FUNDAMENTALS OF CHILLED BEAMS

ANSI/ASHRAE STANDARD 200-2015, METHODS OF TESTING CHILLED BEAMS

Hello!

I am Davor Novosel

I am here because I love to share what I know about chilled beams with you.

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Today

- 08:00 – 10:00 Fundamentals of Chilled Beams
- 10:00 – 10:15 Break
- 10:15 – 11:15 ANSI/ASHRAE Standard 200-2015, *Methods of Testing Chilled Beams*
- 11:15 – noon Panel Discussion: TAB of Chilled Beams

FUNDAMENTALS OF CHILLED BEAMS

Agenda

- 1. Concept
- 2. Passive Chilled Beam
- 3. Active Chilled Beam
- 4. Applications
- 5. System Design
- 6. Passive Beam Selection
- 7. Active Beam Selection
- 8. Commissioning
- 9. Example

References

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- Brzezenski, SP. 2012. Chilled Beams in Historic Buildings. *ASHRAE Journal* 54 (11): 48-55
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- Trox. 2009. Chilled Beams Design Guide
- Vastyan, J. 2011. Chilled Beams Basics. HPAC Engineering (July): 26-28, 42

1.

CONCEPT

A Brief History …

Willis Carrier induction unit

First radiant ceiling system by Norwegian engineer Gunnar Frenger

The first radiant ceiling installed in Gothenburg, Sweden

The first radiant cooling device installed in Gothenburg, Sweden

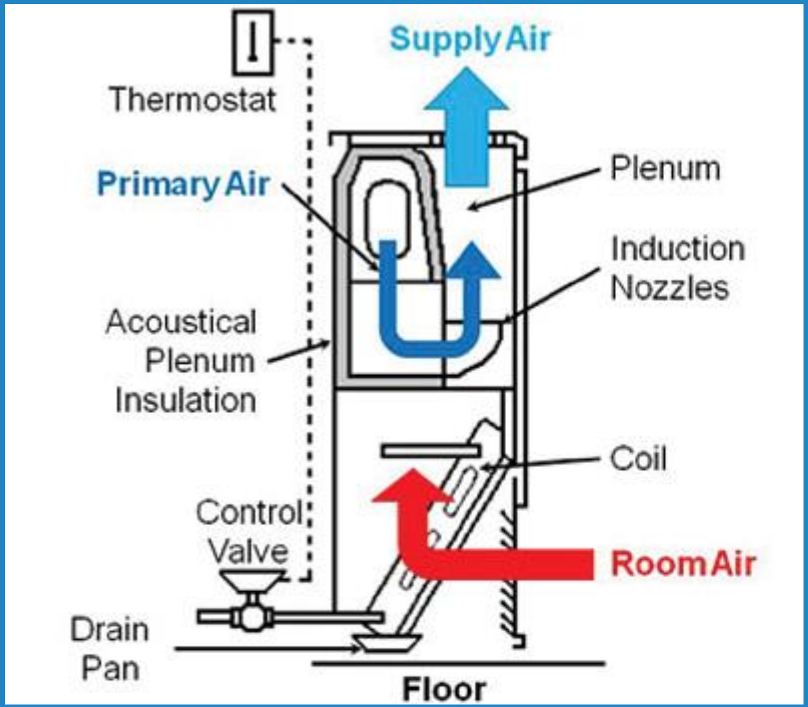
The first passive chilled beam installed in Stockholm, Sweden

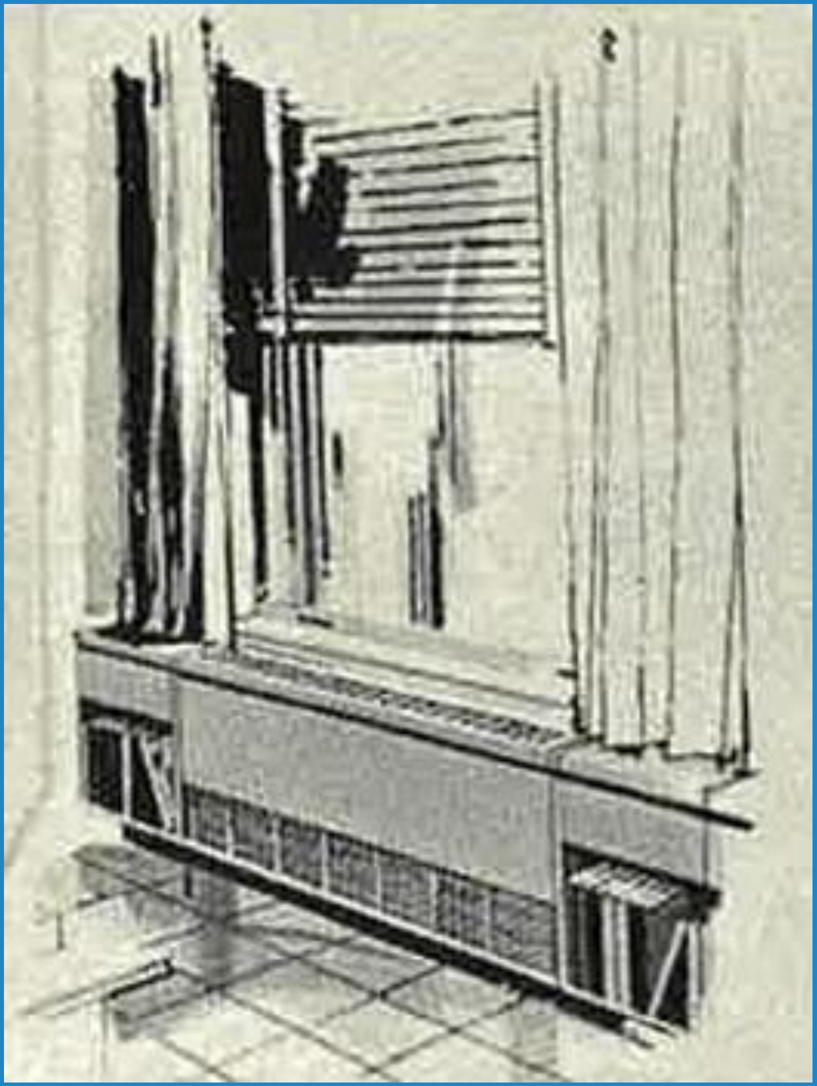
Rapid spread in Europe

Introduced in USA by Trox

1920s 1940s 1960s 1972 1986 1990s 2000s

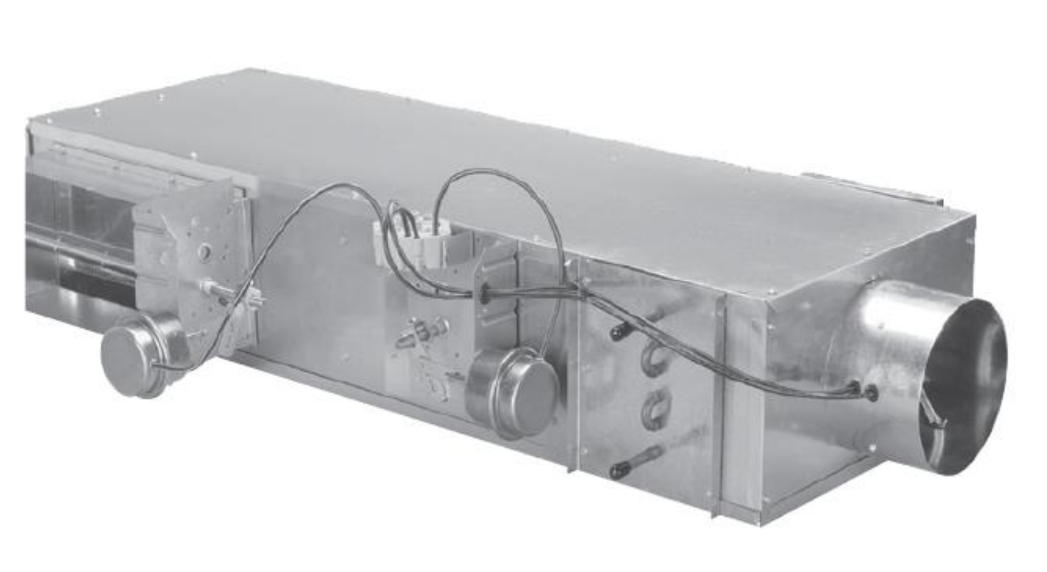
Chilled beam = Linear induction unit





Early 20th century perimeter induction unit

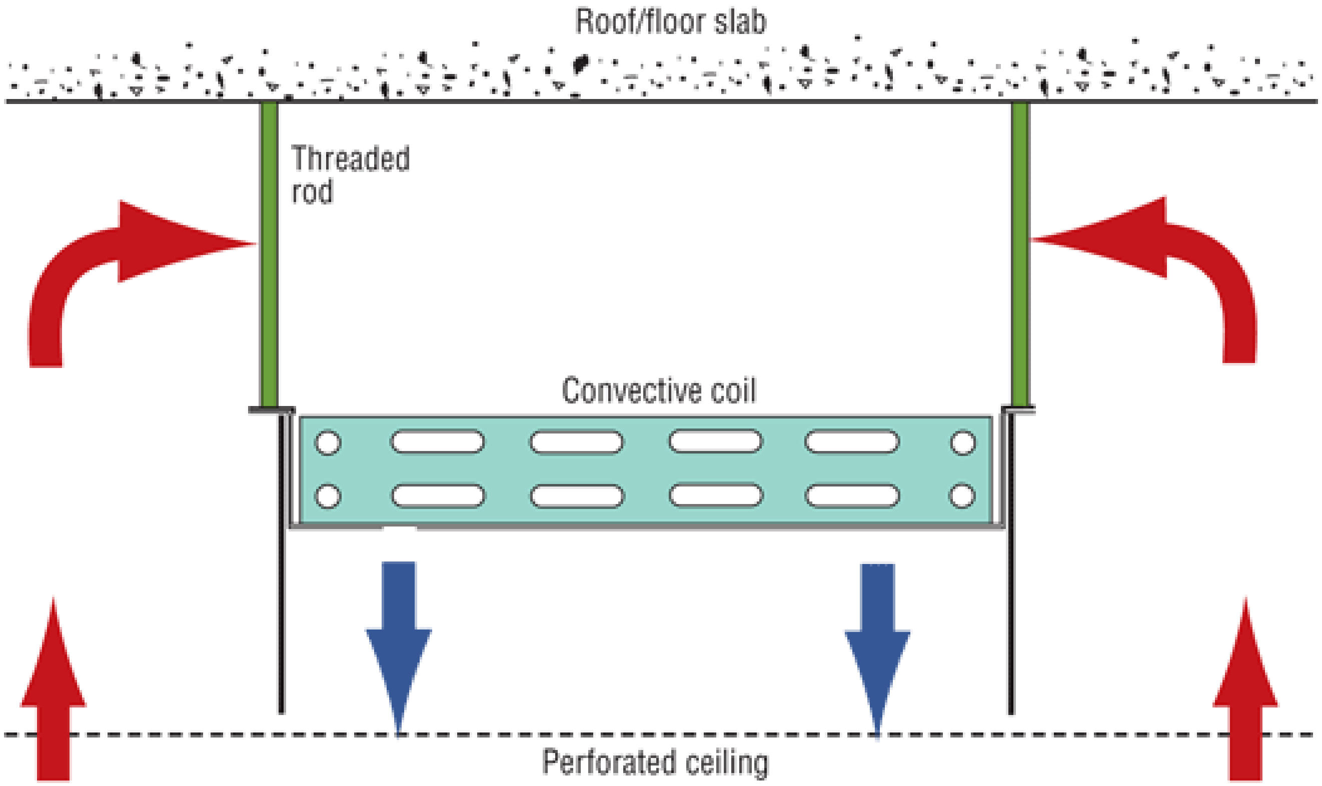
Tuttle & Bailey
Induction air terminal unit



Titus
Fan-powered induction unit

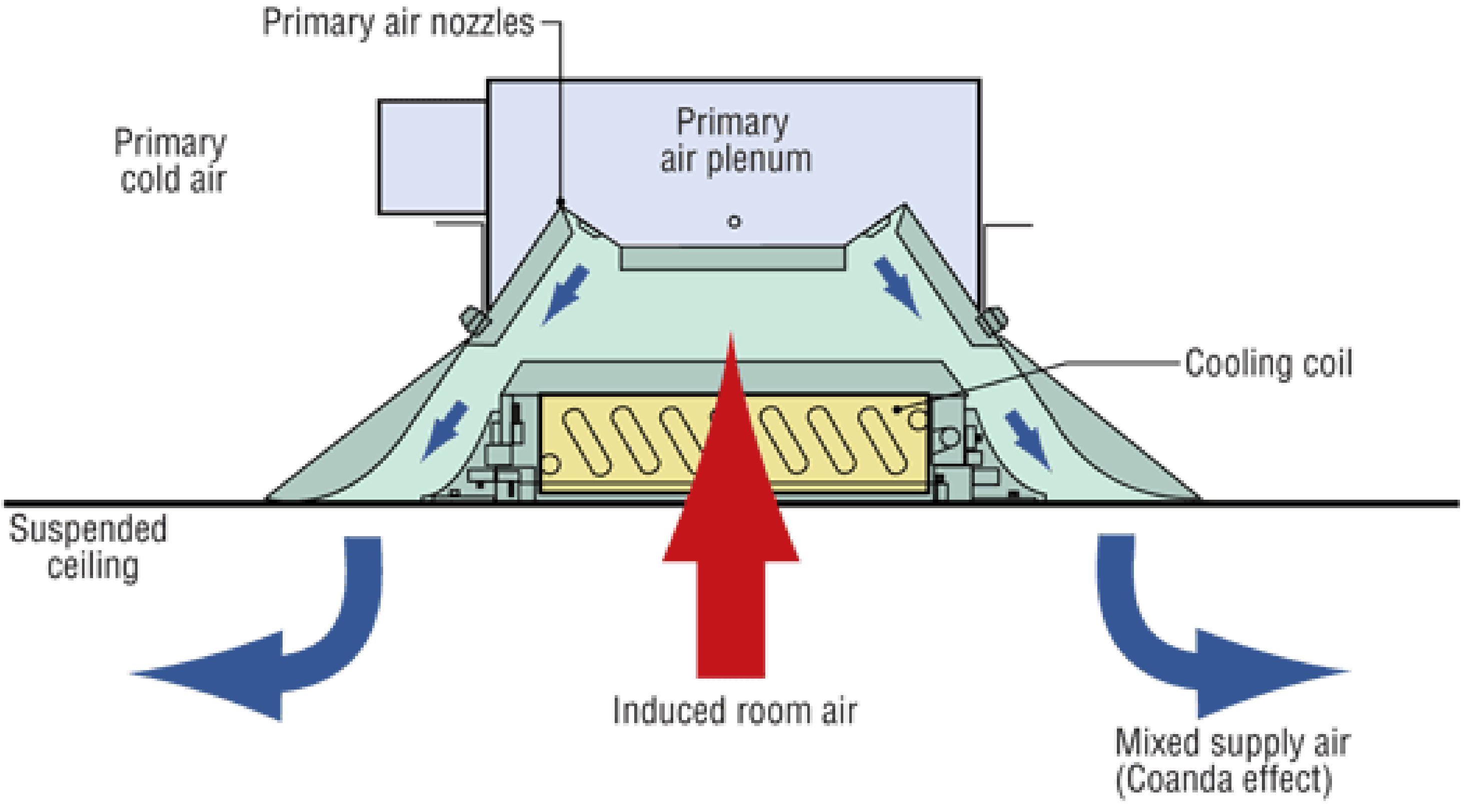
Types of chilled beams

Passive chilled beam



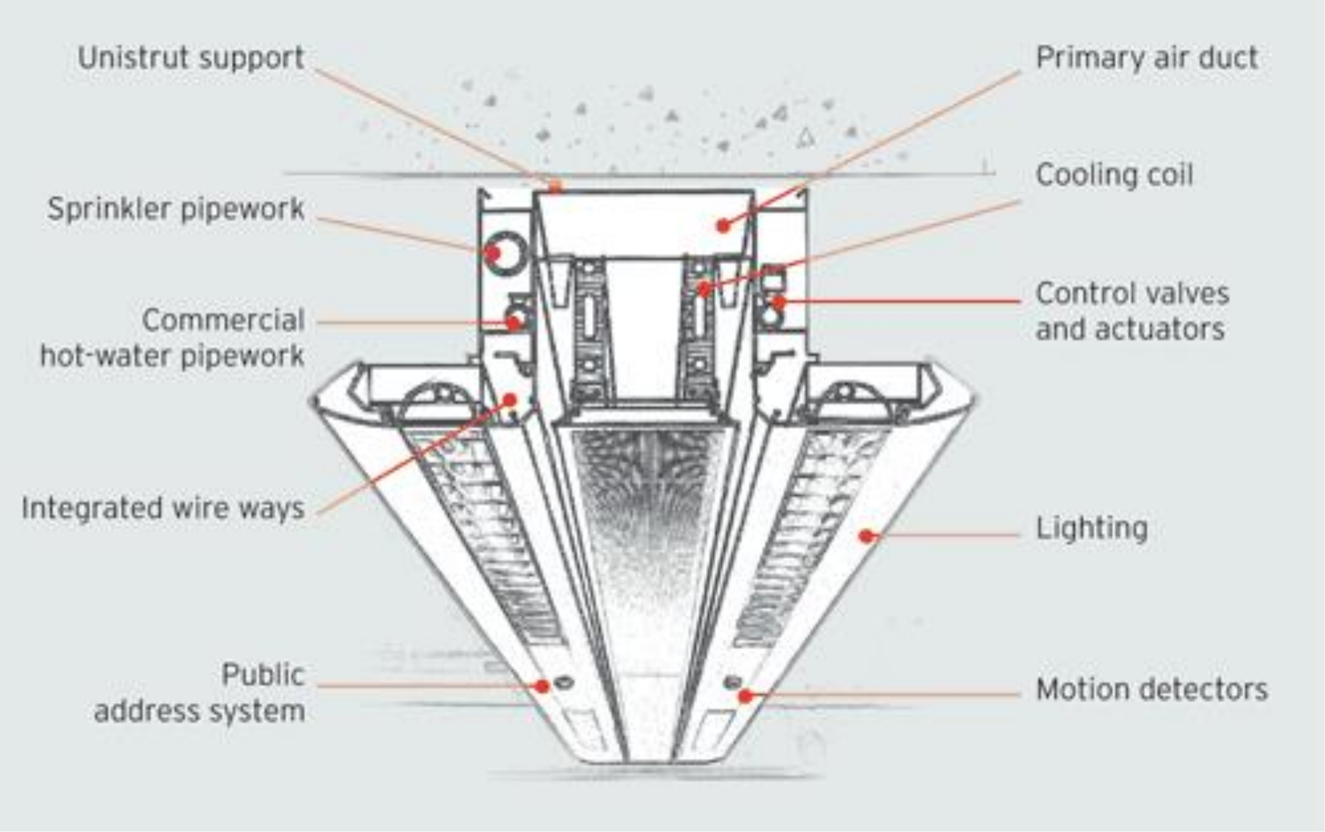
Types of chilled beams

Active chilled beam



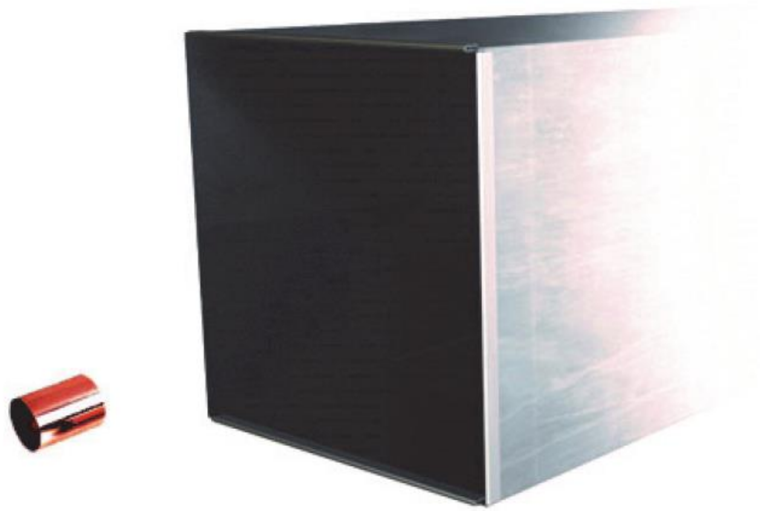
Types of chilled beams

Multi service chilled beam



Why beams? Physics!

