Prepared for the U.S. General Services Administration
By National Renewable Energy Laboratory

February 2014

Multistaged Indirect Evaporative Cooler Evaluation

Jesse Dean

Ian Metzger

The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the National Renewable Energy Laboratory, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the National Renewable Energy Laboratory. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the National Renewable Energy Laboratory.

The work described in this report was funded by the U.S. General Services Administration under Contract No. [WFK91003].

Acknowledgements

United States General Services Administration (GSA) Region 8: Silas Campbell, James Shull, Andrew Bond, Doug Rothgeb, and Jessica Higgins

National Renewable Energy Laboratory: Eric Kozubal

NREL/TP-7A40-61304

For more information contact:

Energy and Environment Team
Facilities Management and Services Programs
Public Buildings Service - Rocky Mountain Region
U.S. General Services Administration
One Denver Federal Center
P.O. Box 25546 (8P2PM)
Denver, CO 80225-0546

Phone: (303)236 - 8000

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Table of Contents

I. Executive Summary 3
A. Background 3
B. What is the Technology? 3
C. Study Design and Objectives 4
D. Project Results/Findings 5
E. Conclusions 6
II. Background 7
A. Introduction 7
B. Opportunity 7
C. Demonstration Project Locations 9
III. Technology Description and Objectives 9
A. Technical Objectives 9
B. Multistage Indirect Evaporative Cooler Technology Description 10
IV. Assessment 15
A. Facility Description 15
B. Technology Specification 16
C. Technology Deployment 17
D. Test Plan 18
E. Instrumentation Plan 18
V. Results 19
A. Commissioning 19
B. Thermal Comfort Performance 22
C. Energy Savings 25
D. Life Cycle Costs 26
E. Considerations 28
VI. Summary Findings and Conclusions 29
A. Overall Technology Assessment at Demonstration Facility 29
B. Best Practices 29
C. Barriers and Enablers to Adoption 30
D. Market Potential within the GSA Portfolio 31
E. Recommendations for Installation and Commissioning 33
Appendices 35
A. Glossary 35

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

I. Executive Summary

A. Background

Air conditioning is the single largest contributor to peak demand on U.S. electricity grids and is the primary cause of grid failures and blackouts.[1] Power generators and refrigeration-based air-conditioning units are least efficient at high ambient temperatures, when cooling demand is highest. This leads to increased pollution, excessive investment in standby generation capacity, and poor utilization of peaking assets.

The US Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) evaluated three multistaged indirect evaporative air conditioners on behalf of General Services Administration (GSA) Rocky Mountain Region (Region 8). The multistaged indirect evaporative cooling technology can reduce energy use by 57% – 92%[2] relative to standard air-cooled, refrigeration-based air-conditioning units, depending on facility type, location, baseline heating, ventilation, and air conditioning (HVAC) equipment, and application.

This technology evaluation was carried out through observation, measurement, and verification (OM&V) of the performance of three multistaged indirect evaporative cooling units that were deployed in the Fitness Center in Building 41 at the Denver Federal Center (DFC) which is located in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zone 5B. This report evaluates the design characteristics, operational efficiency, and life cycle cost effectiveness of the installation.

Nationwide, GSA owns and leases over 354 million square feet (ft^2) of space in 9,600 buildings.[3] This demonstration was hosted by Region 8, yet it can be used to inform GSA nationwide on the appropriate use of the technology. By evaluating the technical and economic feasibility of new ideas and technologies, GSA will be in a better position to select appropriate technology and drive innovation in environmental performance across the agency's portfolio.

GSA is a leader among federal agencies in aggressively pursuing energy efficiency opportunities and installing renewable energy systems to heat and power their facilities. This is especially true in Region 8. The Energy Independence and Security Act (EISA) of 2007 established energy reduction goals for federal facilities, and mandates energy intensity reductions of 3% per fiscal year (FY) relative to a 2003 baseline.

B. What is the Technology?

Direct evaporative coolers (DECs) cool air by directly evaporating water into an airstream. As the water changes phases from a liquid to a vapor through the heat of vaporization, heat is drawn from the air and the air temperature is reduced. In low-humidity areas, evaporating water into the air provides a natural and energy-efficient means of cooling. DECs, also called swamp coolers, rely on this principle, cooling outdoor air by passing it over water-saturated pads, causing the water to evaporate into it. Unlike central air-conditioning systems that recirculate the same air, DECs provide a steady stream of fresh air into the facility and require an exhaust air (EA) path through the building.

---

[1] Heat Wave Nearly Causes Rolling Blackouts in California, http://www.nytimes.com/2000/08/02/us/heat-wave-nearly-causes-rolling-blackouts-in-california.html

[2] Dean, J.; Herrmann, L.; Kozubal, E.; Geiger, J.; Eastment, M.; Slayzak, S. (2012). Dew Point Evaporative Comfort Cooling: Report and Summary Report. 198 pp.; Summary Report: 40 pp.; NREL Report No. TP-7A40-56256.

[3] GSA Portal. http://www.gsa.gov/portal/content/104501, Accessed 5/15/12.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

The Coolerado air conditioner is configured as a multi-staged indirect evaporative cooler (IEC). This technology uses a unique design that maximizes the effectiveness of the direct evaporative cooling stage and indirect evaporative cooling stages of its cooling process. The process works by cooling both the primary (or product) air and the secondary (or working) air in a 20-stage process. The product air flows through the indirect stage and is used to condition the facility and the secondary/working air flows through the direct stage and is exhausted from the unit (Figure 1).

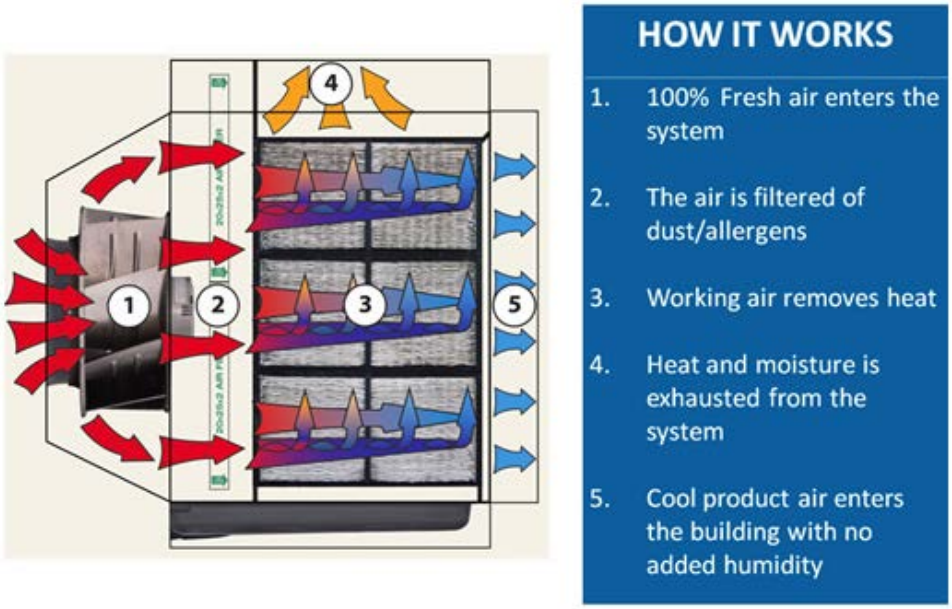

Figure 1. Side view of multistaged indirect evaporative cooler airflow process
(Source: Coolerado)

Each stage contributes to cooling by combining multiple direct stages with a single indirect stage. The cumulative result is a lower product air temperature than is possible with conventional evaporative cooling technologies, as the unit can achieve wet bulb effectiveness (WBE) of 90% – 120%. The key difference between this and other direct/indirect processes is that the working air that accumulates moisture is exhausted at each stage, enabling the product air to be delivered at a lower dry bulb temperature. This thermodynamic process is referred to as the Maisotsenko Cycle (or M-Cycle).

C. Study Design and Objectives

The primary objective of the project was to demonstrate the capabilities of a new high-performance, multistaged IEC technology to reduce energy use and improve thermal comfort in dry climates, while substantially reducing electric peak demand. The project was designed to test three cooling units and provide a side-by-side comparison of energy use, water use, energy performance, and interior thermal comfort. The three multistaged IEC units installed in Building 41 were hung from the rafters and an outside air intake and exhaust duct was installed for each unit. A local thermostat was installed that controlled all three units and the thermostat set point and schedule of the three units was set by a central building automation system. The three units would ramp up and down in unison to meet the space temperature set point. The objectives of the demonstration are provided below:

- Validate the performance of the units relative to standard air-cooled packaged rooftop units (RTU)
- Outline the advantages and disadvantages of the technology
- Identify appropriate applications of the technology.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

D. Project Results/Findings

The three multistaged indirect evaporative cooling units were monitored from June 1st 2012 to August 31st 2012. The performance data for the cooling units for the month of June indicated that the units were not operating correctly and that the units were not providing sufficient cooling. Further testing indicated that the solenoid valve's that regulate the amount of water that is provided to each unit had failed shut and a pressure reducing valve (PRV) needed to be installed in the main water line. A PRV was installed, and all three existing solenoid valves were replaced. The units then operated per design intent for the month of August. The cooling units were able to provide supply air temperatures below 70 °F for the month of August, and maintain the space within the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55-2010 summer comfort zone. The three units had a weighted average energy efficiency ratio (EER) of 63 and achieved *an 80% reduction in energy consumption* compared to a code compliant RTU with an EER of 12. The facility did not have cooling prior to the installation of the multistaged indirect evaporative cooling units and the energy savings and life cycle costs were compared to the costs to install and operate a standard 15-ton RTU. The calculated simple payback for the system was 22.8 years and was life cycle cost effective over a 40 year project lifetime with a net present value of $781. The life cycle cost analysis includes the cost of the water consumed by the units and the operation and maintenance costs of the multistaged IEC were assumed to be equivalent to the operation and maintenance costs of a standard RTU. It should be noted that the system would not have been life cycle cost effective if there was a baseline cooling system installed in the facility. Although the technology reduces energy use it also increases site water consumption, which conflicts with federal mandates to reduce water use.

A market analysis from a previous NREL study indicates that GSA should target regions 6,7,8,9, and 10 for multistaged indirect evaporative cooler installations.[10] The economic analysis indicates that the multistaged indirect evaporative cooler technology has the best economics as a retrofit technology when it is competing against smaller air-cooled air-conditioning systems with energy efficiency ratios (EER) ranging from 8 to 12 [EER is defined as the ratio of cooling output in British thermal units (Btu) divided by the input energy in Watts (Btu/Watt)]. The data center application is the most cost effective application in all five applicable regions and should take precedence over all other applications. For common GSA spaces such as offices, warehouses, and other facilities with internal loads below 2 Watts/ft^2, the system is not life cycle cost effective if the building has an existing cooling system; unless it is installed in locations that require year around cooling such as Phoenix or Las Vegas as an outside air / ventilation air pre-conditioner. The multistaged indirect evaporative cooler system should be considered in new construction and for facilities without existing air conditioning systems in all five climate zones; Figure 2 lists the top three installation priorities for GSA. Given the unique characteristics of the technology, GSA should focus their installation efforts on the three priorities outlined in Figure 2.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

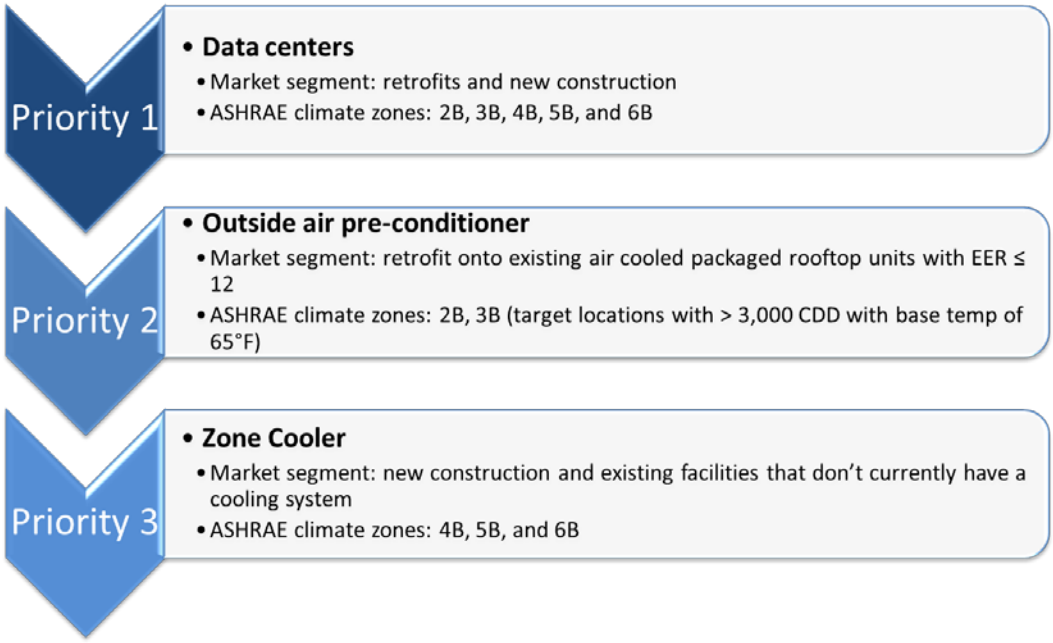

Figure 2. Multistaged indirect evaporative cooler installation priorities

E. Conclusions

The multistaged indirect evaporative cooler achieved an 80% reduction in energy consumption at this particular installation when compared to a typical RTU, and the system is life cycle cost effective over a 40 year project lifetime when using the federal discount and escalation rates. Given the poor performance of the unit prior to the commissioning that was performed through this Green Proving Ground effort, it is critical to monitor the supply air temperatures of the unit and determine the wet bulb effectiveness on an annual basis. The economics of the system were cost effective because the facility did not have cooling prior to the installation of the multistaged indirect evaporative coolers, but would not have been cost effective for this particular building type and application if the facility had cooling and the multistage indirect evaporative coolers were installed to pre condition outside air or as a zone cooler to reduce the total cooling load. The system was also able to maintain the space within the ASHRAE comfort zone during the demonstration. Although the technology reduced energy use and maintained thermal comfort it also increases site water consumption, which conflicts with federal mandates to reduce water use.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

II. Background

A. Introduction

Air conditioning is the single largest contributor to peak demand on U.S. electricity grids and is the primary cause of grid failures and blackouts.[4] Power generators and refrigeration-based air-conditioning units are least efficient at high ambient temperatures, when cooling demand is highest. This leads to increased pollution, excessive investment in standby generation capacity, and poor utilization of peaking assets. Air conditioning accounts for approximately 15% of all source energy used for electricity production in the United States alone (nearly 4 quadrillion British thermal units (Btu)), which results in the release of about 343 million tons of carbon dioxide into the atmosphere every year.[5] Evaporative air conditioners can mitigate the environmental impacts and help meet Energy Independence and Security Act (EISA) 2007 and General Services Administration (GSA) energy policy goals by reducing electricity use and demand.

