective jacket)

In industrial halls the following activity levels are to be considered:
Activity level II: 1.5 met ≙ 150 W
(light work while standing, laboratory work)
Activity level III: 2 met ≙ 200 W
(moderate work while standing)
Activity level IV: 2.5 met ≙ 250 W
(heavy work while standing)

For example, in an industrial hall with
– indoor air temperature 26 °C
– activity level III (2 met)
– clothing 0.9 clo
indoor air velocities up to max. 0.41 m/s are allowable.
At 28 °C indoor air temperature – other conditions being identical – indoor air velocities may amount to max. 0.45 m/s.

Especially in halls with free cooling (HVAC without chiller) indoor air temperatures of more than 30 °C are likely to occur in summer, hence higher indoor air velocities enable to relieve the thermal output of a human's body.

Adjustable displacement outlets are recommended preferably because the activity level of individual workers in the same industrial hall may be different.

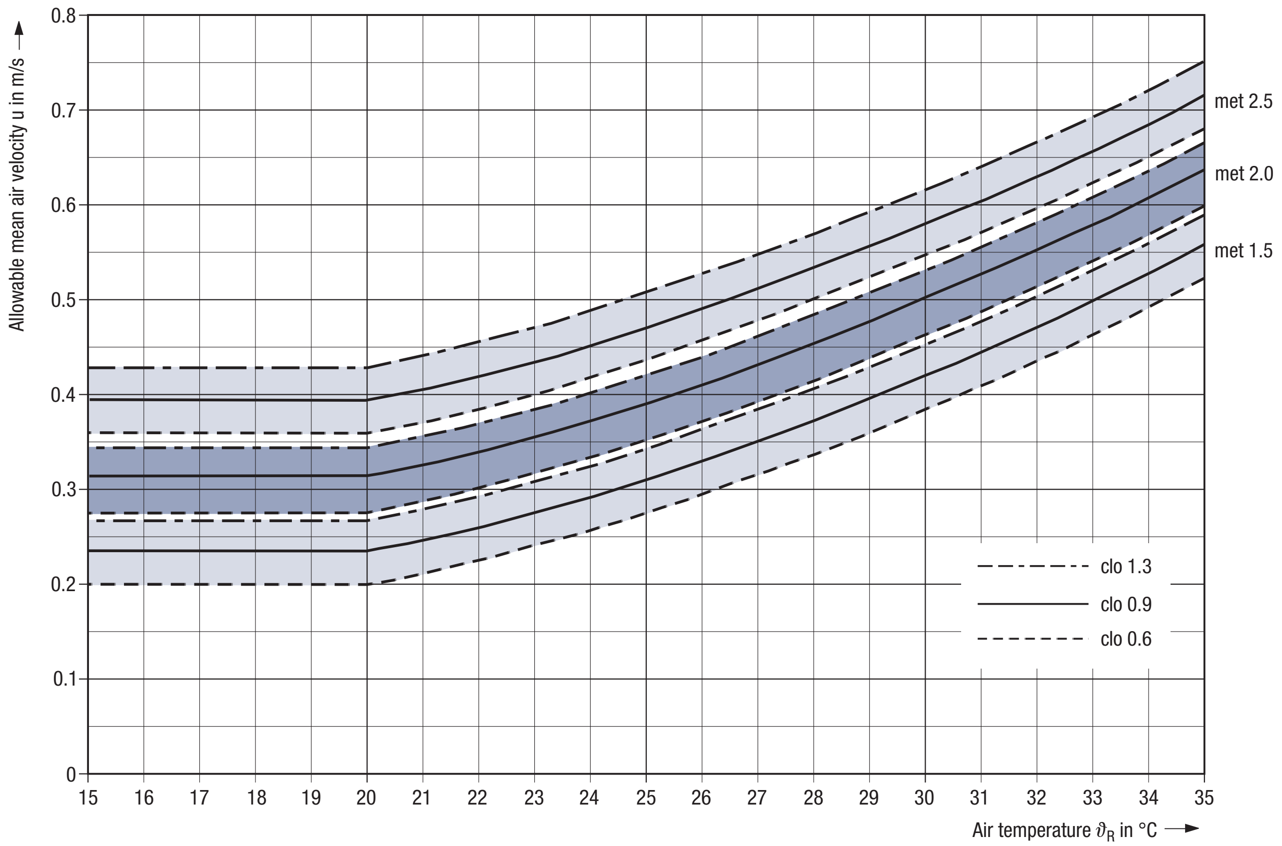

Fig. 9: Allowable mean indoor air velocities in factories as per VDI 3802

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