Water carries significantly more energy than air.



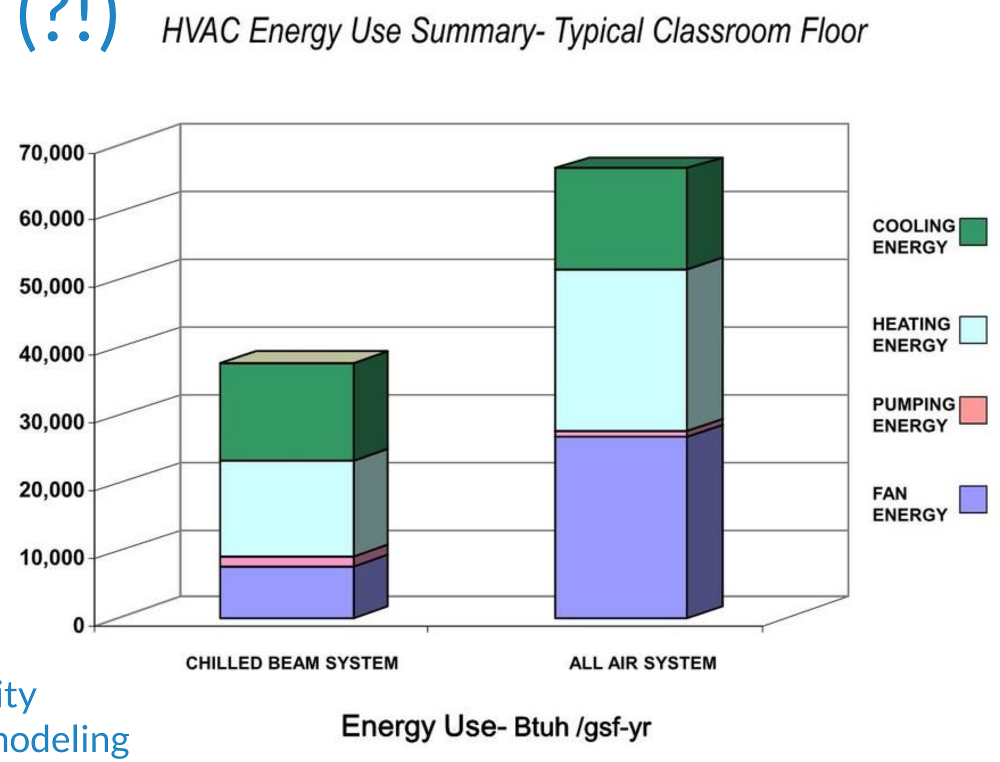
Water pipe diameter circa 25mm / 1”

Air duct circa $450mm^2$ / 18”x18”

Approximate comparison between water and air transporting equivalent energy

Why beams?

▷ … results in more efficient HVAC system with lower operating costs (?!)



Virginia Commonwealth University
new school of medicine; energy modeling
by Sera Engineering

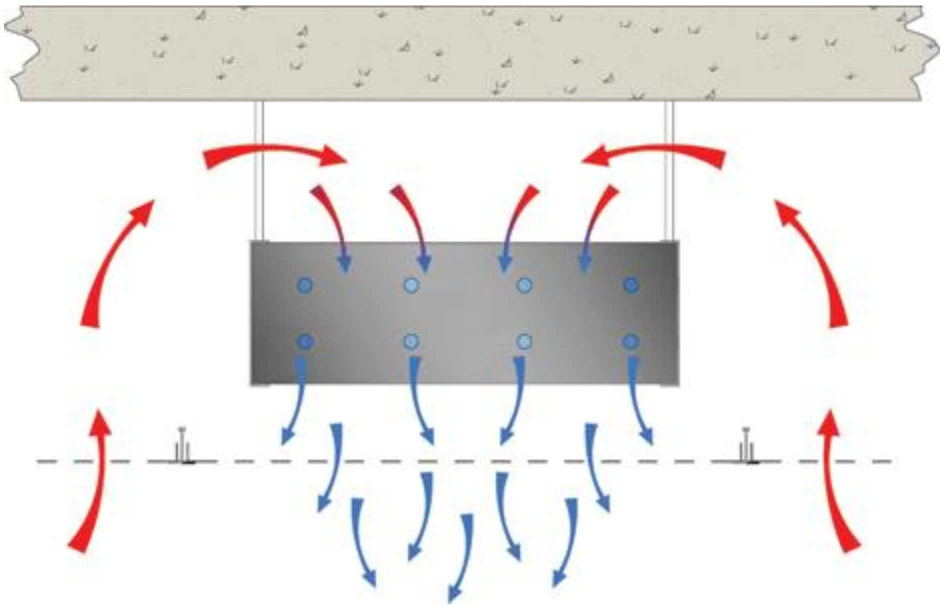
2. PASSIVE CHILLED BEAM

2. Passive Chilled Beam

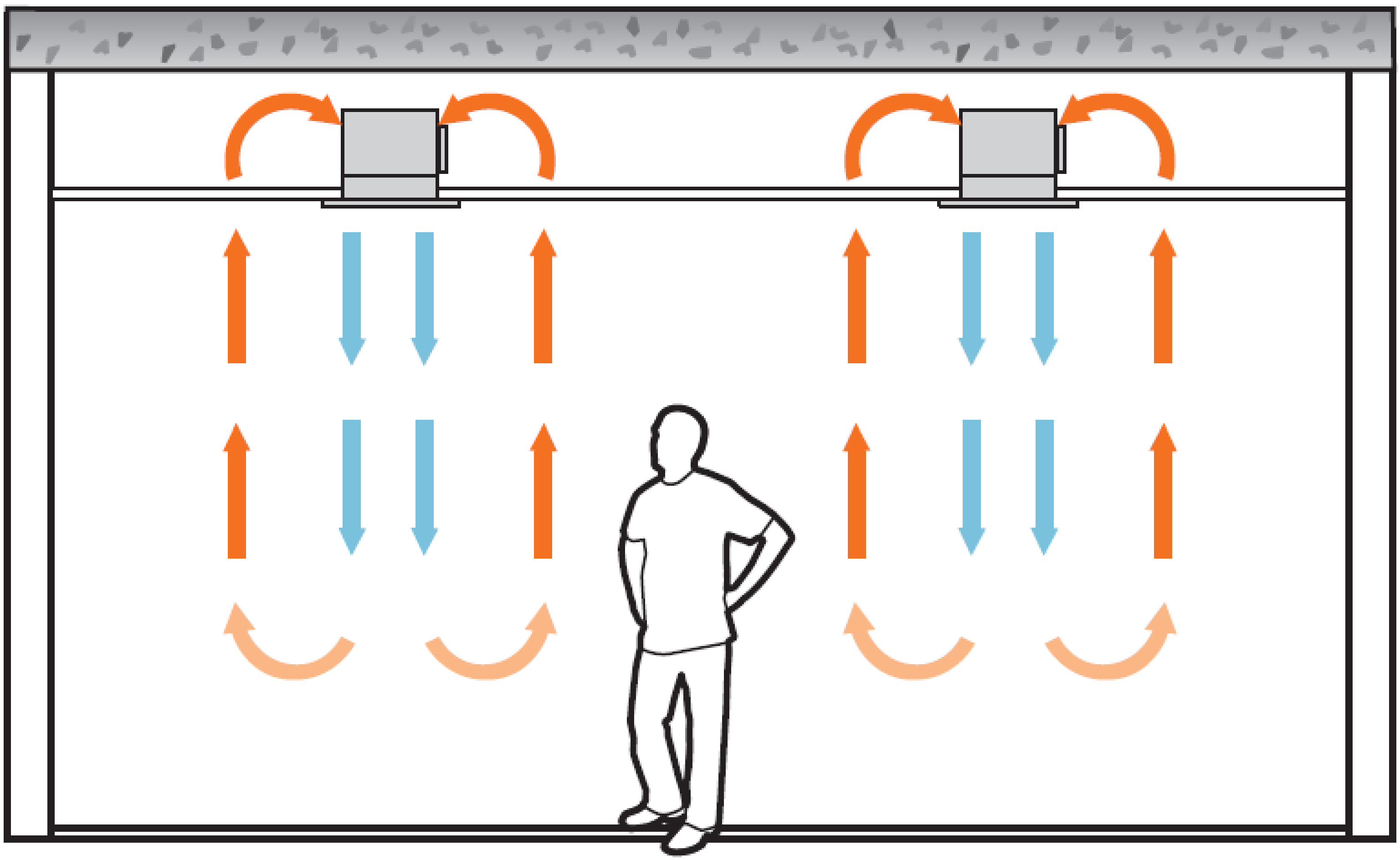
- Passive beams provide sensible cooling from the water coil.
- Heating and ventilation must be handled by complementing systems.

2. Passive Chilled Beam

- Heat transfer is mainly via natural convection.
- Warm air cooled by the heat exchanger flows downward into the space.

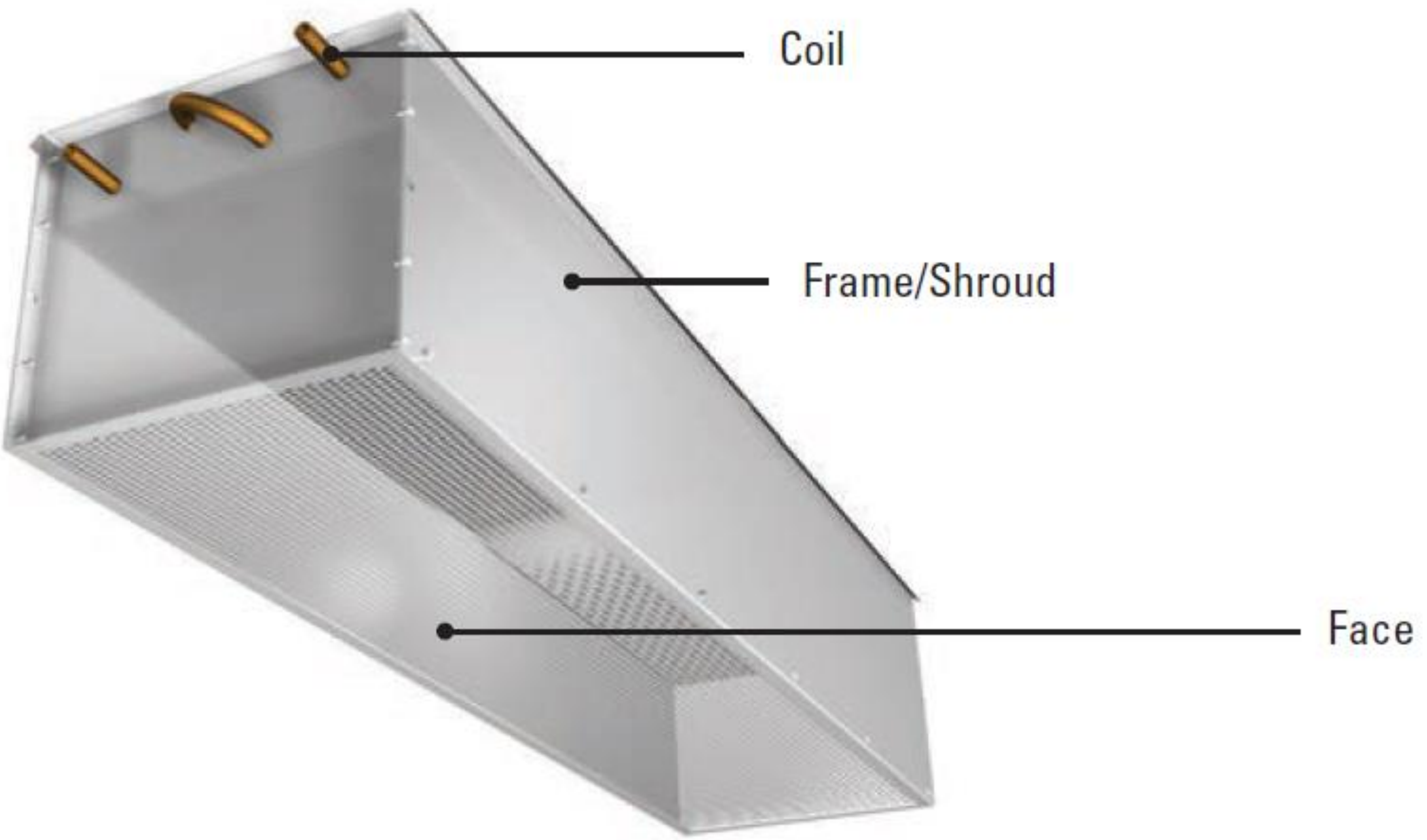


2. Passive Chilled Beam



Room air flow pattern of a passive beam in cooling

2. Passive Chilled Beam



Components of a typical passive chilled beam

2. Passive Chilled Beam

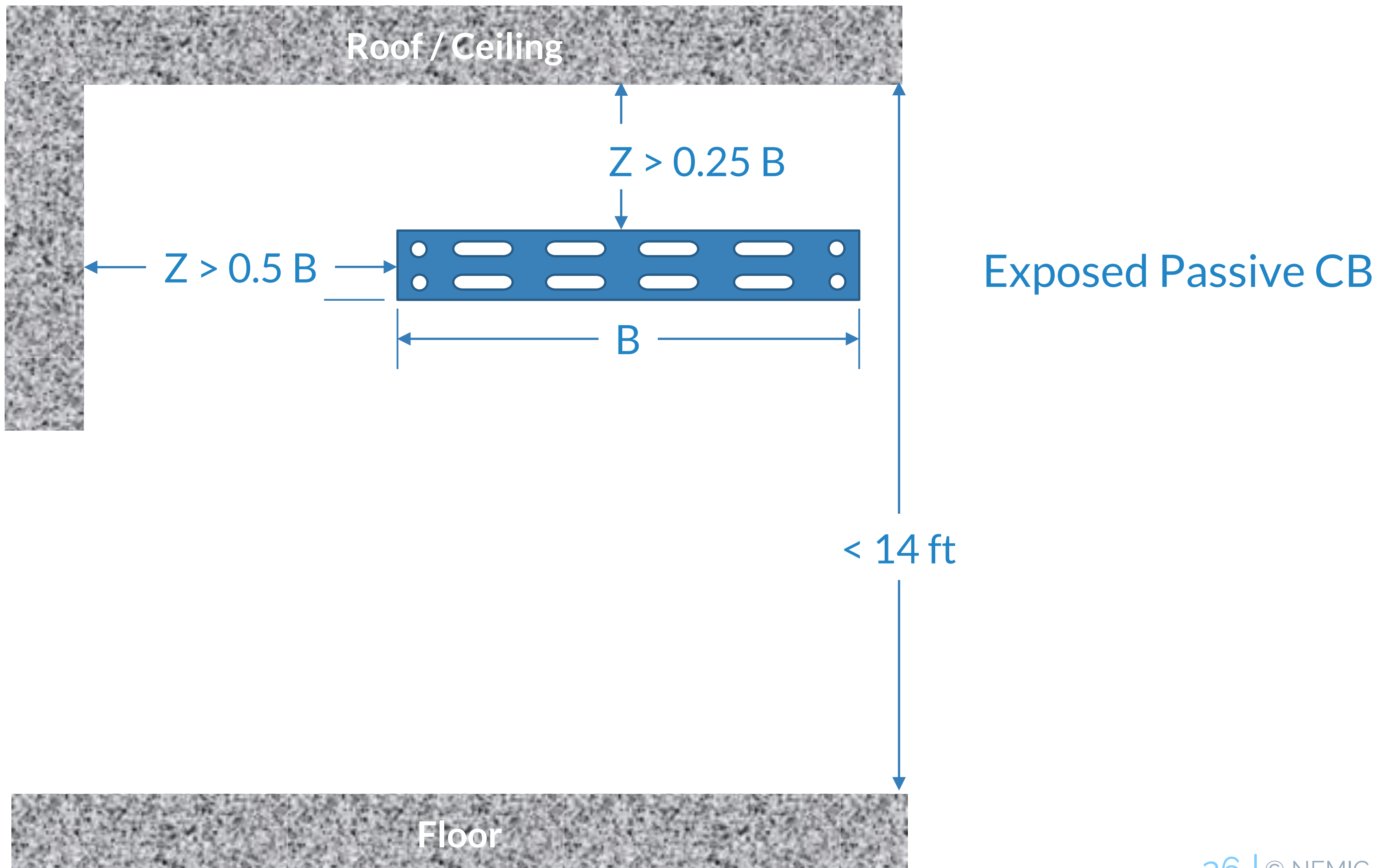
Exposed Passive CB

- Critical issues:
  - Distance between soffit and CB
  - Distance between side wall and CB
  - Distance of CB above floor

