ASHRAE Chapter Meeting

An Introduction to Chilled Beam Technology

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Active Chilled Beams

Typical Installation

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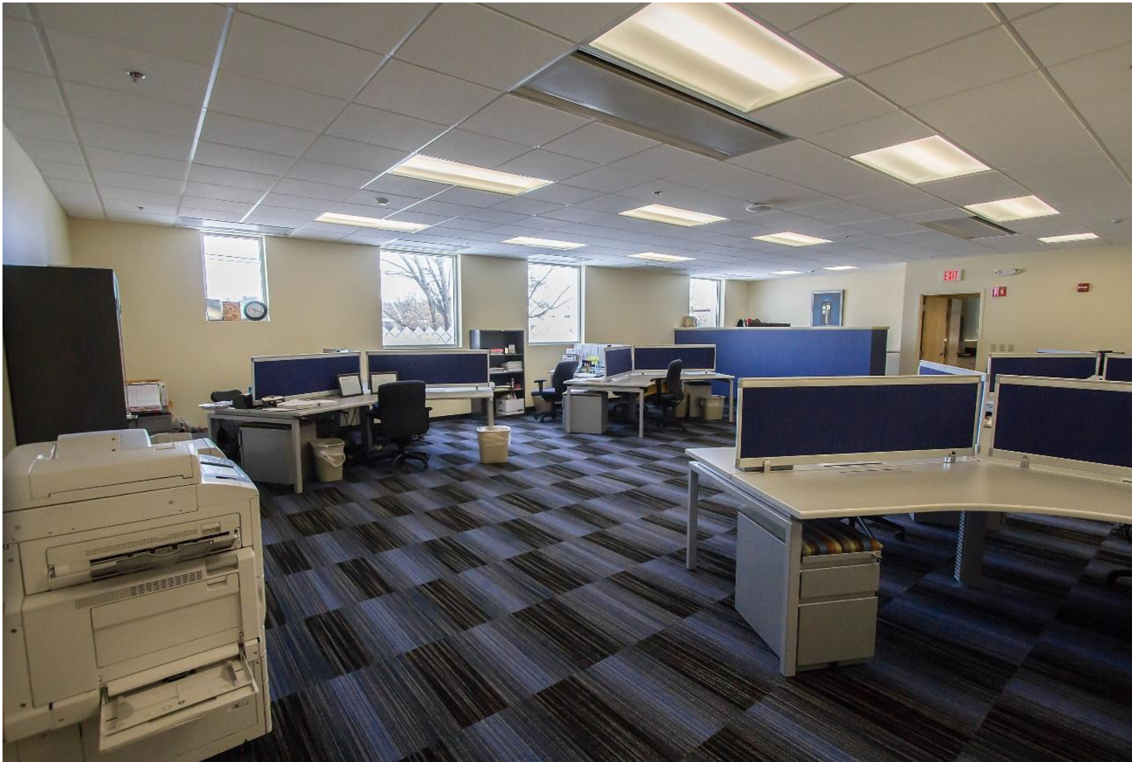
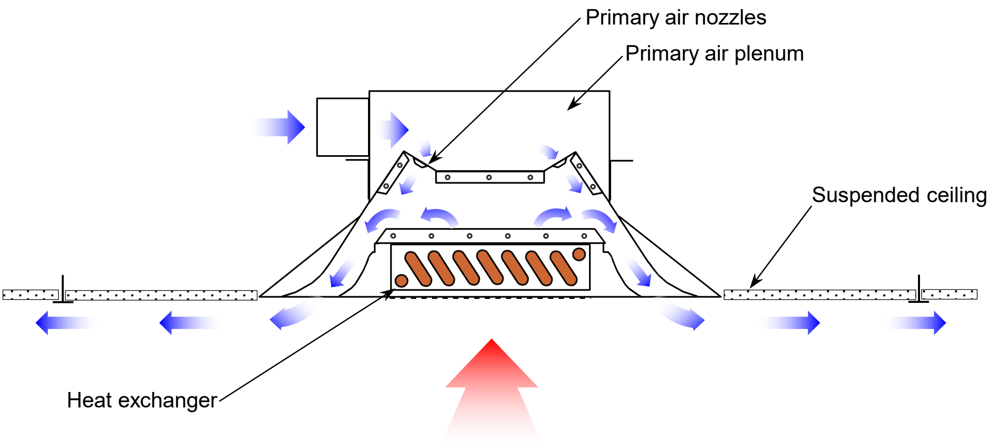


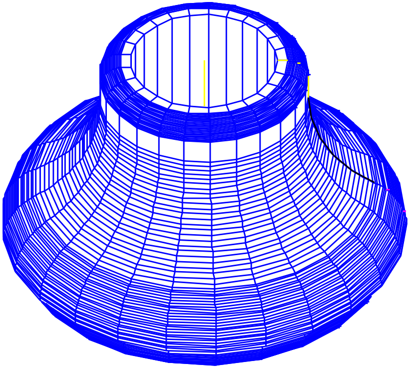
Active Chilled Beams
Typical Installation

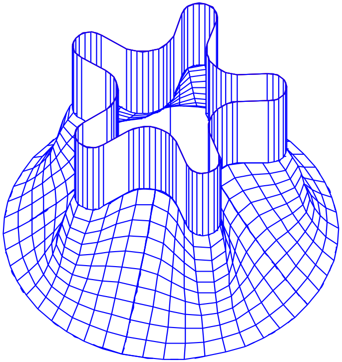
Active Chilled Beam

Operation Principle

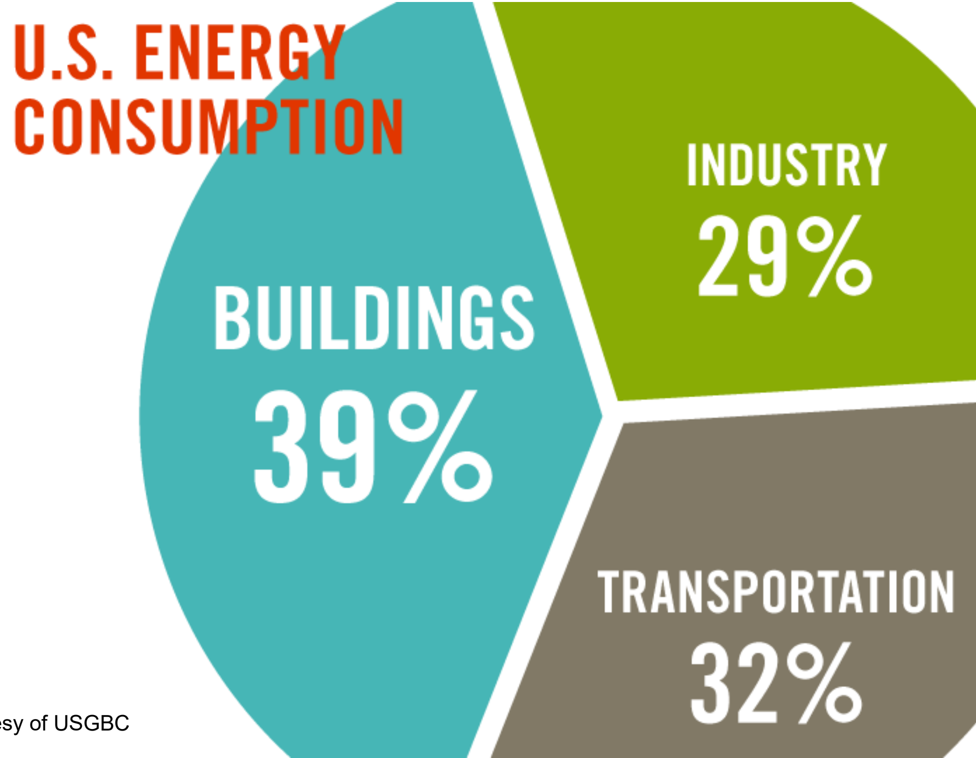


Nozzles



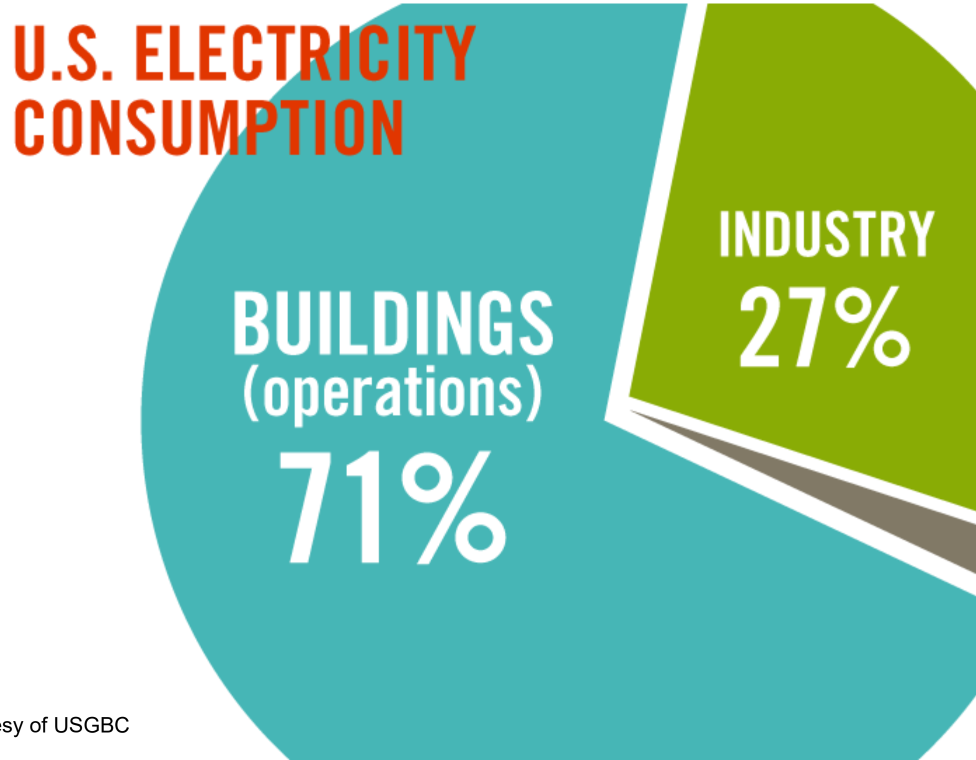


U.S. Energy Consumption



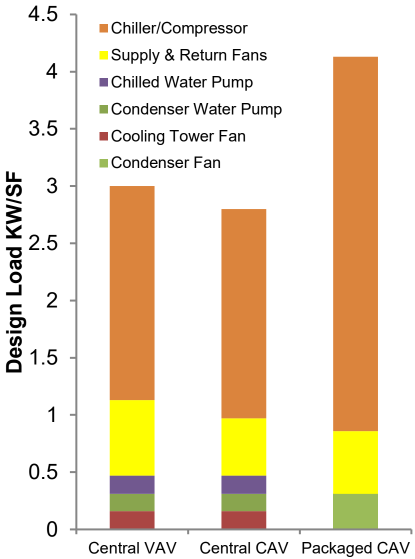
Courtesy of USGBC

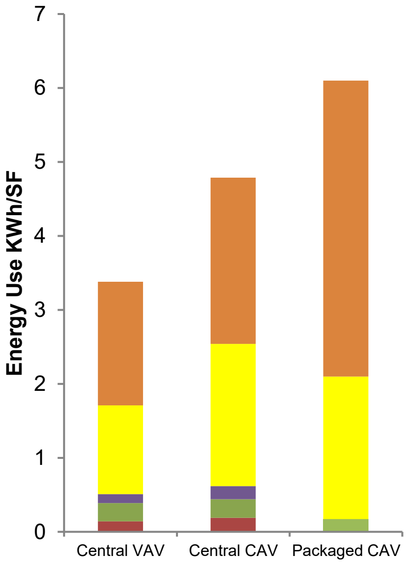
U.S. Energy Consumption



Courtesy of USGBC

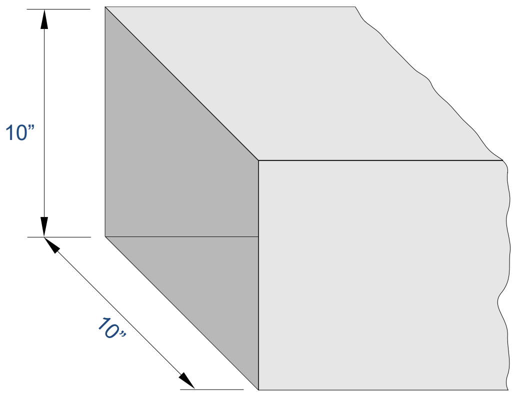
Fan Energy Use in Buildings





"Energy Consumption Characteristics of Commercial Building HVAC Systems" - publication prepared for U.S. Department of Energy

