Department of Defense – Environmental Security Technology Certification Program

- **Goal:** Identify and demonstrate innovative and cost-effective technologies to address DoD’s high-priority environmental requirements

- **Process:** Collect cost and performance data to overcome the barriers to employ state of the art and innovative technologies
Department of Defense – Energy Use Characteristics

- Operate 300,000+ facilities worldwide
- 500+ installations
- Annual facility-related energy bill > $4 billion per year
- Very aggressive energy efficiency and renewable energy goals
DoD ESTCP Program

- Current Demonstrations
  - Automated Continuous Commissioning of Commercial Buildings
  - Wireless Platform for Energy-Efficient Building Control Retrofits
  - Daylight Redirecting Window Films
  - Coupling Geothermal Heat Pumps with Underground Seasonal Thermal Energy Storage
  - Energy Efficient Phase Change Materials (PCM) Insulation
  - Air Source Cold Climate Heat Pump

Reference: http://www.serdp.org/Program-Areas/Energy-and-Water/(list)/1/
Demonstrate the ability of new high performance indirect evaporative cooling technology to:

- Enhance cooling efficiency and comfort in dry climates
- Substantially reduce peak power demand relative to conventional air-conditioning
- Demonstrate improved comfort relative to traditional evaporative coolers
- Quantify water consumption and compare to water consumed at electric plant to power conventional a/c
Innovative indirect evaporative cooling technology developed by Coolerado Corporation

Staged cooling with wet-bulb effectiveness from 90% to 125%

No moisture added to the product airstream.

Fan is the only major energy input.


Image Credit: Coolerado
Technology Description

1. Outside air is pushed into the Coolerado Cooler heat exchanger with a single fan.
2. Product Air Channels.
3. Working Air Channels.
4. Heat from the Product Air is transferred through the thin plastic and into the Wet Channels below.
5. Working Air is backed from entering the building.
6. The blocked Working Air is turned and passed through small holes into Wet Channels below the Product Air stream.
7. The Working Air is now moving through Wet Channels perpendicular or cross flow above and below the Dry Channels.
8. The heat that is passed from the Dry Channel is converted into water vapor.
9. Heat from the Product Air has been converted into water vapor and is now rejected as exhaust to the outside air.
10. The Product Air which has now traveled the length of the heat exchanger, enters the desired space, cold and dry.

Image Credit: Coolerado

Reference:
http://www1.eere.energy.gov/femp/pdfs/tir_coolerado.pdf
Design Considerations

1. Sensitive to external static pressure
   - Image (63 F WB, 95 F DB, 80 F Space)

2. Reduced Capacity at design conditions
   - Zone temperature will float during peak conditions

3. Improved Performance at Partial Loads
# Performance Objectives

<table>
<thead>
<tr>
<th>Performance Objective</th>
<th>Metric</th>
<th>Data Requirements</th>
<th>Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantitative Performance Objectives</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve comfort provided by evaporative cooling</td>
<td>Hours of space temperature inside ASHRAE comfort conditions  Supply air temperature</td>
<td>Indoor thermostat temperature  Indoor humidity  Supply air temperature</td>
<td>&lt;1% of hours outside ASHRAE summer comfort zone  Supply air &lt;70F</td>
</tr>
<tr>
<td>Provide high efficiency cooling</td>
<td>kW/ton of cooling</td>
<td>Air flow  Temperature change  Power consumption</td>
<td>Peak energy &lt;1 kW/ton  Average energy &lt;0.6 kW/ton</td>
</tr>
<tr>
<td>Sustain cooling performance</td>
<td>Wet-bulb effectiveness  Air flow</td>
<td>Atmospheric weather monitoring  Supply air temperature  Air flow</td>
<td>&lt;5% degradation of wet-bulb eff. over 3 years  Negligible increase in supply air pressure drop</td>
</tr>
<tr>
<td>Minimize water consumption (Water Conservation)</td>
<td>gallons/ton-hr of building cooling  site water quality (TDS)</td>
<td>Water inlet flow  Water outlet flow  Water conductivity</td>
<td>Demonstrate conservation approach consuming &lt;2.5 gal/ton-hr</td>
</tr>
</tbody>
</table>
# Performance Objectives

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<tr>
<td><strong>Qualitative Performance Objectives</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintainability (Ease of use)</td>
<td>Ability of an HVAC technician to operate and maintain the technology</td>
<td>Standard form feedback from the HVAC technician on usability of the technology</td>
<td>A single facility technician able to effectively operate and maintain equipment with minimal training</td>
</tr>
<tr>
<td>Maintainability (Cost)</td>
<td>Service Frequency</td>
<td>Standard form feedback from the HVAC technician on time required to maintain</td>
<td>&gt;90% of units fall within nominal IEC maintenance schedule by project end</td>
</tr>
<tr>
<td>Maintainability (Failure)</td>
<td>Biological Fouling Freezing</td>
<td>Visual inspection</td>
<td>No signs of biological growth, including grey-water unit No ruptured water lines</td>
</tr>
</tbody>
</table>
Technical Approach