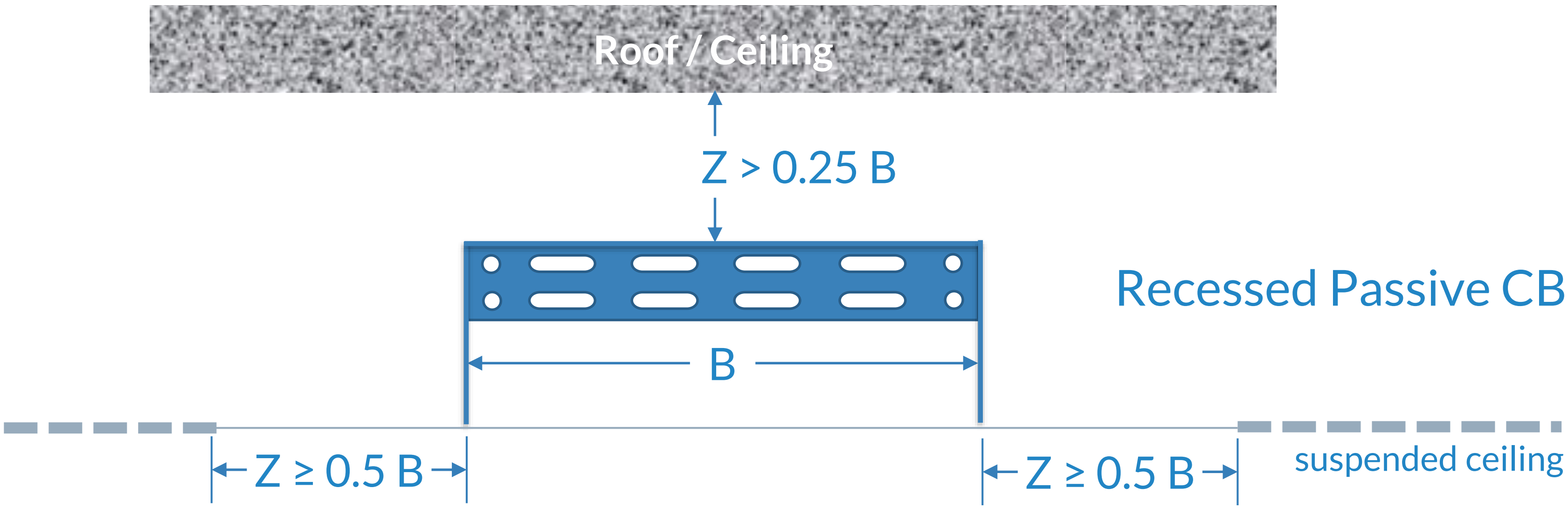
Recessed Passive CB

- Critical issues:
  - Distance between soffit and CB
  - Return air path
  - Net free area of return air path

2. Passive Chilled Beam



2. Passive Chilled Beam



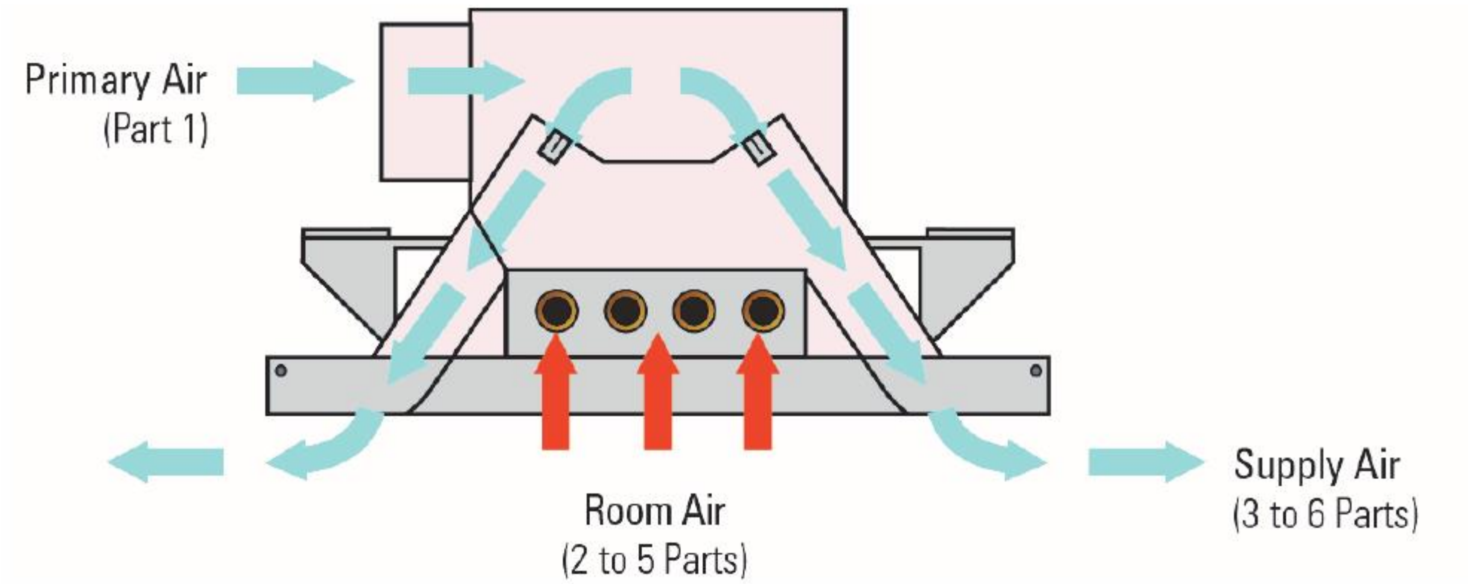
3. ACTIVE CHILLED BEAM

3. Active Chilled Beam

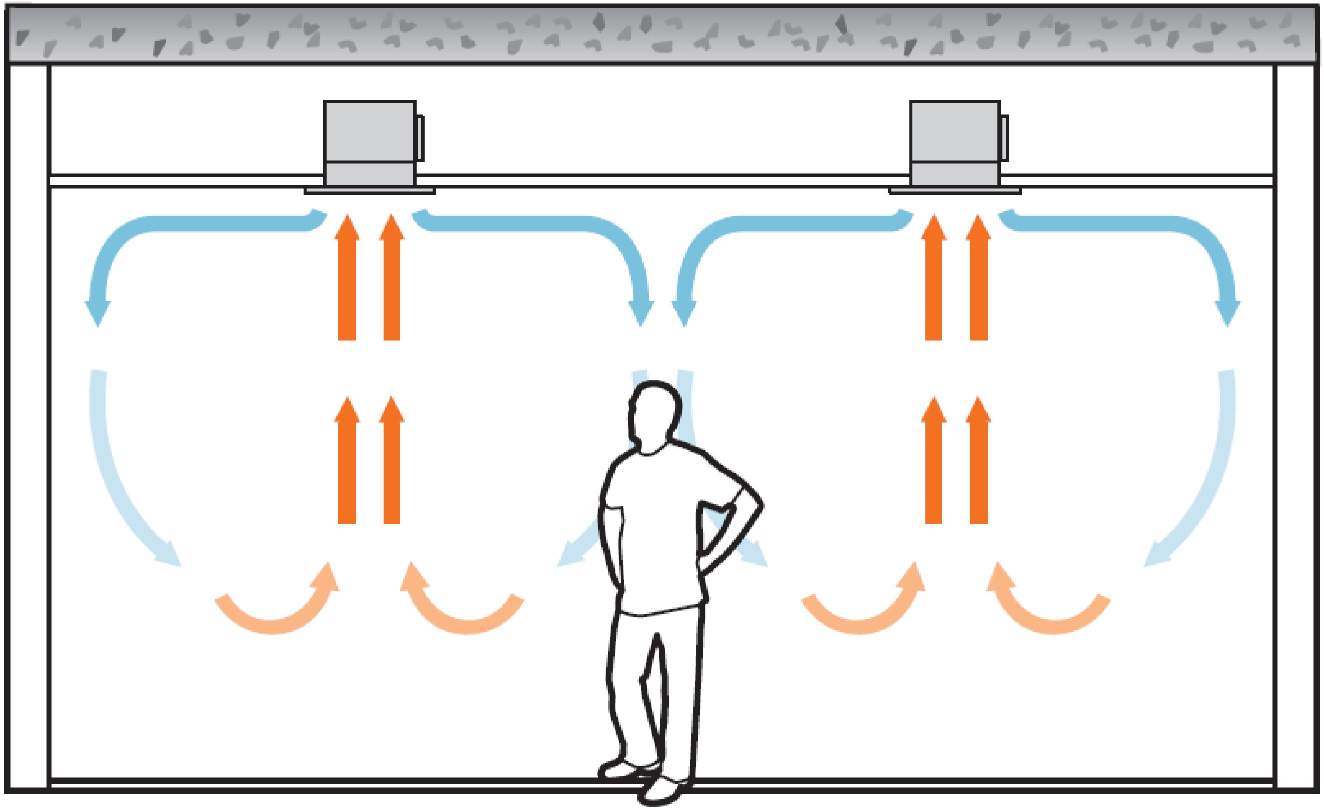
- ▷Active beams are connected to both the primary air as well as the chilled- and heated-water systems
- ▷Constant volume supply air system
- ▷Chilled water temperature > space dew point
- ▷Requires dedicated outdoor air system to remove <u>all</u> (external + internal) latent loads

3. Active Chilled Beam

▷Active beams heat or cool a space through induction and forced convection.



3. Active Chilled Beam



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

3. Active Chilled Beam

ACTIVE BEAM TYPES

- Ceiling mounted
  - One-way and two-way discharge units
  - Four-way discharge units
- Bulkhead chilled beam

Other type of active beams are

- Floor mounted
- Perimeter wall

3. Active Chilled Beam

Frenger Systems Halo™ - Active Chilled Beam

Trox 2-way CB

3. Active Chilled Beam

Trox Type DID-R active chilled diffuser with radial air discharge

3. Active Chilled Beam

Price ACBV Vertical Active Beam/Induction Unit

4. APPLICATIONS

4. Applications

Active beams are a good choice for the following applications:

- ▷Spaces with typical heating and sensible cooling requirements
- ▷Buildings with moderate internal latent loads
- ▷Spaces with limited floor-to-ceiling heights
- ▷Spaces where low noise levels are desired

4. Applications

Suitable building types for active CBs:

- ▷Commercial office buildings
- ▷Schools
- ▷Hospital patient rooms
- ▷Laboratories with high internal loads
- ▷Hotels, dormitories

4. Applications

Applications NOT suitable for CBs:

- ▷Building areas where humidity can be difficult to control (lobbies, atria, egress routes)
- ▷Spaces with high latent loads (pools, etc.)
- ▷Applications with high airflow/ventilation requirements, such as an exhaust driven lab
- ▷Kitchens
- ▷Data centers
- ▷Spaces with high ceilings (> 14ft.)

4. Applications

Passive beams are ideally suited to aisle ways or perimeters of large spaces, such as

- ▷Offices
- ▷Lobbies
- ▷Conference centers
- ▷Libraries
- ▷Any other space that requires perimeter or additional cooling

4. Applications

Humidity control at all times is paramount to proper operation of chilled beam systems

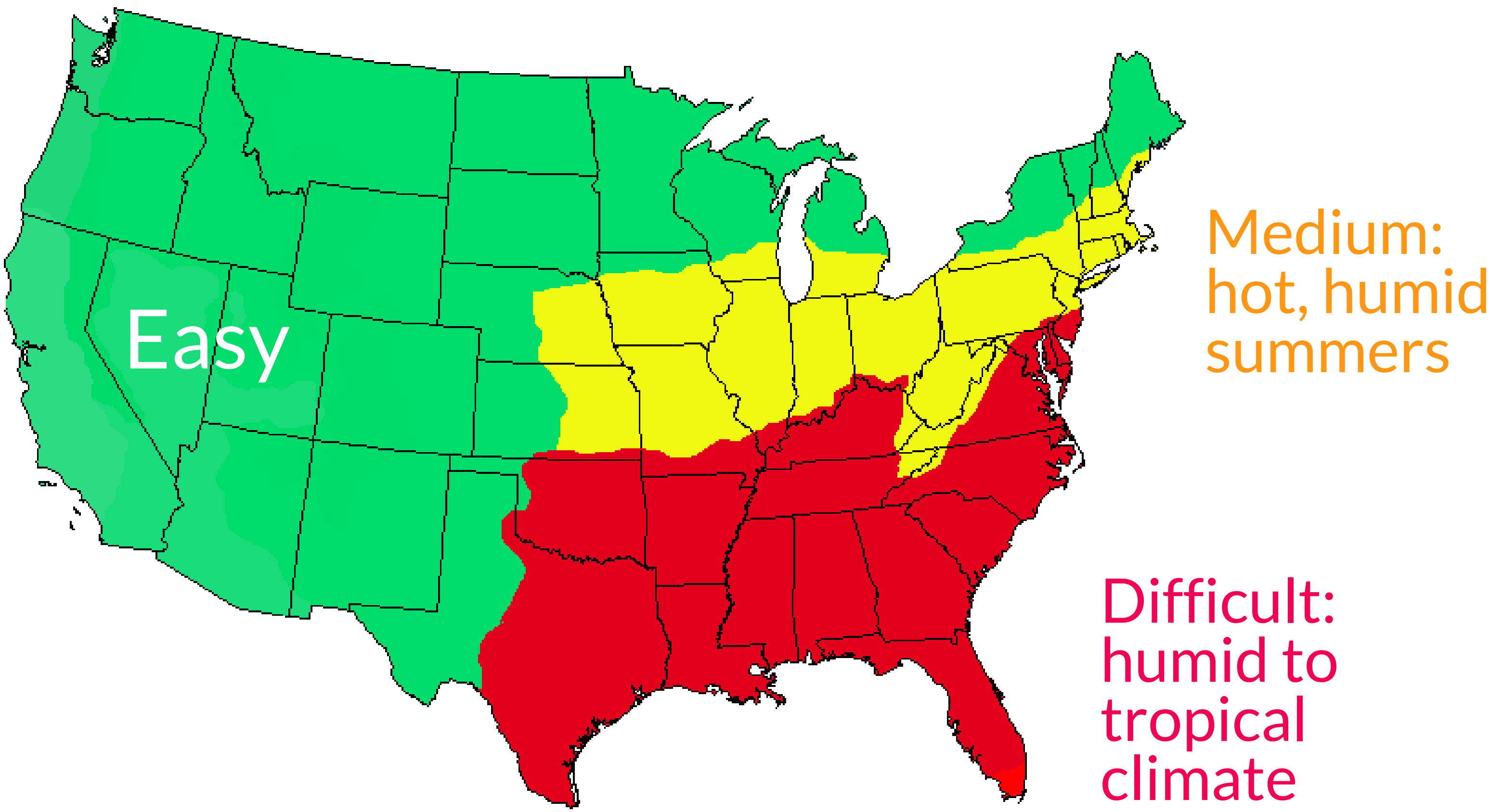
- ▷Dew point controller
- ▷No weekend shutdowns
- ▷Building pressurized at all times

4. Applications

When humidity controls fails …

4. Applications

… of chilled beams by climate zones



4. Applications

Condensation risks

- Near entry points
- At perimeter, mixed-mode ventilation
- Building retrofits with leaky envelope
- Spaces with high variable latent loads:
    - Lunch, coffee rooms
    - Meeting rooms

4. Applications

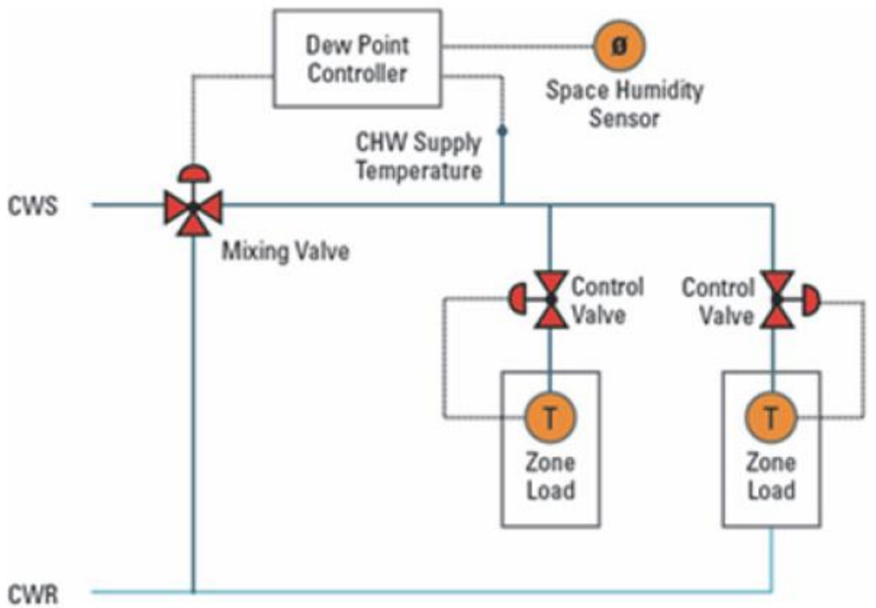
Condensation prevention

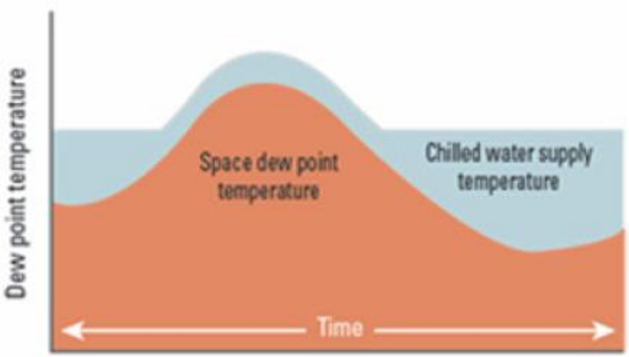
- System meets 100% latent load at peak dew point design
- Limit overcooling
- Chilled water shut-off or reset
- Reset air temperature
- VAV for variable occupancy

