ESTCP

FINAL REPORT

Next Generation Advanced High-efficiency DX Air Conditioner Demonstration

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Advantek Consulting Engineering Inc.

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The over 100,000 package DX air-conditioning and heat-pump units installed at DoD facilities generally are much less energy efficient than the best available technologies. This demonstration of next generation (NexGen) technology addresses challenging DX unit disadvantages and greatly enhances their performance. NexGen units surpass current, future, and anticipated energy efficiency goals; meet demanding ESCO cost, reliability & maintainability requirements; and meet new needs for remote automated fault detection & diagnostics (AFDD). The technology is rendered via lower-cost, readily available components, which are uniquely compatible with DoD facilities design & maintenance realities.

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ACRONYMS AND ABBREVIATIONS

ACOE	Army Corp of Engineers
AFCEC	Air Force Civil Engineering Command
AFINTC	Army Fort Irwin, National Training Center
ASHRAE	American Society of Heating, Refrigerating, and Air-conditioning Engineers
CCSFS	Cape Canaveral Space Force Station
CDD	Cooling Degree Days
CIN	Closed Isolated Network
DCV	Demand Controlled Ventilation
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DX	Direct Expansion
ECU	Environmental Control Unit
EER	Energy Efficiency Ratio
EFLH	Equivalent Full Load Hours (aka FLEOH)
EPA	U.S. Environmental Protection Agency
ESCO	Energy Service Company
ESPC	Energy Saving Performance Contract
ESTCP	Environmental Security Technology Certification Program
FEMP	Federal Energy Management Program
FUPWG	Federal Utility Partnership Working Group
HPT	Heat Pipe Technology Inc.
HVAC	Heating Ventilation Air Conditioning
IEER	Integrated Energy Efficiency Ratio
IoT	Internet of Things
MCASB	Marine Corps Air Station Beaufort
NOTU	Naval Ordnance Test Unit
O&M	Operation and Maintenance
OSJA	Office of Staff Judge Advocate
PNNL	Pacific Northwest National Laboratory
POC	Point of Contact
R&D	Research and Development
REM	Resource Efficiency Manager
RTUCC	Rooftop Unit Comparison Calculator (DOE PNNL software)

SIR	Savings to Investment Ratio
SME	Subject Matter Expert
TRMs	Technical Reference Manual
UESC	Utility Energy Service Contract
UFC	Unified Facility Criteria
VAV	Variable Air Volume

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ABSTRACT

Next Generation Advanced High-Efficiency DX Air Conditioner Demonstration

Package DX units are self-contained systems that enclose all components in one outdoor cabinet that sits on either the roof (RTUs) or to the side of a building. They use direct expansion (DX) of liquid refrigerant to produce cooling, and heating if they are heat pumps. The over 100,000 package units installed at DoD facilities have much lower energy efficiency than the best available technologies. This demonstration of next generation (NexGen) technology addresses challenging DX unit disadvantages and greatly enhances their performance. NexGen equipment provides twice the dehumidification capability at half the energy cost of conventional package equipment. Humidity control is vital for occupant comfort as well as meeting strict requirements for DoD laboratories, control centers, hardware assembly, electronic equipment, and warehouses. Additionally, next generation advanced DX equipment offers an economically viable replacement option for chilled water systems that are aging, where mission changes make a chilled water system upgrade not viable, or where elimination of cooling tower water consumption and maintenance is preferable.

NexGen units surpass current, future, and anticipated energy efficiency goals; meet demanding ESCO cost, reliability & maintainability requirements; and meet new needs for remote automated fault detection & diagnostics (AFDD). The technology is rendered via lower-cost, readily available components, which are uniquely compatible with DoD facilities design & maintenance realities. Performance optimization capabilities include independent control of cooling & dehumidification, comprehensive fault detection & diagnostics with automated performance optimization and technician alerts via text message, continuous adjustment of operating parameters to minimize energy use as load and weather vary, and secure connectivity and monitoring from anywhere.

Two representative package AC units were replaced with NexGen units, at two locations in widely differing climates. At site 1, NOTU Support Building at Cape Canaveral Space Force Station (CCSFS) on the Florida seacoast, equipment is a 15-ton cooling unit with electric heat. At site 2, Office of Staff Judge Advocate Building (OSJA) at Fort Irwin National Training Center in the California high desert, equipment is an 8½-ton heat pump providing cooling in summer and heating in winter. At the CCSFS building, HVAC energy use was reduced by 48%. At the Fort Irwin building, HVAC energy use was reduced by 64%. The CCSFS unit highlights the much stronger dehumidification performance of the advanced units in a severely humid climate: monthly average space humidity was lowered to around $50\%_{rh}$ from the $70\%_{rh}$ baseline average.

The CCSFS advanced unit field-measured operational IEER 21.6 is 54% more efficient than a new high-efficiency model, which is over twice the efficiency level of the baseline unit's AHRI rating. The advanced unit at Fort Irwin IEER 18.3 is 46% more energy efficient than a new high-efficiency model, and nearly twice as efficient at the baseline unit's AHRI rating. Comfort improved measurably as well. The CCSFS comfort baseline was PMV 1.0 / PPD 27% dissatisfied, which improved to PMV 0.39 / PPD 8.8% dissatisfied with the advanced NexGen unit. The Fort Irwin baseline was PMV -0.6 / PMV 13% dissatisfied, which improved to PPD 0.0 / PMV 5.2% dissatisfied with the advanced NexGen unit. The NexGen units provide a more comfortable workspace while also saving considerable energy and easing maintenance tasks.

EXECUTIVE SUMMARY

INTRODUCTION

The over 100,000 package DX air-conditioning and heat-pump units installed at DoD facilities generally are much less energy efficient than the best available technologies. Package DX units are self-contained systems that enclose all components in one outdoor cabinet that sits either on the roof (RTU) or to the side of a building and use direct expansion (DX) of a flow of liquid refrigerant to produce cooling, and heating if the unit is a heat pump. Next generation (NexGen) advanced DX technology was demonstrated to address challenging package unit disadvantages, enhance their performance, and encourage technology transfer.

State-of-art replacements are rarely installed due to limited availability, high first cost and reliability concerns, and because they are complex and can be difficult and costly to maintain with existing resources. Currently available DX package unit models units do not come equipped with non-proprietary controls or intuitive IoT-based user interfaces to support maintenance with web-based fault detection & diagnostic capabilities. This makes proactive / preventive or performance-based maintenance nearly impossible to economically implement, leading to rapid efficiency degradation, early component failures, and higher total cost of ownership. Currently, the high cost and/or low efficiency of available replacement DX units make new equipment installations difficult to justify on energy economics alone.

Moreover, some ultra-high efficiency models have only a single refrigeration circuit, which provides no redundancy to operate in failure mode. When one of the compressors in a tandem circuit fails, the unit becomes non-operational, and the good compressor is contaminated and its longevity severely compromised. It has long been standard military & industrial practice to specify systems with at least two separate refrigeration circuits and isolated compressors to provide the required level of reliability and longevity. Two or more refrigeration circuits ensure that when a component fails, only half or less of the capacity is affected.

Next generation DX air-conditioner technology is a near-term, cost-effective solution applicable at nearly every DoD installation. Package DX equipment is installed at virtually all DoD sites, which accounts for an estimated 54% of facility air conditioning energy use[1]. Most DX units operate at less than half the efficiency – consuming twice the energy per unit of cooling provided – of modern chiller systems. Each individual DX unit is a small fraction of total installation energy consumption and electric demand, making it a challenge for technicians and energy managers to cost effectively improve performance. DX equipment is spread across multiple DoD buildings and may not be readily accessible due to mounting on rooftops, behind security gates, or remote from the installation campus.

Additionally, humidity control is vital for DoD occupant comfort and building moisture mitigation as well as meeting strict environmental requirements for DoD laboratories, control centers, hardware assembly, libraries, auditoriums, housing, and electronic equipment warehouses.

[1] Navigant Consulting. 2011. "Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems." Energy Efficiency and Renewable Energy Building Technologies Program, U.S. Department of Energy.

Next generation DX air-conditioner technology provides twice the dehumidification capability at half the energy cost of conventional package DX equipment. In humid climates, increased dehumidification capacity allows thermostat setpoints to be raised a few degrees if desired, reducing energy consumption, without compromising occupant comfort and productivity.

Additionally, NexGen advanced DX package units offer an economically viable replacement option for DoD chilled water systems that are aging; where mission changes make an aged, chilled water system upgrade not viable, or where elimination of cooling tower water consumption, chemical treatment and maintenance is preferable.

OBJECTIVES

This project demonstrates next-generation advanced ultra-high efficiency DX package air-conditioner technology, with the overarching goal of lifting market barriers and promoting utilization by major air-conditioning equipment manufacturers, energy managers, energy service companies, and operations & maintenance technicians. It is intended that insights from the demonstration influence DoD policy, practices, and guidelines addressing the specification, selection, purchase, and operation of package DX air-conditioning systems.

The project team demonstrated that next generation advanced DX package unit technology is viable and can cost-effectively reduce annual energy consumption while improving reliability, maintainability and building comfort levels for a wide range of DoD installations.

TECHNOLOGY DESCRIPTION

The ClimaTek® *NexGen*™ package air conditioning unit delivers far higher energy efficiency than virtually every current commercially available model. The air conditioner features active real-time performance optimization including dynamic control of airflows and refrigerant flow and level, remote automated fault detection & diagnostics (RAFDD), independent control of sensible cooling, dehumidification and heating, and remote monitoring via a cybersecure web interface. This innovative combination of technologies results in a near doubling of energy efficiency; improved maintainability; and sustainable, measurable, and verifiable energy savings throughout equipment life. The units have nearly twice the dehumidification capability of current models, and dehumidification is achieved without reliance on energy intensive reheat.

