ASHRAE 90.1-related and Cooling Towers Topics Stakeholder Meeting #2

California Statewide Utility Codes and Standards Program

Energy Solutions
Taylor Engineering, LLC
November 10, 2010

Conference Call Number: 661-705-2010
Access Code: 94612#
Agenda

10:00 – 10:15  Introductions
10:15 – 11:00  Cooling Tower Energy Efficiency
11:00 – 12:00  Cooling Tower Water Savings
12:00 – 12:30  Chiller Efficiency
12:30 – 1:30  Lunch
1:30 – 2:15  Kitchen Ventilation
2:15 – 3:00  Garage carbon monoxide (CO) demand control ventilation
3:00 – 3:15  Break
3:15 – 4:00  Variable air volume (VAV) labs and fume exhaust
4:00 – 4:30  Closing Comments
IOU Support for 2011 Title 24

- The California Investor Owned Utilities (IOUs) are actively supporting the California Energy Commission (CEC) in developing the state’s building energy efficiency code (Title 24)
- Their joint intent is to achieve significant energy savings through the development of reasonable, responsible, and cost-effective code change proposals for the 2011 code update and beyond
- As part of the IOU effort, at the request of the CEC, we are hosting stakeholder meetings to get industry input and feedback on our code change proposals
Code Change Activity

- 2011 T-24 Base Code (Part 6 of Title 24)
- 2011 Reach Standard (Part 11 of Title 24)
  - Green Building Standard – i.e. CalGreen
  - Voluntary standards that local governments can adopt
  - Some mandatory measures
- Future Codes
  - 2014 T-24
  - Future Reach Codes
Requirements for a Successful Code Change

- For base code, a measure must:
  - Be cost-effective
    - based on the standards-induced additional first cost, maintenance costs, measure life, and energy cost savings
    - typically according to the Time Dependent Valuation (TDV) life-cycle costing methodology and weather data to be provided by the California Energy Commission
  - Be possible to implement using equipment that is available from multiple providers or that is reasonably expected to be available following the code change
Requirements for a Successful Code Change

● For each code:
  ● The CEC may be developing a separate set of cost-effectiveness metrics
  ● Measure benefits may include emissions benefits to state, benefits of water saved in energy production, etc.
ASHRAE 90.1-related and Cooling Tower CASE Topics for 2011 Title 24 Cycle

- Codes and Standards Enhancement (CASE) Topics
  - Cooling Tower Energy Efficiency
  - Cooling Tower Water Savings
  - Chiller Efficiency
  - Kitchen Ventilation
  - Garage carbon monoxide (CO) demand control ventilation
  - Variable air volume (VAV) labs and fume exhaust

- These CASE topics may have Base Code and/or Reach Code recommendations
Stakeholder Meetings Process

- **Minimum of three meetings:**
  - **First:** present scope, request data
    - Code change direction and possible options
    - Methodology
    - Best practices, market data
  - **Second:** present findings
    - Results of data collection and analysis
    - Cost effectiveness
    - “Strawman” proposed code language
  - **Third/final:** present proposed code language

- All meetings can be attended remotely
Submitting Comments

- **Informal Comment Process**
  - Comments can be submitted to CASE authors, substantive comments will receive responses
  - Questions and responses will not be posted online, but common or frequent questions will be communicated as necessary between stakeholders
  - The team will work with stakeholders to resolve issues as best we can
  - The CEC has a formal comment process during later stages of the official rulemaking process
Schedule: Key Dates

- **Mar 2010 - Dec 2010**
  - CEC develop foundation/methodology
  - IOUs:
    - Conduct research, and cost effectiveness analysis
    - Present results at stakeholder meetings

- **Feb 2011**
  - IOUs finalize code change proposals for submittal to CEC

- **Feb-July 2011 Pre-Rulemaking activities**
  - CEC workshops/First Draft Language

- **September 2011 – CEC rulemaking**
  - CEC opens Rulemaking for Title 24, develop 45-day language

- **March 1, 2012**
  - Title 24 Adoption date

- **July 2013**
  - Building Standards Commission Publication Date

- **Jan. 1, 2014**
  - Title 24 Implementation date
Meeting Protocols

- Please **DO NOT** place your phone on **HOLD**
- Please mute your microphone, unless you want to speak
- Ask questions/comment by “chat” or by voice
- We want to hear your concerns
  - Opposing viewpoints are encouraged
  - We are seeking information, not resolution
- Time is limited
  - Raise your hand and be acknowledged by presenter
  - Clearly state your name and affiliation prior to speaking
  - Speak loudly for the people on the phone
- Minutes and presentation material will be available online – we will distribute link
Cooling Tower Energy Efficiency
Stakeholder Meeting 2

Taylor Engineering, LLC
Energy Solutions
November 10, 2010
Cooling Tower Energy Savings

Agenda

- Measure scope
- Proposed code change
- Methodology
  - Market potential
  - Water and energy savings
  - Water cost savings
  - First costs and EUL
- Preliminary findings
- Next Steps
Cooling Tower Energy Savings

Measure Scope

- New construction and possibly expansion of existing plants
  - Not replacement as space is likely limited and tower basins must be at the same level.
- Commercial/ Industrial/ Institutional
- Evaporative Cooling Towers
  - Cost-effectiveness may determine a minimum size
Cooling Tower Energy Savings

Proposed Code Change

- **Mandatory:**
  - None

- **Prescriptive:**
  - **Minimum Cooling Tower Efficiency**
    - 100 gpm/hp for 24/7 facilities
    - 80 gpm/hp for all others
  - **Minimum Cooling Tower Approach**
    - 5°F approach for 24/7 plants (e.g. data centers, manufacturing facilities and labs)
    - No requirement for other facilities

- **Rationale**
  - Putting this into prescriptive will provide wiggle room for plants with space constraints.
Cooling Tower Energy Savings

Analysis (Office)

• Nominal 900 ton load
• 2 chiller plant (2 x 500t) with a 2-cell cooling tower
• Cooling towers designed for 50% flow turndown
• Used VBA TOPP model
  • The modified DOE 2 model for the chillers (EnergyPlus)
  • The DOE 2.2 model for cooling towers
  • Variable condenser water flow
  • Variable speed drive on towers
  • Optimal controls
Cooling Tower Energy Savings

TOPP Model

- **Input:**
  - Weather: time stamp, OADB, OAWB
  - CHW Load: time stamp, GPM, Ton, CHWST (CHWRT) --- from eQuest model results
  - Equipment schedule and performance curves:
    - Chiller: design data, performance curves, pressure drop
    - Tower: design WB, Ta, Tr, GPM, HP, pressure drop
    - Pumps: design Heat, GPM, BHP, HP, MechEff, MotorEff, pressure drop, Pump Efficiency curve, Pump curve
    - HXs: design cold and hot: Tin, Tout, Q, type of HX, pressure drop
    - Waterloops: design flow, pressure drop

- **Controls:**
  - %Fan = 0%~ 100% at 10% (adj.) increment
  - %Cwflow = 10%~150% at 10% (adj.) increment
  - #chiller online: 1 or 2
  - # tower online: always run maximum number of towers that satisfy towers minimum flow req.
Cooling Tower Energy Savings

Simulations Run (Office)

- **Climate:**
  3C: Oakland
  4B: Albuquerque
  5C: Chicago

- **Plant Load:**
  - Peak Load = 900 ton
  - 10% oversized: Two chillers each 500 ton.

- **Tower: A, B, C, D in the order of increasing design Approach**
  Tower A: approach = 3 ~ 5 °F
  Tower B: approach = 5 ~ 7 °F
  Tower C: approach = 7 ~ 10 °F
  Tower D: approach = 9 ~ 12 °F

- **Range:**
  -1 runs: Range = 9 °F, two CWP each 1500 gpm, 3 gpm/ton
  -2 runs: Range = 12 °F, two CWP each 1100 gpm, 2.2 gpm/ton
  -3 runs: Range = 15 °F, two CWP each 925 gpm, 1.85 gpm/ton

- **Chillers:**
  - A (Trane)
  - B (York)
Cooling Tower Energy Efficiency

Tower Efficiency LCC

1000 ton Oakland Office

- Life Cycle Energy Cost
- Tower & VFD Cost
- Piping Cost
- Cost all pumps & VFDS

90 GPM/HP
70 GPM/HP
50 GPM/HP
Cooling Tower Energy Efficiency

Tower Approach LCCA

**Oakland Office**

- **3F**
- **12F**

**Oakland Data Center**

- **3F**
- **12F**
Cooling Tower Energy Savings

Condenser Water System Costs

- 12 cooling towers
  - Each at 3 different ranges (9F to 15F DT)
  - Low, medium and high efficiency (50 to 100 gpm/hp)
  - 4 approaches (3F to 12F)

- 3 condenser water pumps (one for each range)

- We got contractor’s costs from vendors and added mark-up.
Cooling Tower Energy Savings

Estimating Cooling Tower Market

- This is covered in the next section
Next Steps

- Complete analysis for the rest of the climates
- Repeat simulations (at least a few test cases) for single stage chillers
Cooling Tower Energy Savings

