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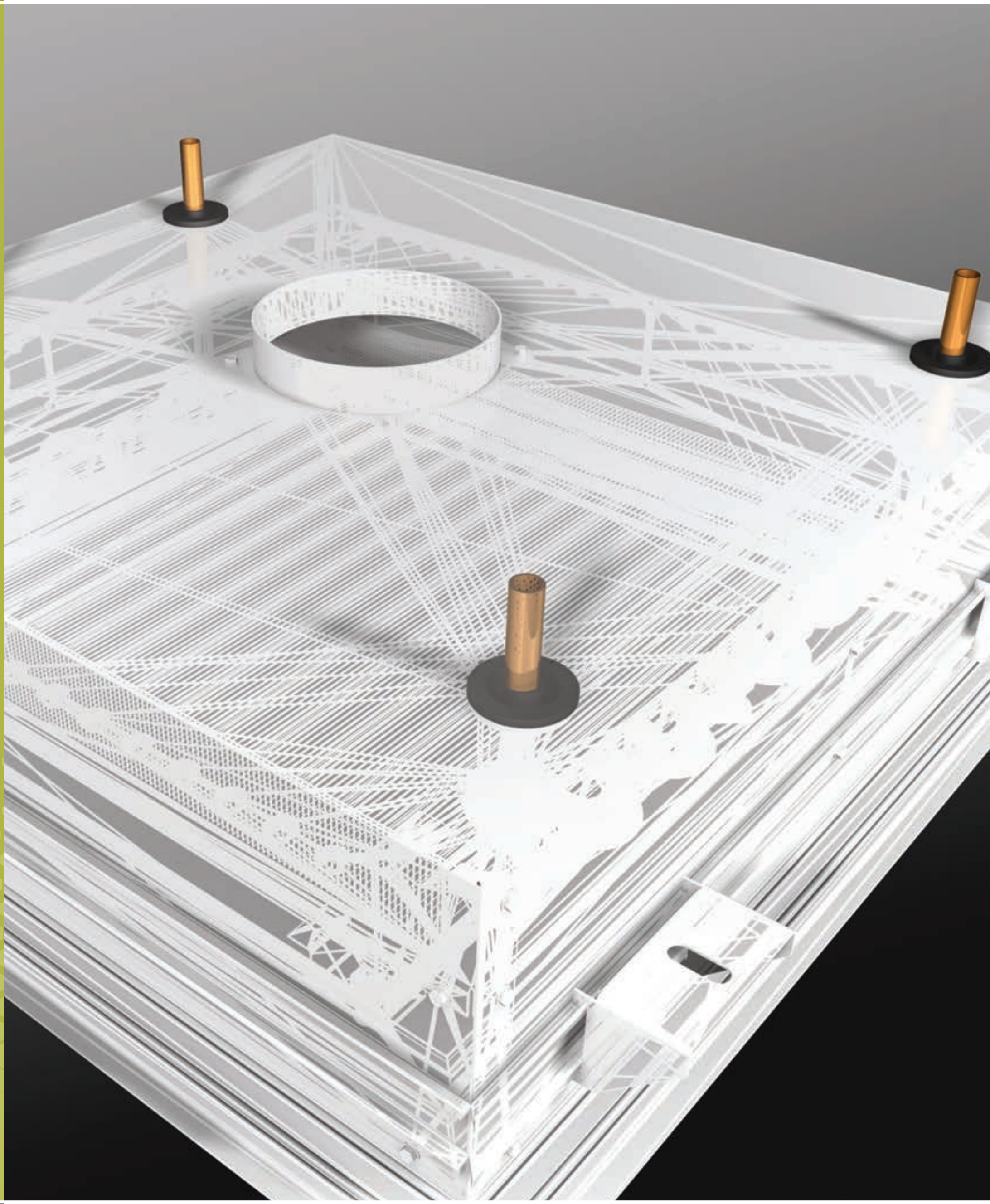

Engineering Guide
Active & Passive Beams

Please refer to the **Price Engineer's HVAC Handbook** for more information on Active & Passive Beams.

Introduction

Like radiant heating and cooling systems, active and passive beam systems use water as well as air to transport energy throughout the building. Like radiant and cooling systems, they offer savings in energy, space and maintenance costs. Unlike radiant heating and cooling systems, however, these technologies deliver the majority of their cooling and heating through convection, often leading to a fully mixed environment. This section introduces active and passive beam systems and their design considerations, and addresses the unique requirements of some of the most common applications.

Management of heat loads can generally be classified into two different types: all-air systems or hybrid systems. All-air systems have been the most prominent in North America during the 20th century and have been in use since the advent of air conditioning. These systems use air to service both the ventilation requirement as well as the building cooling loads. In general, these systems have a central air handling unit that delivers enough cool or warm air to satisfy the building load. Diffusers mounted in the zone deliver this air in such a way as to promote comfort and evenly distribute the air. In many cases, the amount of air required to cool or warm the space or the fluctuations of loads make designing in accordance to these principles difficult.

Hybrid systems combine an air-side ventilation system and a hydronic (or water-side) system. The air-side system is designed to meet all of the ventilation requirements for the building as well as satisfy the latent loads. It is typically a 100% outside air system and because the primary function of the supply air system is ventilation and dehumidification as opposed to sensible cooling it can be supplied at higher supply air temperatures than is typical of traditional mixing air distribution systems. The water-side system is designed to meet the balance of the sensible cooling and heating loads. These loads are handled by water-based products, such as active and passive beams, which transfer heat to the zone by induction.

Concepts and Benefits

Active and passive beam systems provide an effective method for providing heating or cooling to a space while promoting a high level of occupant comfort and energy efficiency. There are two distinct system design philosophies that are considered when applying hydronic heating and/or cooling:

Hydronic heating or cooling where the hydronic systems are integrated with the primary ventilation system. These are active beam systems **(Figure 1)**.

Hybrid heating or cooling systems where water-based devices are used in conjunction with a scaled-down ventilation system, and manage the bulk of the sensible cooling load. These systems generally use passive beams **(Figure 2)**.

Hydronic systems have been successfully used in several applications having dramatically different characteristics. Some examples of areas where active and passive beam systems have been applied include:

- Green Buildings
- Post Secondary Educational Facilities
- Load Driven Laboratories
- K-12 Schools
- Office Buildings
- Cafeterias
- Television Studios

Benefits of Air-Water Systems

There are many benefits to heating and cooling using active or passive beams. Advantages of water-based heating and cooling systems over other mechanical systems include:

- Energy and system efficiency
- Reduced system horse power
- Improved indoor environmental quality
- Improved indoor air quality
- Increased thermal comfort
- Reduced mechanical footprint
- Lower maintenance costs
- Improved system hygiene

Active or passive beam systems are a good choice where:

- Thermal comfort is a major design consideration
- Areas with high sensible loads exist/are present
- Areas requiring a high indoor air quality (100% outdoor air system) exist/are present
- Energy conservation is desired

Energy Efficiency

The heat transfer capacity of water allows for a reduction in the energy used to transport an equivalent amount of heat as an all-air system (Stetiu, 1998). These reductions can be found primarily through reduced fan energy.

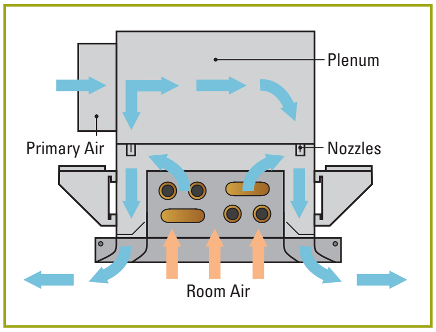

Figure 1: Air flow diagram of a typical linear active beam in cooling

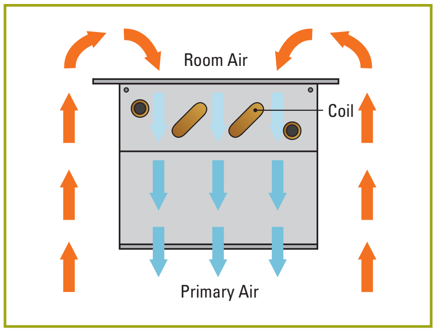

Figure 2: Air flow diagram of a passive chilled in cooling

Figure 3: Active beams installed in an office

Figure 4: Passive beams behind a perforated ceiling

The higher chilled water supply (CHWS) temperatures used with active and passive beam systems, typically around 58 °F [14.5 °C], provide many opportunities for a reduction in energy use, including increased water-side economizer use. This increased CHWS temperature also allows for more wet-side economizer hours than would be possible with other systems where CHWS temperatures are typically ~45 °F [7 °C].

Indoor Air Quality

Depending on the application, under maximum load, only ~15 to 40% of the cooling air flow in a typical space is outdoor air required by code to satisfy the ventilation requirements. The balance of the supply air flow is recirculated air which, when not treated, can transport pollutants through the building. Active and passive beam systems transfer heat directly to/from the zone and are often used with a 100% outdoor air system that exhausts polluted air directly to the outside, reducing the opportunity for VOCs and illness to travel between air distribution zones.

Noise

Active and passive beam systems do not usually have fan powered devices near the zone. This typically results in lower zone noise levels than what is achieved with all-air systems. In situations where passive beams are used in conjunction with a quiet air system, such as displacement ventilation, the opportunities for noise reduction increase further.

Reduced Mechanical Footprint

The increased cooling capacity of water allows the transport system to be reduced in size. Generally, it is not unusual to be able to replace ~60 ft² [6 m²] of air shaft with a 6 in. [150 mm] water riser, increasing the amount of floor space available for use or lease. Due to the simplicity of the systems (i.e. reduction in the number of moving parts and the elimination of zone filters, drain pans, condensate pumps and mechanical components), there tends to be less space required in the interstitial space to support the HVAC system.

Lower Maintenance Costs

With no terminal unit or fan coil filters for motors to replace, a simple periodic coil cleaning is all that is required in order to maintain the product.

When to use Beam Systems

Hygienic System

With the elimination of the majority of filters and drain pans, there is a reduced risk of mold or bacteria growth in the entire mechanical system.

Active and passive beam systems are well-suited to some applications and less so to others. As a result, each application must be reviewed for potential benefits as well as the suitability of these types of systems. One consideration which can assist in the decision to employ hydronic systems as opposed to an all-air system is the air-side load fraction, or the percentage of the total air supply which must be delivered to the zone to satisfy code and dehumidification requirements. **Table 1** shows the load fraction for several spaces. In the table the best applications for hydronic systems are those with the lowest air-side load fraction as they are the ones that will benefit the most from the efficiencies of hydronic systems. Another factor which should be examined is the sensible heat ratio or the percentage of the cooling load which is sensible as opposed to latent. The latent loads must be satisfied with an air system and offer some sensible cooling at the same time due to the temperature of dehumidified air. If the total sensible cooling load is significantly higher than the capacity of the air supplied to satisfy the latent loads, a beam system might be a good choice.

Commercial Office Buildings

In an office building, active and passive beam systems provide several benefits. The lower supply air volume of the air handling system provides significant energy savings. In addition, the smaller infrastructure required to move this lower air flow allows for small plenum spaces, translating into shorter floor-to-floor construction or higher ceilings. The lower supply air volume and elimination of fans at or near the space offers a significant reduction in generated noise. The lower air flow often translates to reheat requirements being reduced. In the case of 100% outside air systems, the lighting load captured in the return plenum is exhausted from the building, lowering the overall cooling load.

Schools

Schools are another application that can benefit greatly from active and passive beam systems. Similar to office buildings, the benefits of a lower supply air volume to the space are lower fan power, shorter plenum height, reduced reheat requirements and lower noise levels (often a critical design parameter of schools).

Hospital Patient Rooms

Hospitals are unique applications in that the supply air volume required by local codes for each space is often greater than the requirement of the cooling and heating load. In some jurisdictions, local code requires these higher air-change rates for all-air systems only. In these cases, the total air-change rate required is reduced if supplemental heating or cooling is used. This allows for a significant reduction in system air volume and yields energy savings and other benefits.

Furthermore, because these systems are generally constant air volume with the potential to reduce the primary air-change rates, reheat and the cooling energy discarded as part of the reheat process is a significant energy savings opportunity. Depending on the application, a 100% outside air system may be used. These systems utilize no return air and therefore no mixing of return air between patient rooms occurs, potentially lowering the risk of hospital associated infections.

Laboratories

In load driven laboratories where the supply air rate is driven by the internal gains (such as refrigerators, testing equipment, etc.) as opposed to the exhaust requirements, active and passive beam systems can offer significant energy savings. In these environments it is not unusual to require a large air-change rate in order to satisfy the load, although significantly less may be required by code (ASHRAE, 2008; CSA, 2010).

In these applications, the difference between the supply air volume required to manage the sensible loads and that required to meet the fume hood air flow requirements provides opportunity for energy savings through the application of active and passive beams. These savings are typically due to the reduction in fan power as well as the energy associated with treating the outside air, which, in the case of a load driven lab, may be significant.

Hotels / Dorms

Hotels, motels, dormitories and similar type buildings can also benefit from active and passive beam systems. Fan power savings often come from the elimination of fan coil units located in the occupied space. The energy savings associated with these "local" fans is similar in magnitude to that of larger air handling systems. It also allows for the elimination of the electrical service required for the installation of fan coil units, as well as a reduction in the maintenance of the drain and filter systems. The removal of these fans from the occupied space also provides lower noise levels, which can be a significant benefit in sleep areas.

Limitations

There are several areas in a building where humidity can be difficult to control, such as lobby areas and locations of egress. These areas may see a significant short term humidity load if the entrances are not isolated in some way (revolving doors or vestibules). In these areas, a choice of a complimentary technology such as fan coil units or displacement ventilation is ideal.

Other applications may have high air flow/ventilation requirements, such as an exhaust driven lab. The majority of the benefit provided by the hydronic system is linked to the reduction in supply air flow. As such, these applications may not see sufficient benefit to justify the addition of the hydronic circulation systems, making them not likely to be a good candidate for this technology.

Application	Total Air Volume (Typ.)	Ventilation Requirement (Typ.)	Air-Side Load Fraction
Office	1 cfm/ft^2 [5 L/s m^2]	0.15 cfm/ft^2 [0.75 L/s m^2]	0.15
School	1.5 cfm/ft^2 [7.5 L/s m^2]	0.5 cfm/ft^2 [2.5 L/s m^2]	0.33
Lobby	2 cfm/ft^2 [10 L/s m^2]	1 cfm/ft^2 [5 L/s m^2]	0.5
Patient Room	6 ach	2 ach	0.33
Load-driven Lab	20 ach	6 ach	0.3

Table 1: Typical load fractions for several spaces in the United States

Passive Beams

Passive Beams

Passive beams use a heat exchanger–usually a coil–to change the temperature of the adjacent transferring heat and create a difference in density with the ambient air. The density difference creates air movement across the heat exchanger, transferring heat from the heat exchanger to the air.

Passive beams condition a space using natural convection and are primarily used for handling the sensible cooling load of a space. They are water-only products, and require a separate air system for ventilation air and to remove the latent load. As warm air in the room rises, it comes into contact with the heat exchanger and flows downward through the cool coils back into the space, as seen in **Figure 5**. In heating mode, passive beams are generally not used, though in some special instances they would condition the space primarily by thermal radiation.

Product Description

Passive beams are available in models that either integrate into standard suspended ceiling systems or are suspended freely from the ceiling. They are also commonly installed behind perforated metal ceilings for a uniform architectural appearance. A perforated metal ceiling helps reduce draft under the beam, however, a minimum free area of 50% is often required to ensure the capacity of the beam is not reduced. Passive beams installed behind a metal perforated ceiling can be seen in **Figure 7**.

Components

The basic components of passive beams include a heat exchanger, comprising of extruded aluminum fins and copper tubing, commonly termed the 'coil', and a frame or shroud. These components are illustrated in **Figure 8**.