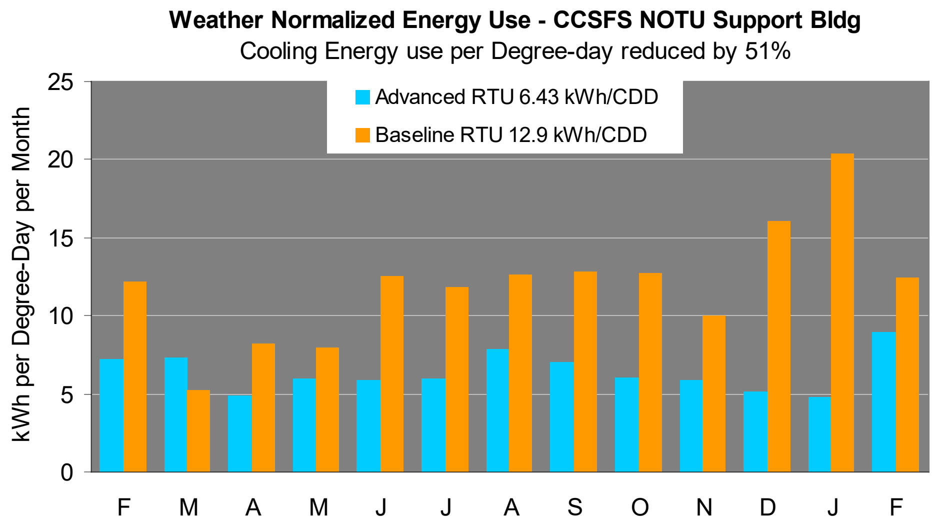
NexGen units feature technology combinations not found in current high-performance models. Innovations include ClimaStat® and EER Optimizer™ (previous ESTCP demonstration successes) along with variable capacity, evaporative condensate reclaim, and airflow management that integrates economizer, variable air volume (VAV), and demand-controlled ventilation (DCV) functions. Pioneering features of these units also include a low loss synchronous blower belt, twisted-airfoil condenser fan blades, and a cloud-connected web-enabled controller with extensive remote automated fault detection diagnostics and corrections. Improved indoor air quality (IAQ) is achieved via precise temperature control, enhanced dehumidification, MERV-13 filtration, UVC germicidal emitters, positive space pressurization and ventilation control to limit space carbon-dioxide level.

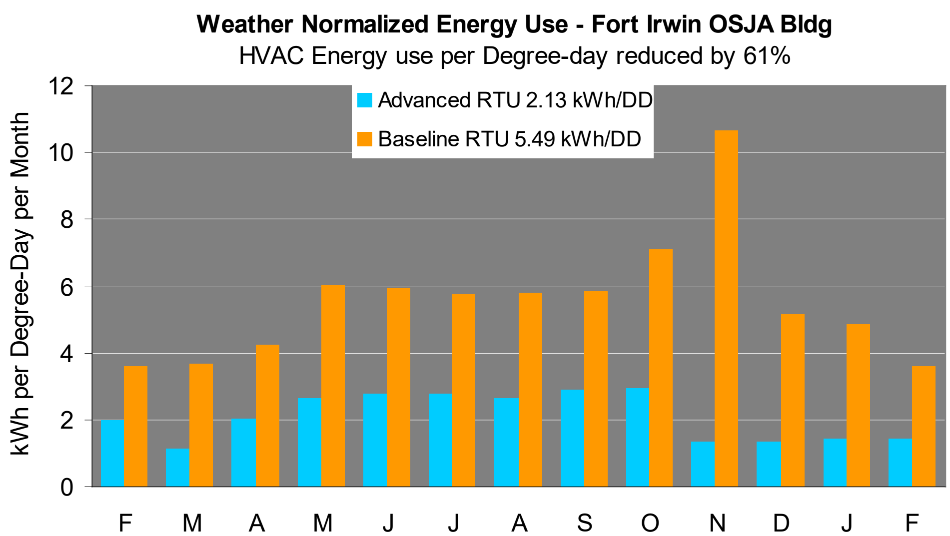
PERFORMANCE ASSESSMENT

Changing from the existing to the advanced air-conditioners reduced HVAC energy use by more than 45% at both demonstration sites, with no sacrifice of comfort or reliability, as compared with the standard technology they replaced. The demonstrated NexGen advanced package units showcase a field measured operational IEER 18 to 21 efficiency level at a projected commercial incremental cost of about $1800 per ton, giving a payback period of under 7 years and favorable SIR[2] above 2.0 for many energy price / climate scenarios.

Comparison of weather-normalized energy usage by the advanced unit against the baseline unit is presented by month in the charts below. Measured monthly kWh energy consumed per degree-day by the NexGen unit is compared with the baseline for CCSFS-NOTU and for Fort Irwin OSJA. At CCSFS-NOTU, weather-normalized cooling energy use was reduced by 51%. At Fort Irwin OSJA, weather-normalized cooling + heating energy use was reduced by 61%. Baseline data from both sites show atypically high weather-normalized energy use in months when weather was mild because standard package units consume energy for ventilation regardless of the need for cooling or heating. The NexGen unit controller minimized this consumption by use of an advanced demand-controlled ventilation algorithm.

[2] SIR – Savings to Investment Ratio is typically used by ESCOs for economic screening of potential projects.

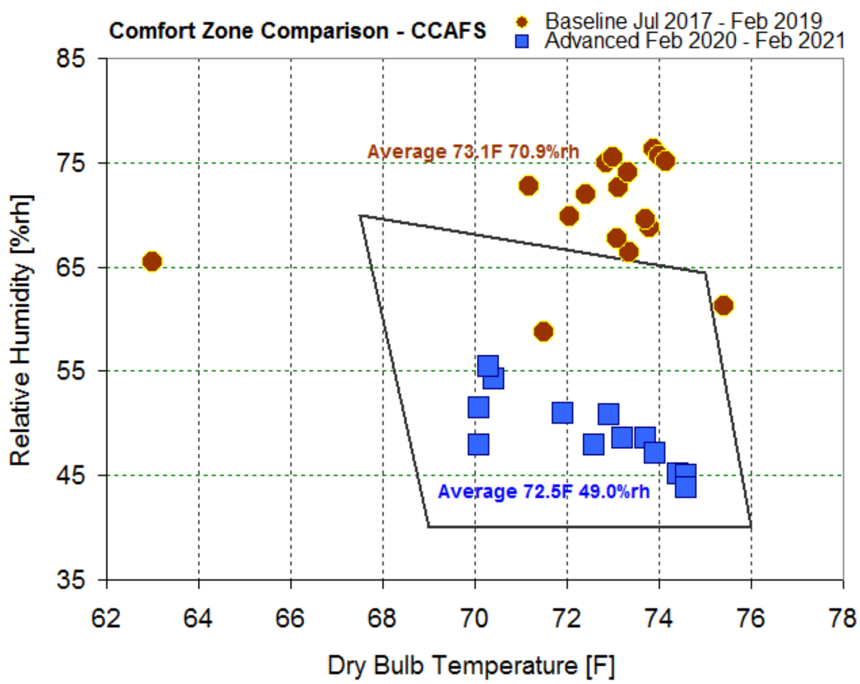




The field-measured cooling efficiency of the NexGen unit at CCSFS-NOTU is EER 19.9 and IEER 20.8, which is 54% improved over the factory rated IEER of 14.0. Improvement over the baseline unit's factory rated IEER 10.2 is 112%, and over the baseline unit's measured operational efficiency IEER 6.7 is 222% improved. This large improvement was realized concurrent with a near doubling of the delivered latent cooling (dehumidification) capacity at CCSFS-NOTU and a perceptible reduction of average space humidity from around $70\%_{rh}$ to $50\%_{rh}$.

The field-measured cooling efficiency of the NexGen unit at Fort Irwin OSJA is EER 14.8 and IEER 19.4, which is 46% improved over the factory rated IEER of 12.5. Improvement over the baseline unit's factory rated IEER 9.3 is 96%, and over the baseline unit's measured operational efficiency IEER 7.4 is 147% improved. The measured annual heat-pump heating efficiency of the NexGen unit at Fort Irwin OSJA is EER 11.2 and IEER 13.0, which is 22% improved over the factory rated IEER of 10.6. Operational heating efficiency gain was lower than cooling improvement because of frequent compressor cycling due to the low space heating load relative to cooling load, where the larger cooling load was the basis for heat pump size selection.

Baseline space humidity levels at the CCSFS-NOTU building were consistently excessive with a median of 70.9%rh. Plotted on the ASHRAE comfort zone below, space conditions were rarely comfortable. The data clearly shows the baseline HVAC system does not adequately dehumidify. Baseline indoor space conditions were within the ASHRAE-defined comfort zone only 5.9% of the time on average, with humidity and/or temperature being excessive 92.9% and 15.9% of the time, respectively. After the advanced NexGen unit was installed, CCSFS baseline indoor space conditions were within the ASHRAE-defined comfort zone 98.2% of the time. Comfort improved measurably as well. The CCSFS comfort baseline was PMV 1.0 / PPD 27% dissatisfied, which improved to PMV 0.39 / PPD 8.8% dissatisfied with the advanced NexGen unit. The Fort Irwin baseline was PMV -0.6 / PMV 13% dissatisfied, which improved to PPD 0.0 / PMV 5.2% dissatisfied with the advanced NexGen unit.