Water = Efficient Transport



1 Ton of Cooling

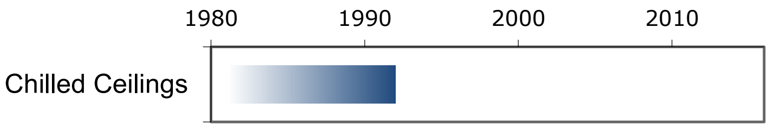
requires 550 CFM of air

or

4 GPM of water

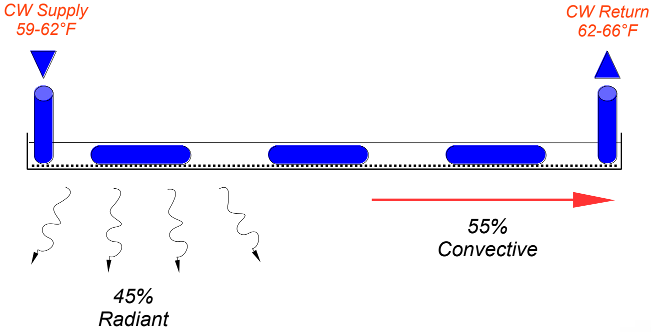
¾” diameter
water pipe

Chilled Ceilings



- Many buildings were heating only
- PC's appearing on desks
- Restricted ceiling cavity

Chilled Ceilings Radiant Effect



Chilled Ceilings

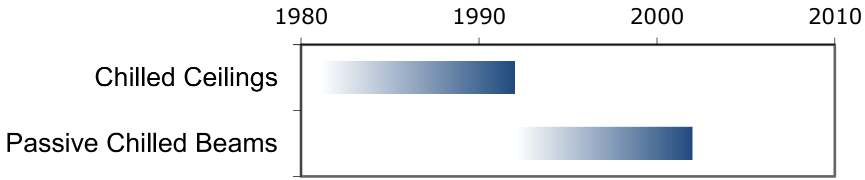
Advantages

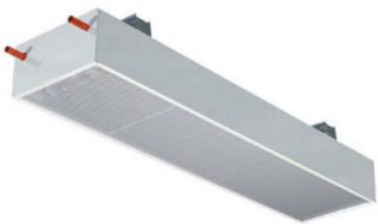
- Excellent thermal comfort
- Reduced space requirements
  - Will fit into 6-8” cavity
- Self regulating
  - Simple controls
- Low noise
- Low maintenance

Design Issues

- Low cooling output
  - 20 to 25 $BTUH/FT^2$ 100% coverage
  - 14 to 18 $BTUH/FT^2$ 70% coverage
- High cost
- Separate air system required

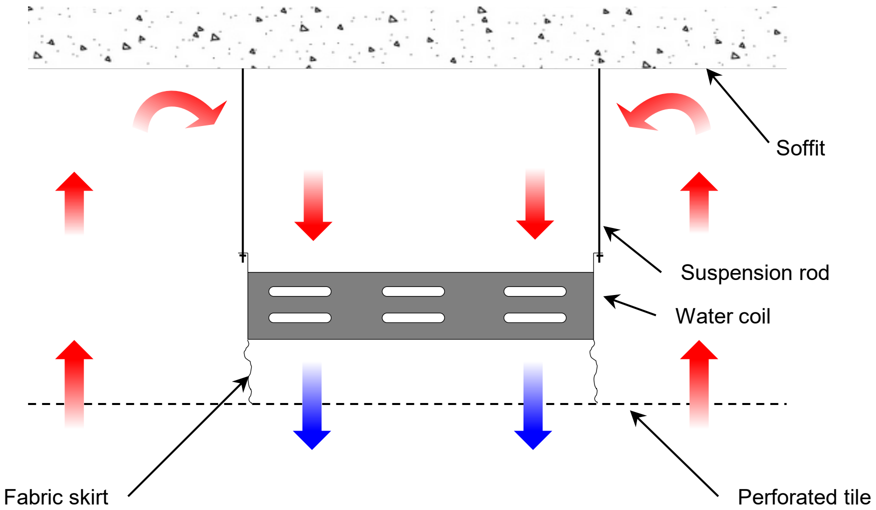
Passive Chilled Beams



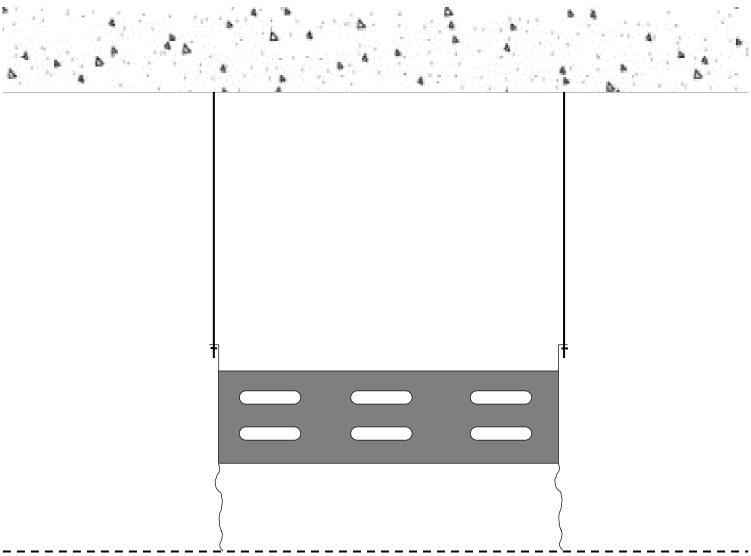


- Increased cooling loads
  - Equipment
  - Occupancy
  - Day-lighting
- Inadequate perimeter cooling

Passive Chilled Beams
Operation Principle

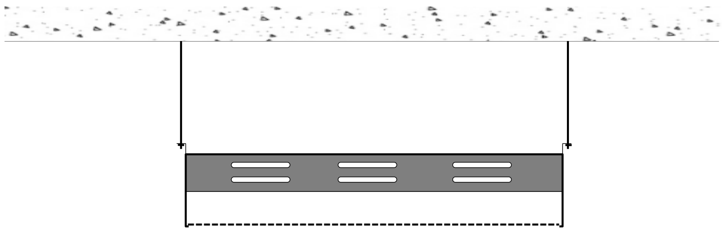


Recessed Passive Beam



- Generally 4' – 10' in length
- Cooling capacity
  - Up to 500 BTUH per linear foot

Exposed Passive Beam



- Generally 4'-10' in length
- Cooling capacity
  - Up to 500 BTUH per linear foot

Passive Chilled Beams
Benefits

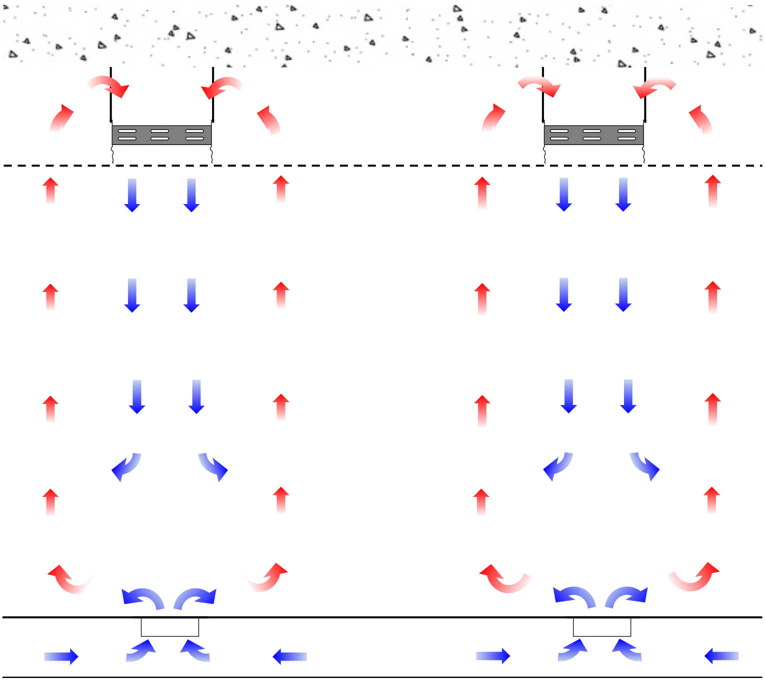
- Good thermal comfort
- Up to 500 BTUH per LF of beam
- Reduced ductwork, riser and plant sizes
  - Water transports most of sensible cooling
- Self regulating
  - simple two position controls
- Low noise
- Low maintenance

Passive Chilled Beams
Design Considerations

- Sensible cooling only
  - Latent gains must be controlled by air system
- High free area perforated metal ceiling required
  - 28% free area minimum
  - Exposed beams (no ceiling) are an option
- Beams cannot be installed tight against slab
  - Typically 40% of beam width required above beam
- Separate heating system must be installed

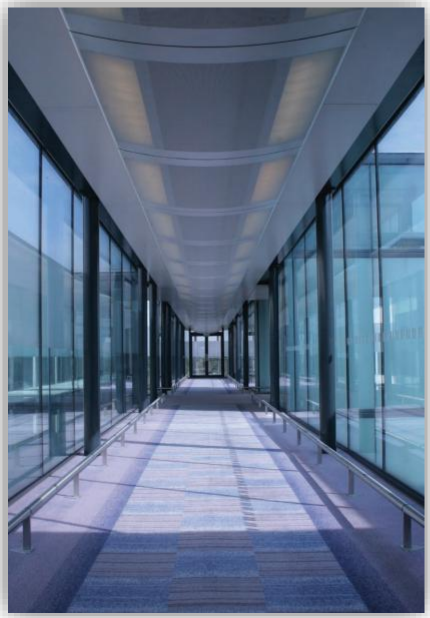
Passive Chilled Beams

Airflow Pattern



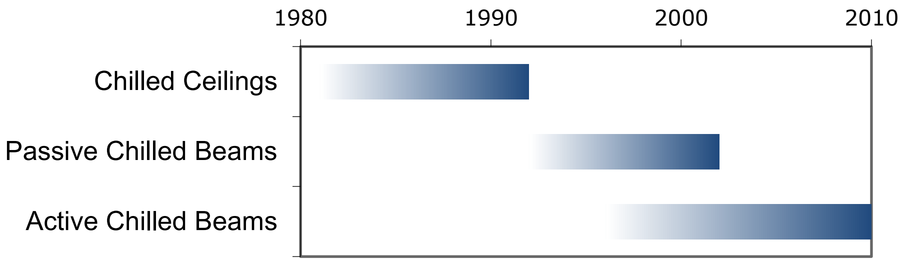
Passive Chilled Beams
Variants

Recessed Passive Beams



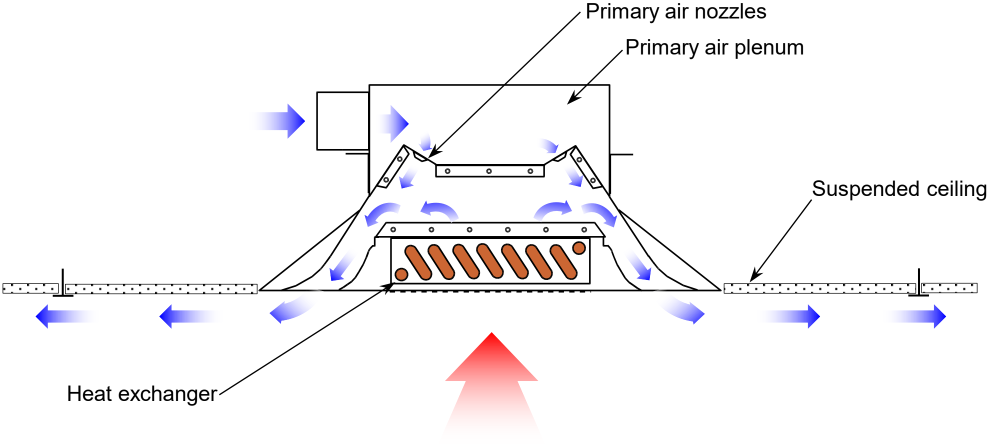
Exposed Passive Beams

Active Chilled Beams



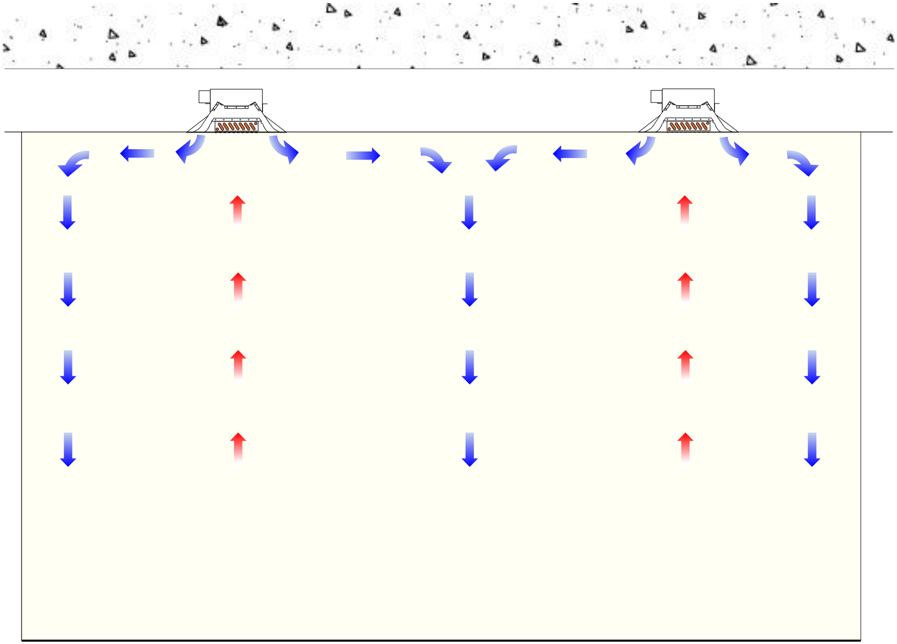
- Higher space loads
- Higher occupant densities
- Combined ventilation/cooling preferred
- Integration into fiber tile ceilings required

