Chilled beam systems in heating mode

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This is the second of a series of three papers covering experiences in the application of Chilled Beam technologies. The first paper published in the May/June issue of IHRACE covered "Taking flexibility into account in designing beam systems". In this current issue the paper explores the performance of Chilled Beams when utilised for heating. Beams can be very efficient when used for heating, water temperatures are kept low to reduce the buoyancy of the air circulating in the space; this is well explained in this paper. Scandinavian countries have been the driving force behind Beam Technologies. In particular the Finns, whose whole philosophy centres on people, the need to improve the indoor air quality and comfort conditions of building occupants. In doing so the health of the occupants is paramount resulting in a reduction of absenteeism, a more productive and happier staff and a more efficient operation for both the Landlord and the tenant.

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WITH CHILLED BEAMS, it is possible to create high-quality indoor climate conditions, including thermal comfort and a low noise level within reasonable life-cycle costs. Chilled beam systems can also be used for heating. The key factor is to control the inlet water temperature at a reasonably low level and thus optimize the temperature gradient in the room space.

BACKGROUND

In traditional heating systems the design is often based on high safety margins when heat losses are calculated. When a chilled beam system is used for heating, proper system operation cannot be achieved by over sizing the heating system. In a new office building 30 –45 W/m2 of heating capacity is typically enough. If the required heating capacity is higher, measures to improve energy efficiency should be considered.

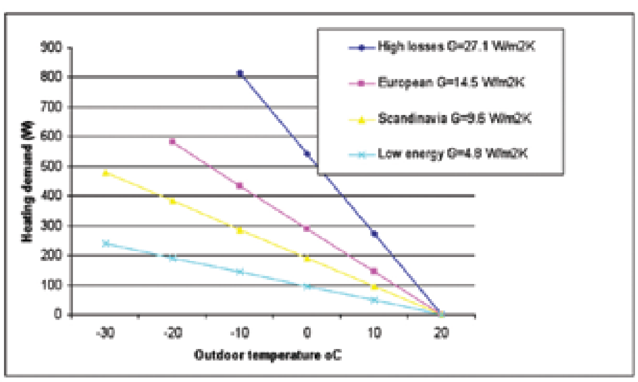
Figure 1 shows the required heating capacity as a function of the average thermal conductance and the outdoor temperature. In this case, the room dimensions are 2.8 m (room width), 4.5 m (room length) and 3.0 m (room height), giving a the floor area of 12.6 m2 and a total external wall area of 8.4 m2. In this case, the glazing ratio of the total outdoor wall area is fixed to 50 %.

In the European case, there is a double-glazed window (U-value 3 W/m2K) and the U-value of the wall is 0.45 W/m2K. In the Scandinavian case, there is a triple-glazed window (U-value 2 W/m2K) and the U-value of the wall is 0.28 W/m2K. Figure 1 also shows an example, which incurs high heat losses: this case is like a European one, except for having a single-glazed window. In addition, a case representing low heating demand is shown. Here, the heat losses are simply fixed 50 % lower than the Scandinavian case.

Based on this calculation, the required heating capacity of 500 W per room-module is enough for the normal case in various European climate and design conditions.

Fig. 1. The required heating capacity as a function of thermal conductance and external temperature for a case room-module (room area 12.6 m2 and external wall area 8.4 m2).

The basic guideline for thermal comfort is laid down in



the ISO 7730 Standard (1990). The major part of this report concerns thermal comfort in terms of the temperature gradient in the room space and the room air velocities. ISO 7330 recommends the following:

- Air velocity (to avoid draughts):
  < 0.15 m/s (winter)
  < 0.25 m/s (summer)
- Vertical air temperature difference:
  < 3°C from foot to head when sitting, 0.1 m to 1.1 m, or standing, 0.1 m to 1.7 m.

With the traditional heating system, the maximum gradient is typically 3 – 5 °C. Of course, the existing conditions considerably affects a lot for the gradient, e.g. heat losses, positioning of the heating device, surface temperatures, and the design temperature levels of system. All in all, the installation has a consequential effect on the gradient: it is more difficult to keep the gradient low when the installation height of the heat emitter is high.

HEATING DESIGN CRITERIA WITH ACTIVE CHILLED BEAMS

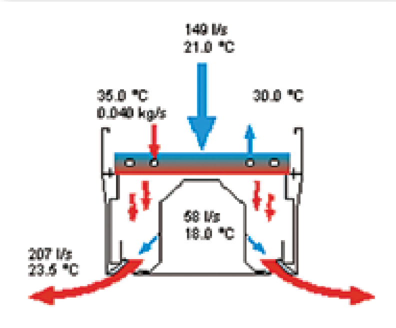
The active chilled beam is one of the most popular air-conditioning systems in Europe. With chilled beams, it is possible to create high-quality indoor climate conditions, including thermal comfort and a low noise level within reasonable life-cycle costs (Virta et. al, 2004). Chilled beam systems are dedicated outdoor air systems to be applied primarily in spaces where internal humidity loads are moderate. They can also be used for heating. In Fig. 2, there is shown a typical exposed beam installation.