The multistaged indirect evaporative cooler (IEC) technology can reduce energy use between 57% and 92% relative to standard air-cooled, refrigeration-based air-conditioning units, depending on facility type, location, baseline heating, ventilation, and air conditioning (HVAC) equipment, and technology application.[2] The main barriers to achieving these increased efficiencies are associated with the climate in which the technology is installed and the efficiency of the baseline cooling equipment. The increased capital costs of this technology need to be carefully accounted for when applying it in a retrofit scenario to ensure that the life cycle cost savings justify the initial investment.

B. Opportunity

The primary advantage of the multistaged IEC is its ability to supply cooler supply air temperatures than traditional evaporative cooling units, which extends the range of applicable climate zones, improves thermal comfort , and displaces more heat-pump based or mechanical cooling. The increased performance over traditional evaporative cooling units comes at a fraction of the energy use and energy cost of mechanical air conditioning. Packaged rooftop units (RTUs) are the most prevalent commercial building air conditioning technology, accounting for 52.6% of all air conditioned floor area, followed by individual air conditioners and central chillers (Table 1).[6] The vast majority of packaged RTUs are constant volume units that utilize air-cooled direct-expansion cooling systems. These systems have cooling efficiencies (energy efficiency ratios (EERs)) that range between 8 and 12.[7] The multistaged IEC can reduce air conditioning energy use by 57%–92% when competing against traditional packaged rooftop units, depending on location and facility type.[2]

---

[4] Heat Wave Nearly Causes Rolling Blackouts in California, http://www.nytimes.com/2000/08/02/us/heat-wave-nearly-causes-rolling-blackouts-in-california.html

[5] Building Energy Databook 2011, http://buildingsdatabook.eren.doe.gov/

[6] http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set8/2003pdf/b41.pdf

[7] Field Demonstration of a High-Efficiency Packaged Rooftop Air Conditioning Unit at Fort Gordon, Augusta, GA, http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15746.pdf

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Table 1 - Type of Cooling Equipment Used in U.S. Commercial Buildings, 2003 (CBECS)*

Cooling Equipment	2003
Packaged Air Conditioning Units	52.6%
Individual Air Conditioners	22.1%
Central Chillers	20.4%
Residential Type AC	19.4%
Heat Pumps	15.9%
District Chilled Water	5.0%
Swamp Coolers	2.7%
Other	2.2%

Note: Each category can be selected more than once for a single facility and the numbers add to greater than 100%

The multistaged IEC can be applied as a single-zone dedicated outside air system, as an outside air pre-conditioner or mixed (outdoor air and return air) air conditioner that feeds into an RTU or air handling unit (AHU). The system can provide improved ventilation rates versus traditional air conditioning, reduce strain on and investment in power distribution grids, and a reduction in harmful refrigerant gases. The multistaged IEC can also provide up to 30% colder supply air temperatures than traditional direct evaporative cooling (DEC) units without adding moisture to the supply air stream.

The target climates for the multistaged IEC are ASHRAE climate zones 2B, 3B, 4B, 5B, and 6B. The Denver Federal Center (DFC) is located in climate zone 5B and the system should be installed as an outside air pre-conditioner in climate zones 2B and 3B and can be applied as a zone cooler for climate zones 4B, 5B, and 6B. An ASHRAE climate zone map is provided in Figure 3.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

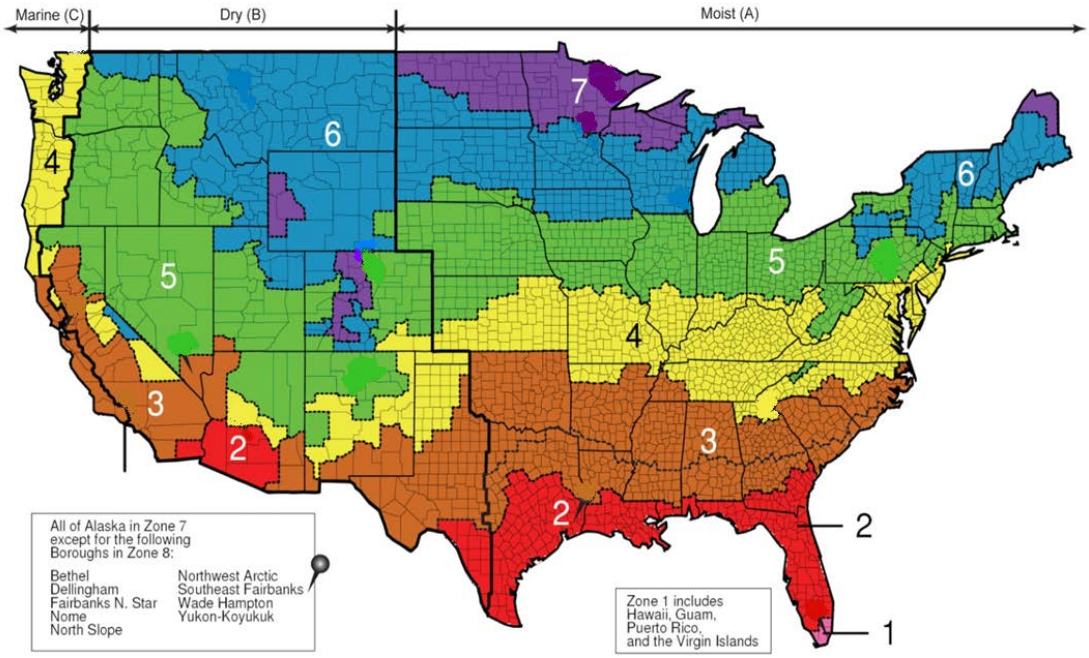

Figure 3. ASHRAE climate zone map
(Source: Joelynn Schroeder, NREL)

Although the technology can be installed in ASHRAE climate zones 1A–7A, the increased outdoor air humidity levels reduce the cooling capacity of the unit and the overall energy savings to the point that the technology cannot provide a favorable return on investment. Other limitations include increased onsite water consumption, inability to dehumidify, and sensitivity to inlet air conditions.

C. Demonstration Project Locations

Three multistaged IEC units (Coolerado Model C60) were installed at the Fitness Center in Building 41 and at the Denver Federal Center. The Denver Federal Center is located in Lakewood, Colorado. The outside air temperatures in Lakewood/Denver, Colorado are typically on the order of 80°F to 90°F during the cooling season and are rarely above 100°F. The outdoor air wet bulb temperatures are low during the cooling season and typically range from 50°F to 64°F, making Denver ideal for evaporative cooling technologies. One disadvantage is that the cooling season is relatively short, typically June through September, with fewer than 600 cooling degree days (base 65°F). The 0.4% ASHRAE evaporative wet bulb design day temperature for Denver is 65.1°F, and the multistaged IEC should be able to supply air below 70°F at all times in this location.

III. Technology Description and Objectives

A. Technical Objectives

The multistaged IEC unit's energy savings potential and ability to maintain acceptable interior thermal comfort was evaluated at the Denver Federal Center. The first technical objective is focused on ensuring the unit supplies enough cold air to maintain the space within the ASHRAE Standard 55-2010 thermal comfort zone while operating. The second objective focuses on the weighted annual operational EER and energy savings versus an incumbent packaged RTU with an air cooled direct expansion (DX) cooling system. Since this facility was not air conditioned prior to the installation of the multistaged IEC units, the life cycle costs were compared against the estimated installed costs and energy performance of a packaged rooftop unit. Specific quantitative performance objectives are outlined in Table 2.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Table 2 – Quantitative Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Thermal Comfort	- Hours outside psychometric comfort zone - Supply air temperature	- Interior space temperature - Interior humidity - Supply air temperature	*- Less than 1% of time outside of ASHRAE comfort zone* *- Supply air temperature < 70 °F*
Energy Savings	- Weighted annual energy efficiency ratio (EER) (total cooling)	- Outside air temperature - Supply air temperature - Energy use	*- Greater than 50% energy savings over an RTU with an EER = 12*
Life Cycle Costs	- Net present value	- Water consumption - Energy consumption - Utility rates - Financial calculation rates	*- Net present value greater than $0 over 40 year project life*

B. Multistage Indirect Evaporative Cooler Technology Description

Direct Evaporative Coolers

Direct evaporative coolers (DECs) cool air by directly evaporating water into an airstream. As the water changes phases from a liquid to a vapor through the heat of vaporization, heat is drawn from the air and the air temperature is reduced. In low-humidity areas, evaporating water into the air provides a natural and energy-efficient means of cooling. DECs, also called swamp coolers, rely on this principle, cooling outside air by passing it over water-saturated pads, causing the water to evaporate into it. Unlike central air-conditioning systems that recirculate the same air, DECs provide a steady stream of fresh air into the building and require an exhaust air path through the house or building.

Conventional evaporative cooling has high potential for significant energy savings in dry climates. Evaporative systems have competitive first costs and significantly reduce operational energy use and peak loads. The primary concern with traditional evaporative cooling units is their ability to maintain comfortable interior conditions. DECs are typically rated with a supply air flow rate (cubic feet per minute (cfm)), rather than a cooling capacity. The temperature of the supply air that an evaporative cooling unit can provide is typically rated as a wet bulb effectiveness (WBE) with the following equation:

$$\varepsilon = \frac{T_{DB} - T_{supply}}{T_{DB} - T_{WB}}$$

Where

ε = wet bulb effectiveness(WBE)

T_{DB} = dry bulb temperature of entering air

T_{supply} = supply air temperature

T_{WB} = wet bulb temperature of entering air

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

The efficiency of a DEC is a function of the following:

- *Evaporative pad effectiveness:* The typical residential DEC will use an aspen pad that has a WBE between 65% and 78%. The pads are typically made from aspen trees, plastic, or paper. A more efficient option for the evaporative pad is a rigid media cooler, which has more surface area per cubic volume and the medium is rigid, which prevents it from sagging over time and can achieve a WBE as high as 90%.[8] The WBE is also a function of pad thickness, the air velocity through the pad, and the effectiveness of the water distribution through the pad (Figure 4).

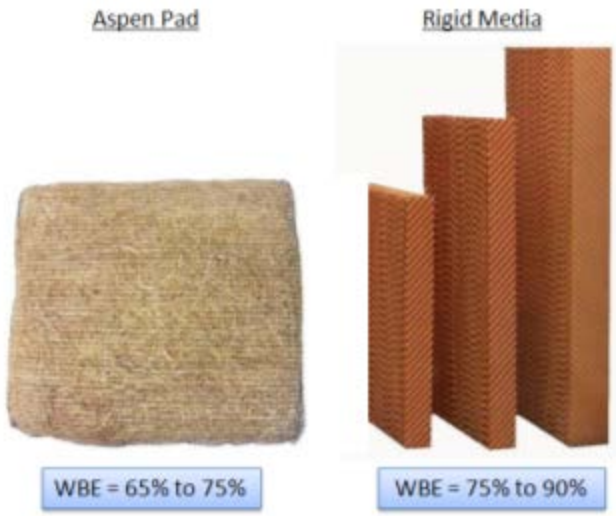

Figure 4. DEC media
(Source: Jesse Dean, NREL)

- *Supply fan and motor efficiency*: The efficiencies of the fan, motor, and belt/drive have a significant impact on unit efficiency. Typical DECs use a centrifugal fan, belt drive, and single-phase induction motor. The motors are typically one or two speed. Single-phase, asynchronous induction motors are not subject to the same efficiency standards as three-phase motors, and can have poor efficiencies, with electrical motor efficiencies as low as 50%. The most efficient designs use high-efficiency centrifugal or backward curved fans, direct drive supply, and electronically commutated motors (ECMs). ECMs have significantly higher electrical efficiencies and allow for fully variable-speed operation, which increases cooling efficiency at part load conditions.

The standard DEC also includes a circulation pump that will draw a small amount of power when it is circulating fluid through the direct evaporative pad. There are a number of commercially available residential and commercial DEC systems.