Active Chilled Beam
Operation Principle

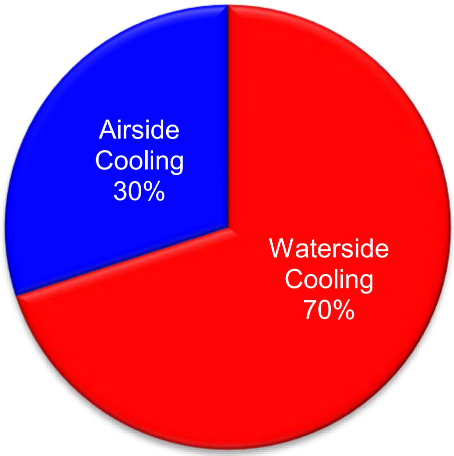


Active Chilled Beam

Airflow Pattern



Heat Removal Ratio



Building Suitability

Building Characteristics that favor Active Chilled Beams

- Zones with moderate-high sensible load densities
  - Where primary airflows would be significantly higher than needed for ventilation
- Buildings most affected by space constraints
  - Hi – rises, existing buildings with induction systems
- Zones where the acoustical environment is a key design criterion
- Laboratories where sensible loads are driving airflows as opposed to air change rates
- Buildings seeking LEED or Green Globes certification

Building Suitability

Characteristics that are less favorable for Active Chilled Beams

- Buildings with operable windows or “leaky” construction
  - Beams with drain pans could be considered
- Zones with relatively low sensible load densities
- Zones with relatively low sensible heat ratios and low ventilation air requirements
- Zones with high filtration requirements for the re-circulated room air
- Zone with high latent loads

Active Chilled Beams

Summary of Benefits

- Very high cooling capacity
  - Up to 100 BTUH/FT^2 floor space
  - Up to 1500 BTUH per LF
- Integrated cooling, ventilation and heating
  - All services in the ceiling cavity
- Suitable for integration into all ceiling types

Active Chilled Beams
Summary of Benefits

- Significant space savings
  - Smaller ductwork saves space in shafts, plant rooms and ceiling
- Can be installed tight up against the slab
  - Reduced floor to floor heights
  - Reduced construction costs on new buildings
- Low noise levels
- Low maintenance
  - No moving or consumable parts

Maintenance

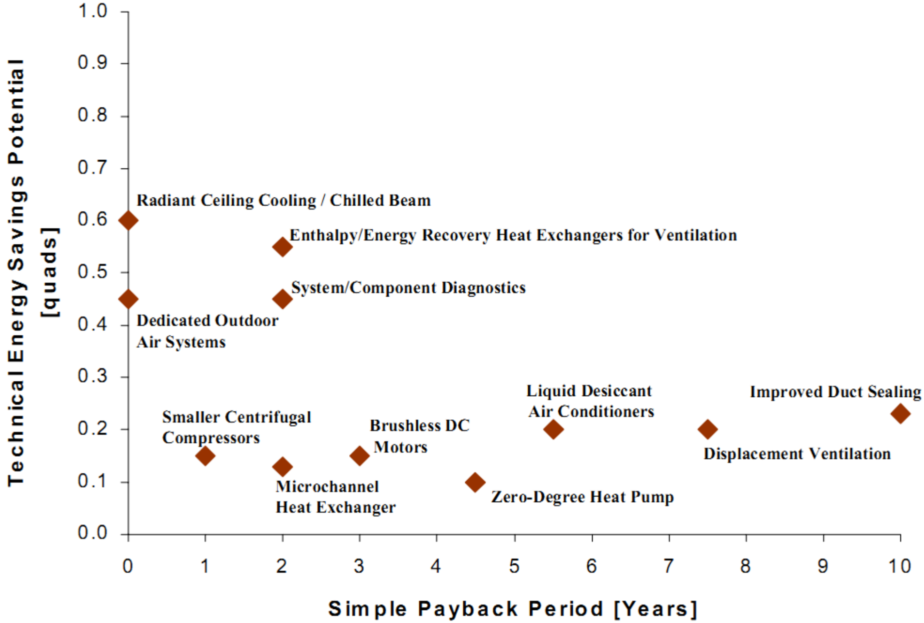
- No moving parts
- No filter
- No condensate pumps
- No consumable parts
- Up to 4 year inspection & clean
- Easy maintenance access

Beam Coil Access

Energy Savings
Compared to VAV

Source	Technology	Application	% Saving*
US Dept. of Energy Report (4/2001)	Beams/Radiant Ceilings	General	25-30
ASHRAE 2010 Technology Awards	Passive Chilled Beams	Call Center	41
ACEE Emerging Technologies Report (2009)	Active Chilled Beams	General	20
ASHRAE Journal 2007	Active Chilled Beams	Laboratory	57
SmithGroup	Active Chilled Beams	Offices	24
*Compared to VAV			

Savings Potential and Payback



"Energy Consumption Characteristics of Commercial Building HVAC Systems" - publication prepared for U.S. Department of Energy

LEED Certification

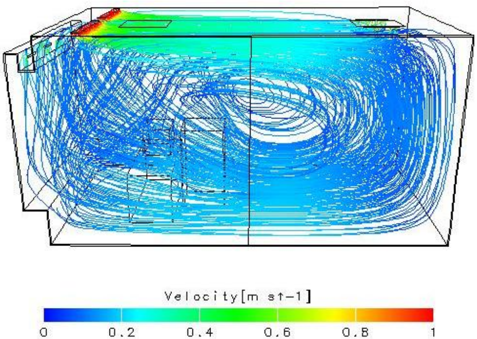
- Optimize Energy Performance
  - up to 48% (new) or 44% (existing) more efficient than ASHRAE 90.1
  (EA Credit 1)
- Increased Ventilation
  - 30% more outdoor air than ASHRAE 62
  (IEQ Credit 2)
- Controllability of Systems
  - individual temperature control
  (IEQ Credit 6.2)
- Thermal Comfort
  - meet ASHRAE 55
  (IEQ Credit 7.1)

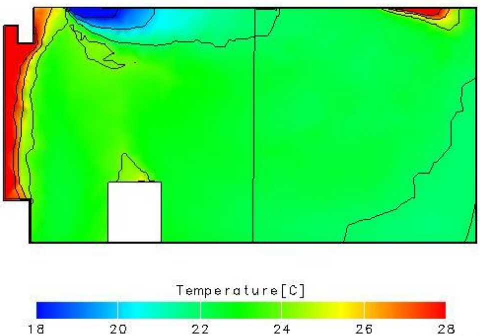
U.S. GREEN BUILDING COUNCIL MEMBER

(Minimum 40 points needed
for certification
out of 100 maximum)

Active Chilled Beams
Typical Installation

Thermal Comfort
Perimeter CFD

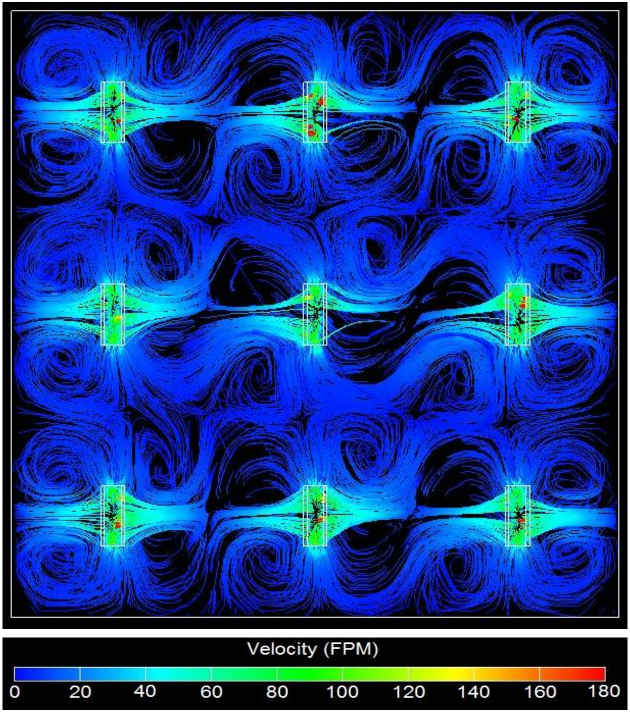




Good air movement throughout the room with ≈ 3-4:1 entrainment ratios

Uniform temperatures and no drafts by thorough mixing of the primary and room air

Thermal Comfort
Interior CFD



ACTIVE CHILLED BEAM DESIGN CONSIDERATIONS

Role of the Primary Air

- Ventilate the occupants according to ASHRAE 62-2004
- Handle all of the latent load in the space
  - Primary air is only source of latent heat removal
- Create induction through chilled beam
- Pressurize the building

Primary Air Design

- Central AHU sized to handle:
  - sensible and latent cooling/heating of the ventilation air
  - portion of the sensible internal cooling/heating loads

AND

  - all of the internal and infiltration latent loads

- Primary air delivered continuously to the chilled beams
  - VAV primary air can be considered for the perimeter if the sensible loads are high
- Chilled beam water coils provide additional sensible cooling/heating to control zones

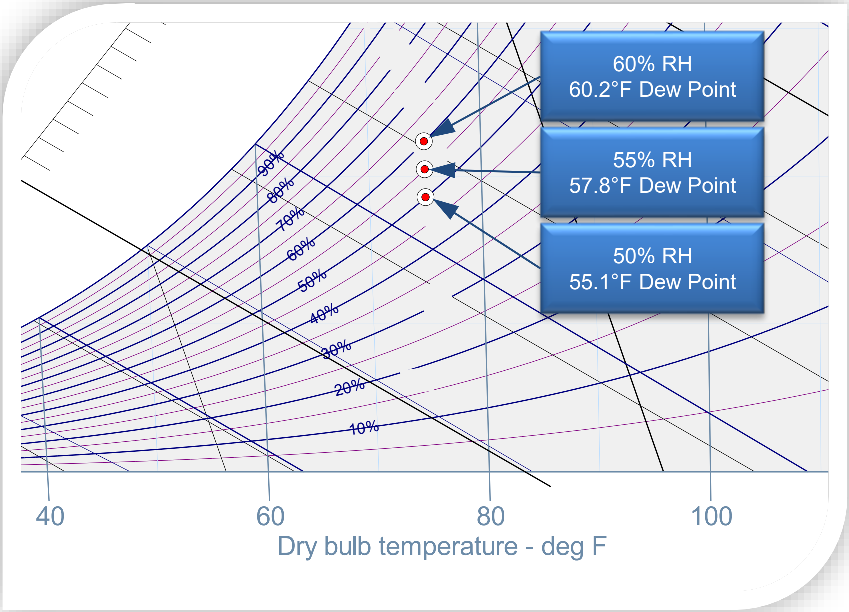
CFM of Primary Air

The CFM of the primary air is determined and set by the largest of the three values below:

1) CFM requirements to meet ASHRAE and code guidelines for ventilation requirements per designed occupancy
2) CFM required to meet the designed sensible load in the space
3) CFM required to meet the latent load in the space

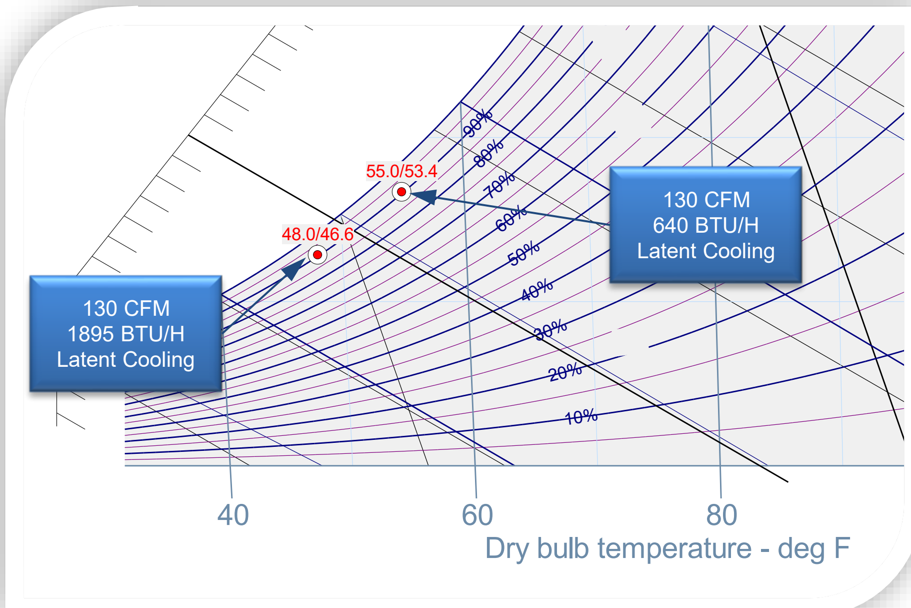
Condensation Considerations

Why is it important to satisfy the latent load in all sensible load conditions?



