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Chilled Beams

Besides chilled ceilings, the use of chilled beams has been increasing over recent years. Chilled beams are a low-cost alternative to chilled ceilings as they have high specific capacities.
They can be used in administrative buildings, exhibition spaces, airport terminals, shopping centres, etc., as well as in industry.

Keywords: chilled beam, cooling capacity, thermal comfort

Introduction

There are two types of chilled beam: the **passive** chilled beam and the **active** chilled beam. The passive chilled beam works only on the basis of gravity; that is why its function is also called "silent cooling". The active chilled beam, in contrast, is additionally fed with primary air (outdoor air) which causes the secondary air (indoor air) to be induced by the cooling coil (heat exchanger). Further, in this way, the chilled beam is supplied with the percentage of outdoor air needed to comply with hygienic requirements. Unlike passive chilled beams, active chilled beams are — due to induction — also suitable for heating. Table 1 lists their main differences.

In spaces fitted with passive chilled beams, the occupants must be provided with the hygienic outdoor air percentage specified by DIN 1946, part 2, in another way. This can be done using a central ventilation plant together with separate air diffusers or using natural ventilation.

Passive chilled beam

Construction design and operation

The passive chilled beam with free convection mainly consists of the open-top housing (Fig. 1), the built-in heat exchanger with connection ends and, possibly, a perforated screen at the bottom.

Indoor air flows into the chilled beam from the top, is cooled off in the air-to-water heat exchanger and discharged into the room for cooling purposes. There must be a certain distance between the concrete ceiling and the chilled beam.

Installation options

There are several installation options for chilled beams. The most common ones are shown in Fig. 2 a– d.

With concealed installation above a perforated false ceiling, there is no need for a perforated screen (see Fig. 3).

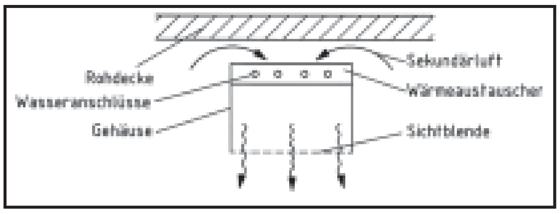

Fig. 1: Sketch of a passive chilled beam

Table 1: Main differences between passive and active chilled beams

	Passive chilled beam	Active chilled beam
Heating	not possible	possible
Cooling	only via water	via water and air
Outdoor air supply	not integrated	integrated

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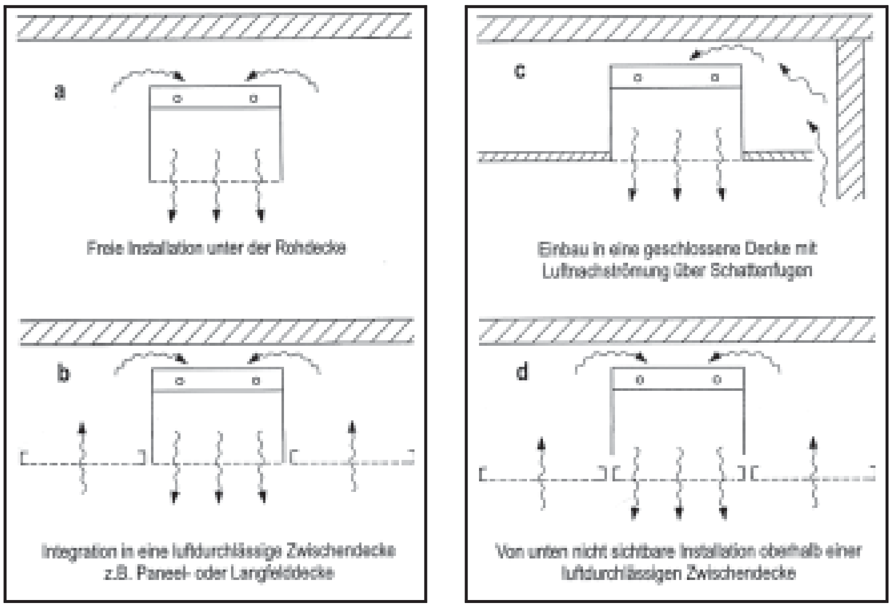


Fig. 2 a—d: Installation options for chilled beams

Fig. 3: Concealed chilled beam installation above a perforated false ceiling

Further, this installation option does not affect the appearance of the ceiling. Yet a free area of minimum 35% is advisable in the ceiling for air circulation to avoid a too strong lowering of the cooling capacity. Fig. 4 shows such an application.