Multistage Indirect Evaporative Cooler Technology Overview

An internally manifolded indirect evaporative cooler (IEC) has made dew point temperature—rather than wet bulb—the new low temperature limit for evaporative cooling. Wet bulb is the temperature at which air will cool

[8] Evaporative Cooling Design Guide, http://www.emnrd.state.nm.us/ecmd/multimedia/documents/EvapCoolingDesignManual.pdf

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

when water is evaporated in unsaturated air. DOE laboratory testing has proven this cooler's ability to supply air at or below ambient wet bulb temperature (between 100% and 120% WBE), surpassing state-of the-art IECs (which are about 70% effective) and even swamp coolers (which are about 90% effective) without adding humidity to the supply air.

Accomplished by elegant use of the multistaged IEC, this approach is 2 to 4 times as energy efficient as conventional air conditioning. It also significantly enhances occupant comfort, enhances the climate range for non-compressive, non-refrigerant-based air conditioners, and displaces a higher percentage of mechanical cooling requirement compared to DEC. In a climate like Denver, Colorado, a DEC will use roughly the same amount of water as the multistage IEC, and the multistaged IEC will use less energy than a standard residential DEC with a standard constant speed fan motor.

Scalable for residential or commercial applications, the evaporative cores are made of plastic to separate the dry supply air flow from the wet exhaust air flows, and can be mass produced by an automated assembly line. The wet exhaust flows serve as progressively colder heat sinks to produce the colder supply temperatures unique to this all-indirect technology. Fresh air is provided to the building at temperatures and relative humidities (RHs) that achieve indoor comfort in climates with design wet bulb temperatures below 70°F, which includes most of the western United States. Ambient dry bulb temperature is irrelevant, as the wet bulb temperature is the dominant factor in determining the supply air temperature provided by the IEC unit.

The multistaged IEC has a unique design that maximizes the effectiveness of the direct and indirect stages of its cooling process. The schematic in Figure 5 illustrates fluid movement through the patented heat and mass exchanger (HMX). The HMX is made of plastic in a geometric design that cools both the product and working airstreams in an isolated heat exchange process.

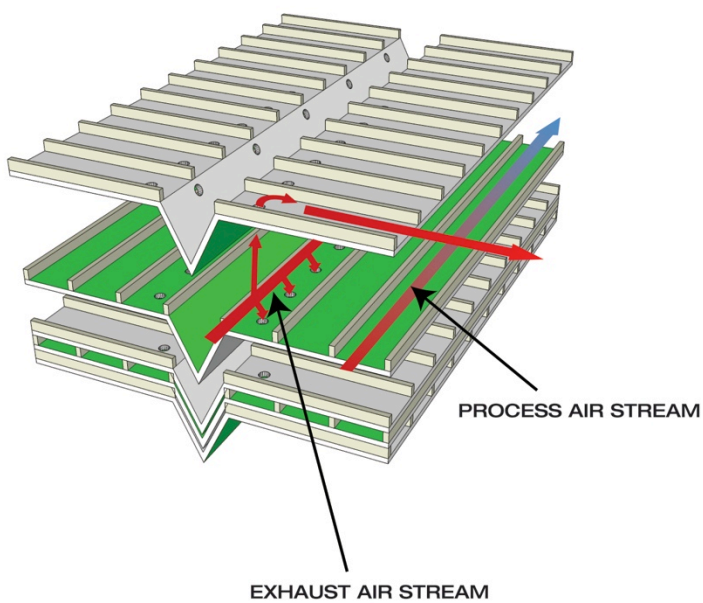

Figure 5. Internal HMX process airstream and EA stream airflow
(Source: NREL)

Figure 6 provides a side view of the multistage IEC and an illustration of the main components.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

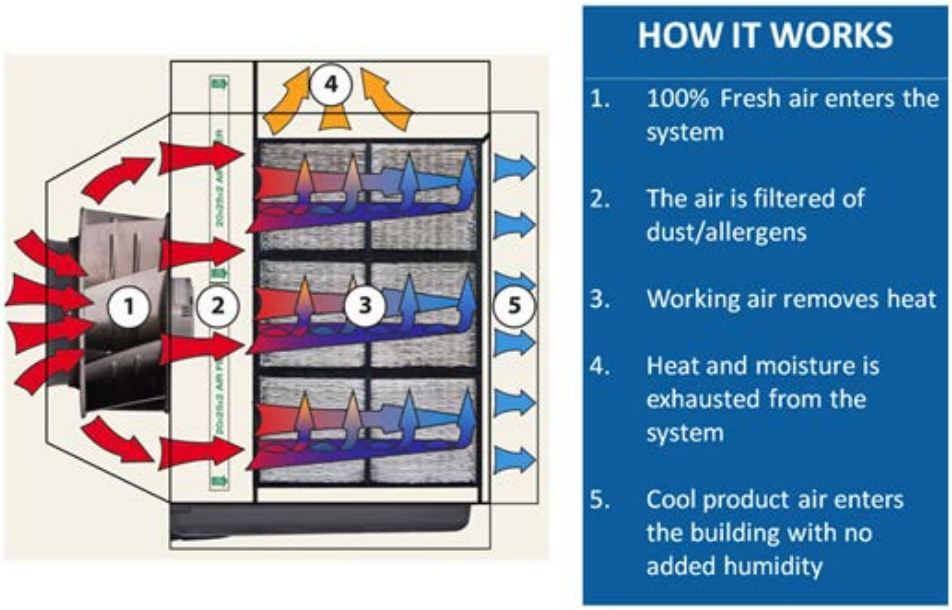

Figure 6. Side view of multistage indirect evaporative cooler airflow process
(Source: Coolerado)

Fan energy is the only form of electrical energy input into the system. The fan is driven by an ECM that is greater than 90% efficient and is variable down to a near 0% flow rate. The inlet air passes through a filter before it enters the unit. The top portion of the inlet air is supplied to the space as the primary/product air stream. The air that flows through the bottom part of the HMX is the seccondary/working air. The system of cascading incremental airflows creates a thermodynamic process called the Maisotsenko Cycle (or M-Cycle) (Figure 5 and Figure 6). The process works by cooling both the primary/product air and the secondary/working air in a 20-stage process. The cumulative result is a lower primary/product air temperature than is possible with conventional evaporative cooling technologies. The key difference between this and other direct/indirect processes is that the secondary/working air that is accumulating moisture is exhausted at each stage, enabling the primary/product air to be delivered at a lower dry bulb temperature. This staging of air flows creates supply air that is driven by the colder dewpoint temperature rather than the wetbulb temperature.

In the psychrometric chart shown in Figure 7, the red arrows indicate the direct evaporative cooling taking place in the secondary/working airstream, which is exhausted at each of the 20 stages. The blue arrows represent indirect cooling of the primary/product airstream through the plastic heat exchange material; no moisture is added to this air stream during this process. This portion of the secondary/working air mixes with the seconday/working airstream during the purge process, so it will mix with air at higher humidities but only in the secondary/working airstream.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

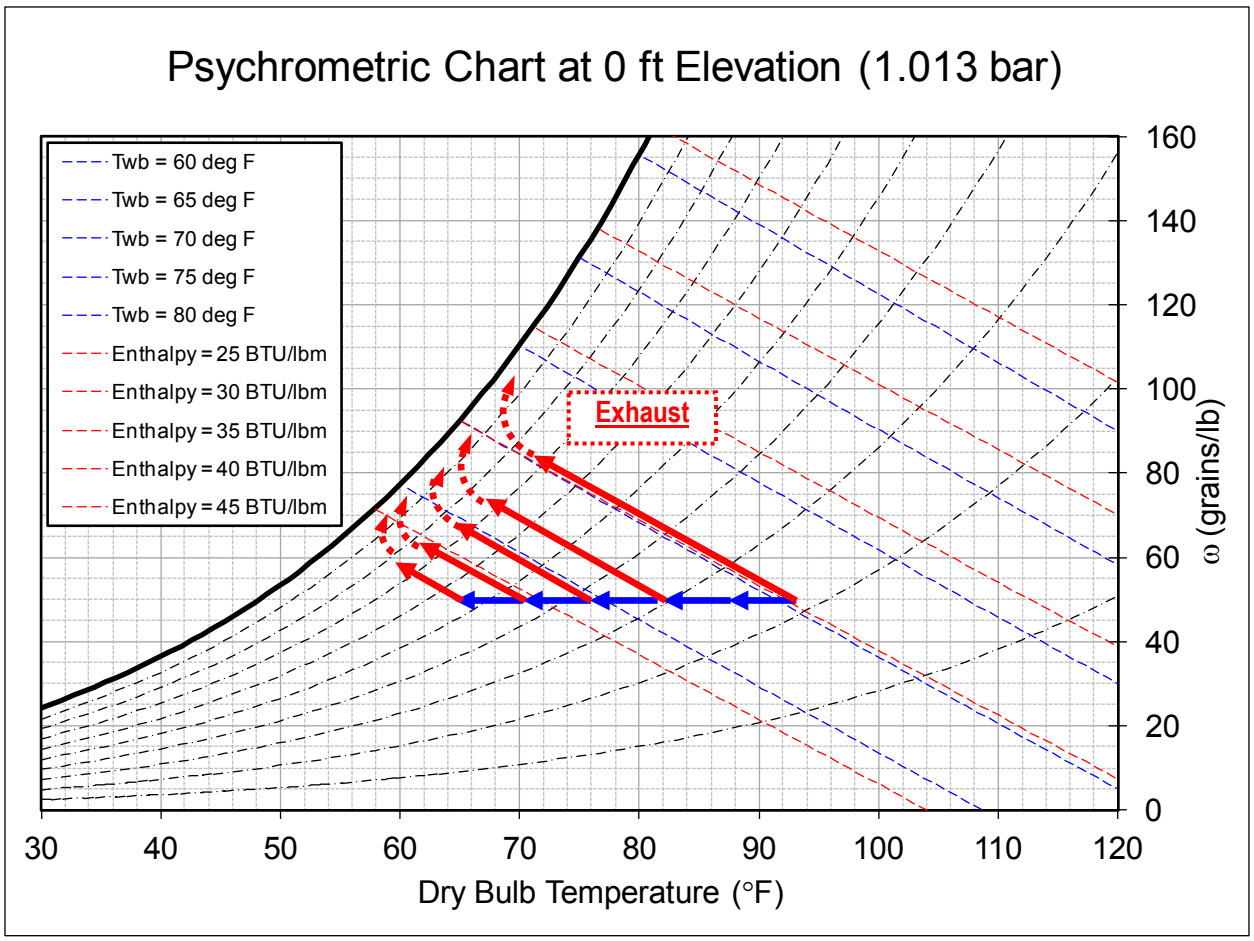

Figure 7. Conceptual psychrometric representation of the staged indirect cooling process

The advantage of the M-Cycle is that the working air is purged repeatedly so the initial conditions are essentially reset, as lower dry bulb and wet bulb temperatures are established with each purge cycle. This allows the eventual supply air temperature to be below what the original initial conditions would indicate possible—below the thermodynamic wet bulb temperature. This key staged-cooling process is essentially what sets the multistaged IEC apart from other IEC and DEC systems and enables greater cooling performance. During this process, no moisture is added to the primary/product air.

Figure 5 and Figure 7 illustrate the continuous purge process. Because of this purging, the multistaged IEC requires greater total airflow than other types of cooling systems. However, because the supply air temperature is lower than that possible with DEC and typical IEC systems, less supply air is required to meet space conditioning needs.[9] Furthermore, the cooling effect on the building is greater during the most humid day and will therefore displace more mechanical cooling when used to suplement mechanical cooling equipment.

[9] http://www.idalex.com/technology/how_it_works_-_technological_perspective.htm

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

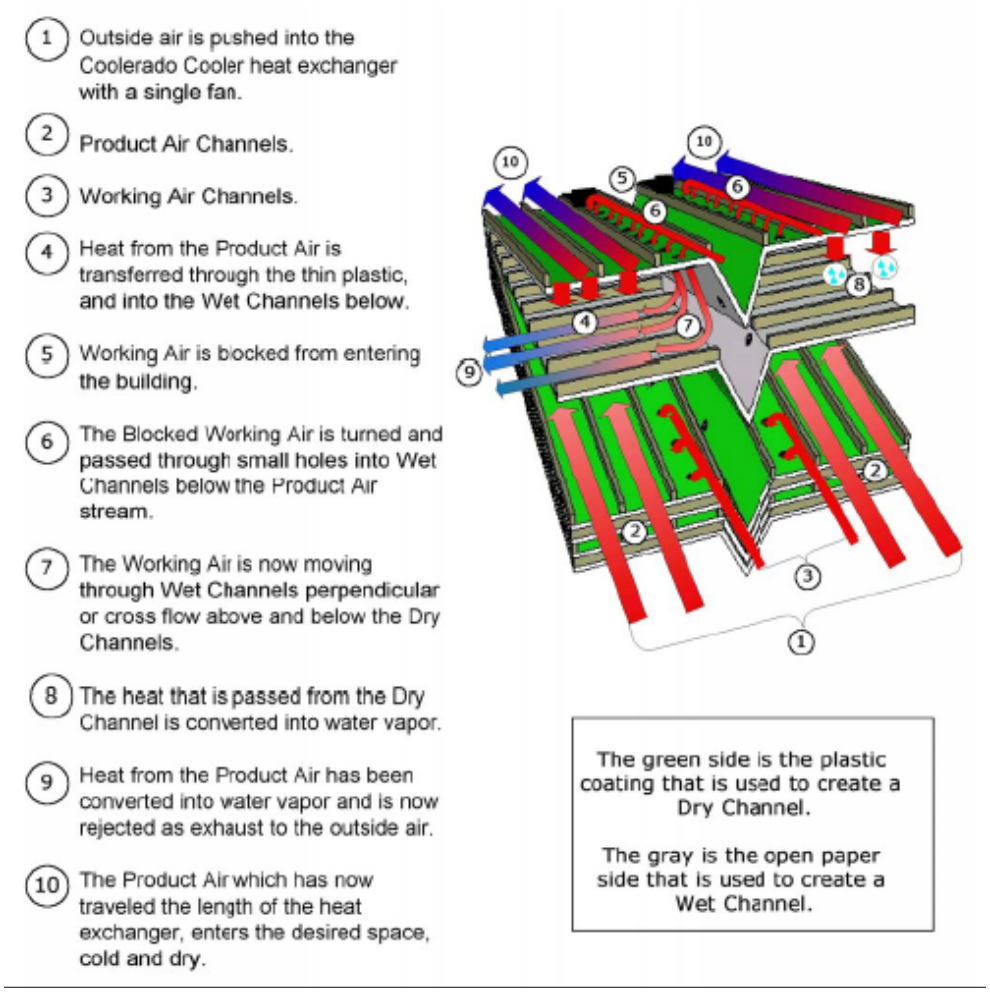

Figure 8. Staged flow of the IEC/DEC process
(Source: Coolerado)