4. Applications

Condensation prevention

▷ Chilled water reset in response to space dew point





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5. SYSTEM DESIGN

5. System Design

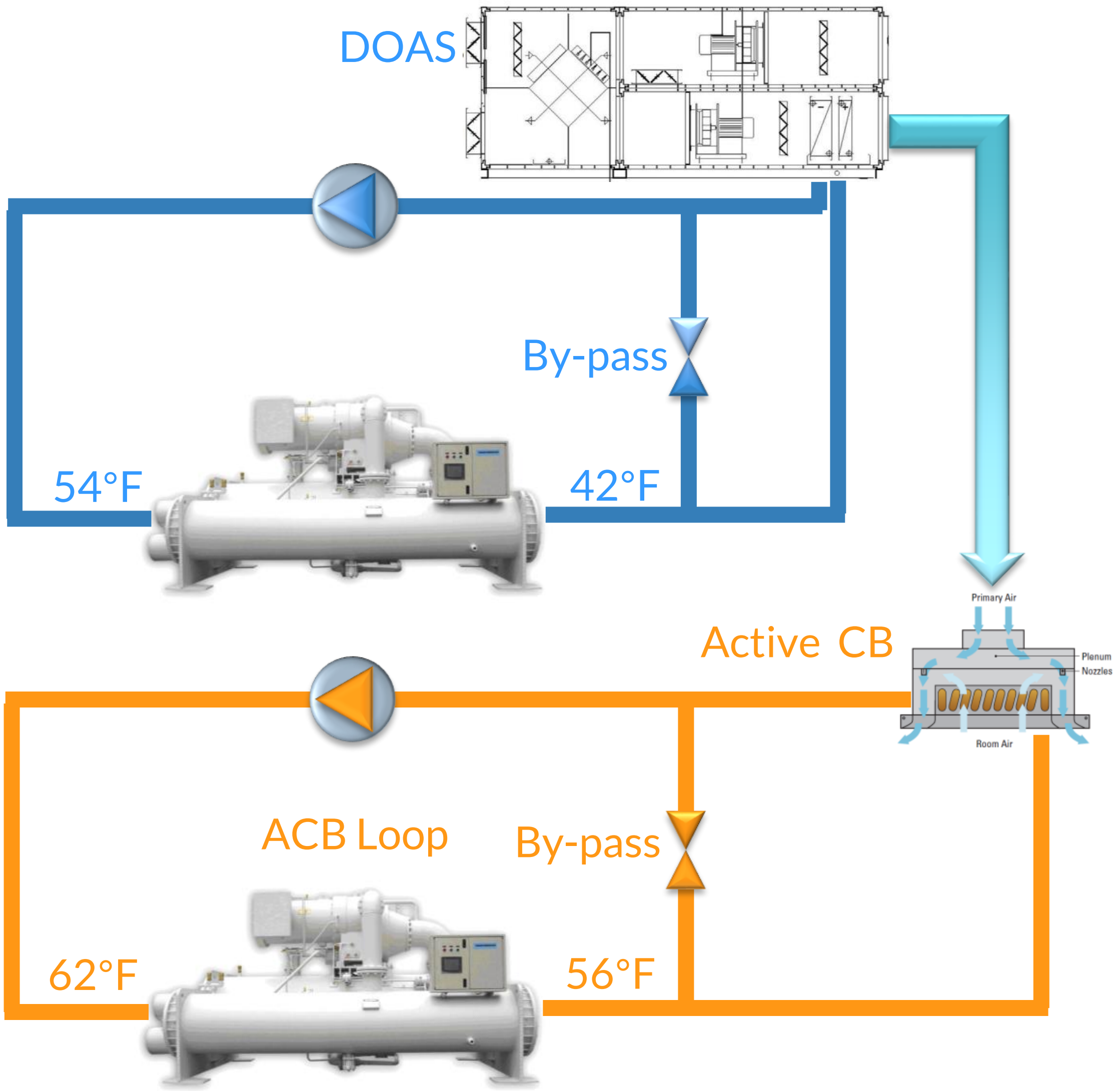
Chilled beam systems require

▷Source of chilled water at two different temperatures

▷Source of hot water (4 pipe system)

▷Supply of primary air

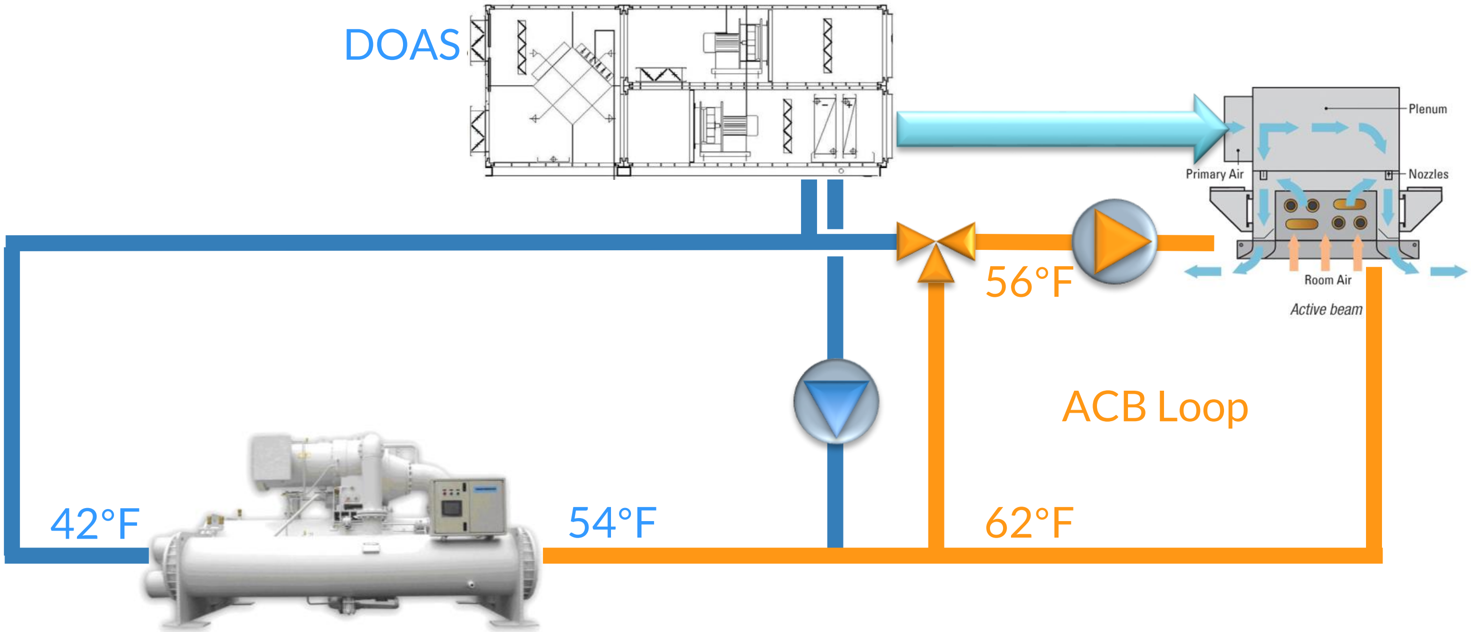
5. Chilled Water System Design



Dedicated Chillers

- Two independent chilled water loops
- Allows for smaller chiller servicing ACB loop
- Allows for high chiller efficiency of the ACB loop
- Higher first cost

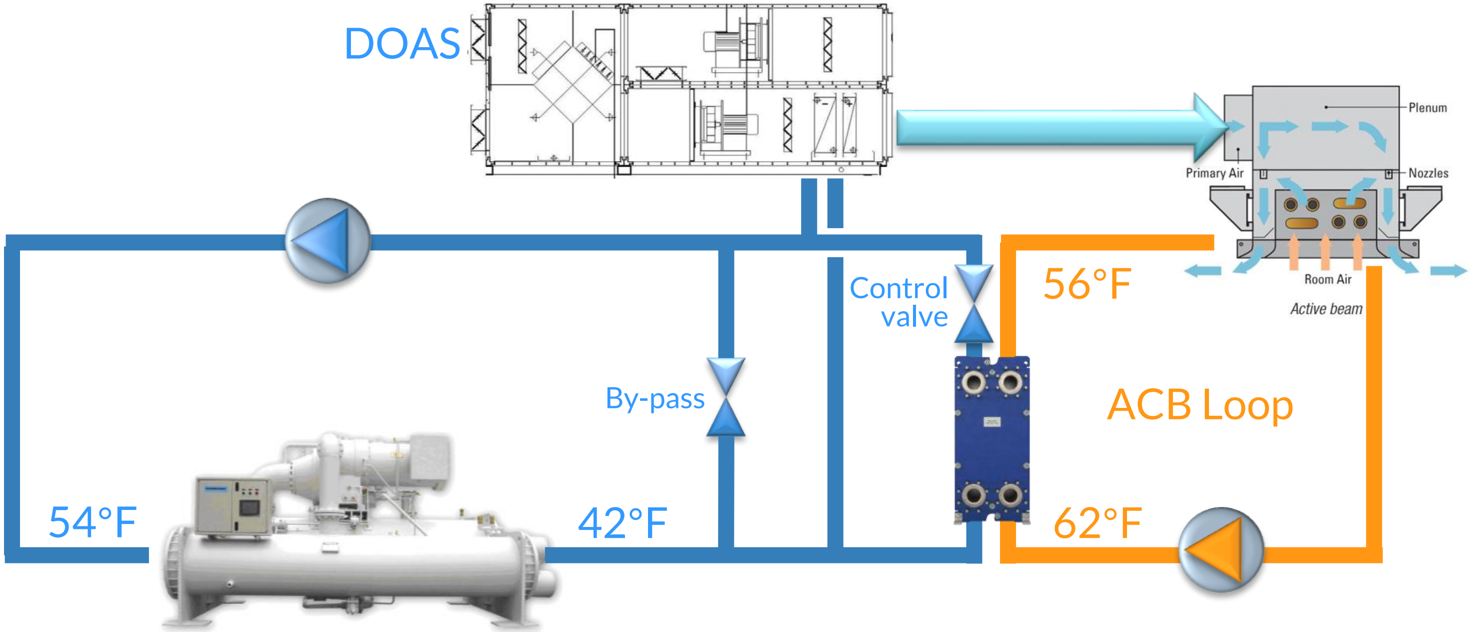
5. Chilled Water System Design



Common chiller

- ▷Chiller downsizing not possible
- ▷Lower EER compared to separate loops
- ▷Higher supply water temperature not feasible
- ▷DOAS load significantly higher the ACB loop one

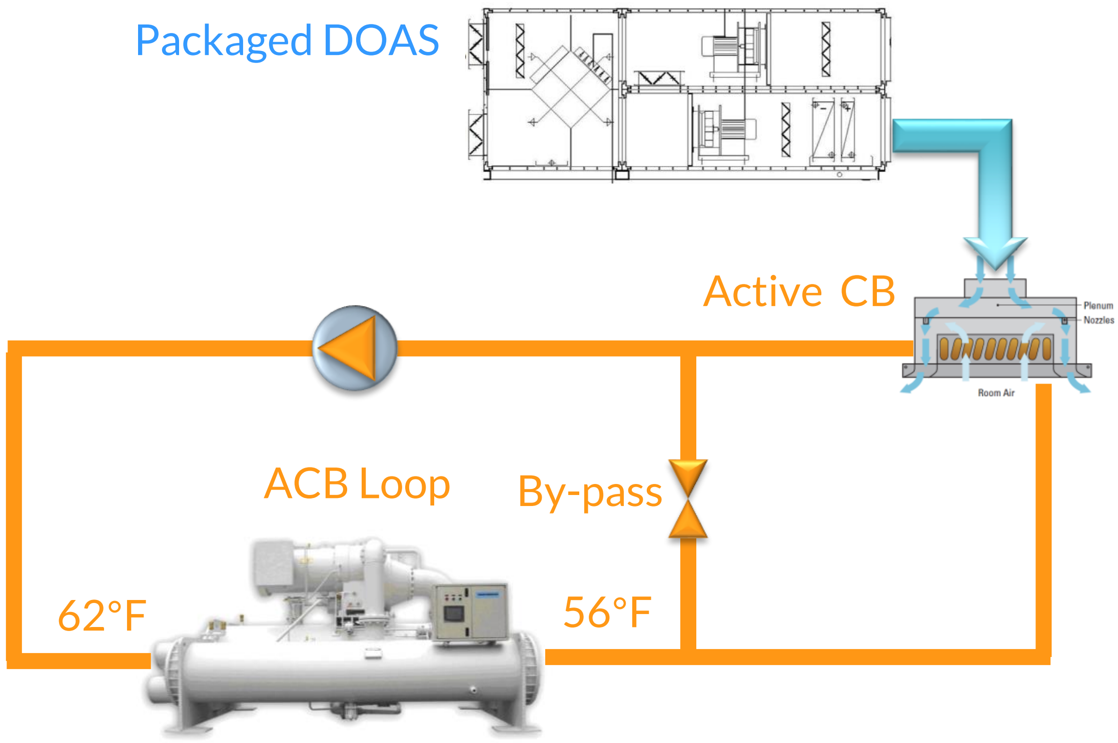
5. Chilled Water System Design



Common chiller with heat exchanger

- Chiller downsizing not possible
- Lower EER compared to separate loops
- Higher supply water temperature not feasible
- DOAS load significantly higher the ACB loop one
- Requirement for isolated chilled water loops

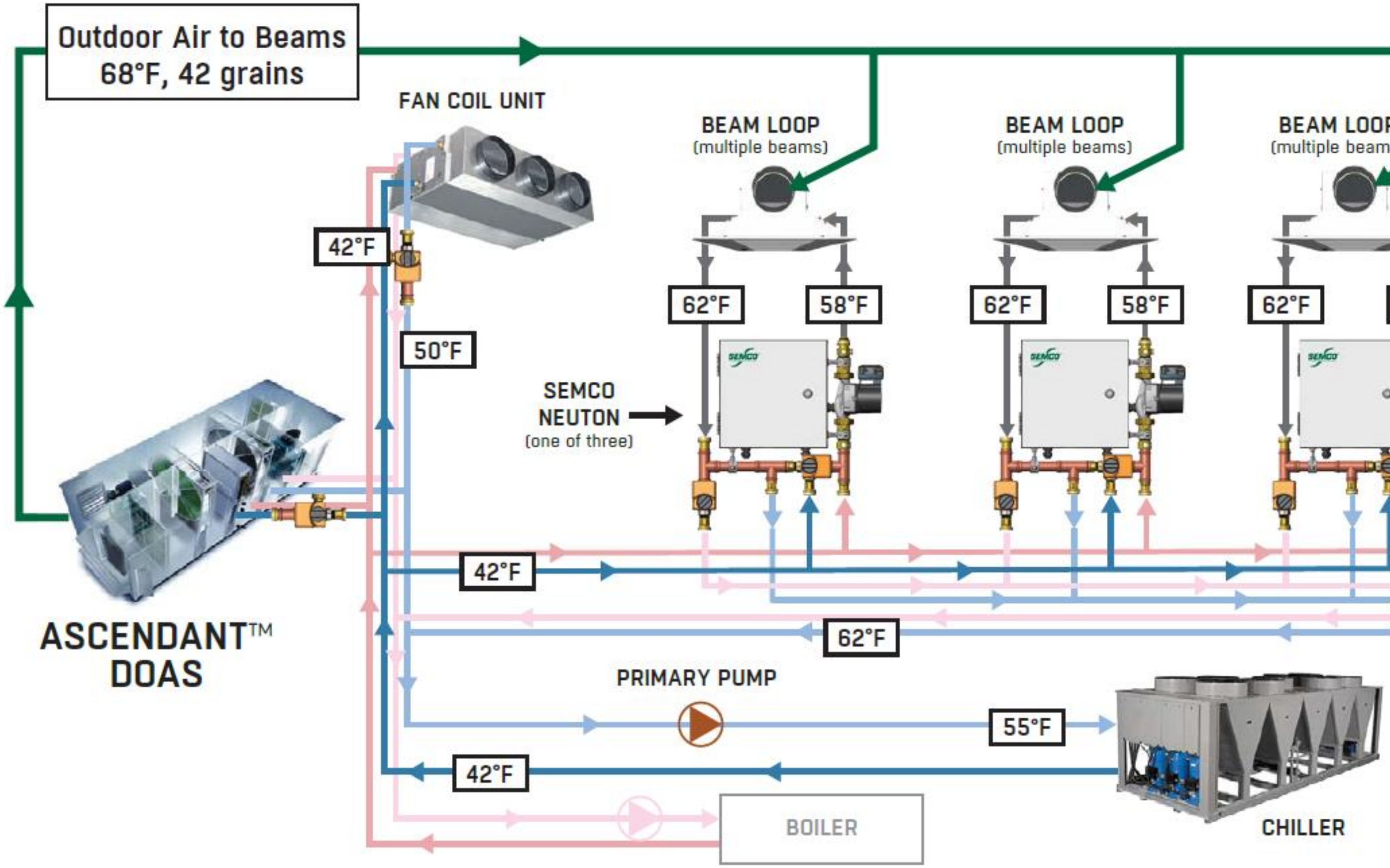
5. Chilled Water System Design



Chiller / Decouples DOAS

- Allows for smaller chiller servicing ACB loop
- Allows for high chiller efficiency of the ACB loop

5. Chilled Water System Design



Source: SEMCO® A Fläkt Woods Company. 5504ASCENDANT Health Care Brochure - SEMCO 2016-02

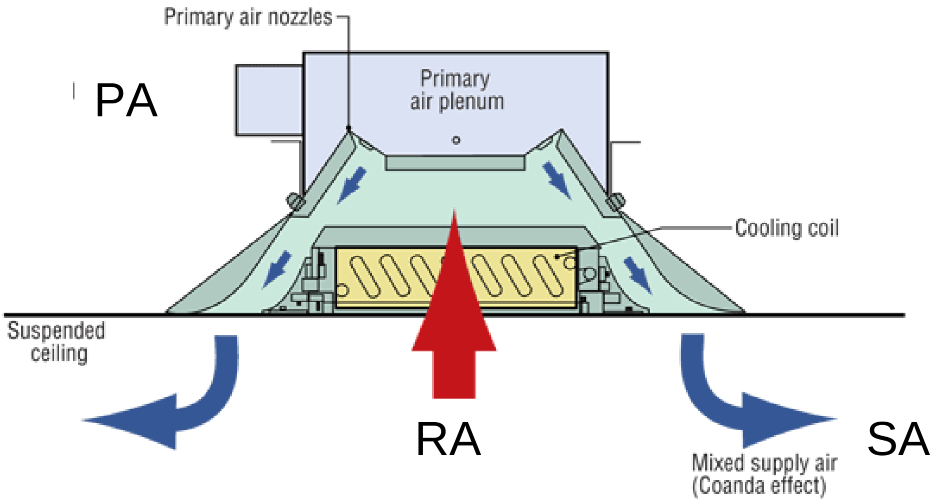
5. Chilled Water System Design

Primary airflow (PA) is based on largest of:

▷Minimum outdoor airflow required (ASHRAE 62.1)

▷Airflow required to offset space latent load (depends on dew point of PA)

▷Airflow needed to induce sufficient room air (RA) to offset the space sensible cooling load



5. System Design-Controls

Beam system controls typically include the following:

- ▷Zone control
- ▷Beam water temperature control
- ▷Primary air-conditioning control
- ▷Condensation prevention

5. System Design-Controls

Airside Control

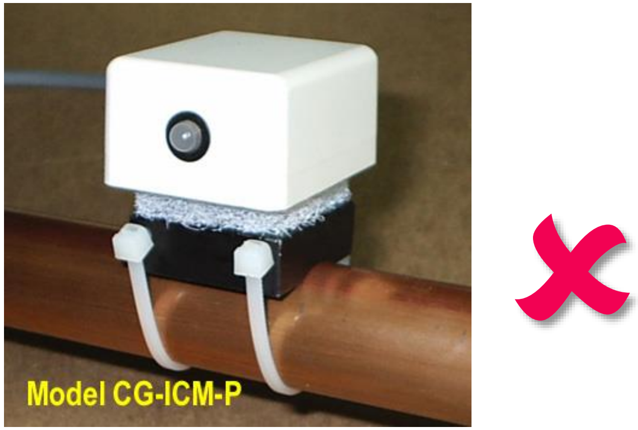
- Primary air
  - Use fully self-contained volume flow limiter (VFL)
  - VFL's are recommended when an AHU also supplies VAV terminals.
- Monitor space dew point
  - Use small quantity of high quality sensors
  - Do not use rel. humidity sensors
  - Locate sensors in room not in ceiling
- Reduce primary moisture content to control space rel. humidity
  - DOAS

5. System Design-Controls

Volume flow limiter (VFL)

5. System Design-Controls

Monitor space dew point

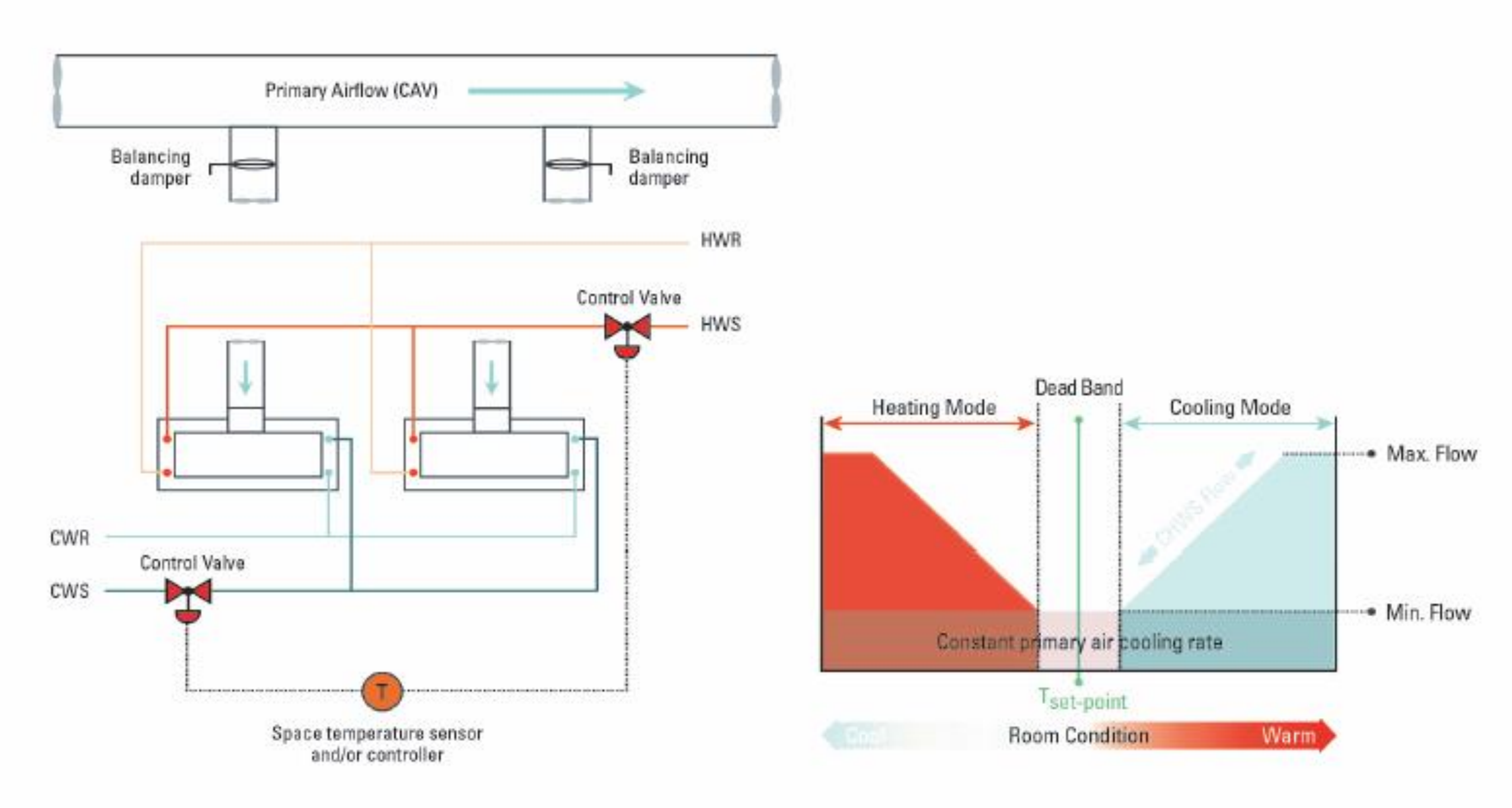


5. System Design-Controls

Waterside Control

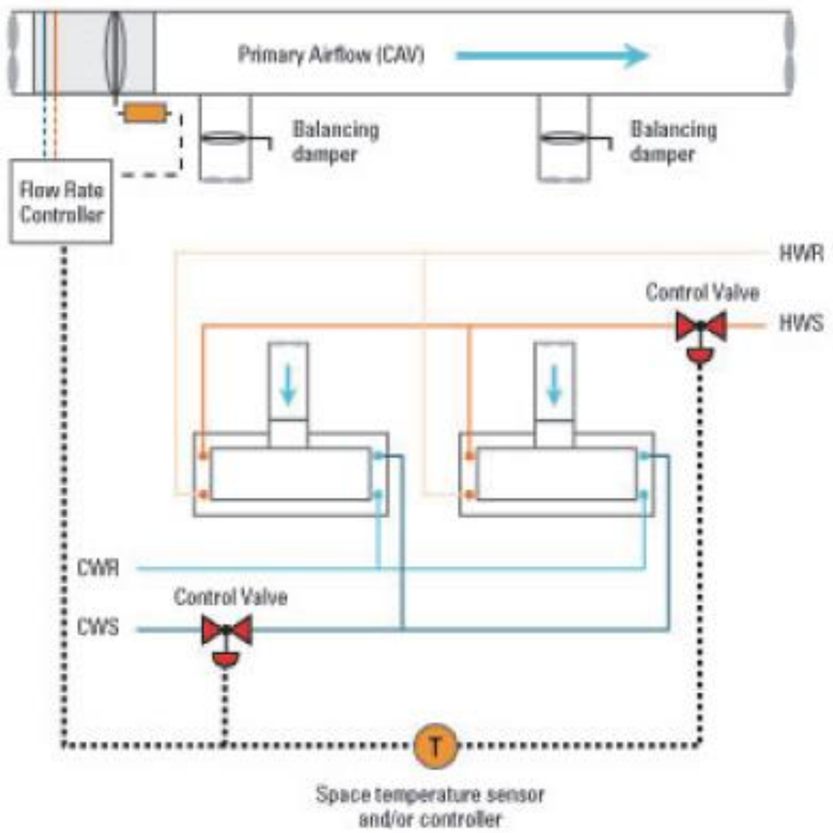
- Variable water flow
  - Pressure independent control
- Two position valves or modulating valves
- 6-way valves can be used on 4 pipe into 2 pipe chilled beams
- Reschedule or shut off chilled beam water supply only if primary moisture content cannot reduced

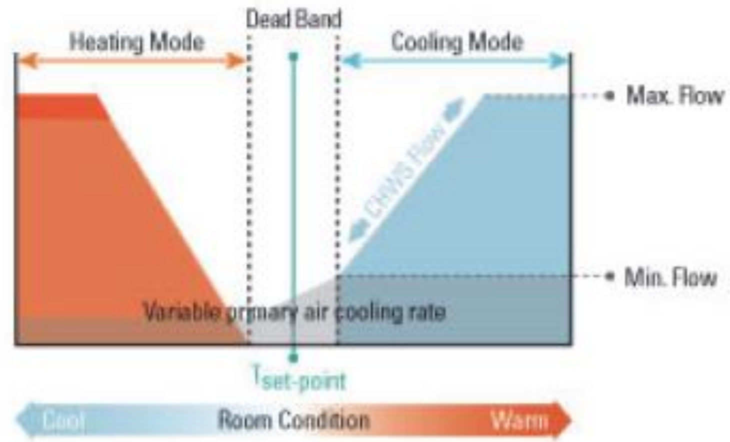
5. System Design-Controls



Beam zone temperature control using constant-volume primary airflow.

5. System Design-Controls

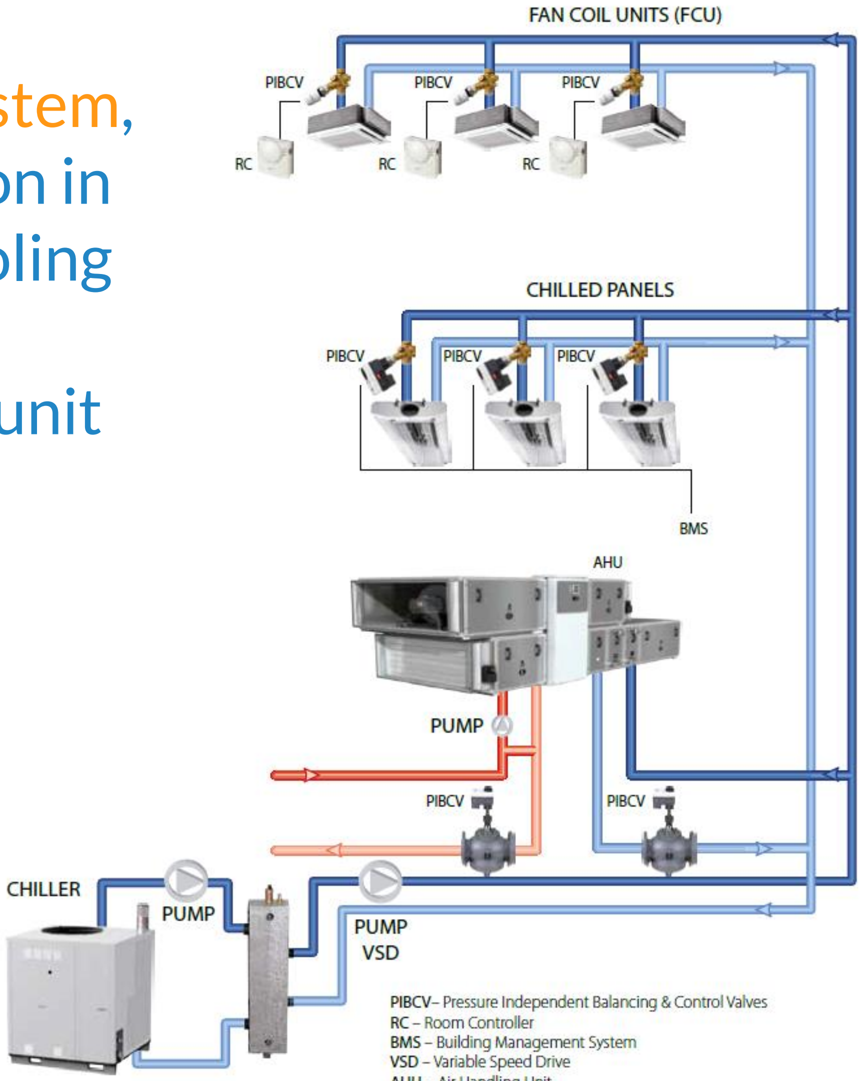




Beam zone temperature control using variable volume primary airflow.

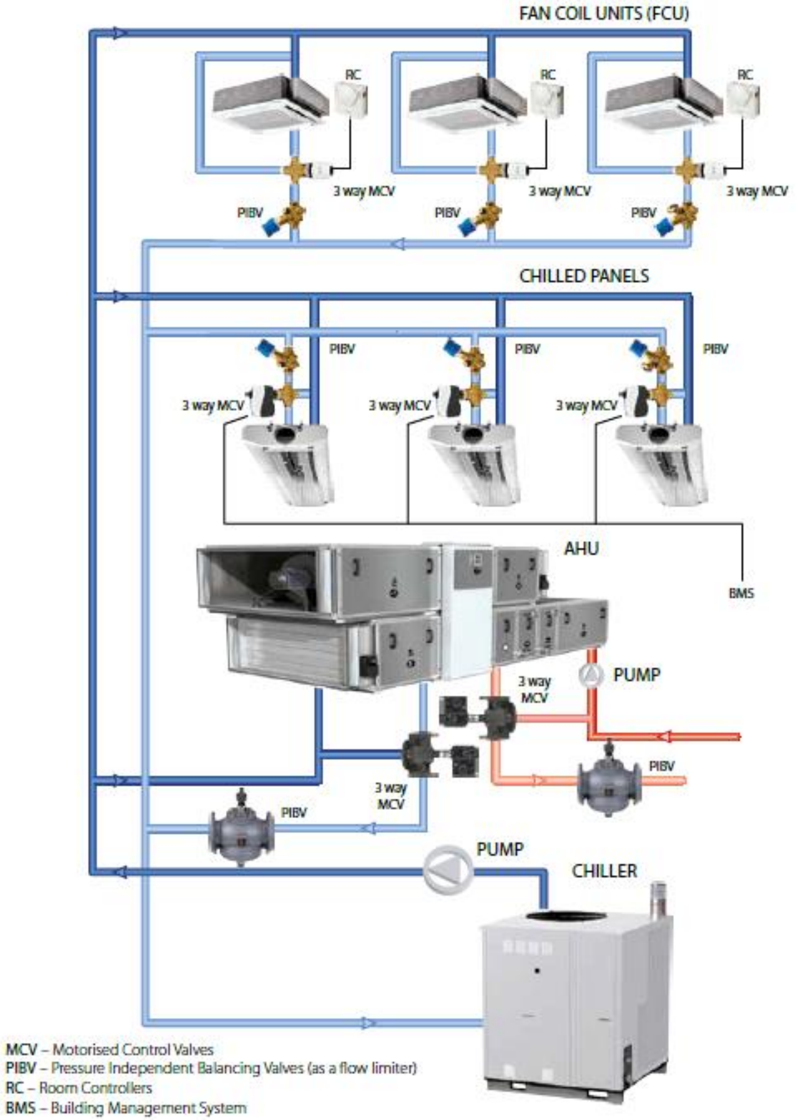
5. System Design-Controls

Variable flow system, typical application in FCU heating-cooling systems and any kind of terminal unit (e.g. AHU)

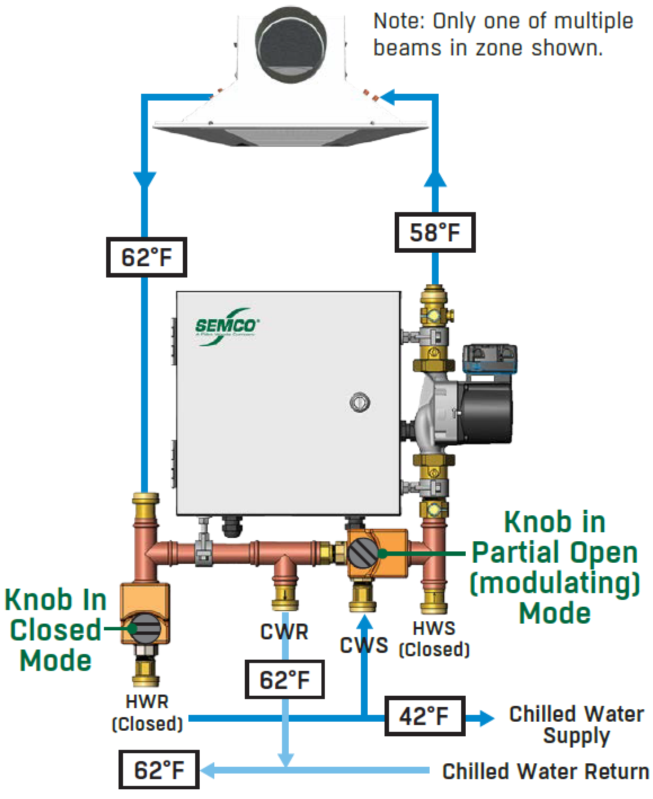


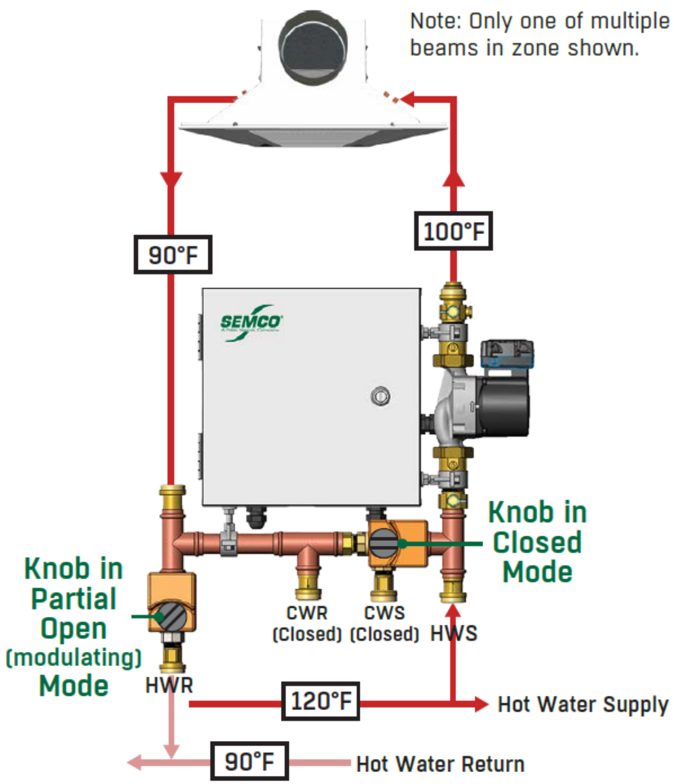
5. System Design-Controls

Constant flow system, typical application in FCU heating-cooling systems and in AHU