Location

Passive beams are ideally suited to aisle ways or perimeters of large spaces such as offices, lobbies, conference centers, libraries, or any other space that requires perimeter or additional cooling. Air flow from a passive beam is straight down so they are not typically placed above where an occupant will be stationed for an extended period of time. While the velocity from a passive beam is low, there is the opportunity for some people in this condition to be uncomfortable.

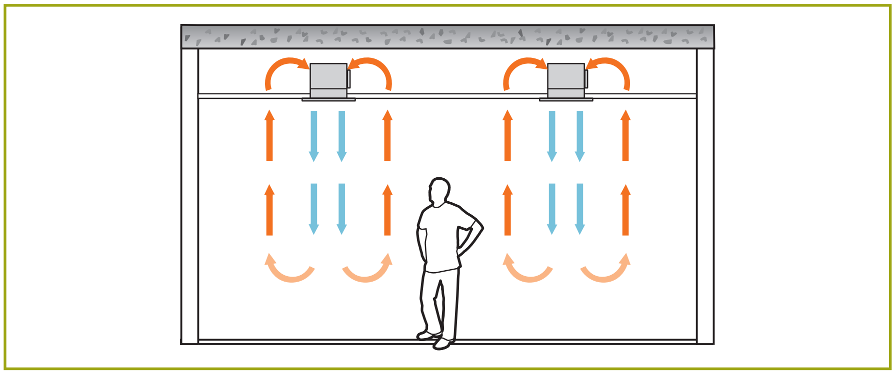

Figure 5: Room air flow pattern of a passive beam in cooling

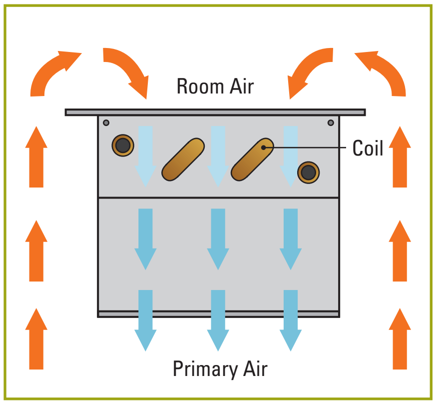

Figure 6: Air flow diagram of a passive beam in cooling

Figure 7: Passive beams installed behind a metal perforated ceiling

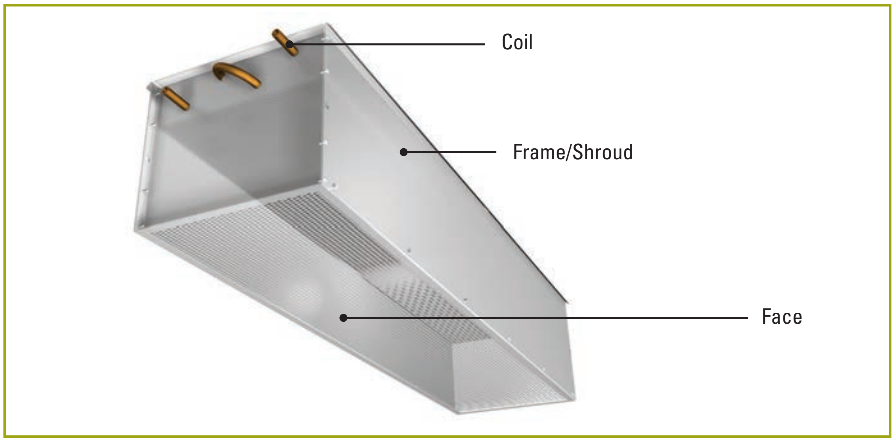

Figure 8: Components of a typical passive chilled beam

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

Active Beams

Active Beams

Active beams use the ventilation system to increase the output of the coil, and to handle both latent and sensible loads of a space. Unlike radiant panels and chilled sails, which rely primarily on thermal radiation to condition a space, active beams heat or cool a space through induction and forced convection. An active beam accepts dry air from the system through a pressurized plenum. This primary supply air is then forced through nozzles in order to create a high velocity air pattern in the area adjacent to the coil. This high velocity causes a reduction in the local static pressure, inducing room air through the heating/cooling coil. The induced air then mixes with the primary supply air and is discharged back into the space via slots along the beam **(Figure 9)**. A typical air flow diagram of a linear active beam in cooling and heating modes can be seen in **Figure 10**, and **Figure 11** respectively.

Components

The basic components of active beams include a heat exchanger with aluminum fins and copper tubing, commonly termed the 'coil,' a plenum box with at least one supply inlet, internal nozzles, a visible face, and a frame. Although the configurations of active beams differ, all general components remain the same. These components are illustrated in **Figures 12**.

Applications

Active beams can be used in offices, meeting rooms, schools, laboratories, hospitals, data centers, airports, any 'green' building application, and large areas such as lobbies, conference facilities, lecture halls or cafeterias.

Two basic types of active beams are:

- Linear Active Beams
- Modular Active Beams

Linear Active Beams

2 Way Discharge

Linear active beams with two-sided discharge are designed to either integrate into standard suspended ceiling systems or be suspended freely in an 'exposed' application. These beams have two linear air slots that run the length of the beam, one on either side.

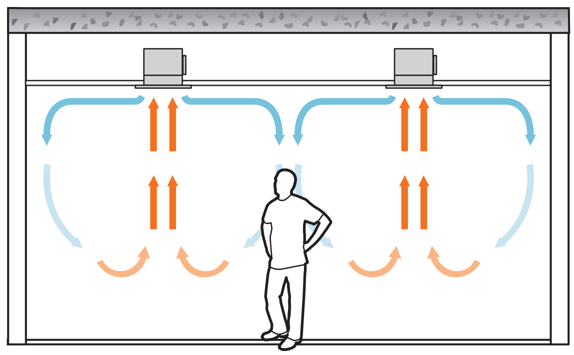

Figure 9: Room air flow pattern of a typical linear active beam in cooling

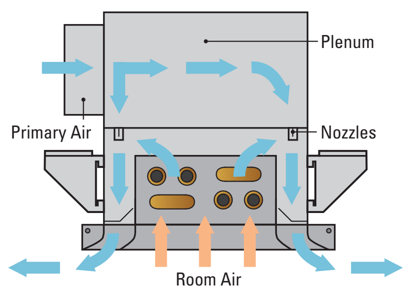

Figure 10: Air flow diagram of a typical linear active beam in cooling

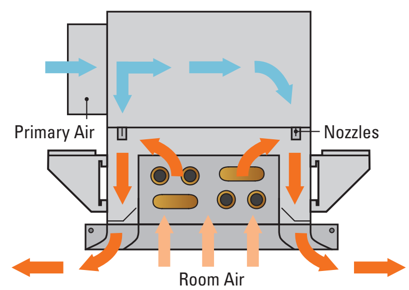

Figure 11: Air flow diagram of a typical linear active beam in heating

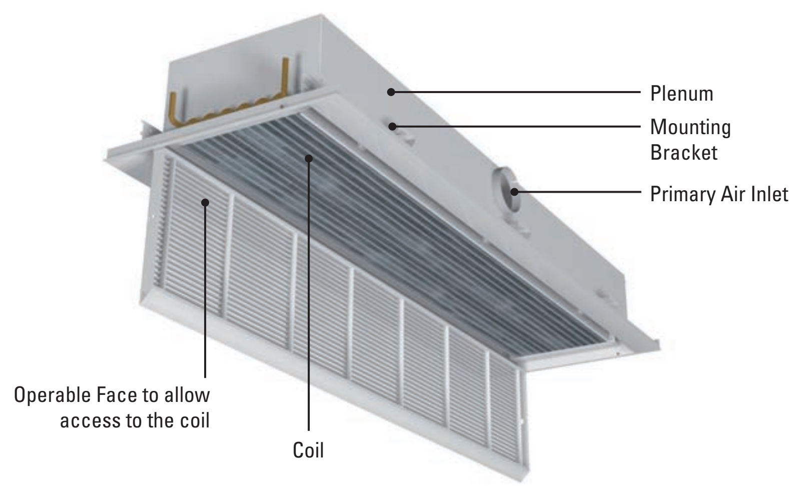

Figure 12: Components of a typical linear active beam

All Metric dimensions ( ) are soft conversion.
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Active Beams

1 Way Discharge

Linear active beams with single-sided air discharge are designed to either integrate into standard suspended ceiling systems or be suspended freely in an 'exposed' application. These beams have only one discharge air slot that runs along one side of the beam.

The general air flow of linear active beams with 1 way air distribution in cooling and heating are seen in **Figures 13** and **Figure 14**. **Figure 15** illustrates the room air flow of a typical 1 way active beam.

PRODUCT TIP

Linear active beams with 1 way air distribution are best suited for placement along a façade or wall. In applications where 1 way beams are used with 2 way beams, a symmetric face may be selected for the 1 way unit to ensure a consistent appearance from the room.

Modular Active Beams

Modular active beams combine fresh air ventilation, hydronic heating and cooling, and four-sided air flow. They are typically available in modular sizes, 2 ft x 2 ft [600 mm x 600 mm], and 2 ft x 4 ft [600 mm x 1200 mm], and are available in models either designed to integrate into standard ceiling tiles or suspend freely from the ceiling.

The typical air flow pattern of a modular beam in cooling and heating is illustrated in **Figure 16** and **Figure 17**. Often, these modular beams can be customized to individually modulate the air flow from each side of the unit. For example, one side of the unit can be blanked off to create a modular beam with three-sided air flow.

PRODUCT TIP

Active beams are typically available in a 2 pipe or 4 pipe configuration. Beams with 2 pipe configurations have one supply and one return pipe for each unit, which serves for either/both heating and cooling purposes. Beams with 4 pipe configurations have two supply and two return pipes for each unit, comprising separate loops for cooling and heating.

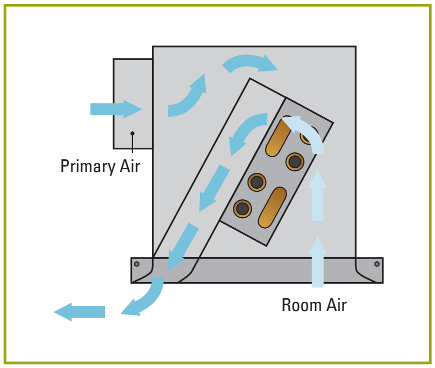

Figure 13: Air flow diagram of a linear active beam in cooling with 1 way discharge

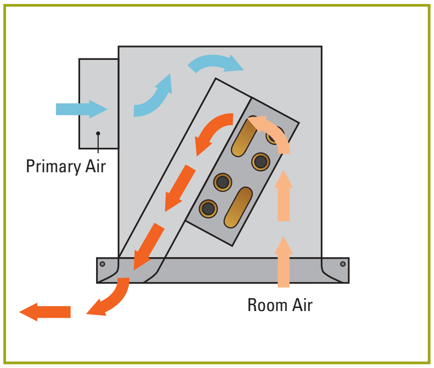

Figure 14: Air flow diagram of a linear active beam in heating with 1 way discharge

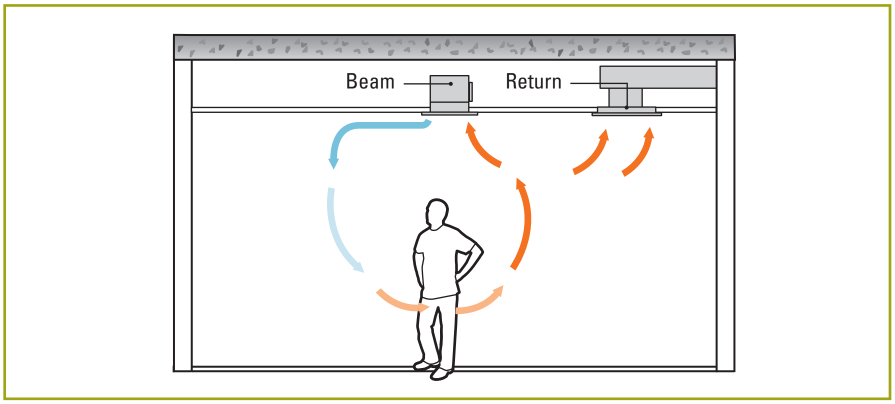

Figure 15: Room air flow pattern of a typical linear active beam in cooling

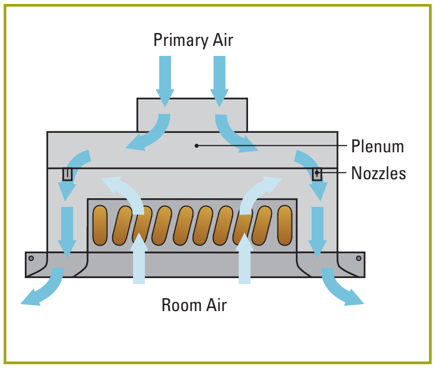

Figure 16: Air flow diagram of a modular beam in cooling

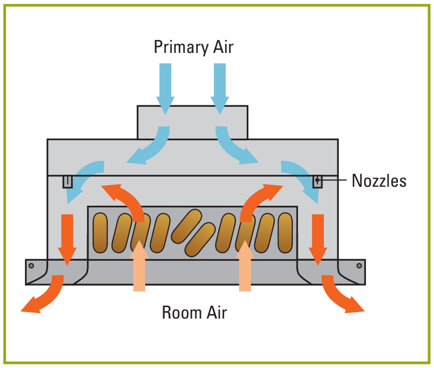

Figure 17: Air flow diagram of a modular beam in heating

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

Passive Beam Selection and Design Procedure

Passive beam systems will vary in performance, configuration and layout depending on the application. There are, however, some characteristics that are common for most systems. Furthermore, the performance of passive beams is largely dependent on a common set of factors. This section will discuss how factors such as chilled water temperature affect the performance and layout of passive beams. **Table 2** shows common design characteristics for passive beam systems.

Product Selection and Location – Passive Beams

Performance

The performance of a passive beam is dependent on several factors:

- Water flow rate
- Mean water temperature and surrounding air temperature
- Shroud height
- Free area of the air paths (internal and external to the beam)
- Location and application

The water flow rate in the coil affects two performance factors: the heat transfer between the water and the coil, which is dependent on whether the flow is laminar (poor) or turbulent (good); and the mean water temperature, or the average temperature, in the coil. The higher the flow rate, the closer the discharge temperature will be to the inlet, thereby changing the average water temperature in the coil. **Figure 18** shows the effect of the flow rate, indicated by Reynolds number, on the capacity of a typical passive beam. As indicated on the chart, increasing the flow rate into the transitional and turbulent ranges (Re > 2300, shaded in the graph) causes an increase in the output of the beam.

The water flow rate is largely dependent on the pressure drop and return water temperatures that are acceptable to the designer. In most cases, the water flow rate should be selected to be fully turbulent under design conditions.