In addition to increased energy efficiency and cost-effectiveness, the project demonstrated how automated fault detection & diagnostics contributes to ease of maintenance by addressing challenging issues that cause decline in operational energy efficiency and equipment service life. The demonstration site buildings have special conditions associated with reliability and maintenance response that were successfully addressed at each demonstration site. The staff and contractors usually responsible for HVAC maintenance were briefed, involved in, and sometimes solely carried out maintenance of the demonstration units. These O&M staff were surveyed via interview to identify concerns and recommendations for maintenance of NexGen equipment and responses were compiled over the course of the demonstration. Questions addressed whether additional or special skills or training is / was needed to maintain the equipment; whether more, same, or less maintenance is / was required; and the relative difficulty of performing preventative maintenance tasks. Typical technician comments below characterize demonstration findings at both sites.

"Techs will need a day or two training on the different components and control use."

"The control panel screen is great, you can really pinpoint how well a unit is running."

"The fault detection is something every HVAC unit should have, that's been very helpful."

"Regarding future installation of these units, yes eventually when servicing catches up. In the meanwhile, would be good to have training."

"A good way to track performance and spot degradation of new units from the day they are installed."

Overall, there was concurrence of HVAC shop staff at CCSFS and contracted staff at Fort Irwin of maintainability using existing technicians and resources, as long as classroom and field training is provided. Most technicians were generally interested and enthusiastic about the NexGen unit and welcomed the opportunity to learn advanced operation and service procedures as a way of easing their future workload and keeping their skills sharp. Comments generally indicated less maintenance was needed, and servicing required a higher skill and knowledge level to perform.

COST ASSESSMENT

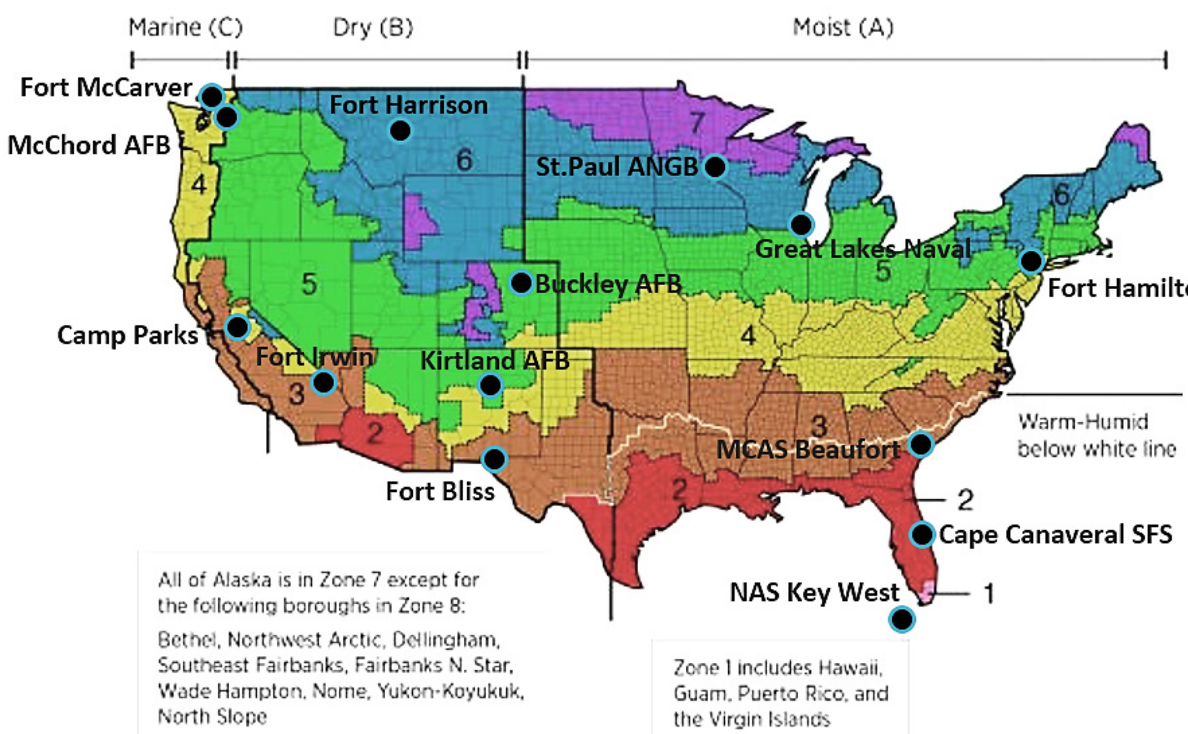
Installation costs for the two demonstration sites were tracked and used to project future costs for replacing an existing standard HVAC unit with an advanced NexGen system. Training needs and costs were documented and projected. Design costs associated with selecting equipment size, components, configuration, and features at both demonstration sites were documented and assigned as a cost to be allocated incrementally to similar future projects at a particular installation.

	Baseline	ClimaTek NexGen	
Cost Element	Estimated Costs	Data Tracked During Demonstration	Projected Costs
Hardware capital cost	$17,223	$22,821	$21,575
Installation & assembly costs	10,288	31,466	13,496
Consumables & materials costs	3,853	34,426	5,409
Facility energy cost $0.062/kWh	44,635	22,269	22,269
Maintenance & service costs	24,975	16,875	14,625
Hardware lifetime	10 years	15 years	15 years
Technician training costs	-	13,200	4,400
Total Ownership Cost (15 years)	$114,730	$141,057	$81,774
Total Ownership $ per Ton	$7,649	$9,404	$5,452

Projected costs are based on large-quantity pricing versus actual energy cost reduction relative to baseline. Costs tracked during the demonstration include more assembly, materials, installation and consumables costs than would be expended for a commercial installation. As broken down in the table, the total projected cost of ownership of a NexGen unit estimated at $81,744 is 29% less than the $114,763 cost of ownership of a baseline unit over 15 years. Utilized as an ECM, each NexGen unit would produce a life cycle savings of about $34k for an additional first cost of about $14k, giving a payback period of 6.2 years and an SIR of 2.4.

A major consideration in cost assessment of NexGen air-conditioner technology is the cost differential between installation and operation of air-conditioning units with remote automated fault detection & diagnostics (RAFDD) technology versus the equipment, staff, and productivity cost of operating and maintaining standard units. The demonstration results provide a basis for DoD installations to make sound financial decisions on whether to deploy RAFDD, or to pay HVAC maintenance staff to continue with standard maintenance practices and deal with untimely equipment replacements.

RTUCC and EFLH models were developed for a 15-ton standard package unit and a 15-ton NexGen advanced package unit. The models were calibrated against field data from the demonstration sites. Modeling results were computed using an electric rate of $0.062 (6.2 cents) per kWh for one unit of size 15-tons with an incremental capital cost of $9,116 between a standard unit and a NexGen unit. No credit was taken for kW demand savings, if any, maintenance savings, or increased dehumidification. Higher electric rate and/or larger unit size will provide more savings, shorter payback period, and higher SIR.



In general, the results show that longer and/or hotter cooling seasons give better NexGen installation economics. Predicted payback periods by the EFLH model average 6.7 years across the 16 DoD locations, with a minimum 4.6 years (Key West NAS, FL) and maximum 14.5 years (Fort Wainwright, AK). RTUCC predicted payback periods average 7.3 years, minimum 3.6 years (Key West NAS, FL) and maximum 11.4 years (Camp Ripley, MN).

Predicted savings-to-investment ratios (SIR) by the EFLH model average 2.4 across the 16 locations, with a maximum 3.3 (Key West NAS, FL) and minimum 1.0 (Fort Wainwright, AK). RTUCC predicted SIRs average 1.7, maximum 3.5 (Key West NAS, FL) and minimum 0.2 (McChord AFB, WA).

IMPLEMENTATION ISSUES

Implementation of this technology at a specific site / building will need to include consideration of certain issues during each step of the project. Lessons learned during each step, including selection of units to be replaced, procurement, connectivity, commissioning, and technical support, are discussed below.

1. Unit Selection

Best economics will be ensured by judiciously examining package units that will soon be due for replacement. Good candidates should be screened by size, condition, and application.

By far the best applications are those requiring space humidity control in hot- and warm-humid climate zones 1A, 2A, 3A and portions of 4A. Typically, these applications are laboratories, assembly shops, clean rooms, meeting and conference facilities, libraries, medical buildings, food service spaces, schools, auditoriums, theatres, gymnasiums, and multi-tenant housing. The ideal candidates for replacement are package units utilizing reheat for humidity control. Look for a hot-gas or warm-liquid reheat coil downstream of the cooling coil in the existing unit, and/or electric resistance heating elements located downstream of the supply blower, in the supply ductwork, or in terminal boxes. Some buildings have a humidistat located on a wall near the thermostat, or a combination thermostat-humidistat.

A general rule is the larger the unit, the shorter the payback period and the higher the savings-to-investment ratio will be. Package units of 15-tons to 30-tons are ideal, with economic potential for units in the full application range of 7½-tons to 60-tons being evaluated on a case-by-case basis. Good candidates are units nearing the end of their useful economic and/or service life, which is commonly 10 to 15 years in most locations, 7-10 years near the seacoast, and 15 or more years in dry climate locations.

2. Procurement

Market research was completed in August 2022 to determine what advanced unitary DX products are available by collecting and analyzing information on the technical capabilities within the marketplace. There are relatively few US-based manufacturers of commercial HVAC package units offering ultra-high efficiency models suitable for industrial / military grade applications, hence a sole-source procurement is likely to be desirable.

