Maximizing the Performance of Leading Edge HVAC Systems

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Foundations in Low Energy Design

Annual Energy Cost by End Use

- Space Heating: 24%
- Domestic Water Heating: 14%
- Space Cooling: 12%
- Fans/Pumps: 8%
- Plug Loads: 13%
- Lighting: 29%

HVAC > 50%
Foundations in Low Energy Design

- Passive heating, cooling and ventilation strategies are the foundation of low energy building designs.
- Building envelop upgrades is money well spent.
- Reduce internal gains
- Better comfort, more individualized control

<table>
<thead>
<tr>
<th>Category</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope</td>
<td>$9,000</td>
</tr>
<tr>
<td>Lighting</td>
<td>$3,500</td>
</tr>
<tr>
<td>Equipment</td>
<td>$2,500</td>
</tr>
<tr>
<td>HVAC</td>
<td>$20,000</td>
</tr>
<tr>
<td>PV</td>
<td>$9,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$44,000</strong></td>
</tr>
</tbody>
</table>
Foundations in Low Energy Design

- Design for part-load operation.
- Use NPLV (or other part load value) when specifying equipment.
- Specify variable systems that can track load.
- Reduced pressure drops (face velocity, duct design, piping design)

### Expression of Chiller Efficiency

<table>
<thead>
<tr>
<th>Expression Of Chiller Efficiency</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of Performance-COP, WW, or Energy Efficiency Ratio - EER, Btu/kW</td>
<td>IPLV or NPLV = 0.01A + 0.42B + 0.455 + 0.12D</td>
</tr>
<tr>
<td>Power Per Ton, kW/ton</td>
<td>IPLV or NPLV = ( \frac{1}{0.01A + 0.42B + 0.45C + 0.12D} )</td>
</tr>
</tbody>
</table>

### Chiller Energy Efficiency, Load

<table>
<thead>
<tr>
<th>Chiller Energy Efficiency, Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>A at 100%</td>
</tr>
<tr>
<td>B at 75%</td>
</tr>
<tr>
<td>C at 50%</td>
</tr>
<tr>
<td>D at 25% — at 0%</td>
</tr>
</tbody>
</table>

### IPLV Rating Conditions

- Condenser, water-cooled only:
  - Entering water temperature, F [°C]: 85 [29.4], 75 [23.9], 65 [18.3], 65 [18.3], 65 [18.3]
  - Flow rate, gpm/ton [Lps per kW]: 3.0 [0.054]
  - Fouling factor, h-ft²°F/8tu [m²·C/W]: 0.00025 [0.000044]

### Evaporator:

- Leaving water temperature, F [°C]: 44 [6.7], —, —, —, 44 [6.7]
- Flow rate, gpm/ton [Lps per kW]: 2.4 [0.043]
- Fouling factor, h-ft²°F/8tu [m²·C/W]: 0.0001 [0.000018]

### NPLV Rating Conditions

- Condenser, water-cooled only:
  - Entering water temperature, F [°C]: As selected
  - Flow rate, gpm/ton [Lps per kW]: As selected
  - Fouling factor, h-ft²°F/8tu [m²·C/W]: As specified

- Evaporator:
  - Leaving water temperature, F [°C]: As selected
  - Flow rate, gpm/ton [Lps per kW]: As selected
  - Fouling factor, h-ft²°F/8tu [m²·C/W]: As specified

### Notes:

- If the chiller manufacturer's recommended minimum entering-condenser water temperature, ECWT, is greater than that specified above, then it may be used in lieu of the specified value.
- Flow rates are to be held constant at full-load values for all part-load conditions.
- For part-load ECWTs, the temperature should vary linearly from the selected ECWT to 65°F [18.3°C] for loads ranging from 100% to 50%, and should be fixed at 65°F [18.3°C] for loads ranging from 50% to 0%. 
HVAC

DOAS / Energy Recovery
Evaporative Cooling
Geothermal
Variable Refrigerant Flow
Thermal Energy Storage
Displacement Ventilation
Chilled Beam
Heating
DOAS with Energy Recovery

- The Problem: Single mixed air systems trying to address thermal comfort and IAQ
- It is difficult to verify that the ASHRAE ventilation standard 62.1 has been met with an all-air system.
DOAS with Energy Recovery

- DOAS = decoupled ventilation load = reduced fan sizing, reduced duct losses/leaks (1/5 airflow of typical VAV system).
- Couples with radiant cooling or heating technologies, distributed heat pump technology.
- DOAS Application: Buildings with large amounts of variably occupied space, such as office buildings, hospitals or schools.
- Reduced plenum height.