The difference between the mean water temperature, $\bar{t}w$, defined as:

$$\bar{t}_w = \frac{t_{supply} + t_{return}}{2}$$

and the surrounding (coil inlet) air temperature is one of the primary drivers of the beam performance. The larger this difference is, the higher the convective heat transfer potential. Conversely, a lower temperature difference will reduce the amount of potential energy exchange, and thereby capacity. As a result, it is desirable from a capacity standpoint to select entry water temperatures as low as possible,

IP	
Room Temperature	74 °F to 78 °F in summer, 68 °F to 72 °F in winter
Water Temperatures, Cooling	55 °F to 58 °F EWT, 5 °F to 8 °F ΔT
Design Sound Levels	< 40 NC
Cooling Capacity	Up to 500 Btu/hft
Ventilation Requirement	0.1 to 0.5 cfm/ft² floor area
SI	
Room Temperature	23 °C to 25 °C in summer, 20 °C to 22 °C in winter
Water Temperatures, Cooling	13 °C to 15 °C EWT, 3 K to 5 K ΔT
Design Sound Levels	< 40 NC
Cooling Capacity	Up to 500 W/m
Ventilation Requirement	0.5 to 2.5 L/s m² floor area

Table 2: Design Values for passive beam systems

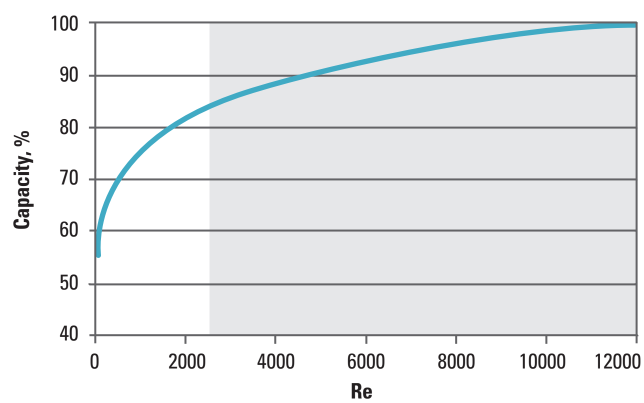

Figure 18: Passive beam capacity vs. water flow

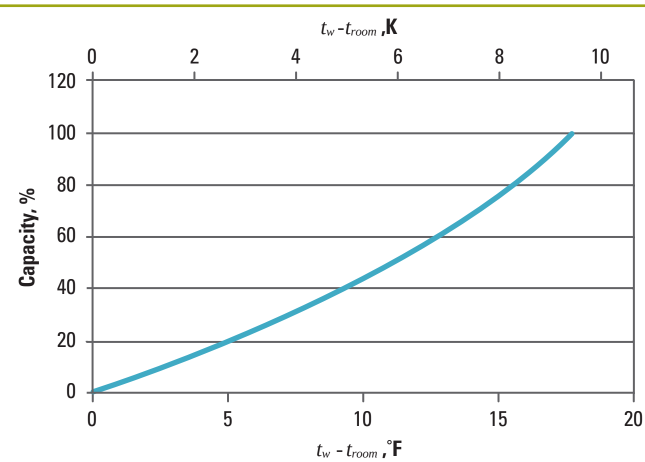

Figure 19: Passive beam capacity vs. difference between mean water and room air temperature

Passive Beam Selection and Design Procedure

while maintaining it above the dew point in the room to ensure sensible cooling only.

In some instances, it might be advantageous to the designer to use higher water temperatures, where it makes sense from an equipment standpoint. This may also offer some control simplification where the output of the beam is determined by the load in the room:

- As the load increases, the air temperature rises and increases the difference between it and t_w, thereby increasing beam performance.
- As the load decreases, the air temperature falls and reduces the cooling capacity of the beam.

A passive beam uses buoyancy forces and the "stack" effect to drive air through the coil. The stack effect is a phenomenon that can be used to increase the rate of circulation through the coil by increasing the momentum of the falling air. As the air surrounding the coil fins decreases in temperature, it becomes more dense than the surrounding air, causing it to fall down into the zone below. **Figure 20** shows a cross section of a passive beam and how the shroud, or skirt, of the beam separates the cool air from the surrounding air, allowing it to gain momentum and draw an increasing volume of air into the coil from above.

The taller this stack is, the more air is drawn through the coil, increasing the cooling potential of the beam. As the volume of air is increased, the velocity of the air falling below the beam is also increased. It is not uncommon to adjust the height of the stack in order to adjust the capacity and velocities in order to suit application requirements.

Figure 21 shows the increase in capacity when the stack height is changed from 6 in. [150 mm] to 12 in. [300 mm] vs. the difference between t_{room} and $\bar{t}w$. The graph indicates that the increase in capacity from the larger shroud reduces as the overall capacity of the beam increases. A practical lower limit where the mean water temperature is 18 °F [10 K] below the room temperature translates to a capacity increase of 25% with the taller stack.

Because the air flow through the beam is driven by buoyancy forces, any restriction to the air paths will impact the performance of the beam. **Figure 22** shows the various factors that affect performance, including:

- Face design of the beam when exposed
- Perforated ceiling below the beam when not exposed
- Gap between the beam and the slab
- Restrictions of the return air path when the ceiling is closed (either return grilles or perforated ceiling tiles)

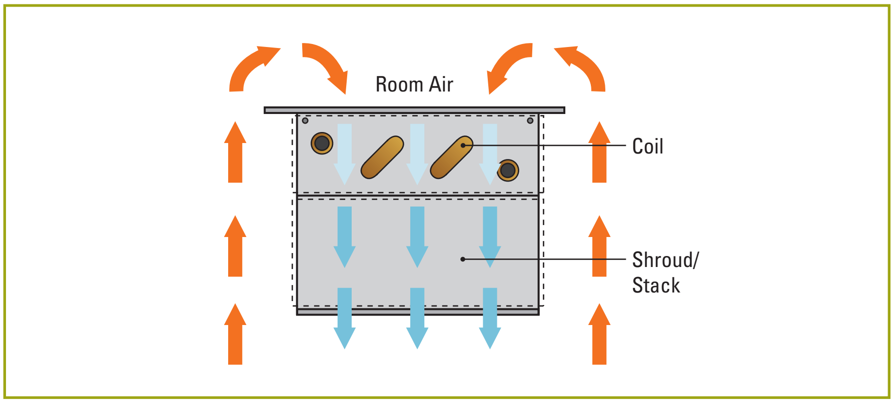

Figure 20: Passive beam air flow pattern

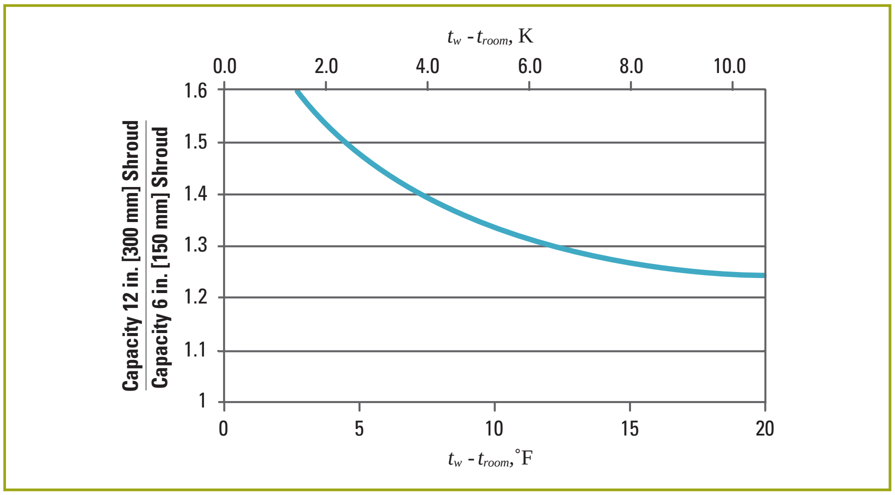

Figure 21: Passive beam capacity vs. temperature difference

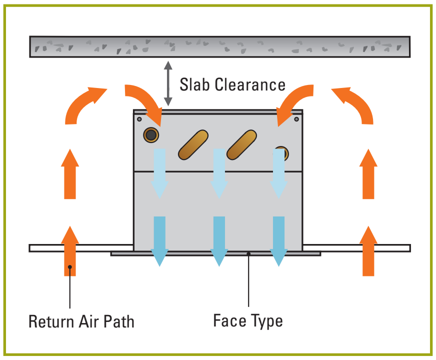

Figure 22: Factors that affect performance of passive beams

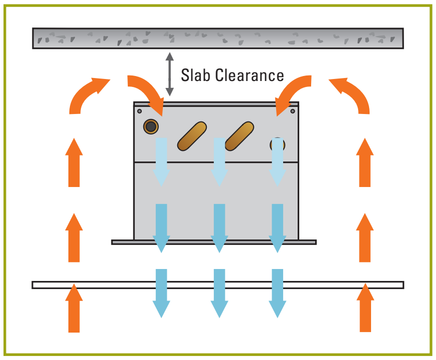

Figure 23: A passive beam installed above a perforated ceiling

ENGINEERING GUIDE - ACTIVE & PASSIVE BEAMS

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Passive Beam Selection and Design Procedure

The design of the face material may restrict air falling through the face. If the beam is installed behind a perforated ceiling, as shown in **Figure 23**, the air falling below the beam will hit the ceiling, spread out, and fall into the zone below over a larger area. As long as there is enough free area in the ceiling to allow the air to fall through (as well as rise through in order to feed the beam with warm air), there should not be a reduction in the capacity of the unit. Use of a perforated ceiling is also a good way to reduce velocities below the beam, if required.

The distance between the top of the beam and the structure can reduce the air flow and capacity of the passive beam if it is too narrow. **Figure 24** shows the impact of the gap between the beam and the slab in terms of the beam width (gap/width).

In most cases, a clearance of 20 to 25% of the beam width is recommended. These products are generally selected to be 18 in. [450 mm] or less in width, which would require a gap up to 4.5 in. [115 mm].

There are other factors that affect performance, including the application, choice of ventilation system, and location. It is possible to increase the capacity of the passive beam through induction. If a high velocity is located near a passive beam, it may pull air through the coil at a higher rate than the natural convection would alone, as indicated in **Figure 25**. It is also possible to trap thermal plumes at the building envelope and force this air though a passive beam, as shown in **Figure 26**.

The performance of the beam under non-standard conditions, such as those described above, can be difficult to estimate. For example, the plume coming up from the façade may be so strong, and the inlet to the plenum so narrow, that the plume comes across the face of the beam. This would disturb the air movement through the coil, dramatically reducing the capacity of the beam. In these instances, it is best to conduct a building mockup or use simulation software to understand how the various parameters affect each other.

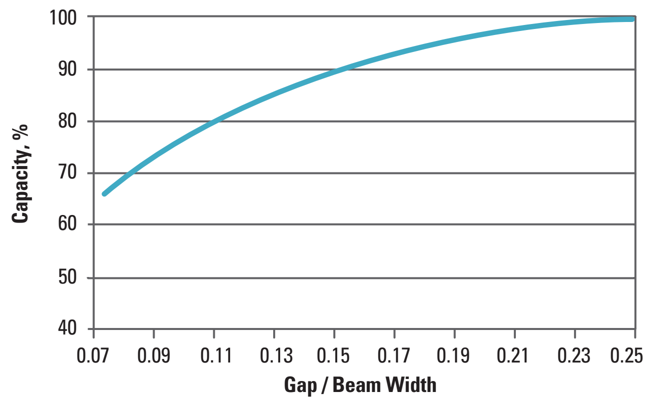


Figure 24: The impact on the capacity of the gap between a passive beam and building structure

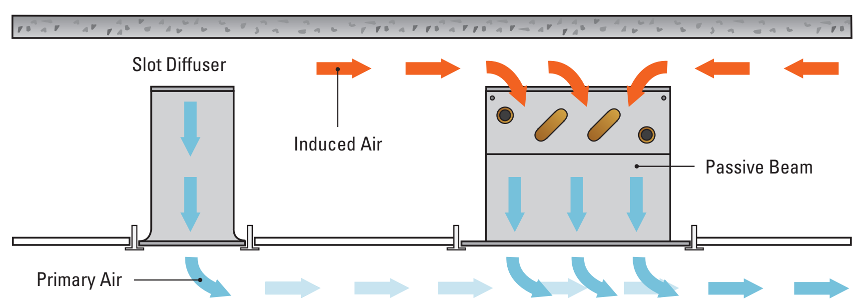


Figure 25: Inducing air through the passive beam with increased velocity across the face

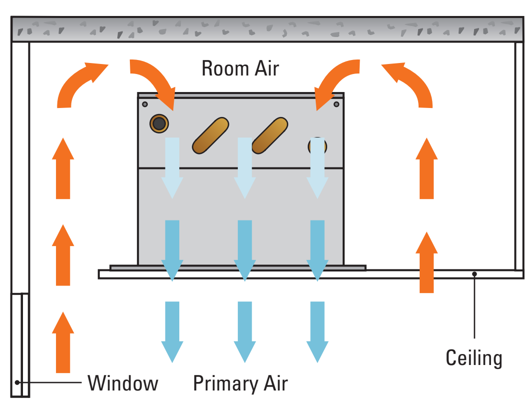


Figure 26: Capturing the plume at the perimeter may increase passive beam performance

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

Passive Beam Selection and Design Procedure

Selection and Location

Due to the air cascade below the passive beam, it is common to locate the beam above aisles or along walls. Depending on the capacity and the expected velocity below the beam, the air may pose a risk of draft to occupants who are regularly located beneath them. **Figure 27** shows the velocity below an 18 in. [450 mm] wide passive beam vs. beam capacity.

In most cases, it is desirable to maintain the velocity in the occupied zone below 50 fpm [0.25 m/s], though this value will depend on the temperature of the air. From **Figure 27**, the average velocity (the solid line) ranges from 35 fpm [0.175 m/s] to 50 fpm [0.25 m/s], operating between 150 Btu/hft [145 W/m] and 300 Btu/hft [290 W/m].

The installation height is not a critical factor because the plumes will make their way down into the occupied zone. Even with a displacement ventilation system where there may be thermal plumes rising from the occupants and heat sources, these tend to slide past each other as opposed to mixing.

Selection of passive beams is fairly straightforward. Manufacturers generally provide data for standard product that has capacity vs. flow rate for standard values $\bar{t}_w - t_{room}$. In most cases, it is preferable to use software because it allows greater control of the design parameters and more selection options. It is important to consider both the capacity as well as the velocity beneath the beam. This usually means selecting longer, narrower beams which typically cause lower velocities below them for applications where they are located above stationary occupants.

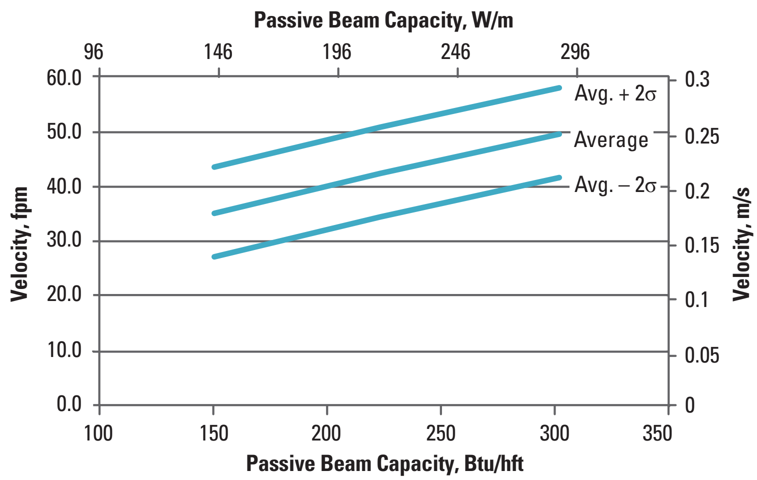


Figure 27: Expected velocities below an 18 in. wide passive beam

Design Procedure – Passive Beams

1. Determine the ventilation requirement

The ventilation requirement should be calculated to meet ventilation codes. For example, using ASHRAE Standard 62-2004 to determine the minimum fresh air flow rate:

$$Q_{oz} = R_p P_z + R_a A_z \qquad \text{H1}$$

2. Determine the required supply dew-point temperature to remove the latent load

$$q_L = C_l Q_s \Delta W \qquad \text{H2}$$

If the required humidity ratio is not practical, recalculate the supply air volume required with the desired humidity ratio.