Procurement of DX equipment to meet specified air temperature, relative humidity, and air quality requirements is challenging and energy intensive to satisfy with standard HVAC package units while also complying with Unified Facilities Criteria (UFC) commissioning, life-cycle cost, energy performance, humidity control, and corrosion protection requirements. A sole-source justification template (justification for use of other than full and open competition), is available by contacting the PI directly (mikewest@adantekinc.com). This procurement process can take as long as 12 months, sometimes spanning across an entire fiscal year, so initiating the process well before candidate units' expected end of life is advisable.

3. Connectivity

The EERoptimizer unitary DX controller needs a connection to the ClimaTek cloud server for full functionality, which includes setpoint optimization, fault logging, trend charting, and remote user interface viewing. The connection is via a closed isolated network (CIN) which avoids the need for any physical connection to the military or facility LAN, thereby minimizing cybersecurity concerns.

The CIN is a data communications enclave that operates in a single security domain, implements a security policy administered by a single authority, does not connect to any other network, and has a single, common, continuous security perimeter[3]. The only devices on the EERoptimizer CIN are internal to EERoptimizer controller embedded in the NexGen package HVAC unit. Typically, implementing this connection is accomplished via a commercial internet service provider (e.g., CenturyLink, Google Fiber, Xfinity, Frontier) either by cable modem or DSL, or cellular data service provided by AT&T, with a dedicated firewall.

4. Commissioning

NexGen units are fully tested in all modes of operation when assembled according to a quality control / quality assurance protocol. These procedures are continued at the field site by a ClimaTek engineer at the time of package unit installation. Onsite commissioning tasks include checking sensor calibrations, communication verification, and testing and documenting all operating modes; cooling, heating, and ventilation capacity; and EER and IEER. Continuous ongoing commissioning is provided remotely via monitoring of diagnostic fault and sensor alerts and alarms, and periodic charting to visually identify unusual trends or other behaviors that might indicate a developing issue. Continuous commissioning maintains the unit as close to like-new operational condition as is physically possible, while detecting and correcting small issues before they grow and become problematic.

5. Technical Support

A training session for onsite HVAC technicians is scheduled after installation and commissioning. ClimaTek engineers supported by offsite contracted technicians are available to provide backing to onsite technicians as needed.

[3] NIST Risk Management Framework https://csrc.nist.gov/Projects/risk-management/sp800-53-controls/overlay-repository/government-wide-overlay-submissions/closed-isolated-network

1.0 INTRODUCTION

The over 100,000 package DX air-conditioning and heat-pump units installed at DoD facilities generally are much less energy efficient than the best available technologies. Package DX units are self-contained systems that enclose all components in one outdoor cabinet that sits either on the roof (RTU) or to the side of a building and use direct expansion (DX) of liquid refrigerant to produce cooling, and heating if the unit is a heat pump. While package units have the same internal components and operational characteristics as package-terminal air conditioners (PTACs), split systems, and mini-splits; this demonstration project focuses on the self-contained package units larger than five tons commonly installed at DoD facilities.

This demonstration offers next generation (NexGen) advanced HVAC technology to address challenging DX package unit disadvantages and enhance their performance. Currently, the operating energy efficiency of package units is much less than that of central water-cooled chiller systems and the efficiency gap widens as systems age[4]. State-of-art replacements are rarely installed due to limited availability, high first cost and reliability concerns, and because they are complex and can be difficult and costly to maintain with existing resources. The relatively poor energy efficiency of most existing DoD package equipment is a consequence of:

1. Specification of low-cost models and/or low-bid contracts rather than high performance units, driving manufacturers to compete by offering the lowest prices rather than the best performance value;
2. Rapid deterioration of performance that typically occurs after installation when units are not well-maintained. Typical package air-conditioner controllers do not automatically report operational faults the way chilled water systems do, so performance-based preventive maintenance is often deemed not cost-effective, or repairs are deferred until equipment performance becomes unacceptable or equipment failure occurs; and
3. Inadequate maintenance resources result in package units being run to failure, with emergency replacement necessitating quick purchase of the low efficiency "bare bones" AC units that are usually stocked by HVAC equipment distributors.

1.1 BACKGROUND

1.1.1 Current Technology State of the Art

The DOE energy efficiency minimum standards for commercial package DX equipment are relatively low compared to the best available technology. Furthermore, standards development is a slow, gradual, and often contested process that is not keeping pace with rapid technology innovation. For example, the minimum efficiency standard for 20-ton package units was raised from the current IEER[5][6] 10.1 up to 11.6 as of January 2018, and to IEER 13.2 as of January 2023[6].

[4] Cowan, A. Review of Recent Commercial Rooftop Unit Field Studies in the Pacific Northwest and California, Northwest Power and Conservation Council and Regional Technical Forum, Portland, Oregon, 2004.

[5] IEER – Integrated Energy Efficiency Ratio [Btuh/Watt] is a weighted energy efficiency at four load levels.

[6] Energy Conservation Standards for Small, Large, and Very Large Air-Cooled Commercial Package Air Conditioning and Heating Equipment and Commercial Warm Air Furnaces; Direct final rule https://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0007-0113

While these 15% efficiency increases are significant, manufacturer-driven DX minimums are still much lower than the current chilled water system minimum IEER 20.1 and DOE's high performance IEER 18 target specification for rooftop package units, established in 2011. At present, nearly all current package DX models meet the 2023 minimums.

Only three current package DX models meet DOE's 2011 high performance rooftop unit "IEER 18" specification[7], yet these models fail to address two of the three key factors hindering widescale utilization: first cost and maintainability. Customer acceptance of "High Performance Challenge [8]" models has correspondingly lagged expectations. Sales in the US since 2013, soon after they first came on the market, have been only 34,000 IEER 18+ units out of 600,000 total commercial package DX units sold in the U.S. – less than 6% market penetration. The price of currently available IEER 18 models is over twice that of standard IEER 11 models; installed costs can rival those of a chilled water system; and specialized service rates are as high as $160 per hour. Cost is nearly that of a chilled water system, which would be 35% more energy efficient[8]. In addition to having higher cost, current IEER 18 models use highly complex components such as inverter / digital scroll compressors, proprietary controllers, and electronic expansion valves, which are unfamiliar to most service technicians[9], costly to replace when they fail, and raise reliability and maintainability questions.

Additionally, current IEER 18 units do not come equipped with non-proprietary controls or intuitive IoT-based user interfaces to support maintenance with remote fault detection & diagnostic capabilities. This makes proactive / preventive or performance-based maintenance nearly impossible to economically implement, leading to rapid efficiency degradation, early component failures, and higher total cost of ownership. Moreover, current IEER 18 models only have a single refrigeration circuit, which provides no redundancy to operate in failure mode. When one of the compressors in a tandem circuit fails, the unit becomes non-operational, and the good compressor is contaminated and its longevity severely compromised. It has long been standard DoD practice to specify systems with at least two separate refrigeration circuits and isolated compressors to provide the required level of reliability and longevity. Two or more refrigeration circuits ensure that when a component fails, only half or less of the capacity is affected.

1.1.2 Current State of Technology in DoD

DoD facilities are conditioned by two types of HVAC systems: chilled water or direct expansion (DX), such as package or rooftop units and split systems. The key difference is the working fluid for cooling / heating spaces. Chilled water systems circulate refrigerated water through cooling coils, and hot water through heating coils. Direct expansion units expand high pressure refrigerant, such as R-22, R-32, R-134a, R-410a, R-454b, R-466a or R-470a directly into cooling coils, and the cycle is reversed in heat pumps. DX equipment – installed at virtually all DoD sites – accounts for an estimated 54% of facility air conditioning energy use[10]. Most DX units operate at less than half the efficiency – consuming twice the energy per unit of cooling provided – of modern chiller systems.

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[7] DOE EERE Better Buildings Alliance High Performance Rooftop Unit, January 2011. https://www4.eere.energy.gov/alliance/activities/technology-solutions-teams/space-conditioning/rtu [5] High Performance Rooftop Unit Challenge, DOE EERE website accessed August 2016. http://www1.eere.energy.gov/buildings/alliances/rooftop_specification.html

[8] High efficiency all variable optimized chiller plant IEER 24.3 (0.49 kW/ton), (24-18)/18 = 35%

[9] W. Wang, S. Katipamula, H. Ngo, R.M. Underhill. "Field Evaluation of the Performance of the RTU Challenge Unit: Daikin Rebel," Pacific Northwest National Laboratory, March 2015.

[10] Navigant Consulting. 2011. "Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems." Energy Efficiency and Renewable Energy Building Technologies Program, U.S. Department of Energy.

Each individual DX unit is a small fraction of total installation energy consumption and electric demand, making it a challenge for technicians and energy managers to cost effectively improve performance. DX equipment is spread across multiple DoD buildings and may not be readily accessible due to mounting on rooftops, behind security gates, or remote from the installation campus.

1.1.3 Technology Opportunity

Next generation (NexGen) DX air-conditioner technology is a near-term, cost-effective solution applicable at nearly every DoD installation using package DX equipment. Demonstration of NexGen advanced DX equipment adds replacement of low performing DX package units to the arsenal of efficiency improvements included in ESCO performance contracts, UESCs, and capital projects. Within 10 years DoD could expect to achieve broad implementation of next generation technology with the retirement of existing low-performance equipment inventory and new construction. Currently, the high cost and/or low efficiency of available replacement DX units make new equipment installations difficult to justify on energy economics alone.