IV. Assessment

A. Facility Description

Three multistaged IEC units were installed in the fitness center in Building 41. This space was not air conditioned prior to the installation of the cooling units. Building 41 is a large facility and all the systems were set up as zone coolers with 100% outside air. A floor plan of Building 41 is provided in Figure 9. The fitness center in Building 41 is a large open room with a number of treadmills, exercise machines, and free weights.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

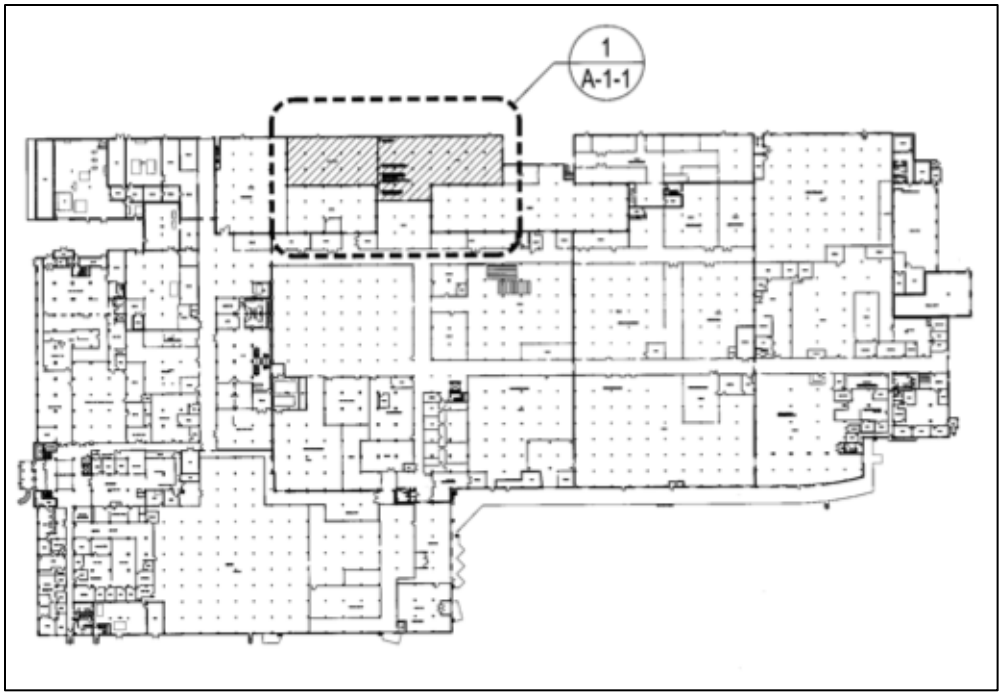

Figure 9. Building 41 Floor Plan
(Source: GSA Region #8)

B. Technology Specification

This particular manufacturer offers three standalone products, the M30, M50, and C60. The M30 is the smallest unit and is typically applied to residential and small commercial units (Figure 10).

Figure 10. Multistage indirect evaporative cooler Stand Alone Products
(Source: Coolerado)

The C60 unit can provide 1,670 cfm of supply air when 0 inches of static pressure are applied to the supply and has a wet bulb effectiveness that ranges from 89% to 120%. The total cooling provided by the unit changes as a function of inlet air conditions and fan speed, but the peak cooling capacity is around 4 tons. The cooling capacity is a function of inlet air conditions and the 4 tons is relative to total air conditioning (delta between supply air and outside air).

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

The water consumption rate of the unit will also fluctuate with cooling rate, but typically ranges from 3 to 6 gallons per hour.

C. Technology Deployment

The most common application of the multistaged IEC is a zone cooler that conditions 100% outside air (Figure 11). This type of installation is limited to ASHRAE climate zones 4B, 5B, and 6B because the unit cannot supply cold enough air in locations with higher ambient humidity levels. The advantages of this type of configuration are related to its simple installation, increased ventilation rates, and potential for significant energy savings relative to standard packaged RTUs with DX cooling systems. The DFC is located in ASHRAE climate zone 5B and a graphical representation of the installation of two of the three units installed at Building 41 is provided in Figure 11.

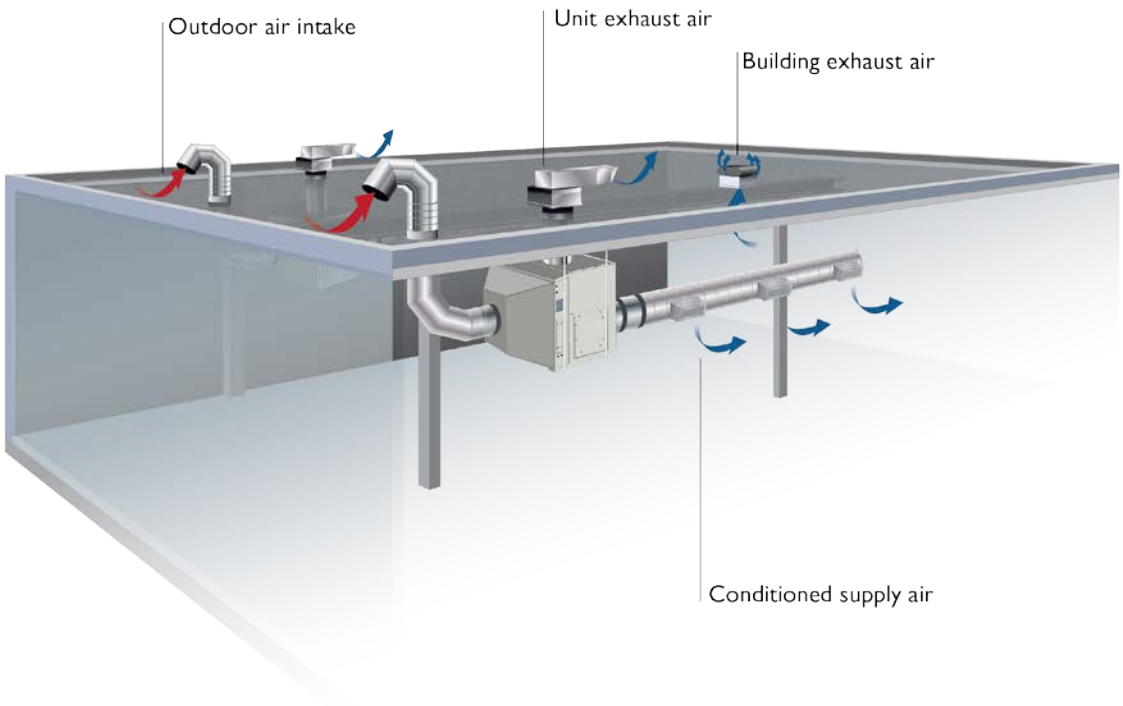

Figure 11. 100% Outside Air Zone cooler
(Source: Joshua Bauer, NREL)

The three multistaged IEC units installed in Building 41 were hung from the rafters and an outside air intake and exhaust duct was installed for each unit. Since the units were installed as 100% outside air units, a relief air damper was installed in the middle of the room in order to avoid over pressurization (Figure 12). A local thermostat was installed that controlled all three units and the thermostat set point and schedule of the three units was set by the central building automation system for the campus. The three units would ramp up and down in unison to meet the space temperature set point. A main water line was also ran into the room that provided water to all three units and the water line for each unit branched off from the main water line.

Rather than installing 100% outside air systems, the designer could have chosen to have one or two units draw 100% return air. This strategy would have eliminated the need for the building air exhaust, and would have reduced the overall energy usage at the installation.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

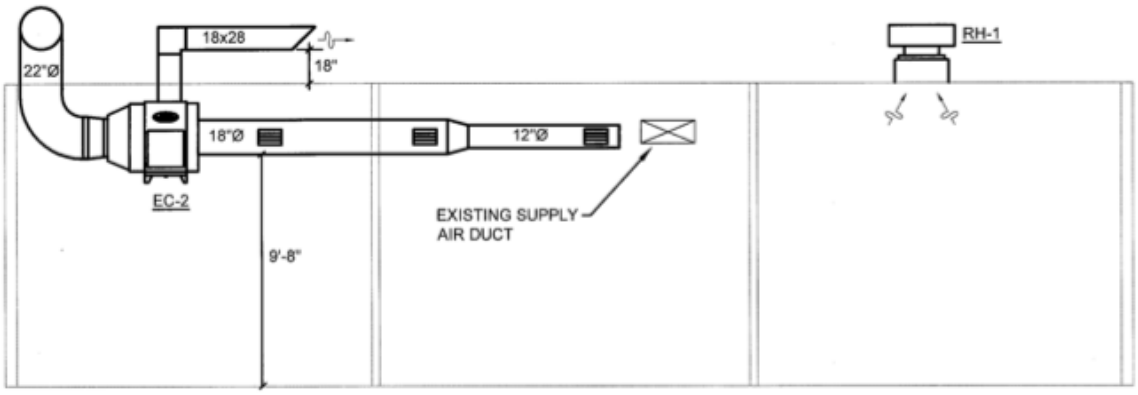

Figure 12. Multistage indirect evaporative cooler installation side view

D. Test Plan

The multistaged IEC units were studied in order to characterize their performance, and compare their energy usage to a traditional packaged RTU with an air cooled DX cooling system. The system was monitored for three months and a list of monitoring points are provided below:

Electrical Monitoring

- Total power for all three units was measured at the main electrical panel

Outside Air Conditions

- Outside air temperature was monitored via the onsite building automation system
- Outside air relative humidity was monitored via the onsite building automation system

Supply Air Conditions

- Supply air temperature was measured in the main supply air duct for all three units with a resistance temperature detector (RTD) temperature sensor

Space Conditions

- Space temperature was measured in three locations with a space temperature sensor
- Space relative humidity was measured in three locations with a space relative humidity sensor

Water Consumption

- Water consumption was measured at the main inlet pipe that supplies water to all three units with a Dyansonics ultrasonic flow meter

E. Instrumentation Plan

The electricity use, supply air conditions, and outside air conditions were all monitored continuously over the three month period at one minute time intervals. The space conditions were monitored at 5-minute time intervals and the water consumption was monitored at 1-second time intervals. The units use a solenoid valve to cycle water through the units and the small bursts of water can only be captured at 1 second intervals and the water use was only measured over a two week period.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Data Acquisition System

The data acquisition system (DAS) that was installed consisted of a number of stand alone Onset Data loggers, a Dent ElitePro SP power logger, and a Dynasonics water flow meter. Table 3 summarizes the monitoring points, equipment location, and instrument accuracy.

Table 3 - Monitoring Equipment

Input	Logging Equipment Description	Location	Instrument Accuracy
Outside Air Temperature	*Building automation system*	*Unknown*	*Unknown*
Outside Air Relative Humidity	*Building automation system*	*Unknown*	*Unknown*
Supply Air Temperature	*Onset TMC1-HD Air temperature*	*Supply air duct*	*± 0.45°F from 32° to 122°F*
Space Temperature	*Onset HOBO U10*	*North, south and center of room*	*± 0.95°F from 32° to 122°F*
Space Relative Humidity	*Onset HOBO U10*	*North, south and center of room*	*± 3.5% from 25% to 85%*
Electricity Use	*Dent ElitePro SP™*	*Main electrical panel*	*< 1%*
Water Use	*Dynasonics TFX Ultra*	*Inlet water pipe*	*1% of reading at rates*

V. Results

A. Commissioning

A sampling of data taken between May 2012 and July 2012 revealed that the multistaged IEC units were producing high supply air temperatures despite favorable outside air conditions that should have resulted in substantially lower supply air temperatures. Figure 13 shows the supply air temperatures and outside air conditions during operating hours for the three units over a typical week in July.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