3. Determine the supply air volume

The supply air volume is the maximum volume required by code for ventilation and the volume required for controlling the latent load:

$$Q_s = \max\left[Q_{oz}, Q_L\right] \qquad \text{H3}$$

4. Determine the sensible cooling capacity of the supply air

IP

$$q = \rho \, c_p Q \Delta t \qquad \text{H4}$$

SI

$$q = 60 \rho \, c_p Q \Delta t \qquad \text{H4}$$

5. Determine the sensible cooling required from the water side

$$q_{s,hydronic} = q_t - q_{s,air} \qquad \text{H5}$$

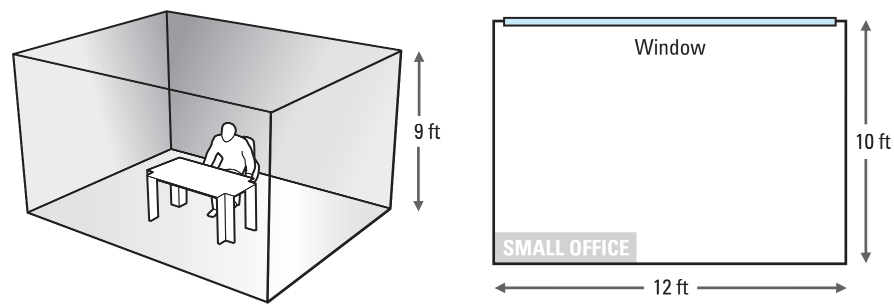
6. Select a beam or series of beams

Select a beam or series of beams that will provide the appropriate amount of cooling using an appropriate entry water temperature.

7. Locate the beams to minimize draft as well as piping length

Example 1 - Small Office Passive Beams Selection (IP)

Consider a small office with a southern exposure. The space is designed for two occupants, a computer with LCD monitor, T8 florescent lighting, and has a temperature set-point of 75 ° F. The room is 10 ft wide, 12 ft long, and 9 ft from floor to ceiling.



Space Considerations

One of the primary considerations when using an active or passive beam system is humidity control. As previously discussed, it is important to consider both the ventilation requirements and the latent load when designing the air-side of the system. ASHRAE Standard 62.1-2010 stipulates the ventilation requirements, but these are often not sufficient to control humidity without specialized equipment.

The assumptions made for this example are as follows:

- Load/person is 250 Btu/h sensible and 155 Btu/h latent
- Lighting load in the space is 6.875 Btu/hft^2
- Computer load is 300 Btu/h (CPU and LCD Monitor)
- Total skin load is 1450 Btu/h
- Specific heat and density of the air are 0.24 Btu/lb°F and 0.075 lb/ft^3 respectively
- Design conditions are 75 °F, with 50% relative humidity
- Design dew point = 55 °F

Design Considerations	
Occupants	2
Set-Point	75 °F
Floor Area	120 ft^2
Exterior Wall	108 ft^2
Volume	1080 ft^3
q_{oz}	800 Btu/h
q_l	825 Btu/h
q_{ex}	1450 Btu/h
q_T	3075 Btu/h

Determine:

a) The ventilation requirement.
b) The suitable air and water supply temperatures.
c) A suitable passive beam to meet the cooling requirement.
d) A practical layout for the space.

Example 1 - Small Office Passive Beams Selection (IP)

Solution:

a) Determine the ventilation requirement

The ventilation requirement should be calculated to meet ventilation codes. For example, using ASHRAE Standard 62-2004 to determine the minimum fresh air flow rate for a typical office space:

$$Q_{oz} = R_p P_z + R_a A_z$$

$$Q_{oz} = (5\ \text{cfm/person})(2\ \text{occupants}) + (0.06\ \text{cfm/ft}^2)(120\ \text{ft}^2) = 17\ \text{cfm}$$

b) Determine the required supply dew-point temperature to remove the latent load

From equation H2:

$$q_L = 0.68 Q_s \Delta W$$

Using the ventilation rate:

$$\Delta W = \frac{q_L}{0.68 Q_{oz}} = \frac{310\ \text{Btu/h}}{0.68\,(17\ \text{cfm})} = 27\ \text{gr/lb}$$

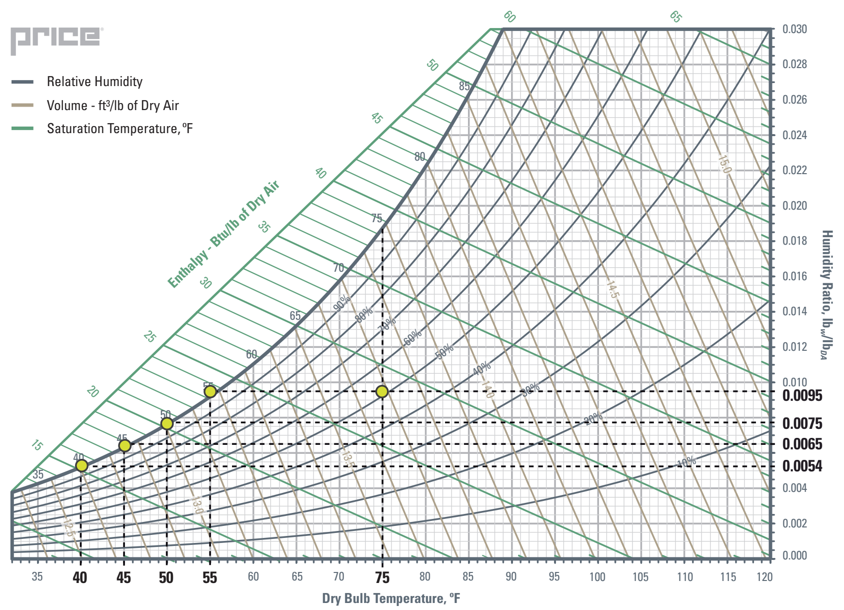
At the design conditions (75 °F, 50% RH), the humidity ratio is 65 gr/lb, requiring a difference in humidity ratio between the supply and room air of:

$$W_s = W_{Design} - \Delta W = 65 - 27 = 38\ \text{gr/lb} = 0.00543\ \text{lb/lb}$$

From the figure below, the dew point corresponding to the humidity ratio is 40 °F, which is too cool for standard equipment.

Evaluating the humidity ratio at several temperatures:

	Humidity Ratio	
Dew Point	lb/lb	gr/lb
40	0.00543	38
45	0.0065	46
50	0.0075	53
55	0.0095	67



Example 1 - Small Office Passive Beams Selection (IP)

Evaluating the humidity ratio at several temperatures shown in the table led to the selection of a dew point of 50 °F in order to use less expensive equipment while also minimizing the supply air volume required to control humidity. The required air volume to satisfy the latent load is:

$$q_L = 0.68 Q_L \Delta W$$

$$0.68 Q_L = \frac{q_L}{0.68 \Delta W} = \frac{310 \text{ Btu/h}}{0.68(65-53)} = 38 \text{ cfm}$$

The supply air volume to the office is the maximum volume required by code for ventilation and the volume required for controlling the latent load:

$$Q_s = \max[Q_{oz}, Q_L] = 38 \text{ cfm}$$

Determine the sensible cooling capacity of the supply air

Using equation H4:

$$q_{s,air} = 60 \rho c_p Q_{air} \; \Delta t_{air} = 1.08(38 \text{ cfm})(75\,°\text{F} - 50\,°\text{F}) = 1026 \text{ Btu/h}$$

Determine the sensible cooling required from the water side

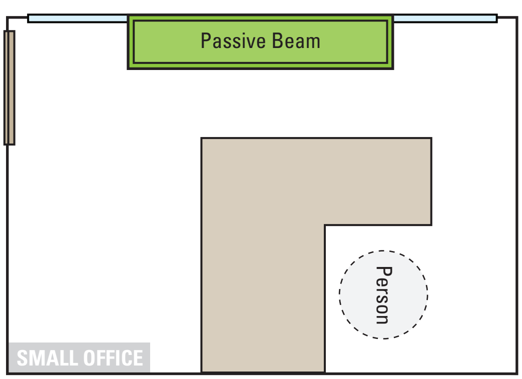
$$q_{s,hydronic} = q_t - q_{s,air}$$

$$q_{s,hydronic} = 3075 \text{ Btu/h} - 1026 \text{ Btu/h} = 2049 \text{ Btu/h}$$

Assuming a chilled water supply temperature 2 °F above the design dew point in order to avoid condensation provides a maximum temperature difference between the MWT and Troom of 75 °F - 57 °F = 18 °F. Using selection software to generate a suitable selection provides the following performance:

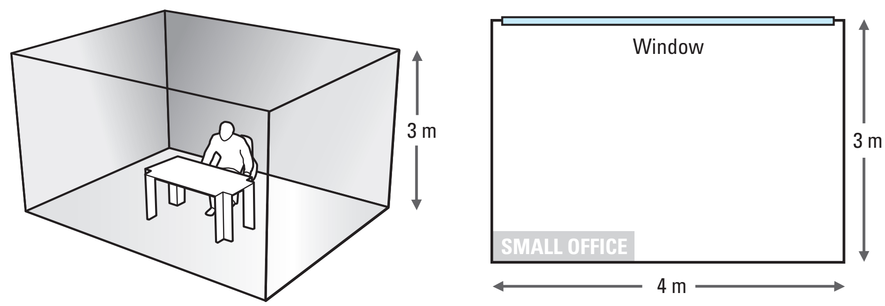
Performance	
Capacity	2049 Btu/h
Length	72 in.
Width	24 in.
Water flow rate	1.01 gpm
Water pressure drop	4.9 fthd

It is practical to locate passive beams along a wall where occupants are not regularly located. In this case, the area beside the desk is a good choice.



Example 1 - Small Office Passive Beams Selection (SI)

Consider a small office with a southern exposure. The space is designed for two occupants, a computer with LCD monitor, T8 florescent lighting, and has a design temperature set-point of 24 °C. The room is 3 m wide, 4 m long, and 3 m from floor to ceiling.



Space Considerations

One of the primary considerations when using an active or passive beam system is humidity control. As previously discussed, it is important to consider both the ventilation requirements and the latent load when designing the air side of the system. ASHRAE Standard 62.1-2010 stipulates the ventilation requirements, but these are often not sufficient to control humidity without specialized equipment.

The assumptions made for the example are as follows:

- Load/person is 75 W sensible and 55 W latent
- Lighting load in the space is 25 W/m²
- Computer load is 90 W (CPU and LCD Monitor)
- Total skin load is 405 W
- Specific heat and density of the air are 1.007 kJ/kgk and 1.3 kg/m3 respectively
- Design conditions are 24 °C, with 50% relative humidity
- Design dew point = 13 °C

Design Considerations	
Occupants	2
Set-Point	24 °C
Floor Area	12 m²
Exterior Wall	12 m²
Volume	36 m³
q_{oz}	240 W
q_l	300 W
q_{ex}	405 W
q_T	945 W

Determine:

a) The ventilation requirement.
b) The suitable air and water supply temperatures.
c) A suitable passive beam to meet the cooling requirement.
d) A practical layout for the space.

Example 1 - Small Office Passive Beams Selection (SI)

Solution:

a) Determine the ventilation requirement

The ventilation requirement should be calculated to meet ventilation codes. For example, using ASHRAE Standard 62-2004 to determine the minimum fresh air flow rate for a typical office space:

$$Q_{oz} = R_p P_z + R_a A_z$$

$$Q_{oz} = (2.5\ \mathrm{L/s\ person})(2\ \mathrm{occupants}) + (0.3\ \mathrm{L/sm^2})(12\mathrm{m^2}) = 9\ \mathrm{L/s}$$

b) Determine the required supply dew-point temperature to remove the latent load

From equation H2:

$$q_L = 2500 \rho Q_l \Delta W$$

Using the ventilation rate:

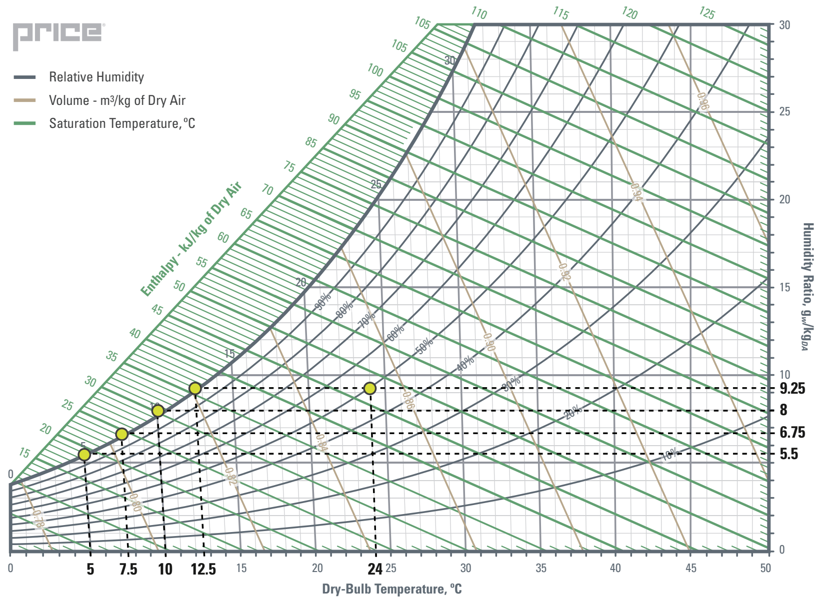
$$\Delta W = \frac{q_L}{2500 \rho Q_{oz}} = \frac{110\ \mathrm{W}}{2500\ \mathrm{W/LsK}(1.3\ \mathrm{kg}/m^3)(9\ \mathrm{L/s})} = 4\ \mathrm{g/kg}$$

At the design conditions (24 °C, 50% RH), the humidity ratio is 9.5 g/kg, requiring a difference in humidity ratio between the supply and room air of:

$$W_s = W_{Design} - \Delta W = 9.5 - 4 = 5.5\ \mathrm{g/kg}$$

From the figure below, the dew point corresponding to the humidity ratio is 5 °C, which is too cool for standard equipment. Evaluating the humidity ratio at several temperatures:

Dew Point	Humidity Ratio g/kg
5	5.5
7.5	6.75
10	8
12.5	9.25



Example 1 - Small Office Passive Beams Selection (SI)

Evaluating the humidity ratio at several temperatures shown in the table led to the selection of a dew point of 10 °C in order to use less expensive equipment while also minimizing the supply air volume required to control humidity. The required air volume to satisfy the latent load is:

$$q_L = 2500 \rho Q_L \Delta W$$

$$Q_L = \frac{q_L}{2500 \rho \Delta W} = \frac{110 \text{ W}}{2500\,(1.3)(0.0095 - 0.008)} = 22.5 \text{ L/s}$$

The supply air volume to the office is the maximum volume required by code for ventilation and the volume required for controlling the latent load:

$$Q_s = \max[Q_{oz}, Q_L] = 22.5 \text{ L/s}$$

Determine the sensible cooling capacity of the supply air

Using equation H4:

$$q_{s,air} = \rho c_p Q_{air}\, \Delta t_{air} = 1.2\,(22.5 \text{ L/s})(24\,°\text{C} - 10\,°\text{C}) = 378 \text{ W}$$

Determine the sensible cooling required from the water side

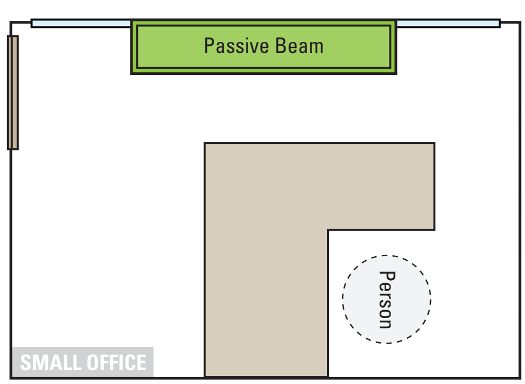
$$q_{s,hydronic} = q_t - q_{s,air}$$

$$q_{s,hydronic} = 945 \text{ W} - 378 \text{ W} = 567 \text{ W}$$

Assuming a chilled water supply temperature 1 K above the design dew point in order to avoid condensation provides a maximum temperature difference between the $\bar{t}w$ and t_{room} of 24 °C – 14 °C = 10 K. Using selection software to generate a suitable selection provides the following performance:

Performance	
Capacity	567 W
Length	1800 mm
Width	600 mm
Water flow rate	230 L/h
Water pressure drop	14.6 kPa

It is practical to locate passive beams along a wall where occupants are not regularly located. In this case, the area beside the desk is a good choice.