Cooling capacities

Though passive chilled beams are rather simple in design, there are several determinants that affect their capacity. The main ones are shown in Fig. 5.

Chilled beams are usually designed for a difference of $\Delta\Theta_{R,W} = -10$ K between the mean water temperature and the indoor air temperature. Fig. 6 shows for this standard layout the specific cooling capacity per metre of beam length in relation to the beam width and its distance to the ceiling.

Fig. 6 applies for a beam height of 250mm. It is clear that especially wide chilled beams need a greater distance to the ceiling to enable unobstructed air reflow.

If there is too little space available, the beam height H can be reduced. This, however, lowers the cooling capacity, e.g. by 13% if the beam height is reduced from 250mm to 180mm and by 20% if reduced to 150mm.

The cooling capacity is also affected by the suspended ceiling or the screen due to their resistance to air flow. Common screens with a free area of ≥ 50% reduce the cooling capacity by maximum 7% only. The same applies for entire suspended ceilings. In the latter case a smaller free area may be required for aesthetic reasons, yet it should not be less than 35%. The resulting 15% drop in capacity is still acceptable.

Fig. 4: Application with concealed installation above a perforated ceiling

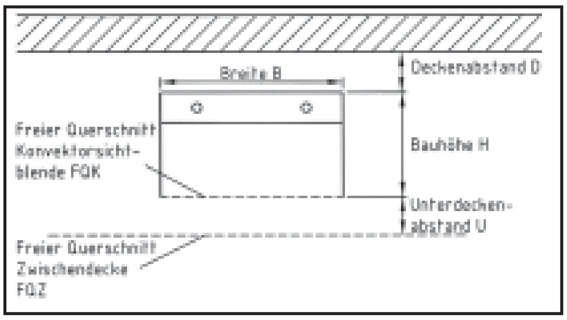


Fig. 5: Determinants for cooling capacity

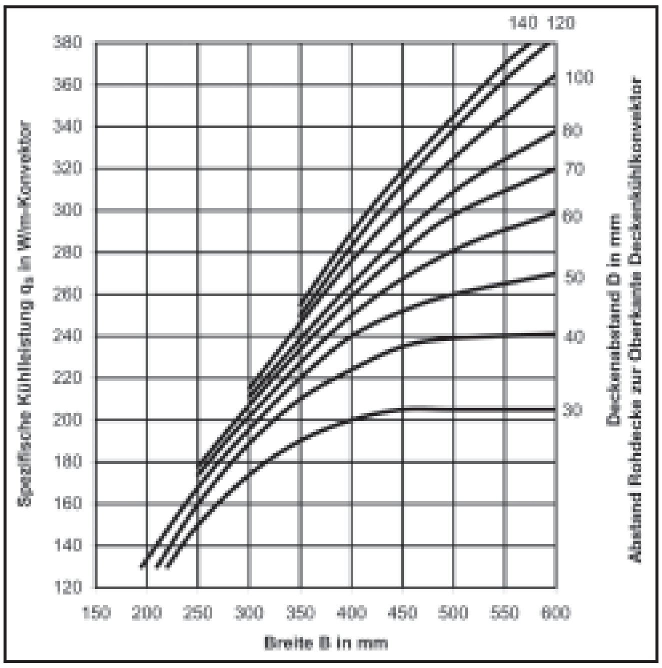


Fig. 6:
Specific cooling capacity of passive chilled beams

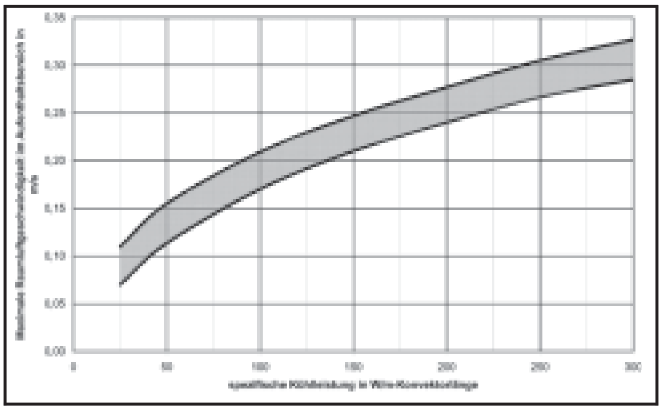


Fig. 7:
Indoor air velocities below passive chilled beams in relation to the specific cooling capacity