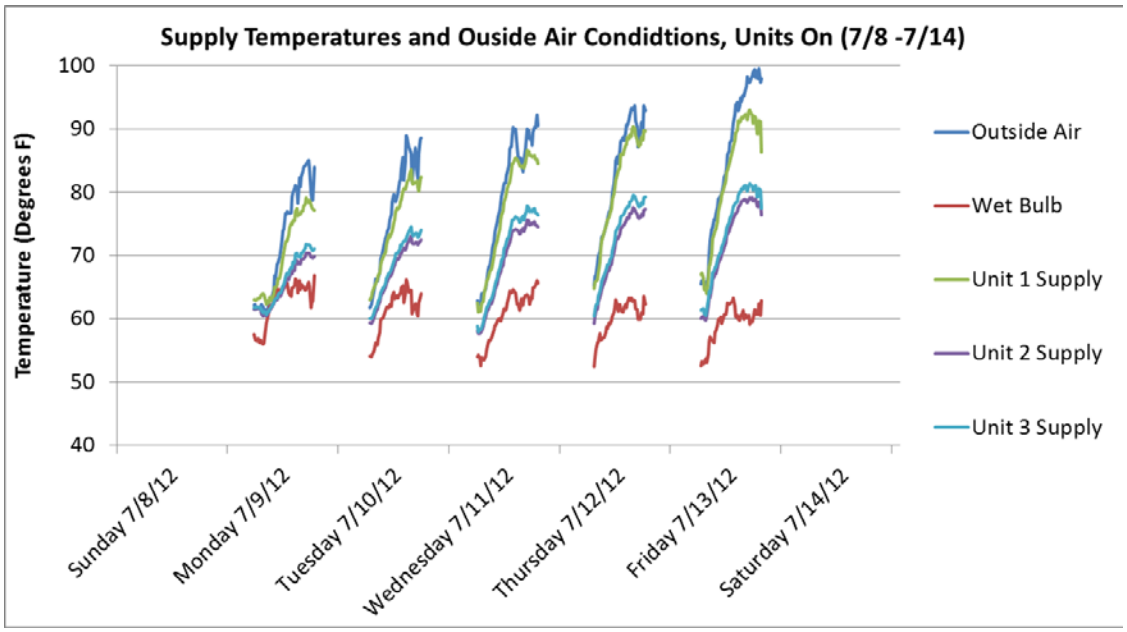

Figure 13. Supply air temperatures for three multistage indirect evaporative cooler units in July

The supply temperatures in Figure 13 show inconsistent behavior between the three units, with unit 1 tracking the outside air temperature and units 2 and 3 providing slightly cooler supply air. Overall, the supply air temperatures are closer to the outside air temperatures (approaching 80°F) and significantly higher than the wet bulb temperature which suggests that the multistage IEC units were not providing effective space cooling. This poor performance is also reflected below in Figure 14, showing the WBE for all three units over the same period in July.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

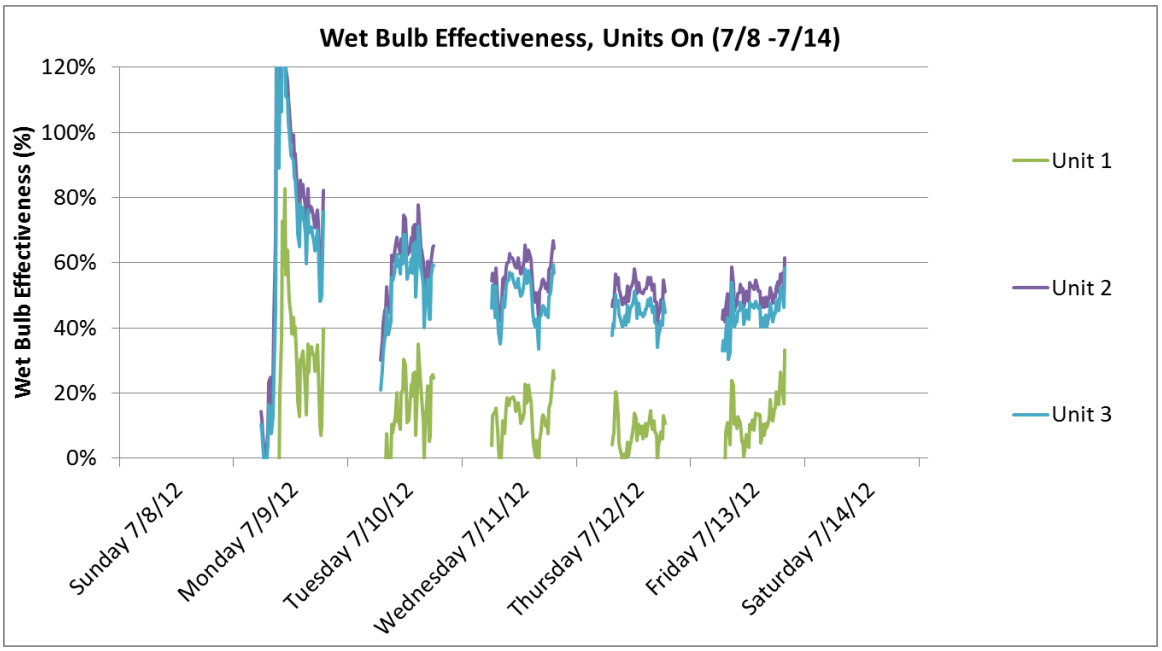

Figure 14. Wet bulb effectiveness for three multistage indirect evaporative cooler units in July

Figure 14 shows the WBE of the three units with an average around 50% for units 2 and 3, while unit one operated consistently lower, with a WBE of 20%.

Examination of the water use data showed that the three units were using very little water. While the three cooling units should use around 9 gallons per hour, the units at the Federal Center were using roughly 1.5 gallons per hour. The poor air conditioner performance along with the low water use data led to an investigation of the multistaged IEC units themselves. It was determined that the solenoid valve on all three units was only allowing small amounts of water into the air conditioners. With the restricted water flow rates, it was impossible for them to achieve optimal cooling.

Further investigation found that the city water pressure exceeded the required pressure range on the multistaged IEC units, which was 40 to 60 pounds per square inch (psi) at the time of the installation, and the increased water pressure broke the solenoid valves. A pressure-reducing valve (PRV) was installed in early August, and a significant performance improvement was achieved. August performance data was compared to laboratory test results from NREL's Thermal Test Facility and the correlation resulted in an R^2 value of 0.97, confirming proper operation.[10] Figure 15 shows the graphical results of the correlation, ensuring confidence that the system was fixed and is now performing as intended.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

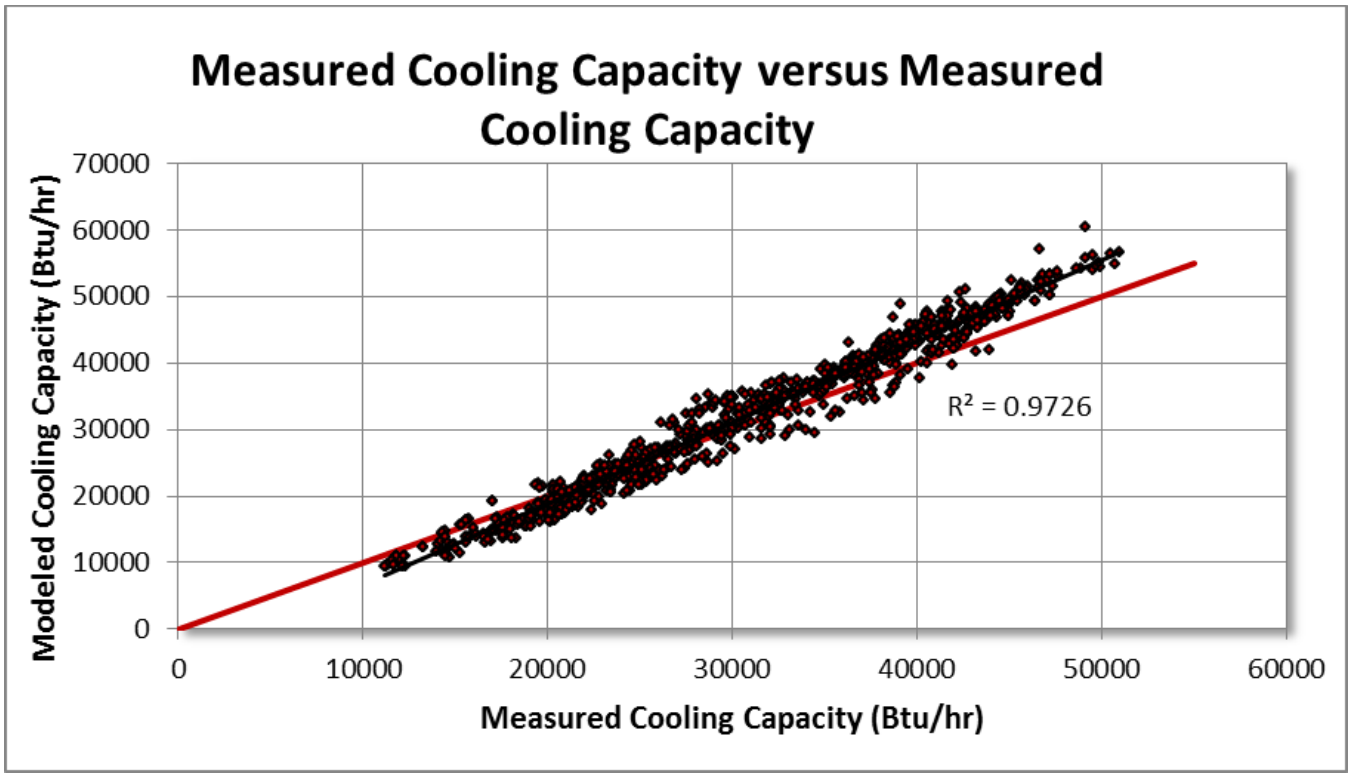

Figure 15. Measured data correlated to laboratory tested ideal performance

B. Thermal Comfort Performance

The supply temperatures in Figure 16 show consistent behavior between the three units for the month of August. Overall, the supply air temperatures are tracking very close to the outside air wet bulb temperatures suggesting that the multistaged IEC units are providing effective space cooling. This performance is also reflected below in Figure 17, showing consistently high WBE for all three units over the same period in August.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

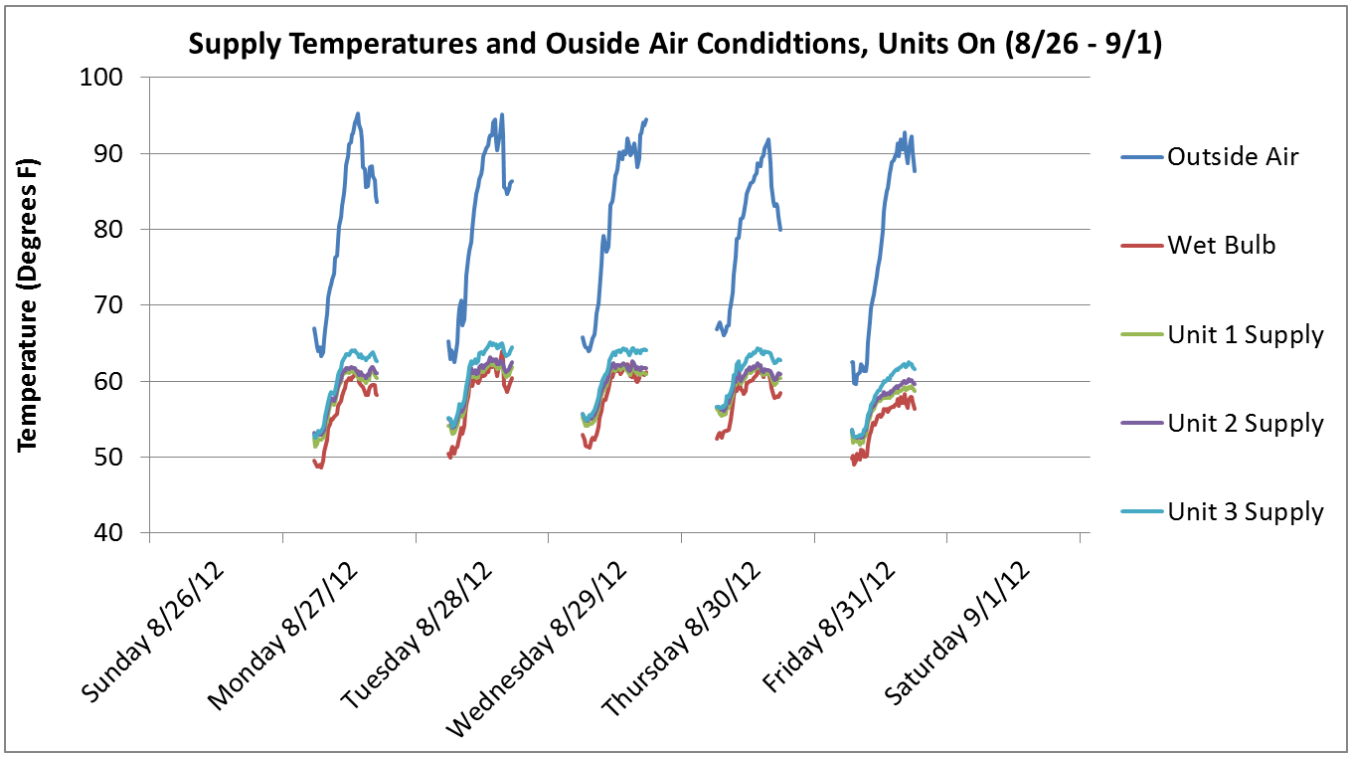

Figure 16. Supply air temperatures for three multistage indirect evaporative cooler units in August.