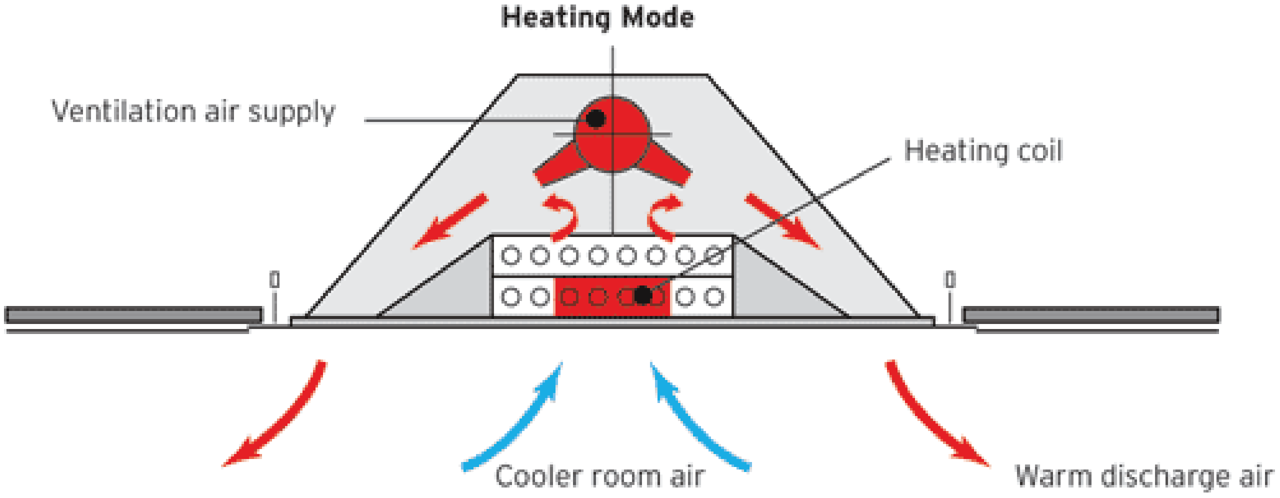
5. System Design-Controls





5. System Design-Controls

Heating with active chilled beams



5. System Design-Controls

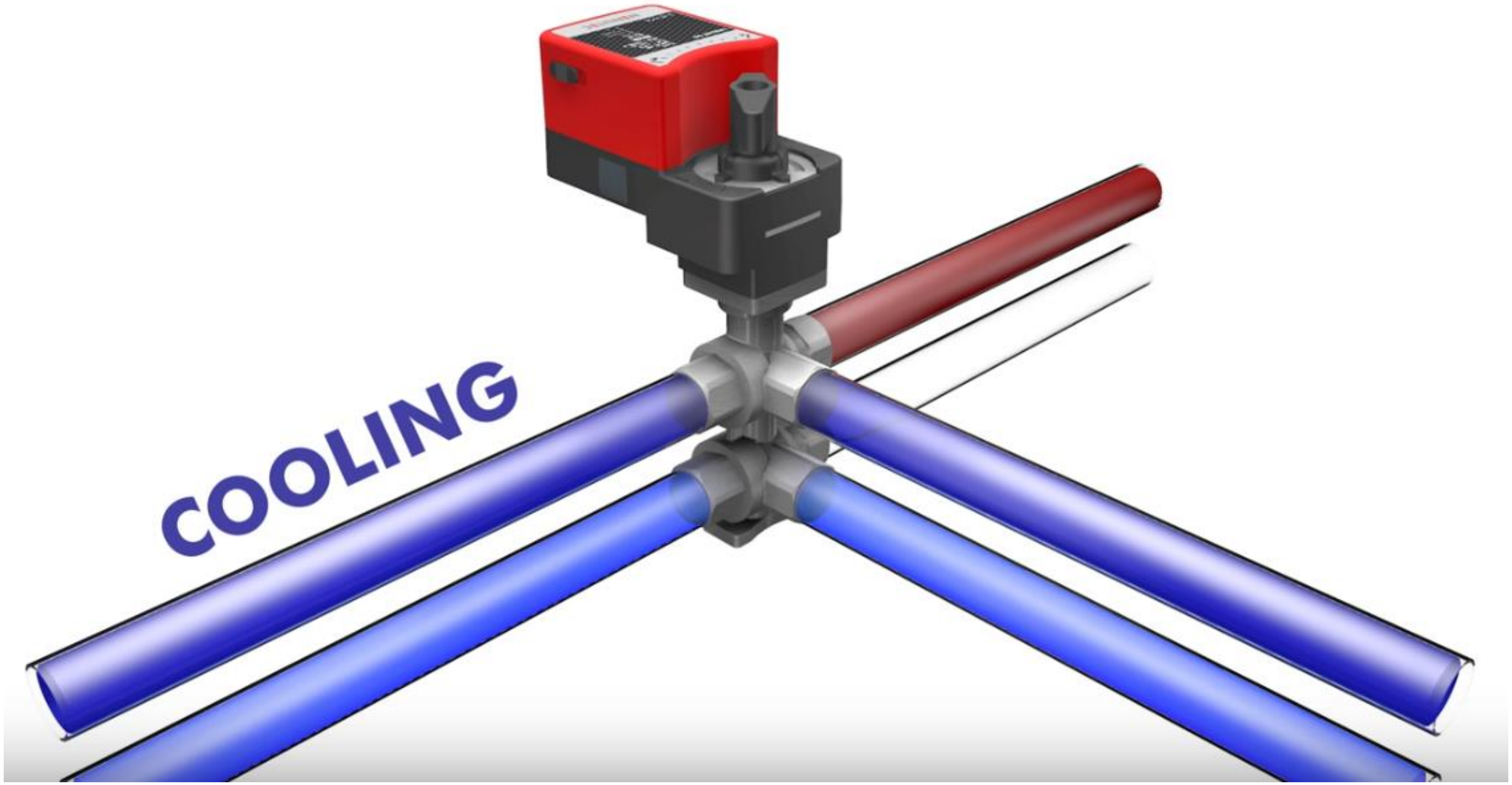
Heating with active chilled beams

- Active CB available in 2-pipe or 4-pipe configuration
- Application limited by output capacity:
  - Zones < 300 Btu/h/ft^2 ✓
  - Zones 300 – 400 Btu/h/ft^2 ✓
    Air discharge towards window at 75fpm
  - Zones > 400 Btu/h/ft^2 ✗

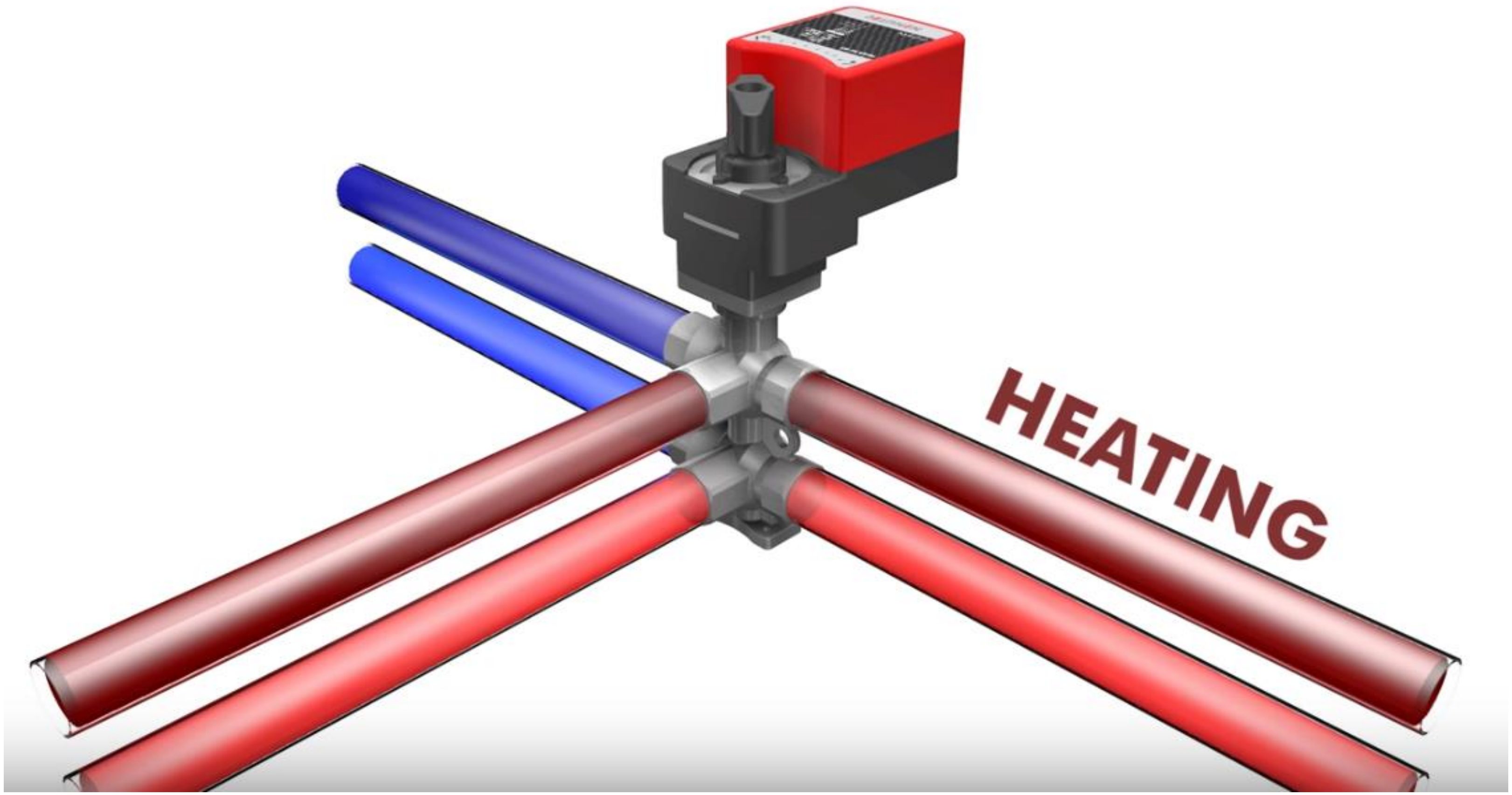
5. System Design-Controls

- 6-way ball valve is a combination valve for connecting heating and cooling 4 pipe system into a single coil

5. System Design-Controls



5. System Design-Controls



6. PASSIVE BEAM SELECTION

6. Passive Beam Selection

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

6. Passive Beam Selection

General Application Parameters

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	$\leq$ 500 Btu/h ft_{CB}
Ventilation Requirement	0.1 to 0.5 cfm/ft^2 floor area

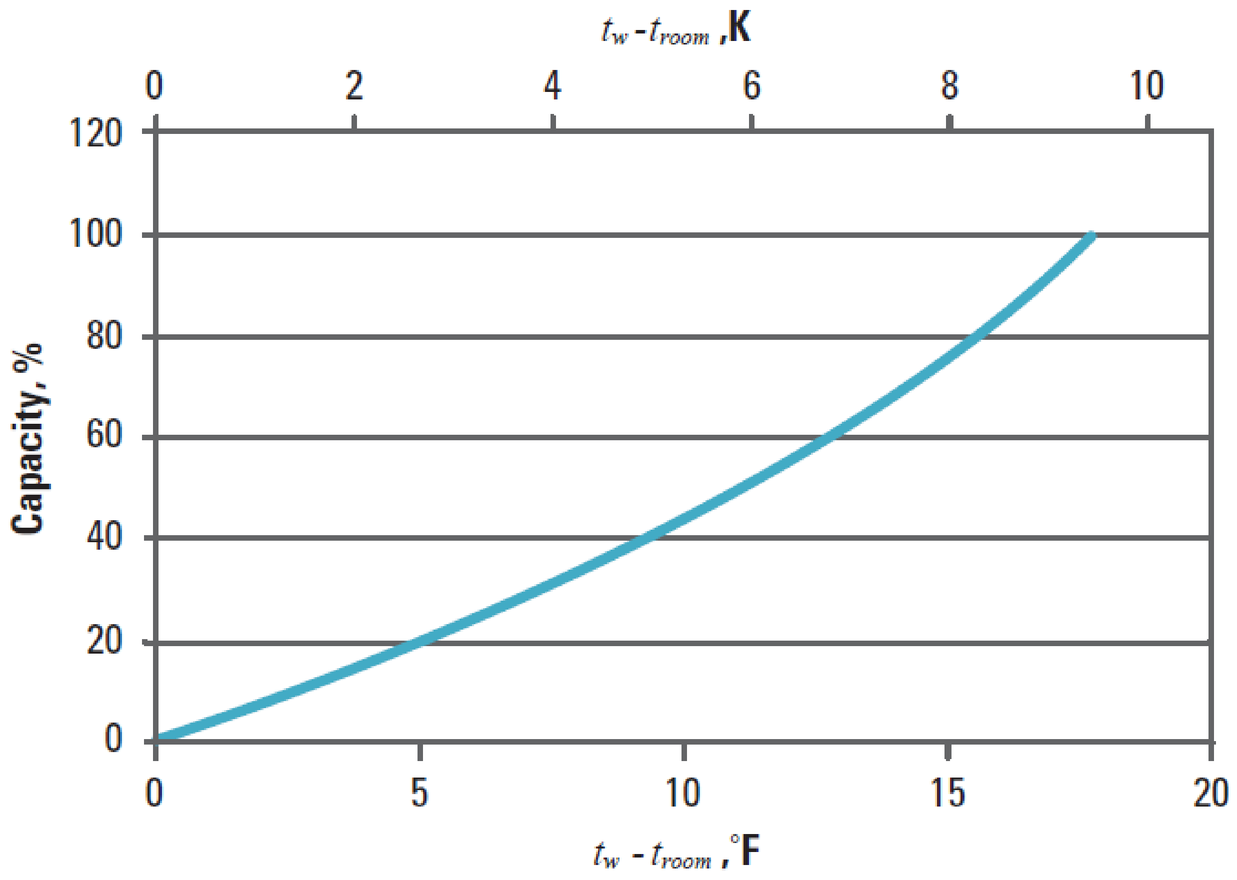
6. Passive Beam Selection

The difference between the mean water temperature, $\overline{t_w}$, defined as:

$$\overline{t_w} = \frac{t_{supply} + t_{return}}{2}$$

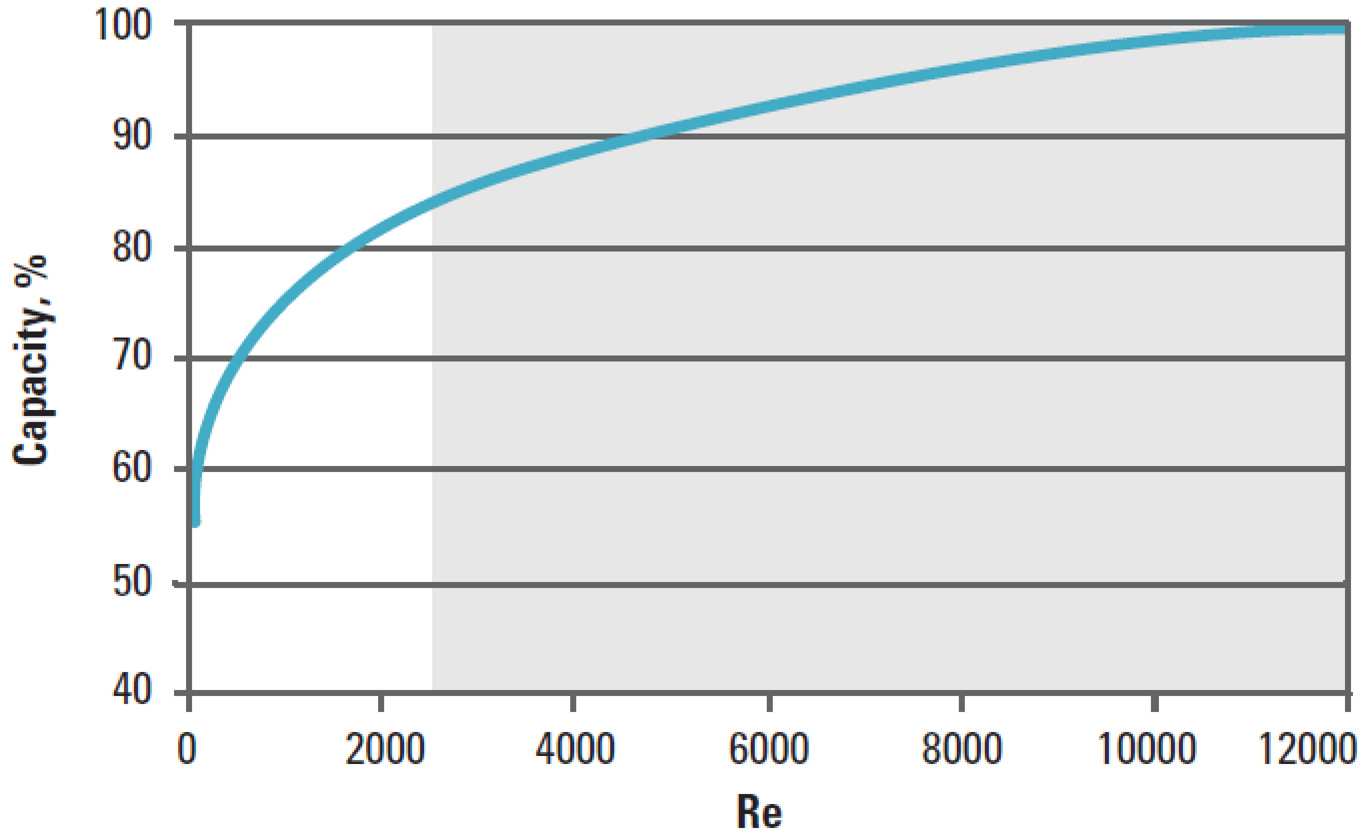
and the surrounding (coil inlet) air temperature is one of the primary drivers of the beam performance

6. Passive Beam Selection



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

6. Passive Beam Selection



Passive beam capacity vs. water flow

6. Passive Beam Selection

$$Re = \frac{u\ d_h}{v}$$

where

Re = Reynolds Number (non dimensional)

u = velocity (ft/s)

d_h = hydraulic diameter (ft)

ν = kinematic viscosity (ft^2/s)

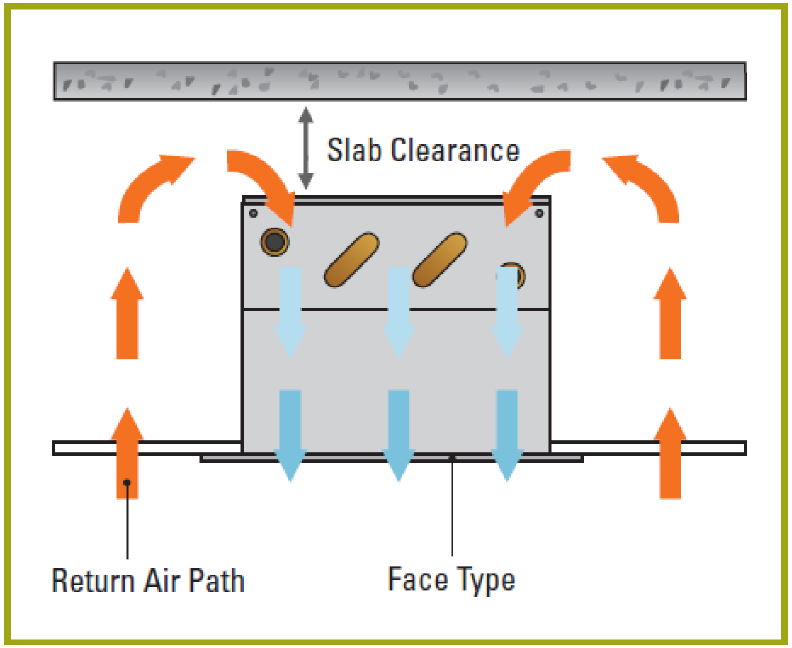
Below are two links to online Reynolds Number Calculators.

