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Delivering Building Performance and Energy Efficiency

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Active Chilled Beams (ACB): Rising Contender or Passing Fad
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Presentation available at: http://doas.psu.edu/FTL.pptx
Presentation outline

Introduction

History of Chilled Beams

Basic ACB defined

ACB enhancements available

Primary air to the ACB

Emergence of ACB technology in the USA

Primary errors observed in US applications.

Conclusion
Introduction

• Technical expertise represented in this session, Eng., contractors, owners, service, investor, manuf.
• Experience with ACBs represented in this session
• Experience with DOAS represented in this session
• Service areas west of the Rocky Mountains.
History of ACBs

- Carrier induction boxes (IB)

The perimeter induction terminal system was the system of choice for 1930’s to 1950’s mid-town high-rise office towers.
History of ACBs

IBs fell into disfavor and were replaced during the 1950’s with fan coil units in the USA.

• Negative aspects of the perimeter wall induction terminal:
  o Excessive fan energy associated with the high pressure primary air requirements of the nozzles (up to 2 in. wg) and
  o Rezoning difficulties did not meet the needs of new building occupancy profiles.
  o So the perimeter induction terminal system became a system of the past and was replaced largely by fan coil units.
History of ACBs

- Impact of the October 1973 Middle East Oil Embargo on HVAC systems:
  - Europe, focus was concentrated on chilled ceilings and beams. Their major changes from the US IB approach:
    - Ceiling vs window placement
    - Much more efficient nozzles, capable of high induction with 80% lower primary air pressures—reducing fan energy (< NC 30).
  - USA, focus shifted from constant volume systems to VAV.
Basic ACB defined

A chilled beam is an air distribution device with an integral coil that may be installed within a space in order to provide sensible cooling and heating.

ACBs are those that have ductwork supplied to them providing a specific amount of primary air to the pressurized plenum within the device to be discharged through induction nozzles, mix with entrained air, and ventilate the room.
Basic ACB defined

Main elements
- Air box
- Induction nozzles
- Sen. Coil
- Room air grill
- M.A. Disc louver
- Condensate pan
Basic ACB defined

Manuf. Lit. has rich design information including:

• Control
  o Air flow
  o Water flow
  o Condensation

Chilled Beam Design Guide
ACB enhancements available:

- Mounting configurations
Open Office Area
Individual Office Area
Beam above pendant light
ACB enhancements available:

- Multi-Service Beams:
  - services can include,
    - heating & cooling,
    - fresh air supply,
    - uplighting, downlighting, emergency lighting, and fully addressable lighting solutions etc.
    - ATC sensors, control valves & condensation detectors
    - fire alarms and sprinkler heads
    - acoustic insulation
    - pipework, ductwork & compartmental trunking
ACB enhancements available:

• Multi-Service Beam
# Primary air to the ACB

## Default Values

<table>
<thead>
<tr>
<th>Occupancy Category</th>
<th>Default Values</th>
<th>Combined Outdoor Air Rate (see Note 5)</th>
<th>Air Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occupant Density (see Note 4)</td>
<td>cfm/person</td>
<td>L/s·person</td>
</tr>
<tr>
<td></td>
<td>#/1000 ft² or #/#100 m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educational Facilities</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Daycare (through age 4)</td>
<td>25</td>
<td>17</td>
<td>8.6</td>
</tr>
<tr>
<td>Daycare sickroom</td>
<td>25</td>
<td>17</td>
<td>8.6</td>
</tr>
<tr>
<td>Classrooms (ages 5–8)</td>
<td>25</td>
<td>15</td>
<td>7.4</td>
</tr>
<tr>
<td>Classrooms (age 9 plus)</td>
<td>35</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Lecture classroom</td>
<td>65</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Office Buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office space</td>
<td>5</td>
<td>17</td>
<td>8.5</td>
</tr>
<tr>
<td>Conference/meeting</td>
<td>50</td>
<td>6</td>
<td></td>
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</table>

- ~45°F DPT
- ~36°F DPT
- ~25°F DPT
Unit to condition Primary ACB ventilation air

SA DBT, DPT to decouple space loads?
Hot & humid OA condition
Ft. Lauderdale, FL:

- Wet, 7,280 hours
- Triangle, 965 hours
- Dry, 515 hours
Alternate Unit to condition Primary ACB ventilation air
Primary air to the ACB

- Functions:
  - Remove the entire space Latent Load (generally requires low SA DPTs — 45-50F)
Primary air to the ACB