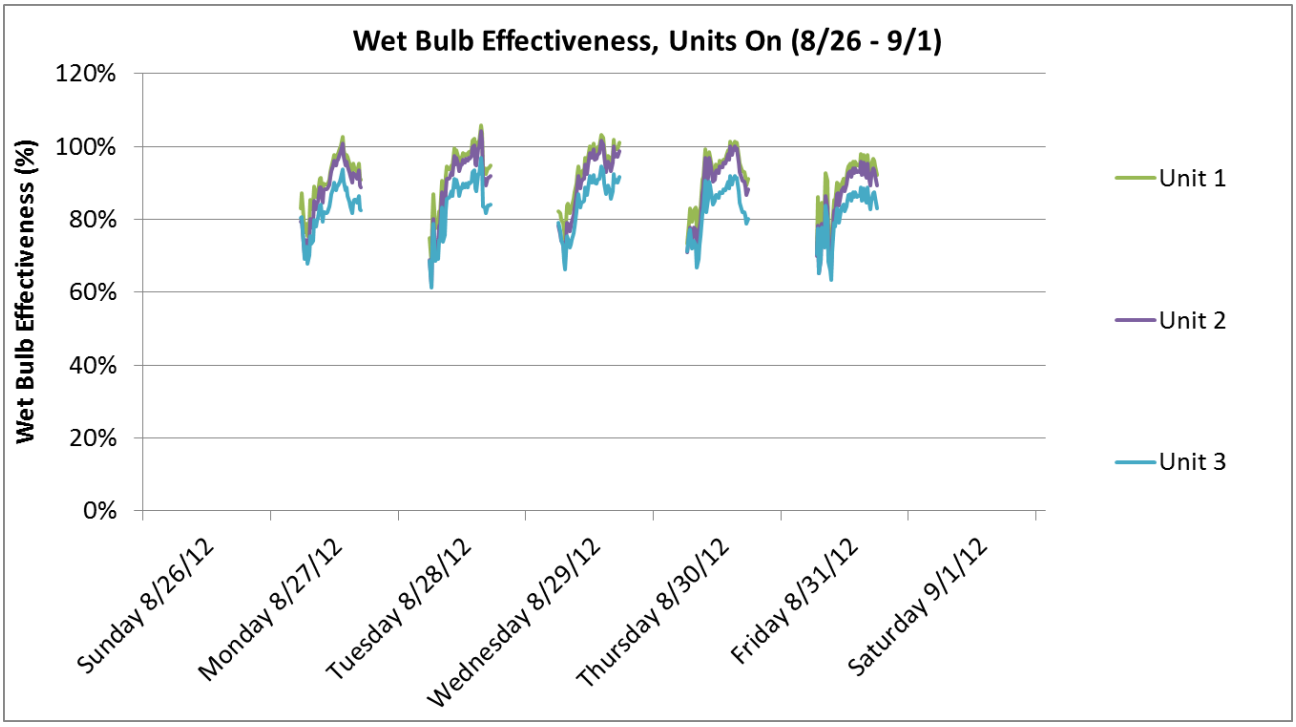

Figure 17. Wet bulb effectiveness for three multistage indirect evaporative cooler units in August

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Figure 17 shows the WBE of the three units with an average around 90% for all units. The design of the M-Cycle allows the units to potentially achieve greater than 100% WBE, which is observed for a few hours of the illustrated data.

Figure 18 shows the graphical results of the outside air temperature, average space air temperature, and average supply air temperatures. The space temperature was maintained between 70 °F and 74°F, even when the outside air reached temperatures above 90°F. Supply temperatures trended with outside air, but were able to maintain set-point comfort conditions during all hours of the displayed hot summer week.

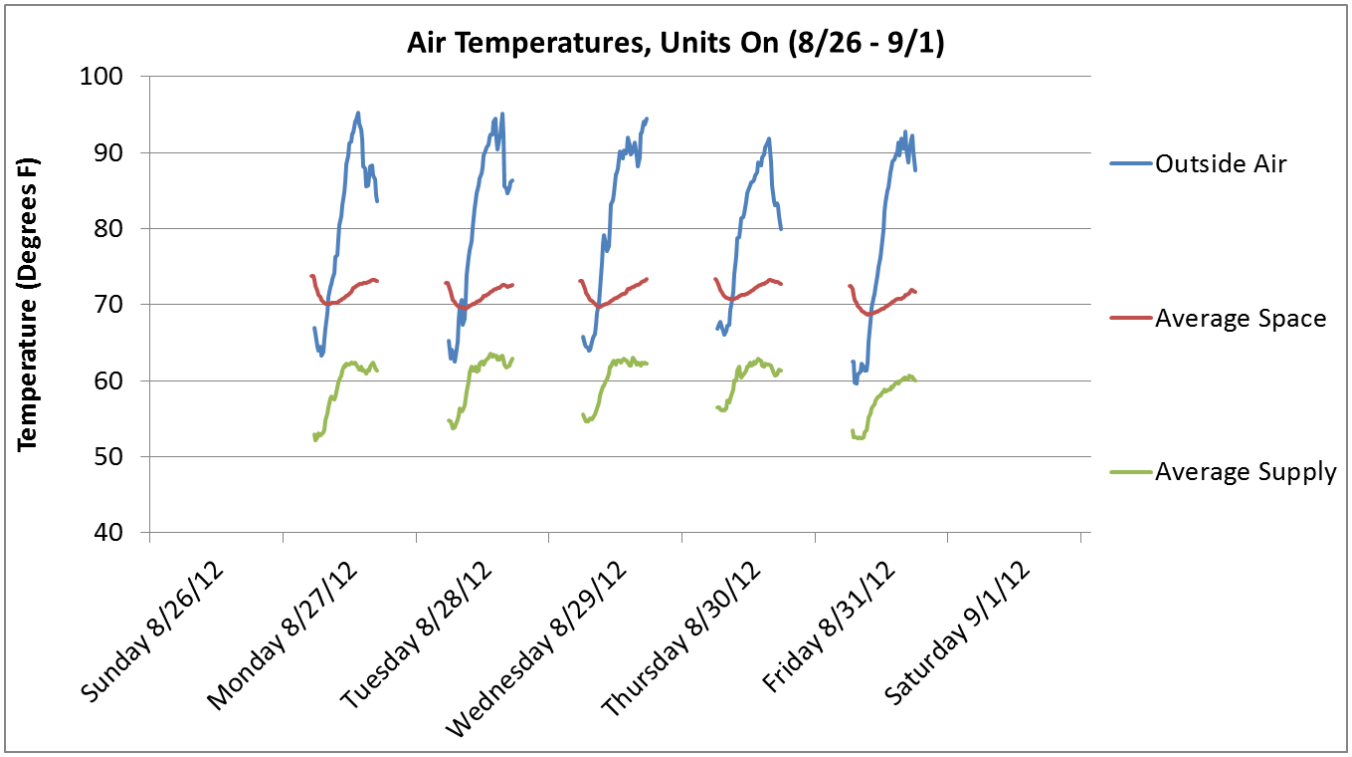

Figure 18. Air temperature trends for outside air, space air, and supply air in August

Figure 18 shows that on the hottest week in August with outside air temperatures peaking at 95°F, the average supply air temperature peaked at 63°F. Therefore, the multistaged IEC units were able to maintain supply air temperatures less than 70°F during peak conditions, successfully achieving its performance objective.

The space temperatures inside of the fitness center in Building 41 were monitored and compared to the ASHRAE thermal comfort zones. Figure 19 shows a psychrometric chart with the average space temperature for each hour of operation during a 4 week period in August (8/6/2012 – 9/4/2012), plotted with respect to the ASHRAE summer comfort zone.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

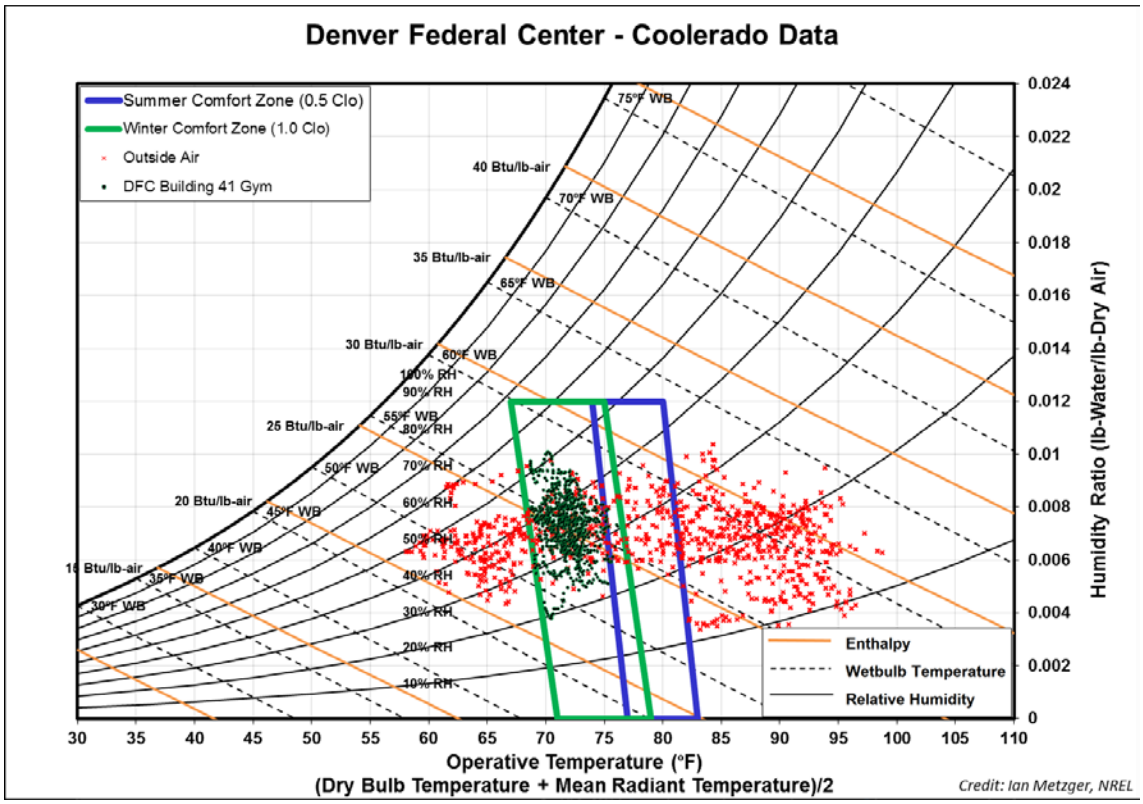

Figure 19. Space conditions with respect to ASHRAE summer comfort zones on psychrometric chart

The multistaged IEC units were able to maintain comfortable space conditions within the defined ASHRAE comfort zones for all operating hours during a 4 week period in August (8/6/2012 – 9/4/2012). Therefore, the units achieved the performance metric to achieve less than 1% of time outside of ASHRAE comfort zone.

C. Energy Savings

During a 4 week period in August (8/6/2012 – 9/4/2012) operating during working hours (4:45am – 4:30pm) the three cooling units were able to achieve 20.62 million British thermal units (MMBtu) of cooling, while only consuming 360 kilowatt-hours (kWh) of electricity and 9,106 gallons of water. The resulting average EER during this period was 63, which is five times greater than the average EER of typical air conditioning equipment. Table 4 summarizes the energy and water performance of the three multistaged IEC units, and the overall performance.

Table 4 – Energy and Water Performance Results

System	Cooling (MMBtu)	Energy Consumption (kWh)	Efficiency (EER)	Water Consumption (Gallons)
Unit 1	7.00	119	65	1,652
Unit 2	6.97	122	62	1,685
Unit 3	6.65	119	62	1,652
Total	***20.62***	***360***	***63***	***4,989***

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

The water consumption over the monitoring period was estimated on a gallons per ton hour basis based on the two weeks' worth of metered water data. The energy savings were calculated over a typical cooling season using the measured average EER across all three units and the name plate EER of a code minimum RTU. The EER of the multistaged IEC units was calculated based on the temperature difference between the outside air and the supply air and assumes that the RTU would process 100% outside air. Based on the size of the multistaged IEC units and the ASHRAE 62.1 ventilation requirements for this space, the multistaged IEC or RTU should only be providing around 1,287 cfm of outside air. Although the RTU's should be set up to limit the outside air intake and condition as much return air as possible, as noted above these multistaged IEC units could also be set up such that one unit conditions outside air the other two condition return air. The comparison below assumes both the RTU and IEC condition 100% outside air as a true apples to apples comparison.

Table 5 – Extrapolated Energy Consumption

System	EER	Annual Energy Use (kWh)
RTU	12	7,561
Multistage indirect evaporative cooler	63	1,442
Energy Savings (kWh)		***6,119***

Table 5 shows the extrapolated energy performance, assuming a 4-month cooling season for a 100% outside air unit. The extrapolated total annual energy reduction is estimated to be 6,119 kWh/yr. The multistaged IEC achieves an 80% reduction in energy consumption compared to a typical RTU. Therefore, the energy performance exceeds the goal of greater than 50% energy savings over RTU with an EER of 12.

D. Life Cycle Costs

The financial viability of the multistaged IEC units was examined to study whether the cost savings outweigh the increased cost of the unit compared to a typical RTU. Table 6 shows the implementation costs of the cooling units compared to typical RTU quotes gathered by GSA project managers. There is an incremental cost difference of $10,092 between the two options.

Table 6 – Implementation Cost Quotes Provided by GSA Project Managers

System	Implementation Cost
Typical 15 ton RTU	$85,841
Multistage indirect evaporative cooler	$95,933

Table 7 shows the results of the economic analysis. Cost savings assume a blended electric rate of $0.084/kWh, based on $0.04/kWh electricity rate and $9.65 monthly demand rate. The blended rate was calculated based on the measured performance of the multistaged IEC units, assuming an annual consumption 360 kWh per year with a peak demand of 1.65 kW. Increased water consumption costs are calculated assuming water rate of

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

$3.64/1000 gallons. The operation and maintenance costs of the multistaged IEC were assumed to be equivalent to the operation and maintenance costs of a standard RTU since the multistaged IEC units were located inside and didn't have to be winterized. If the units were located outside and needed to be shut down for the winter then the maintenance costs for the multi staged IEC would be higher. Net present value (NPV) assumes a project lifetime of 40 years, inflation rate of 0.9%, real discount rate of 2.7%, and electricity escalation rate of 0.2%, as per the guidelines for federal projects. Incremental replacement costs throughout the equipment life are assumed to be equivalent between the RTU and multistage IEC unit, and are therefore not considered in the incremental cost analysis. Figure 20 shows the cash flow diagram of the detailed yearly costs-to-savings analysis.

