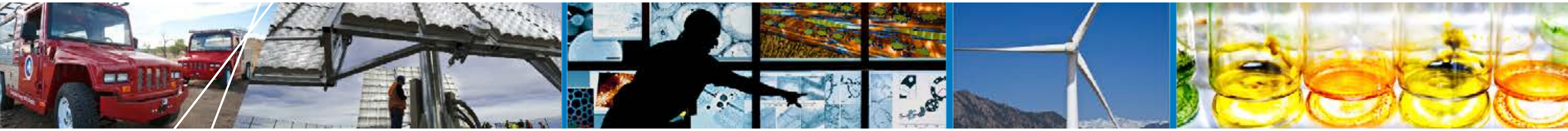
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Dew-Point Evaporative Comfort Cooling



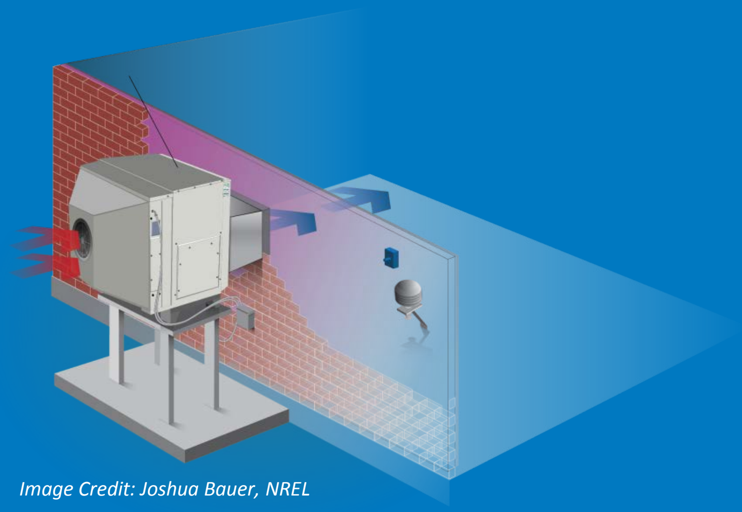


Image Credit: Joshua Bauer, NREL

Jesse Dean

April 20, 2012

Rocky Mountain Chapter ASHRAE Technical Conference

Lakewood, Colorado

NREL/PR-7A40-55837

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

DoD ESTCP Program

- **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

DoD ESTCP Program

- **Department of Defense – Energy Use Characteristics**
  - Operate 300,00 + facilities world wide
  - 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

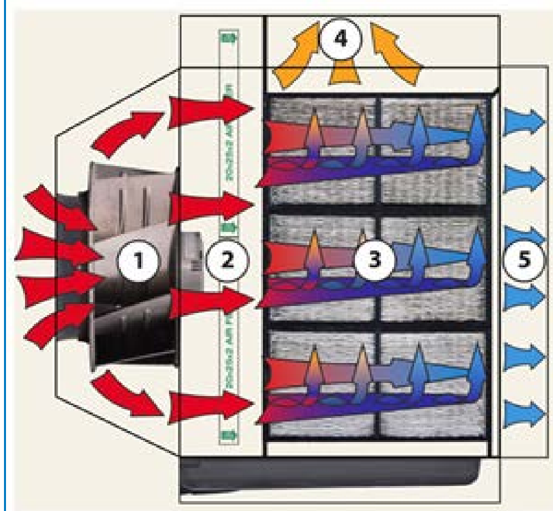
Reference: http://www.serdp.org/Program-Areas/Energy-and-Water/(list)/1/

Project Objective

- **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

Technology Description

- 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.



HOW IT WORKS

1. 100% Fresh air enters the system
2. The air is filtered of dust/allergens
3. Working air removes heat
4. Heat and moisture is exhausted from the system
5. Cool product air enters the building with no added humidity

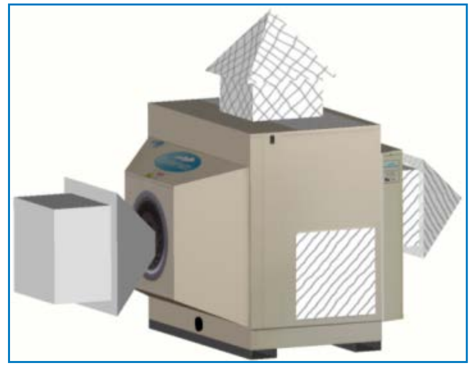


Image Credit: Coolerado

Reference: http://www.coolerado.com/products/how-it-works/

Technology Description

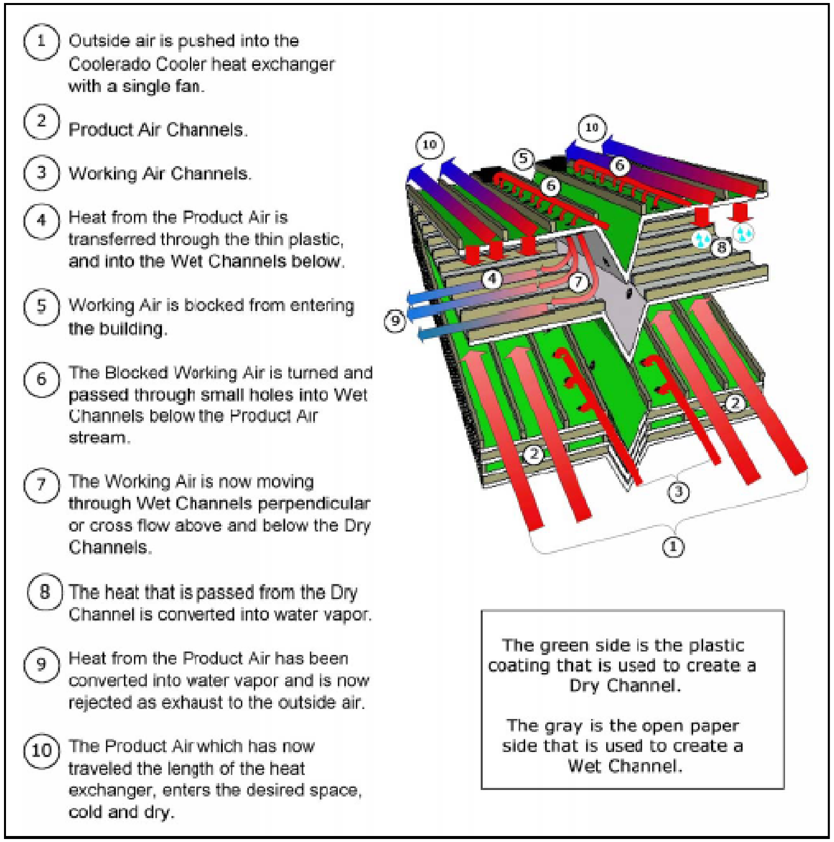
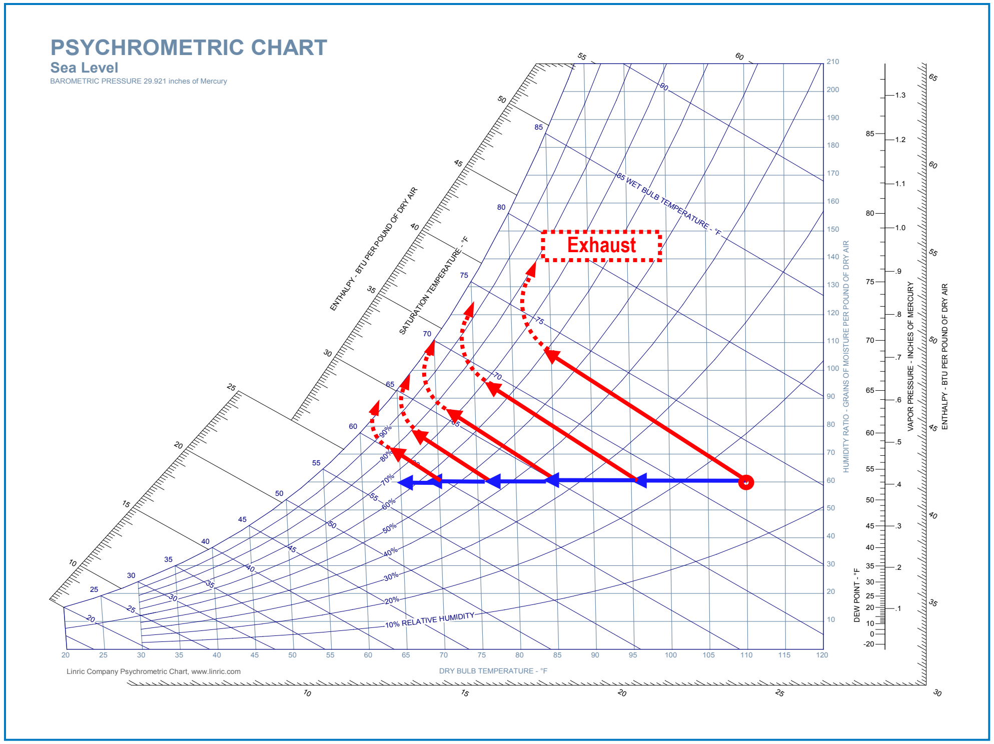


