Air-Water Systems

Chilled Ceilings and Beams

Early 1980’s

- Buildings well insulated for heating
- Advent of personal computers
- Need to remove heat from space
- Limited space available

1980 1990 2005

Chilled Ceilings

Principle of Operation

Chilled Ceiling Panels

CWS = 59 to 62°F
CWR = 62 to 66°F

45% Radiant
55% Convective

Radiant Effect on Occupants

Chilled Ceiling Panels

Dry Bulb Temp. 77°F
Effective Radiant Temp. 74.5°F
**Cooling Capacity Comparison**

- **Flow Cross Section Ratio**: 1:327
- **18" x 18" Air Duct**
- **1" diameter Water Pipe**

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**Chilled Ceiling Systems**

- Improved thermal comfort
- Minimal space requirements
- Low energy cooling solution

- **Limited Cooling Capacity**
  - 25 BTUH/FT² of active panel
  - 18 BTUH/FT² of floor area (based on 70% active ceiling)

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**Chilled Ceilings and Beams** *Early 1990's*

- **Chilled Ceilings**
  - 1980
  - 1990
  - 2000
  - 2005
- **Passive Beams**
  - Ceiling manufacturers begin to sell high free area perforation panels competitively
  - Convective coils replace ceiling panels

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**Passive Chilled Beams**

- Increased equipment loads
- Greater occupant densities
- Inadequate perimeter cooling
Concrete soffit

Passive Chilled Beams

Air Distribution Pattern

Recessed Beams

Exposed Beams

Support Rods

W

W x 2
Passive Beam Installations

Exposed Passive Beam

Heat Transfer Coil
Support Rods
Cabinet

Chilled Ceilings and Beams
Mid 1990’s

Greater occupant densities
Gypsum board tiles become common
Combine cooling and ventilation
**Active Chilled Beams**

- Sensible loads up to 100 BTU/FT²
- Primary air delivered at conventional (50 to 55°F) temperatures at or near minimum ventilation flow rate
- Can be used with fiberglass ceiling tiles or without any ceiling

**Active Beam Installation**
Typical Output

<table>
<thead>
<tr>
<th>Device Capacity</th>
<th>Chilled Ceiling</th>
<th>Cooling Effect (BTU/FT²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 BTU/FT²</td>
<td>Passive Beam</td>
<td>18 BTU/FT²</td>
</tr>
<tr>
<td>400 BTU/LF</td>
<td>Active Beam</td>
<td>40 BTU/FT²</td>
</tr>
<tr>
<td>800 BTU/LF</td>
<td></td>
<td>100 BTU/FT²</td>
</tr>
</tbody>
</table>

Comparative Energy Costs

![Bar chart showing typical annual HVAC energy cost comparison between different systems.]

- **Legend**:
  - Cost to transport air
  - Cost to cool air
  - Cost to transport water
  - Cost to chill water

Passive Chilled Beams

*For UFAD Applications*

![Bar chart showing device capacity and cooling effect for passive chilled beams.]

UFAD Perimeter Treatment

*Decoupled Sensible Cooling System*

![Diagram illustrating UFAD perimeter treatment with passive chilled beams and floor diffusers.]

![Timeline chart showing the evolution of chilled ceilings and passive beams from 1980 to 2005.]

![Diagram showing UFAD with passive chilled beam and floor diffusers.]

6
Supply Airflow Requirements

Fan Terminals vs. Chilled Beams

For a floor plate that is 60% interior space

**Fan Powered Perimeter Solution:**
- Interior: 0.6 CFM/ft²
- Perimeter (design): 3.0 CFM/ft²
- Perimeter Diversity: 70%
- Overall: 1.2 CFM/ft²

**Chilled Beam Perimeter Solution:**
- Interior: 0.6 CFM/ft²
- Perimeter: 0.6 CFM/ft²
- Overall: 0.6 CFM/ft²

50% reduction in supply airflow

Active Chilled Beams

For Laboratory HVAC Applications

- 1990
- 2000
- 2005

- Chilled Ceilings
- Passive Beams
- Active Beams

Case Study

Laboratory Design for Pharmaceutical Company

- Location: St. Louis, MO
- Outdoor Design Conditions: 94DB/75WB
- Laboratory Space: 54,000 FT²
- Minimum Ventilation Rate: 8 ACH¹
- Space Sensible Heat Gain: 72 BTUH/FT²