Documentation

- **TOPP Model:**

- **Modified DOE2 (chiller) model:**

- **DOE 2.2 Cooling Tower Model:**
  - DOE 2.2 Engineering Manual

- **Available from** [http://tinyurl.com/23xegku](http://tinyurl.com/23xegku)
Cooling Tower Energy Savings

Questions or comments

QUESTIONS & COMMENTS
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Cooling Tower Water Savings
Stakeholder Meeting 2

California Statewide Utility Codes and Standards Program

Erika Walther
Energy Solutions
November 10, 2010
Agenda

- Measure scope
- Proposed code change
- Overview of cooling tower water use
- Methodology
  - Cooling tower market
  - Water savings
  - Water cost savings
  - First costs
  - Estimated useful life
- Preliminary LCC analysis
- Discussion
- Next Steps
Measure Scope

- New construction, major renovation, and replacement of existing cooling towers
- Commercial/Industrial/Institutional
- Open/evaporative cooling towers
  - Cost-effectiveness may determine a minimum size
Cooling Tower Water Savings

Proposed Code Change

- New cooling tower installations (new construction and replacements) and major retrofits of cooling towers must include installation of conductivity controller, flow meter on the makeup water line, and overflow alarm
  - Document max cycles of concentration, which building owner aims to meet, based on local water quality conditions
    - Requires PE review and signature
- Probable move to reach code:
  - Install water storage tank, plumbing, and treatment to utilize bleed water, e.g., for landscape irrigation, OR
  - Offset a minimum of 10% of makeup water with reclaimed or on-site water reuse
Cooling Tower Operation

- Use evaporative cooling to remove heat from water-cooled A/C systems and from industrial processes that produce heat
- Water Balance: \( M = E + B + D \)
- Typical cooling tower circulates \(~3\) gpm per ton of cooling; loses 1-2\% to evaporation, blowdown and drift
Cooling Tower Water Use

- **Cycles of concentration** is a measurement of the concentration of dissolved solids in tower water
  - 3 cycles = 3x TDS in tower as in make-up water
  - Evaporation of pure water leaves dissolved solids behind
  - Increased cycles = less bleed

- **Cooling tower system water chemistry** is managed to control:
  - Scale
  - Corrosion
  - Biological fouling
Commercial and Institutional new construction (2013): 106,027 tons
  - ~29,000,000 sq ft in 2013 (Energy Commission model)
  - Assumes 61% of CA floorspace is cooled (extrapolated from US data - 2001 Arthur D. Little report)

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Water-cooled</th>
<th>Air-cooled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Health Care</td>
<td>45%</td>
<td>55%</td>
</tr>
<tr>
<td>Lodging</td>
<td>70%</td>
<td>30%</td>
</tr>
<tr>
<td>Mercantile and Service</td>
<td>70%</td>
<td>30%</td>
</tr>
<tr>
<td>Office</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Public Buildings</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>Warehouse/ Storage</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

- Assume 100% water-cooled chiller served by cooling towers
- 0.0037 tons /sqft (average of DEER data)
Cooling Tower Market

- **Installed cooling towers in CII sectors: 19.4 million tons**
  - Using water-cooled chillers as a proxy
  - Assumes EUL of chiller is 18 years – comparable for CT?

- **Annual replacement rate**
  - e.g., (1/18 per year * 15 years)

- **Industrial new construction: TBD**

- **Typical practices of new cooling tower installations with regard to controls: TBD**
Water Savings – Controls

- Input cycles of concentration and load into a model that calculates evaporation and blowdown in each CA climate zone
  - Baseline statewide average of typical practices of cycles
  - Proposed code requirements assumed to result in running CTs at maximum cycles of concentration
  - Population-weighted statewide average for max cycles
  - Max cycles by hydrologic and climate zones
Water Savings – Controls

- Calculating maximum cycles of concentration
  - Considered three limiting factors
    - Silica ($\leq 150$ ppm)
    - Langelier Saturation Index ($\leq 2.5$)
    - pH in new cooling towers using galvanized metal ($\leq 8.3$)
      - True until metal is passivated (3-6 months)
      - Apply to new construction max cycles analysis - TBD

LSI predicts scaling: Indicates whether water will precipitate, dissolve, or be in equilibrium with calcium carbonate, and is a function of hardness, alkalinity, conductivity, pH and temperature. LSI is expressed as the difference between the actual system pH and the saturation pH.
Water Savings – Controls

- Compile water quality data from CA water utilities in major metropolitan areas, representing the 10 hydrologic regions and 16 climate zones and calculate maximum cycles of concentration
  - Sample results:

<table>
<thead>
<tr>
<th>Water Agency</th>
<th>Max cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>LADWP</td>
<td>3.47</td>
</tr>
<tr>
<td>EBMUD</td>
<td>9.75</td>
</tr>
<tr>
<td>SFPUC</td>
<td>9.25</td>
</tr>
<tr>
<td>SJ Muni</td>
<td>7.1</td>
</tr>
<tr>
<td>SCVWD</td>
<td>5.6</td>
</tr>
<tr>
<td>City of Napa</td>
<td>5.35</td>
</tr>
<tr>
<td>City of Fresno</td>
<td>3.55</td>
</tr>
<tr>
<td>Long Beach</td>
<td>3.4</td>
</tr>
<tr>
<td>City of Sac</td>
<td>7.85</td>
</tr>
<tr>
<td>City of Riverside</td>
<td>2.45</td>
</tr>
<tr>
<td>City of San Diego</td>
<td>3.17</td>
</tr>
<tr>
<td><strong>Straight Average</strong></td>
<td><strong>5.54</strong></td>
</tr>
</tbody>
</table>

- Provide exceptions as necessary (e.g., for areas where max cycles < statewide average baseline cycles) - based on hydrologic region (?)
- Will be population-weighted
Water Savings – Controls

- Baseline cycles of concentration currently assumed to average 3.5 across the state

- Actual data points from water treatment companies are welcome
Water Savings – Overflow Alarm

- Attribute a percentage savings based on water savings, customers affected, or both
- If no data available, measure may need to be dropped
Water Cost Savings

- 2009 Water costs for commercial and industrial customers
  - Black & Veatch 2009/2010 Water/Wastewater Rate Survey
    - Typical monthly water and wastewater bills for commercial and industrial customers for top 50 cities based on population
  - Population-weighted for California’s ten largest cities
Water Cost Savings

- Water cost projections - TBD
  - Possible approaches
    - Develop projection based on past water costs
    - Develop projection based on trending water bills (2001-2009) for non-res customers, subtracting out effects of increases in use
    - Approximate projections based on residential projections
      - DWR “Current Trends” scenario – 20% over 30 years
      - Black and Veatch urban water-price survey (1991-2001) – 1.1%/ year
    - U.S. CPI for Water, Sewer and Trash Service

Nov. 10, 2010
## First Costs

<table>
<thead>
<tr>
<th>Measure</th>
<th>Subcategory</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity Controller</td>
<td>Automates bleed based on conductivity</td>
<td>$750</td>
</tr>
<tr>
<td></td>
<td>Automates bleed and feed</td>
<td>$1,000 - $1,500</td>
</tr>
<tr>
<td>Conductivity Probe</td>
<td></td>
<td>$150</td>
</tr>
<tr>
<td>Makeup Flow Meter</td>
<td>Insertion or turbine</td>
<td>$265 - $1,000</td>
</tr>
<tr>
<td>Overflow Alarm/ Float Level</td>
<td></td>
<td>$500 - $1,500</td>
</tr>
</tbody>
</table>

- Mark-up and installation costs: TBD
- Scale costs to reflect CT size?
## Estimated Useful Life

<table>
<thead>
<tr>
<th>Measure</th>
<th>Subcategory</th>
<th>Warranty (years)</th>
<th>Anecdotal EUL (years)</th>
<th>EUL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity Controller</td>
<td>Automates bleed based on conductivity</td>
<td>2 to 5</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Automates bleed and feed</td>
<td>2 to 5</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Conductivity Probe</td>
<td></td>
<td>1</td>
<td>n/a</td>
<td>??</td>
</tr>
<tr>
<td>Makeup Flow Meter</td>
<td>Insertion</td>
<td>1</td>
<td>n/a</td>
<td>??</td>
</tr>
<tr>
<td></td>
<td>Turbine</td>
<td>1</td>
<td>n/a</td>
<td>??</td>
</tr>
<tr>
<td>Overflow Alarm/ Float Level</td>
<td></td>
<td>1</td>
<td>n/a</td>
<td>??</td>
</tr>
</tbody>
</table>

- Insertion, turbine, or paddlewheel meter okay for makeup line? Stainless steel and brass okay?
Preliminary LCC Analysis - Assumptions

● 15 year analysis. Year 1 = 2013

● Cycles of concentration
  - Used simplified calculation: bleed = evap/ (cycles -1)
  - Assumed 500 ton cooling tower (evap losses = 1%)
  - Baseline cycles = 3.5
  - Maximum cycles = 5.5

● Water rate held constant at $8.36/ kgal

● No savings yet applied for use of overflow alarms

● “Basic” conductivity controller

● “Middle-of-the-road” flow meter

● Installation costs not well-accounted for
Preliminary LCC Analysis - Results

- **Measure cost:** $6,000
  - First cost: $2,000
  - Replacement parts over 15 years: $4,000