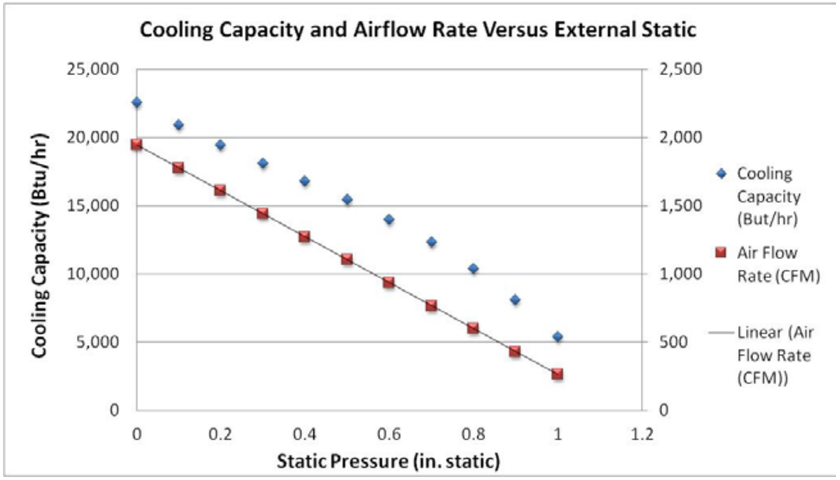
Image Credit: Coolerado



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

Design Considerations

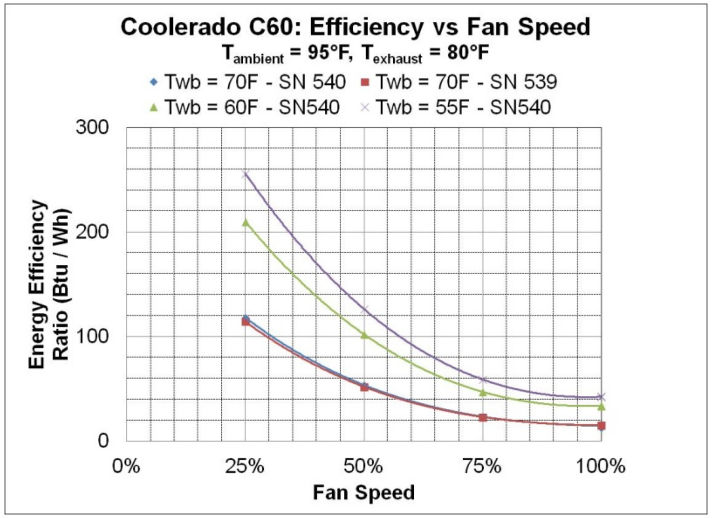
1. **Sensitive to external static pressure**
   - Image (63 F WB, 95 F DB, 80 F Space)



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

3. **Improved Performance at Partial Loads**

Coolerado C60 Performance Characteristics with 80 F Return Temp and CoC = 5						
Design Wet Bulb and Dry Bulb		50 F/ 95 F	55 F/ 95 F	60 F / 95 F	65 F/ 95 F	70 F / 95 F
Number of Cooling Cores		6	6	6	6	6
Cooling Capacity at Design Cond.	*Btu/hr*	*39,615*	*32,319*	*25,139*	*18,070*	*11,109*
Product Flow	cfm	1,780	1,780	1,780	1,780	1,780
Supply Air Temperature	*°F*	*55*	*59.4*	*63.9*	*68.3*	*72.8*
Wet Bulb Effectiveness	%	89%	89%	89%	89%	89%
Fan Power	hp	0.8	0.8	0.8	0.8	0.8
Coeficient of Performance		*20.5*	*16.7*	*13*	*9.4*	*5.7*
Exhaust Flow	cfm	1,162	1,162	1,162	1,162	1,162
Percent Exhaust	%	39%	39%	39%	39%	39%
Exhaust Air Temperature	F	65.2	68.5	71.8	75.1	78.4
Total Water Consumption	gph	27.66	25.7	23.52	21.09	18.33
Gal per Ton/hr OA		5.24	5.52	5.82	6.13	6.44



Performance Objectives

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

Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Qualitative Performance Objectives			
Maintainability (Ease of use)	Ability of an HVAC technician to operate and maintain the technology	Standard form feedback from the HVAC technician on usability of the technology	*A single facility technician able to effectively operate and maintain equipment with minimal training*
Maintainability (Cost)	Service Frequency	Standard form feedback from the HVAC technician on time required to maintain	*>90% of units fall within nominal IEC maintenance schedule by project end*
Maintainability (Failure)	Biological Fouling Freezing	Visual inspection	*No signs of biological growth, including grey-water unit* *No ruptured water lines*

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

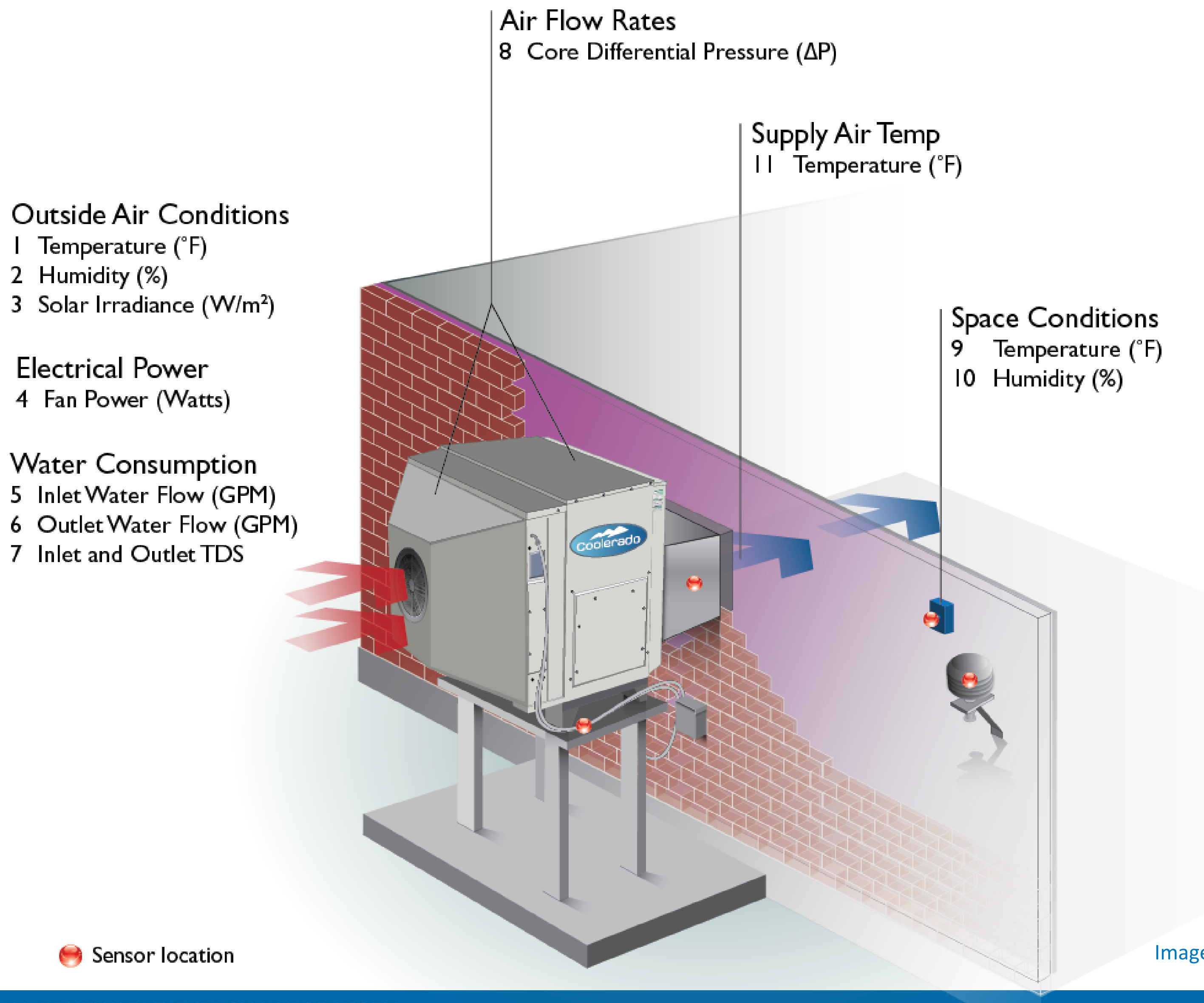
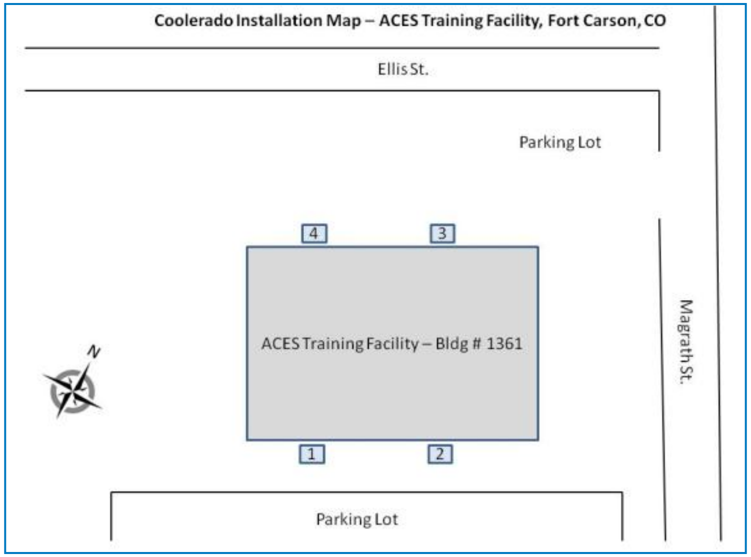
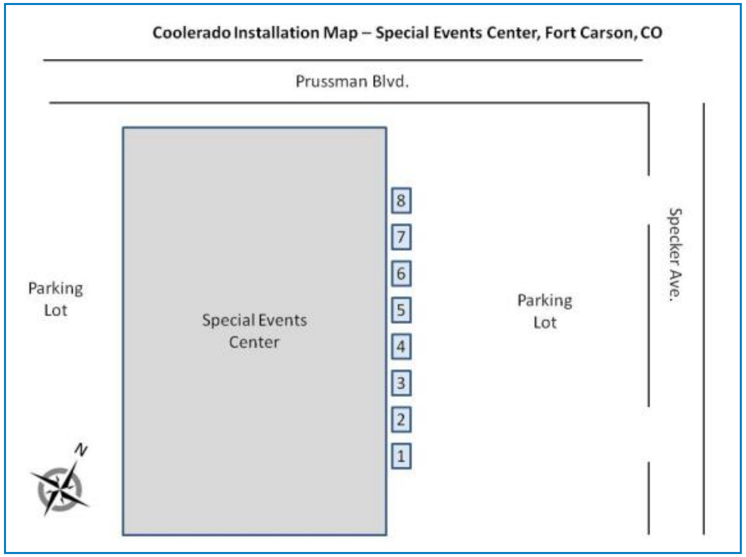