Additionally, NexGen advanced DX package units offer an economically viable replacement option for DoD chilled water systems that are aging; where mission changes make an aged, chilled water system upgrade not viable; or where elimination of cooling tower water consumption, chemical treatment and maintenance is preferable. This demonstration will stimulate acceptance of next generation package unit technology as economical and highly maintainable, while using familiar components and intuitive controls, and applicable to both equipment replacements and new construction.

With HVAC accounting for about 33% of primary building electric use[11], installing next generation advanced DX equipment has the potential to reduce DoD energy intensity by 7,100 Btu/GSF and energy costs by $300 million per year. This would be an energy intensity reduction of 6% relative to FY2003 baseline, raising the current DoD reported reduction of 17.7% up to 23.7% – a significant increase towards reaching the 30% DoD energy use intensity reduction goal.

Additionally, humidity control is vital for DoD occupant comfort and building moisture mitigation as well as meeting strict environmental requirements for DoD laboratories, control centers, hardware assembly, and electronic equipment warehouses. Next generation DX air-conditioner technology provides twice the dehumidification capability at half the energy cost of conventional package DX equipment. In humid climates, increased dehumidification capacity allows thermostat setpoints to be raised a few degrees, reducing energy consumption, without compromising occupant comfort and productivity. Dehumidification is addressed by current package unit models with energy-intensive hot gas and/or warm liquid reheat, an option installed at an additional cost of about $240 per ton of capacity, or with notoriously inefficient field-installed electric reheat. Reheat is a heating coil placed downstream of the cooling coil, which cancels some or all of sensible cooling, leaving latent cooling for dehumidification. Reheat negates a significant portion of the energy savings promised by nameplate IEER ratings; reheat significantly extends the payback period and raises energy consumption as much as two-fold.

[11] DOE Buildings Energy Data Book, Table 1.1.4, http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=1.1.4 accessed August 2016.

1.2 OBJECTIVE OF THE DEMONSTRATION

This project demonstrates next-generation advanced ultra-high efficiency DX package air-conditioner technology, with the overarching goal of lifting market barriers and promoting utilization by major air-conditioning equipment manufacturers, energy managers, energy service companies, and operations & maintenance technicians. It is intended that insights from the demonstration influence DoD policy, practices, and guidelines addressing the specification, selection, purchase, and operation of package DX air-conditioning systems.

1.3 REGULATORY DRIVERS

ASHRAE STANDARDS	**ASHRAE Energy Efficiency Standard 90.1** Establishes the minimum energy efficiency requirements of commercial and high-rise residential building design and construction.
	ASHRAE Green Standard 189.1 ASHRAE Guidance for designing, building, and operating high-performance green buildings.
	ASHRAE IAQ Standard 62.1 (2013 section 5.9) ASHRAE Standards for ventilation system designs and IAQ, provides guideline for space carbon dioxide (CO_2) and relative humidity (%RH) levels.
EXECUTIVE ORDERS AND ACTS	**Energy Policy Act of 1992/2005** EPA Act intended to help combat energy problems in the US and to create clean, reliable, and affordable energy. Provides tax credits and tax incentives.
	Energy Independence and Security Act of 2007 Act intended to move US towards better energy independence as well as improve energy consumption and performance in the Federal Government. Also provides goals of increasing the energy efficiency of automobiles and buildings while protecting the end consumer. Tightens goals set forth in prior Acts.
	Executive Order 13693 Act that was implemented to cut greenhouse emissions by the government by 40% over the following decade (signed in 2015.) However, this Order was revoked by EO 13834.
STANDARDS AND INSTRUCTIONS	**Installations Energy Instructions DODI 4170.11** DoD Instruction implementing policy of installation energy management to provide infrastructure that is safe, reliable, and energy efficient. Also calls on DoD to invest in cost effective renewable energy sources and energy efficient facility designs.
	GSA 2010 Facilities Standards (P100) GSA Building performance and design criteria standards. To be used when programming, designing, and documenting GSA buildings.
	Federal Leadership in High Performance and Sustainable Buildings MOU 2006 Memorandum of Understanding between several Federal agencies to establish a common set of strategies and principles to operate and design new buildings to be energy efficient and sustainable.
DOE PERFORMANCE PLAN	**Strategic Sustainability Performance Plan, Energy Security MOU with DOE** DOE 2016 Strategic Sustainability Plan report to the White House outlining the work done to achieve the DOE's sustainability goals and requirements. Nine goals were outlined in the report. The goals are: greenhouse gas reduction, sustainable buildings, clean and renewable energy, water use efficiency and management, fleet management, sustainable acquisition, pollution prevention and waste reduction, energy performance contracts, electronics stewardship and data centers, and climate change resilience.

Installations Energy Instruction DODI 4170.11

http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/417011p.pdf

Energy Policy Act of 1992 / 2005 https://www.ferc.gov/enforcement/enforce-res/EPAct2005.pdf

Energy Independence and Security Act of 2007 https://www.epa.gov/laws-regulations/summary-energy-independence-and-security-act

Executive Order 16393

https://obamawhitehouse.archives.gov/the-press-office/2015/03/19/executive-order-planning-federalsustainability-next-decade

GSA 2010 Facilities Standards (P100)

https://www.gsa.gov/real-estate/design-construction/architecture-engineering/facilities-standards-p100overview

ASHRAE Energy Efficiency Standard 90.1

http://bcapcodes.org/getting-started/energy-codes-101/ashrae-90-1/

ASHRAE Green Standard 189.1

https://www.ashrae.org/file%20library/doclib/publications/189-1faq.pdf

ASHRAE IAQ Standard 62.1 (2013 section 5.9)

https://www.slideshare.net/MohamedNafeel1/ashrae-621-2013-ventilation-for-acceptable-indoor-airquality

Federal Leadership in High Performance and Sustainable Buildings MOU 2006

https://www.wbdg.org/FFC/FED/HPSB-MOU.pdf

Strategic Sustainability Performance Plan, Energy Security MOU with DOE

https://energy.gov/sites/prod/files/2016/09/f33/DOE%202016%20SSPP%20Revision%2009022016.pdf

2.0 TECHNOLOGY DESCRIPTION

The ClimaTek® *NexGen*™ package air conditioning unit is built on simpler, lower-cost, readily available components, using a platform that is distinctively compatible with DoD design & maintenance realities, while delivering higher energy efficiency than virtually every current commercially available model. The advanced NexGen DX package air conditioner unit features active real-time performance optimization including dynamic control of airflows and refrigerant flow and level, remote automated fault detection & diagnostics (RAFDD), independent control of sensible cooling, dehumidification and heating, and remote monitoring via a cybersecure web interface. This innovative combination of technologies results in a near doubling of energy efficiency; improved maintainability; and sustainable, measurable, and verifiable energy savings throughout equipment life. The units have nearly twice the dehumidification capability of current models, and dehumidification is achieved without reliance on energy intensive reheat.

2.1 TECHNOLOGY OVERVIEW

2.1.1 Description

The demonstrated NexGen technology is more energy efficient than nearly every currently available model, and significantly less costly to purchase and maintain than comparable ultra-high performance models. IEER and contractor wholesale equipment cost per ton of the demonstrated *ClimaTek Expert* unit are compared with current models offered by major manufacturers Trane, Carrier, and Daikin, as well as the *ClimaTek Foundation* unit, in Figure 1 below. NexGen technology features comprehensive performance optimization including control of airflows and refrigerant flow and level, remote automated fault detection & diagnostics (RAFDD); independent control of sensible cooling, dehumidification and heating; and remote monitoring via a cybersecure web interface. Next generation technology is a near-term, cost-effective solution applicable at nearly every DoD installation.

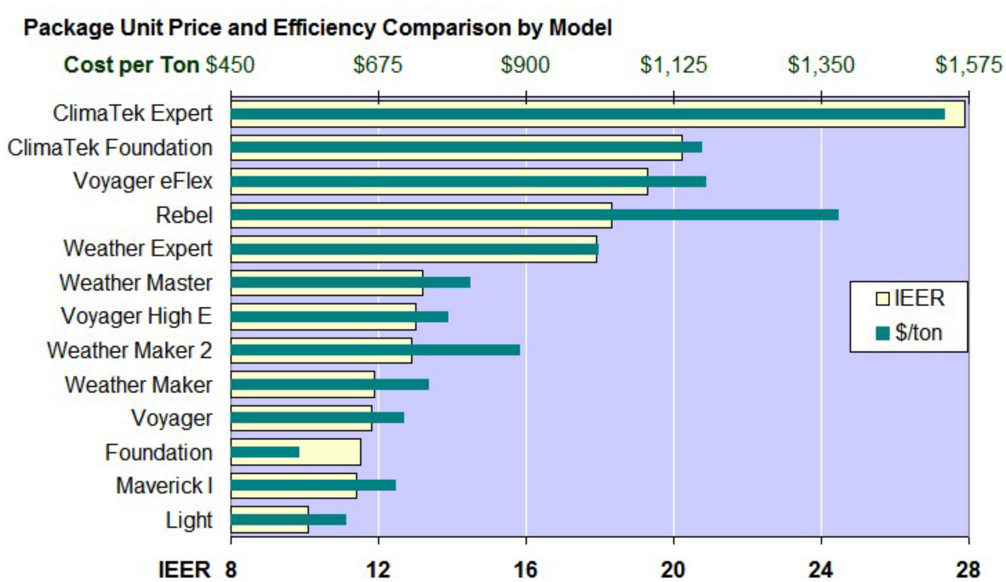

Figure 1. Package Unit Price and Energy Efficiency Comparison by Model.