Active Beam Selection and Design Procedure

Active beam systems will vary in performance, configuration and layout depending on the application. There are, however, some characteristics that are common for most systems. Furthermore, the performance of active beams is largely dependent on a common set of factors. This section will discuss how factors such as supply air volume and chilled water temperature affect the performance and layout of active beams. **Table 3** shows common design characteristics for active beam systems.

Product Selection and Location – Active Beams

Performance

The performance of an active beam is dependent on several factors:

- Active beam configuration
- Coil circuitry
- Primary air flow (plenum pressure)
- Water flow

As discussed previously, there are several configurations of active beams. The most common is the linear type, which is available in both 1 way and 2 way air patterns. A third type is modular and typically has a 4 way discharge.

Active beams are appropriate for heating and cooling. The coil circuitry has a large effect on the beam performance. If the beam is to be used for cooling and heating, it would usually have a 4 pipe coil. A 4 pipe coil shares fins between two separate circuits. If the beam is used for either cooling or heating only, the beam may make use of the entire coil with a single circuit, thereby allowing additional heat transfer from the water to the air. The primary driver of active beam capacity is the plenum pressure. **Figure 30** and **Figure 31** show the air path of linear and modular beams in cooling.

As discussed, it is the primary air that induces the room air through the coil, the rate of which is determined by the nozzle size and the plenum pressure. A good measure for the overall performance of an active beam is known as the transfer efficiency. This is the ratio of total heat transferred by the coil per unit volume of primary air:

$$\eta = \frac{q_{sensible}}{Q_{primary\ air}}$$

Typical values for transfer efficiency vary by application type but in general, the higher the efficiency, the more energy savings are available for a given system. The transfer efficiency is largely dependent on the air-side load fraction and the sensible heat ratio.

IP	
Room Temperature	74 °F to 78 °F in summer, 68 °F to 72 °F in winter
Water Temperature, Cooling	55 °F to 58 °F EWT, 5 °F to 8 °F ΔT
Design Sound Levels	< 40 NC
Cooling Capacity	Up to 1000 Btu/h /ft
Water Temperature, Heating	110 °F to 130 °F EWT, 10 °F to 20 °F ΔT
Heating Capacity	Up to 1500 Btu/h /ft
Ventilation Requirement	0.1 to 0.5 cfm/ft2 floor area
Ventilation Capability	5 to 30 cfm/ft
Primary Air Supply Temperature	50 °F to 65 °F
Inlet Static Pressure	0.2 in. w.g. to 1.0 in. w.g. external
SI	
Room Temperature	23 °C to 25 °C in summer, 20 °C to 22 °C in winter
Water Temperature, Cooling	13 °C to 15 °C EWT, 3 K to 5 K ΔT
Design Sound Levels	< 40 NC
Cooling Capacity	Up to 1000 W/m
Water Temperature, Heating	60 °C to 70 °C EWT, 5 K to 12 K Δ
Heating Capacity	Up to 1500 W/m
Ventilation Requirement	0.5 to 2.5 L/s m^2 floor area
Ventilation Capability	7 to 40 L/s m^2
Primary Air Supply Temperature	10 °C to 18 °C
Inlet Static Pressure	50 Pa to 250 Pa external

Table 3: Design values for active beam systems

Figure 28: Linear type active beam

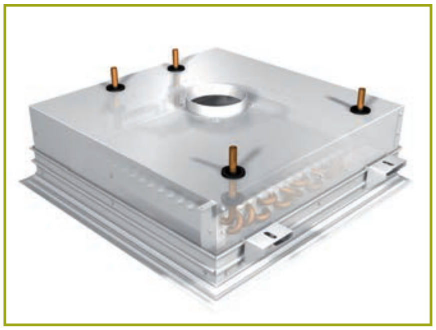


Figure 29: Modular type active beam

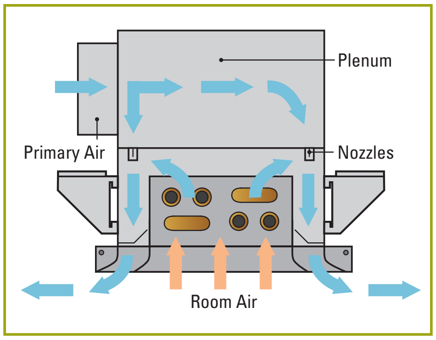


Figure 30: Air flow diagram of a typical linear active beam in cooling

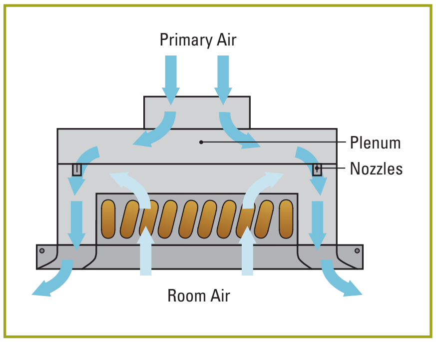


Figure 31: Air flow diagram of a modular beam in cooling

Active Beam Selection and Design Procedure

The higher the sensible load fraction is, the smaller the beam nozzle can be, resulting in a higher induction ratio, defined as the ratio of the induced mass air flow to that of the primary air:

$$induction\ ratio = \frac{Q_{induced\ air}}{Q_{primary\ air}}$$

The selection of smaller nozzles also results in higher plenum pressures for a fixed primary air flow rate. Larger nozzles will have a lower induction ratio but allow more primary air to be supplied, though at a lower transfer efficiency, as shown in **Figure 32**.

Figure 33 shows the water-side performance of a typical beam vs. air flow. The curves correspond with various nozzle sizes increasing in diameter from left to right. The length of the curves is defined by standard operating pressures. It is noted from the graphs that the capacity of the beam increases as more air is supplied, though not in a linear fashion.

Figure 34 shows how the increase in capacity is dependent on the air volume. As shown in the figure, as the nozzle size increases to provide a five-fold increase in air volume, only a 175% increase in the water-side capacity is realized, while the transfer efficiency has reduced by 65%.

The water flow rate in the coil affects two performance factors:

The heat transfer between the water and the coil which is dependent on whether the flow is laminar (poor) or turbulent (good).

The mean water temperature, or the average temperature in the coil. The higher the flow rate, the closer the discharge temperature will be to that of the inlet, assuming no change in heat transfer, thereby changing the average water temperature in the coil.

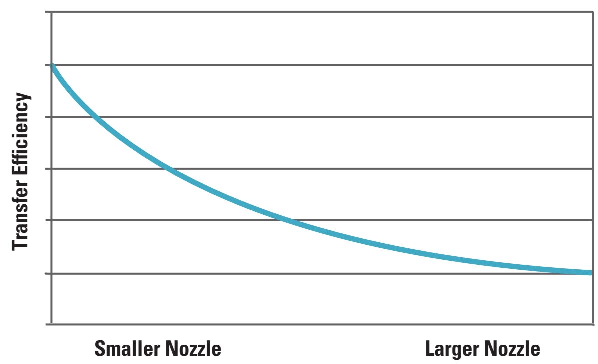


Figure 32: Transfer efficiency is reduced by increasing nozzle size

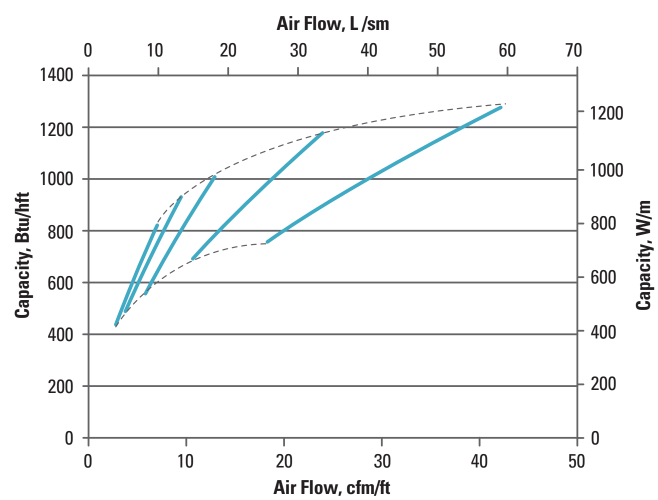


Figure 33: Capacity of a typical active beam vs. primary air flow

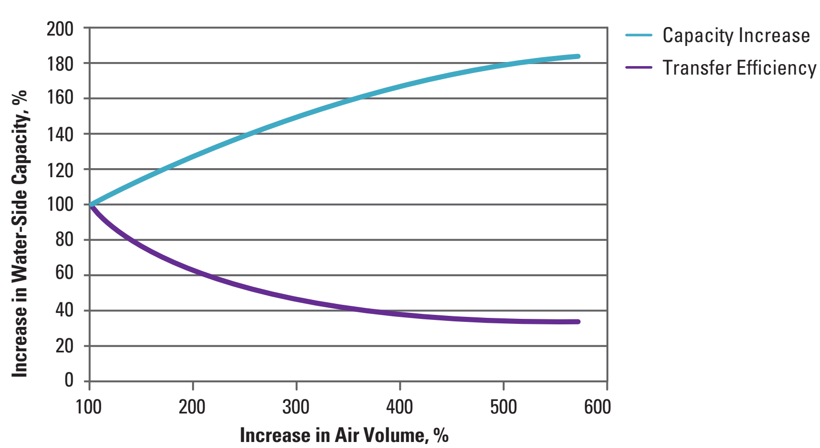


Figure 34: Capacity vs. air volume

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

Active Beam Selection and Design Procedure

Figure 35 shows the effect of the water flow rate, indicated by Reynolds number, on the capacity of a typical active beam. As indicated on the chart, increasing the flow rate into the transitional and turbulent ranges (Re > 2300, shown in blue on the graph) causes an increase in the output of the beam.

The water flow rate is largely dependent on the pressure drop and return water temperature that are acceptable to the designer. In most cases, the water flow rate should be selected to be fully turbulent under design conditions.

The difference between the mean water temperature and the room air temperature is one of the primary drivers of the beam performance. The larger this difference is, the higher the convective heat transfer potential, as shown in **Figure 36**. Conversely, a lower temperature difference will reduce the amount of exchange, and thereby capacity. As a result, it is desirable from a capacity standpoint to select an entry water temperature as low as possible, while maintaining it above the dew point in the room to ensure sensible-only cooling.

In some instances, it might be advantageous to have higher supply and return water temperatures, where it makes sense from an equipment standpoint. This may also offer some control simplification where the output of the beam is determined by the load in the room:

As the load increases, the air temperature rises and increases the difference between it and $\bar{t}_w$, thereby increasing beam performance.

As the load decreases, the air temperature falls and reduces the cooling capacity of the beam.

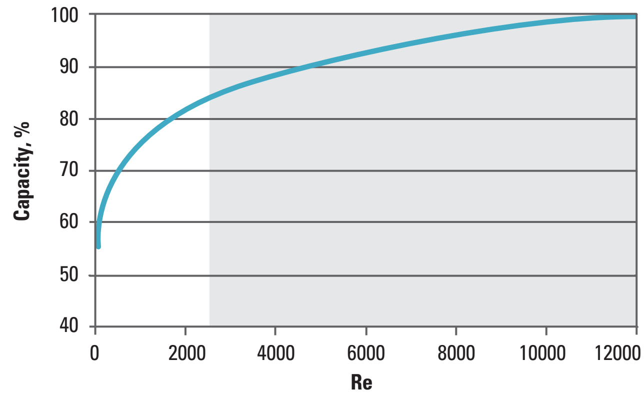


Figure 35: Active beam capacity vs. water flow

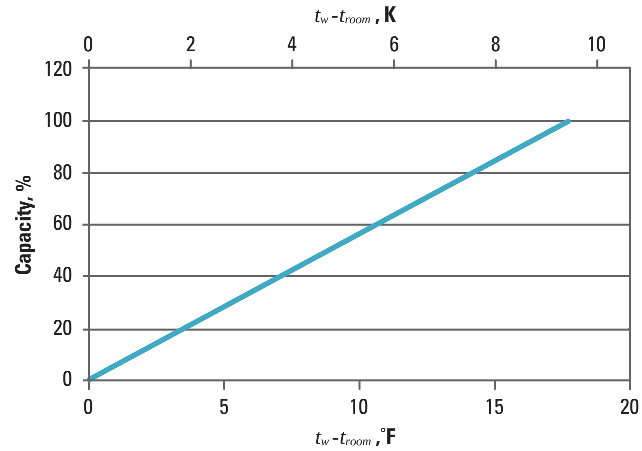


Figure 36: Active beam capacity vs. difference between the mean water and room air temperatures

ENGINEERING GUIDE - ACTIVE & PASSIVE BEAMS

Design Procedure – Active Beams

1. Determine the ventilation requirement
The ventilation requirement should be calculated to meet ventilation codes. For example, using ASHRAE Standard 62-2004 to determine the minimum fresh air flow rate:

$$Q_{oz} = R_p P_z + R_a A_z \qquad \text{H1}$$

2. Determine the required supply dew-point temperature to remove the latent load

$$q_L = C_l Q_s \Delta W \qquad \text{H2}$$

If the required humidity ratio is not practical, recalculate the supply air volume required with the desired humidity ratio.

3. Determine the supply air volume
The supply air volume is the maximum volume required by code for ventilation and the volume required for controlling the latent load:

$$Q_s = \max[Q_{oz}, Q_L] \qquad \text{H3}$$

4. Determine the sensible cooling capacity of the supply air

IP

$$q = \rho c_p Q \Delta t \qquad \text{H4}$$

SI

$$q = 60 \rho c_p Q \Delta t \qquad \text{H4}$$

5. Determine the sensible cooling required from the water side

$$q_{s,hydronic} = q_t - q_{s,air} \qquad \text{H5}$$

6. Select a beam or series of beams
Select a beam or series of beams that will provide the appropriate amount of cooling and heating using appropriate entry water temperatures and throw distances.

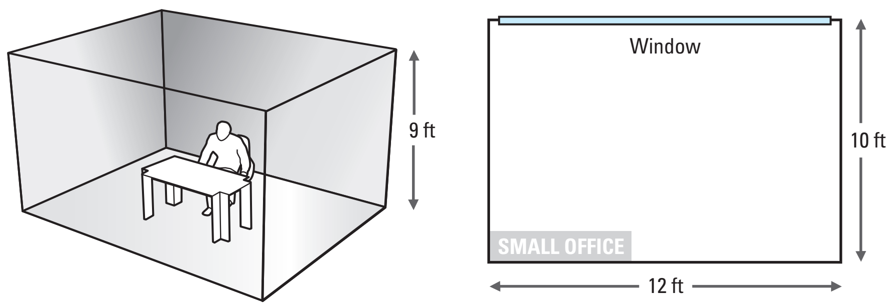
7. Review that the primary air calculation in (3) is still appropriate

$$Q_s = \max[Q_{oz}, Q_L, Q_{beams}] \qquad \text{H6}$$

8. Lay out the beams in such a way that the comfort in the space is maximized

Example 2 - Small Office Active Beam Selection (IP)

Consider the small office presented in Example 1 - Small Office Passive Beam Selection.



Design Considerations	
Occupants	2
Set-Point	75 °F
Floor Area	120 ft^2
Exterior Wall	108 ft^2
Volume	1080 ft^3
q_{oz}	800 Btu/h
q_l	825 Btu/h
q_{ex}	1450 Btu/h
q_T	3075 Btu/h
Q_s	38 cfm
t_s	50 °F
t_{CHWS}	57 °F

Determine

a) A suitable active beam to meet the cooling requirement.
b) A practical layout for the space.

Solution

From example 1 - Small Office Passive Beam Selection.