Humidity Control

Primary Air Temperature & Latent Cooling



Condensation Considerations

75ºF db room design temperature at 50% relative humidity
55ºF dew point temperature

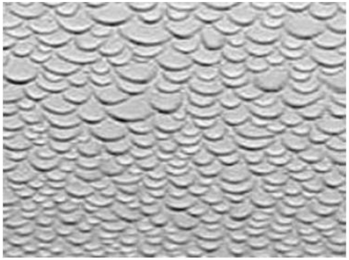
Theoretically condensation will form on the coil when the chilled water temperature is 55ºF.

Apparent room dew point is 2-3ºF lower
due to insulating effect of air film on coil fins

In reality at this room design condition, condensation will not begin to form until the water temperature is 52-53ºF.

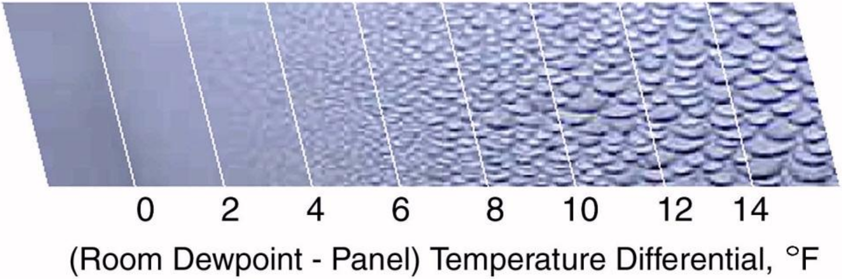
Condensation Considerations

Radiant Panel Condensation Test



Condensation after 8.5 hours on a chilled surface intentionally held 7.8°F colder than the space DPT. Not one droplet fell under these conditions

Chilled Ceilings in Parallel with Dedicated Outdoor Air Systems: Addressing the Concerns of Condensation, Capacity, and Cost Stanley A. Mumma, Ph.D., P.E.



Active Chilled Beam

Induction of secondary air directly from the room
2-way discharge or 1-way discharge
2-pipe or 4-pipe
2’ width x 2 - 10’ lengths

Active Chilled Beam

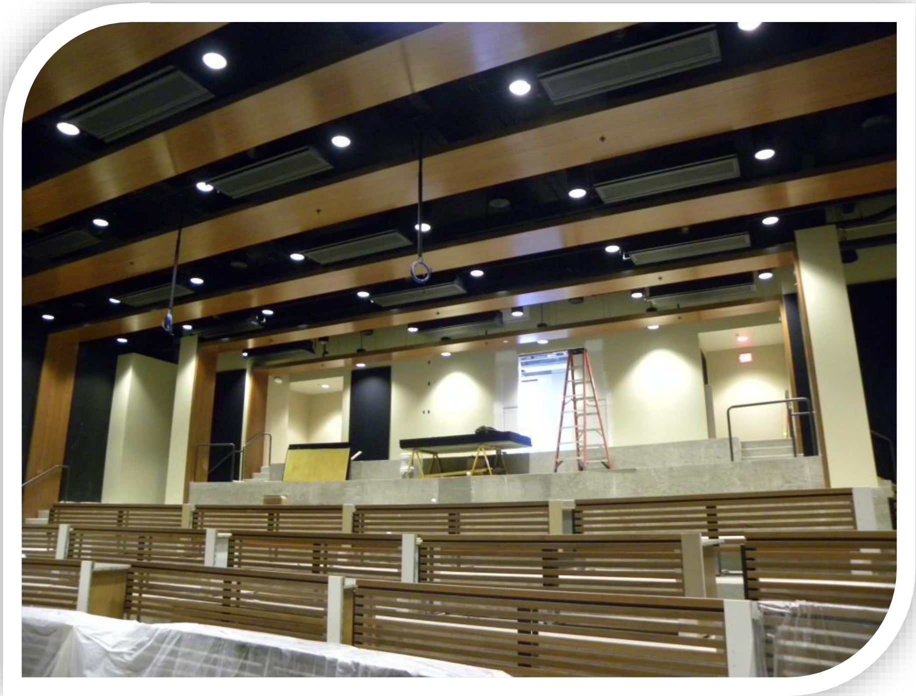
Active Chilled Beam

Active Chilled Beam

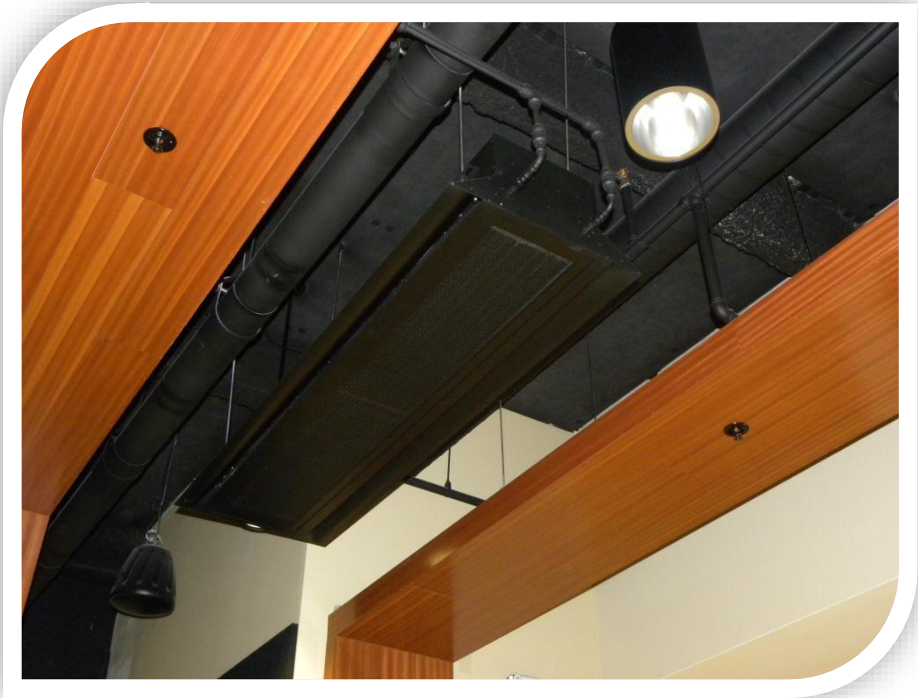
Active Chilled Beam

Active Chilled Beam

Exposed Active Beams



Exposed Active Beams



Active Chilled Beam

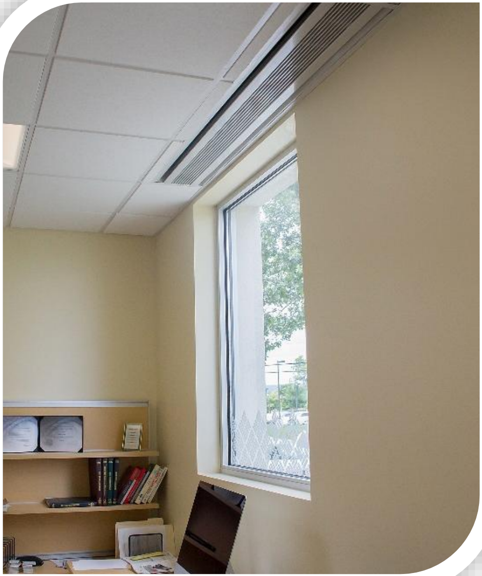
Active Chilled Beam

Active Chilled Beam

Induction of secondary air directly from the room
2-way discharge or 1-way discharge
2-pipe or 4-pipe
1’ width x 2’ - 10’ lengths

Active Chilled Beam

Active Chilled Beam

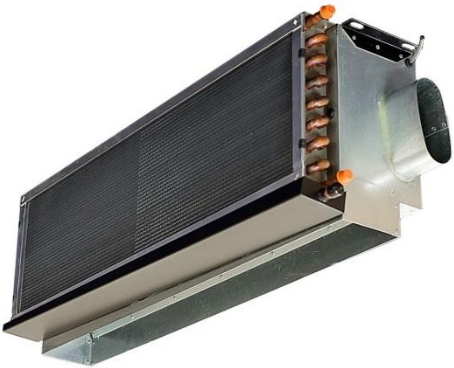


Active Chilled Beam

Induction of secondary air directly from the room
2-way discharge
2-pipe or 4-pipe
2’ width x 2’ - 10’ lengths
with vertical coils and drain pans

Active Chilled Beams

Active Chilled Beam



Induction of secondary air from the return air plenum

1 or 2-way discharge

2-pipe or 4-pipe

2’ to 6’ lengths

with vertical coil and drain pan

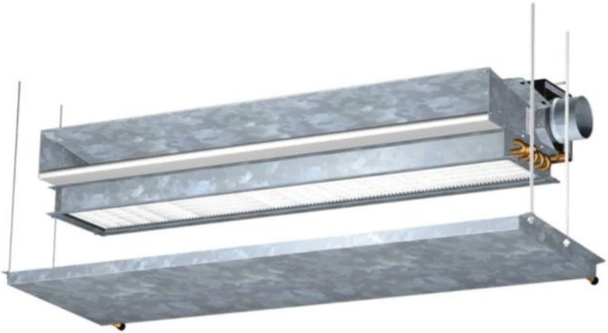
Active Chilled Beam

Active Chilled Beam

Active Chilled Beam

Active Chilled Beam

Active Chilled Beam

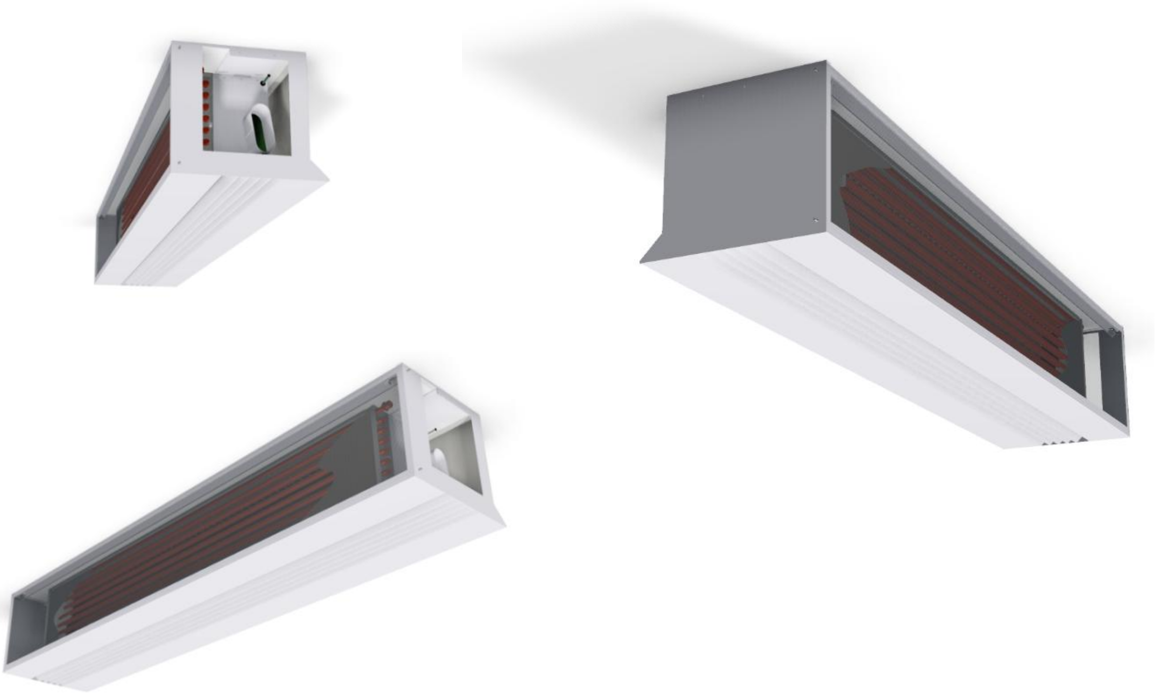


- Horizontal discharge
- 2-Pipe or 4-Pipe
- 2’ to 6’ length
- With auxiliary condensate drain pan
- Cooling capacity up to 1200 BTUH per LF
- Up to 20 CFM/ft primary air capacity
- Hotels, dorms, atriums and lobbies