Image Credit: Joshua Bauer, NREL

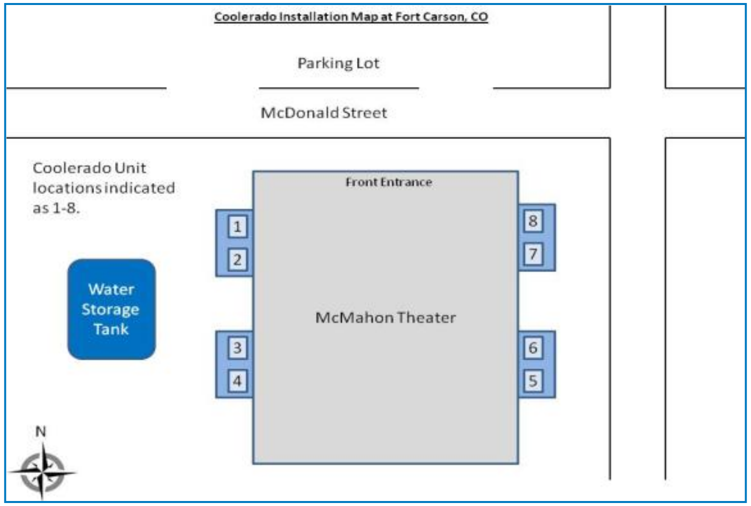
Building Installations



Classroom



Event Center



Theater

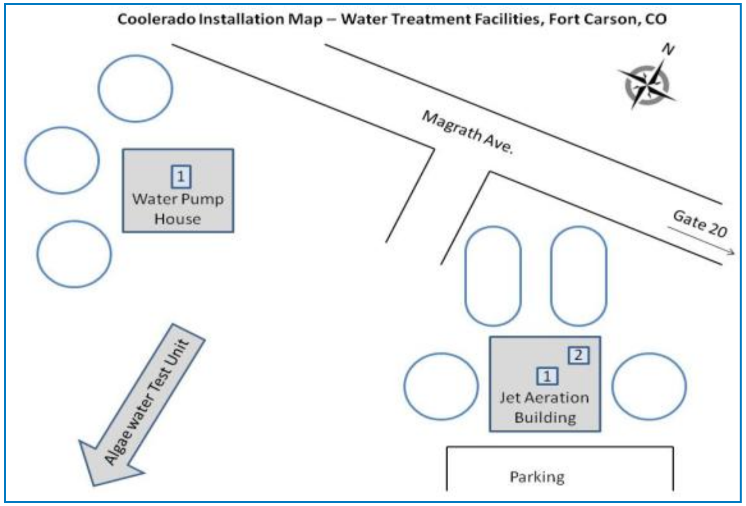
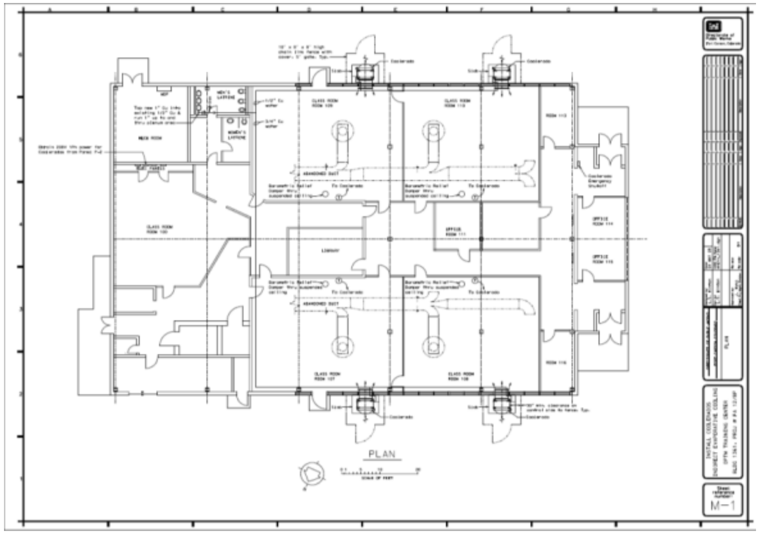


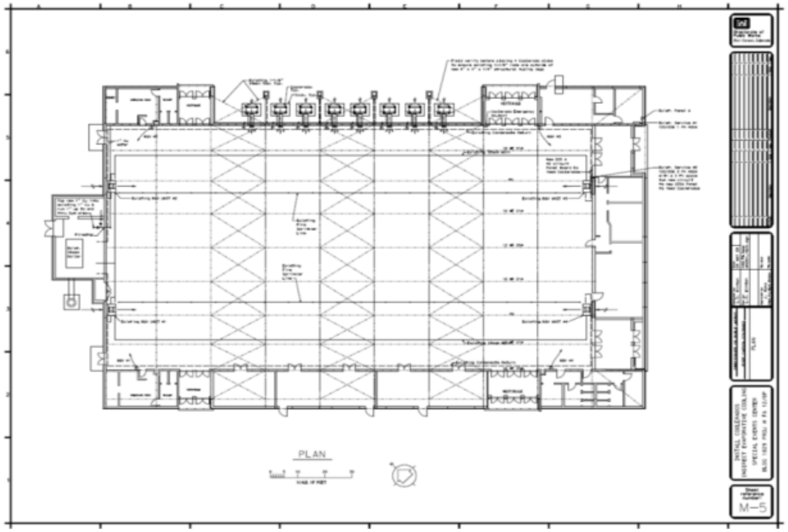
Image Credit: Coolerado

Jet Aeration and Pump House

Construction Drawings



Classroom



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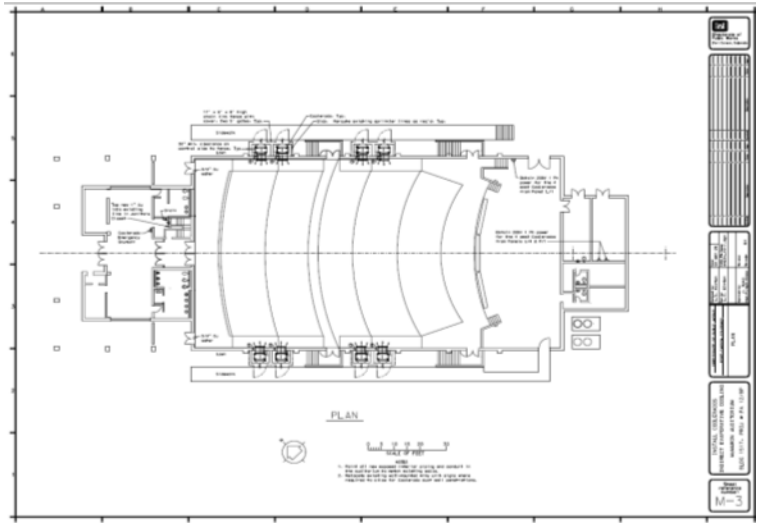
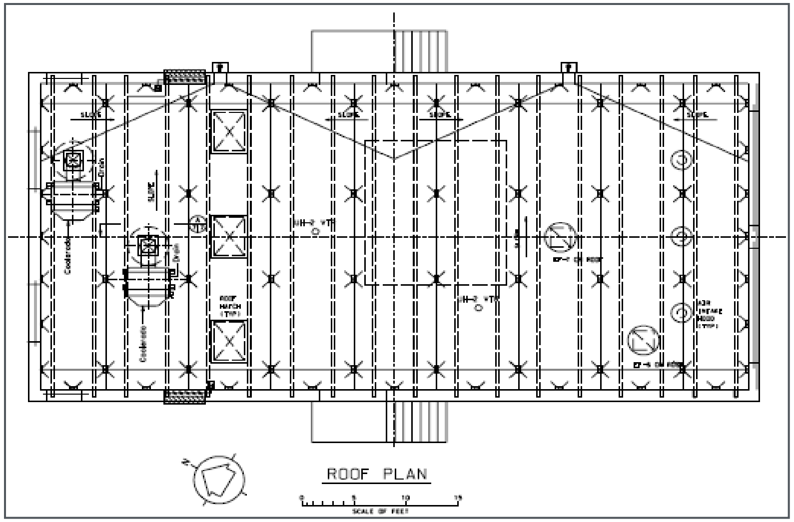


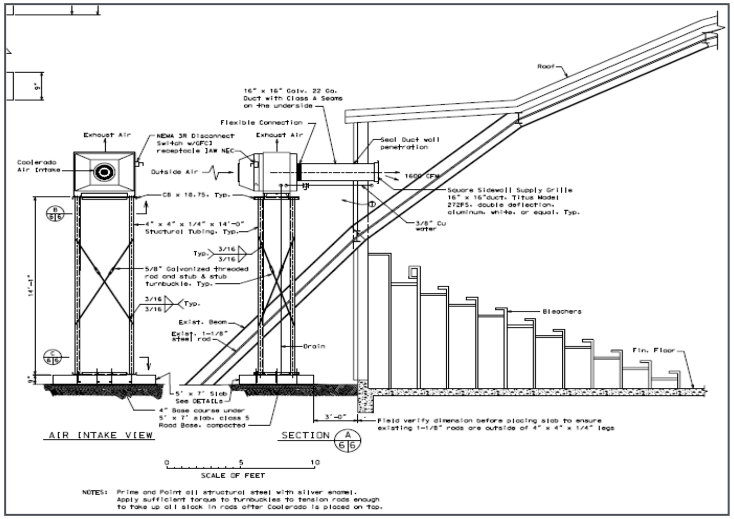
Theater



Pump House

Image Credit: NREL

Construction Drawings and Photographs



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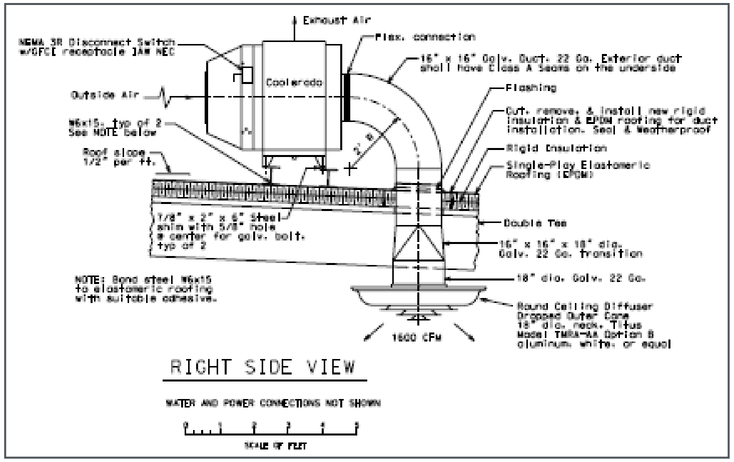


Jet Aeration

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.