NexGen units have nearly twice the dehumidification capability of current models, and dehumidification is achieved without energy intensive reheat in all but the most extreme humid conditions. Dehumidification is automatically adjusted to minimal levels when dry conditions are experienced to further reduce energy consumption. The *ClimaTek NextGen* units demonstrated have an IEER of 18.3 to 21.6 MBH/kW, and contractor cost is projected to be approximately $1800/ton[12] when produced commercially on a high-volume assembly line.

Equipment for the demonstration is built on simpler, lower-cost, readily available components, using a platform that is distinctively compatible with DoD design & maintenance realities, while delivering higher energy efficiency than nearly every currently available model. NexGen units feature technology combinations not found in current high-performance models, which pre-date these innovations. Innovations include ClimaStat® and EER Optimizer™ (previous ESTCP demonstration successes) along with variable capacity, evaporative condensate reclaim, and airflow management that integrates economizer, variable air volume (VAV), and demand-controlled ventilation (DCV) functions. Pioneering features of these units also include a low loss synchronous blower belt, twisted-airfoil condenser fan blades, and a cloud-connected web-enabled controller with extensive remote automated fault detection diagnostics and corrections. Figure 2 below illustrates the various innovative and advanced technology components integrated into a package air-conditioner.

Figure 2. Next Generation Advanced DX Package Unit Component Layout.

UFC 3-410 401.1 adopts ASHRAE Std 62.1 but prohibits use of CO2 sensors for ventilation control unless approved by AHJ (authority having jurisdiction). It's not clear which wording applies only to Army and Air Force, or all branches. NREL (Technical Report NREL/TP-5500-61072 March 2014) reported "Based on correspondence with NAVFAC, the reason for this stipulation is regarding the concern that CO2 sensors are inaccurate and will drift overtime. There are a wide range in CO2 sensor quality and different methods by which these sensors auto-calibrate overtime. If the AHJ decides that CO2 sensors will not provide sufficient accuracy over time then the DCV feature of the ARC technology will need to be eliminated." the NexGen package unit uses a CO2 sensor by manufacturer SyxthSense, at both CCSFS-NOTU and Fort Irwin, which is an auto-calibrating sensor.

[12] Cost analysis dated August 2016 itemized costs of $1168 per ton for the ClimaTek Foundation model, and $1537 per ton for the ClimaTek Expert model. Updated 2022 estimates are $1401 and $1841 per ton.

The manufacturer states "ABCLogic is a result of over 15 years R&D for the CO2 measurement. ABCLogic measures the background CO2 level and uses advanced statistical analysis to correct the readings automatically, removing the need for expensive calibration." Additional documentation from SyxthSense confirms this, and, we have tested the calibration feature to confirm it works as claimed.

2.1.2 Chronological Summary

The demonstrated next generation advanced DX package units are well-developed production prototypes ready for early-adopter commercialization. Technology development stages and performance confirmations prerequisite to demonstration have been successfully completed. An engineering prototype was constructed with readily available components assembled into a fully tested and proven system. Configuration and operational issues uncovered during lab testing were resolved. Fully equipped DX package units can be assembled and thoroughly tested within 16 weeks.

Table 1. Technology Features of ClimaTek Next-generation High-performance DX Unit.

Technology features of next-generation advanced high-performance RTU.

Technology	Description	Benefit
ClimaStat	Refrigeration cycle enhancement	Higher cycle COP, lower seasonal energy usage
EER Optimizer	Optimizing control system	Tunes operation for highest EER, detects & diagnoses faults
VCC	Variable compressor capacity	Continuously matches compressor capacity to cooling load
Condensate Reclaim	Evaporative pre-cooled subcooling coils	Lower refrigerant pressure, higher COP
VAV-DCV-Economizer	Integrated airflow control	Outdoor / Recirculated airflow controlled for highest EER
i-Optimize	Performance-based maintenance system	Mitigate performance degradation over equipment life

EER - Energy Efficiency Ratio = cooling provided [Btuh] per unit of energy [Watts], also in units [MBH/kW]

COP - Coefficient of Performance - a unitless metric of refrigeration cycle energy efficiency, such as Btuh/Btuh or kW/kW

Advantek / Climatek has a fully equipped shop for assembly, pre-shipment testing and quality assurance. Field maintenance and support needs have been thoroughly identified over the three years of demonstration operation, are well documented, and have been implemented at pilot scale.

The constituent technologies are mature, and the combination built into the next generation advanced DX package units are compatible and synergistic. ClimaStat® is a commercialized retrofit that has been installed at 14 customer sites since 2012. EER Optimizer™ is operational at three DoD demonstration sites and two commercial-sector customer sites. Variable capacity is a proven technology; mostly limited to multi-zone split systems outside the U.S. since it was commercialized several years ago[13]. The VAV-DCV-Economizer is assembled using readily available U.S. made dampers and modulating actuators. Condensate reclaim is an innovative improvement on commercialized products, such as MistBox[14], CoolDraft[15], and MistCooling[16].

[13] Daikin, Fujitsu, Hitachi, Mitsubishi, Toshiba, and Samsung offer split systems with variable capacity technology.
[14] Evaporative cooling has been used on commercial AC units for decades http://www.mistbox.com/
[15] CoolDraft supplies pumps and atomizing nozzles http://cooldraft.com/index.php/
[16] Misting systems have been commercialized for over 10 years http://www.mistcooling.com/

Low-loss blower drives and airfoil fan blades are commercially available high-performance components from U.S. manufacturers and are straightforwardly integrated.

Table 2. IEER Improvement Breakdown

IEER Improvement Breakdown	
Technology	
ClimaStat	28%
EER Optimizer	25%
Variable Capacity	36%
Condensate Reclaim	7%
VAV-DCV-Economizer	11%
Airfoil Fan	6%
Simple Sum of Increases	113%
Overall Increase from Testing	76%
Baseline IEER	11.5
Tested IEER	20.2

A next generation advanced package DX unit was initially proven as an engineering prototype developed, built, operated, and evaluated at the Advantek / ClimaTek facility in Melbourne, Florida. Advantek / ClimaTek developed and integrated a number of performance-enhancing DX technologies and the project team moved forward with an advanced high-efficiency package unit for field demonstrations, which was the next logical stage. Fundamental configuration and operational issues identified during lab testing were successfully resolved and proven in the field.

While two of the efficiency-enhancing component technologies, ClimaStat® and EER Optimizer™, had been rigorously proven in prior successful ESTCP field demonstrations, and are in the commercial diffusion stage, the NexGen package units should be considered to be at the adoption stage due to early-stage demonstration and limited market penetration to date. The technology is ready for early adopters and the value proposition is clear and compelling.

2.2 TECHNOLOGY DEVELOPMENT

Advantek has a proven history of development & testing of advanced package unit technologies. A bench scale prototype incorporating innovative refrigeration cycle modifications was first completed by Advantek in 2004. Development of a high efficiency package unit prototype was first completed in 2005 under Florida Energy Office / DOE project DEPS26-3NT41635. Testing of on-board controller prototypes were successfully completed in 2009-10. On-going operational performance testing is quantitatively confirming benefits predicted by theoretical analysis using the ORNL Heat Pump Model, FrigoSim, RefSim software and NIST Cycle_D analysis.

The ClimaStat refrigerant circuit modification has been commercially available since 2009 and has been demonstrated at two DoD sites (ESTCP project EW-201144), with measured annual energy savings of 29% at Marine Corps Air Station Beaufort (MCASB), and 24% at Cape Canaveral Air Force Station (CCSFS). EER Optimizer demonstrations at MCASB, CCSFS, and Fort Irwin (project EW-201338) were operational for well over five years with measured savings of 20 to 35%.

These package DX unit innovations, one a fundamental technology advancement and the other an improvement in control and diagnostics applicable to single or multiple DX units, have been integrated with other proven technologies in the ClimaTek NexGen, a unit that offers significant additional energy savings and improved maintainability. This incremental approach to building the next generation DX package unit technology holds great promise for a technology transition and commercial success.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Advantages

NexGen technology offers double the energy efficiency and twice the dehumidification capability of baseline units, at potentially lower initial cost than other high-efficiency models, and with a payback period suitable for ESPC and UESC projects. Simpler O&M than other ultra-high IEER systems is achieved with remote automated fault detection diagnostics (RAFDD), web-based monitoring, and off-the-shelf generic non-proprietary and longer lifespan components wherever possible. Improved indoor air quality (IAQ) is achieved via precise temperature control, enhanced dehumidification, MERV-13 filtration, UVC germicidal emitters, positive space pressurization and ventilation control to limit space carbon-dioxide level. The demonstrated NexGen advanced package units showcase a field measured operational IEER 18 to 21 efficiency level at an estimated incremental product cost of about $1800 per ton, giving a payback period of under 7 years and favorable SIR[17] above 2.0 for many energy price / climate scenarios.

2.3.2 Limitations

Load profiles vary greatly from site to site, and building to building, so RTUCC or similar HVAC hourly modeling should be used to apply demonstration results to other buildings or installations based on climate. Although the technology is considerably less complex than other ultra-high efficiency air-conditioners, O&M requirements include knowledge of digital controls and networking in addition to basic DX equipment knowledge. Condition of existing systems, especially controls and ductwork, can affect energy savings and life cycle economics. This limitation has proven to be manageable by identifying repair & reconditioning needs and is well documented.