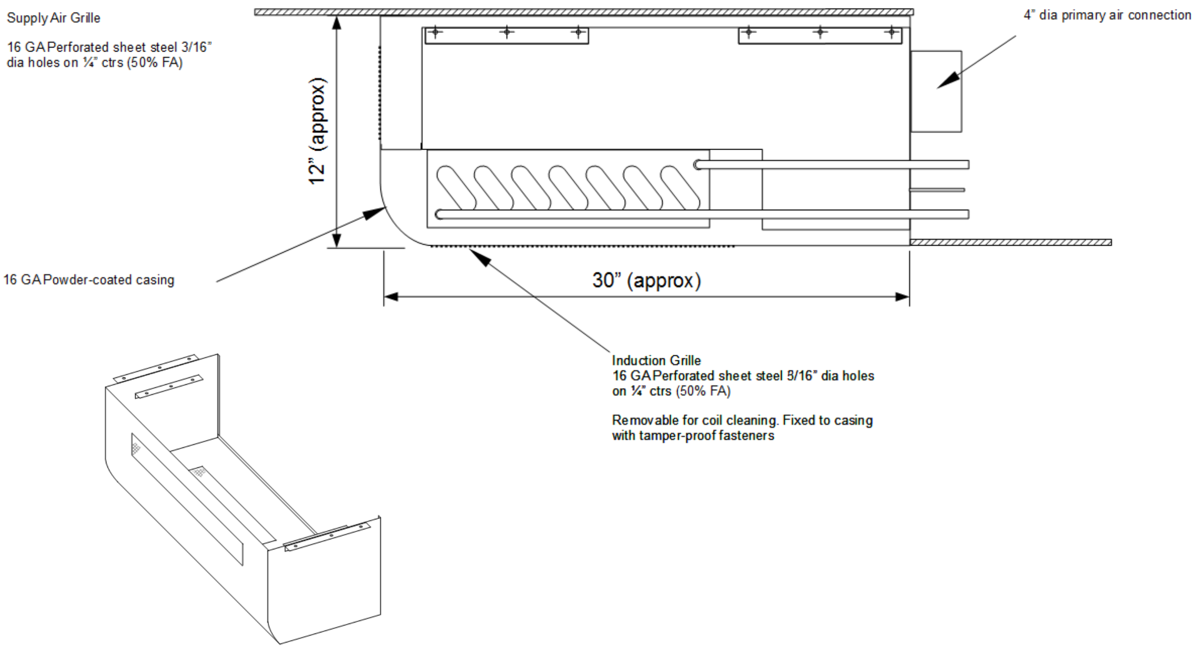
Active Chilled Beam

Active Chilled Beam

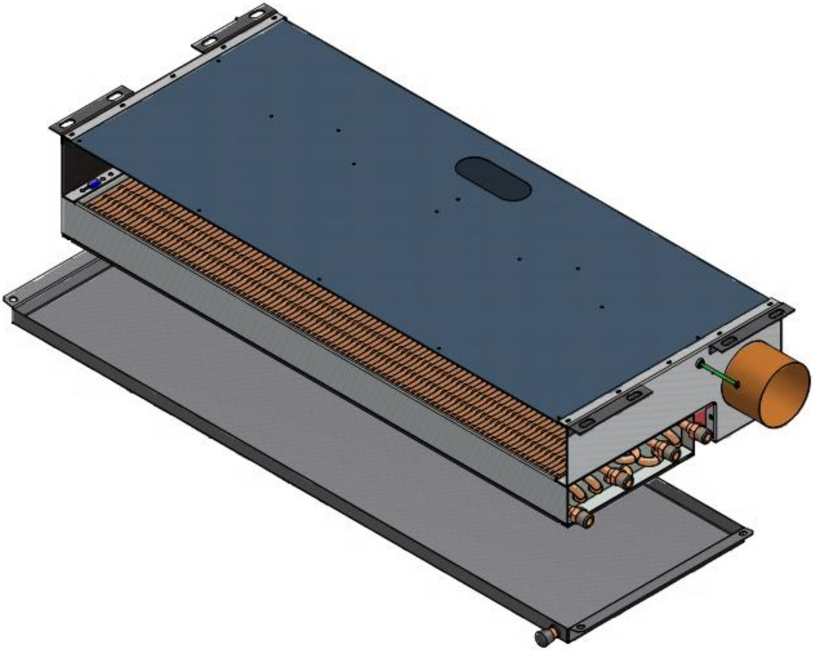
Custom Chilled Beams



Bulkhead Security Beam



Bulkhead Security Beam



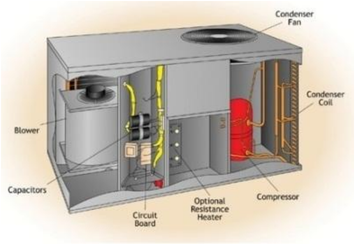
Replacement Induction Units

Vertical Discharge
2’ to 6’ Lengths

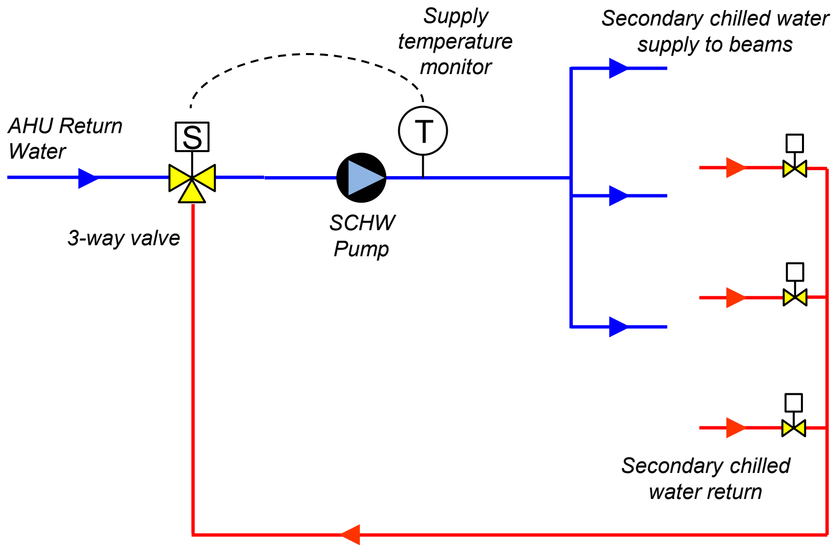
WATER SYSTEM DESIGN

CHW System Design Options

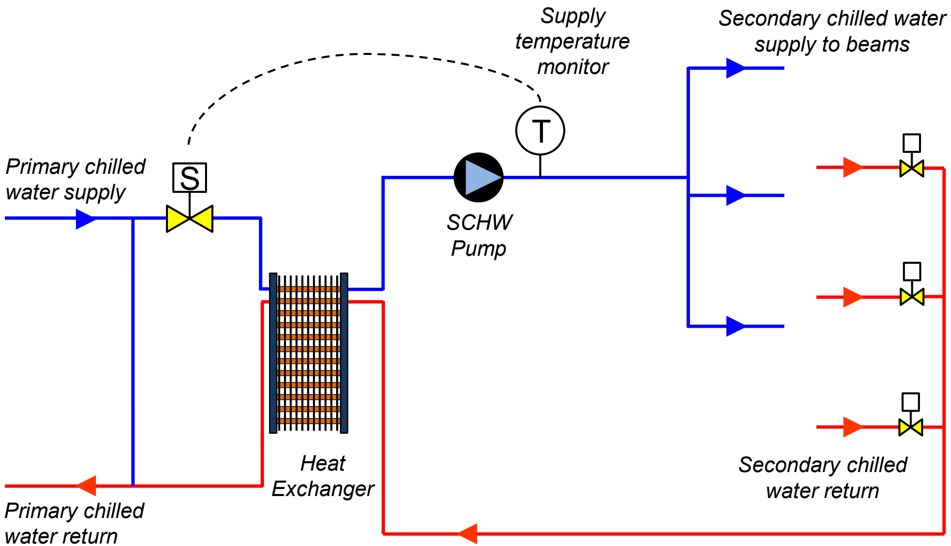
- Secondary loop
  - Tap into district CHW loop
  - Heat exchanger into return – no GPM demand
  - Can increase main plant efficiency
- Dedicated chiller & DX
  - Dehumidification by DX AHU
- Twin chillers
  - One for AHU's
  - One for chilled beam circuit



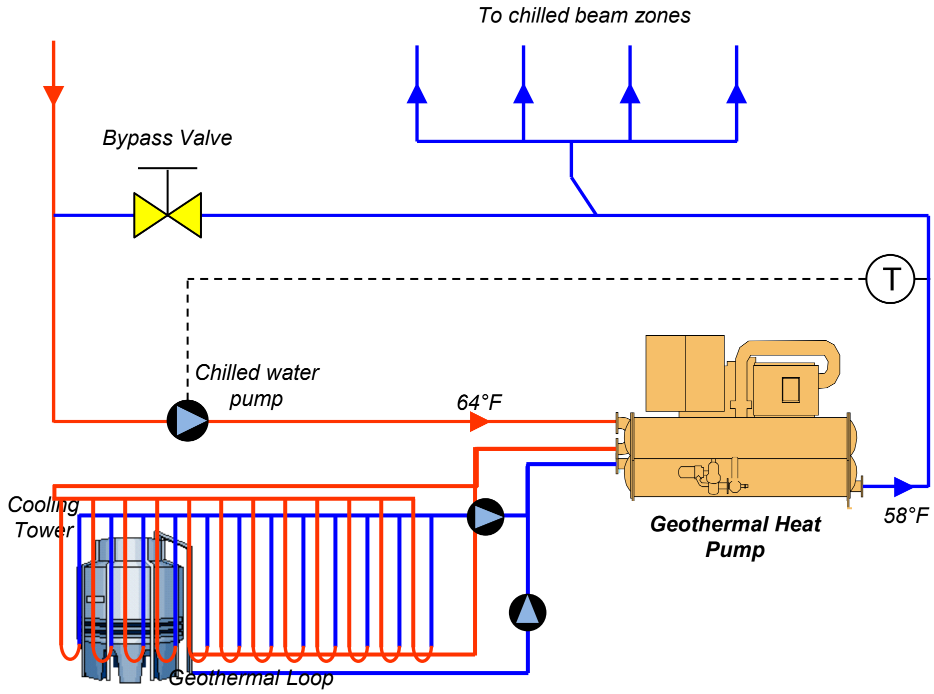
Three Way Valve



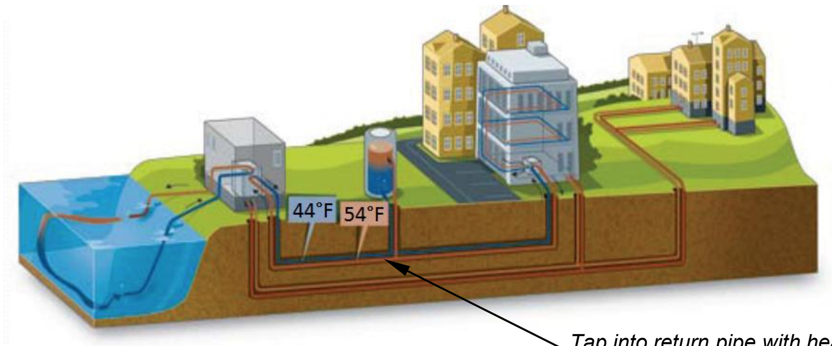
Secondary Loop



Dedicated Chiller



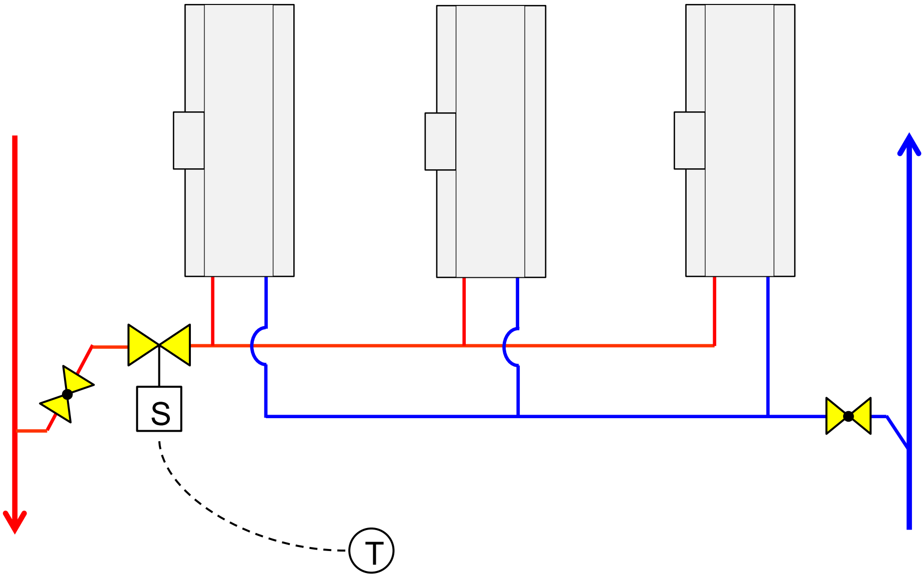
District Chilled Water Loops



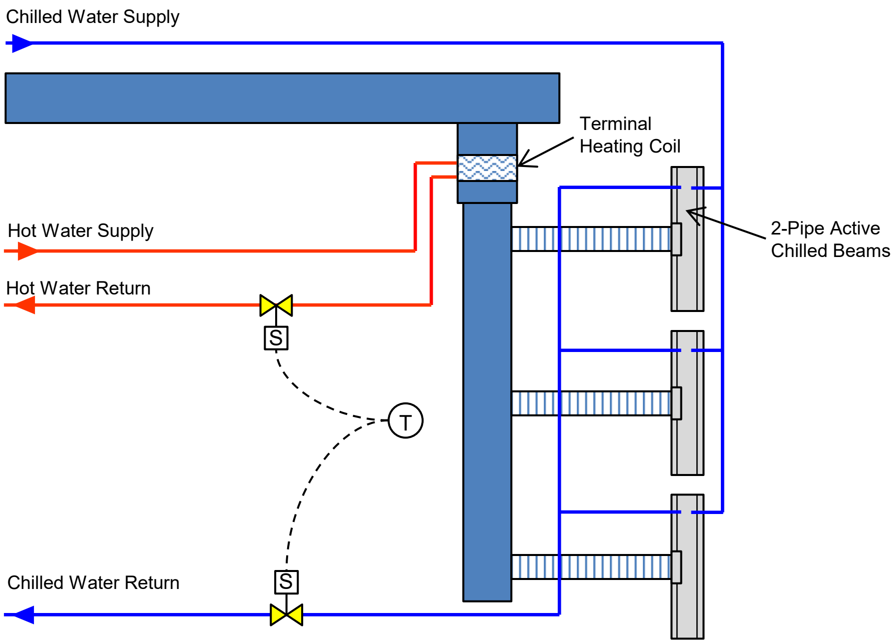
Tap into return pipe with heat exchanger and secondary loop