[Waste Water Unit]

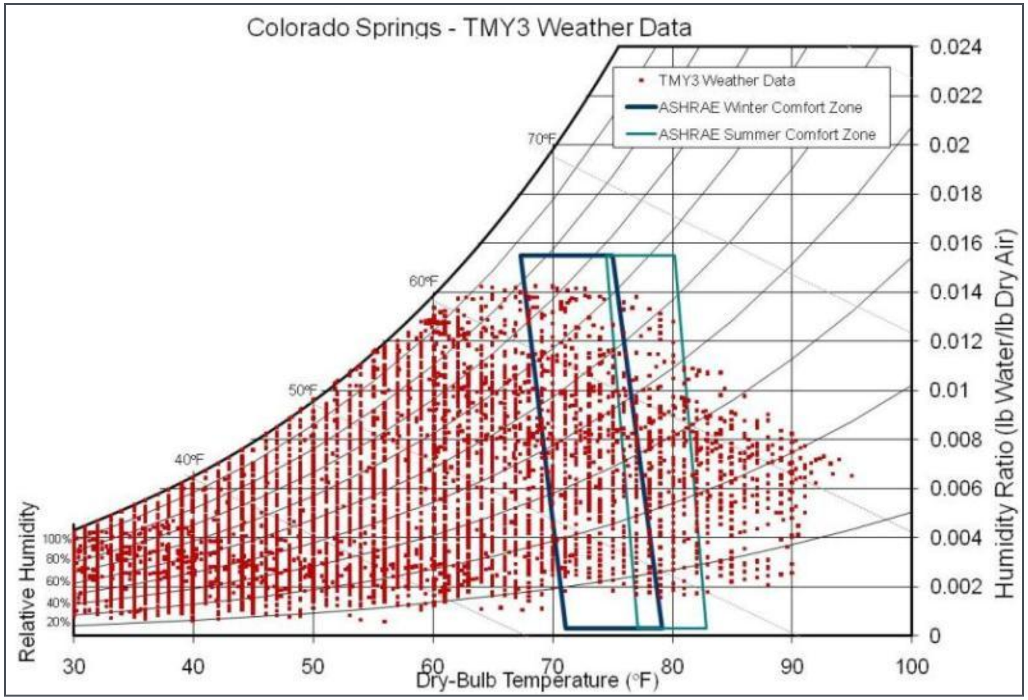
[Waste Water Unit]

Image Credit: NREL

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:

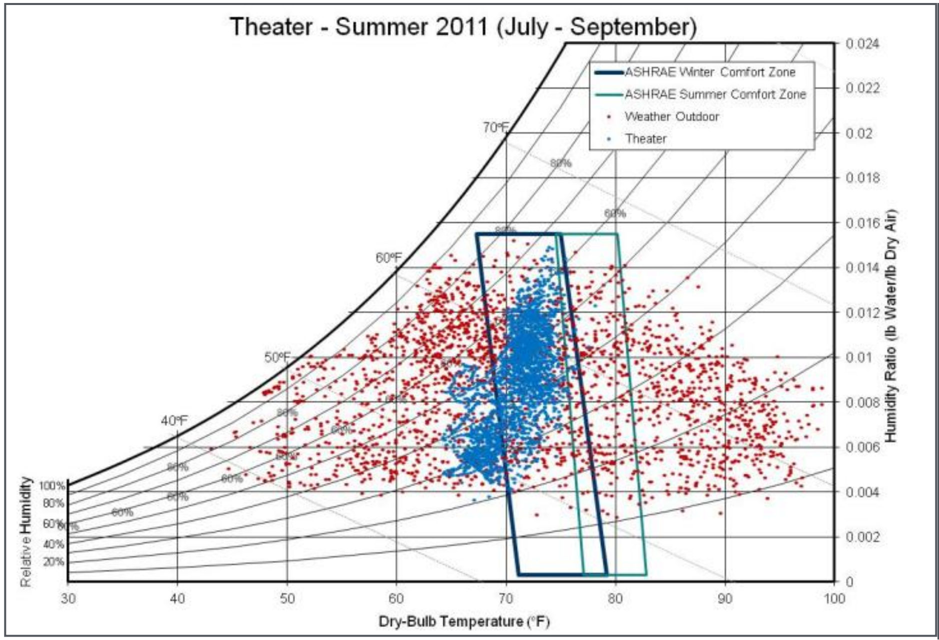
- **Max Conditions July – September**
  - T_{db} : 98.85 °F, MC T_{wb} : 65.5 °F
  - Maximum T_{wb} :67.74 °F

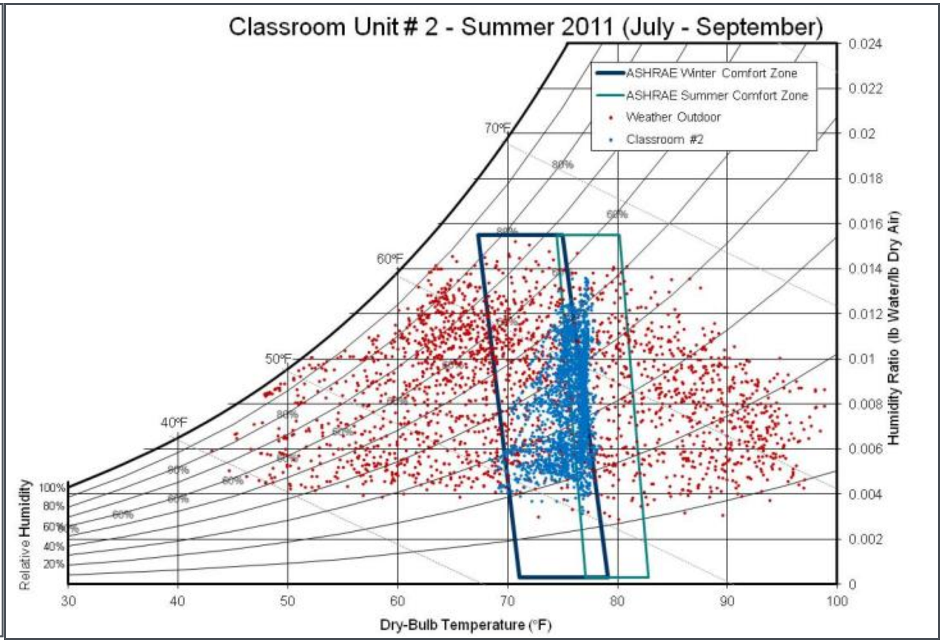
Maximum Outside Air Temperature (F)	Maximum Outside Air Wetbulb Temperature (F)	Number of Hours Above 0.4% Design	Percent of Cooling Season Hours above 0.4% Design (%)
98.85	67.74	161	1.8%