According to DIN 1946, part 2 on HVAC plants, the air velocity limit is 0.23 m/s at a room temperature of 26 °C for a sedentary activity of level I. This velocity limit is based on a turbulence intensity of 30% which was confirmed by our own tests.

If a chilled beam is to be placed immediately above a workplace in an office, the recommended maximum cooling capacity according to Fig. 7 is 150 W/m.

According to DIN 1946, part 2, for activity level II (as, for instance, in shopping centres, airport terminals or exhibition halls) a higher air velocity value is allowable: 0.32 m/s at 26 °C indoor air temperature and 30% turbulence intensity. Thus, in such spaces, chilled beams can be designed for 300 W/m.

Where higher cooling capacities are required, the chilled beams should be installed at places where occupants do not stay longer or stay only seldom directly below these beams. In office buildings the best placement is near the façade or a corridor wall as shown in Fig. 9 and Fig. 10.

Thermal comfort

Unlike chilled ceilings, passive chilled beams have only a negligible amount of radiation in heat transfer. As heat transfer is nearly purely convective, indoor air velocities below the chilled beam are of great importance for compliance with thermal comfort criteria.

The maximum indoor air velocities are mainly dependent on the cooling capacity. Fig. 7 shows the maximum mean values for indoor air velocity below chilled beams. The graph is based on a number of measurements where the beam width was increased according to the cooling capacity.

As is made visible with smoke tracer in Fig. 8, there is a narrow area with increased convective flow and thus higher velocities only below the chilled beam as per Fig. 7.