Table 7 – Economic Analysis Results

Economic Analysis	
Energy Savings (kWh/yr)	6,119
Cost Savings ($/yr)	$515
Increased Water Cost ($/yr)	$73
Incremental Cost ($)	$10,092
Payback Period (yrs)	22.8
Discounted Payback Period (yrs)	35.25
Net Present Value ($)	$781

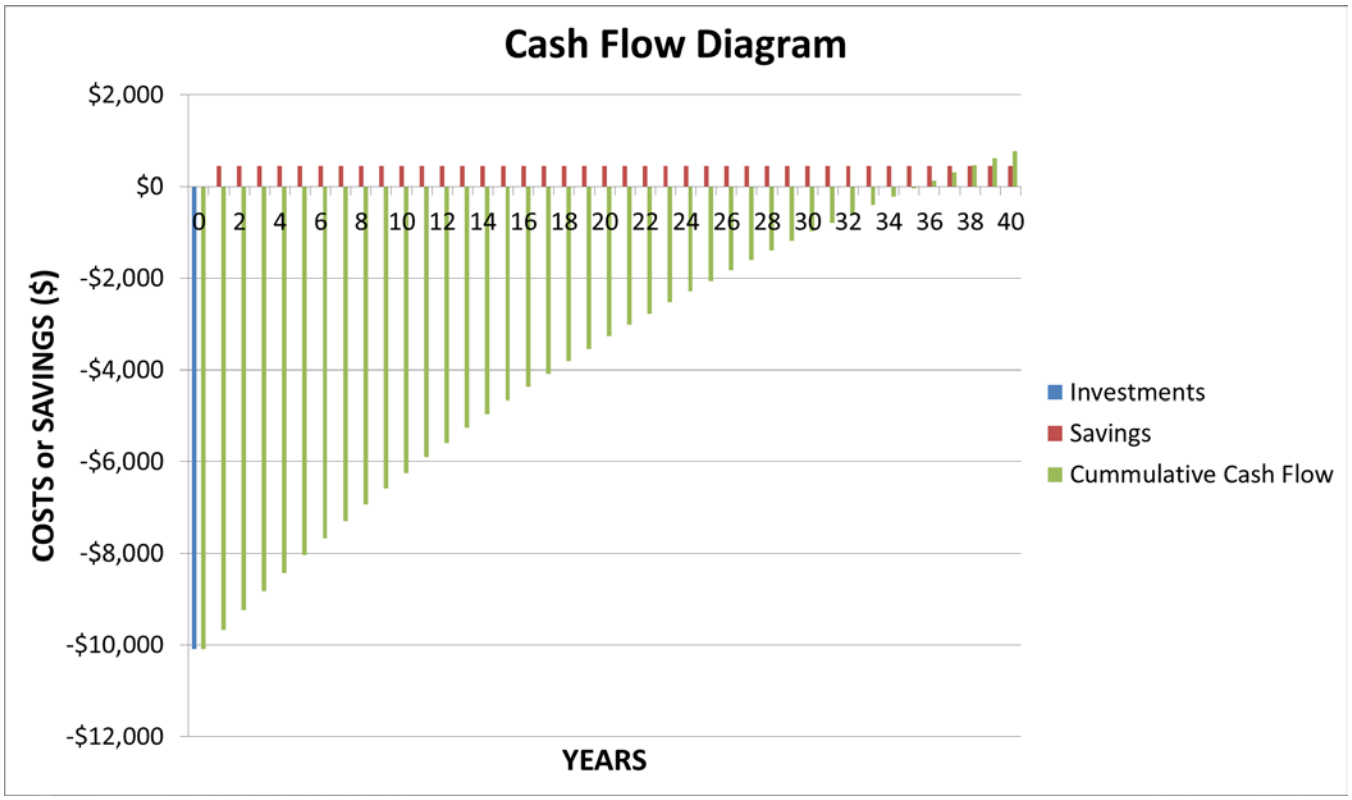

Figure 20. Cash flow diagram

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

The economic analysis reveals a simple payback period of 22.8 years, a discounted payback period of 35.25 years, and a NPV of $781 dollars over a 40-year project term. Therefore, the multistage IEC units successfully achieved the performance metric of a positive NPV over a 40-year term.

E. Considerations

The NREL team observed that the quotes obtained for the typical RTU were relatively high. Industry rules of thumb describe typical RTU installed costs of $1,500 per ton of cooling. If this were the case, the payback period would be significantly longer and not meet the federal life cycle costing requirements. A sensitivity analysis on incremental cost was conducted to impact on simple payback period. Figure 21 shows the correlation from the sensitivity analysis. As illustrated, the percent increase in capital cost relative to this multistaged IEC can significantly prolong the payback period.

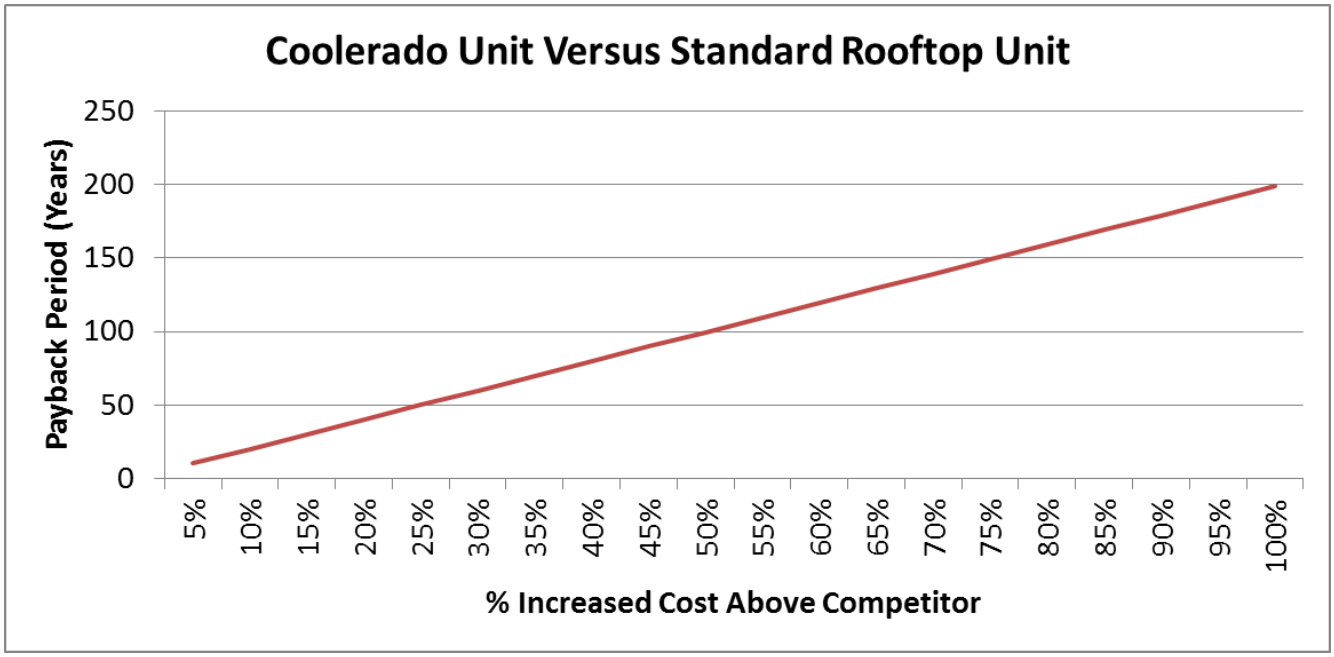

Figure 21. Sensitivity analysis showing the impact of % increased cost on payback period

For example, if the payback period was calculated assuming a baseline RTU was already installed and the mutlistaged IEC was installed as a retrofit, the payback period would be 200 years and is indicative of a typical retrofit in Denver Colorado using the installed costs at the GSA site. It should be noted that the multistaged IEC installed costs at this GSA site were over 3 times higher than a typical installation and this also impacts the sensitivity analysis.

Another topic to consider is that this demonstration project measured the performance of a 100% outside air unit. However, in many building environments, recirculated air accounts for the majority of the air supplied to the space. Outside air is typically only used to meet ventilation requirements. When considering applications where recirculated air may be used in combination with ventilation air, the measured EER would be impacted. The EER for a minimum outside air application would be less than the 63 EER measured for this demonstration and the annual cooling load on the air conditioner would also be reduced.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

VI. Summary Findings and Conclusions

A. Overall Technology Assessment at Demonstration Facility

The multistaged IEC units achieved an 80% reduction in energy consumption compared to a typical RTU and the system is life cycle cost effective over a 40-year project lifetime when using the federal discount and escalation rates. Given the poor performance of the unit prior to the commissioning that was performed through this Green Proving Ground effort, it is critical to monitor the supply air temperatures of the unit and determine the WBE periodically. The economics of the system were cost effective because the facility did not have cooling prior to the installation of the multistage IEC units, but would not have been cost effective for this particular building type and application if the facility had cooling and the multistage IEC units were installed to pre-condition outside air, or as a zone cooler to reduce the total cooling load. The system was also able to maintain the space within the ASHRAE comfort zone during the demonstration. Although the technology reduced energy use and maintained thermal comfort it also increases site water consumption, which conflicts with federal mandates to reduce water use.

B. Best Practices

NREL worked on a similar demonstration of the multistage IEC C60 units in Colorado Springs and conducted an analysis that focused on determining appropriate building types and locations for the multistaged IEC units in a retrofit application.[10] The building types that were evaluated included a small classroom (400 ft^2), a data center (19,994 ft^2), and a quick-serve restaurant (2,500 ft^2). The performance of the multistaged IEC units was compared to common cooling technologies with respect to energy savings, net regional water savings, and life cycle cost effectiveness. Energy savings, simple payback period, and NPV results are presented below.

The baseline HVAC systems included a packaged single zone (PSZ) unit with DX coils (EER of 9) for the small classroom, a constant volume AHU with an air-cooled screw chiller (EER of 8.76) for the data center, and two constant volume RTUs for the quick-serve restaurant (one serving the kitchen, one serving the dining area). For the small classroom, a multistaged IEC (model C60) was modeled as a standalone zone cooler if the unit was able to meet 98% of the cooling load; otherwise, the M30 was modeled as an outside air pre-conditioner for the packaged unit. Thirty M30 units were modeled as zone coolers in the data center model. One C60 unit was modeled as a pre-cooler retrofit on the RTU serving the kitchen in the quick-serve restaurant.

The results for the energy simulations are provided in Table 8 and the energy savings, simple payback, and NPV of the multistaged IEC units are compared to the baseline HVAC technologies. Note that the consumables, and O&M costs used in the baseline models were taken from the RS Means Facilities Maintenance and Repair 2011 Data Book. Results show annual the multistaged IEC units energy savings ranging from 57% to 92% across all locations and building types. The economics were calculated using an installed cost of $11,000 per C60 unit (which is 67% less expensive than the GSA installation), the federal life cycle costing procedures outlined in the Federal Energy Management Program Building Life Cycle Costing, and the project lifetime is specified as 40 years.

[10] Dean, J.; Herrmann, L.; Kozubal, E.; Geiger, J.; Eastment, M.; Slayzak, S. (2012). Dew Point Evaporative Comfort Cooling: Report and Summary Report. 198 pp.; Summary Report: 40 pp.; NREL Report No. TP-7A40-56256

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Table 8 - Multistage indirect evaporative cooler Market Analysis Economics

Location	Metric	Small Classroom	Data Center	Quick-Serve Restaurant
Phoenix, AZ	Percent Energy Use Reduction	65%	77%	70%
	Simple Payback (yrs)	11	14.3	9.9
	Net Present Value	$6,552	$1,241,631	$1,999
Las Vegas, NV	Percent Energy Use Reduction	68%	76%	
	Simple Payback (yrs)	12.7	13.1	
	Net Present Value	$5,599	$1,666,419	
Los Angeles, CA	Percent Energy Use Reduction	63%	81%	
	Simple Payback (yrs)	52.1	16.5	
	Net Present Value	-$3,016	$969,384	
Albuquerque, NM	Percent Energy Use Reduction	66%	86%	
	Simple Payback (yrs)	173.5	17.7	
	Net Present Value	-$12,345	$638,040	
Colorado Springs, CO	Percent Energy Use Reduction	64%	88%	57%
	Simple Payback (yrs)	275.2	13	61.8
	Net Present Value	-$8,827	$1,091,370	$-6,835
Helena, MT	Percent Energy Use Reduction	65%	92%	
	Simple Payback (yrs)	345.4	14.4	
	Net Present Value	-$9,002	$1,060,271	

The multistaged IEC technology has the best economics in data center applications due to their year-round cooling requirements. Simple payback periods and NPV vary across location due to variable capital costs, onsite water and electricity costs, O&M costs, and, application. The quick service restaurant had favorable economics in Phoenix and unfavorable economics in Colorado Springs, and the simple payback was better in both climate zones than the single zone classroom. The single zone classroom unit showed favorable economics in Phoenix and Las Vegas. The multistaged IEC system should be considered in new construction and for facilities without existing air conditioning systems in all five climate zones. It should also be noted that the installation costs will come down over time and will improve the economics presented in Table 8.

