

Chilled Beam Selection

By **Dan Int-Hout** and **Lilli Wilbar**

Chilled beams have been prevalent in Europe for many years, and have become one of the latest HVAC products to be adopted by engineers in the U.S. In fact, millions of square feet (square meters) are heated and cooled with these devices every day. Simply put, they are air-to-air induction diffusers with a coil. Much like any other piece of building equipment, there is a need to balance both first cost and effective performance. However, the complexity of the product is such that if improperly selected, may lead to unsatisfactory room temperatures, drafty conditions, or wasted energy.

History of Chilled Beams

Chilled beam technology is not new by any means; in fact, it was originally conceived and patented by Willis Carrier in 1939, with the first installation occurring sometime after World War II. Back then, they were typically located under a window and used relatively high pressure (3 in. w.c. [750 Pa]) to induce room air near the floor, which was passed through a coil, then out the top of the unit. By keeping the water in the coils above dew point, they were able to prevent condensation, which eliminated the need for a drain pan. By the mid 1990s, European engineers had fabricated a linear slot diffuser with induction nozzles and a coil. Their design reduced the required inlet pressure to 0.75 in. w.c. (190 Pa), which was mainly due to a different design for the induction nozzles and having reduced the fins per inch on the coil to open it up. Similar to today's designs, these products were installed in, or hung from, the ceiling where they projected air along that plane.

Why Chilled Beams?

Given their success in Europe along with their potential energy savings, it is no surprise that building owners are often the driving force behind the decision to use chilled beams. A few of the features and benefits include reduced building fan airflow rates (where only outside/ventilation air is provided by a dedicated outdoor air unit or DOAS), small ducts, low unit heights, and the use of water, which when slightly above the building's dew point, can allow for water-side economizer mode. By the nature of the system, they can also eliminate the need for a building's central air handler, freeing up interior space.

Chilled Beam Selection Considerations

Aside from operational savings, there is also a desire to minimize first costs. We often see engineers accomplish this by both minimizing the active length and maximizing capacity of the units. While well intentioned, this action is likely to result in a non-uniform load capacity, creating pockets of hot and cold air as well as drafts. However, design errors like this can be avoided once there is a better understanding of the issues regarding proper selection.

Principle of Induction

To begin, let us discuss the principle of induction. For chilled

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beams, there are typically two induction sites. One is inside the unit, where primary air is introduced through nozzles, which create high velocity jets that in turn generate low pressure and induce room air at the bottom of the unit through a coil. The second location is just outside the unit where the jet of leaving air (through the slot) induces room air at the ceiling. By using the potential energy stored in the form of pressure in the primary airstream, room air is drawn through the coil and delivered to the space with low building fan energy use.

Induction Rate

At a constant supply pressure, the induction rate is a function of the airflow rate and external pressure. If the airflow varies, the induction rate will vary by the square or cube of the airflow rate, depending on the geometry of the device. Most chilled beams are used as constant volume devices and have a fixed induction rate, which allows them to control room temperature by regulating the water flow through the coil. What this means is that the load capacity range is limited by the water coil heat transfer rate.

It also suggests that the measurement of the 'induction rate' is complex and difficult to arrive at without affecting the rate itself. In the latest version of the ASHRAE test method for chilled beams, capacities will be determined using procedures similar to those currently used for fan coils and other types of equipment, which measure actual Btu/h delivered into a space.

Avoiding Condensation

To avoid condensation, both the primary air and chilled water need to be at or above the space's dew point. On average, that temperature is around 60°F (15°C), with the discharge air temperature just a few degrees higher. So, if our target room temperature is 73°F (23°C), one would probably want to design for a supply temperature at about 63°F (18°C) or a room discharge ΔT of 10°F (5°C).