- Instrument and monitor (20) 1,800 cfm Coolerado coolers in (5+1) buildings at Fort Carson (Colorado Springs)

- Prior to deployment, representative units were fully characterized at NREL’s Advanced HVAC Lab ±5%

- Monitor for two cooling seasons – annual and peak energy use compared to conventional air conditioning

Credit: NREL

Credit: NREL Pix: 16929
Data Acquisition System

Outside Air Conditions
1. Temperature (°F)
2. Humidity (%)
3. Solar Irradiance (W/m²)

Electrical Power
4. Fan Power (Watts)

Water Consumption
5. Inlet Water Flow (GPM)
6. Outlet Water Flow (GPM)
7. Inlet and Outlet TDS

Air Flow Rates
8. Core Differential Pressure (ΔP)

Supply Air Temp
9. Temperature (°F)

Space Conditions
10. Humidity (%)
Building Installations

Classroom

Event Center

Theater

Jet Aeration and Pump House

Image Credit: Coolerado
Construction Drawings

Classroom

Event Center

Theater

Pump House

Image Credit: NREL
Construction Drawings and Photographs

Event Center

Jet Aeration

Event Center

Theater

Image Credit: NREL
Waste Water Demonstration

- Demonstration unit using treated waste water effluent in a remote setting
  - Waste water had significant algae growth and unit immediately clogged with Algae in filter and in test unit.
Colorado Springs Weather Data (TMY3)

Design Days for Cooling:
- Cooling Design Day (0.4%)
  - $T_{db}$: 90.3 °F
  - Mean Coincident $T_{wb}$: 58.8 °F
- Evaporative Design Day (0.4%)
  - $T_{wb}$: 63.3 °F
  - Mean Coincident $T_{db}$: 78.3 °F

Measured at Site 2011:
- Max Conditions July – September
  - $T_{db}$: 98.85 °F, MC $T_{wb}$: 65.5 °F
  - Maximum $T_{wb}$: 67.74 °F

<table>
<thead>
<tr>
<th>Maximum Outside Air Temperature (F)</th>
<th>Maximum Outside Air Wetbulb Temperature (F)</th>
<th>Number of Hours Above 0.4% Design</th>
<th>Percent of Cooling Season Hours above 0.4% Design (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>98.85</td>
<td>67.74</td>
<td>161</td>
<td>1.8%</td>
</tr>
</tbody>
</table>
Improve Comfort Provided by Evaporative Cooling

Success criteria #1: <1% of hours outside ASHRAE summer comfort zone

✓ Performance objective met for all facilities
Improve Comfort Provided by Evaporative Cooling

Success criteria: supply air less than 70 °F
× Performance objective met for >95% of the time

<table>
<thead>
<tr>
<th>Percent Supply Air Temp &lt; 70 °F</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>95.4%</td>
<td>99.5%</td>
<td>100.0%</td>
<td>96.9%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent Supply Air Temp &lt; 70 °F</th>
<th>Unit 1</th>
<th>Unit 3</th>
<th>Unit 5</th>
<th>Unit 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0%</td>
<td>95.4%</td>
<td>99.5%</td>
<td>99.8%</td>
<td></td>
</tr>
</tbody>
</table>
**Improve Comfort Provided by Evaporative Cooling**

**Success criteria:** supply air less than 70 °F
\[\times\]  Performance objective met for >70% of the time

<table>
<thead>
<tr>
<th>Unit</th>
<th>Percent Supply Air Temp &lt; 70 °F</th>
<th>Percent Supply Air Temp ≤ 70 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>83.5%</td>
<td>69.0%</td>
</tr>
<tr>
<td>10</td>
<td>98.1%</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>93.5%</td>
<td>78.7%</td>
</tr>
</tbody>
</table>

**Theater Supply Air Temperature**

**Jet-Aeration Facility Supply Air Temperature**
Supply Air Temperature Performance Objective Analysis
Supply Air Temperature Performance Objective Analysis
Provide High Efficiency Cooling

**Success criteria:** Peak energy < 1 kW/ton, Average energy < 0.6 kW/ton

✓ Performance objective met for all facilities
Minimize Water Consumption

Success criteria: Demonstrate conservation approach using <2.5 gal/ton-hr

 multiplicities. Performance objective not met (heat of vaporization 1.3 to 1.4 gal/ton-hr)

[Graphs showing water use efficiency over time for Event Center and Jet-Aeration Facility]
Additional Performance Metrics:

- **Sustain Cooling Performance:**
  - <5% degradation of wet-bulb eff. over 3 years
  - Negligible increase in supply air pressure drop