• Functions:
  ○ Keep the space DPT low enough that the ACB coils can remove the design space sensible loads without:
Primary air to the ACB

- Functions:
  - Pressurize the building
Primary air to the ACB

- Functions:
  - Source of reserve latent cooling capacity
Primary air to the ACB

- Functions:
  - Vehicle to induce room air across the ACB sensible cooling coils
Primary air to the ACB

- Functions:
  - Provide a part of the space sensible cooling
Primary air to the ACB

• Functions:
  o DCV is effective at minimizing overcooling with low primary air temperatures in spaces with highly variable occupancy patterns (a variable volume supply of primary air)
Primary air to the ACB

• Another name for systems employing such primary air along with ACBs: Dedicated Outdoor Air Systems (DOAS).

Link:  http://doas-radiant.psu.edu
Emergence of ACB technology in the USA

• Proper ACB system design advantages over all-air VAV system designs
  o Fan energy
  o Chiller op cost
  o Comfort
  o Enhanced IEQ
  o Reduced Op cost
  o Reduced First cost Low maintenance costs (No moving parts)
  o Cooling Capacity: \( \sim 32 \text{ – } 125 \text{ Btuh/ft}^2 \)
Emergence of ACB technology

- First major systems
- ACB availability domestically and internationally
- Existence of an ACB association of manufacturers

Chilled Ceilings
Passive Chilled Beams
Active Chilled Beams
Emergence of ACB technology in the USA, Cons
Emergence of ACB technology in the USA, Cons

ASHRAE Journal May 2013 feature article

VAV Reheat Versus Active Chilled Beams & DOAS

By Jeff Stein, P.E., Member ASHRAE; and Steven T. Taylor, P.E., Fellow ASHRAE
Emergence of ACB technology in the USA, Cons

ASHRAE Journal May 2013 feature article conclusion.

- the VAV reheat system had:
  - the lowest first and energy costs
  - many of the supposed advantages of ACB+DOAS relative to VAVR turned out to be largely overstated, such as:
    - improved indoor air quality and
    - a lower floor/floor height.
Emergence of ACB technology in the USA, Cons

- ASHRAE Journal May 2013 article **ERRORS**:

  1. The 33,900 cfm of ventilation air used in the design exceeds by 250% the 13,574 cfm minimum required by ASHRAE Std. 62.1.

  2. At 24 cfm/p it is difficult to achieve the 49.4F DPT with the 45 F campus CHWS, and even more difficult when supplying 17 cfm/p at 46.7F SA DPT.
Emergence of ACB technology in the USA, Cons

• ASHRAE Journal May 2013 article **ERRORS**:

3. The highly variable occupancy classrooms should be equipped with DCV. As a result, the DOAS SA flow rate would vary with occupancy, constrained by a space DBT override, thus operate much like a conventional VAV system.

4. The office design SA flow is 41% greater than required by 62.1. Providing the extra air adds significantly to the first and operating cost, particularly since all free cooling is eradicated by reheating to 63F.
Emergence of ACB technology in the USA, Cons:

- ASHRAE Journal May 2013 article

5. Reheating air from below 50F to 63F in an effort to minimize terminal reheat is an absolute energy and first cost travesty. Reheating that air wastes 145,000 ton-hours of cooling plus the reheat energy, and this is just the tip of the problem. Minimal if any reheat would be required in the classrooms employing DCV, and it would be most difficult to overcool the office areas with 0.09 cfm/ft$^2$ of SA at 56F.

Primary errors observed in US applications.

- SA DBT near 70F rather than 48-50F
- SA DPT near 55F which requires a much higher SA flow rate to completely remove the entire space latent load.
- SA is a mix of 100% OA and centrally recirculated air
30' X 40' office space w/ 6 occupants

Assumed Sensible Loads:

At 0.6 cfm/ft², (i.e. internal)

\[ Q_S = 1.08 \times 0.6 \times 1,200 \times (75-55) \]

\[ Q_S = 15,550 \text{ Btu/hr} \]

At 1.0 cfm/ft², (i.e. external)

\[ Q_S = 1.08 \times 1.0 \times 1,200 \times (75-55) \]

\[ Q_S = 25,920 \text{ Btu/hr} \]
Manufacturers selection software
ACB configuration used
## Manufacturers selection software