Reynolds Number Calculator

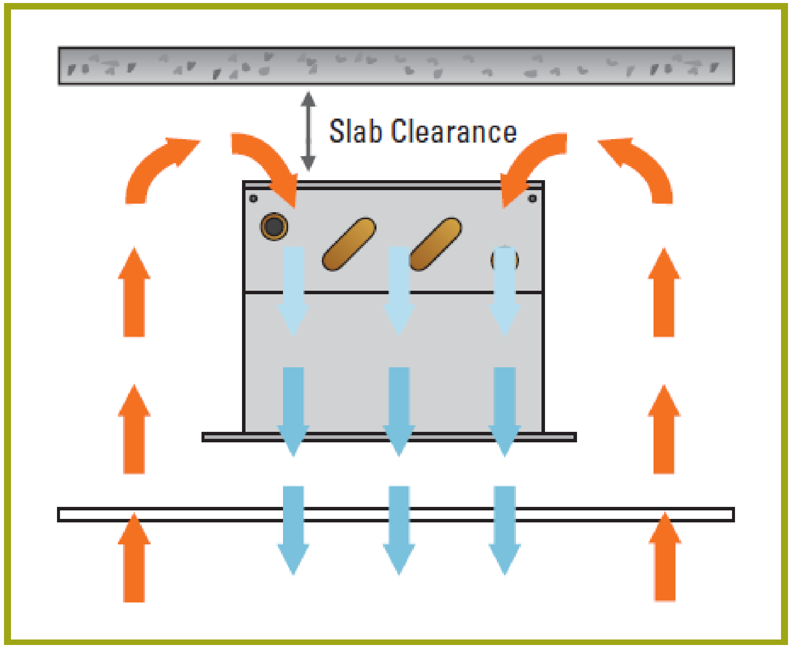
Reynolds Number Calculator

Temperature (°F)	Kinematic Viscosity - ν - (10^{-5} ft^2/s)
32	1.924
40	1.664
50	1.407
60	1.210
70	1.052
80	0.926
90	0.823
100	0.738
120	0.607
140	0.511
160	0.439
180	0.383
200	0.339
212	0.317

6. Passive Beam Selection

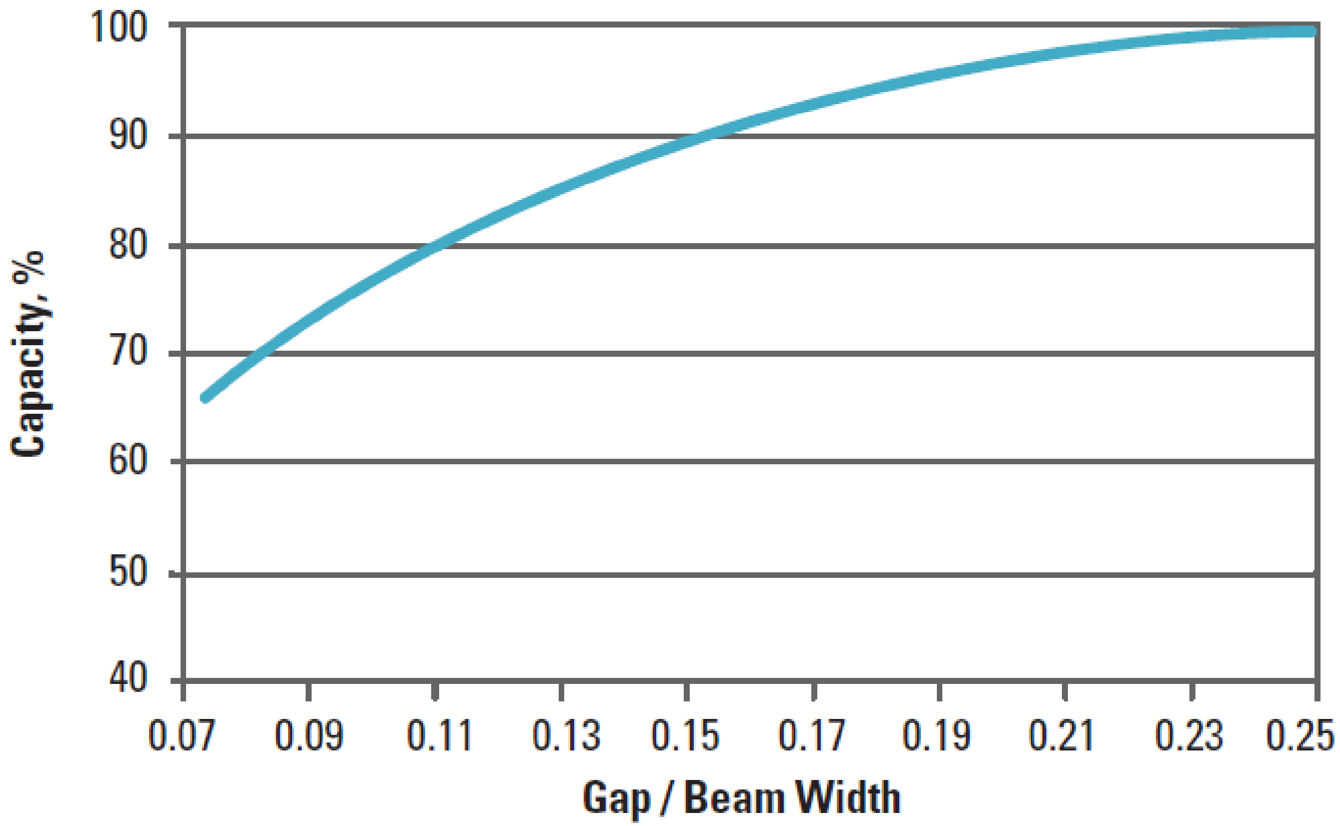


Factors that affect performance of passive beams



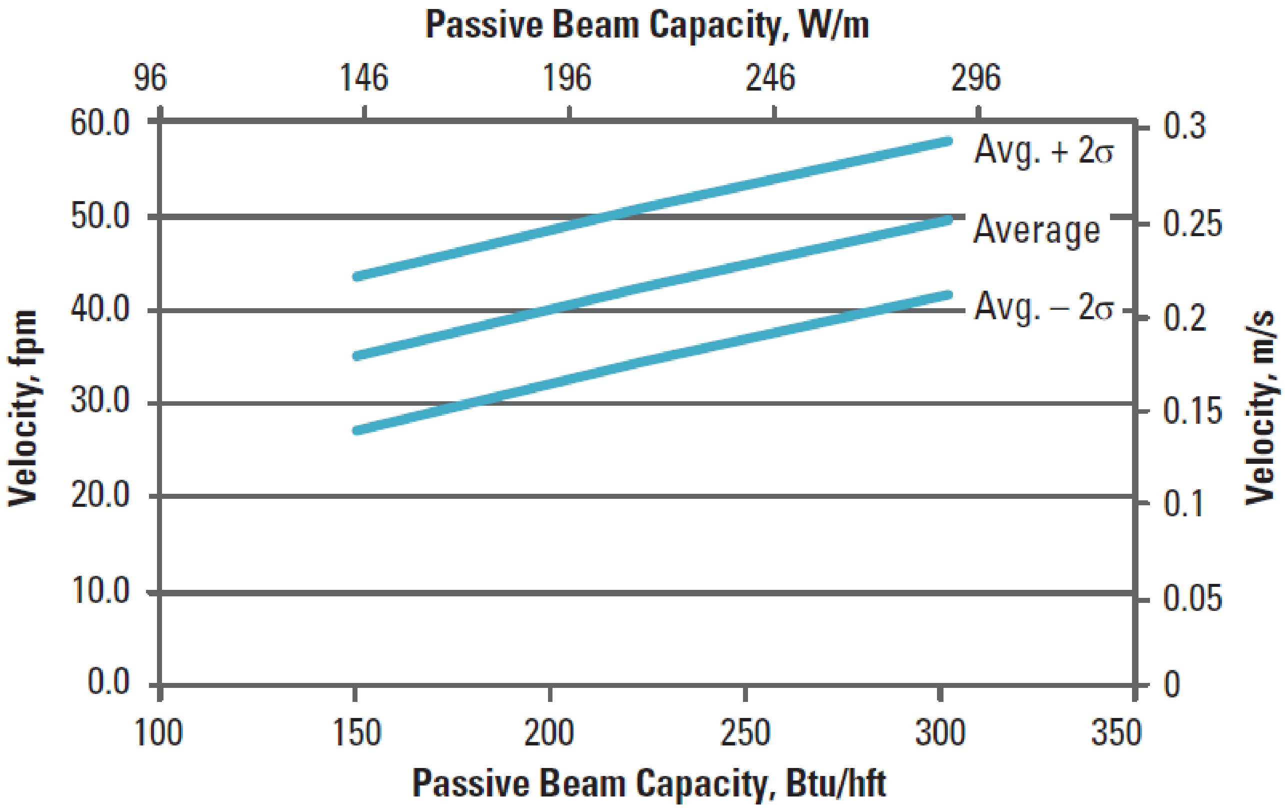
A passive beam installed above a perforated ceiling

6. Passive Beam Selection



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

6. Passive Beam Selection



Expected velocities below an 18 in. wide passive beam

7. ACTIVE BEAM SELECTION

7. Active Beam Selection

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

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

7. Active Beam Selection

General Application Parameters

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	≤ 1,000 Btu/h ft_{CB}
Water Temperature	Heating 110 °F to 130 °F EWT, 10 °F to 20 °F ΔT
Heating Capacity	≤ 1,500 Btu/h ftCB
Ventilation Requirement	0.1 to 0.5 cfm/ft^2 floor area
Ventilation Capability	5 to 30 cfm/ft
Primary Air Supply Temp.	50 °F to 65 °F
Inlet Static Pressure	0.2 in. w.g. to 1.0 in. w.g. external

7. Active Beam Selection

Transfer efficiency = measure for the overall performance of an active beam

This is the ratio of total heat transferred by the coil per unit volume of primary air:

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

- ▷The higher the efficiency, the higher the energy savings
- ▷The transfer efficiency is largely dependent on the airside load fraction and the sensible heat ratio.

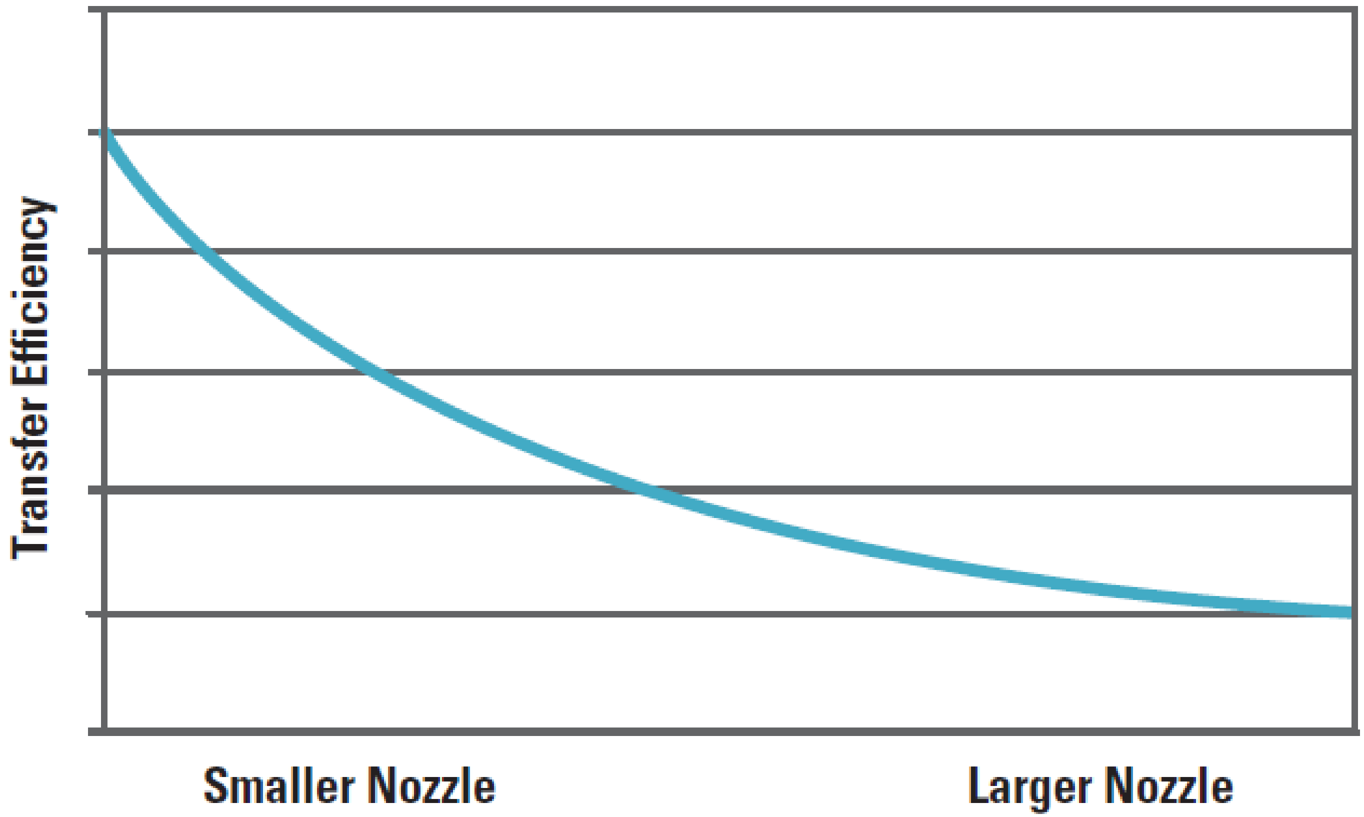
7. Active Beam Selection

- 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:

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

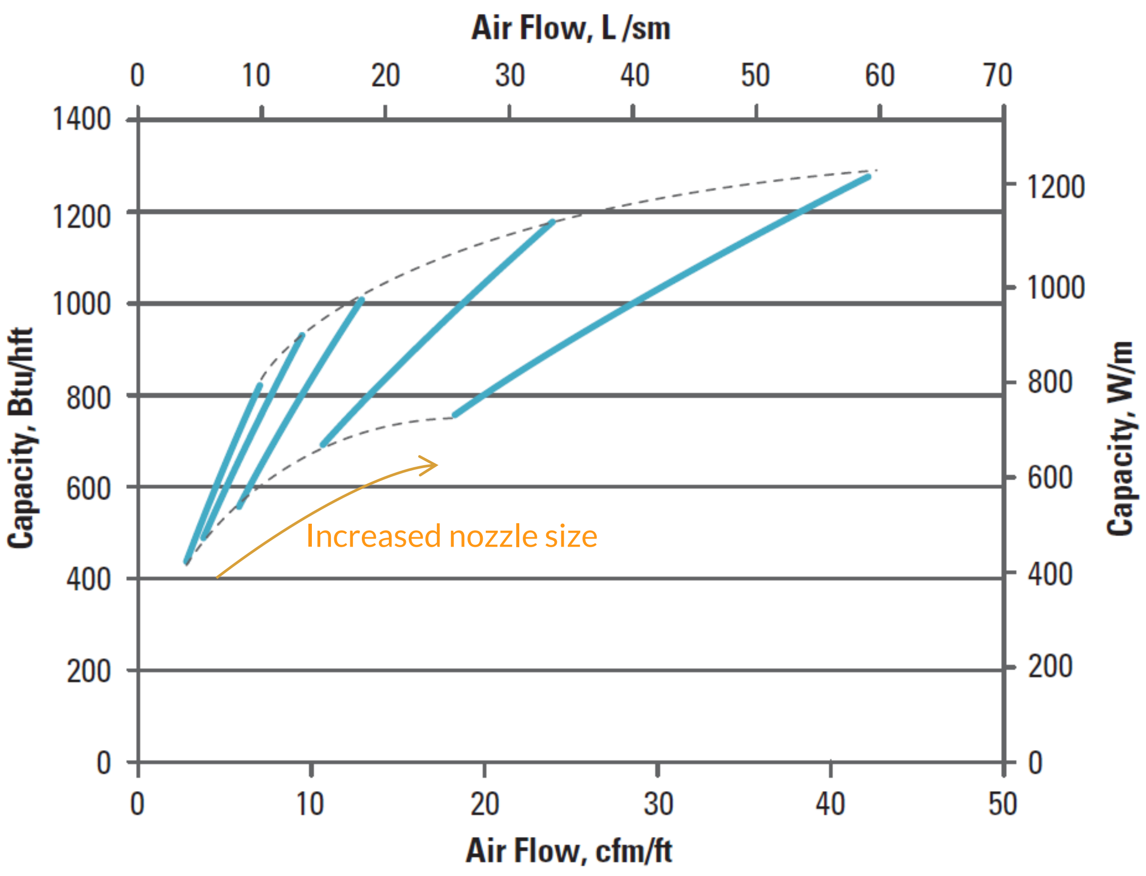
- Smaller nozzles result in higher plenum pressures for a fixed primary air flow rate.
- Larger nozzles will have a lower induction ratio but allow more primary air to be supplied, though at a lower transfer efficiency