- **Water savings:** 3,600 kgals

- **Water cost savings:** $30,096
  - $2,006/ year

- **Net savings over 15 years:** $24,096
Discussion

- Availability of industrial new construction projections
- Metric for converting square feet of conditioned space to tons of installed cooling tower – 0.0037?
- Typical practices of control use in cooling towers
- Can building owners/cooling tower operators get water quality they need, e.g., silica?
- Is LSI = 2.5 for maximizing cycles reasonable?
- Baseline cycles of concentration – enough data availability, e.g., from water treatment companies?
- Availability of water cost projections – if not, best option for developing?
- Estimating installation cost of measures – who responsible for install?
- Knowledge of EULs observed for various measures
Next Steps

- Finalize market data
  - Industrial new construction
  - Finalize installed tons/square foot conversion factor (0.0037 - ?)
- Complete water savings research
  - Refine water quality data - assure all hydrologic zones represented
  - Develop savings for overflow alarms
- Model water savings across climate zones
- Develop methodology for water cost projections
- Additional research on measure costs and EULs
  - Esp. overflow alarm/float level
- Finalize LCC
- Calculate statewide savings
- Develop code language
Cooling Tower Water Savings

QUESTIONS & COMMENTS

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ASHRAE 2 – Chiller Efficiency Stakeholder Meeting 2

California Statewide Utility Codes and Standards Program

Taylor Engineering, LLC
Energy Solutions
November 10, 2010
Overview

- Chiller efficiency unchanged since 2001
- Chillers not federally pre-empted but T24 has always followed 90.1
- 90.1-2007 Addenda M, BL, BT
  - Higher efficiencies
  - Two paths for compliance (Path A & Path B)
- Several options for T24 (Base code)
  - Option 1: Adopt 90.1 chiller changes
  - Option 2: Adopt 90.1 changes use only one number for each chiller category (A or B) based on LCCA
  - Either option – adopt all other 90.1 changes:
    - Delete air-cooled without condenser
    - Consolidate reciprocating and pos. displacement
    - Adopt non-standard equation and delete non-standard tables 112-H, I, J, K, L, M
### ASHRAE 2 – Chiller Efficiency

**Minimum Efficiency in 90.1-2010 and T24-2011**

**Title 24 will not allow this option**

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Size Category</th>
<th>90.1-2001</th>
<th>90.1-Addendum M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Path A</td>
<td>Path B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Full</td>
<td>IPLV</td>
</tr>
<tr>
<td>Air-cooled chillers</td>
<td>&lt;150 tons</td>
<td>9.553</td>
<td>10.407</td>
</tr>
<tr>
<td></td>
<td>&gt;=150 tons</td>
<td>9.553</td>
<td>10.407</td>
</tr>
<tr>
<td>Water cooled, Positive displacement</td>
<td>&lt;75 tons</td>
<td>0.790</td>
<td>0.676</td>
</tr>
<tr>
<td></td>
<td>75-&lt;150 tons</td>
<td>0.790</td>
<td>0.676</td>
</tr>
<tr>
<td></td>
<td>150-&lt;300 tons</td>
<td>0.718</td>
<td>0.628</td>
</tr>
<tr>
<td></td>
<td>&gt;=300 tons</td>
<td>0.639</td>
<td>0.572</td>
</tr>
<tr>
<td>Water cooled, Centrifugal</td>
<td>&lt;150 tons</td>
<td>0.703</td>
<td>0.670</td>
</tr>
<tr>
<td></td>
<td>150-&lt;300 tons</td>
<td>0.634</td>
<td>0.596</td>
</tr>
<tr>
<td></td>
<td>300-&lt;600 tons</td>
<td>0.577</td>
<td>0.550</td>
</tr>
<tr>
<td></td>
<td>&gt;=600 tons</td>
<td>0.577</td>
<td>0.550</td>
</tr>
</tbody>
</table>
### 90.1-2010 – Covered Centrifugal Chillers

<table>
<thead>
<tr>
<th></th>
<th>Current T24 and Old 90.1</th>
<th>New 90.1 and proposed T24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaving chilled water</td>
<td>40 F to 48 F</td>
<td>&gt; 36 F</td>
</tr>
<tr>
<td>Entering condenser water</td>
<td>75 to 85 F</td>
<td>&lt; 115 F &gt; LCHWT+20 F</td>
</tr>
</tbody>
</table>
Proposed Code Change

6.4.1.2 Minimum Equipment Efficiencies—Listed Equipment—Nonstandard Conditions.

6.4.1.2.1 Water-cooled centrifugal chilling packages. Equipment not designed for operation at ARI Standard 550/590 test conditions of 44°F leaving chilled-water temperature and 85°F entering condenser water temperature with 3 gpm/ton condenser water flow (and thus cannot be tested to meet the requirements of Table 6.8.1C) shall have maximum full-load kW/ton and NPLV ratings adjusted using the following equation:

Adjusted maximum full-load kW/ton rating

= \frac{\text{(full-load kW/ton from Table 6.8.1C)}}{K_{adj}}

Adjusted maximum NPLV rating

= \frac{\text{(IPLV from Table 6.8.1C)}}{K_{adj}}

where

K_{adj} = A \times B

where

A = 0.00000014592 \times (\text{LIFT})^4 - 0.0000346496 \times (\text{LIFT})^3 + 0.00314196 \times (\text{LIFT})^2 - 0.147199 \times (\text{LIFT}) + 3.9302

\text{LIFT} = \text{LvgCond} - \text{LvgEvap} (°F)

\text{LvgCond} = \text{Full-load leaving condenser fluid temperature} (°F)

\text{LvgEvap} = \text{Full-load leaving evaporator fluid temperature} (°F)

B = 0.0015 \times \text{LvgEvap} + 0.934
**Proposed Code Change**

The adjusted full-load and NPLV values are only applicable for centrifugal chillers meeting all of the following full-load design ranges:

- Minimum Leaving Evaporator Fluid Temperature: 36°F
- Maximum Leaving Condenser Fluid Temperature: 115°F
- LIFT \( \geq 20°F \) and \( \leq 80°F \)

Manufacturers shall calculate the adjusted maximum kW/ton and NPLV before determining whether to label the chiller per 6.4.1.5. Compliance with 90.1-2007 or -2010 or both shall be labeled on chillers within the scope of the Standard.

Centrifugal chillers designed to operate outside of these ranges are not covered by this standard.

**6.4.1.2.2 Positive displacement (air- and water-cooled) chilling packages.** Equipment with a leaving evaporator fluid temperature higher than 32°F, shall show compliance with Table 6.8.1C when tested or certified with water at standard rating conditions, per the referenced test procedure.
## Proposed Code Change

### ASHRAE 2 – Chiller Efficiency

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Size Category</th>
<th>Path B</th>
<th>Test Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-Cooled Chillers</td>
<td>&lt;150 tons</td>
<td>NA&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥150 tons</td>
<td>NA&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Air-Cooled without Condenser, Electrical Operated</td>
<td>All Capacities</td>
<td>Air-cooled chillers without condensers must be rated with matching condensers and comply with the air-cooled chiller efficiency requirements</td>
<td></td>
</tr>
<tr>
<td>Water cooled, Electrically Operated, Reciprocating</td>
<td>All Capacities</td>
<td>Reciprocating units must comply with water cooled positive displacement efficiency requirements</td>
<td>ARI 550/590</td>
</tr>
<tr>
<td></td>
<td>&lt;75 tons</td>
<td>≤0.800 kW/ton</td>
<td>≤0.600 IPLV</td>
</tr>
<tr>
<td></td>
<td>≥75 tons and &lt; 150 tons</td>
<td>≤0.790 kW/ton</td>
<td>≤0.586 IPLV</td>
</tr>
<tr>
<td></td>
<td>≥150 tons and &lt; 300 tons</td>
<td>≤0.718 kW/ton</td>
<td>≤0.540 IPLV</td>
</tr>
<tr>
<td></td>
<td>≥300 tons</td>
<td>≤0.639 kW/ton</td>
<td>≤0.490 IPLV</td>
</tr>
<tr>
<td>Water Cooled Electrically Operated, Positive Displacement</td>
<td>&lt;150 tons</td>
<td>≤0.639 kW/ton</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥150 tons and &lt; 300 tons</td>
<td>≤0.450 IPLV</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥300 tons</td>
<td>≤0.600 kW/ton</td>
<td>≤0.400 IPLV</td>
</tr>
<tr>
<td></td>
<td>≥600 tons</td>
<td>≤0.590 kW/ton</td>
<td>≤0.400 IPLV</td>
</tr>
</tbody>
</table>
Rationale for a Single Path

- Lower life-cycle cost
- Less confusion
Estimated Energy Savings

- **Energy savings estimated by energy model**
  - Large office building (10 floors, 100,000 sqft)
  - 5 zones per floor
  - Undiversified internal loads

<table>
<thead>
<tr>
<th></th>
<th>Lighting (W/sqft)</th>
<th>Equipment (W/sqft)</th>
<th>Occupancy (sqft/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st floor perimeter zones</td>
<td>1.00</td>
<td>0.52</td>
<td>100</td>
</tr>
<tr>
<td>1st floor interior zone</td>
<td>0.76</td>
<td>0.34</td>
<td>215</td>
</tr>
<tr>
<td>2nd - 8th floor perimeter zones</td>
<td>1.31</td>
<td>1.48</td>
<td>85</td>
</tr>
<tr>
<td>2nd - 8th floor interior zones</td>
<td>1.05</td>
<td>0.98</td>
<td>80</td>
</tr>
</tbody>
</table>