<table>
<thead>
<tr>
<th>Input DID</th>
<th>2 water circuits</th>
<th>1 water circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\text{water DID}</td>
<td>1.0000 GPM</td>
<td>0.4845 GPM</td>
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<tr>
<td>Unit length</td>
<td>8.0 ft</td>
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<tr>
<td>Nozzle-type</td>
<td>b</td>
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<tr>
<td>V\text{air-primary DID}</td>
<td>60.0 CFM</td>
<td></td>
</tr>
<tr>
<td>No-nozzles active</td>
<td>28.3 l/s</td>
<td>60</td>
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### Input temperatures

<table>
<thead>
<tr>
<th></th>
<th>cooling</th>
<th>heating</th>
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<tbody>
<tr>
<td>T\text{air-primary}</td>
<td>48.0 °F</td>
<td>56.0 °F</td>
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<tr>
<td>T\text{room / rel. Humidity}</td>
<td>74.0 °F</td>
<td>70.0 °F</td>
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<tr>
<td>T\text{water-flow}</td>
<td>56.0 °F</td>
<td>100.0 °F</td>
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### Manufacturers selection software

<table>
<thead>
<tr>
<th>results</th>
<th>2 water circuits</th>
<th>1 water circuit</th>
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<tr>
<td>$\Delta t_{\text{water}}$</td>
<td>cooling: -5.2 °F</td>
<td>heating: 14.8 °F</td>
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<tr>
<td></td>
<td>cooling: -8.1 °F</td>
<td>heating: 13.6 °F</td>
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<tr>
<td>$T_{\text{water-return}}$</td>
<td>61.2 °F</td>
<td>85.2 °F</td>
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<tr>
<td></td>
<td>64.1 °F</td>
<td>86.4 °F</td>
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<tr>
<td>$\Delta T$ room - water flow</td>
<td>-18.0 °F</td>
<td>30.0 °F</td>
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<tr>
<td></td>
<td>-18.0 °F</td>
<td>30.0 °F</td>
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<tr>
<td>$\Delta T$ Room water average</td>
<td>-15.4 °F</td>
<td>22.6 °F</td>
</tr>
<tr>
<td></td>
<td>-13.9 °F</td>
<td>23.2 °F</td>
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<tr>
<td>$Q_{\text{water DID}}$</td>
<td>-2626 BTUH</td>
<td>1852 BTUH</td>
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<td></td>
<td>-1973 BTUH</td>
<td>3288 BTUH</td>
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<tr>
<td>$Q_{\text{air DID}}$</td>
<td>-1713 BTUH</td>
<td>-919 BTUH</td>
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<tr>
<td></td>
<td>-1713 BTUH</td>
<td>-919 BTUH</td>
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<tr>
<td>$Q_{\text{DID}}$</td>
<td>-4339 BTUH</td>
<td>933 BTUH</td>
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<td></td>
<td>-3686 BTUH</td>
<td>2369 BTUH</td>
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<td>$\Delta P_{\text{water}}$</td>
<td>7.1 ft WG</td>
<td>0.2 ft WG</td>
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<tr>
<td></td>
<td>1.3 ft WG</td>
<td>1.2 ft WG</td>
</tr>
<tr>
<td>$\Delta P_{\text{air}}$</td>
<td></td>
<td>0.3 inches WG</td>
</tr>
<tr>
<td>$NC$ (incl. 10 dB absorption)</td>
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<td>17.1</td>
</tr>
</tbody>
</table>
DOAS + Local Recirc. for 15,550 Btu/hr. Sen. Space load

120 cfm DOAS, 48 F

Q_s = 4,339 Btu/hr Ea

1,175 air
2,625 Coil

8'

1,714 air
2,625 Coil

Q_s = 3,800 Btu/hr Ea

FCU Q_s = 2,335 Btu/hr

120 cfm 56 F
Don’t Turn Active Beams Into Expensive Diffusers

By Andrey Livchak, Ph.D., Member ASHRAE; and Chris Lowell, Member ASHRAE
A DOAS set of Thermodynamic State Points

ASHRAE 0.4%
Dehumidification Design
Cond.: Ft. Lauderdale

120 cfm, 84.7F,
152 gr/lb, 44.5 Btu/lb

Coil load
\[ Q_T = 4.5 \times 120 \times (44.5 - 19.17) \]
\[ Q_T = 13,680 \text{ Btu/hr} \]

OA load
\[ Q_{OA} = 13,680 - (1,140 + 3,370) \]
\[ Q_{OA} = 9,170 \text{ Btu/hr} \]