Performance	
Total Capacity	3075 Btu/h
Air flow Required for Dehumidification	38 cfm
Supply Air Temperature	50 °F
CHWS Temperature	57 °F

Example 2 - Small Office Active Beam Selection (IP)

Using selection software to select beams with these parameters provides several possible solutions:

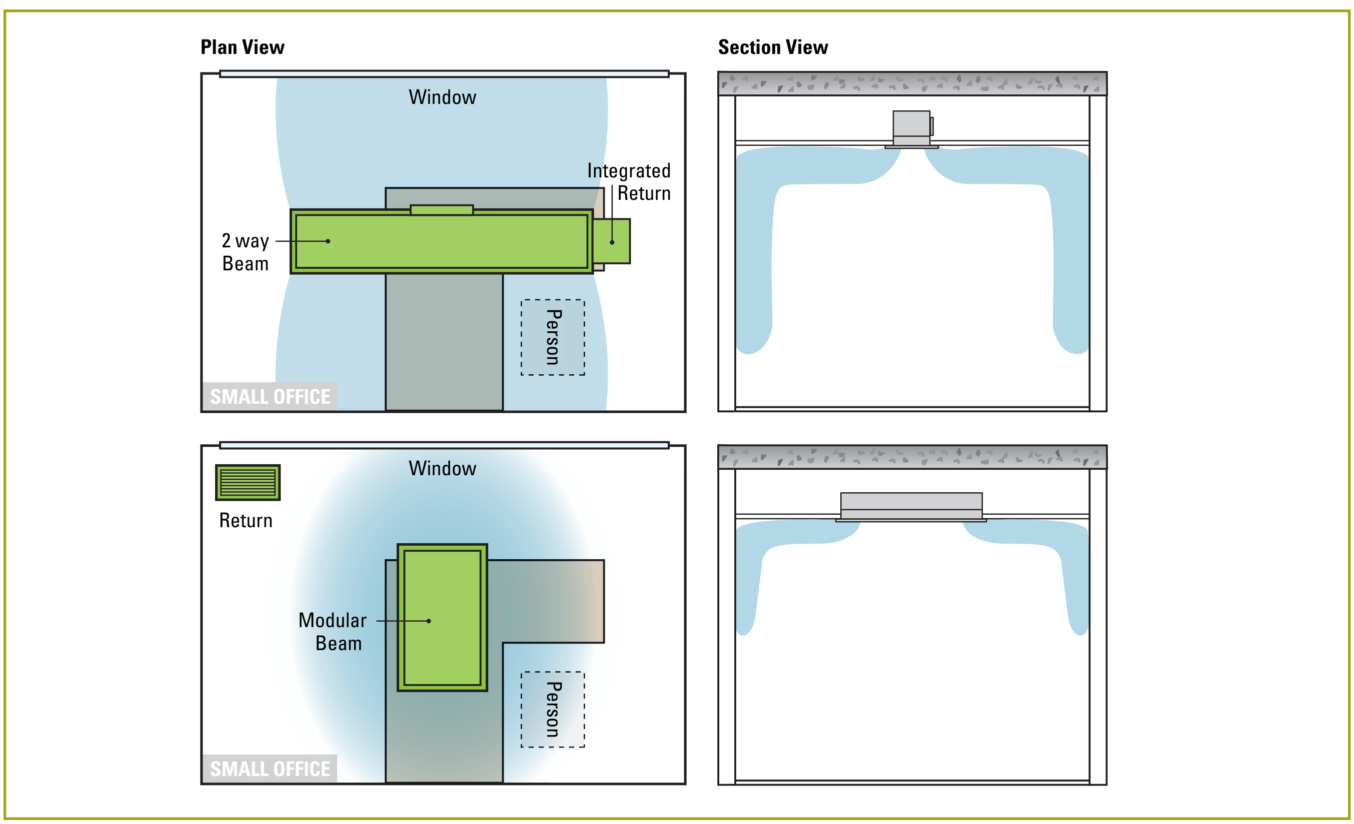
Parameter	Option 1 (ACBL)	Option 2 (ACBL)	Option 3 (ACBM)
Total Capacity	3074 Btu/h	3076 Btu/h	3077 Btu/h
Length	72 in.	48 in.	48 in.
Width	24 in.	24 in.	24 in.
Air flow	35 cfm	40 cfm	40 cfm
Throw @ 50 fpm	10 ft	13 ft	10 ft
Air Pressure Drop	0.75 in.	0.42 in.	0.56 in.
Transfer Efficiency	88 Btu/h cfm	77 Btu/h cfm	77 Btu/h cfm
Water Flow Rate	0.41 gpm	1.2 gpm	0.61 gpm
Water Pressure Drop	0.63 ft hd	3.1 ft hd	1.26 ft hd
NC	15	18	17

The first option meets the capacity requirements though has slightly lower air flow than that required to handle the latent loads; it is also the most efficient option. The second and third options both meet the capacity and air flow requirements.

Revisiting the air volume required:

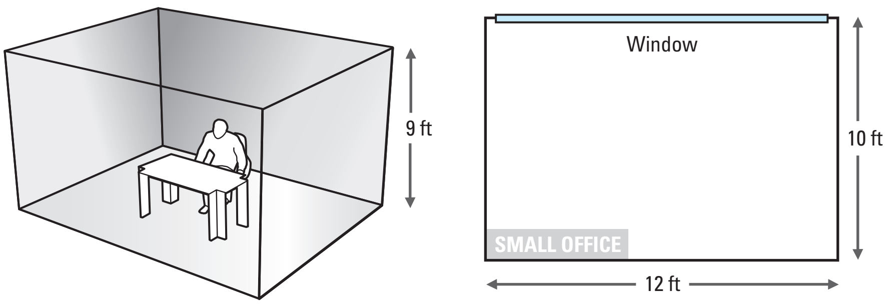
$$Q_s = \max\left[Q_{oz}, Q_L, Q_{Beams}\right] = 40 \text{ cfm}$$

For the private office, either selection (2) or (3) is appropriate. The modular unit has the advantage of lower throw and would result in lower occupied zone velocities. The linear unit can be selected with an integrated return grille, increasing the overall length of the beam while allowing the return to appear to be a part of the beam. Both of these layouts are shown below:



Example 2 - Small Office Active Beam Selection (SI)

Consider the small office presented in Example 1 - Small Office Passive Beam Selection.



Design Considerations	
Occupants	2
Set-Point	24 °C
Floor Area	12 m²
Exterior Wall	12 m²
Volume	36 m³
q_{oz}	240 W
q_l	300 W
q_{ex}	405 W
q_T	945 W
Q_s	22.5 L/s
t_s	10 °C
t_{CHWS}	14 °C

Determine

a) A suitable active beam to meet the cooling requirement.
b) A practical layout for the space.

Solution

From example 1 - Small Office Passive Beam Selection.

Performance	
Total Capacity	945 W
Air flow Required for Dehumidification	22.5 L/s
Supply Air Temperature	10 °C
CHWS Temperature	14 °C

Example 2 - Small Office Active Beam Selection (SI)

Using selection software to select beams with these parameters provides several possible solutions:

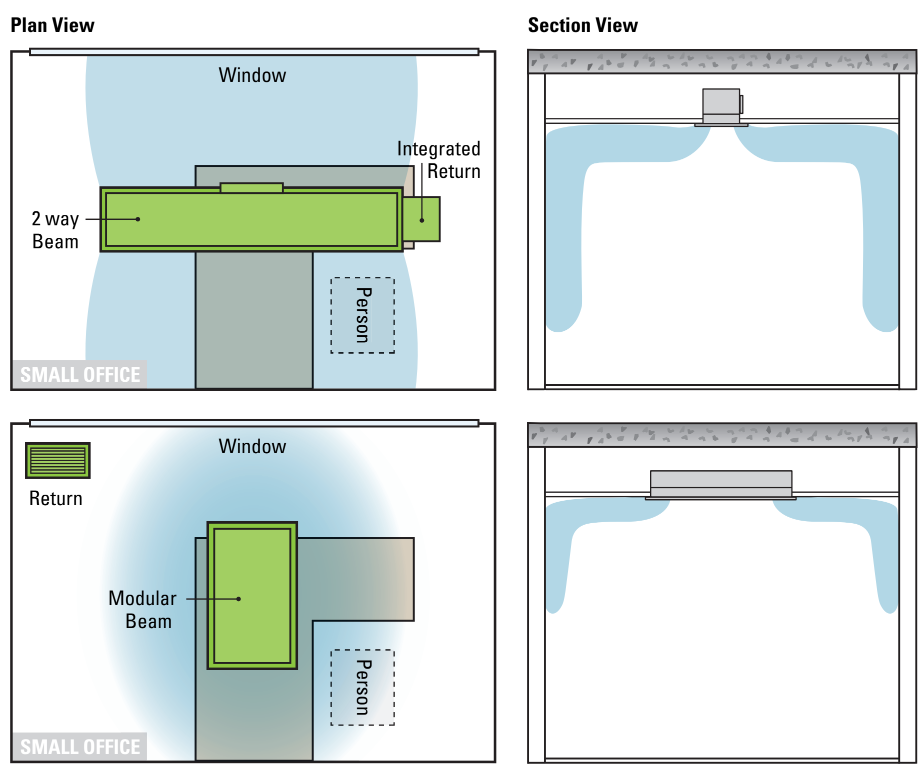
Parameter	Option 1 (ACBL)	Option 2 (ACBL)	Option 3 (ACBM)
Total Capacity	945 W	946 W	952 W
Length	1.8 m	1.2 m	1.2 m
Width	0.6 m	0.6 m	0.6 m
Air flow	16.5 L/s	22.5 L/s	22.5 L/s
Throw @ 50 fpm	3.9 m	3.7 m	3 m
Air Pressure Drop	187 Pa	107 Pa	100 Pa
Transfer Efficiency	48 Ws/L	25 Ws/L	25 Ws/L
Water Flow Rate	93 L/h	216 L/h	148 L/h
Water Pressure Drop	1.88 kPa	8.07 kPa	4.18 kPa
NC	15	21	17

The first option meets the capacity requirements though has slightly lower air flow than that required to handle the latent loads; it is also the most efficient option. The second and third options both meet the capacity and air flow requirements.

Revisiting the air volume required:

$$Q_s = \max\left[Q_{oz}, Q_L, Q_{Beams}\right] = 22.5 \text{ L/s}$$

For the private office, either selection (2) or (3) is appropriate. The modular unit has the advantage of lower throw and would result in lower occupied zone velocities. The linear unit can be selected with an integrated return grille, increasing the overall length of the beam while allowing the return to appear to be a part of the beam. Both of these layouts are shown below:



Managing Primary Air Volume and Capacity

In active beam selection, there is often a trade-off required between the primary air volume and the beam length. When the total capacity of the beam is considered there is an increase in the capacity with an increase in the primary air volume; though, as indicated in **Figure 37,** this is largely due to the increased capacity of the primary air and only slightly due to an increase in the performance of the cooling coil. The overall effect of an increase in primary air volume is invariably a reduction in the transfer efficiency of the beam; therefore, care must be taken when increasing the air volume past what is required to satisfy the ventilation requirements and latent loads.

In order to determine if it is necessary to increase the air volume beyond that which is required, several factors should be weighed:

1. Beam Size
With higher capacity per unit length of beam it is possible to reduce the size of the beam, which may reduce the visual impact of the HVAC system. It may also help to fit beams into spaces with high specific loads, such as a corner office in a hot climate like Phoenix or Dubai.

2. First Cost
The reduction in overall size of the beam does offer some first cost savings, though these should be compared to the first cost additions required of the air handling system, including equipment and ductwork. In most applications, these costs are similar and may not offer the benefit sought.

3. Energy
By decreasing the transfer efficiency (or increasing the percentage of the load managed by air rather than water), there is usually a reduction in the overall efficiency of the system. In most cases, it is more efficient to pump energy through the building with water than air, and so an increase in the load managed by air may cause an increase in the system horsepower.

4. Noise
Active beam noise is largely dependent on primary air flow, therefore an increase in the primary air volume to the beam will increase the noise levels in the space.

5. Control
With additional air supplied to the beam, there is an increased risk of overcooling the zone under part-load conditions. These systems are typically constant volume, which reduces the system's ability to control the zone temperature if the minimum capacity of the beam is increased due to an increase in primary air volume.

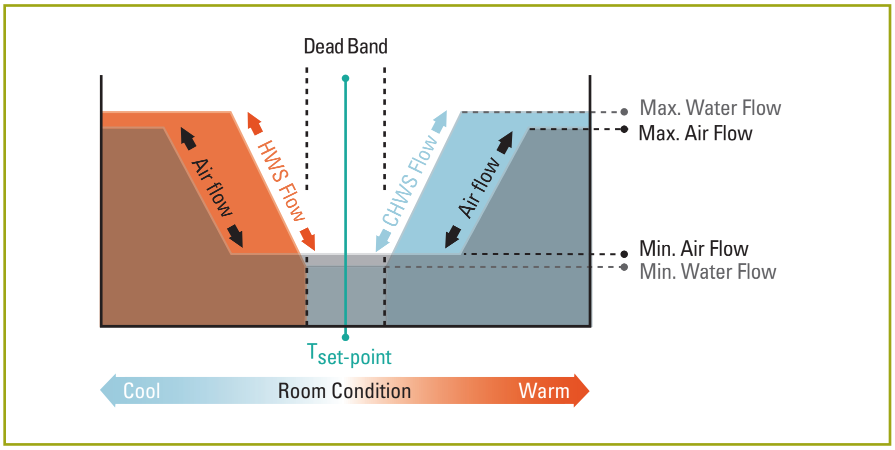


Figure 37: VAV control sequence

6. Life-Cycle Cost
This type of design decision is often best made with a life-cycle cost analysis to determine the cost impact over the life of the building.

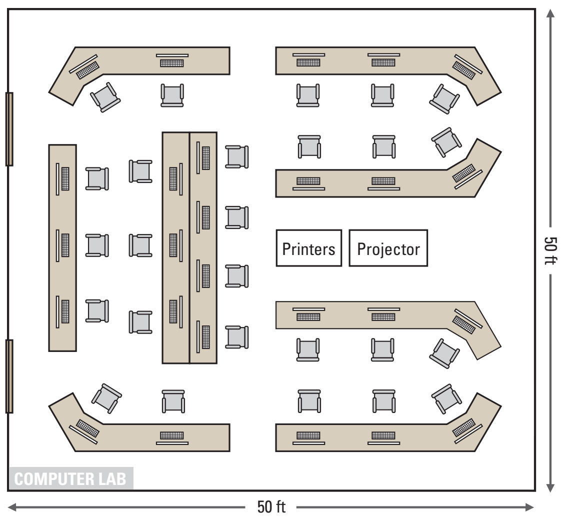
There are applications where an increase in air volume is a reasonable design decision, either due to very large specific loads or high ventilation rates, such as in a health care application. In situations where the specific load is high, there are some options that will allow the system to meet the required capacity but will also maximize the energy efficiency:

1. Select an active beam and a passive beam together.
This allows the designer to minimize the air and add sensible cooling capacity where required. This also significantly increases the transfer efficiency of the room by keeping the air volume as low as possible while increasing the sensible capacity.

2. Employ a variable air volume (VAV) strategy.
Whether for an individual office or for a larger zone, VAV allows the system to supply the capacity required under design conditions while allowing the air volume to be turned down to minimum during off-peak hours. The most efficient configuration would have the air turn up/down only as the second stage of cooling, as shown in the diagram below.

Example 4 - Active Beams in a Computer Lab (IP)

This space is a school computer lab designed for 26 occupants, 26 computers with one LCD monitor each, a projector, three printers, T8 florescent lighting, and has a temperature set-point of 75 °F at 50% RH in the summer. The room is 50 ft long, 50 ft wide, and has a floor-to-ceiling height of 9 ft. The ceiling is exposed, with possible duct connections in the interior of the space.