Improve Comfort Provided by Evaporative Cooling

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

✓ *Performance objective met for all facilities*

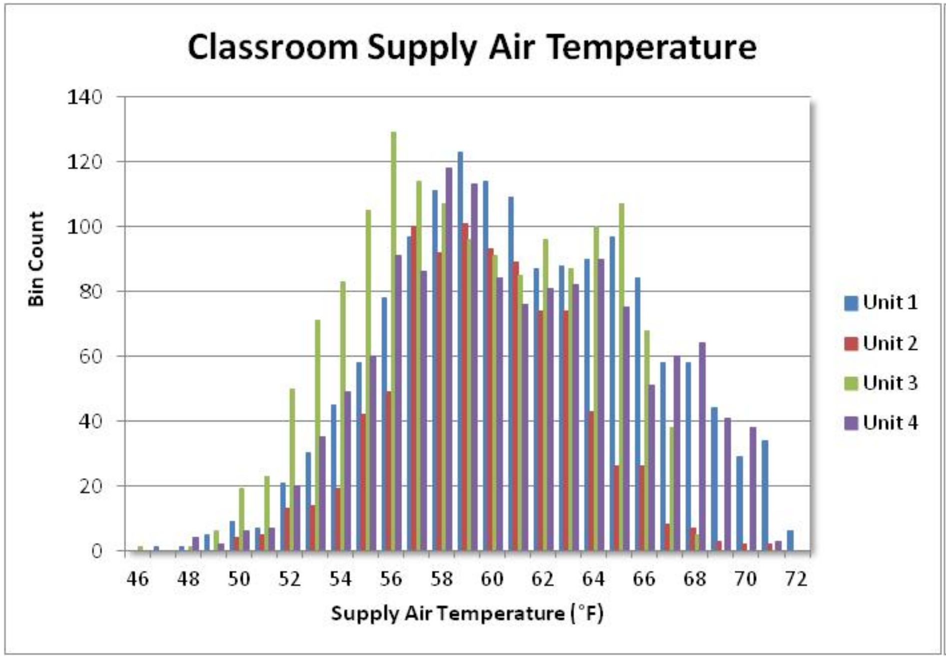


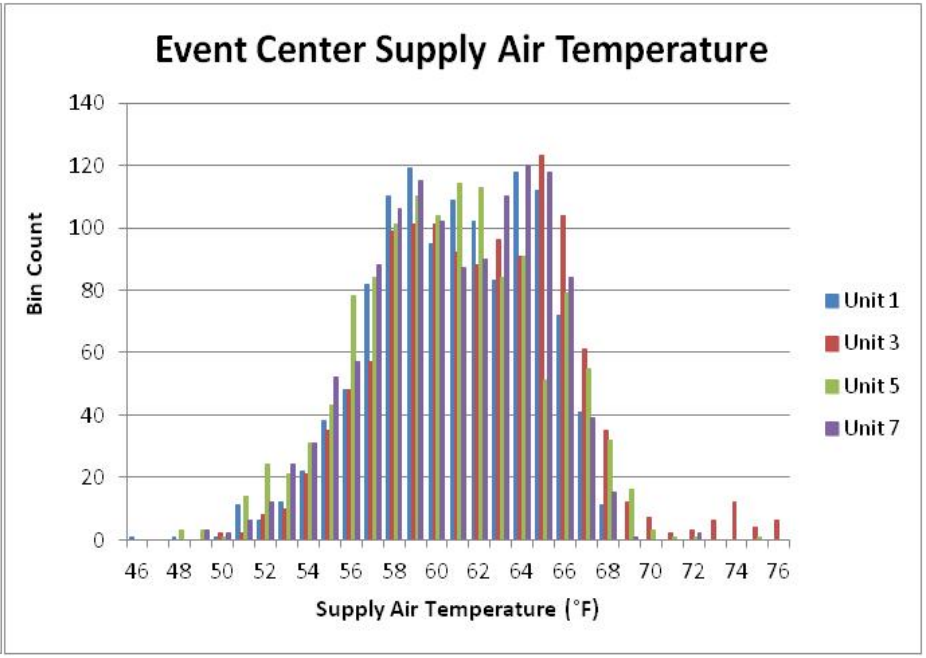


Improve Comfort Provided by Evaporative Cooling

Success criteria: supply air less than 70 ° F

- *Performance objective met for >95% of the time*





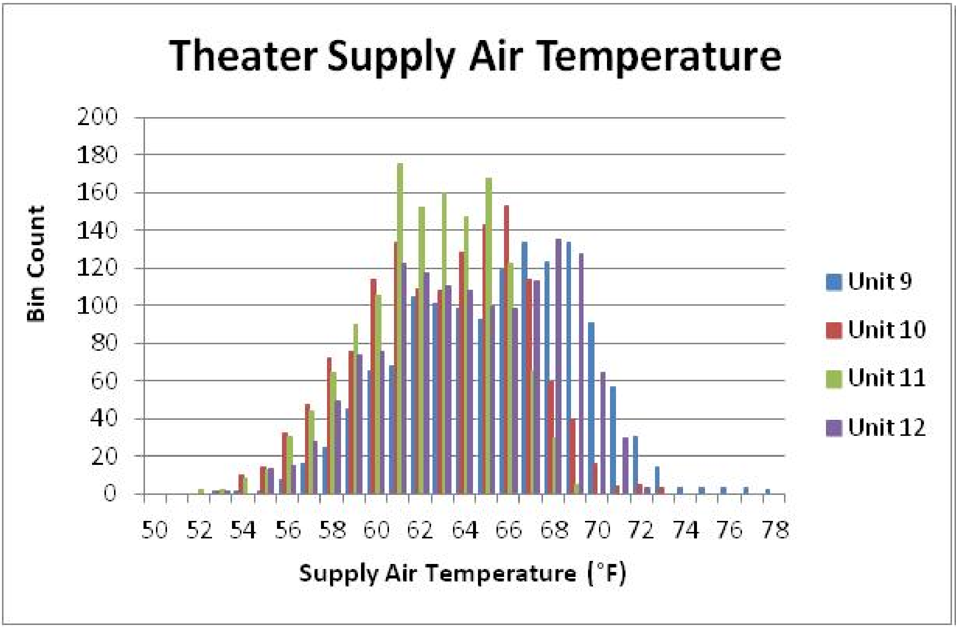
Percent Supply Air Temp < 70 °F			
Unit 1	**Unit 2**	**Unit 3**	**Unit 4**
95.4%	99.5%	100.0%	96.9%

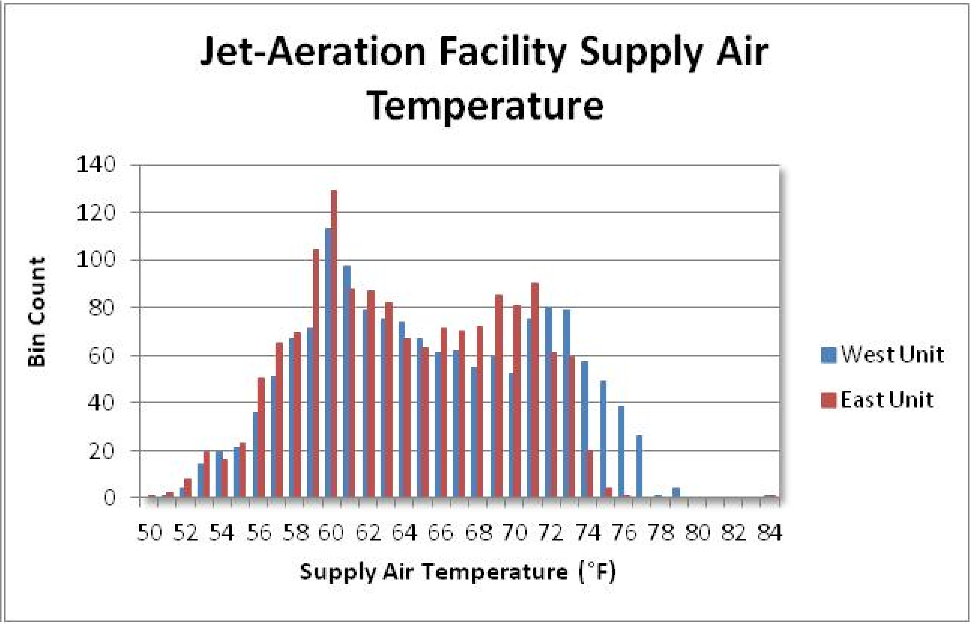
Percent Supply Air Temp < 70 °F			
Unit 1	**Unit 3**	**Unit 5**	**Unit 7**
100.0%	95.4%	99.5%	99.8%

Improve Comfort Provided by Evaporative Cooling

Success criteria: supply air less than 70 ° F

- *Performance objective met for >70% of the time*

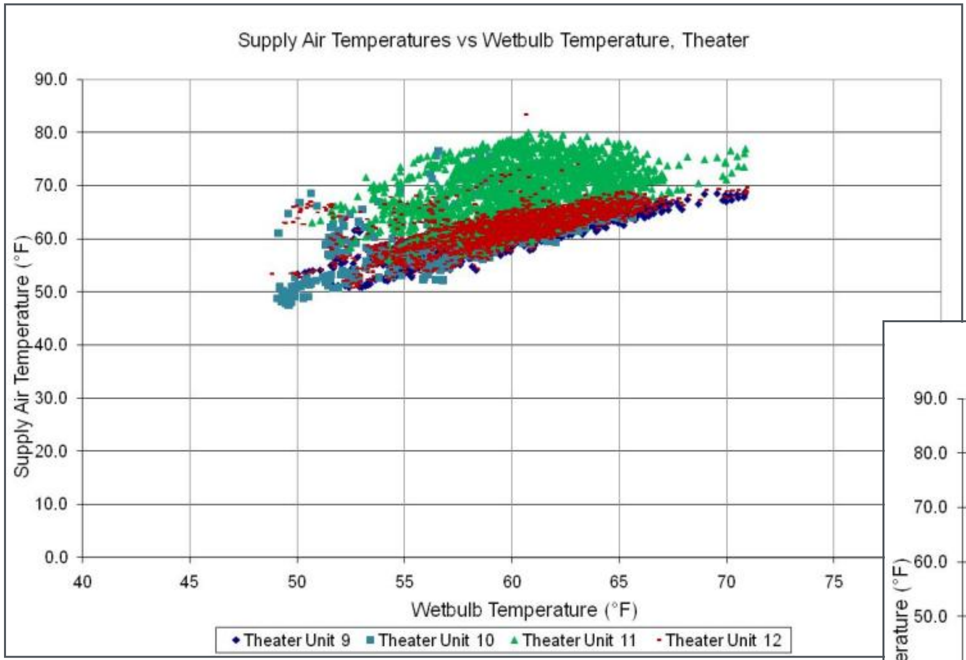


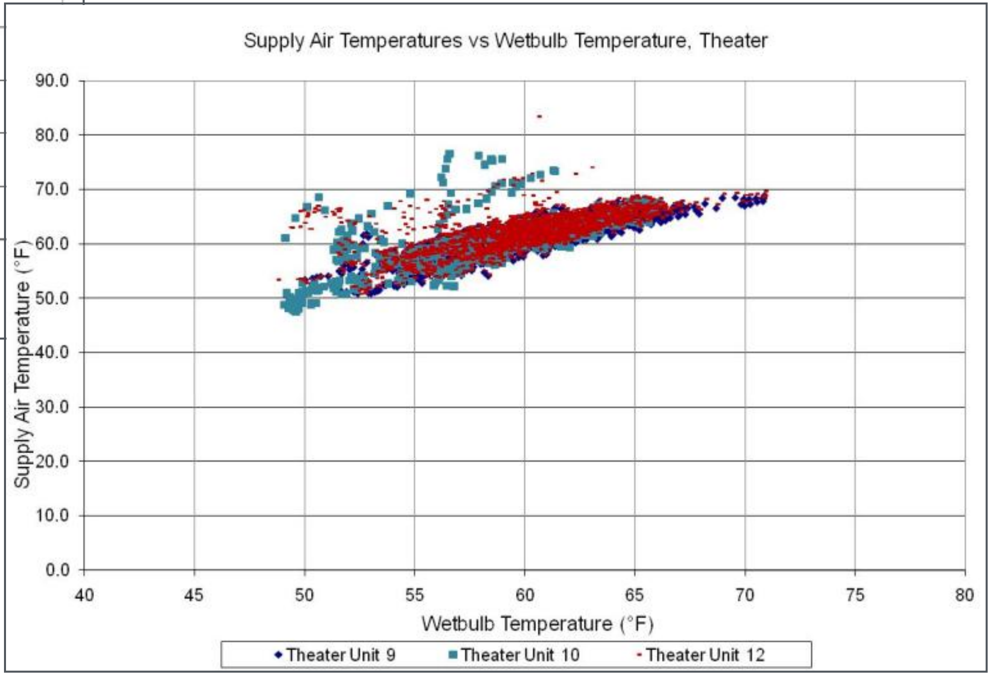


Percent Supply Air Temp < 70 °F			
Unit 9	**Unit 10**	**Unit 11**	**Unit 12**
83.5%	98.1%	100.0%	93.5%