- **Maintainability:**
  - A single facility technician able to effectively operate and maintain equipment with minimal training

- **Maintainability:**
  - >90% of units fall within nominal IEC maintenance schedule by project end

- **Maintainability:**
  - No signs of biological growth, including grey-water unit
Additional 2011 Activities

- Waste Water catchment
  - Installed a waste water catchment system at Theater
  - One 1,500 gallon tanks w/sump pump

Image Credit: NREL
1. **Maintenance:**
   - Frozen pipes in one facility
   - Most maintenance issues were identified and resolved in first year

2. **Solenoid Failures:**
   - Three solenoid failures in first year (failed open)
   - Newer Coolerado units place solenoid inside unit with higher quality solenoid.

3. **Heat Exchanger Temperature Variation:**
   - 20% of units didn’t meet performance objectives
     - Heat exchanger performance is a function of water and air distribution

4. **Excess Water Use:**
   - Standard control sequence set to 1.6 Cycles of Concentration
     - Need to set unit at 5 Cycles of Concentration

5. **Thermostat:**
   - DoD has option to use BACnet compliant thermostat that ties into DDC system
Coolerado HMX Improvements

2009 Version: Free-form

Advantages of 2011 Version:

1. More economical
2. Easier to replace/install
3. Self-supporting structure preserves HMX integrity over time
4. Integrated water distribution with single point of entry per HMX reduces water usage
5. Yields a more consistent and reliable product

2011 Version: Modular Cassette

Image Credit: Coolerado
### Coolerado Water Solenoid and Regulator Comparison

#### 2009 Version: Fiero Fluid Power (FFP)

- **Disadvantages:**
  - Regulator very sensitive to building water pressure fluctuations.
  - Requires a narrow range of building water pressures (e.g., 40-65 psi).
  - Working Pressure must be set at the work site by installation contractors.
  - Susceptible to damage from freezing, requiring it to be drained before winter or installed indoors.

#### 2011 Version: Tyco/Cash Valve

- **Advantages:**
  - Regulator more robust and less sensitive to building water pressure fluctuations.
  - Accommodates a wider range of building water pressures (e.g., 20-75 psi).
  - Working Pressure is set at the factory before shipment.
  - Self-draining design prevents damage from freezing, allowing it to be installed inside of unit outdoors.
Design Options

- **100% Outside Air Systems**
  1. Through the wall zone cooler
  2. Outside air pre-conditioner (packaged RTU or AHU)

- **Integrated Solutions**
  1. Zone cooler with return air
  2. Integrated into air handling unit mixing box
  3. Packaged Rooftop unit (H-80)
100% Outside Air – Zone Cooler

- **Advantages**
  - Simple installation
  - High OA ventilation rates
  - Significant energy savings relative to DX units

- **Disadvantages**
  - Not integrated w/HVAC
  - Higher water and energy use
  - Limited climate zones
  - Maintenance
    - Shut down and winterized swing seasons

Image Credit: Joshua Bauer, NREL
**Advantages**
- Simple installation
- Integrated with HVAC System
- Can be applied to large systems
- Appropriate for ASHRAE climate zones (2B, 3B, 4B, 5B)

**Disadvantages**
- Higher water and energy use
- Maintenance
  - Shut down and winterized swing seasons

Image Credit: Joshua Bauer, NREL
Integrated Solution – Integrated into Mixing Box

- **Advantages**
  - Greater energy and water savings
  - Applicable to more climate zones

- **Disadvantages**
  - Complicated installation
  - Difficult exhaust run
  - Higher installed costs
  - Geared towards new construction

Image Credit: Joshua Bauer, NREL
Integrated Solution – Integrated into Mixing Box

Image Credit: Joshua Bauer, NREL
Integrated Solution – Zone Cooler with Return Air

- **Advantages**
  - Greater energy and water savings
  - Applicable to more climate zones

- **Disadvantages**
  - Higher installed costs
  - Better fit for single story facilities
  - Controls need to be integrated with existing HVAC
Coolerado Performance Model

- Developed from empirical curve fits (lab test and field test data)
- Developed VBA and will be built into Energy Plus
- Verified to within 3% of laboratory test results and 12% of field test results
- Includes sizing tool and annual simulation tool
Preliminary Market Analysis

- Single zone building model (similar to classroom)
- 600 ft$^2$ w/ south facing wall/window and 3 adiabatic walls
- 20 people, 1.49 Watt/ft$^2$ lighting, 5 Watt/ft$^2$ plug loads
- Modeled in four climate zones relative to single zone DX with EER 8

Image Credit: NREL
Next Steps

- Reprogram Coolerado model into Energy Plus module
- Finalize market analysis – includes comparison to other evaporative cooling technologies – energy use, water use, O&M
Contact

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