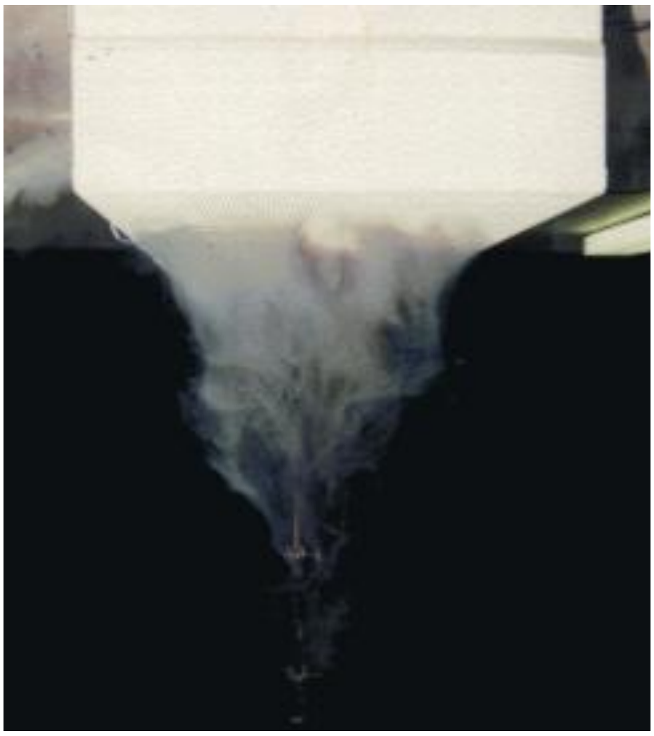


Fig. 8:
Flow pattern with passive chilled beam

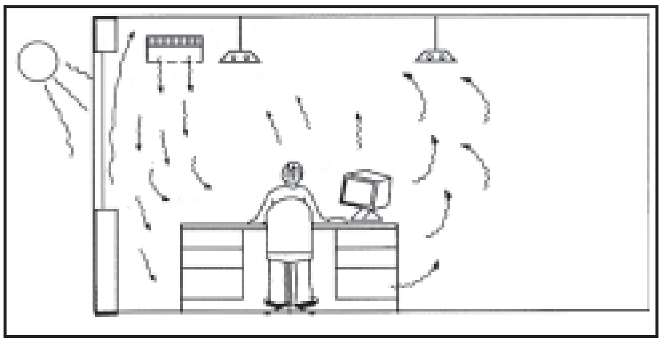


Fig. 9: Chilled beam near the façade

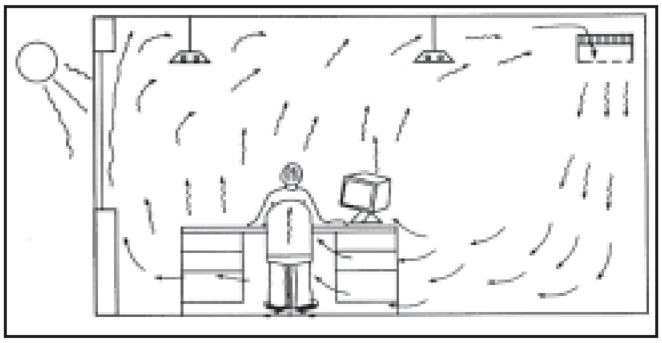


Fig. 10: Chilled beam at or near the corridor wall

This type of placement prevents air draughts in the head region; thus, although the cooling capacity can be set higher, thermal comfort will be ensured at the workplaces. Approx. 500mm clearance should be kept between the façade and the chilled beam to ensure that the upward warm convective flow (due to solar radiation) along the façade can enter the chilled beam from the top. This is also recommended for a concealed chilled beam installation above a perforated ceiling.

Fig. 10 shows a steady indoor air flow with tangential air patterns upwards along the façade (due to solar radiation in summer and heating in winter) and downwards along the corridor wall.

Placing a cabinet below a chilled beam does not impair the beam capacity if its distance to the beam underside is at least equal to the beam width. If the chilled beam is placed against a wall on one side as in Fig. 10, the distance to the ceiling set as per Fig. 6 should be doubled in order to offset the drawback resulting from air reflow on one side only.

Active chilled beam

Unlike the passive type, the active chilled beam can be fed with the percentage of outdoor air needed to comply with hygienic requirements. It can also be used for heating.

Construction design and operation

The active chilled beam (Fig. 11) mainly consists of a housing with primary air connection (at a side or at the top) and air discharge slots on two sides. Between these two slots there is a screen and above it a heat exchanger (usually a 4-pipe system).
The primary air flows downwards into the shafts between the housing sidewalls and the heat exchanger, and induces the secondary air from the room. The secondary air is either cooled or heated in the heat exchanger.

The air nozzles should be made from a metallic material which, unlike plastic, is non-combustible. The screen should be easy to remove to allow for cleaning of the heat exchanger.

Fig. 12 shows another design option which has the same function as the one described above but discharges air on one side only. This design option is intended for applications where the chilled beam is to be installed parallel to the façade.

In both design options the secondary air enters the chilled beam from the room side. This offers advantages against air entrance from the top: If the chilled beam is to be integrated into a suspended ceiling, there is no need for reflow openings within the ceiling. This is also an advantage from an architectural point of view.