- No demand in district loop GPM
- Increases main chiller plant COP

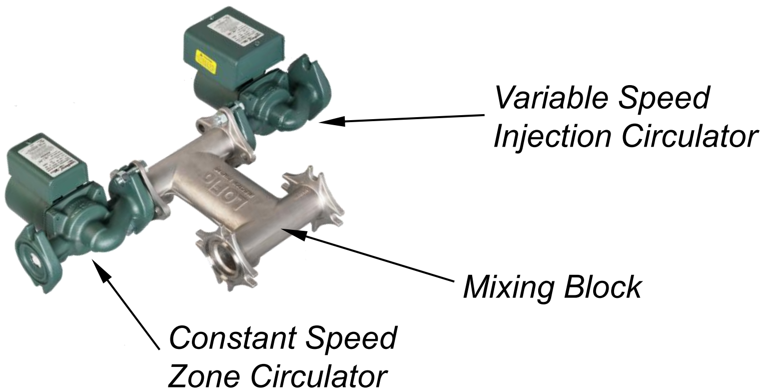
Reverse Return Pipe Design

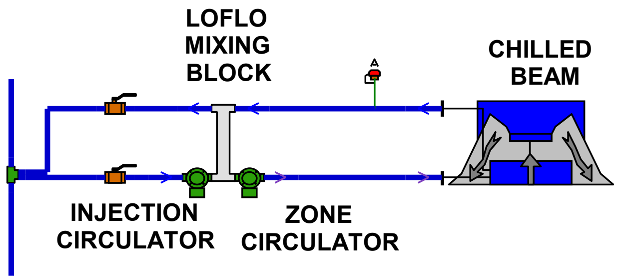


2-Pipe Beams and Terminal Heating

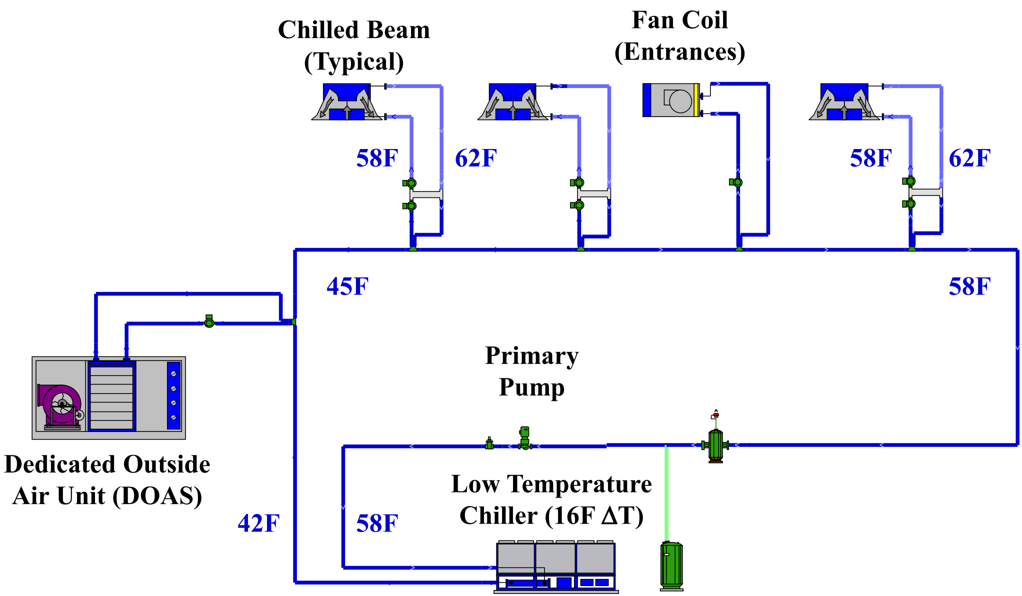


Injection Pump Mixing Block



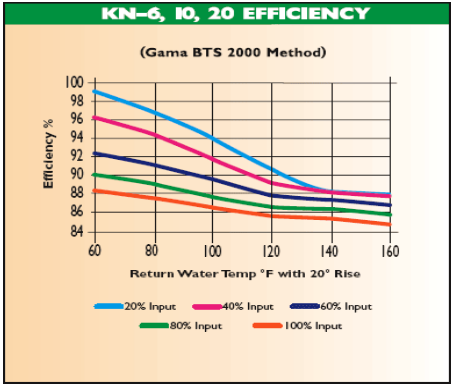


Single Pipe Chilled Water Circuit



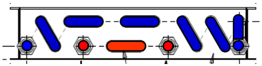
Boiler Efficiency
Lower Hot Water Temp

- Hot water typically 90-130°F
- Reduce boiler energy consumption by maximizing efficiency of a condensing boiler through very low return water temperatures
- Use of water to water heat pumps



Advantages of 2-Pipe Beams Versus 4-Pipe

- Higher coil performance
  - 4 pipe performance is compromised
  - 75% Cooling (12 pipes)
  - 25% Heating (4 pipes)



- Fewer or shorter beams
- Lower hot water temperatures
  - 90°F for 2 pipe
  - 130°F for 4 pipe

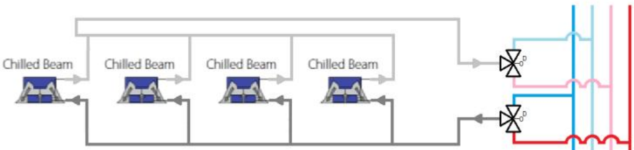
6 Way Valve Waterside Control

- 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 SCHW only if primary moisture content cannot reduced

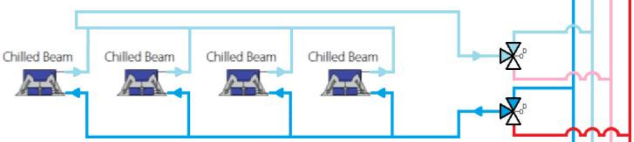
6-Way Valve

- One valve per zone
- 4-pipe to zone then 2-pipe to chilled beams
- Half controls costs
- Increased chilled beam performance
- Increased energy efficiency

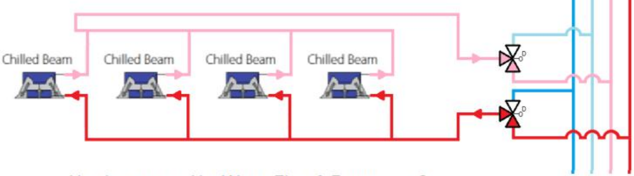
6-Way Valve



Both Chilled Water & Hot Water are Isolated



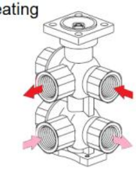
Cooling Mode - Chilled Water Flow & Return are Open
Hot Water is Isolated

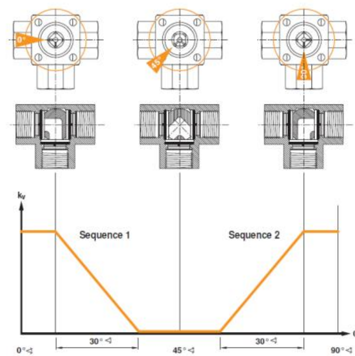


Heating Mode - Hot Water Flow & Return are Open
Chilled Water is Isolated

Cooling

Heating





CONTROL CONSIDERATIONS

Airside Control

- Constant volume air
  - Reduces cost
  - Maintains constant control of humidity
- Monitor room dew point
  - Use small quantity of high quality sensors
  - Do not use RH sensors
  - Locate sensors in room not in ceiling
- Reduce primary moisture content to control room RH
  - Avoid turning off or rescheduling SCHW temp

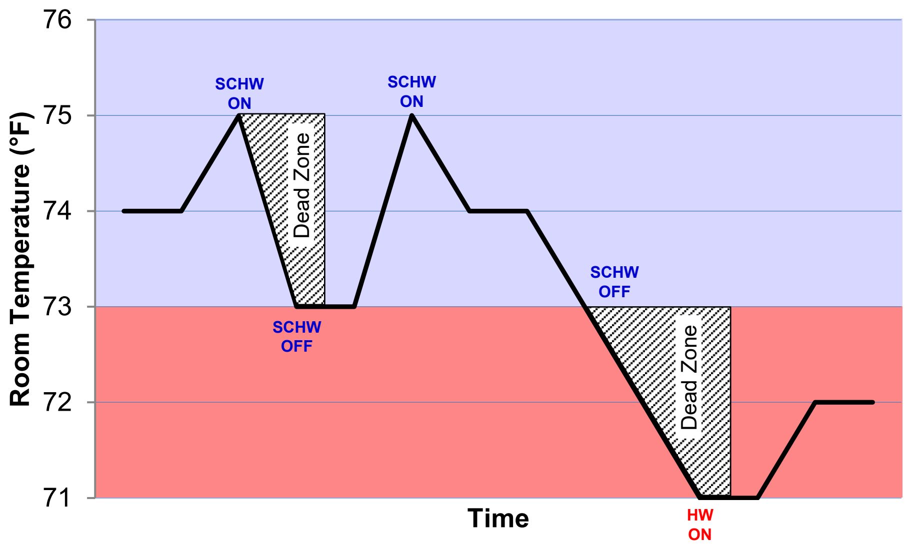
Using VAV with ACB's

- VAV is sometimes used in:
  - Perimeter zones with high sensible loads
  - Laboratories
  - Zones where set back mode is required
- Benefits:
  - Potential reduction in fan energy consumption
  - Potential to reduce reheating
  - Reduced risk of overcooling
- Issues / Discussion Items:
  - Cost
  - Latent cooling capacity reduced during turndown
  - Increased control complexity

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 SCHW only if primary moisture content cannot reduced

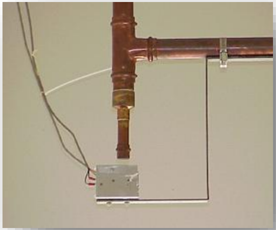
Typical Waterside Control Sequence



Condensation and dew point sensors

Dew point sensor

Condensation sensor



Drip sensor

Typical Start Up Control Sequence

- Dry out cycle before engaging SCHW pumps
- Setback primary air humidity ratio
- ONLY initiate pumps when room dew point is within design limits

CHILLED BEAMS FOR HEALTHCARE APPLICATIONS

ASHRAE Std 170-2008
Addendum h

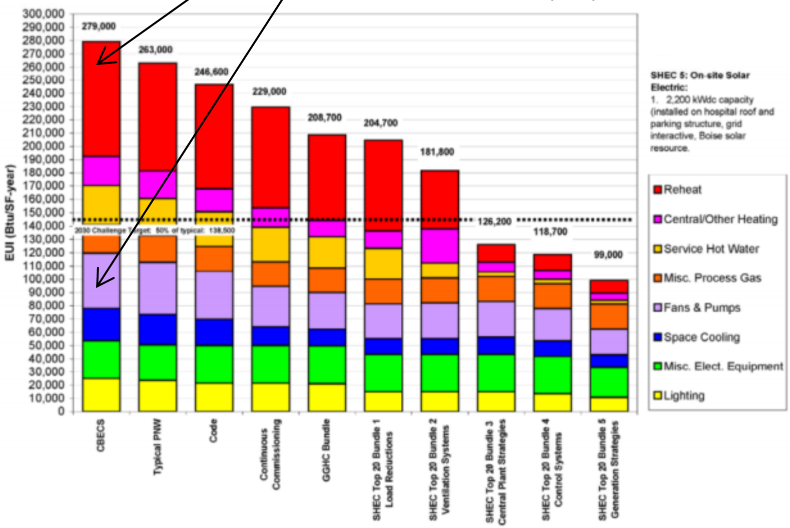
- Recirculation through room units now count towards total air changes
- Recirculation units must serve a single space
- Minimum Merv 6 filters required ONLY on recirculation units designed to condense water
- Recirculation units must receive filtered and conditioned outdoor air