Load Considerations

One of the first considerations in any design should be satisfying room loads, both latent and sensible. The primary air will help fulfill the requirements of the latent load, but it is important that it have a dew point lower than the actual supply temperature. For the sensible load, this is handled by a combination of cool primary and induced air passing through a cool coil. Given these properties, chilled beams are best employed in spaces that have low latent and relatively constant sensible loads. Of course, if the local space loads are lower than the

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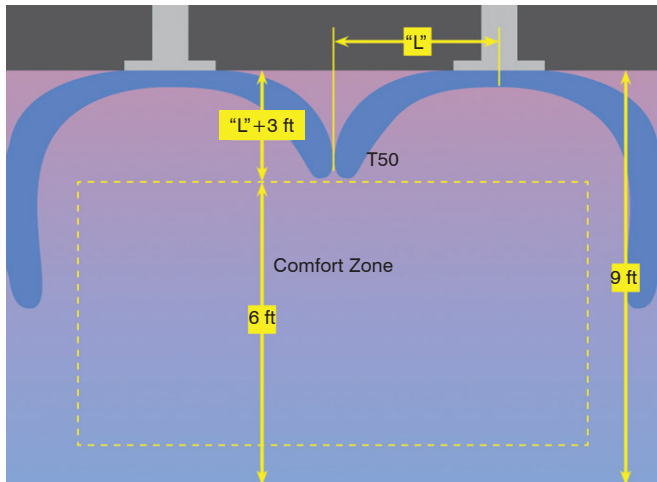


Figure 1: Jet collision.

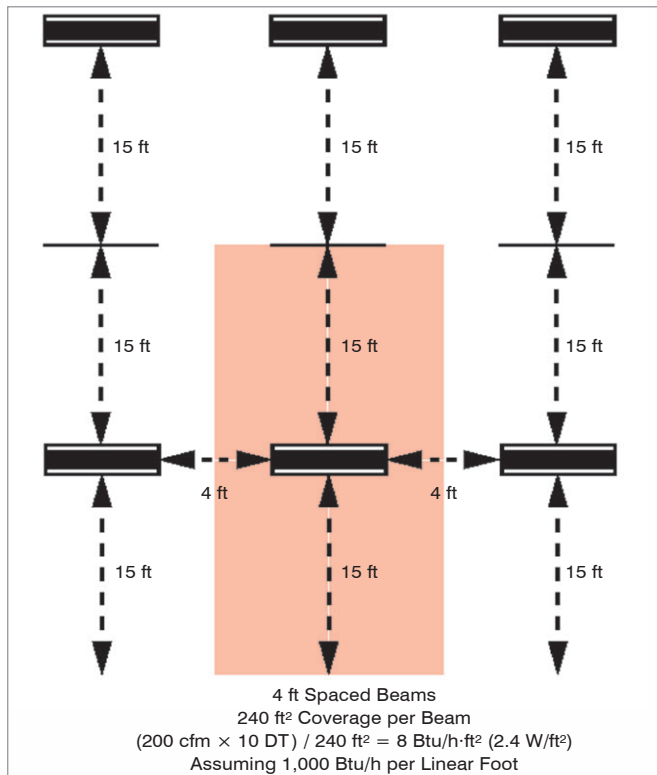


Figure 2: Four foot spaced beams.

minimum load capacity (water off, DOAS air providing cooling and dehumidification), the space will either become subcooled or the unit will go into heating mode.

Reducing First Costs

To reduce first costs, we often see designs that maximize the capacity and reduce the required length of a beam. While no doubt a good first cost strategy, it may be a poor choice in providing uniform (and acceptable) temperatures throughout a space. Much like linear slot diffusers, chilled beams have the same type of air distribution limitations. They both provide two-way discharge air patterns and create collisions from opposing units, with stagnant spaces between the ends.