- System: large VAV AHU with CWH & HW coils, 55°F SAT
- Chiller plant
  - 2 equally-sized chillers
  - Chillers sized based on load
  - 1 2-cell cooling tower (water-cooled chillers)
  - CHW loop: 10°F delta T, CW loop: 18°F delta T
  - CHWST: 44°F with reset up to 47°F, CWST: fixed 65°F
ASHRAE 2 – Chiller Efficiency

Estimated Energy Savings

- Chiller models from Dick Lord, Trane. Used by 90.1.
- Water-cooled Centrifugal, 150 - 300 tons
AHRAE 2 – Chiller Efficiency

Estimated Energy Savings

- Chiller models
- Water-cooled Centrifugal, 150 – 300 tons
  - Path B chillers have a lower kw/ton at low part load ratios.
**ASHRAE 2 – Chiller Efficiency**

**Estimated Energy Savings**

- Chiller load profile, CZ 03: shows majority of hours are at low load condition.
ASHRAE 2 – Chiller Efficiency

Estimated Energy Savings

- Annual energy savings over ASHRAE 2007 per ton chiller capacity

![Graph showing estimated energy savings](image-url)
### ASHRAE 2 – Chiller Efficiency

#### Estimated Cost

- **Incremental cost from chiller manufacturers**
  - Cost source: AHRI

<table>
<thead>
<tr>
<th>Category</th>
<th>Incremental $/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Cooled &gt;150 tons</td>
<td>Path B</td>
</tr>
<tr>
<td>Air Cooled &lt;150 tons</td>
<td>Path A</td>
</tr>
<tr>
<td>Centr. &gt;600 tons</td>
<td>Path B</td>
</tr>
<tr>
<td>Centr. &gt;300 and &lt;600</td>
<td>Path A</td>
</tr>
<tr>
<td>Centr. &gt;150 and &lt;300</td>
<td>Path B</td>
</tr>
<tr>
<td>Centr. &lt;150 tons</td>
<td>Path A</td>
</tr>
<tr>
<td>WCPD &gt;300 tons</td>
<td>Path B</td>
</tr>
<tr>
<td>WCPD &gt;150 and &lt;300</td>
<td>Path A</td>
</tr>
<tr>
<td>WCPD &gt;75 and &lt;150</td>
<td>Path B</td>
</tr>
<tr>
<td>WCPD &gt;75 and &lt;150</td>
<td>Path A</td>
</tr>
<tr>
<td>WCPD &lt;75 tons</td>
<td>Path B</td>
</tr>
<tr>
<td>WCPD &gt;300 tons</td>
<td>Path A</td>
</tr>
</tbody>
</table>

The diagram above illustrates the incremental costs for different categories of chillers, with two paths (A and B) indicated for each category.
ASHRAE 2 – Chiller Efficiency

Cost Effectiveness

- Simulation results: 15-year life-cycle cost of chillers per ton

![Cost Effectiveness Chart](chart.png)
ASHRAE 2 – Chiller Efficiency

Cost Effectiveness

- Simulation results: 15-year life-cycle cost of chillers per ton
ASHRAE 2 – Chiller Efficiency

Next Steps

- Run simulation in remaining 12 climate zones
- Calculate state-wide savings
ASHRAE 2 – Chiller Efficiency

QUESTIONS & COMMENTS

Contact Jeff Stein at Taylor Engineering
jstein@taylor-engineering.com
510-263-1547
Kitchen Ventilation Proposals
Stakeholder Meeting #2

California Statewide Utility Codes and Standards Program

Jeff Stein
Taylor Engineering
November 10, 2010
ASHRAE 5 – Kitchen Ventilation

Agenda

- Current Code – T24, 90.1
- Proposal 1 – Scope and Definitions
- Proposal 2 – No Short Circuit Hoods
- Proposal 3 – Must Use Available Transfer Air
- Proposal 4 – Maximum Hood CFMs
- Proposal 5 – Required Energy Features: DCV, or ERV, or…
- Proposal 6 – Acceptance Testing
ASHRAE 5 – Kitchen Ventilation

Current Code Requirements

- No Current Kitchen Ventilation Requirements in T24
- **ASHRAE 90.1-2007:**
  - Kitchen Hoods. Individual kitchen exhaust hoods larger than 5000 cfm shall be provided with makeup air sized for at least 50% of exhaust air volume that is
    - unheated or heated to no more than 60°F and
    - uncooled or cooled without the use of mechanical cooling.
- **ASHRAE 90.1-2010:**
  - Major changes from 90.1-2007
  - The proposed requirements on the following slides are the same as 90.1-2010 with minor changes
Proposal 1 – Scope and Definitions

Scope

- Make it clear that kitchen ventilation cannot use the process exception

Nonresidential Standard Section 3.2 Definitions

Add new terms:

- Makeup Air = direct OA into kitchen
- Transfer Air = air from nearby zone (e.g. dining)
- Replacement Air = makeup + transfer + infiltration
- Other necessary terms listed in ASHRAE Standard 154
Proposal 2 – Direct Replacement of Hood Exhaust Air Limitation: Code Statement

**Proposed Code Statement:**

Replacement air introduced directly into the hood cavity of kitchen exhaust hoods shall not exceed 10% of the hood exhaust airflow rate.
Proposal 2 – Direct Replacement of Hood Exhaust Air Limitation: Rationale

- AGA and CEC have shown direct supply greater than 10% of hood exhaust in Short-circuit Hoods significantly reduces Capture and Containment (C&C)
- Poor C&C does not remove cooking heat and smoke from kitchen
- Exhaust rates generally higher to offset poor C&C
  - Higher exhaust fan energy
  - Higher Exhaust rates increase Room Makeup Air rates
    - Higher MUA fan and conditioning energy
Proposal 2 – Direct Replacement of Hood Exhaust Air Limitation: Planned Analysis

Lifecycle Cost Analysis Comparing

A. Short-circuit exhaust system
B. Equally effective C&C Non-short-circuiting hood system

Equipment Cost Differential

<table>
<thead>
<tr>
<th>Description</th>
<th>1,500 CFM Exhaust Only Hood System</th>
<th>3,000 CFM Short-circuit Hood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hood Cost</td>
<td>$ 1,339</td>
<td>$ 2,283</td>
</tr>
<tr>
<td>Exhaust Fan Cost</td>
<td>$ 700</td>
<td>$ 816</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 2,039</strong></td>
<td><strong>$ 3,643</strong></td>
</tr>
<tr>
<td>Cost Difference</td>
<td></td>
<td><strong>$ 1,604</strong></td>
</tr>
<tr>
<td>BHP</td>
<td>0.405</td>
<td>0.935</td>
</tr>
<tr>
<td>1,500 CFM Exhaust Only Hood</td>
<td></td>
<td>3,000 CFM Short-Circuit Hood</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.405</strong></td>
<td><strong>1.237</strong></td>
</tr>
<tr>
<td>BHP Difference</td>
<td></td>
<td>0.83 hp</td>
</tr>
</tbody>
</table>

(Cost Data provided by equipment vendors)
Proposal 2 – Direct Replacement of Hood Exhaust Air Limitation: Statewide Savings

- Short-circuit Hoods represent approximately:
  - 20% of U.S. Market
  - 1% of California Market
Proposal 3 – Conditioned Makeup Air Limitations: Code Statement

Mechanically cooled or heated makeup air delivered to any space with a kitchen hood shall not exceed the greater of:

a) The supply flow required to meet the space heating and cooling load

b) The hood exhaust flow minus the available transfer air from adjacent spaces.

Available transfer air is that portion of outdoor ventilation air serving adjacent spaces not required to satisfy other exhaust needs, such as restrooms, not required to maintain pressurization of adjacent spaces, and that would otherwise be relieved from the building.
Proposal 3 – Conditioned Makeup Air Limitations: Rationale

- Supplying conditioned makeup air when transfer air is available is a wasteful design practice and should be prohibited.

- Using available transfer air saves energy and reduces the first cost of the kitchen makeup unit and the exhaust system in the adjacent spaces.

- A previous version of this proposal did not allow makeup air if 100% transfer air was available (i.e. a recirc unit was required for conditioning). It turns out, however, that a MAU unit is more efficient than a recirc unit so this version of the proposal is now essentially the same as the 90.1 requirement.
Proposal 3 – Conditioned Makeup Air Limitations: DCV

- Note that the dining room is exempt from the DCV requirement per:
  - EXCEPTION 2 to Section 121(c)3: Where space exhaust is greater than the design ventilation rate specified in Section 121(b)2B minus 0.2 cfm per ft² of conditioned area.