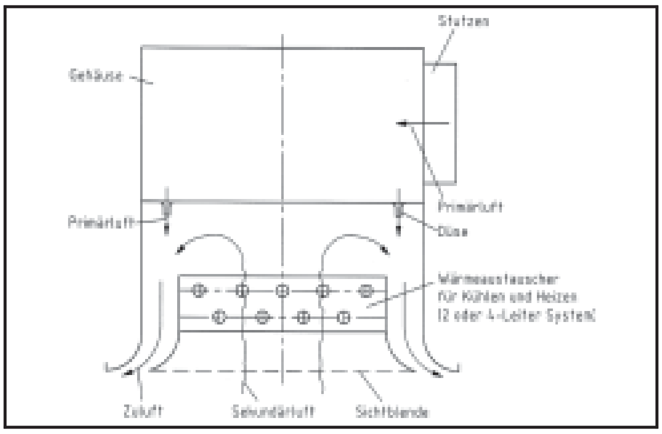


Fig. 11: Sketch of an active chilled beam with two-way air discharge

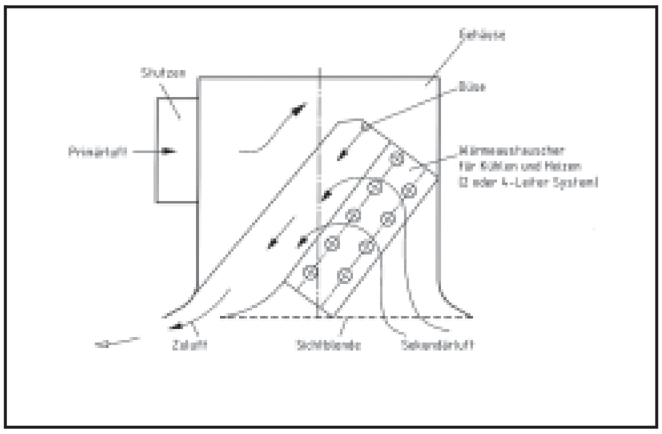


Fig. 12: Sketch of an active chilled beam with one-way air discharge

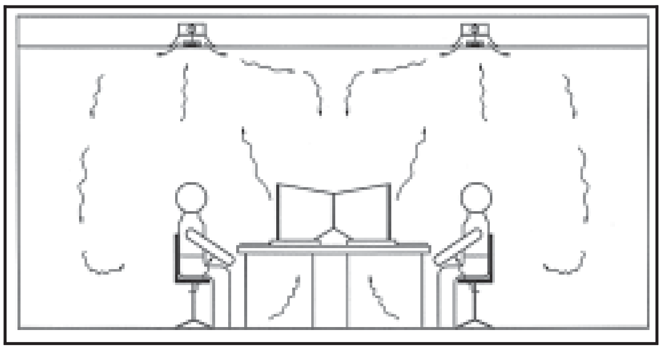


Fig. 13: Active chilled beam with two-way discharge

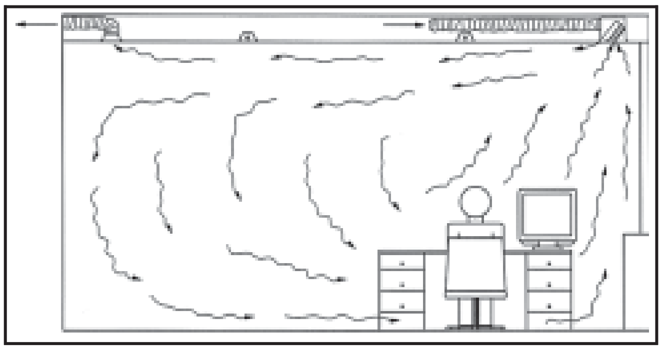


Fig. 15: Active chilled beam with one-way discharge

Installation options

Chilled beam with two-way discharge

This is the classic type of chilled beam which is mounted perpendicular to the façade, usually in the middle of the room, or in any façade axis. Where chilled beams are installed without suspended ceiling, it is a great advantage to keep the storage capacity of the concrete ceiling, which helps attenuate cooling load peaks in the room.

The chilled beams can be fitted with so-called wings (see Fig. 14) which serve to conceal pipes, etc., e.g. when the beams are exposed under the concrete ceiling. Further, the screen design can be customized.

Chilled beam with one-way discharge

This design option is particularly suitable for installation parallel to the façade. In many cases it is integrated into a suspended linear strip ceiling. Here it is important that the warm convective air, which moves upwards along the glazing due to solar radiation, flows most directly into the heat exchanger (Fig. 15). Thus the difference between the mean water temperature and the air temperature rises and, with it, the cooling capacity.

Cooling capacities

On active chilled beams the cooling and heating capacities include the waterside and airside values. The layout for the cooling mode is usually based on a difference of —10 K between the mean water temperature and the indoor air temperature.
For the air it is common to select a temperature difference of —8 K between the supply and indoor air. Fig. 16 shows the waterside cooling capacity range for these parameters.

The range refers to 300mm beam width and depends on the primary air flow rate and nozzle diameter. With a layout at the lower limit, the pressure drop and the sound power level are consequently lower. The sound power levels are between 20 and 38 dB(A) and the pressure drop values between 30 Pa and 100 Pa.