7. Active Beam Selection



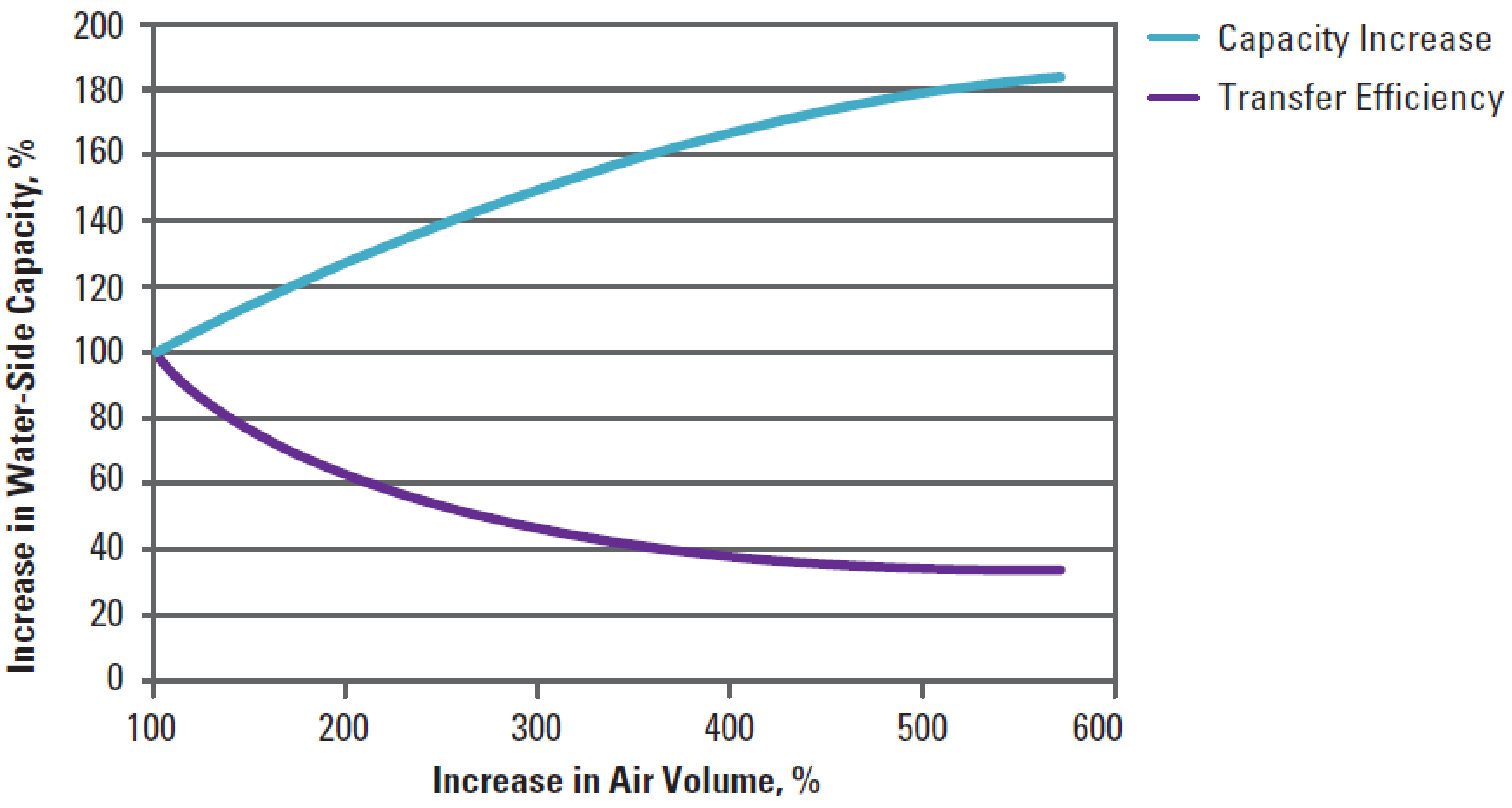
Transfer efficiency is reduced by increasing nozzle size

7. Active Beam Selection



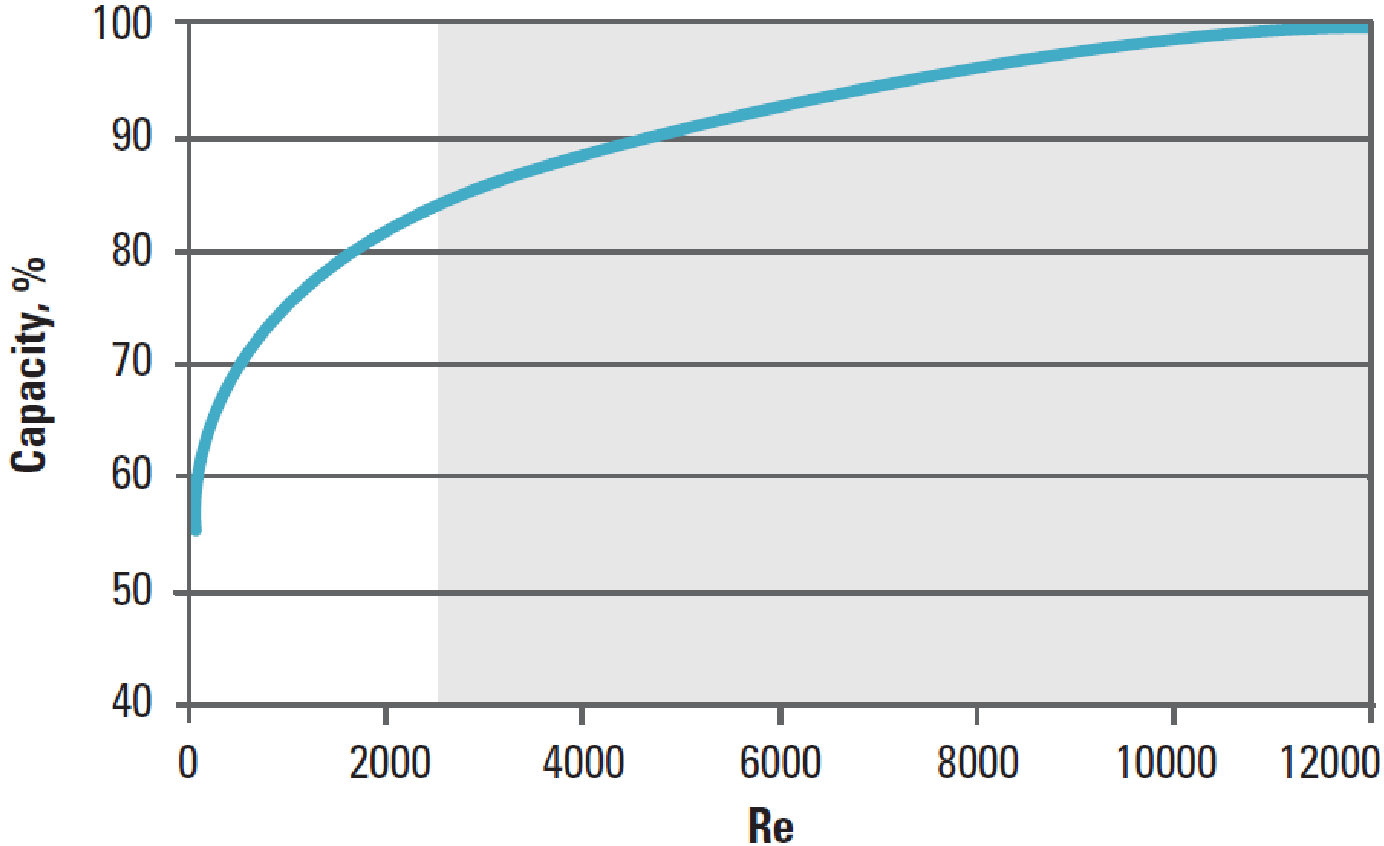
Capacity of a typical active beam vs. primary air flow

7. Active Beam Selection



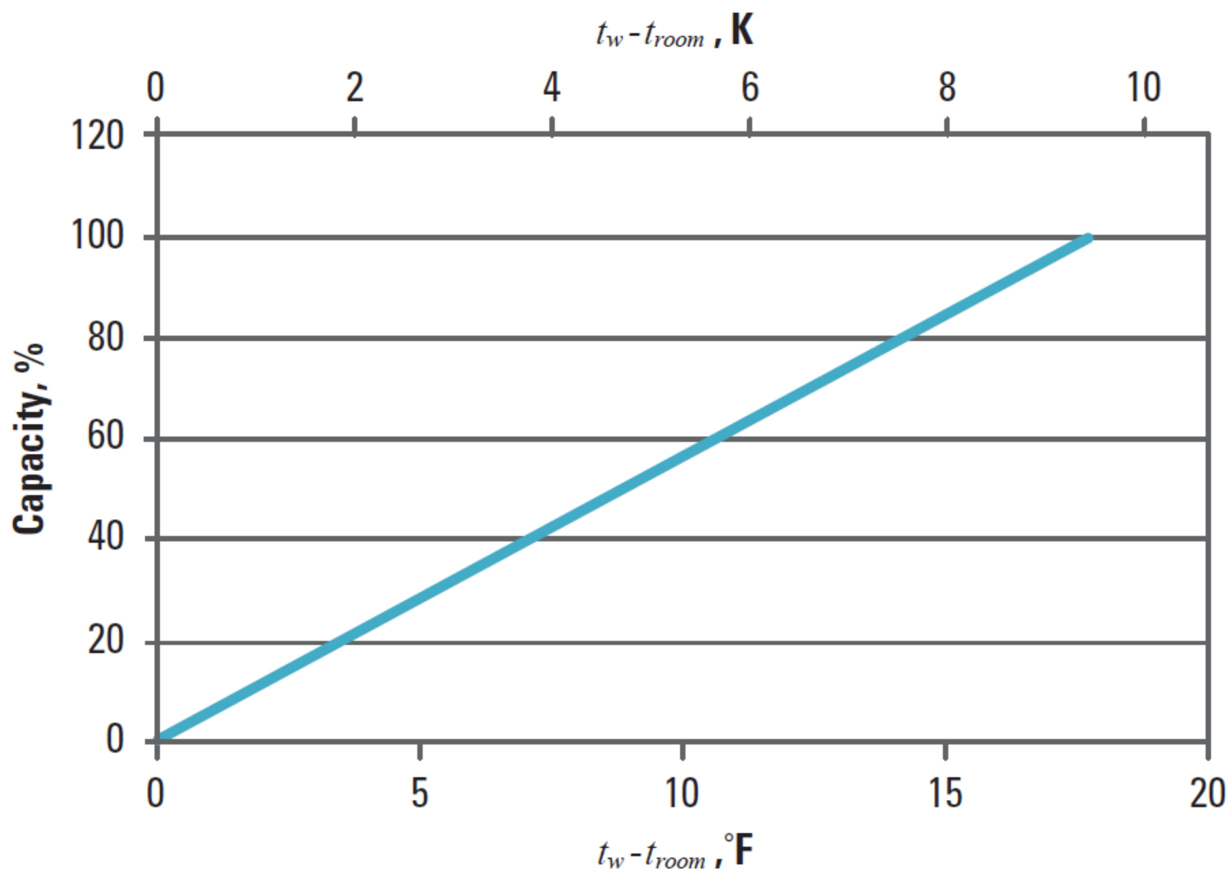
Capacity vs. air volume

7. Active Beam Selection



Active beam capacity vs. water flow

7. Active Beam Selection



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

8. COMMISSIONING

8. Commissioning

Initial steps should ensure that

▷the coil is free of dust and debris by visual inspection

▷the beam is free of all transportation packaging.

▷the primary air supply rate and temperature is within tolerance.

▷the supply water flow rate(s) and temperature(s) are within tolerance

8. Commissioning

Control Components

Testing of the typical sensors associated with the beam as appropriate:

- ▷ Breathing on dew-point or humidity sensors.

  This local increase of humidity from breath should be sufficient to develop moisture on the device.
- ▷ Dripping water on condensation sensors
- ▷ Opening the window to trip the contact

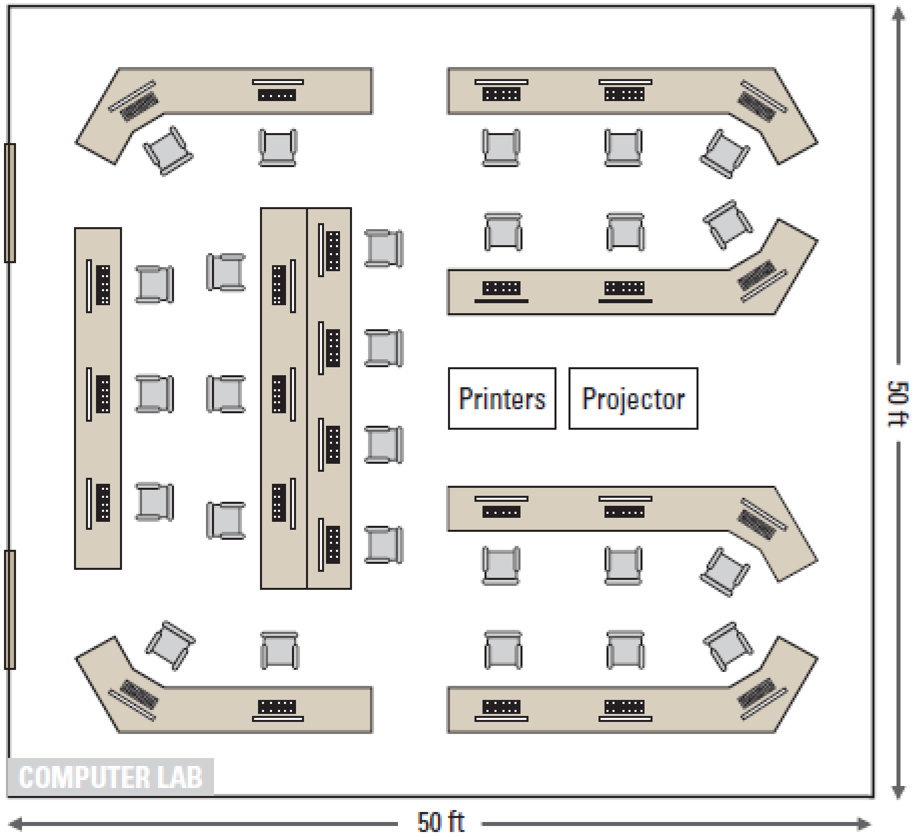
9. EXAMPLE

Active Beams in a Computer Lab

9. Example - Active Beams in a Computer Lab

- This space is a school computer lab designed for 26 occupants, 26 computers with one LCD monitor each, a projector, three printers, and T8 florescent lighting
- Temperature set-point is 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.

9. Example - Active Beams in a Computer Lab



Assumptions

▷Infiltration is minimal, and is neglected for the purposes of this example.

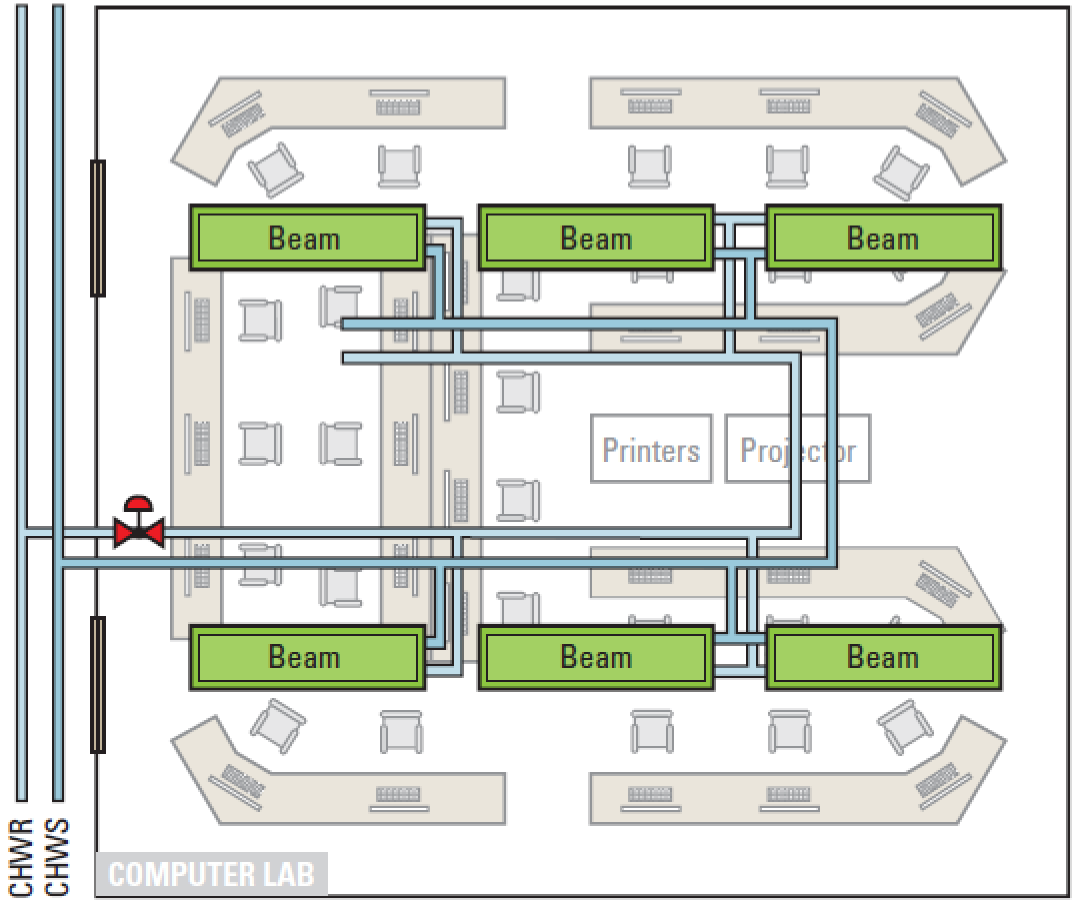
▷The specific heat and density of the air for this example will be 0.24 Btu/lb°F and 0.075 lb/ft2 respectively.

▷The air handling system utilizes energy recovery to provide 65 °F at 50 °F dew point.

9. Example - Active Beams in a Computer Lab

Selected Active CB Specifications		Required System Performance
Total Capacity	**33044 Btu/h**	32902 Btu/h
Quantity	6	
Length	96 in.	
Width	24 in.	
Airflow	780 cfm	632 cfm
Throw	17 ft.	Supply Air Temperature : 65 °F
Air Pressure Drop	0.76 in.	
Transfer Efficiency	42.4 Btu/h cfm	
Water Flow Rate	6.48 gpm	
Water Pressure Drop	4.6 ft hd	
NC	30	

9. Example - Active Beams in a Computer Lab



Thanks!
Any questions?

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Next

ANSI/ASHRAE Standard 200-2015, Methods of Testing Chilled Beams