- We will clarify in the users manual that "space exhaust" includes kitchen hood exhaust in adjacent spaces.
Proposal 3 – Conditioned Makeup Air Limitations: New Economizer Exception

• “Each individual cooling fan system that has a design supply capacity over 2,500 cfm …shall include an … economizer…”

• EXCEPTION 7 to Section 144(e)1: If supply flow never exceeds required exhaust flow by more than 2,500 cfm.
Proposal 3 – Conditioned Makeup Air Limitations: System Schematic

ASHRAE 5 – Kitchen Ventilation

(KITCHEN MIN OA: 500 CFM)

SUPPLY AIR TO COOL KITCHEN AT 55F: 2,000 CFM

GREASE EXHAUST: 5,000 CFM

KITCHEN

AVAILABLE TRANSFER AIR: 5,000 CFM

TOILET EXHAUST: 500 CFM

SUPPLY AIR: 10,000 CFM

MIN OA: 5,500 CFM

DINING
Proposal 3 – Conditioned Makeup Air Limitations: System Schematic

OPTION 1: MAU = COOLING CFM

KITCHEN

DINING

MIN OA: 5,500 CFM

SUPPLY AIR: 2,000 CFM

OUTSIDE AIR: 2,000 CFM

RECYCLED AIR: 0 CFM

TRANSFER AIR: 3,000 CFM

TOTAL EXHAUST: 2,500 CFM

SUPPLY AIR: 10,000 CFM

(GREASE EXHAUST: 5,000 CFM)

(KITCHEN MIN OA: 500 CFM)
Proposal 3 – Conditioned Makeup Air Limitations: System Schematic

**OPTION 2: RECIRC ONLY**

(KITCHEN MIN OA: 500 CFM)

OUTSIDE AIR: 0 CFM

SUPPLY AIR: 2,000 CFM

RECYCLED AIR: 2,000 CFM

GREASE EXHAUST: 5,000 CFM

TRANSFER AIR: 5,000 CFM

TOTAL EXHAUST: 10,000 CFM

MIN OA: 6,000 CFM

KITCHEN

DINING

SUPPLY AIR: 10,000 CFM
Proposal 3 – Conditioned Makeup Air Limitations: System Schematic

NOT ALLOWED: MAU = HOOD CFM

(KITCHEN MIN OA: 500 CFM)

OUTSIDE AIR: 5,000 CFM

GUARDIAN AIR: 5,000 CFM

SUPPLY AIR: 5,000 CFM

RECIRCULATED AIR: 0 CFM

TRANSFER AIR: 0 CFM

TOTAL EXHAUST: 5,500 CFM

SUPPLY AIR: 10,000 CFM

MIN OA: 5,500 CFM

KITCHEN

DINING
Proposal 3 – Conditioned Makeup Air Limitations: Cost Analysis

- **Cost Analysis Comparison**
  - Examine the makeup heating/cooling energy costs at all transfer rates
  - Analyze a typical kitchen exhaust and heating/cooling scenario
  - Markets: San Francisco, Sacramento, Riverside
  - Cooling CFM: 2,000 cfm
  - Exhaust CFM: 10,000 cfm
  - Most Cost Effective when transfer CFM equals Exhaust CFM minus COOLING CFM
Proposal 3 – Conditioned Makeup Air Limitations: Analysis

ASHRAE 5 – Kitchen Ventilation

100% TRANSFER EQUIVALENT TO 100% RECIRCULATION COOLING

Transfer CFM = Exhaust CFM – Cooling CFM
Proposal 3 – Conditioned Makeup Air Limitations: Statewide Savings

- Current estimated number of restaurants in California by type:
  - 30,000 quick serve restaurants (e.g. McDonald’s)
  - 30,000 full serve restaurants (e.g. Applebee’s)
  - 30,000 institutional kitchens (e.g. school cafeterias)
  - Estimated CA: 178M sf Food Service, 276M Exh CFM.
- Estimated that 2.75 million square feet of kitchen is being built per year
- Estimated 15% savings in makeup fan electrical usage and demand using available transfer air
- Estimated savings of 50% when heating and cooling energy savings are included
Proposal 4 – Exhaust Hood Airflow Limitations: Code Statement

**Proposed Code Statement:**

A kitchen/dining facility having a total kitchen hood exhaust airflow rate greater than 5,000 cfm shall be equipped with hoods with exhaust rate that complies with Table 4.

- Single hoods or hood sections installed over appliances of different duty ratings shall have maximum allowable flow rates not exceeding the Table 4 values for the highest appliance duty rating under that hood or hood section. Refer to ASHRAE Standard 154 for definitions of hood type, appliance duty, and net exhaust flow rate.
ASHRAE 5 – Kitchen Ventilation

Proposal 4 – Exhaust Hood Airflow Limitations: Code Statement

Proposed Code Statement:

Table 4: Maximum Net Exhaust Flow Rate, CFM per Linear Foot of Hood Length

<table>
<thead>
<tr>
<th>Type of Hood</th>
<th>Light Duty Equipment</th>
<th>Medium Duty Equipment</th>
<th>Heavy Duty Equipment</th>
<th>Extra Heavy Duty Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall-mounted Canopy</td>
<td>140</td>
<td>210</td>
<td>280</td>
<td>385</td>
</tr>
<tr>
<td>Single Island</td>
<td>280</td>
<td>350</td>
<td>420</td>
<td>490</td>
</tr>
<tr>
<td>Double Island</td>
<td>175</td>
<td>210</td>
<td>280</td>
<td>385</td>
</tr>
<tr>
<td>Eyebrow</td>
<td>175</td>
<td>175</td>
<td>Not Allowed</td>
<td>Not Allowed</td>
</tr>
<tr>
<td>Backshelf/Pass-over</td>
<td>210</td>
<td>210</td>
<td>280</td>
<td>Not Allowed</td>
</tr>
</tbody>
</table>

● Exceptions:

At least 75% of all the replacement air is transfer air that would otherwise be exhausted.
Proposal 4 – Exhaust Hood Airflow Limitations: Rationale

- Exhaust airflow rates in Table 4 are 30% below the minimum airflow rates in ASHRAE Standard 154-2003, which are for unlisted hoods.
- Values in Table 4 are supported by ASHRAE RP-1202 for listed hoods.
- Intended to eliminate wasteful common practice of specifying excessive exhaust airflow by selecting hoods that are not listed or have not been subjected to a recognized performance test.
- Should not increase first cost and in many cases will reduce first cost through downsizing of exhaust, supply and cooling equipment.
Proposal 4 – Exhaust Hood Airflow Limitations: Planned Analysis

- Lifecycle Cost Analysis Comparing
  - BASE CASE: Hood design using unlisted hood and code minimum (ASHRAE Standard 154 rates) exhaust rates
  - PROPOSED CASE: Hood design using listed hood and 30% better than ASHRAE Standard 154 Rates
  - EQUIPMENT COSTS SAVINGS

<table>
<thead>
<tr>
<th></th>
<th>Exhaust Hood CFM</th>
<th>Exhaust Hood Cost</th>
<th>Exhaust Fan Cost</th>
<th>Makeup Unit Cost</th>
<th>Net Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlisted Hood System, ASHRAE Std 154</td>
<td>5,550</td>
<td>$1,300</td>
<td>$2,090</td>
<td>$16,830</td>
<td>$20,220</td>
</tr>
<tr>
<td>Listed Hood System, 30% Better than Std 154</td>
<td>3,850</td>
<td>$1,300</td>
<td>$1,463</td>
<td>$11,781</td>
<td>$14,544</td>
</tr>
</tbody>
</table>

- FAN ENERGY COST SAVINGS (Excluding Heating/Cooling Savings)

<table>
<thead>
<tr>
<th></th>
<th>Exhaust Hood CFM</th>
<th>Exhaust Hood HP</th>
<th>Makeup Unit HP</th>
<th>Annual Electrical Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlisted Hood System, ASHRAE Std 154</td>
<td>5,500</td>
<td>2.98</td>
<td>4.37</td>
<td>$3,552</td>
</tr>
<tr>
<td>Listed Hood System, 30% Better than Std 154</td>
<td>3,850</td>
<td>2.32</td>
<td>1.88</td>
<td>$2,029</td>
</tr>
</tbody>
</table>
ASHRAE 5 – Kitchen Ventilation

Proposal 5 – Makeup Airflow Limitations: Code Statement

If a kitchen/dining facility has a total kitchen hood exhaust airflow rate greater than 5,000 cfm then it shall have one of the following:

a) At least 50% of all replacement air is transfer air that would otherwise be exhausted.

b) Demand ventilation system(s) on at least 75% of the exhaust air. Such systems shall:
   a) include controls necessary to modulate airflow in response to appliance operation and to maintain full capture and containment of smoke, effluent and combustion products during cooking and idle
   b) include failsafe controls that result in full flow upon cooking sensor failure
   c) allow occupants the ability to temporarily override the system to full flow
   d) be capable of reducing exhaust and replacement air system airflow rates to the larger of:
      a) 50% of the design exhaust and replacement air system airflow rates
      b) The ventilation rate required per Section 121

c) Listed energy recovery devices with a sensible heat recovery effectiveness of not less than 40% on at least 50% of the total exhaust airflow.

d) at least 75% of exhaust air volume that is
   a) unheated or heated to no more than 60°F and
   b) uncooled or cooled without the use of mechanical cooling.
Proposal 5 – Makeup Airflow Limitations: Demand Control Ventilation Systems (DCV)
Proposal 5 – Makeup Airflow Limitations: Demand Control Ventilation Systems (DCV)