The airside cooling capacity, which depends on the primary air volume flow rate, is to be added to the waterside capacity. Fig. 17 shows a related graph. Cooling capacities of more than 600 W/m are achievable. Yet the chilled beam layout must take account of the thermal comfort criteria mentioned in the next section.

Fig. 14: Active chilled beam with "wings" concealing ceiling utilities

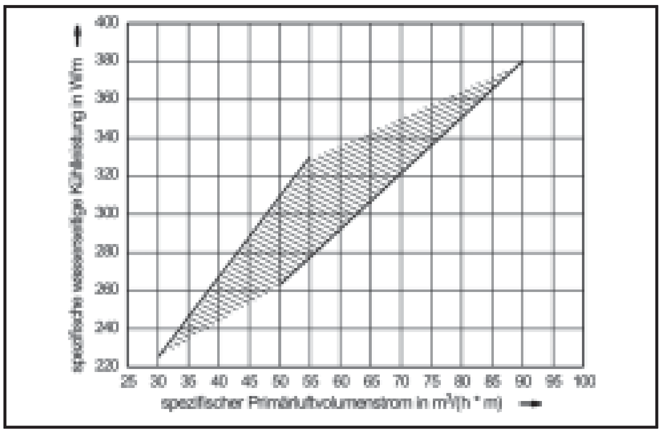


Fig. 16: Waterside cooling capacity of active chilled beams

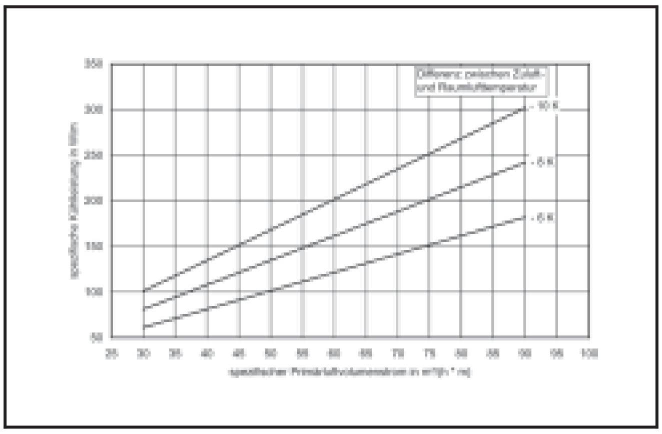


Fig. 17: **Airside cooling capacity of active chilled beams**

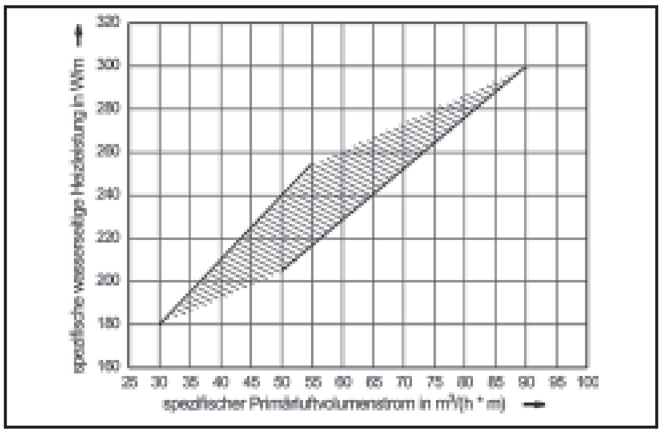
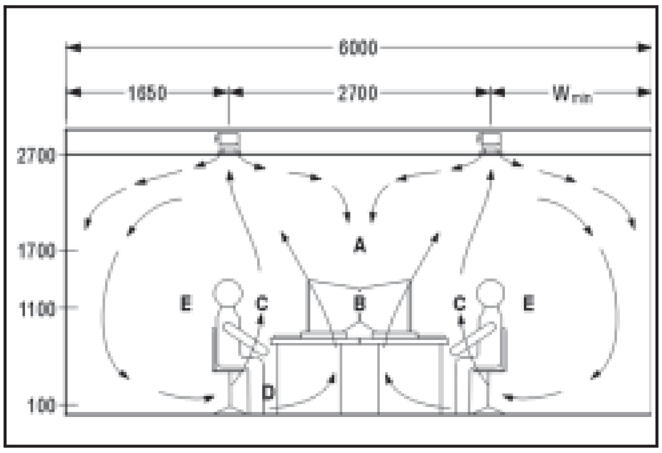