Expected logistic difficulties with connection to the cloud server can be successfully addressed. The proven capability of the system to achieve a Risk Management Framework (RMF) Cybersecurity Authorization as outlined in the ESTCP Cybersecurity Guidance document for a <u>closed restricted network</u> physically separate from the installation network(s) is essential to achieving full functionality and realizing all the benefits the technology is capable of providing.

[17] SIR – Savings to Investment Ratio is typically used by ESCOs for economic screening of potential projects.

3.0 PERFORMANCE OBJECTIVES

The project team demonstrated that next generation advanced DX package unit technology is viable and can cost-effectively reduce annual energy consumption while improving reliability, maintainability and building comfort levels for a wide range of DoD installations.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

The demonstration has the performance objectives listed in the table below.

Table 3. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Increase A/C unit's energy efficiency	Energy used by A/C units vs cooling and/or heating provided	MBH/kW relative to baseline MBH/kW	35% increase in field-measured energy efficiency as IEER
Improve facility Indoor Air Quality (IAQ)	Fraction of time that IAQ meets ASHRAE 62.1 criteria	CO_2 level and % RH of conditioned space, relative to baseline	10% increase in fraction of hours IAQ is satisfactory
Demonstrate cost effectiveness	Cost of installed technology relative to energy savings	Projected costs, energy cost reduction relative to baseline	Overall payback period of 7 years or less
Demonstrate Reliability	Percentage of time the system performs as designed	Hours non-functional or comfort conditions are unacceptable	50% reduction in downtime relative to baseline
Qualitative Performance Objectives			
Manageability using existing facility HVAC staff & resources	Field assessment by HVAC technicians at demonstration sites	Identify critical areas of maintenance, performance, and training needs	Concurrence of HVAC staff supervisors at sites of maintainability
Reliability relative to reliability of base unit	Field assessment by HVAC SME at demonstration sites	Document runtime and downtime versus base unit	Concurrence that advanced unit performs as well or better than base unit
User satisfaction	Likert Scale	Survey responses	No decrease in satisfaction over baseline

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

Metrics used to measure success are:

A. Operational IEER [Integrated Energy Efficiency Ratio = Btuh cooling or heating per total unit Watts] or operational HSPF [Heating Seasonal Performance Factor = Btuh heating per Watt input].

B. Measured electric kW demand and kWh normalized to annual energy cost using site-measured cooling degree-days and heating degree-days.

C. Actual and projected equipment and labor first-costs and realized electric savings calculated as the reduction in electric usage from the baseline unit that was replaced.

D. Tracked maintenance actions, costs and technician comments.

E. Occupied space temperature, humidity, and CO_2 relative to ASHRAE[18] envelope limits.

3.2.1 Quantitative Performance Objectives

The demonstration project's quantitative performance objectives are: Increase energy efficiency, improve facility indoor air quality (IAQ), demonstrate cost effectiveness, and demonstrate reliability.

Increase in energy efficiency relative to the baseline unit was measured over a period of 12 months. The kW of electric energy used by the NexGen A/C unit vs the MBH amount of cooling and/or heating it provided to the occupied space was calculated in units of MBH/kW relative to the baseline A/C unit's factory rated MBH/kW. Note that energy efficiency expressed as MBH/kW (thousands of Btuh per thousand-Watts) is equivalent to Btuh per Watt, the standard EER and IEER rating metric. The increase in field-measured energy efficiency as IEER is 54% at CCSFS relative to the base Trane package AC unit, and 46% at AFINTC relative to the base Carrier package heat pump unit, well exceeding the 35% success criteria by more than double the measurement uncertainty of ±4.6%.

Facility Indoor Air Quality (IAQ) was improved as measured by the fraction of time that IAQ meets ASHRAE Standard 62.1 criteria regarding CO_2 level and %RH in the conditioned space. The fraction of hours IAQ was satisfactory relative to baseline was 94% greater than baseline at CCSFS, and 0% greater (no change from 100% satisfactory) at AFINTC; the success criteria is an increase of 10%.

The project had insufficient information to demonstrate cost effectiveness in terms of expected expenditure for installed equipment relative to energy savings because the demonstration units are hand-built prototypes having a much higher engineering and assembly labor cost than comparable base models, which are manufactured at very low cost on a high-volume production line. Projected costs based on large-quantity component pricing versus actual energy cost reduction relative to baseline indicates an overall payback period potential of 7 years or less. Various typical scenario assumptions resulted in a simple payback period on the projected incremental cost of advanced technology integrated into factory assembled units of 5.1 years or less.

Reliability was demonstrated as the reduction in equipment downtime relative to baseline by comparing the percentage of operational hours that the baseline versus the NexGen systems performed as designed, versus non-functional hours or hours when comfort conditions were unacceptable. The reduction in downtime hours at CCSFS was 87%, and downtime was reduced by 91% at AFINTC.

[18] ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy and ANSI/ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality

3.2.2 Qualitative Performance Objectives

The demonstration project's qualitative performance objectives address manageability using existing facility HVAC staff & resources, reliability relative to reliability of baseline unit, and user satisfaction.

Manageability using existing facility HVAC staff & resources was gauged according to field service and assessment comments provided by HVAC technicians at both demonstration sites. DoD technicians addressed areas of maintenance, performance, and training needs. The overall objective is concurrence of HVAC staff at both sites of overall maintainability. Technicians were generally interested and enthusiastic about the RAFDD controller and welcomed the opportunity to learn advanced operation and service procedures as a way of easing their future workload.

Reliability relative to the base unit was gauged according to subjective assessment by the HVAC SME and Energy Manger at both demonstration sites, runtime and downtime of the NexGen unit versus the baseline unit, along with technician comments. The overall objective is concurrence that the advanced unit performs as well or better than base unit. There was general agreement that the NexGen units had fewer outages and downtime than the units they replaced and are easier to service as long as training is provided to interested technicians, although in general, reliability comparison of new equipment in its first year of operation against old equipment at or near end of serviceable life isn't necessarily conclusive. The DoD personnel agreed that the NexGen units were at least as or more reliable as other new package unit equipment at their respective installations.

User satisfaction was gauged by comparing responses to statements regarding comfort on a Likert scale where respondents indicated their level of agreement or disagreement on a symmetric agree-disagree scale, as shown in Figure 3. Survey data indicates a possible small increase in user satisfaction over baseline.

Figure 3. Likert Scale Comfort Survey Questions and Explanation of Response Choices.

4.0 DEMONSTRATION SITE DESCRIPTION

The two selected demonstration locations span the wide range of climate conditions where DoD package DX equipment is most often installed. Naval Ordnance Test Unit at Cape Canaveral Space Force Station (CCSFS) in Florida, and Fort Irwin National Training Center (AFINTC) in California are at two ends of a geographical climate line along many DoD installations in the Southern CONUS where cooling is a large portion of energy use. The humid coastal Florida climate is comparable to tropical DoD locations such as Guam, Bahamas, and Hawaii. The High Desert California climate is comparable to much of the US desert Southwest and the Middle East.

4.1 SITE LOCATION AND OPERATIONS

Naval Ordnance Test Unit (NOTU) is located entirely within CCSFS about 50 miles east of Orlando and 25 miles north of Advantek's office and lab facility in Melbourne FL. NOTU supports sea-based weapons systems and the multiple mission capabilities of Navy submarines. NOTU operates the Navy Port at Port Canaveral, supporting submarines and surface ships of the Atlantic Fleet. The demonstration was conducted at the NOTU Operations building, a two-story concrete block structure served by DX air-conditioning equipment. The demonstration HVAC system is a 15-ton package unit located on the ground, building number 81701.

Fort Irwin houses the seven square mile National Training Center (NTC) located in the Mojave Desert in Southern California, about halfway between Los Angeles CA and Las Vegas NV. The National Training Center conducts tough, realistic desert operations. This is accomplished by pitting soldiers against the harsh desert environment and a determined and menacing opposing force. The HVAC demonstration was conducted at a single-story frame building occupied by the Office of the Staff Judge Advocate (OSJA), building number 242, served by an 8.5-ton package unit located on the ground.

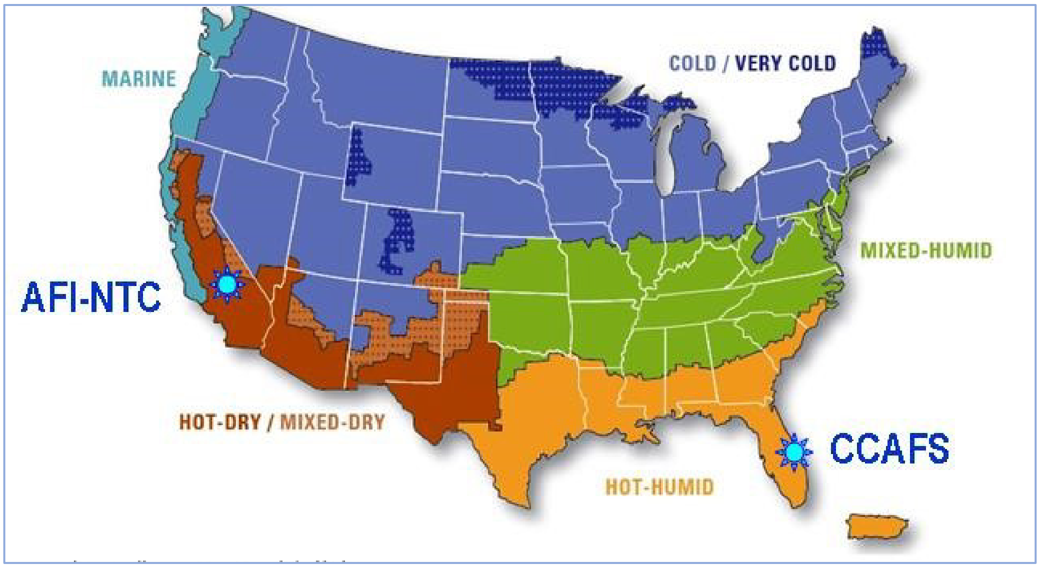

Figure 4. Map of CONUS Showing HVAC Climate Zones and the Two Demonstration Sites.