Average Energy Use Intensity

In Western USA Acute Care Hospitals

30% of the Average Energy Use Intensity (EUI) for Acute Care Hospitals in the Western U.S. is used for Reheat

15% is used for fans and pumps



Source: Mike Hatten PE, Solarc

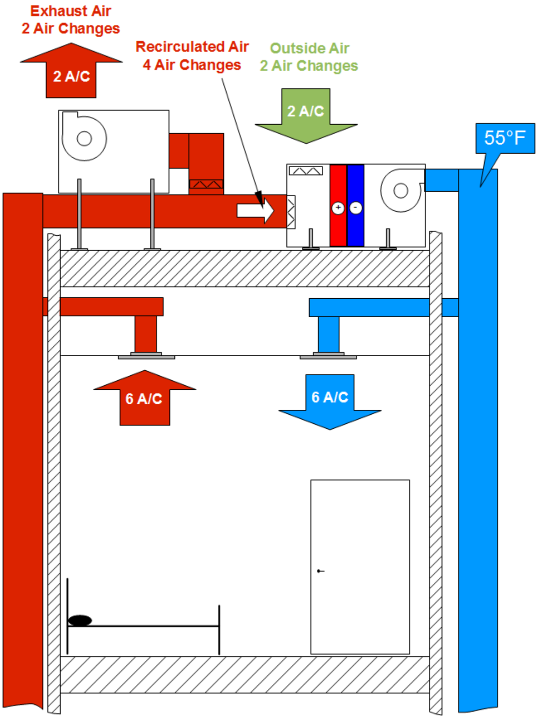
Airflow Rates & Loads
Typical Patient Room

- Room size
  - 10’ x 10’ x 10’
- Cooling Load
  - 25 BTU/H ft^2
  - 2500 BTU/H
- Minimum total air change rate
  - 6 per hour
  - 100 CFM
- Minimum outdoor ventilation rate
  - 2 air changes
  - 34 CFM
- Recirculated air
  - 4 air changes
  - 67 CFM

Air change rates as per ASHRAE Handbook and AIA Guidelines

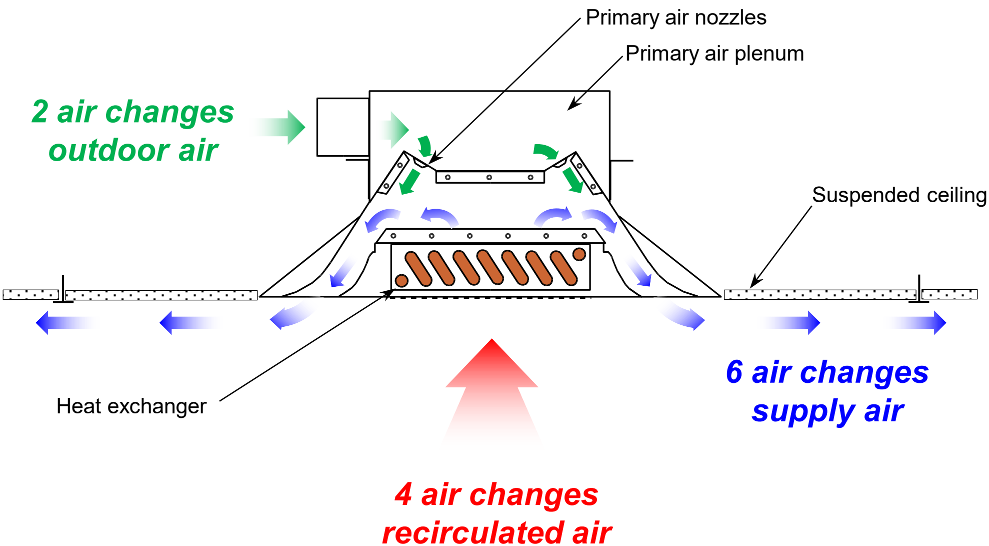
All Air System Design

- Minimum air flow (6 A/C)
  - 100 CFM
- Maximum air flow (cooling)
  - 114 CFM
- Cooling range without reheat
  - 2200 to 2500 BTU/H
- Air change range
  - 6.0 to 7.0
- % turndown without reheat
  - 12%
- Takeoff duct size
  - 6” diameter



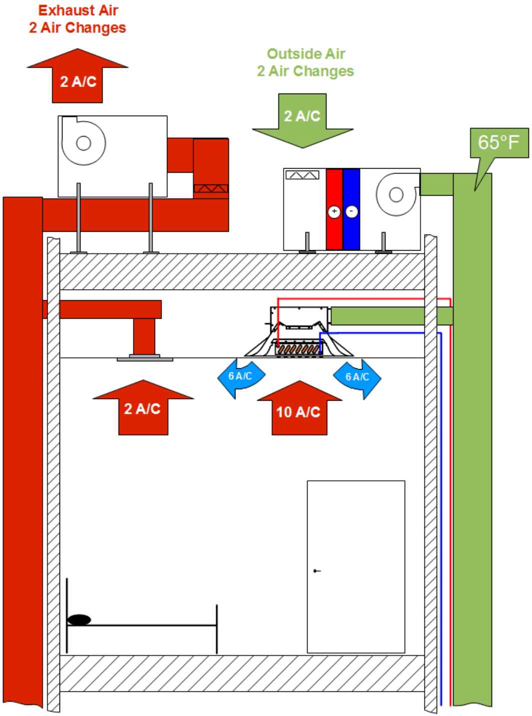
Delivering Air Changes

With Active Beams



Active Beam Design

- Primary air flow rate
  - *35 CFM*
- Primary air temperature
  - *65°F*
- Induced air flow
  - *170 CFM*
- Total air flow
  - *205 CFM*
- Total air changes
  - *12*
- Min. cooling (water off)
  - *385 BTU/H*
- % turndown without reheat
  - *85%*
- Chilled beam length
  - *4'*
- Duct size
  - *4" diameter*



Systems Compare

All Air

- Min turndown w/o reheat
  - 12%
- Total air changes
  - 7
- Duct size
  - 6” diamete

Chilled Beam

- Min turndown w/o reheat
  - 85%
- Total air changes
  - 12
- Duct size
  - diameter

Reheat Eliminated!

Health Benefits

- Use of DOAS units possible
- Room to room contamination reduced
- Ventilation effectiveness increased due to higher air change rate

ASHRAE Std 170-2008

Addendum h

- Recirculation through room units now count towards total air changes
- Recirculation units must serve a single space
- Minimum Merv 6 filters required ONLY on recirculation units designed to condense water
- Recirculation units must receive filtered and conditioned outdoor air

Rooms Where Beams Can Be Used

Permitted

- Patient Rooms
- Treatment Rooms
- Examination Rooms
- Labor
- Radiology
- Pharmacy

Not Permitted

- Operating Theatre
- Critical & Intensive Care
- Recovery Room
- Trauma
- ER Waiting Rooms

Active Chilled Beams

Typical Installation

Active Chilled Beams

Typical Installation

ACTIVE CHILLED BEAMS
FOR LABORATORY APPLICATIONS

Laboratory Design Issues

- Sensible heat gains of up to 70 BTUH/ft^2
- Space ventilation requirements of 6 to 8 ACH
- Laboratories where chemicals and gases are present require 100% outdoor air
- *Air systems require 15 to 20 ACH of outside air to satisfy sensible load*

Cooling Load and ACH

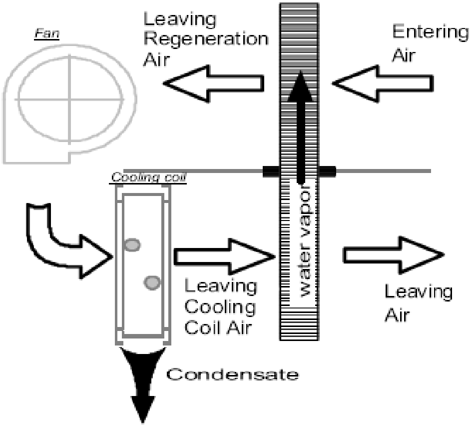
Total Cooling Load Including Lights, People, Building Envelope And Equipment	Required Air Change Rate For Safety (Air Changes Per Hour)	Air Change Rate for Cooling (Assumes 55°F Supply Air and 75°F Exhaust Air)	Air Change Rate Driven By:
10 W/ft^2	6 ACH	9.4 ACH	Cooling
15 W/ft^2	6 ACH	14.1 ACH	Cooling
20 W/ft^2	6 ACH	18.8 ACH	Cooling
10 W/ft^2	8 ACH	9.4 ACH	Cooling
15 W/ft^2	8 ACH	14.1 ACH	Cooling
20 W/ft^2	8 ACH	18.8 ACH	Cooling
10 W/ft^2	10 ACH	9.4 ACH	**Safety**
15 W/ft^2	10 ACH	14.1 ACH	Cooling
20 W/ft^2	10 ACH	18.8 ACH	Cooling
10 W/ft^2	12 ACH	9.4 ACH	**Safety**
15 W/ft^2	12 ACH	14.1 ACH	Cooling
20 W/ft^2	12 ACH	18.8 ACH	Cooling

Benefits of Active Beams in Labs

- Eliminated or reduced reheat
  - Reheat can account for 20% or more HVAC energy costs
- Water more efficient transport medium
  - Reduces fan energy costs
- Smaller space requirements
  - System sized for 6 ACH instead of 1

Room Neutral Air

- Sensible recovery device (downstream of coil)
- Desiccant dehumidification units
- Passive dehumidification wheels



Reheat Reduction

VAV System

- Minimum Airflow
  - 6 ACH = 760 CFM
- Cooling Load
  - 65 BTU/H ft^2
  - 41,000 BTU/H Peak
- Maximum Airflow
  - 1,860 CFM (15 ACH)
- Minimum Cooling without reheat
  - 6 ACH @ 55°F
  - 16,600 BTU/H
- Turndown without reheat
  - 16,600/41,000
  - 59%

ACB System

- Minimum Airflow
  - 6 ACH = 760 CFM
- Cooling Load
  - 65 BTU/H ft^2
  - 41,000 BTU/H Peak
- Maximum Airflow
  - 760 CFM
- Minimum Cooling without reheat
  - **6 ACH @ 65°F**
  - **8,300 BTU/H**
- Turndown without reheat
  - 8,300/41,000
  - **80%**

Labs with High Air Changes

- Size ACB’s for sensible load and minimum ACH
- Chilled beams constant volume
- FC make up air delivered in parallel VAV using:-
  - Perforated diffusers
  - Swirl diffusers
  - Dummy chilled beams
- Room neutral air eliminates local reheat
- Pressure controlled by VAV system