Space Considerations

- Some of the assumptions made for this space are as follows:
- Infiltration is minimal, and is neglected for the purposes of this example.
- The specific heat and density of the air for this example will be 0.24 Btu/lb°F and 0.075 lb/ft2 respectively.
- The air handling system utilizes energy recovery to provide 65 °F at 50 °F dew point. Determine the ventilation requirement

Design Considerations		**Total**
Occupant Load	250 Btu/h person	6500 Btu/h
Lighting Load	3 Btu/hft$^2_{floor}$	7500 Btu/h
Computer Loads	450 Btu/h person	11700 Btu/h
Projector Load	188 Btu/h	188 Btu/h
Printer Loads	444 Btu/h	444 Btu/h
Envelope Load	14.6 Btu/hft$^2_{façade}$	6570 Btu/h
Total Load		**32902 Btu/h**
Latent Load - Occupant Load	200 Btu/h person	5200 Btu/h

The ventilation requirement should be calculated to meet ventilation codes. For example, using ASHRAE Standard 62-2004 to determine the minimum fresh air flow rate for a typical office space:

$$Q_{oz} = R_p P_z + R_a A_z$$

$$Q_{oz} = (10 \text{ cfm/person})(26 \text{ occupants}) + (0.12 \text{ cfm/ft}^2)(2500 \text{ ft}^2) = 560 \text{ cfm}$$

Determine the required supply dew-point temperature to remove the latent load

$$q_L = 4840\ Q_s \Delta W$$

Using a humidity ratio of the supply air at 50 °F dew point and the design conditions (75 °F, 50% RH):

$$Q_s = \frac{q_L}{4840\ \Delta W} = \frac{5200 \text{ Btu/h}}{4840(.0092 \text{ lb}_{water}/\text{lb}_{DA} - 0.0075 \text{ lb}_{water}/\text{lb}_{DA})} = 632 \text{ cfm}$$

Example 4 - Active Beams in a Computer Lab (IP)

The supply air volume to the office is the maximum of the volume required by code for ventilation and the volume required for controlling the latent load:

$$Q_s = \max\left[Q_{oz}, Q_L\right] = 632 \text{ cfm}$$

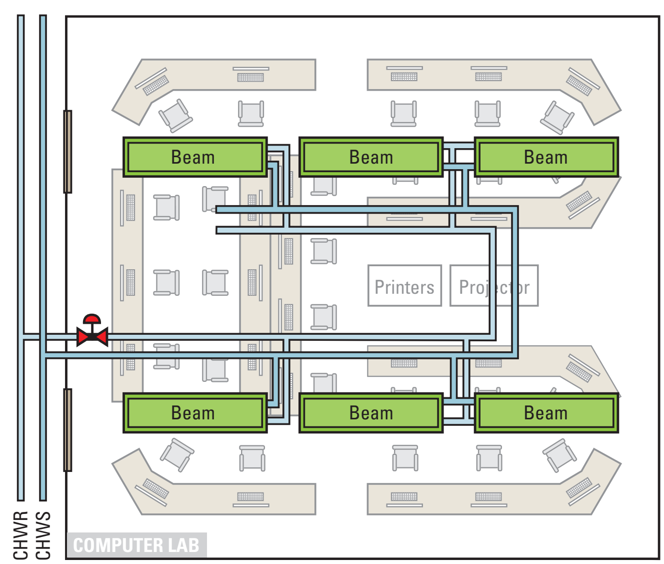
Using software to select a beam with the following requirements:

Performance	
Total Capacity	32902 Btu/h
Air Flow Required for Dehumidification	632 cfm
Supply Air Temperature	65 °F

Arrives at the following options:

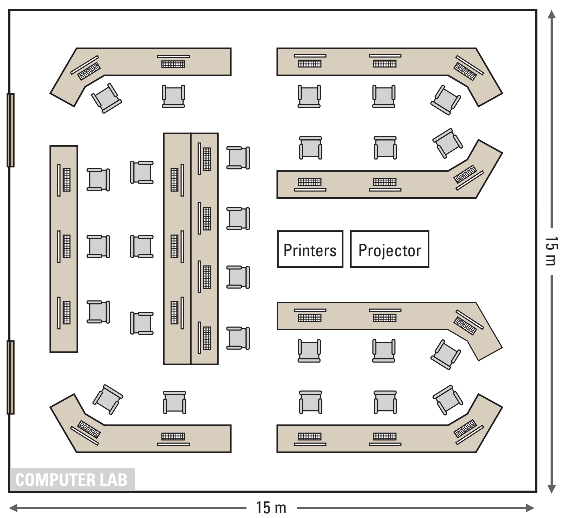
Parameter	**Option 1 (ACBL)**	**Option 2 (ACBL)**	**Option 3 (ACBM)**
Total Capacity	32197 Btu/h	33044 Btu/h	32933 Btu/h
Quantity	4	6	6
Length	120 in.	96 in.	48 in.
Width	24 in.	24 in.	24 in.
Air Flow	640 cfm	780 cfm	870 cfm
Throw	11 ft	17 ft	-
Air Pressure Drop	0.99 in.	0.76 in.	0.83 in.
Transfer Efficiency	50.3 Btu/h cfm	42.4 Btu/h cfm	37.9 Btu/h cfm
Water Flow Rate	5.96 gpm	6.48 gpm	9.42 gpm
Water Pressure Drop	9.9 ft hd	4.6 ft hd	0.71 ft hd
NC	27	30	-

Of these options, the second combination of six 8 ft long beams is the best combination of capacity, efficiency and throw. With six beams, these could be laid out as shown below:



Example 4 - Active Beams in a Computer Lab (SI)

This space is a school computer lab designed for 26 occupants, 26 computers with one LCD monitor each, a projector, 3 printers, T8 florescent lighting, and has a temperature set-point of 24° C at 50% RH in the summer. The room is 15 m long, 15 m wide, and has a floor-to-ceiling height of 3 m. The ceiling is exposed, with duct connections possible in the interior of the space.



Space Considerations

Some of the assumptions made for this space are as follows:

- Infiltration is minimal, and is neglected for the purposes of this example.
- The specific heat and density of the air will be 1.007 kgK and 1.3 kg/m3 respectively.
- The air handling system utilizes energy recovery to provide 18 °C at 10 °C dew point.

Design Considerations		Total
Occupant Load	75 W/person	1950 W
Lighting Load	25 W/m$^2_{floor}$	5625 W
Computer Loads	130 W/person	3380 W
Projector Load	55 W	55 W
Printer Loads	130 W	130 W
Envelope Load	46 W/m$^2_{façade}$	2070 W
Total Load		**13210 W**
Latent Loads - Occupant Load	60 W/person	1560 W

Determine the ventilation requirement

The ventilation requirement should be calculated to meet ventilation codes. For example, using ASHRAE Standard 62-2004 to determine the minimum fresh air flow rate for a typical office space:

$$Q_{oz} = R_p P_z + R_a A_z$$

$$Q_{oz} = (5\ \text{L/s person})(26\ \text{occupants}) + (0.6\ \text{L/s m}^2)(225\ \text{m}^2) = 265\ \text{L/s}$$

Determine the required supply dew-point temperature to remove the latent load.

$$q_L = 2500\rho\ Q_s \Delta W$$

Using a humidity ratio of the supply air at 10 °C dew point and the design conditions (24 °C, 50% RH):

$$Q_{oz} = \frac{q_L}{2500\rho\Delta W} = \frac{1560\ \text{W}}{2500\ \text{W/LsK}\,(1.3\ \text{kg/m}^3)(9.5\ \text{g/kg} - 8\ \text{g/kg})} = 320\ \text{L/s}$$

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

Example 4 - Active Beams in a Computer Lab (SI)

The supply air volume to the office is the maximum volume required by code for ventilation and the volume required for controlling the latent load:

$$Q_s = \max[Q_{oz}, Q_L] = 320 \text{ L/s}$$

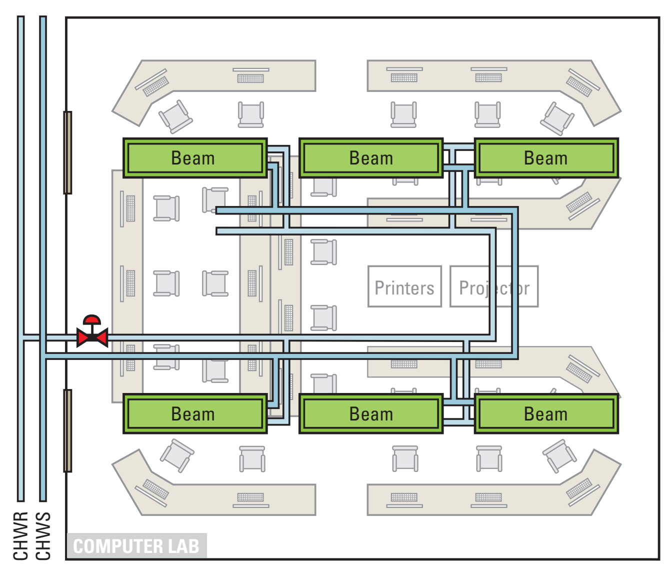
Using software, select a beam with the following requirements:

Performance	
Total Capacity	13210 W
Air Flow Required for Dehumidification	320 L/s
Supply Air Temperature	18 °C

Arrives at the following options:

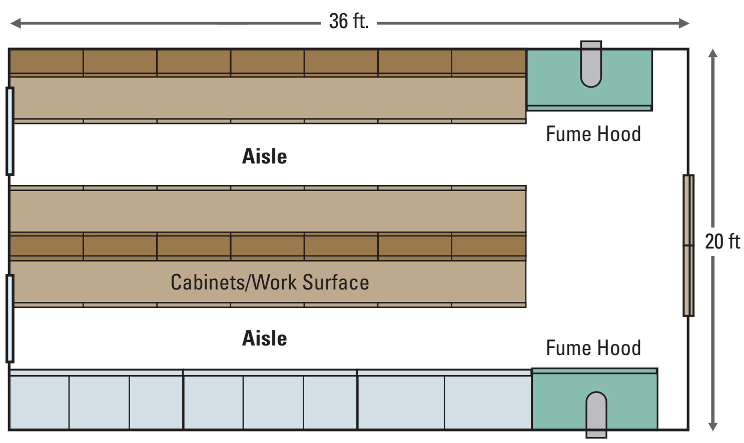
Parameter	Option 1 (ACBL)	Option 2 (ACBL)	Option 3 (ACBM)
Total Capacity	13221 W	13216 W	13220 W
Quantity	6	7	8
Length	3000 mm	2400 mm	1200 mm
Width	600 mm	600 mm	600 mm
Air Flow	426 L/s	497 L/s	696 L/s
Throw	3.3 m	6 m	-
Air Pressure Drop	220 Pa	250 Pa	193 Pa
Transfer Efficiency	31 W s/L	17 W s/L	19 W s/L
Water Flow Rate	302 L/s	345 L/s	368 L/s
Water Pressure Drop	9.92 kPa	10.32 kPa	9.12 kPa
NC	27	33	-

Of these options, the second combination of six 2.4 m beams is the best combination of capacity, efficiency and throw. With six beams, these could be laid out as shown below:



Example 5 - Active Beams in Laboratories (IP)

This hospital laboratory is used for the testing of specimens associated with patient care. The layout features one island bench and two wall benches to accommodate a maximum of ten clinical lab technicians. Florescent lighting, refrigeration equipment and other bench devices all generate heat within the lab. There are also two low-flow fume hoods in the corners of the room, operating at a constant volume exhaust flow rate of 480 cfm each. The room is 36 ft long by 20 ft wide, with a ceiling height of 12 ft. The space is an interior zone of the building with no envelope load.



Space Considerations

Some of the assumptions made for this space are as follows:

- Load/person is 250 Btu/h sensible and 200 Btu/h latent
- Lighting load in the space is 8.3 Btu/hft^2
- The specific heat and density of the air for this example are 0.24 Btu/lb°F and 0.075 Btu/hft^2 respectively
- Minimum exhaust flow rate of 6 ach in accordance with ASHRAE Standard 170-2008
- Maintain a 20% offset between supply and exhaust volume in order to maintain negative pressure

Design Considerations	
Area	720 ft^2
Ceiling Height	12 ft
Design Conditions	Summer – 75 °F, 50% RH
Occupants	10
Occupant Load	2500 Btu/h sensible 2000 Btu/h latent
Lighting Load	6000 Btu/h sensible
Equipment Load	31800 Btu/h sensible
Total load, q_t	40300 Btu/h sensible 2000 Btu/h latent
Number of lab hoods	2
Fume Hood Exhaust Air Volume	960 cfm

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

Example 5 - Active Beams in Laboratories (IP)

1. Determine the exhaust requirement

The exhaust requirement is dictated by the exhaust required by the fume hoods, as well as by local codes. For example, using ASHRAE Standard 170-2008 to determine the minimum fresh air flow rate:

$$Q_{exhaust} = \max\left[Q_{hoods}, Q_{code}\right] = \max\left[Q_{hoods}, V_{room}(\text{ach})\right]$$

$$Q_{exhaust} = \max\left[960\ \text{cfm}, \left((20\ \text{ft})(36\ \text{ft})(12\ \text{ft})(6\ \text{ach})\frac{h}{60\ \text{min}}\right)\right] = \max\left[960\ \text{cfm}, 864\ \text{cfm}\right] = 960\ \text{cfm}$$

2. Determine the ventilation requirement

In order to maintain negative pressure, the ventilation requirement is taken as 80% of the exhaust air flow rate:

$$Q_{oz} = (1 - 20\%)Q_{exhaust}$$

$$Q_{oz} = (0.8)(960\ \text{cfm}) = 768\ \text{cfm}$$

3. Determine the required supply dew-point temperature to remove the latent load

From equation H2:

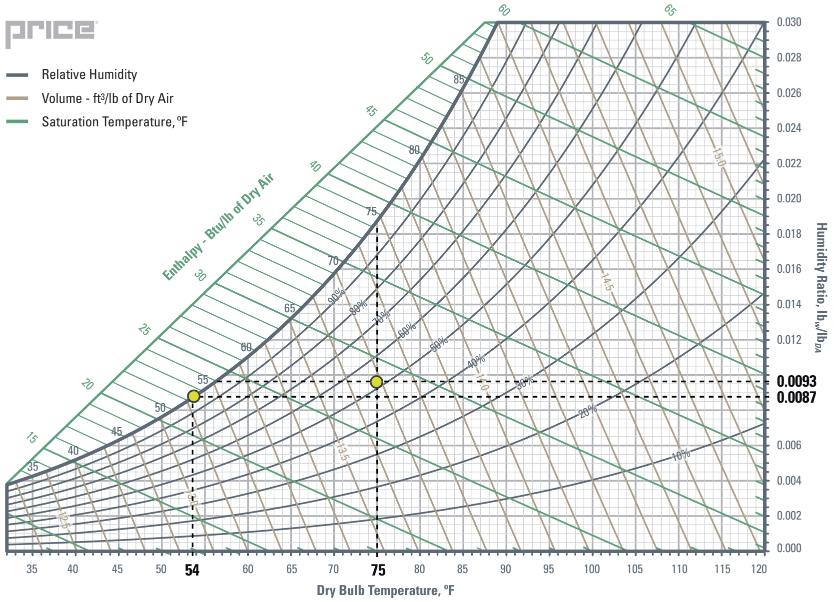
$$q_L = 0.68 Q_s \Delta W$$

$$\Delta W = \frac{q_L}{0.68 Q_{oz}} = \frac{2000\ \text{Btu/h}}{0.68(768\ \text{cfm})} = 3.8\ \text{gr/lb}$$

At the design conditions (75 °F, 50% RH), the humidity ratio is 65 gr/lb of dry air, requiring:

$$W_s = W_{sp} - \Delta W = 65 - 3.8 = 61.2\ \text{gr/lb} = 0.0087\ \text{lb/lb}$$

From the figure below, the dew point corresponding to the humidity ratio is 54 °F. This is readily achieved by standard equipment, and therefore does not need to be adjusted. With the air change requirement determined by code nearly equivalent to the air volume requirement dictated by the fume hood exhaust, we will, in this application, opt to use a constant volume supply air system.