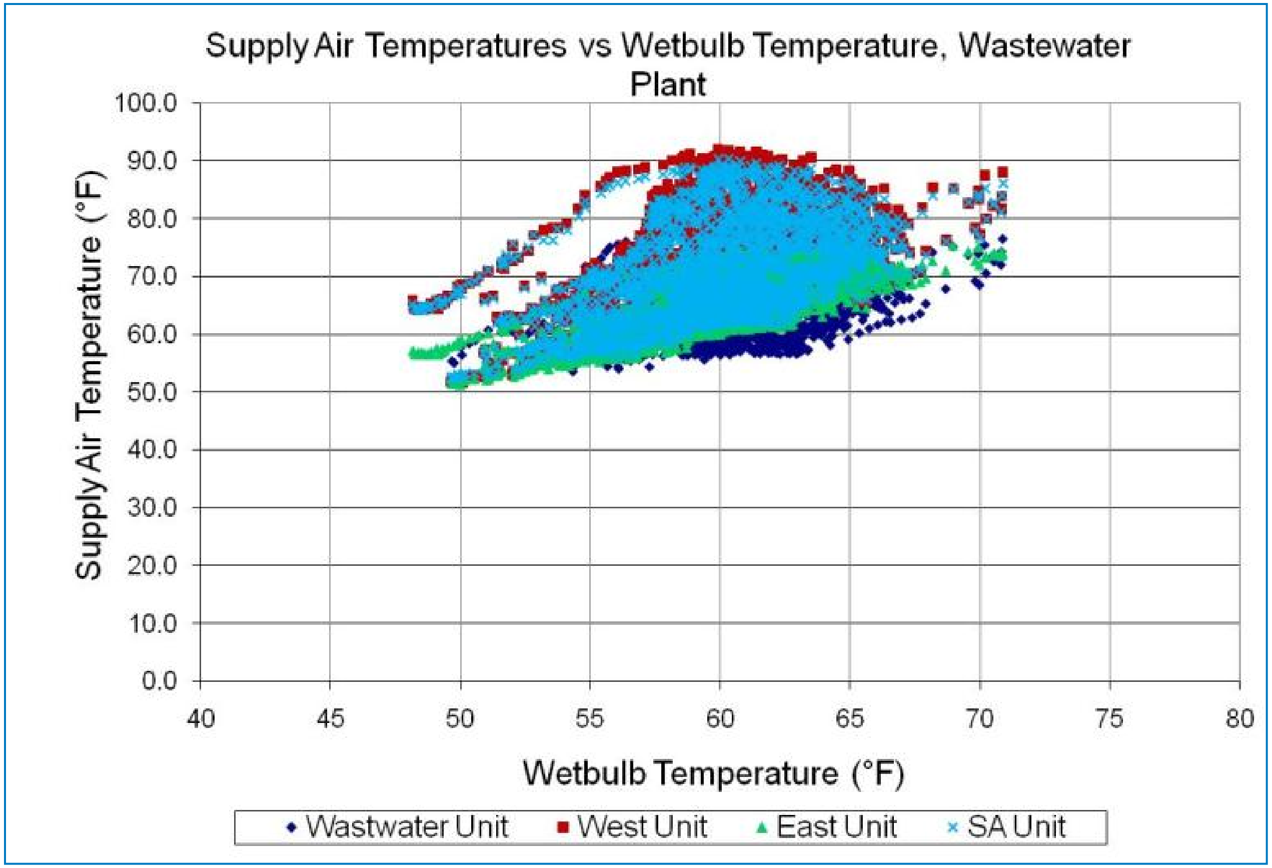
Percent Supply Air Temp ≤ 70 °F	
West Unit	**East Unit**
69.0%	78.7%

Supply Air Temperature Performance Objective Analysis





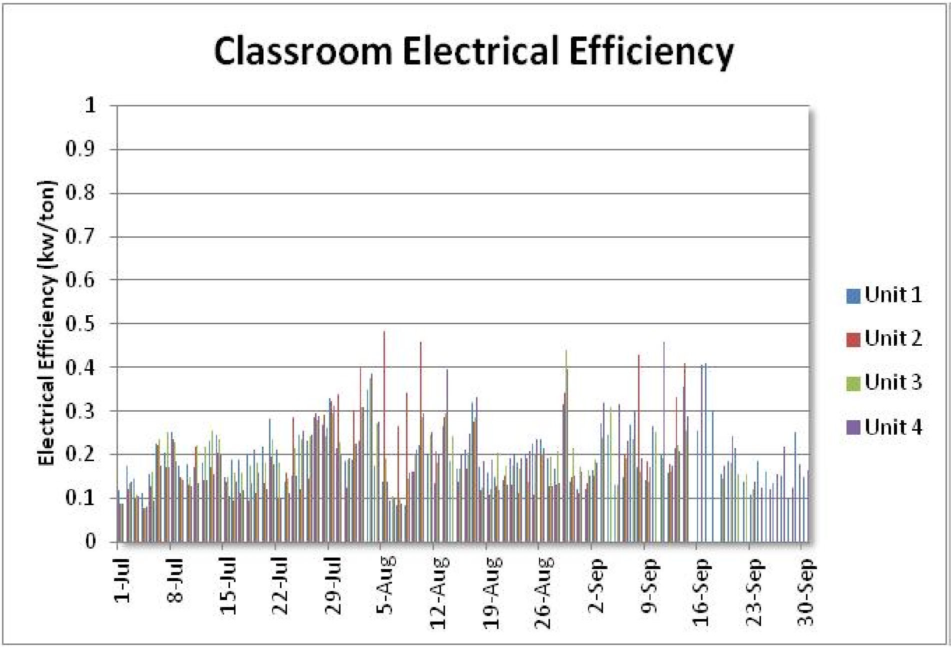
Supply Air Temperature Performance Objective Analysis

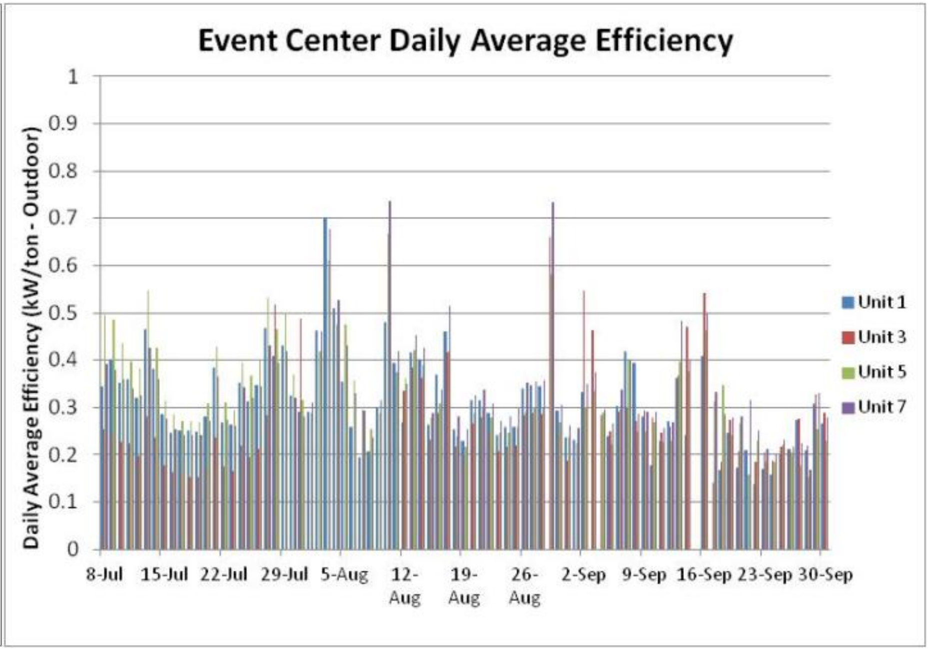


Provide High Efficiency Cooling

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

- ✓ *Performance objective met for all facilities*

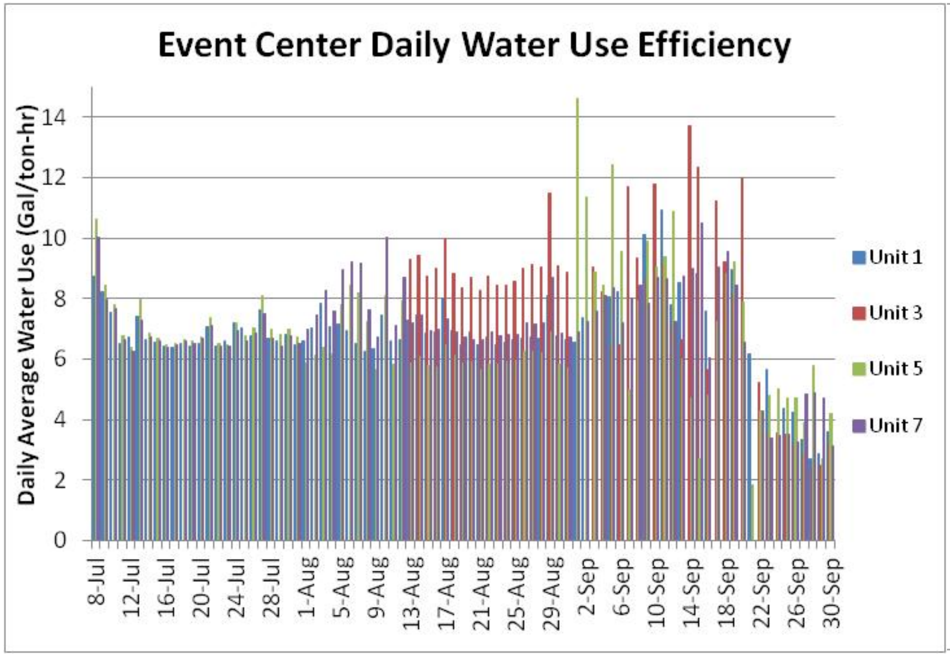


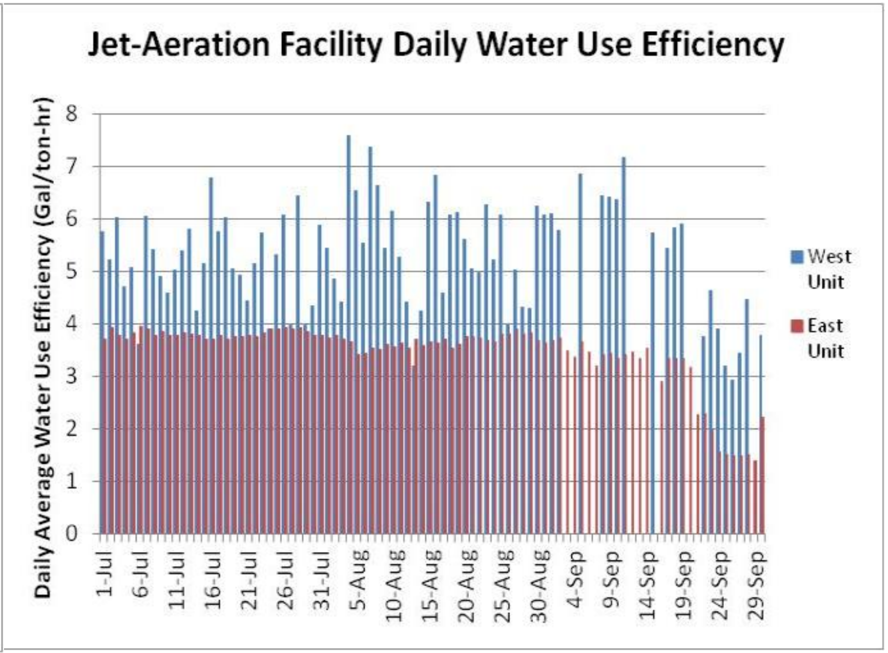


Minimize Water Consumption

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

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





Additional Performance Metrics:

- **Sustain Cooing 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

Lessons Learned & Product Development

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.