Laboratory Design Issues

- Space sensible heat gains of 60 to 75 BTUH/FT²
- Ventilation requirements of 6 to 8 ACH¹
- Laboratories where chemicals and gases are present require 100% OA
- All air systems require 16 to 20 ACH¹ to satisfy sensible load
- Active beams remove over 60% of sensible heat via chilled water circuit
- Require only 40% the primary airflow rate (6-8 ACH¹) of all-air system
### Equipment Requirements

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Conventional VAV</th>
<th>Active Chilled Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Handling Units</td>
<td>180,000 CFM</td>
<td>72,000 CFM</td>
</tr>
<tr>
<td>Cooling</td>
<td>1,477 Tons</td>
<td>587 Tons</td>
</tr>
<tr>
<td>Heating</td>
<td>21,617 lbs/hr</td>
<td>8,588 lbs/hr</td>
</tr>
<tr>
<td>Duct Distribution</td>
<td>285,493 lbs.</td>
<td>214,120 lbs.</td>
</tr>
<tr>
<td>Control Points</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Chilled Beams</td>
<td>1,056</td>
<td></td>
</tr>
<tr>
<td>Piping Distribution</td>
<td>4,200 LF</td>
<td></td>
</tr>
<tr>
<td>Sensible Cooling Chiller System</td>
<td>200 Tons</td>
<td></td>
</tr>
</tbody>
</table>

### Energy Comparisons

**Active Chilled Beam (Parallel Sensible Cooling)**

- Reduced fan power – 32 % from Base VAV
- Reduced cooling energy – 46 % from Base VAV
- Reduced ductwork sizes – 18-20 ACPH to 6-8 ACH⁻¹
- Higher Pumping energy – 15% - Offset by other savings
- Higher cooling system efficiencies

**Overall 35% Reduction in Energy Costs**

### Displacement Beams

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Conventional VAV</th>
<th>Active Chilled Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Handling Units</td>
<td>$2,264,335</td>
<td>$899,610</td>
</tr>
<tr>
<td>Cooling</td>
<td>$1,627,799</td>
<td>$646,717</td>
</tr>
<tr>
<td>Heating</td>
<td>$244,267</td>
<td>$97,046</td>
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<tr>
<td>Duct Distribution</td>
<td>$1,481,709</td>
<td>$1,111,282</td>
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<tr>
<td>Control Points</td>
<td>$1,200,000</td>
<td>$1,140,000</td>
</tr>
<tr>
<td>Chilled Beams</td>
<td>$1,652,984</td>
<td></td>
</tr>
<tr>
<td>Piping Distribution</td>
<td>$266,444</td>
<td></td>
</tr>
<tr>
<td>Sensible Cooling Chiller System</td>
<td>$265,373</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>$6,818,109</td>
<td>$6,079,456</td>
</tr>
</tbody>
</table>
Displacement Conditioning

Advantages

- Identical classrooms
- Tests conducted over two week period
- CO₂ concentration at six foot level monitored
  - Mixed system: 1200 PPM
  - DV System: 400 PPM

Minnesota Elementary School

<table>
<thead>
<tr>
<th>CO₂ Concentration (PPM)</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>800</td>
</tr>
<tr>
<td>600</td>
<td>1000</td>
</tr>
<tr>
<td>800</td>
<td>1200</td>
</tr>
<tr>
<td>1000</td>
<td>1400</td>
</tr>
</tbody>
</table>

Displacement System Air Handling Unit Design

Exhaust Air
2700 CFM @ 84°F

Return Air
8100 CFM @ 83°F

Outside Air
2700 CFM @ 84°F

Supply Air
8100 CFM @ 83°F
**Displacement with Induction**

Cooling mode operation

- **Primary Airflow** 450 CFM (52 to 55°F)
- **Chilled Water**
- **Room Air** 900 CFM (75 to 78°F)
- **Supply Airflow** 1350 CFM (52 to 68°F)
- **Return Air** 450 CFM (82 to 85°F)
- 100% Exhausted