Active chilled beams are connected to both the ventilation supply air ductwork, and the chilled water system. When desired, hot water can be used in this system for heating. The main air-handling unit supplies primary air into the various rooms through the chilled beam. Primary air supply induces room air to be recirculated through the heat exchanger of the chilled beam. In order to cool or heat the room either cold (14-18°C) or warm (30-45°C) water is circulated through the heat exchanger. Recirculated room air and the primary air are mixed prior to diffusion in the space. Room temperature is controlled by the water flow rate through the heat exchanger. In Figure 3, there is described the operation principle of a chilled beam in heating mode.

Fig. 2. Typical exposed installation of active chilled beams in office environment.

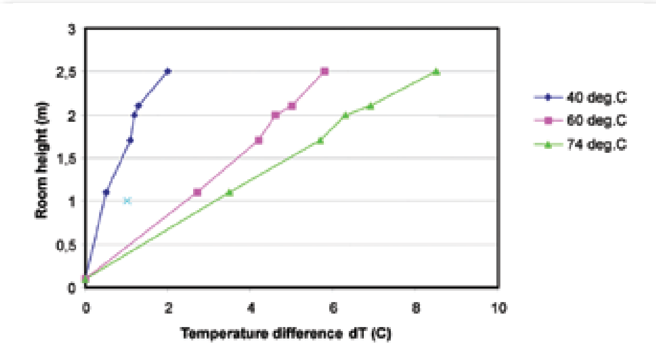
If the heating inlet water temperature of a chilled beam is higher than 45°C (linear output of an active beam is higher than 150 W/m) in a typical installation, secondary air is often too warm to mix properly with the room air. With high inlet temperature, the temperature gradient in the space will increase and through that the deterioration of the energy efficiency and thermal comfort will happen.

Fig. 3. Typical example of an active chilled beam system operation principle in heating mode.



This has been confirmed in a previous study where both the heating capacity and the temperature gradient of the room were analyzed (Kosonen et. al 2000). In that study, the effect of the inlet water temperature on the performance of a chilled beam system was analyzed. The studies inlet water temperature levels were 40°C, 60°C and 74°C.

Fig. 4. Temperature gradient in the space with different inlet water temperatures.



The effect of the inlet water temperature level on the temperature gradient is presented in Fig. 4. With relatively high temperatures, the temperature gradient in the room rises: the temperature level of 74 °C leads to far too high gradient 8 – 10 °C in the room. The inlet water temperature of 40 °C gives much lower gradient in the room (under 3 °C). Increasing the supply airflow rate decreases also the temperature gradient but in the measured case, using 22 l/s instead of 13 l/s reduced the gradient only about 1 °C.

The key factor is to control the inlet water temperature at a reasonably low level. With the temperature level of 40 °C, it is possible to reach the heating capacity of 500 W, which is in most cases enough.

The mixing is also dependent on the window size and surface temperature. The higher and colder the window, the colder the air falling down to the floor, and the temperature gradient between secondary air and room air becomes higher. For this reason using beams for heating is recommended when the heat transmission of the windows is moderate (e.g. surface temperature is higher than 14°C and height is not more than 1.5 m).

The control principle in heating case is very important. It can be on-off, time proportional on-off or modulating. In most cases all the above mentioned control principles provide reliable operation of the system.

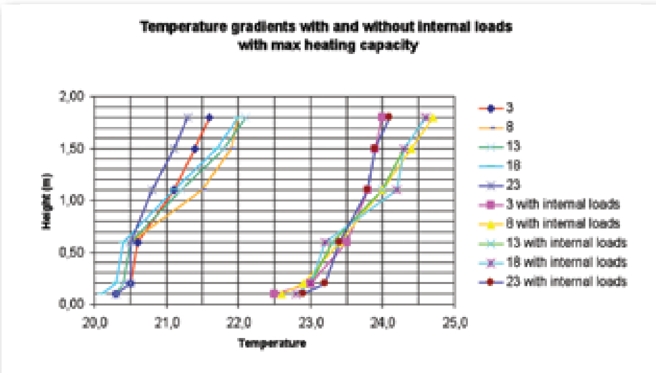
In cases where the difference between the design and normal operating conditions is large (e.g. the design is based on a much higher heating capacity level than the actual normal level), time proportional on-off or modulating controls are recommended. Otherwise the mixed air temperature of chilled beam becomes too warm too quickly, and there is no sufficient mixing in the space and therefore the occupied zone becomes too cold.

The heating capacity of active beams is dependent on the primary airflow rate. This is why ventilation must be operating when heating is required. When an office room is occupied, the internal heat sources reduce the required heating output and the temperature gradient decreases.

In a case-study (Virta and Kosonen 2006), the effect of internal loads on the temperature level and temperature were analyzed. In that conducted study, temperature gradient was less than 2˚C in unoccupied conditions. This depicts that the airflow from chilled beam is well mixed with room air. In addition, it also shows relatively good energy efficiency of system with exhaust air temperature of 21.7˚C (Fig. 5).

With normal internal loads (lights, occupants and computers all together 55 W/m2), the room air temperature increases approx. 2˚C when water flow rate was not reduced. This means that even the maximum heating output is defined with room air temperature of 21˚C, in practice the personal control of +2˚C can be achieved.

Fig. 5. Temperature gradients are lower than 2˚C throughout



the whole floor area. Measurement point 3 is the nearest from the window and 23 is close to the door. All the points are in the middle of the room halfway between the chilled beams. With internal loads, the room air temperature is approx. 2˚C warmer when water flow rate is not reduced. ■

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