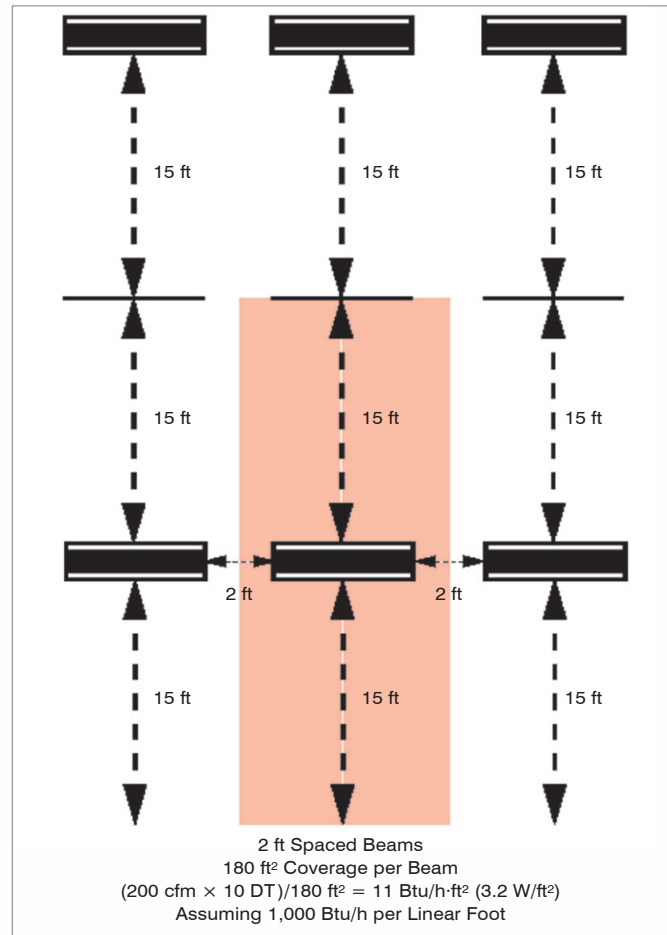


Figure 3: Two foot spaced beams.

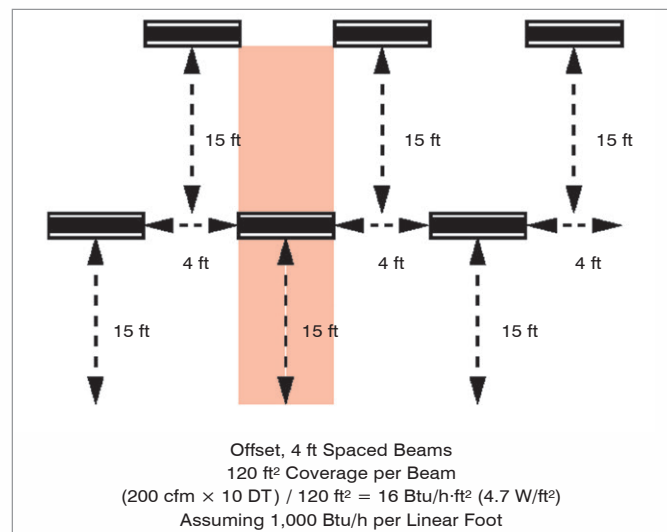


Figure 4: Staggered beams.

Spacing and Jet Collisions

Few manufacturers publish throw data for chilled beams, so it makes predicting jet collisions difficult, if that is all we are referencing. However, if we look at the chilled beam as a linear slot diffuser, it does give us the ability to make estimations that we could not

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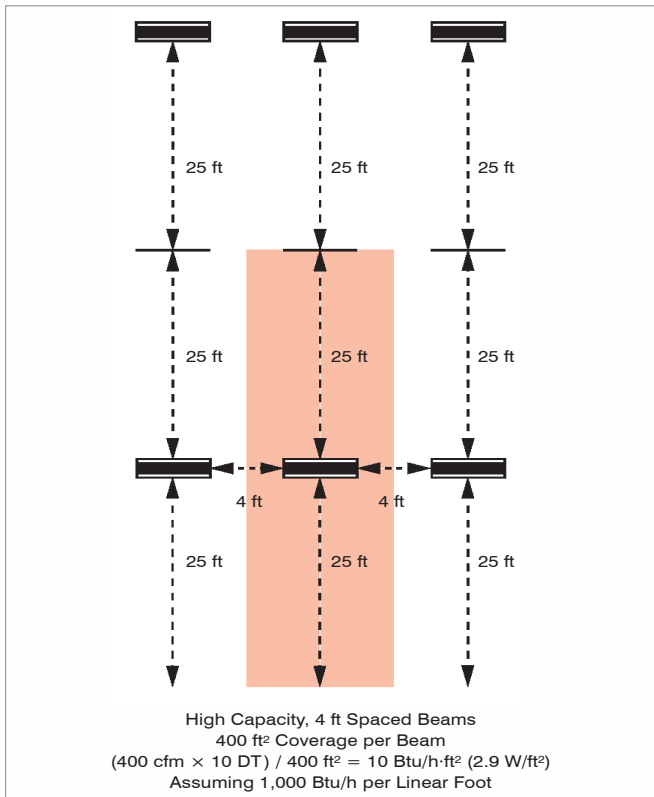


Figure 5: High capacity beams.

make otherwise. That being said, if we take the per foot capacity of the chilled beam and divide it by 10 (the typical ΔT), we are able to calculate the effective cfm/foot. Then, referencing that value in the performance data for a two-way throw of a similar linear slot diffuser (at that flow rate), we can see if a collision is likely. Typically, the goal is for the 50 fpm (0.25 m/s) throw values to be no greater than one-half of the diffuser spacing (L) plus the distance from 6 ft (1.8 m) to the ceiling as shown in Figure 1.