Example 5 - Active Beams in Laboratories (IP)

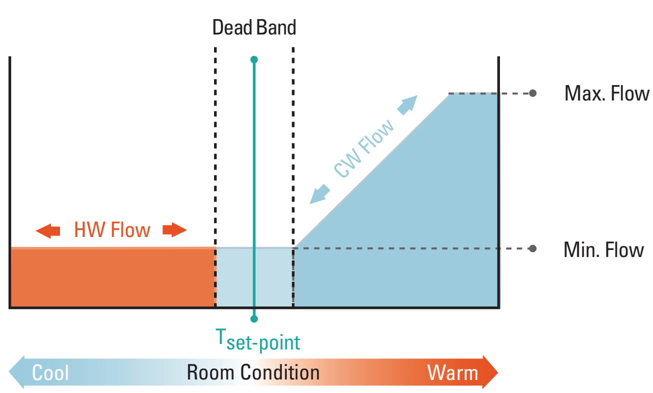
4. Select the active beams using software with the following requirements:

Requirements	
Total Capacity	40300 Btu/h
Air Volume	768 cfm
Supply Air Temperature	54 °F
Supply Water Temperature	57 °F
Room Set-Point Temperature	75 °F

Parameter	**Option 1**	**Option 2**
Configuration	Linear – Cooling Only	Linear – Cooling Only
Size	120 in x 24 in.	120 in x 24 in.
Quantity	4	4
Total Capacity	40530 Btu/h	40328 Btu/h
CHWS Temperature	57 °F	58 °F
Water Flow Rate	1.0 gpm	1.2 gpm
Water Pressure Drop	4.8 ft hd	6.7 ft hd
Air Flow	864 cfm	864 cfm
Throw	14 ft	14 ft
Air Pressure Drop	0.67 in.w.g.	0.78 in.w.g.
Transfer Efficiency	47 Btu/h cfm	47 Btu/h cfm
NC	31	31

These two selections are largely similar with both meeting the capacity required at the ventilation rate. The water flow rate is higher in the second case, as is the chilled water supply temperature. This allows for more range to modulate the water flow to control room temperature as the loads in the lab change over time. Furthermore, the increase in CHWS temperature will increase the return water temperature to the system, potentially increasing the efficiency of the chiller plant.

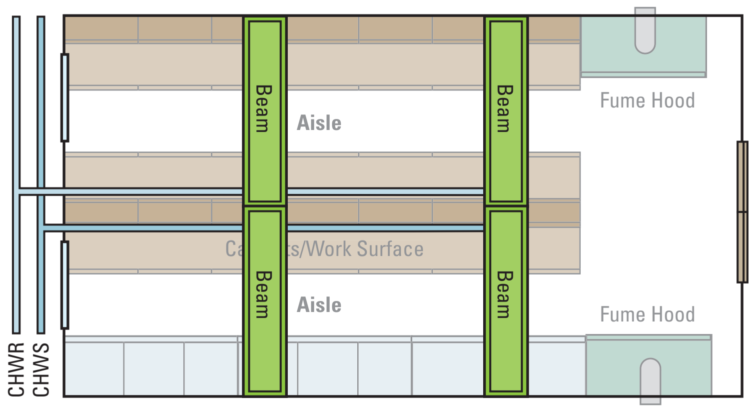
Opting for option (2) and a modulating control sequence, which will allow the air system to the optimized for the ventilation rate, and simple control of the beams to accommodate any load fluctuations:



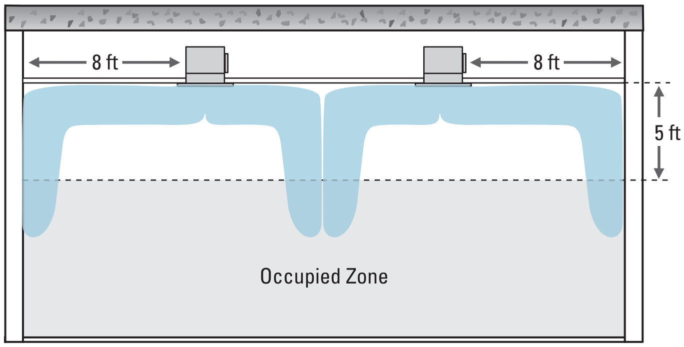
All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimeter.

Example 5 - Active Beams in Laboratories (IP)

Alternatively, the CHWS temperature can be modulated to control the load, though it will increase the complexity of the water system. With the selection of 10 ft long beams with Coanda wings to ensure pattern in an exposed application, these can be arranged in two rows parallel to the short dimension in the room:

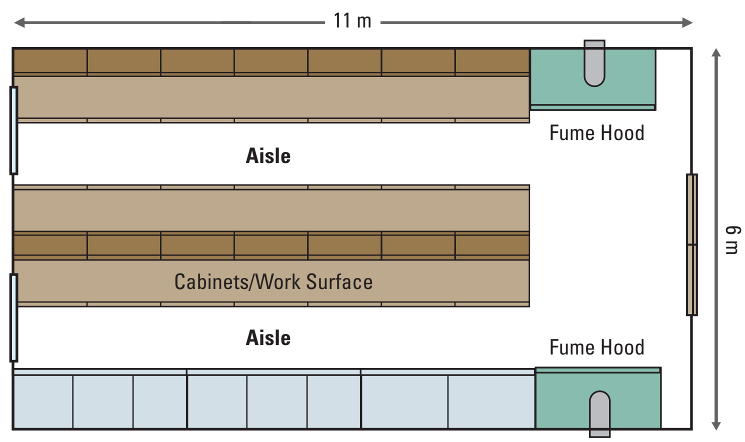


With this spacing, the 14 ft throw to 50 fpm will cover the room well with 9 ft of throw to the wall and opposing air pattern and 5 ft from the ceiling to the top of the occupied zone. It is logical to run the supply and return piping down the middle of the room and have the water connections for the beams face each other, as indicated on the diagram.



Example 5 - Active Beams in Laboratories (SI)

This hospital laboratory is used for the testing of specimens associated with patient care. The layout features one island bench and two wall benches to accommodate a maximum of ten clinical lab technicians. Florescent lighting, refrigeration equipment and other bench devices all generate heat within the lab. There are also two low-flow fume hoods in the corners of the room operating at a constant volume exhaust flow rate of 225 L/s each. The room is 11 m long by 6 m wide, with a ceiling height of 3.75 m. The space is an interior zone of the building with no envelope load.



Space Considerations

Some of the assumptions made for this space are as follows:

- Load/person is 75 W sensible and 60 W latent
- Lighting load in the space is 25 W/m^2
- The specific heat and density of the air for this example are 1.007 kgK and 1.21 kg/m^3 respectively
- Minimum exhaust flow rate of 6 ach in accordance with ASHRAE Standard 170-2008
- Maintain a 20% offset between supply and exhaust volume in order to maintain negative pressure

Design Considerations	
Area	66 m^2
Ceiling Height	3.75 m
Design Conditions	Summer – 24 °C, 50% RH
Occupants	10
Occupant Load	750 W sensible 600 W latent
Lighting Load	1650W sensible
Equipment Load	9500 W sensible
Total load, q_t	11900 W sensible 600 W latent
Number of lab hoods	2
Fume Hood Exhaust Air Volume	450 L/s

Example 5 - Active Beams in Laboratories (SI)

1. Determine the exhaust requirement

The ventilation requirement should be calculated to meet ventilation codes. For example, using ASHRAE Standard 170-2008 to determine the minimum fresh air flow rate:

$$Q_{exhaust} = \max\left[Q_{hoods}, Q_{code}\right] = \max\left[Q_{hoods}, V_{room}(\text{ach})\right]$$

$$Q_{exhaust} = \max\left[450\frac{\text{L}}{\text{s}}, (11\text{ m})(6\text{ m})(3.75\text{ m})(6\text{ ach})\frac{\text{h}}{3.6}\right] = \max\left[450\frac{\text{L}}{\text{s}}, 413\frac{\text{L}}{\text{s}}\right] = 450\frac{\text{L}}{\text{s}}$$

2. Determine the ventilation requirement

In order to maintain negative pressure, the ventilation requirement is taken as 80% of the exhaust air flow rate:

$$Q_{oz} = (1 - 20\%)Q_{exhaust}$$

$$Q_{oz} = (0.8)\left(450\frac{\text{L}}{\text{s}}\right) = 360\frac{\text{L}}{\text{s}}$$

3. Determine the required supply dew-point temperature to remove the latent load

From equation H2

$$q_L = 2500\rho Q_s \Delta W$$

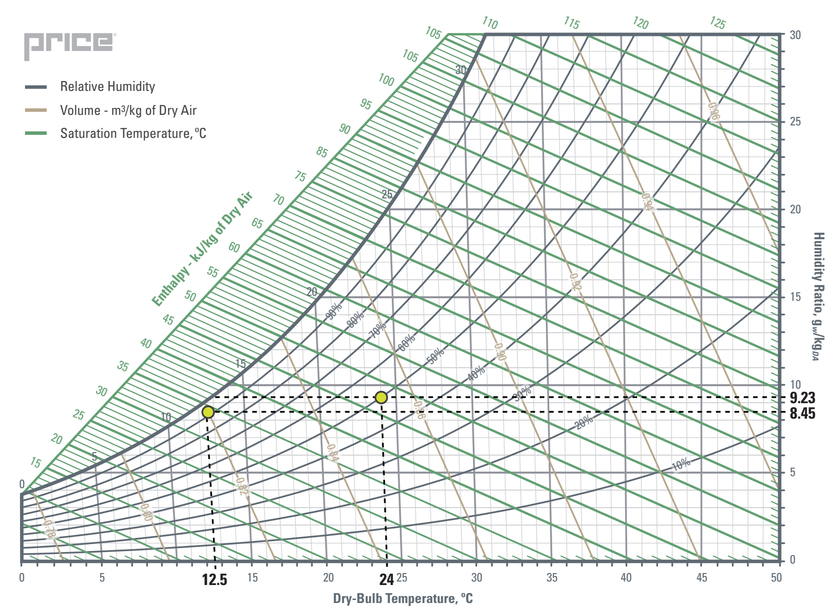
Using the ventilation rate:

$$\Delta W = \frac{q_L}{2500\rho Q_{oz}} = \frac{600\text{ W}}{2500\text{ W/LsK}(1.21\text{ kg/m}^3)(360\text{ L/s})} = 0.55\text{ g/kg}$$

At the design conditions (24 °C, 50% RH), the humidity ratio is 9.5 g/kg, requiring:

$$W_s = W_{sp} - \Delta W = 9.5 - 0.55 = 8.95\text{ g/kg}$$

From the figure below, the dew point corresponding to the humidity ratio is 12.5 °C. This is readily achieved by standard equipment, and therefore does not need to be adjusted. With the air change requirement determined by code nearly equivalent to the air volume requirement dictated by the fume hood exhaust, we will, in this application, opt to use a constant volume supply air system.



Example 5 - Active Beams in Laboratories (SI)

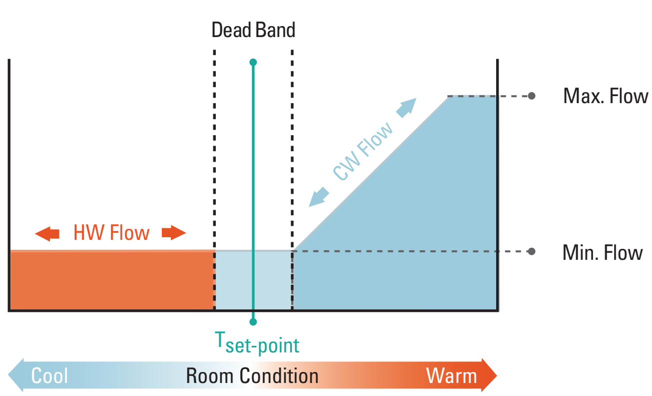
4. Select the active beams using software with the following requirements:

Requirements	
Total Capacity	11900 W
Air Volume	360 L/s
Supply Air Temperature	12.5 °C
Supply Water Temperature	14 °C
Room Set-Point Temperature	24 °C

Parameter	**Option 1**	**Option 2**
Size	300 mm x 600 mm	300 mm x 600 mm
Configuration	Linear – Cooling Only	Linear – Cooling Only
Quantity	4	4
Total Capacity	13022 W	12689 W
CHWS Temperature	14 °C	15 °C
Water Flow Rate	245 L/h	318 L/h
Water Pressure Drop	16.7 kPa	26.6 kPa
Air Flow	453 L/s	453 L/s
Throw	4.6 m	4.6 m
Air Pressure Drop	202 Pa	202 Pa
Transfer Efficiency	46 Ws/L	45 Ws/L
NC	-	-

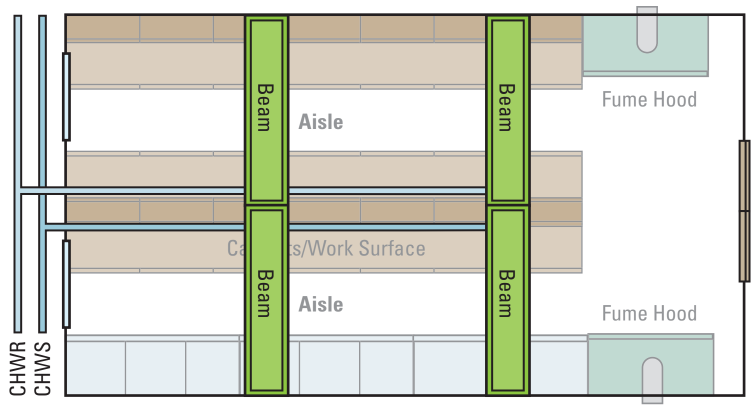
These two selections are largely similar with both meeting the capacity required at the ventilation rate. The water flow rate is higher in the second case, as is the chilled water supply temperature. This allows for more range to modulate the water flow to control room temperature as the loads in the lab change over time. Furthermore, the increase in CHWS temperature will increase the return water temperature to the system, potentially increasing the efficiency of the chiller plant.

Opting for option (2) and a modulating control sequence which will allow the air system to the optimized for the ventilation rate and simple control of the beams to accommodate any load fluctuations:

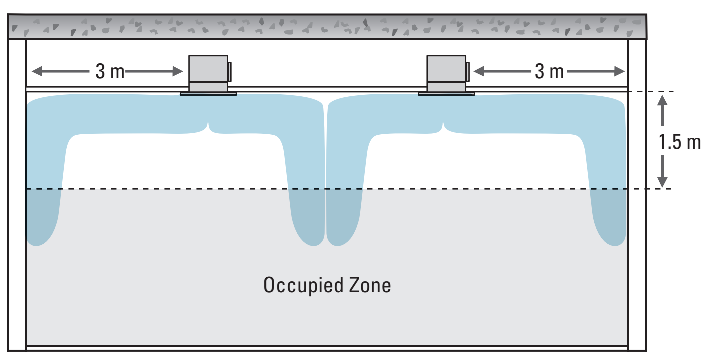


Example 5 - Active Beams in Laboratories (SI)

Alternatively, the CHWS temperature can be modulated to control the load, though it will increase the complexity of the water system. With the selection of 3 m long beams with Coanda wings to ensure pattern in an exposed application, these can be arranged in two rows parallel to the short dimension in the room:



With this spacing, the 4.5 m throw to 0.25 m/s will cover the room well with 3 m of throw to the wall and opposing air pattern and 1.5 m from the ceiling to the top of the occupied zone. It is logical to run the supply and return piping down the middle of the room and have the water connections for the beams face each other, as indicated on the diagram.



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