- **Common Kitchen Exhaust Systems**
  - Typical control strategy: ON/OFF, Exhaust and Makeup Air fans full speed or off
  - Reality:
    - Food not being cooked at all times
    - Peak exhaust requirements not necessary at all times
    - Fans often run 24/7 to avoid fire alarms when operators forget to turn on the hood

- **DCV Exhaust Systems (e.g. – Melink or Halton MARVEL)**
  - Reduce exhaust and make up air fan speeds
  - Use sensors to determine min. exhaust required for C&C
  - In the event the operator forgets to turn the fan switch on in the morning, the system will automatically turn on as the duct temperature rises above 90F degrees. Similarly, the system will automatically turn off as the temperature drops below 75F.
Proposal 5 – Makeup Airflow Limitations: Rationale

- Kitchen designers can maximize environmental comfort and energy savings by conditioning makeup air while using a combination of available energy reducing strategies.
Proposal 5 – Makeup Airflow Limitations: Planned Analysis

- **Lifecycle Cost Analysis Comparing**
  - Base case: A kitchen system based on a non-modulating exhaust airflow and non-modulating makeup airflow
  - Proposed case: A kitchen system based on a modulating demand control exhaust airflow and modulating makeup airflow

- **Data Required**
  - Use the real life case studies presented in “Demand Control Ventilation for Commercial Kitchen Hoods”, SCE/FSTC, 2006
  - Based on Melink installations in El Pollo Loco, Panda Express, and Farmer Boys restaurants, Desert Springs Marriot, Westin Mission Hills
  - Study includes installation costs and measured energy savings
Proposal 5 – Makeup Airflow Limitations: Cost Analysis – El Pollo Loco

- Test Case: El Pollo Loco, El Monte, CA
- Retrofit Melink DCV with Variable Volume Exhaust Hood and Makeup Air System in Quick Service application.
- Retrofit Costs: $15,500
- Annual Fan Savings: 9,871 kWh per year (Exhaust and Makeup fan savings only)
- Annual Fan Savings (@ 2010 TDV $0.17): $1,718
- Breakeven Annual Maintenance (Sensors, VFD’s): $350
- Simple Payback: 11.9 years
- This is a Worst Case Scenario. (i.e.- Retrofit, Low HP, Low Diversity, excluding heating/cooling savings)
- Shorter payback in new construction, High HP, High diversity applications. (e.g. – Hotels)
Proposal 5 – Makeup Airflow Limitations: Measured Demand Reduction – El Pollo Loco

- Exhaust Fan and Makeup Air Unit Electrical Demand Before and After the DCV Retrofit. No Heating/Cooling Savings.
### Proposal 5 – Makeup Airflow Limitations: Installation Costs and Savings Summary—All Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Installation Costs ($)</th>
<th>Annual Fan EnergySaved kWh/year</th>
<th>Annual Fan Energy Cost Savings (Avg. $0.15/kWh)</th>
<th>Simple Payback (Years) (Excl Maintenance/Heating/Cooling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Pollo Loco</td>
<td>$15,500</td>
<td>9,871</td>
<td>$1,481</td>
<td>10.47</td>
</tr>
<tr>
<td>Panda Express (New Construction)</td>
<td>$8,000</td>
<td>15061</td>
<td>$2,259</td>
<td>3.54</td>
</tr>
<tr>
<td>Farmer Boys</td>
<td>$9,000</td>
<td>7884</td>
<td>$1,183</td>
<td>7.61</td>
</tr>
<tr>
<td>Desert Springs Marriott</td>
<td>28,000</td>
<td>150189</td>
<td>$22,528</td>
<td>1.24</td>
</tr>
<tr>
<td>Westin Mission Hills</td>
<td>$22,000</td>
<td>60,439</td>
<td>$9,066</td>
<td>2.43</td>
</tr>
</tbody>
</table>
Proposal 6 – Performance Testing: Code Statement

A field test method using test procedures and validations shall be used to evaluate design air flow rates and demonstrate proper capture and containment

1. This field test shall be conducted with all the appliances under the hood at operating temperatures, with all sources of ventilation and exhaust air functioning and containment visually observed with smoke or steam produced by actual or simulated cooking.

2. Systems that do not pass initially shall be modified (e.g. by adding side panels or rear ledges, reducing makeup air velocity, etc.) and retested.

3. Flow rates may be reduced below the design flow rates as long as proper capture and containment is demonstrated.

4. Where demand ventilation systems are utilized to meet Measure 5, additional performance/acceptance testing shall be required to demonstrate proper capture and containment at minimum airflow conditions.
Proposal 6 – Performance Testing: Rationale

- This section is fundamental to the kitchen exhaust system commissioning and performance verification which protects public health and safety.
- Hood systems are a field assembly of various components including hoods, fans, replacement air systems, duct and distribution systems and require testing once installed to assure specified system performance is met.
- This section requires verification of hood system performance and operation, and supports Title 24 Acceptance Test purpose and scope.
ASHRAE 5 – Kitchen Ventilation

Proposal 6 – Performance Testing: Non-DCV Acceptance Test

Equipment Testing - Design/Maximum Exhaust Conditions (Non-DCV Systems)

Step 1: Set all kitchen hoods, makeup air and transfer systems to Design Airflows

Step 1.a: Record all Design CFM's for Type I Exhausts, All Other Exhausts, Makeup Air, and Transfer Systems.

Step 2: Operate all heat producing cooking equipment at full operational conditions. Apply sample cooking products when appropriate. Observe any escaping plume of heat and/or cooking smoke beyond the edges of the Type I Hoods.

Step 2.a: Adjust Exhaust CFM until the cooking plume extends no more than 3” from hood edge.
Step 2.b: Record new Exhaust CFM.
Step 2.c: Adjust Makeup Air System CFM to match adjustment in exhaust CFM.
Step 2.d: Record new Makeup Air CFM
Proposal 6 – Performance Testing: Systems Including DCV Acceptance Test

Equipment Testing - Design/Maximum Exhaust Conditions (DCV Systems)

Step 1: Set all kitchen hoods, makeup air and transfer systems to Design Minimum Airflows

Step 1.a: Record all Design Minimum CFM’s for Type I Exhausts, All Other Exhausts, Makeup Air, and Transfer Systems.
Step 1.b: Record all Design Maximum CFM’s for Type I Exhausts, All Other Exhausts, Makeup Air, and Transfer Systems.

Step 2: Operate all heat producing cooking equipment at full operational conditions. Apply sample cooking products when appropriate. Observe any escaping plume of heat and/or cooking smoke beyond the edges of the Type I Hoods.

Step 2.a: Observe Exhaust and Makeup Air System Ramp Up in reaction to heat and smoke.
Step 2.b: Adjust Exhaust Maximum CFM until the cooking plume extends no more than 3” from hood edge.
   Record new Maximum Exhaust CFM.
Step 2.c: Record new Maximum Exhaust CFM
Step 2.d: Adjust new Maximum Makeup Air System CFM to match adjustment in exhaust CFM.
Step 2.e: Record new Maximum Makeup CFM
Proposal 6 – Performance Testing: Sample Acceptance Test

### 2011 ACCEPTANCE REQUIREMENTS FOR CODE COMPLIANCE

<table>
<thead>
<tr>
<th>Requirement Type</th>
<th>Kitchen Hood Acceptance Document</th>
<th>Design/Minimum Exhaust Conditions (Non-DCV Systems)</th>
<th>Design/Minimum Exhaust Conditions (DCV Systems)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>Date</td>
<td>Type 1 Kitchen Hood Acceptance Document</td>
<td>MECH 16.A</td>
</tr>
<tr>
<td>1. Equipment Testing</td>
<td>Design/Minimum Exhaust Conditions (Non-DCV Systems)</td>
<td>Results</td>
<td>Step 1: Set all kitchen hoods, makeup air and transfer systems to Design Airflows</td>
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<tr>
<td>2. Sum of all Type I Kitchen Hood Exhausts</td>
<td>CFM</td>
<td>Step 2: Operate all heat producing cooking equipment at full operational conditions. Apply sample cooking products where appropriate. Observe any escaping plume of heat and/or cooking smoke beyond the edges of the Type I Hoods.</td>
<td></td>
</tr>
<tr>
<td>3. Sum of all other Kitchen Exhausts</td>
<td>CFM</td>
<td>6. Type I Exhaust Fan Tag</td>
<td></td>
</tr>
<tr>
<td>4. Sum of all Makeup Air Systems</td>
<td>CFM</td>
<td>7. Adjust grease exhaust hood CFM until the plume extends no more than 3' from hood edge</td>
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<tr>
<td>5. Sum of all Transfer Air Systems</td>
<td>CFM</td>
<td>8. Final Design Maximum Exhaust CFM</td>
<td></td>
</tr>
<tr>
<td>6. Equipment Testing</td>
<td>Design/Minimum Exhaust Conditions (DCV Systems)</td>
<td>Results</td>
<td>9. Adjust Makeup Air airflow up or down to match Exhaust adjustment</td>
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<tr>
<td>7. Final Design Maximum Makeup Air CFM</td>
<td>CFM</td>
<td>10. Final Design Maximum Makeup Air CFM</td>
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</tr>
<tr>
<td>8. Type I Exhaust Fan Tag</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>9. Exhaust and Makeup Air System Ramp Up in relation to heat and smoke</td>
<td>Y/N</td>
<td></td>
<td></td>
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<tr>
<td>10. Adjust grease exhaust hood Max CFM until the plume extends no more than 3' from hood edge</td>
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<td></td>
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<tr>
<td>11. Final Design Maximum Exhaust CFM</td>
<td>CFM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Adjust Makeup Air airflow up or down to match Exhaust adjustment</td>
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<td></td>
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<tr>
<td>13. Final Design Maximum Makeup Air CFM</td>
<td>CFM</td>
<td></td>
<td></td>
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<tr>
<td>14. Step 3: Repeat test for each Type I Hood</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Acceptance Form:** MECH-16.A | **Date:** March 2004