48F, 49 gr/lb,
19.17 Btu/lb

Space latent load met
based on 74F, 50%, 63 gr/lb
\[ Q_L = 0.68 \times 120 \times (63 - 49) \]
\[ Q_L = 1,140 \text{ Btu/hr or } 190 \text{ Btu/hr/p} \]

Space sensible load met
\[ Q_S = 1.08 \times 120 \times (74 - 48) \]
\[ Q_S = 3,370 \text{ Btu/hr} \]
DOAS + Local Recirc. for 25,920 Btu/hr. Sen. Space load

110 cfm DOAS, 48 F
3,138 air, 3979 Coil

Q_S = 7,117 Btu/hr

Q_S = 6,140 Btu/hr Ea

2,161 air, 3,979 Coil

56 F

220 cfm

Q_S = 6,420 Btu/hr

110 cfm

10’
DOAS w/o Local or Central Recirc. for 25,920 Btu/hr. Sen. Space load

440 cfm DOAS, 52.6 F

Q_S = 6,600 Btu/hr Ea

2,621 air
3,979 Coil

10’
A DOAS set of Thermodynamic State Points

440 cfm, 84.7°F, 152 gr/lb, 44.5 Btu/lb

Coil load

\[ Q_T = 4.5 \times 440 \times (44.5 - 21.81) \]
\[ Q_T = 44,930 \text{ Btu/hr} \]

Space latent load met based on 74°F, 50%

\[ Q_L = 0.68 \times 440 \times (63 - 59.2) \]
\[ Q_L = 1,140 \text{ Btu/hr} \]

OA load

\[ Q_{OA} = 44,930 - (1,140 + 10,170) \]
\[ Q_{OA} = 33,620 \text{ Btu/hr} \]

Space sensible load met

\[ Q_S = 1.08 \times 440 \times (74 - 52.6) \]
\[ Q_S = 10,170 \text{ Btu/hr} \]
DOAS w/ Central Recirc. for 25,920 Btu/hr. Sen. Space load

MA: 110 cfm OA & 330 cfm Recirc., 52.6 F

\[ Q_s = 6,600 \text{ Btu/hr} \text{ Ea} \]
A Mixed Air set of Thermodynamic State Points

110 cfm, 84.7F, 152 gr/lb, 44.5 Btu/lb

440 cfm, 76.7F, 85.45 gr/lb, 31.78 Btu/lb

330 cfm, 74F, 63 gr/lb, 27.53 Btu/lb

52.6 F, 59.2 gr/lb, 21.81 Btu/lb

Coil load

\[ Q_T = 4.5 \times 440 \times (31.78 - 21.81) \]

\[ Q_T = 19,740 \text{ Btu/hr} \]

\[ Q_{OA} = 8,430 \text{ Btu/hr} \text{ (110 cfm)} \]

Space latent load based on 74F, 50%

\[ Q_L = 0.68 \times 440 \times (63 - 59.2) \]

\[ Q_L = 1,140 \text{ Btu/hr} \]
DOAS + Local Recirc. for 25,920 Btu/hr. Sen. Space load

110 cfm DOAS, 48 F

$Q_s = 7,117$ Btu/hr

$Q_s = 4,700$ Btu/hr Ea (all coil)

480 cfm Recirc, 74 F
Fan Terminal Unit (FTU)
DOAS w/ local rec. for 25,920 Btu/hr. Sen. Space load

- 110 cfm 48°F
- 330 cfm recirc
- 440 cfm 52.6°F primary air
- $Q_s = 6,600$ Btu/hr Ea
- 10'
High Performance Air-Distribution Systems

By Dan Int-Bout, Fellow ASHRAE

With a proper combination of diffuser selection and variable volume series-flow fan boxes (which make ECM motors accurate, efficient, and practical), it promises to be an extremely efficient system. When paired with sensible cooling coils on the fan side (usually on the induction inlet to minimize pressure loss), one may consider eliminating the conventional air handler altogether and relying on a dedicated outdoor air system (DOAS) unit for economizer, ventilation, and humidity control.
DOAS w/ local rec. for 25,920 Btu/hr. Sen. Space load

110 cfm 48F
DOAS

1,090 cfm recirc

1,200 cfm 54.5 F SA

FTU

Diffuser
Conclusion

Active Chilled Beams (ACB): Rising Contender or Passing Fad?

- Already a big success here and abroad.
- Future look good when:
  - The ACB does not become an expensive diffuser.
  - Errors identified are all eliminated.
  - Temptation by some to make ACBs the solution for all applications is resisted.
- Time still needed to assess the FTU impact on ACB future.
Questions