Background

- VAV systems are being currently designed with minimum turndowns of 30-50% of their maximum.

- Reasons:
  - Concern over diffusers dumping unmixed cold air on occupants
  - Concern over VAV controller stability (this recently proven a non-issue)

- The fan, cooling, and reheat energy consequences are very large.

- Minimum flows of 10% meet code requirements for outside air.

- Some buildings appeared to be comfortable operating at 10% minimum flow in spite of the fear of dumping cold air.

- This project was to sort out what are the consequences of reducing the minimum flow rate in overhead systems.

*But we actually found a lot more…*
Project Overview

Objectives
- Measure energy savings (CEC-PIER funding)
- Determine comfort issues that may occur at low flow (ASHRAE funding)

Method
- Field study in 7 buildings
  - Background survey
  - “Right now” survey matched to zone trends
  - Energy monitoring
- Laboratory Study
  - Air distribution for various diffuser types

Status
- Final report and papers to ASHRAE next month
Evaluation of Low-Flow Operation for Energy Savings and Comfort

Intervention schedule, over 1.5 years

**Yahoo! Building**

- LOW minimum: 5-15%
- HIGH minimum: 30%+

- Nov. 4, 2010 to Dec. 13, 2010
- June 1st, 2011 to Aug. 5, 2011
- Oct. 10, 2011 to August 2012

**800 Ferry Building**

- HIGH minimum flow rate: 35-50%
- LOW minimum flow rate: 5-15%

- February 2011 to October 5, 2011
- September 2012

Temperature satisfaction survey results (an example: Yahoo! summer season)

"How satisfied are you with the temperature in your workspace?"

(Yahoo! warm season - 1851 votes)

- % of dissatisfied people
  - LOW min flow rate
  - HIGH min flow rate
  - selected days

Center for the Built Environment April 2013

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"How satisfied are you with the temperature in your workspace?"

<table>
<thead>
<tr>
<th>% Dissatisfied people</th>
<th>HIGH</th>
<th>LOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 Ferry summer</td>
<td>27.3%</td>
<td>12.5%</td>
</tr>
<tr>
<td>Yahoo! winter</td>
<td>8.7%</td>
<td>9.4%</td>
</tr>
<tr>
<td>Yahoo! summer</td>
<td>20.1%</td>
<td>10.3%</td>
</tr>
</tbody>
</table>

Thermal sensation distribution (Yahoo! summer)

How do you feel in your workspace right now?

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**Sense of air movement (800 Ferry building)**

*Have you noticed any air movement in your workspace?*

- No air movement
- A little
- A moderate amount
- Strong air movement

---

**Measured flow fractions: Yahoo! campus**

*Summer – All Occupied Hours*

*Winter – All Occupied Hours*
Loads are surprisingly low

California T24 minimum ventilation

140 Zones, 2 buildings, 1 warm month (Sept)

What happens when loads are lower than the VAV minimum?

Zones spend a lot of time at heating setpoint in cooling season.

Explanation for summer cold complaints. See ASHRAE 2012 Chicago Seminar 14, “Why Are We Over Cooling Buildings in the Summer”
800 Ferry average temperature vs. Standard 55

<table>
<thead>
<tr>
<th>°F</th>
<th>Building 1</th>
<th>Building 2</th>
<th>Building 3</th>
<th>Building 4</th>
<th>Building 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>(18.9)</td>
<td>(20.0)</td>
<td>(21.1)</td>
<td>(22.2)</td>
<td>(23.3)</td>
</tr>
<tr>
<td>Heating Setpoint</td>
<td>69-75 °F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling Setpoint</td>
<td>9-15% VAV mins</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ASHRAE 55 SUMMER COMFORT ZONE

Electricity Savings (Fan & Cooling)

<table>
<thead>
<tr>
<th>Building</th>
<th>High minimums</th>
<th>Low minimums</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building 1</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Building 2</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Building 3</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>Building 4</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>Building 5</td>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>

Savings:

Gas Savings (Reheat)

<table>
<thead>
<tr>
<th>Building</th>
<th>Traditional Logic</th>
<th>Dual Maximum Logic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building 1</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>Building 2</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>Building 3</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>Building 4</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>Building 5</td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>
Diffuser air distribution lab testing at Price Industries

- Diffuser types
  - square plaque
  - perforated w/ blades in neck
  - perforated w/ blades in face
  - high side wall
  - linear slot
  - round cone
- Flowrate: 18% - 80%
- Simulated load
- Measurement points: 4", 24", 42" and 66" height

Perforated diffuser temperature results

Temperature 42" above floor

Model PDN
Perforated w/ blades in neck

Distance from Diffuser (ft.) - diffuser in center of 20' wide room
**Perforated diffuser air speed results**

![Perforated diffuser air speed results graph]

- **Air Speed 42" above floor**
- **Distance from Diffuser (ft)**
- **Diffuser in center of 20' wide room**

**Diffuser testing observations**

**Diffusers mounted on ceiling – with coanda effect**
- Excellent air distribution (ADPI) down to 10% flow
- Discharge air temperature has small effect
- Air speeds decrease at lower flow

**Diffusers w/o ceiling – i.e., no coanda effect**
- Worse air distribution at low flow & potential discomfort
- Architectural and HVAC implications that need further study

*More detail will be provided by ASHRAE RP-1546*
Key findings

Comfort
- Comfort improves rather than gets worse at low flow
- Dumping & draft are not found to be an issue at low flow
- High minimums are likely a key cause of overcooling in US office buildings

Energy
- Energy savings is significant and similar to simulation predictions

Diffuser air distribution
- Good air distribution performance at low flow – supports field study findings (Exception is for diffusers without ceilings)
- Draft risk increases at high flow, not low flow

Implications

Change Standard Practice
- Market barriers removed: Controllability, comfort, air distribution
- Demonstrated benefits: Energy savings, reduced overcooling

Cost effective
- Less than 1 year payback opportunity in existing buildings
- Instantaneous payback in new construction due to minimal first cost add

Changing Codes and Standards
- Title 24-2008 requires no greater than 20% minimum (slow adoption will likely improve as a result of this project)
- Proposed ASHRAE 90.1-2013 – similar to Title 24-2008
- ASHRAE Standard 55 – potential requirement to prevent overcooling

Ongoing efforts
- CEC-PIER project will investigate potential code requirements for lower than 20%
- ASHRAE Standard 195P (proposed) – method of test for VAV controllers
Thank you

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Additional detailed discussion of results
ASHRAE RP-1515 Final Report
In progress

ASHRAE Seminar 70, Dallas, January 2013
Save Energy and Improve Comfort with Advanced VAV Zone Controls
Steve Taylor, Gwelen Paliaga, Edward Arens

ASHRAE Journal, December 2012
Dual Maximum VAV Box Control Logic
Steve Taylor, Jeff Stein, Gwelen Paliaga, Hwakong Cheng

ASHRAE Seminar 14, Chicago, January 2012
Why Are We Over Cooling Buildings in the Summer?
Presenter #2: Why is it too cold? Explanations & Solutions
Gwelen Paliaga