**Displacement with Induction Air Handling Unit Design**

Airflow quantities based on 6 classrooms per AHU

- **Exhaust Air** 2700 CFM @ 84°F
- **Return Air** 450 CFM @ 83°F
- **Outside Air** 2700 CFM @ 94°F
- **Primary Air** 2700 CFM @ 51°F

**Chilled Ceilings and Beams**

*Early 2000's*

- **Chilled Ceilings**
- **Passive Beams**
- **Active Beams**
- **Multi-service Beams**

- Reduced trade coordination
- Reduced construction cycles
- Production vs. construction

**The Future**

- CHW & HW piping
- Sprinkler pipes
- Primary air duct
- Control valves & actuators
- Lighting
- Occupancy and/or smoke sensors
- PA system
Multi Service Beams

Indirect Lighting

Passive Multi-Service Beam

Production vs Construction

- Reduce on site fixed costs
- Reduce trade coordination
- Improved quality control
- Reduce design coordination
- Reduce construction schedule
- Deliver building earlier
MSCB Economics

Cost Calculations

- Class A Office Building
- Location: Chicago, Illinois
- 250,000 NSF, 200,000 RSF
- 10 Floors, 25,000 ft² per floor
- Construction Cost: $150 per ft²
- Fixed Site Costs: 12%
- Construction Time: 24 months
- Net Lease Rate: $25 per ft²

Capital Costs

- Building Construction Cost: $37,500,000
- Fixed Site Costs: 12% of $37,500,000 = $4,500,000
- Construction Loan Interest: 5% of $18,750,000 = $938,000
- Accelerated Revenue: $5,000,000

$37,500,000
$4,500,000
$938,000
$5,000,000

$43,000 per week
$16,000 per week
$96,000 per week
$157,000 per week

First Cost Comparison

Conventional VAV System
- HVAC Run out Costs: $2,000,000
- Air Handling Units: $675,000
- Air Cooled Chillers: $240,000

Multi-service Beams
- MSCB’s: $4,180,000
- Air Handling Units: $270,000
- Air Cooled Chillers: $240,000

Less: Lighting Installation Costs ($1 per ft²): $250,000
Less: Suspended Ceiling ($4 per ft²): $1,000,000

$4,690,000
$4,180,000
$1,000,000

$18.76/ft²
$18.76/ft²
$13.76/ft²

$2,270,000
$2,000,000
$1,000,000

$11.07/ft²
$10.70/ft²
$13.06/ft²

$1,000,000
$1,000,000

$3,440,000
$1,000,000

$13.76/ft²
$10.70/ft²

$3,060,000

$765,000

Premium for MSCB over VAV: $765,000

* Annual interest cost
### Capital Costs

**Actual Scenario (worst case):**
- Owner is able to rent 25% of space immediately
- MSCB reduce construction time by 10% (10 weeks)

- Building Construction Cost: $37,500,000
  - $250,000 ft² x $150/ft²
- Fixed Site Costs: 12% of $37,500,000 = $4,500,000
- Construction Loan Interest: 5% of $18,750,000 = $938,000
- Accelerated Revenue: 25% x 200,000 ft² x $25/ft² = $1,250,000

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Weekly Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Construction</td>
<td>$37,500,000</td>
<td></td>
</tr>
<tr>
<td>Fixed Site Costs</td>
<td>$4,500,000</td>
<td>$43,000</td>
</tr>
<tr>
<td>Construction Loan Interest</td>
<td>$938,000</td>
<td>$18,000</td>
</tr>
<tr>
<td>Accelerated Revenue</td>
<td>$1,250,000</td>
<td>$24,000</td>
</tr>
</tbody>
</table>

**Net cash result** = $850,000

*Annual interest cost*

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### Payback Analysis

**Worst Case Scenario**

- Initial Cost Premium: $765,000*
- Early Delivery Worst Case Cash Flow Effect: $850,000

**Immediate Payback!**

HVAC Energy Savings ($0.50/ft²) = $125,000 annually