---

**CA Utilities 2011 Title 24 Stakeholder Meeting for Proposed Code Changes**

Nov. 10, 2010
QUESTIONS & COMMENTS

Contact Jeff Stein at Taylor Engineering

jstein@taylor-engineering.com
510-263-1547
Garage Ventilation
Stakeholder Meeting 2

California Statewide Utility Codes and Standards Program

Jeff Stein
Taylor Engineering, LLC
November 10, 2010
403.7.1 The ventilation rate for enclosed parking garages may be modulated by a ventilation control system that conforms to all of the following:

1. CO is monitored with at least one sensor per 7,000 ft² and CO concentration at all sensors is maintained ≤ 25 ppm at all times. CO sensors shall be:
   - Certified by the manufacturer to be accurate within plus or minus 5% of measurement at a 5 to 200 ppm concentration when measured at sea level and 25°C
   - Factory calibrated or calibrated at start-up
   - Certified by the manufacturer to drift no more than 5% per year
   - Certified by the manufacturer to require calibration no more frequently than once a year. Upon detection of sensor failure, the system shall provide a signal which resets to supply ventilation in accordance with the requirements in Table 4-4.

2. If more than 20% of the vehicles stored are nongasoline–fueled then NO₂ is monitored with at least one sensor per 7,000 ft² and NO₂ concentration at all sensors is maintained ≤ 1.0 ppm at all times

3. The ventilation rate shall be at least 0.15 cfm/ft² when the garage is occupied

4. The system maintains the garage at negative or neutral pressure relative to other spaces when occupied
Proposed Code Change – Title 24

Exhaust air systems serving enclosed parking garages where the design airflow rate is greater than or equal to 5,000 cfm shall automatically detect contaminant levels and stage fans or modulate fan airflow rates to 50% or less of design capacity provided acceptable contaminant levels are maintained and shall have controls and/or devices that will result in fan motor demand of no more than 30 percent of design wattage at 50% of design airflow.
ASHRAE 8 – Garage Ventilation

Typical Practice

• Most new garages have DCV with CO
  • Generally sold with a maintenance program
  • Some sensors turn themselves off after 2 years if not calibrated

• Many existing garages are constant volume
  • Many of these have arbitrary fan schedules
    • e.g. fans operate from 7am to 9am and from 4pm to 6pm
  • Note that when garage fans are turned off stack effect sucks garage air into the building above
ASHRAE 8 – Garage Ventilation

Findings

- **Sensor Accuracy**
  - CO sensors use electrochemical and solid state sensors that have been used in critical life safety and industrial applications for over 60 years (e.g. mines)
  - Not same technology as CO₂ sensors
  - Recent studies:
    - 26 sensors in garages showed ~5% drift/yr after 2 years
    - Taylor Engineering study shown later
  - UL conducted a study on residential sensors over a period of four years. Overall they found the sensors to be very reliable (residential sensors must meet UL Std 2034)
  - Garages use an array of sensors and control to the highest signal so failure of a single sensor has little risk
ASHRAE 8 – Garage Ventilation

Estimated Energy Savings

- Energy savings based on trend reviews of actual garages with CO monitoring systems
Estimated Energy Savings

- Trend reviews done on two garages with systems installed.
- Result: 80 – 90% fan energy savings
## Estimated Cost

- Product, installation, and maintenance costs from manufacturers (with markup)

### Product Costs

<table>
<thead>
<tr>
<th>Product</th>
<th>Cost</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO sensor</td>
<td>$325</td>
<td>$/CO sensor</td>
</tr>
<tr>
<td>NO2 sensor</td>
<td>$400</td>
<td>$/NO2 sensor</td>
</tr>
<tr>
<td>Controller (&lt;32 sensors)</td>
<td>$3,000</td>
<td>$/controller</td>
</tr>
<tr>
<td>Controller (&gt; 32 sensors)</td>
<td>$4,000</td>
<td>$/controller</td>
</tr>
<tr>
<td>VFD</td>
<td>$3,338</td>
<td>$/VFD (assume 1 per 10,000 cfm)</td>
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</table>

### Installation costs

<table>
<thead>
<tr>
<th>Installation</th>
<th>Cost</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sensor installation</td>
<td>$1,650</td>
<td>$/sensor for system installation</td>
</tr>
<tr>
<td>VFD</td>
<td>$1,708</td>
<td>$/VFD (assume 1 per 10,000 cfm)</td>
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</tbody>
</table>

### Maintenance costs

<table>
<thead>
<tr>
<th>Maintenance</th>
<th>Cost</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Replace CO sensor</td>
<td>$325</td>
<td>$/sensor/5 years</td>
</tr>
<tr>
<td>Calibrate CO sensor</td>
<td>$75</td>
<td>$/sensor</td>
</tr>
<tr>
<td>Replace NO2 sensor</td>
<td>$400</td>
<td>$/sensor/2 years</td>
</tr>
<tr>
<td>Calibrate NO2 sensor</td>
<td>$75</td>
<td>$/sensor</td>
</tr>
</tbody>
</table>
**ASHRAE 8 – Garage Ventilation**

**Cost Effectiveness**

- Calculated for CZ03
- Cost-effective for all garages greater than 5,000 cfm (15-year life).

![15-year Life-Cycle Cost, CO sensors](image)
ASHRAE 8 – Garage Ventilation

Cost Effectiveness

Payback period, CO sensors only

Design Ventilation Airflow, (cfm)
**Cost Effectiveness**

- Requiring NO2 sensors in all garages is cost-effective above 13,000 cfm.

![15-year Life-Cycle Cost, CO and NO2 sensors](chart.png)
CO Sensor Field Study

- Testing sensors already installed in garages to see how they perform at various CO concentration levels.
- Garage 1: 5/5 sensors failed

<table>
<thead>
<tr>
<th>Sensor</th>
<th>0 ppm</th>
<th>35 ppm</th>
<th>50 ppm</th>
<th>100 ppm</th>
<th>200 ppm</th>
<th>Conclusion</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>volts</td>
<td>ppm</td>
<td>volts</td>
<td>ppm</td>
<td>volts</td>
<td>ppm</td>
</tr>
<tr>
<td>Sensor 1</td>
<td>0.45</td>
<td>9</td>
<td>2.29</td>
<td>45.8</td>
<td>1.2 - 0</td>
<td>-</td>
</tr>
<tr>
<td>Sensor 2</td>
<td>0.39</td>
<td>7.8</td>
<td>0.24</td>
<td>4.8</td>
<td>0.24</td>
<td>4.8</td>
</tr>
<tr>
<td>Sensor 3</td>
<td>0.44</td>
<td>8.8</td>
<td>0.24</td>
<td>4.8</td>
<td>0.24</td>
<td>4.8</td>
</tr>
<tr>
<td>Sensor 4</td>
<td>0.49</td>
<td>9.8</td>
<td>2.28</td>
<td>45.6</td>
<td>2.29</td>
<td>45.8</td>
</tr>
<tr>
<td>Sensor 5</td>
<td>0.42</td>
<td>8.4</td>
<td>0.23</td>
<td>4.6</td>
<td>0.23</td>
<td>4.6</td>
</tr>
</tbody>
</table>

- Garage 2: 4/5 sensors failed

<table>
<thead>
<tr>
<th>Sensor</th>
<th>0 ppm</th>
<th>35 ppm</th>
<th>50 ppm</th>
<th>100 ppm</th>
<th>200 ppm</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>volts</td>
<td>ppm</td>
<td>volts</td>
<td>ppm</td>
<td>volts</td>
<td>ppm</td>
</tr>
<tr>
<td>Sensor 1</td>
<td>0.98</td>
<td>0.63</td>
<td>0.98</td>
<td>1</td>
<td>0.98</td>
<td>1</td>
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<tr>
<td>Sensor 2</td>
<td>0.98</td>
<td>0.62</td>
<td>2.33</td>
<td>85</td>
<td>2.67</td>
<td>106</td>
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<tr>
<td>Sensor 3</td>
<td>0.98</td>
<td>0.00</td>
<td>0.98</td>
<td>0</td>
<td>0.98</td>
<td>0</td>
</tr>
<tr>
<td>Sensor 4</td>
<td>0.99</td>
<td>0.00</td>
<td>0.99</td>
<td>0</td>
<td>0.99</td>
<td>0</td>
</tr>
<tr>
<td>Sensor 5</td>
<td>0.98</td>
<td>0.00</td>
<td>0.98</td>
<td>0</td>
<td>0.98</td>
<td>0</td>
</tr>
</tbody>
</table>
CO Sensor Field Study