- ERV = Saving of 70% on outdoor air load
- Demand savings: From reduction in peak cooling power draw
- Application: Buildings in hot-humid climates or cold climates
- Reduces heating/cooling load, need for dedicated exhaust systems.
- Design considerations:
  - balance airflows
  - avoid energy penalty
DOAS with Energy Recovery
Mixed-Mode Ventilation

- Combination mechanical ventilation/natural ventilation
  - Concurrent
  - Change Over
- Alerts for occupant in some
- Moisture sensors
- CFD Analysis
- Benefits
  - Lower energy consumption
  - More controllability/satisfaction
- Drawbacks
  - Pollutant Control
  - Energy Increase
  - Cost/complexity
  - Security

- The Chesapeake Bay Foundation Environmental Center - 2000
- 37 Btu/sf/yr
Evaporative/"Free" Cooling
Evaporative Cooling

- Two-Stage Evaporative Cooling (Airside)
- Savings of up to 75% versus compressor-based cooling
- Paybacks 8 – 17 years
- Need supplemental refrigeration-based cooling
Evaporative Cooling

• Two-Stage Evaporative Cooling (Airside)
Evaporative Cooling
Water-Cooled Equipment

- **Two Stage Evaporative Cooling (Water Side)**
- Useful for direct feeding high temperature cooling applications
- Increased efficiency for compressor-based cooling systems
Evaporative Pre-Cooling
Air-Cooled Equipment

- ~10% efficiency gain
- Reduce head pressure
- Peak demand savings
- Increase capacity

Pre-Cool Module

Misting
Ground Source Heat Pump

• Takes advantage of cool ground temperatures
• DR friendly
• Reduces energy costs by up to ~40% over existing /base efficient systems
• Demand charges can be an issue

• 10-20 years SPB
• Ground loop design critical
Geothermal

- Hybrid with Ground Water “Economizer”
- Consider hybrid if 1) space constrained site, 2) to correct load imbalance, 3) high drilling cost exists

*Figure 1a* Primary/secondary loop configuration with dedicated outdoor air and GSHP ventilation mode.
*Source: Peter D’Antonio*
Geothermal

Solar Assist
**VFRZ**

- Application: Offices, schools, hotels, hospitals and other multi-room buildings where personalize conditioning is desired. Historical buildings where duct install is difficult or expensive.
- Summer peak utilities can benefit - off-peak winter load that can improve capital utilization and ROI. Decide to support based on local rates, reserve margins, regulatory environment & other factors
- Peak demand savings: Marginal, mostly part-load energy savings and savings through ability to simultaneously heat/cool.
- DR friendly

\[
\text{IEER} = (0.020 \times 100\%) + (0.617 \times 75\%) + (0.238 \times 50\%) + (0.125 \times 25\%)
\]
Schematic of a VRF heat recovery system illustrating zone control and simultaneous heating and cooling capabilities.

VFRZ

SCHE – Simultaneous Heating and Cooling efficiency
Thermal Energy Storage

- Storage of cold water via ice or water based storage system
- Demand savings: Replacing all or a portion of cooling operation during peak demand periods with stored “cooling” from off-peak chilled water production.

<table>
<thead>
<tr>
<th>% of Total</th>
<th>Building Type</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2</td>
<td>Hospital</td>
<td></td>
</tr>
<tr>
<td>23.6</td>
<td>Housing</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>Industrial</td>
<td></td>
</tr>
<tr>
<td>4.7</td>
<td>Laboratory/R&amp;D</td>
<td></td>
</tr>
<tr>
<td>22.2</td>
<td>Office</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>Prison</td>
<td></td>
</tr>
<tr>
<td>4.6</td>
<td>School</td>
<td></td>
</tr>
<tr>
<td>16.2</td>
<td>Services</td>
<td></td>
</tr>
<tr>
<td>16.7</td>
<td>Storage</td>
<td></td>
</tr>
<tr>
<td>~0</td>
<td>Utility</td>
<td></td>
</tr>
</tbody>
</table>

- Good to Excellent Potential
- Average to Good Potential
- Poor to Average Potential
Thermal Energy Storage

Evaporative TES
- 50% energy savings
- ~3 year SPB

Chiller Based TES
- ~3 year SPB on incremental cost
- Energy Savings may exist too
Thermal Energy Storage

- For winter peaking utilities, storage of heat
- Dual fuel flexibility / Hybrid Design
- Electric
- Solar Thermal
Thermal Energy Storage
Building Fabric