C. Barriers and Enablers to Adoption

The primary enablers to adoption are:

- ***Energy cost savings*** – the energy savings are significant for this technology, and there are very few technologies that can offer the energy savings benefits of the multistaged IEC over a standard RTU.
- ***Peak demand reduction*** - A significant benefit to electric utilities is the peak demand reduction during peak summer months.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

- ***Green house gas reduction*** – the system reduces green house gas emissions through the onsite energy savings and if the unit replaces a standard RTU, it also reduces the amount of harmful refrigerant gasses emitted to the atmosphere. For example the global warming potential of R410 is 2,100.[11]

The primary barriers to adoption are:

- ***Applicable climate zone*** – The target climates for the multistaged IEC are ASHRAE climate zones 2B, 3B, 4B, 5B, and 6B. The system should be installed as an outside air pre-conditioner in climate zones 2B and 3B and can be applied as a zone cooler for climate zones 4B, 5B, and 6B. Although the technology can be installed in ASHRAE climate zones 1A through 7A, the increased outdoor air humidity levels reduce the cooling capacity of the unit and the overall energy savings to the point that the technology cannot provide a favorable return on investment.
- ***Water consumption*** – The technology increases onsite water consumption and although onsite water consumption increases, the *Dew Point Evaporative Comfort Cooling* report indicates that the multistaged IEC doesn't increase overall regional water consumption in certain utility markets such as Denver, Colorado. The thermally driven power plant water use associated with the increased electricity consumption is approximately equivalent to the onsite water use of the multistaged IEC unit.
- ***Inability to dehumidify –*** The multistaged IEC cannot dehumidify the supply air and should not be installed in applications that require dehumidification.
- ***Economics –*** The increased capital costs of the system need to be carefully accounted for when conducting a life cycle cost analysis. There are many retrofit applications where the increased capital costs, and increased water consumption costs out weigh the energy cost savings on a life cycle costs basis.

D. Market Potential within the GSA Portfolio

The economic analysis indicates that the multistaged IEC technology has the best economics as a retrofit technology when it is competing against smaller air cooled air conditioning systems with energy efficiency ratios (EER) ranging from 8 to 12. GSA should target regions 6, 7, 8, 9, and 10 for multistage IEC installations.

[11] 2010 ASHRAE Refrigeration Handbook, Chapter 6 Refrigerant System Chemistry

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

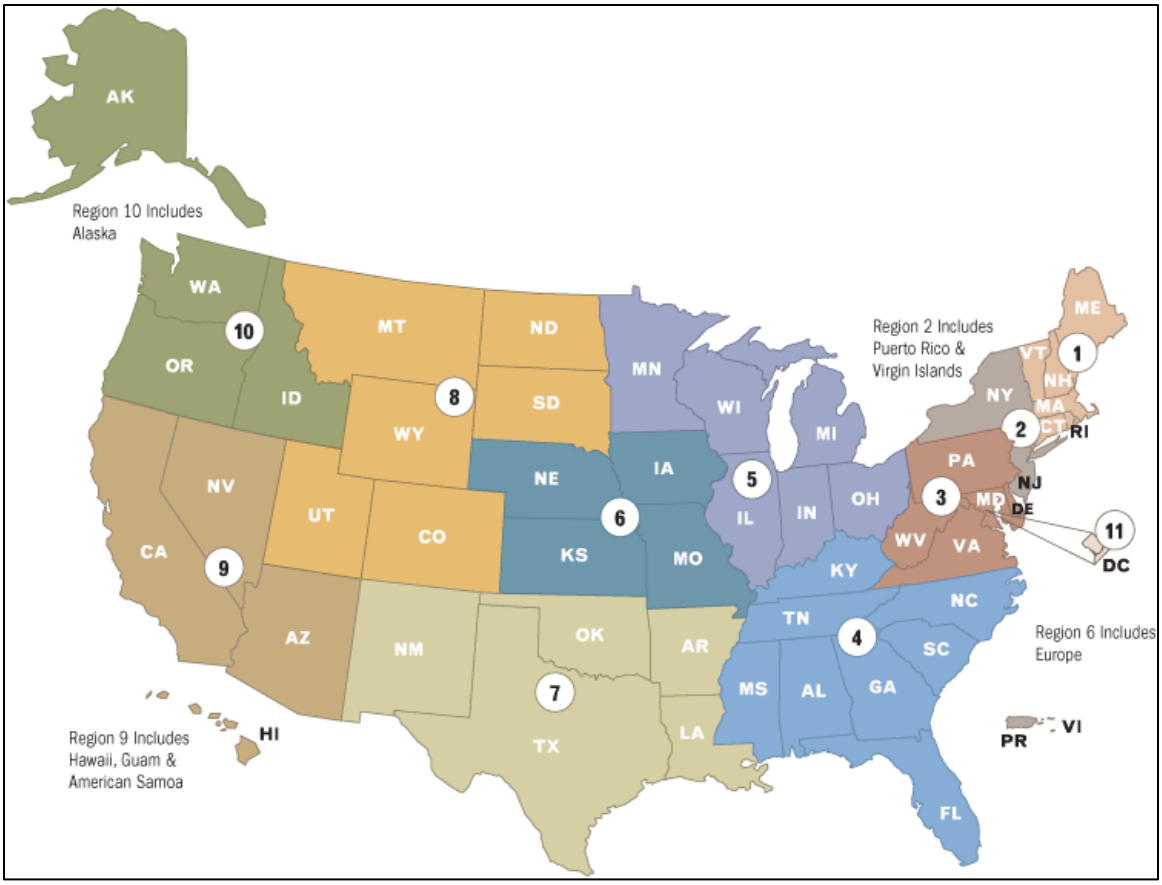

Figure 22. GSA regional map

The data center application is the most cost effective application in all five applicable regions and this application should take precedence over all other applications. For common GSA space types such as offices, warehouses, and other facilities with internal loads below 2 Watts/ft^2, the system is not life cycle cost effective if the building has an existing cooling system, unless it is installed in really hot locations such as Phoenix or Las Vegas as an outside air pre conditioner.

As a general rule of thumb the technology should not be applied as a retrofit for facilities that already have air conditioning in region 8 and region 10 for common GSA space types, other than data centers because the energy savings does not pay for the capital investment over the life of the project. The technology should be considered as a retrofit for facilities that have air conditioning in regions 7 and 9 for more traditional facility types but the site needs to be careful when calculating economics to ensure the system is life cycle cost effective. The multistaged IEC system should also be considered in new construction and for facilities without existing air conditioning systems in all five climate zones. Figure 23 lists the top three installation priorities for GSA.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

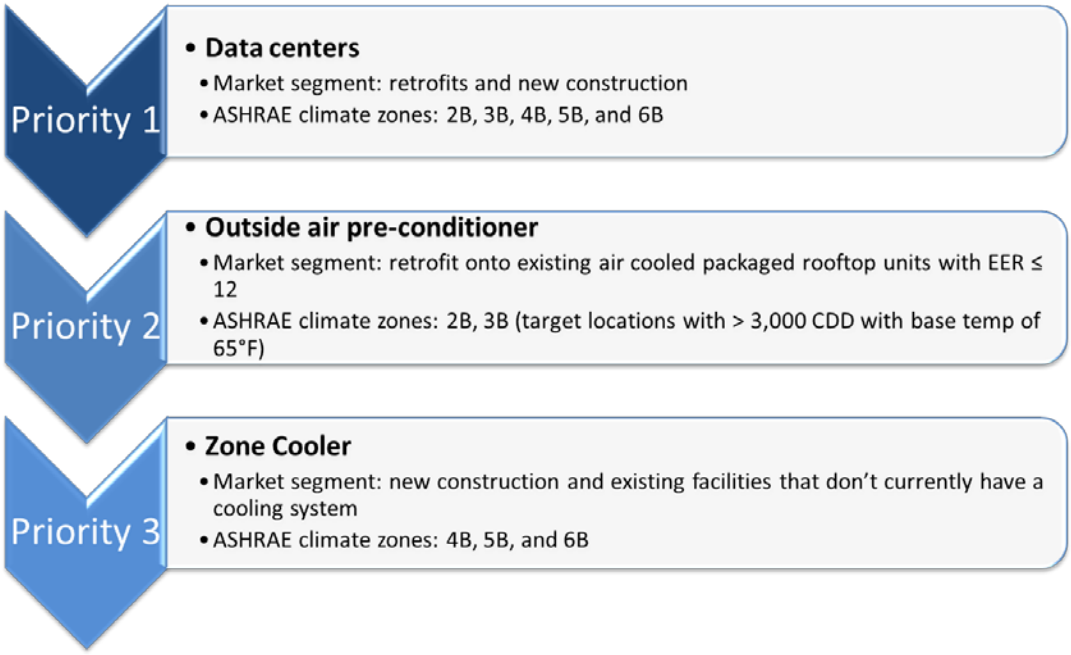

Figure 23. Multistaged indirect evaporative cooler installation priorities

E. Recommendations for Installation and Commissioning

Although the multistaged IEC unit can significantly reduce cooling energy use, it also has a number of unique design and operational characteristics that need to be understood and accounted for when designing and installing the system.

- ***External static pressure.*** As the external static pressure (SP) on the supply air increases, a larger fraction of the inlet air is forced through the exhaust air channels by the natural physics of the HMX. The external SP on the supply air consists of pressure drop associated with air filter fouling, duct SP, and building SP. This reduces cooling capacity and the total supply air flow rate (cfm).
    - For example, using inlet air conditions of 63°F wet bulb, 95°F dry bulb, 80°F return air temperature, and an elevation of 5,702 ft., the airflow rate at 0 inches (in.) of external SP is approximately 1,950 cfm for the C60 unit, dropping to less than 500 cfm at 1 in. of SP. At the given set of inlet air design conditions, the cooling capacity at 0 in. of external SP is close to 2 tons and less than 1⁄2 ton at 1 in. of external SP. Thus, duct and building SP should be reduced as much as possible and designs with more than 0.25 in. of SP should be avoided.
- ***Water consumption settings.*** The multistaged IEC unit is configured with single-pass cooling water. Some inlet water is evaporated in the exhaust air stream and some passes through the unit and drains from the outlet piping. One cycle of concentration (CoC) indicates half the water is evaporated and the mineral concentration of the drain water doubles (for example would go from 100 part per million (ppm) to 200 ppm). Two CoCs means 2 parts evaporated for one part drained and the mineral concentration of the drained water triples. A dip switch is used to set the CoC for the unit. As a best practice, the onsite water consumption should be minimized by setting the CoC to 5, reusing excess water for irrigation, and potentially capturing rainwater as an inlet water supply for the units.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

- ***Reduced capacity at design conditions.*** A common design issue with all standalone evaporative cooling units is reduced cooling capacity at design conditions. At ASHRAE 0.4% evaporative design conditions, the design wet bulb temperatures reduce the temperature difference between the achievable supply air temperatures and space temperature (or return air temperature). Depending on the extremity of the climate, the cooling capacity of the multistaged IEC unit could be as low as 25% of the cooling capacity at off-design conditions. Assuming a design return air temperature of 80°F and an altitude of 5,702 ft., the C60 unit can provide greater than 3 tons of cooling when the wet bulb temperature is 50°F, and a less than 1 ton of cooling at wet bulb temperature of 70°F. This is arguably the largest barrier to the adoption of standalone evaporative cooling units, because a design engineer would need to install a number of additional cooling units to meet the design space cooling load or let the space temperature float up to higher values under peak conditions.
- ***Improved performance at part load.*** The multistaged IEC unit's WBE and part load performance significantly increase at partial loads. The WBE at 100% fan speed with 0 in. of external SP is 88% at an elevation of 5,702 ft.; the WBE is 116% at 20% fan speed. If the external SP applied to the unit is 0.25 in. at 100% fan speed, the WBE is 91% and 119% at 20% fan speed. In addition, the part load electrical efficiency increases nonlinearly with fan speed; EERs between 50 and 120 are achievable.
    - If the multistaged IEC unit is installed as an outdoor air pre-conditioner and the fan speed is set to less than 100%, the unit can continuously achieve WBE greater than 100% and operate with high annual EERs.

Proper commissioning of the multistage IEC technology is also critical to ensuring the water consumption settings are correct, the waterside solenoid valves are working correctly, and that the unit is providing sufficient cooling. When the unit is started up, the site should measure water use, outside air conditions and supply air conditions. This data should be provided to the manufacturer to ensure proper operation. In addition, to start up commissioning, the water use and supply air temperatures should be periodically checked to ensure proper operation over the life of the project.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Appendices

A. Glossary

AHU – Air handling unit

ASHRAE – American Society of Heating, Refrigerating, and Air Conditioning Engineers

BAS – Building Automation System

Btu – British thermal units

CFM – Cubic Feet per Minute

DAS – Data Acquisition System

DEC – Direct Evaporative Cooler

DFC – Denver Federal Center

DOE – Department of Energy

DX – direct expansion

EA – exhaust air

ECM – Energy Conservation Measure

EER – energy efficiency ratio

EISA – Energy Independence and Security Act

F – Fahrenheit

ft. – feet

ft^2 – square feet

FY – Fiscal Year

GPM – Gallons per Minute

GSA – General Services Administration

HMX – Heat and Mass Exchanger

HVAC – Heating, Ventilation, and Air Conditioning

IEC – Indirect Evaporative Cooler

LCC – Life Cycle Cost

M-Cycle – Maisotsenko Cycle

MBtu – million British thermal units

NPV – net present value

NREL – National Renewable Energy Laboratory

OAT – Outdoor Air Temperature

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

O&M – Operations and Maintenance

PRV – Pressure Reducing Valve

PSZ – packaged single zone

RTU – Rooftop Unit

WBE – Wet Bulb Effectiveness

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.