Let us run through an example for a chilled beam that produces 500 Btu/h-ft (481 W/ft).

First, we reference the performance data of a linear slot diffuser with similar unit specifications.

- 4 ft (1.2 m) long unit
- 2 in. (51 mm) slots (quantity two)
- Two-way throw pattern
- 50 cfm/ft (77 L/s-m)

The catalog data we reference for this example states that the throw to 50 fpm (0.25 m/s) is 18 ft (5.5 m).

What this means is that if we have a 9 ft (2.7 m) ceiling, the chilled beams would have to be 30 ft (9 m) apart to avoid collisions of the opposing airstreams entering into the occupied zone. So, if we take a 4 ft (1.2 m) chilled beam on 30 ft (9 m) centers that produces 2,000 Btu/h and has a 4 ft (1.2 m) gap between the ends, it would provide 240 ft² (22 m²) coverage or 8 Btu/h-ft² (25 W/m²) and is probably the right design for a typical open plan office (Figure 2, Page 59).

For instances where the load might be higher, it is likely that drafts will be created if the units are placed closer together, so to

combat this, the end spacing should be reduced. Giving a 2 ft (0.6 m) gap between the ends will allow coverage for 180 ft² (17 m²) or 11 Btu/h-ft² (35 W/m²) (Figure 3).

Some would say an effective strategy to avoid collisions would be to offset opposing units. This can work, but only if the end spacing is equal to the active length of the unit. Done correctly, the units could be placed closer together, which would then increase the per square foot (square meter) load capability, delivering 16 Btu/h-ft² (50 W/m²) (in our example). There has been some push back from architects with regard to this type of configuration, but often times, locating the lights in the gaps seems to be an acceptable solution (Figure 4).

Some manufacturers offer a high capacity chilled beam, which is around 1,000 Btu/h-ft (961 W/m). For units this large, the airflow might be near 100 cfm/ft (155 L/s-m) (at 10°F ΔT) and provide throws upwards of 28 ft (8.5 m). To avoid jet collisions, the units would need to be spaced about 50 ft apart (Figure 5).

Turndown

Reducing the supply airflow rate in response to lower loads tends to complicate the situation. As the primary flow is reduced, the induction nozzle velocity drops, which in turn lowers the induction effect and pressure across the coil. While one might think that the supply airflow and throw may lower in proportion to each other, this is not always the case. To make matters worse, if the flow rate to one chilled beam is varied, it will affect the flow to all the others in the system, so for those particular cases, a pressure independent supply damper would be required to effectively employ this strategy. If you recall, the ASHRAE Journal article published in April 2012 titled Don't Turn Active Beams Into Expensive Diffusers, explains this issue very well.

In the recently completed ASHRAE Research Project 1515, it was found that interior loads at the Yahoo facility in California were as low as 6 Btu/h-ft² (19 W/m²). This is a far lower number than many buildings are designed around today, which on average is 23 Btu/h-ft² (73 W/m²) or more. So, if a typical design load is used, the turndown of the chilled beam is an important consideration. As mentioned earlier, at constant primary flow, the unit's response to water flow rate will determine the reduction in discharge temperature.

Finally, there are limitations that are inherent to the design of chilled beams that may make the ability to handle high perimeter loads problematic, whether it is heating or cooling. Reference the article from the ASHRAE Journal published in August 2014 titled 'Variable Volume DOAS Fan-Powered Terminal Unit,' which discusses the use of a 'chilled box' that employs many similar system features, but differs in that it uses an integral ECM fan to help overcome the performance that results from using induction from a central fan.

Conclusion

While not a new technology, chilled beams are not without complexities or challenges. To ensure that designs using these devices are comfortable, energy efficient, and able to realize expected loads (both imagined and actual), it is important that engineers not only become more familiar with the product, but also take into account the many selection considerations, including first cost, that can make or break its success. ❄️