Thermodeck System

Phase Change Materials
Dupont Energain PCM Panel

Corvid Wall
Thermal Energy Storage

Trombe Wall
Displacement Ventilation

- Application: Buildings with high ceilings, moderate peak load densities, and require small quantities of fresh air with high air quality, such as offices, public buildings.
- Range of supply velocities and discharge temperature (60-65°F) is limited. More difficult to address high heating and cooling loads.
- Use chilled beam or radiant floor to overcome. Or recirculate portion of room air.
Displacement Ventilation

- Demand savings: Up to 20% on ASHRAE design ventilation requirements

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Supply Air Conditions</th>
<th>$E_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling supply of cool air and ceiling return</td>
<td>Supply air temperature is cooler than room air.</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>COOLING</td>
<td>Thermal displacement</td>
<td>Supply air temperature is cooler than room air and delivered at a low velocity to achieve unidirectional flow and thermal stratification.</td>
<td>1.2</td>
</tr>
<tr>
<td>Underfloor air distribution</td>
<td>Supply air temperature is cooler than room air and delivered at 150 fpm so that the supply air jet reaches at least 4.5 ft above the floor.</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>
# Displacement Ventilation

## Rectangular 1-Way Displacement Diffuser

**DF1 Series**

## Performance Data — Imperial Units

<table>
<thead>
<tr>
<th>Unit Size [Face Area, in²]</th>
<th>Inlet Size in.</th>
<th>Face Velocity FPM</th>
<th>Airflow CFM</th>
<th>Total Pressure in.wg.</th>
<th>Static Pressure in.wg.</th>
<th>Noise Criteria NC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24x24x13 [3.6]</td>
<td>8</td>
<td>20</td>
<td>72</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>30</td>
<td>108</td>
<td>0.02</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>40</td>
<td>144</td>
<td>0.03</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>50</td>
<td>180</td>
<td>0.05</td>
<td>—</td>
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<tr>
<td></td>
<td>48x24x13 [7.4]</td>
<td>8</td>
<td>20</td>
<td>148</td>
<td>0.02</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>30</td>
<td>222</td>
<td>0.04</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>40</td>
<td>295</td>
<td>0.07</td>
<td>0.02</td>
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<td></td>
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<td>8</td>
<td>50</td>
<td>363</td>
<td>0.11</td>
<td>0.04</td>
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<tr>
<td></td>
<td>20x24x13</td>
<td>8</td>
<td>20</td>
<td>162</td>
<td>0.03</td>
<td>20</td>
</tr>
</tbody>
</table>
Displacement Ventilation

- DV & UAFD – Not the same. UAFD actually produces mixing.
Radiant Cooling / Chilled Beams

• Application: Tight buildings with high sensible cooling loads, located in low-humidity cooling climates.
• Not buildings with appreciable latent loads (health/fitness clubs, pools).
• Demand Savings: Higher chilled water temperatures (55-63°F = increase cooling efficiency. Also fan energy savings (50-75%) from reduced airflow.
• Genomic Science Building at the University of North Carolina lowered HVAC costs by 20 percent.

![Diagram of Radiant Cooling / Chilled Beams](image)
Heating

Water Based Systems
- Variable flow primary
- Hybrid-Efficiency Plant
- Reduced Supply Temperature
- Large Delta T
- Biomass and Solar
- Transpired Solar Collector
Verifying Performance

- Controls
- Commissioning
- Performance Tracking

![Graph 1](image1.png)

**AHU 1-6 Primary Duct Static, WC**

- Linear regression equation: $y = 0.0077x + 0.8883$
- Coefficient of determination: $R^2 = 0.1615$

![Graph 2](image2.png)

**Total AHU 1-6 Supply Fan CFM**

- Linear regression equation: $y = 437.82x + 19024$
- Coefficient of determination: $R^2 = 0.4422$

![Graph 3](image3.png)

**Cooling Tower Fan Speed % vs. OSA Bin**

- Cooling Tower Fan Speed %
- OSA Bin #

![Graph 4](image4.png)

**Cooling Tower Fan Speed % vs. OSA Bin**

- Bin #
- OSA Bin # 1-19
Barriers to Adoption

• May take 10-20 years to achieve any significant market penetration after a technology is introduced into the market.¹

• Higher equipment costs compared to other, less efficient, technologies. New technologies do not achieve market penetration unless SPB < 2 years. ¹

Barriers to Adoption

• Installation-specific design and difficulty evaluating the suitability of individual installation sites.
• Lack of knowledge base in design, operation, servicing and maintenance and ownership costs (Education and Research).
• Perception and natural resistance to change.
• Performance uncertainties.
• Manufacturer support and spare parts availability.
For More Information

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