- **Garage 3: 5/5 sensors performing well**

<table>
<thead>
<tr>
<th></th>
<th>0 ppm</th>
<th>35 ppm</th>
<th>50 ppm</th>
<th>100 ppm</th>
<th>200 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ppm</td>
<td>measured ppm</td>
<td>% Diff of Full Scale</td>
<td>ppm</td>
<td>measured ppm</td>
</tr>
<tr>
<td>Sensor 1</td>
<td>0</td>
<td>31</td>
<td>-2%</td>
<td>49</td>
<td>0%</td>
</tr>
<tr>
<td>Sensor 2</td>
<td>0</td>
<td>30</td>
<td>-2%</td>
<td>46</td>
<td>-2%</td>
</tr>
<tr>
<td>Sensor 3</td>
<td>0</td>
<td>33</td>
<td>-1%</td>
<td>47</td>
<td>-1%</td>
</tr>
<tr>
<td>Sensor 4</td>
<td>0</td>
<td>35</td>
<td>0%</td>
<td>53</td>
<td>1%</td>
</tr>
<tr>
<td>Sensor 5</td>
<td>0</td>
<td>40</td>
<td>2%</td>
<td>62</td>
<td>5%</td>
</tr>
</tbody>
</table>

- All sensors are responsive. The readings that are more than a few % off are reading too high (err on the side of safety).

- **Preliminary conclusions**
  - Older garages may not be maintained well. Sensors are not calibrated when required and consequently fail.
  - New systems that are maintained work well.
  - Must somehow require quality sensors are installed and are maintained.
Ensuring Quality Sensors and Maintenance

- Potential solutions for ensuring quality sensors are installed and maintained:
  - Require a service package that includes testing, calibration, and replacement be sold with any CO-monitoring system.
  - Require sensors controller to check if sensors have failed on a regular basis and reset system to design ventilation upon a sensor failure.
  - Require sensors to automatically shut down and reset system to design ventilation after 1 year of no calibration or service.
ASHRAE 8 – Garage Ventilation

Next Steps

- Complete garage field study
- Run analysis in all 16 climate zones.
- Estimate state-wide savings.
QUESTIONS & COMMENTS

Jeff Stein
jstein@taylor-engineering.com
510-263-1547
ASHRAE 1 – Lab Exhaust Stakeholder Meeting 2

California Statewide Utility Codes and Standards Program

Jeff Stein
Taylor Engineering, LLC
November 10, 2010
6.5.7 Exhaust Systems

6.5.7.2 Laboratory Exhaust Systems. Buildings with laboratory exhaust systems having a total exhaust rate greater than 5,000 cfm shall include at least one of the following features:

a. VAV laboratory exhaust and room supply system capable of reducing exhaust and makeup air flow rates and/or incorporate a heat recovery system to precondition makeup air from laboratory exhaust that shall meet the following:

\[ A + B \geq 50\% \]

Where:

- \( A \) = Percentage that the exhaust and makeup air flow rates can be reduced from design conditions.
- \( B \) = Percentage sensible recovery effectiveness.

b. VAV laboratory exhaust and room supply systems that are required to have minimum circulation rates to comply with code or accreditation standards shall be capable of reducing zone exhaust and makeup air flow rates to the regulated minimum circulation values, or the minimum required to maintain pressurization relationship requirements. Non regulated zones shall be capable of reducing exhaust and makeup air flow rates to 50% of the zone design values, or the minimum required to maintain pressurization relationship requirements.

c. Direct makeup (auxiliary) air supply equal to at least 75% of the exhaust air flow rate, heated no warmer than 2°F below room set point, cooled to no cooler than 3°F above room set point, no humidification added, and no simultaneous heating and cooling used for dehumidification control.
Proposed Code Change

Laboratory Exhaust Systems

A. Buildings with laboratory exhaust systems having a total exhaust rate greater than X cfm (or ft2) and a minimum air change rate greater than Y air changes per hour shall incorporate a heat recovery system to precondition makeup air from laboratory exhaust. The heat recovery system must have a sensible recovery effectiveness of greater than or equal to X.

B. Buildings with laboratory exhaust systems where the minimum circulation rate to comply with code or accreditation standards is X% or less than the design exhaust airflow shall be capable of reducing zone exhaust and makeup airflow rates to the regulated minimum circulation values, or the minimum required to maintain pressurization relationship requirements.

(NOTE: office spaces in labs are already required to meet reheat limitations in Section 144)
**ASHRAE 1 – Lab Exhaust**

**Typical Practice**

- 6-12 ACH ventilation
- 100% OSA constant volume reheat systems
- 3,000 fpm exhaust at the stack
- 4”-6” pressure on the supply and exhaust fans
- Supply air temperature reset?
- Constant volume fume hoods
VAV Fume Exhaust

- Standard off the shelf technologies
- Saves fan energy (supply and exhaust)
- Reduces reheat, heating and cooling
- Improves comfort
- Safer during remodels and retrofits
- Not possible on all hoods
ASHRAE 1 – Lab Exhaust

Estimated Cost - VAV

- **Retrofits**
  - Case studies of actual labs retrofitted from constant volume to VAV gives worst-case
  - Average cost: $22/cfm. $/cfm cost decreases as design airflow increases.

- **New construction**
  - Case study done by Labs 21: $4.2/cfm
Estimated Energy Savings - VAV

- **Retrofits**
  - Case studies of retrofit labs
  - Estimated energy savings: $4.05/CFM

- **New construction**
  - Case study done by Labs 21
  - Estimated energy savings: $1.30/CFM

- **Simulation results**
  - Actual lab at Stanford
  - Vary minimum ACH
    - Decreasing savings as minimum/design airflow ratio increases.
ASHRAE 1 – Lab Exhaust

Estimated Energy Savings - VAV

- Simulation results
ASHRAE 1 – Lab Exhaust

Cost Effectiveness - VAV

- Preliminary simulation results, 15-year LCC (CZ03)
ASHRAE 1 – Lab Exhaust

Next Steps- VAV

- Run energy model and life-cycle cost analysis in more climate zones.
- Determine minimum/design airflow ratio threshold below which to require VAV.
Estimated Cost, Heat Recovery

- Compiled case studies for incremental cost from designers, manufacturers, and researchers

<table>
<thead>
<tr>
<th>Area (sqft)</th>
<th>Airflow (CFM)</th>
<th>Total</th>
<th>Per cfm</th>
<th>Per sqft</th>
</tr>
</thead>
<tbody>
<tr>
<td>NREL, Science and Technology Facility, Golden, CO</td>
<td>71,347</td>
<td>71,347</td>
<td>$80,000</td>
<td>$1.12</td>
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<tr>
<td>Gilbert Hall, sample quote from Konvekta</td>
<td>129,000</td>
<td>80,400</td>
<td>$376,961</td>
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<td>OSU Linus Pauling in Corvallis, OR</td>
<td>100,000</td>
<td>180,000</td>
<td>$116,250</td>
<td>$0.65</td>
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</tbody>
</table>

- In process of gathering more cost data
**ASHRAE 1 – Lab Exhaust**

**Energy Savings – Heat Recovery**

- Collected case studies to get estimated energy savings and design criteria.

- Savings heavily dependent on climate zone.

<table>
<thead>
<tr>
<th>Description</th>
<th>Location</th>
<th>Airflow (CFM)</th>
<th>Annual Energy Savings ($/cfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labs 21 Case Study</td>
<td>NREL, Science and Technology Facility, Golden, CO</td>
<td>71,347</td>
<td>$0.51</td>
</tr>
<tr>
<td>Labs 21 Best Practices</td>
<td>City: Minneapolis</td>
<td>1</td>
<td>$0.91</td>
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<td>Labs 21 Best Practices</td>
<td>City: Denver</td>
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<td>Labs 21 Best Practices</td>
<td>City: Seattle</td>
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<td>180,000</td>
<td>$0.02</td>
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</tbody>
</table>
ASHRAE 1 – Lab Exhaust

Energy Savings – Heat Recovery

- Preliminary results
  - Lower cooling energy
  - Lower heating energy
  - Higher fan energy (added pressure drop of coil)
  - Higher pumping energy

<table>
<thead>
<tr>
<th></th>
<th>Annual Savings ($/cfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electricity</td>
</tr>
<tr>
<td>CZ03</td>
<td></td>
</tr>
<tr>
<td>CV, eff = 0.30</td>
<td>-$0.035</td>
</tr>
<tr>
<td>CV, eff = 0.50</td>
<td>-$0.029</td>
</tr>
<tr>
<td>VAV, eff = 0.30</td>
<td>-$0.006</td>
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<tr>
<td>VAV, eff = 0.50</td>
<td>-$0.006</td>
</tr>
</tbody>
</table>
Next Steps – Heat Recovery

- Finalize energy model and run in more climate zones.
- Get more cost data for implementing heat recovery.
- Determine threshold design airflow above which to require heat recovery.
QUESTIONS & COMMENTS

Contact Jeff Stein at Taylor Engineering

jstein@taylor-engineering.com
510-263-1547