Fig. 18: **Waterside heating capacity of active chilled beams**



	Primary air volume flow rate in $m^3/(h \cdot m)$				
	90	70	50	40	30
W_{min} in mm	1600	1300	1000	800	600
Zone	Total cooling capacity in W/m (air $\Delta\Theta_{Z,R} = -8$ K and water $\Delta\Theta_{WK/R} = -10$ K)				
	620	530	420	360	300
A	0.34	0.31	0.28	0.18	0.16
B	0.29	0.27	0.25	0.16	0.14
C	0.20	0.17	0.15	0.14	0.13
D	0.22	0.20	0.18	0.14	0.13
E	0.22	0.18	0.16	0.14	0.12

Fig. 19: **Air flow pattern and indoor air velocities with two-way discharge chilled beam**

For the heating mode, the layout is made on the water side with a difference of 15 K between the mean water temperature and the air temperature. In most cases there is no need for additional heating with the primary air as the façade is usually screened off by heating panels. Fig. 18 shows capacity values.

Thermal comfort

Active chilled beams can achieve rather high cooling capacities although they require little space. A 300mm wide beam can achieve more than 600 W/m. Extrapolated to $1m^2$ this corresponds to a capacity of 2000 W. Such high cooling capacities are not applicable to office buildings because of specified thermal comfort criteria; they are rather for applications with higher activity level.

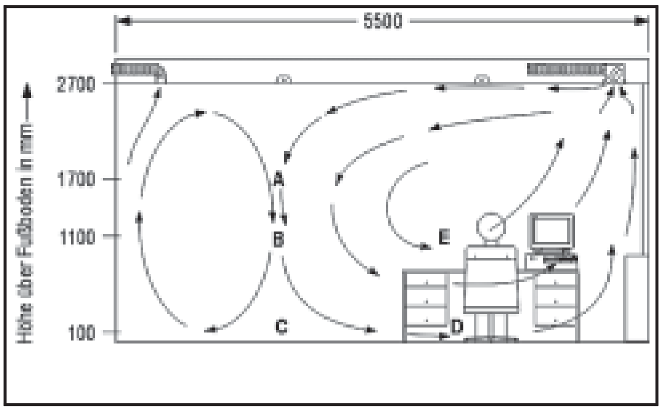
Fig. 19 shows measured indoor air velocities in relation to the capacity for a two-way discharge chilled beam placed perpendicular to the façade while Fig. 20 shows such values for a one-way discharge chilled beam placed parallel to the façade. The values listed are the sum of waterside and airside cooling capacities. In office buildings, 360 W/m are achievable taking account of the maximum allowable indoor air velocities at 26 °C room temperature according to DIN 1946, part 2.

The vertical temperature stratification is less than 0.8 K/m in all cases, i.e. far below the 2 K/m specified by DIN 1946.

Fig. 21 shows an air flow pattern made visible in a lab test. The beam "wings" are only a design option, they are not required for the beam function.

Summary

Chilled beams are an alternative to chilled ceilings. They require rather little space but achieve high specific capacities. There are two types available: passive and active chilled beams. The active chilled beam has a primary air connection and thus supplies the room occupants with the outdoor air percentage required to comply with hygienic requirements. Unlike passive beams, active chilled beams also have a heating function.



Zone	Primary air volume flow rate in $m^3/(h \cdot m)$				
	90	70	50	40	30
	Total cooling capacity in W/m (air $\Delta\Theta_{Z,R} = -8$ K and water $\Delta\Theta_{WK/R} = -10$ K)				
	620	530	420	360	300
A	0.26	0.24	0.22	0.20	0.20
B	0.21	0.19	0.17	0.16	0.15
C	0.36	0.29	0.19	0.16	0.16
D	0.15	0.11	0.13	0.12	0.11
E	0.13	0.11	0.10	0.08	0.07

Fig. 20: Air flow pattern and indoor air velocities with one-way discharge chilled beam

Fig. 21: Active chilled beams in a lab test

Several installation options are possible: under the concrete ceiling, integrated into a suspended ceiling, or concealed, i.e. not visible from the room – above a suspended ceiling. In the latter case, however, the ceiling must let enough air in and out.

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