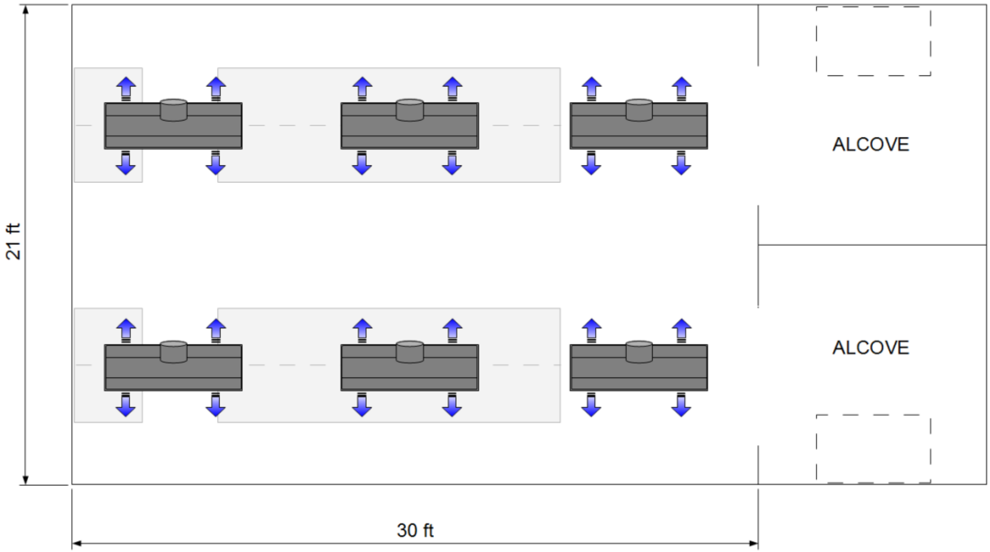
Active Chilled Beam Design

Cooling Load = 65 BTU/H ft^2

Ventilation Rate = 6 Air Changes

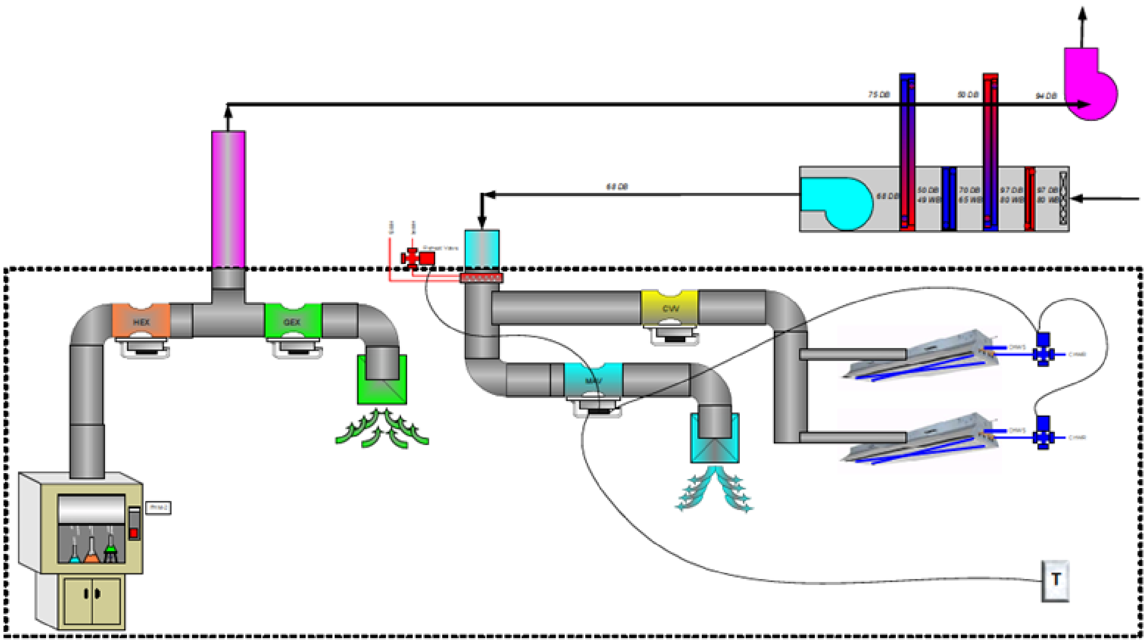
VAV Solution = 15 Air Changes

Chilled Beam Solution = 6 Air Changes



Active Chilled Beam Solution = 6 x 6' Long, 130 CFM each

Labs with Variable Ventilation Rates

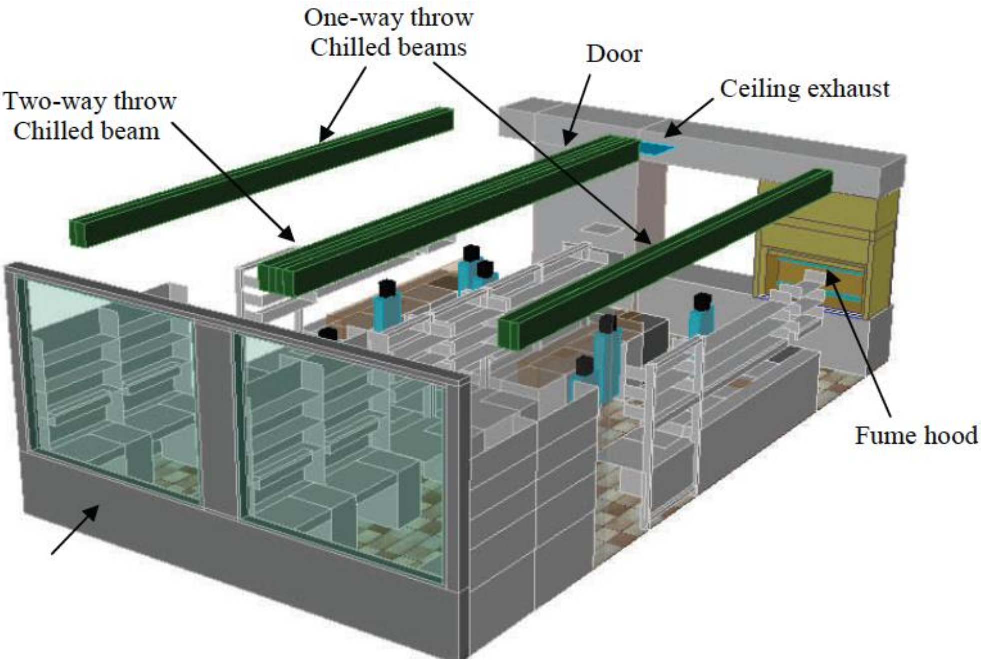


Fume Hoods

- Careful layout of chilled beams to minimize air velocity near sash
- Use 1-way beams throwing away from hoods

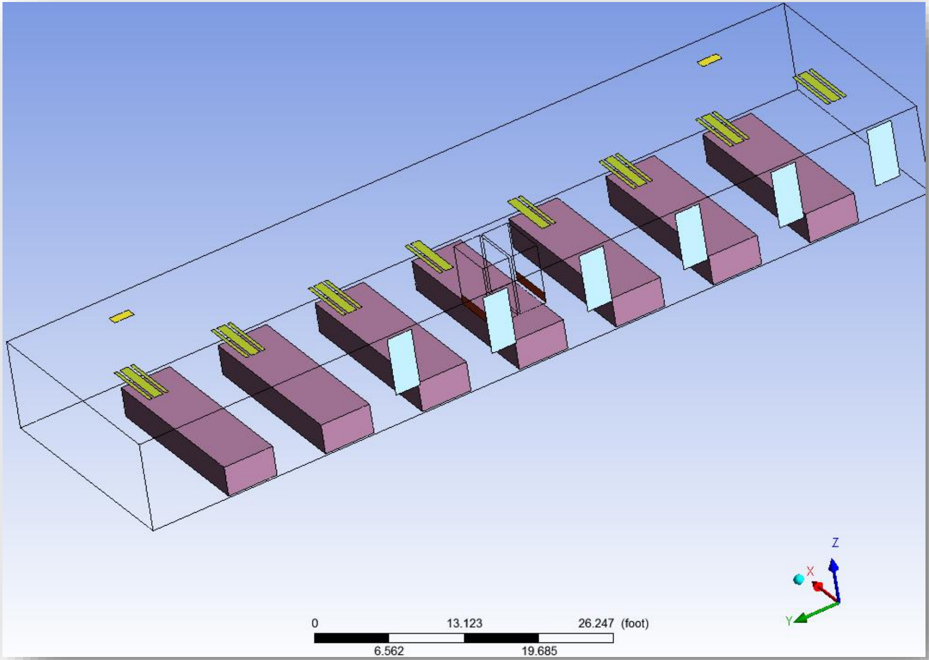
Beam Location

Over Benches or Aisles?

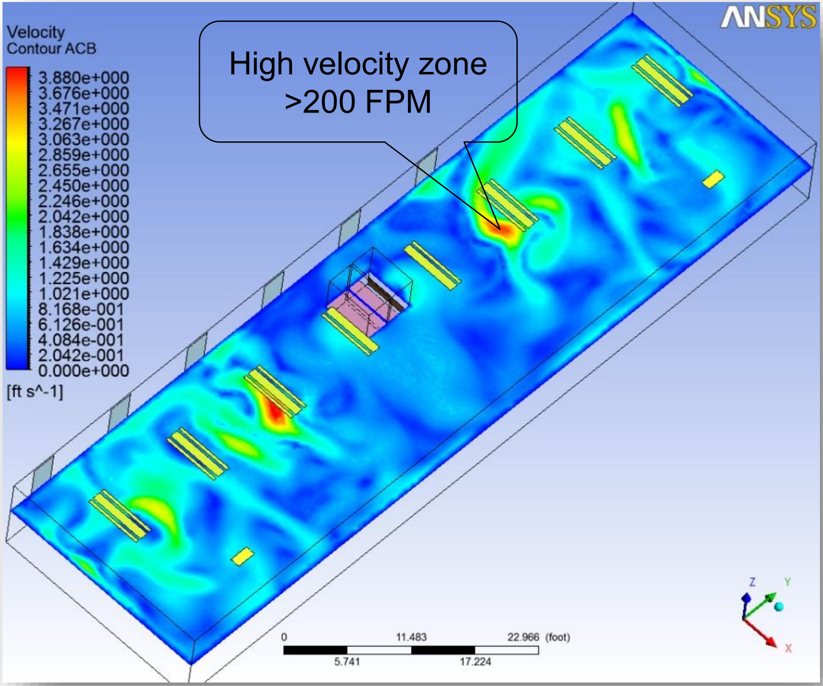


Thermal Comfort

CFD Modeling

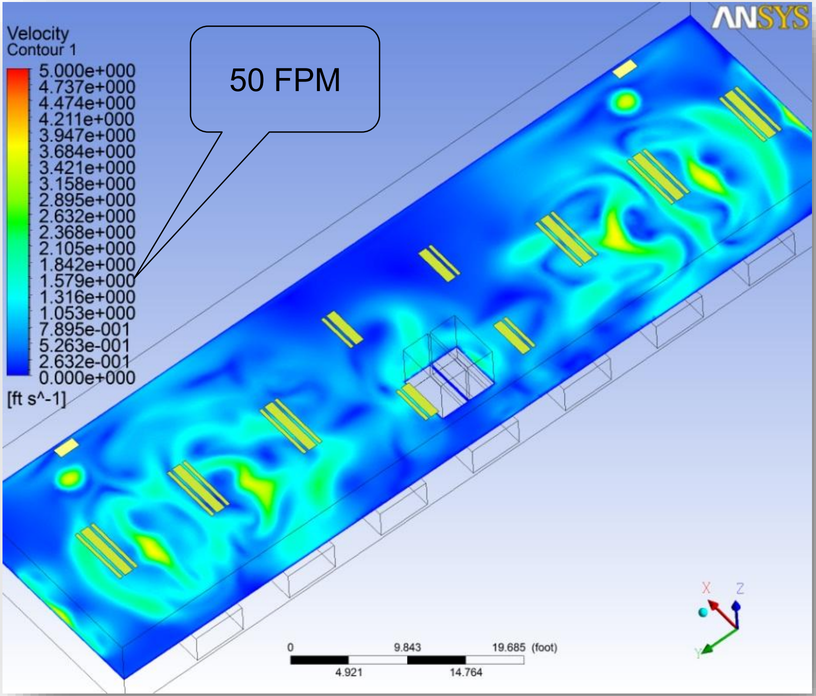


CFD Analysis

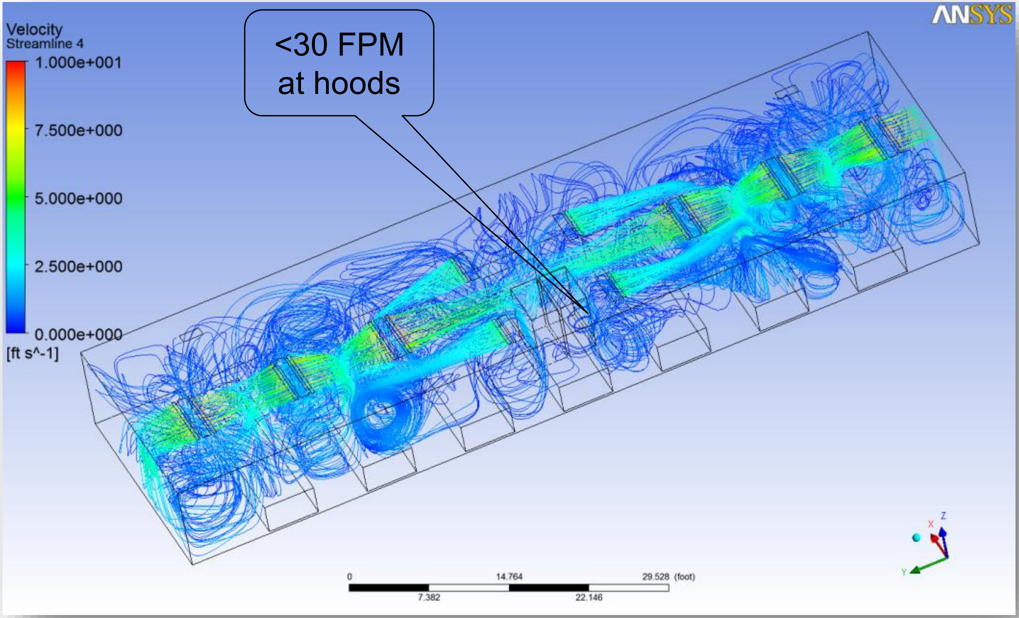


Revised Layout

Improved Thermal Comfort



Hood Velocities



Questions?

Thank You