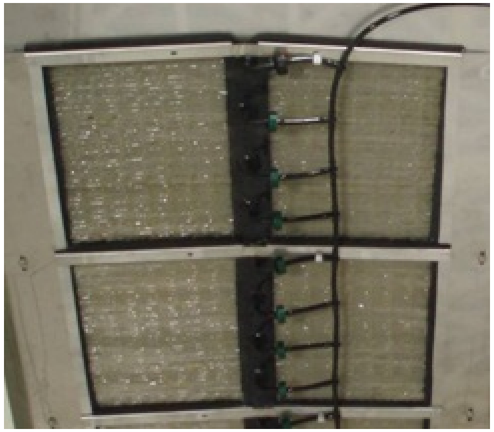
3. **Heat Exchanger Temperature Variation:**
   - 20% of units didn't meet performance objectives
     - Heat exchanger performance is a function of water and air distribution

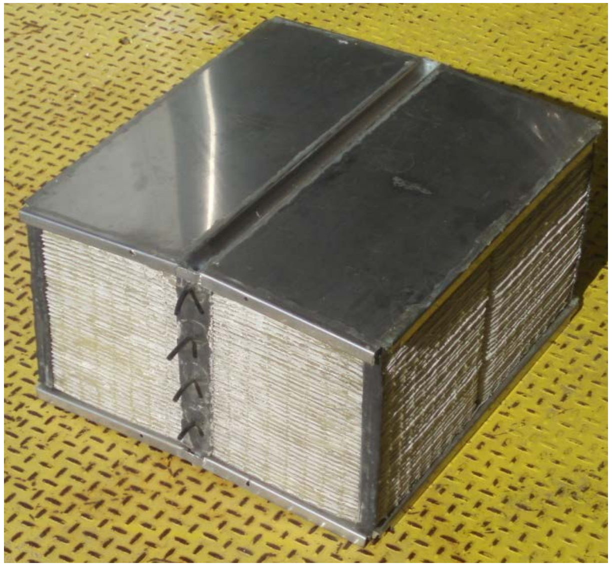
4. **Excess Water Use:**
   - Standard control sequence set to 1.6 Cycles of Concentration
     - Need to set unit at 5 Cycles of Concentration

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

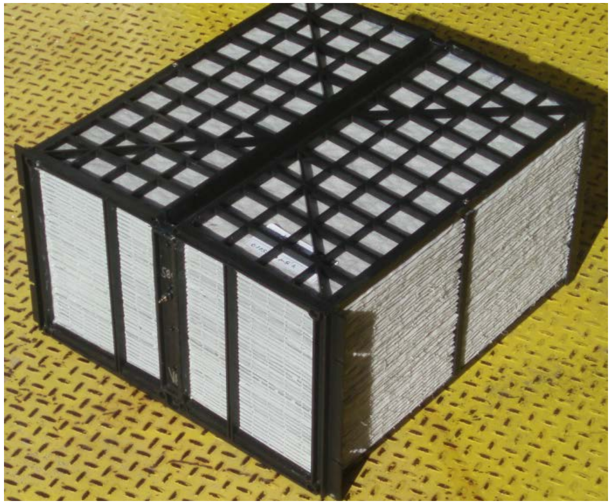


Image Credit: Coolerado

Coolerado Water Solenoid and Regulator Comparison

2009 Version: Fiero Fluid Power (FFP)

Image Credit: NREL

2011 Version: Tyco/Cash Valve

Image Credit: NREL

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.

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

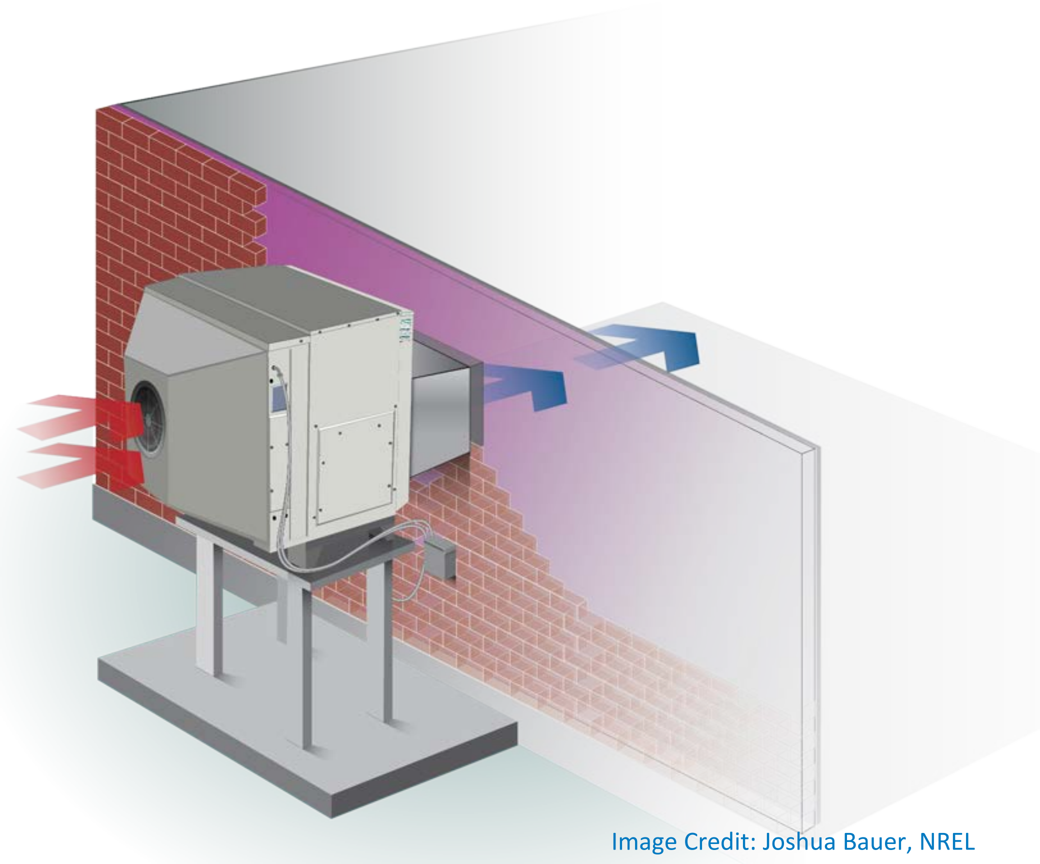


Image Credit: Joshua Bauer, NREL

100% Outside Air – Pre Conditioner

- **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

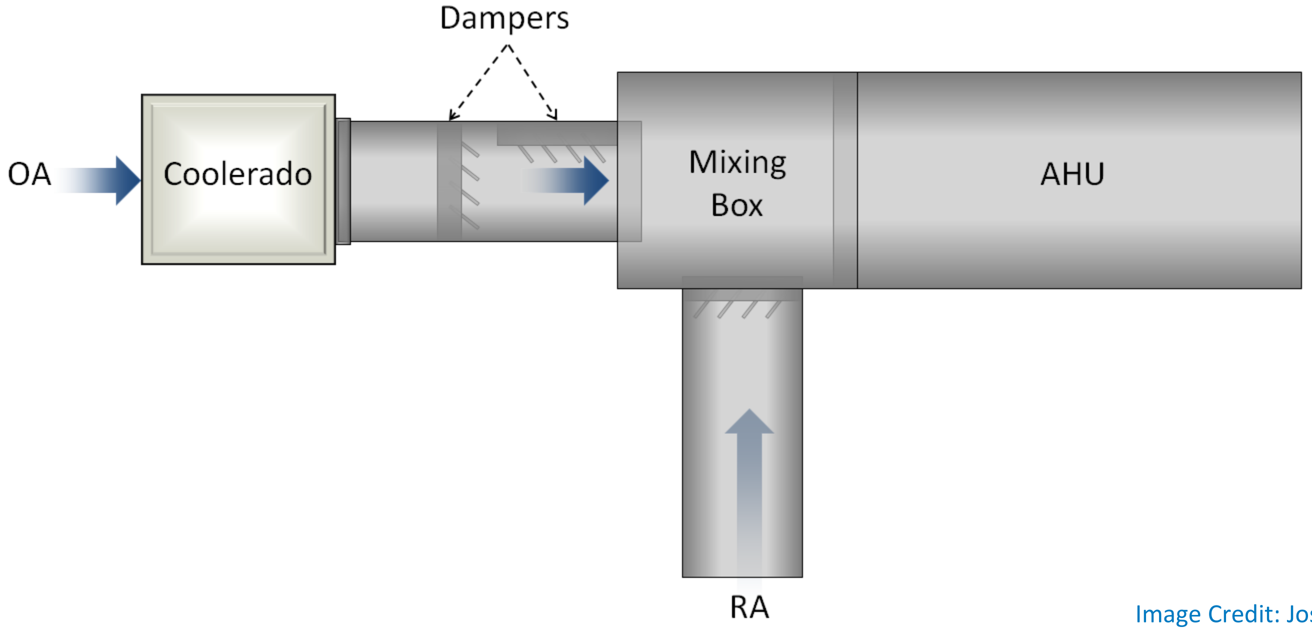


Image Credit: Joshua Bauer, NREL

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

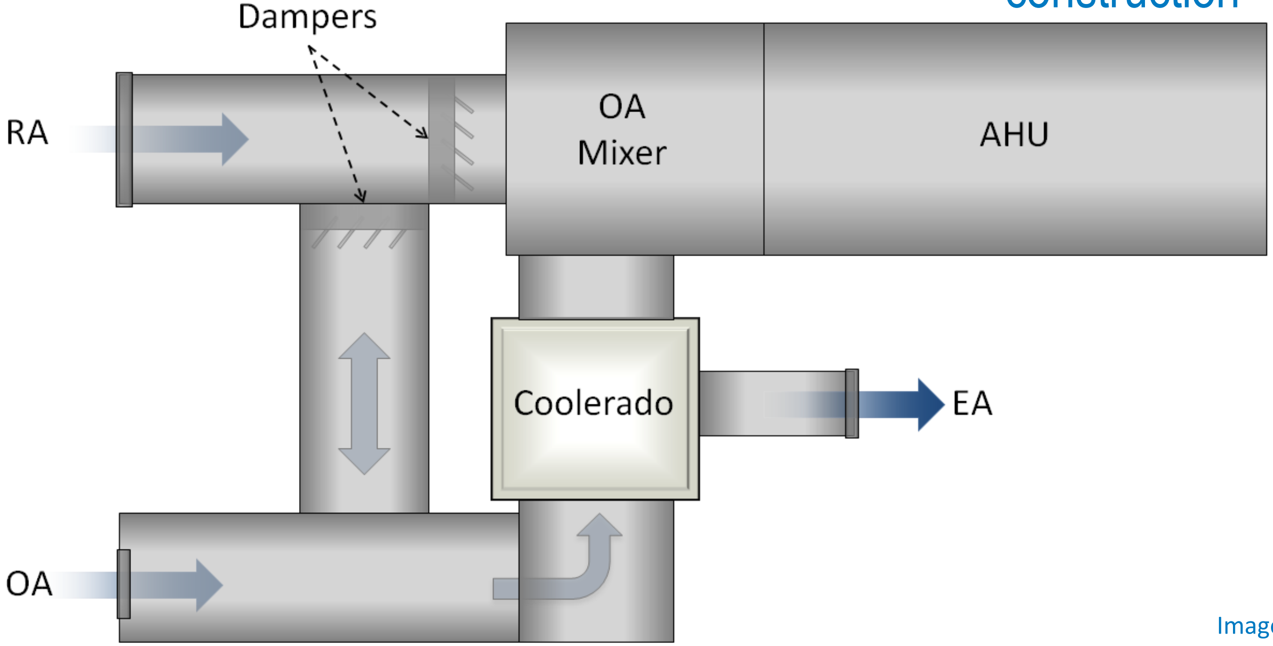


Image Credit: Joshua Bauer, NREL

Integrated Solution – Integrated into Mixing Box

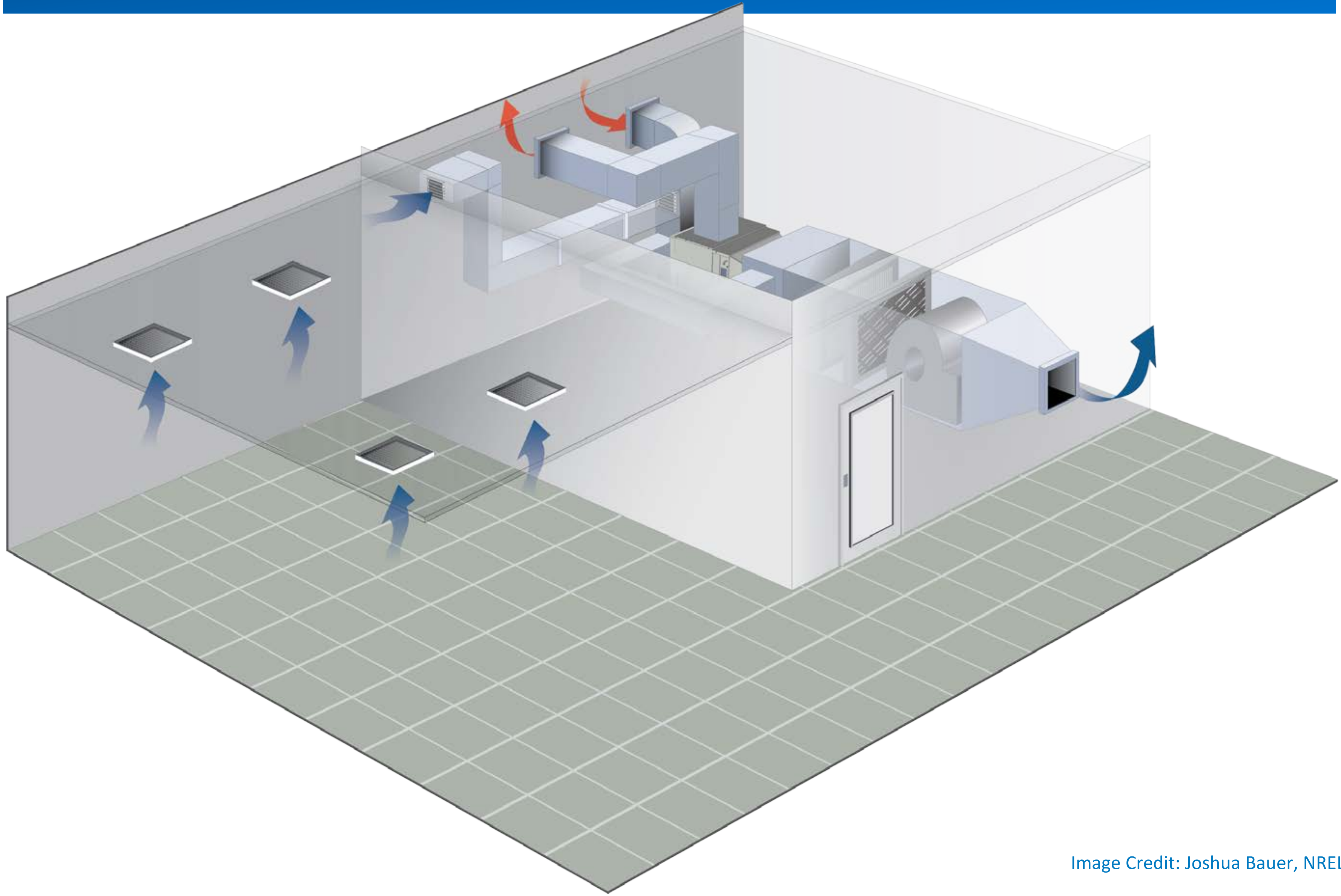
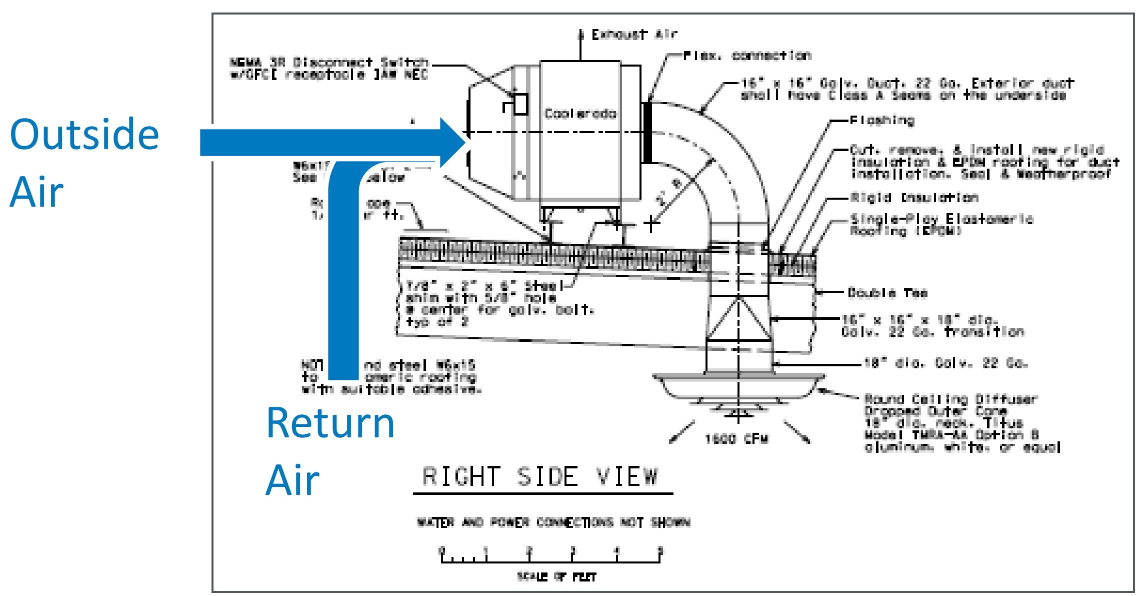


Image Credit: Joshua Bauer, NREL

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

- **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

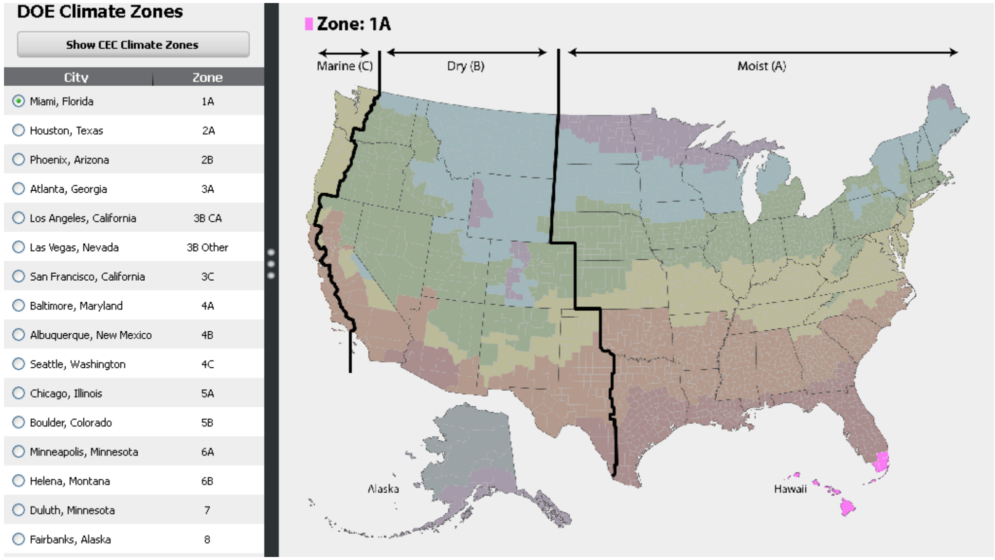


Image Credit: NREL

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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