Figure 5. Map Showing Location of CCSFS Relative to Orlando, FL and Melbourne, FL

Figure 6. Map Showing Location of Fort Irwin Relative to Los Angeles, CA and Las Vegas, NV.

4.2 FACILITY / SITE CONDITIONS

NOTU / CCSFS is located on flat coastal terrain in hot & humid climate zone 2A with 3633 cooling degree-days (CDD) and 711 heating degree-days (HDD). Fort Irwin National Training Center in California is in low-mountainous high-desert terrain in hot & arid climate zone 2B with 3225 CDD and 2175 HDD. Climate is important for this demonstration, with both sites having a long summer season and over 3000 cooling hours, and for the heat pump a significant heating load. Package unit performance is strongly influenced by humidity levels and vice versa, so end-point climates are ideal. Winter heating at NOTU is mostly by electric resistance and at Fort Irwin with heat pumps, providing a variety of equipment types for demonstration. The NOTU Operations building is typical of many concrete / steel high thermal mass / large glass area facilities on many DoD campuses, while the Fort Irwin OSJA building is typical of numerous wood frame / low thermal mass structures at many DoD installations.

Figure 7. Overhead View of Fort Irwin NTC OSJA Building Looking NE, Heat Pump Unit Circled.

Figure 8. Overhead View of CCSFS NOTU Building 81701 Looking NNW, Baseline AC Unit Circled.

5.0 TEST DESIGN

Fundamental Problem: *Package air-conditioners installed at DoD facilities have much higher energy usage than the best available high-performance technologies.*

Demonstration Question: *Will changing from the existing package unit to the advanced package unit result in at least a 35% decrease of annual energy usage measured as kWh, with no sacrifice or some improvement of comfort and reliability?*

5.1 CONCEPTUAL TEST DESIGN

Hypothesis: The working hypothesis is that changing from the existing package unit to the advanced package unit will result in at least a 35% increase in energy efficiency, measured as both an increase in IEER and corresponding decrease in kWh electric usage, with no reduction of comfort, indoor air quality (IAQ), and reliability and no increase in maintenance needs.

Independent variables: A binary change of status 'with' versus 'without' the subject technology, the existing package unit versus the advanced package unit; along with the background independent variables of ambient temperature (F), ambient humidity (%RH), ambient carbon dioxide level (ppm), building occupancy level, and time of day / of week.

Dependent system-level variables continuously measured were: System power demand (kW) and energy consumption (kWh); system cooling or heating delivered in terms of both sensible, latent (Btuh) and sensible heat ratio (SHR); and occupied space air temperature (F), relative humidity (%RH), and carbon dioxide level (ppm) differential with respect to ambient carbon dioxide level.

Dependent component-level variables continuously measured were: Compressor and fan electric (kW and kWh), refrigerant pressures and temperatures at the inlet and outlet of the compressor (psig and F); refrigerant flow rate (gpm and lb_m/min); and inter-component air and refrigerant temperatures and pressures (psig and F).

Controlled variables are the use and occupancy of the building to the best ability of the project team, and thermostat user temperature set point.

Test Design: The project team used detailed performance metrics measured directly from the demonstration sites to compare "before" versus "after" replacement of the existing DX units in the first summer cooling and heating seasons (12 months) with the next generation advanced units in the second summer cooling and heating seasons (12 months).

Success criteria is a 35% energy efficiency increase as IEER along with a 35% decrease in annual energy usage as kWh, payback of projected commercialized incremental first-cost within 7 years, 10% increase in comfort zone hours, relative to the existing units, and some increase in reliability or decrease in maintenance needs.

5.2 BASELINE CHARACTERIZATION

Collection of one full year of baseline performance data as described above from the existing package air-conditioners occurred over the first summer cooling and winter heating seasons of the demonstration project, from approximately early June through the end October for cooling and for heating at Fort Irwin from January through the end of March. The existing units were comprehensively instrumented with 45-channel data loggers to monitor power usage, cooling and heating delivered and indoor comfort and ventilation conditions for the first full year of the project. At least 12 full months of data was collected continuously at 1-minute intervals from each existing package unit to provide annual energy usage.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

The NexGen advanced units are air-cooled package units that were engineered with optimized components and controls. The unit installed at CCSFS-NOTU is 15-ton dual compressor cooling with 18 kW electric heat. The unit at Fort Irwin is an 8.5-ton dual compressor heat pump. The advanced NexGen package units replaced existing units of same size and configuration. Existing ductwork was retained. The unit at Fort Irwin provides cooling and heating to the entire building. The unit at CCSFS provides cooling and heating to the west wing of the building. Key technology components of the package unit system to be demonstrated are described in detail below.

Advanced technology components integrated into the NexGen package units include ClimaStat® refrigeration enhancement, EER Optimizer™ controller, variable capacity, and volume, condensate reclaim, and VAV-DCV-Economizer.

- **ClimaStat®** refrigeration technology enhances the traditional vapor-compression cycle at a fundamental level by improving evaporator refrigerant / two-phase heat transfer; increasing suction density to improve compressor volumetric efficiency; and providing variable sensible heat ratio to optimize dehumidification performance. The patented technology is rendered by installation of two liquid-suction heat-exchanger separators (LSHX-separator), patented segmented evaporator circuiting, and supporting controls upgrades. The ESTCP demonstration of ClimaStat® was awarded Energy Project of the Year 2013.
- **EER Optimizer™** remote automated fault detection & diagnostic (RAFDD) controller tunes all operating parameters to achieve maximum efficiency while precisely meeting sensible (cooling), latent (dehumidification) and heating loads. The controller continuously adjusts blower speed, condenser fan speed, compressor speed, refrigerant flow and charge, supply air temperature, coil temperature, and economizer damper. It features remote monitoring and access via a cybersecure cloud-based web interface, data logging / trending, and reporting of EER, COP, IEER, power usage, cooling/heating capacity and all other performance parameters. Energy efficiency faults, such as low refrigerant or fouled coil, are detected & diagnosed before becoming significant. The interface is user friendly and designed to reduce the time needed for technicians to address faults. The user interface can be viewed live at EEROptimizer.com via a secure (https) web browser, and the data logging and database are easily-accessed on screen and in downloadable CSV files. Prior to this demonstration, three ESTCP demonstrations of EER Optimizer™ were active from August 2015 through October 2017 with an overall result of 26% energy savings.

- **Variable Capacity** is a proven new technology currently used in multi-zone split-system, DOAS, and mini-split equipment. The advanced DX unit demonstration is the first to render variable capacity using matched variable frequency drives (VFD) mated to off-the-shelf compressors in single-zone package units. This component utilization combines the benefits of variable capacity with the maintainability of familiar, relatively simple components. The EER Optimizer system controls the matched set of VFDs to optimize airflows, refrigerant flow and refrigerant volume as cooling, dehumidification and heating demands vary, to achieve the maximum possible energy efficiency at any given operating condition.
- **Condensate Reclaim** utilizes evaporator coil condensate that usually goes to waste – literally, cold clean water down the drain. Condensate is distilled water that forms when water vapor is condensed from air as it passes through the cooling coil. A 10-ton unit will produce about 3.5 gallons per hour of mineral-free condensate at standard conditions. The condensate is captured, disinfected by UVC light, and pumped under pressure to atomizing micro-nozzles upstream of the subcooling rows of the condenser coil. A technician can turn the condensate spray pump off, if desired, from the Setup screen on the controller interface, or manually at the pump power disconnect. With the condensate spray turned off, at near standard rating conditions of 80F dry bulb / 67F wet bulb / 50%rh / 60F dew point, R-410a condensing pressure increased by an average of 17 PSI and EER decreased by about 7%, or around 1 EER point on average. The increase in efficiency afforded by the condensate spray depends on climate and weather conditions, with dryer air producing more evaporative cooling and performance gain.
- **VAV-DCV-Economizer** integrates variable air volume (VAV), demand-controlled ventilation (DCV) and Economizer functions to maximize energy efficiency, enhance simplicity and ease of maintenance, and reduce equipment and energy costs. The advanced DX unit features a single damper/actuator serving all three functions, reducing failure points and maintenance complexity. The controller calculates the optimum blower speed and damper position as outdoor temperature / humidity, indoor comfort conditions, occupancy and carbon dioxide level vary. The controller also monitors economizer function to immediately detect, compensate for and report misalignment or failure.

5.4 OPERATIONAL TESTING

The project team assessed all operational modes of the technology at the two demonstration sites over a period of 12 months, as well as results of third-party modeling and data verification performed by University of Maryland Center for Environmental Energy Engineering.[19] The advanced NexGen package units were bench tested prior to installation, and then again onsite upon installation.

[19] UM-CEEE provides innovative solutions to industry's research and development challenges and cost-effective, timely technology transfer. CEEE has developed a highly flexible and task-oriented consortium structure that emphasizes pre-competitive research. https://ceee.umd.edu/

5.4.1 Operational Testing of Cost and Performance

Once the advanced NexGen units were set and connected for onsite startup, as seen below in Figures 9 and 10, the units underwent a thorough commissioning protocol to identify and correct minor operation and sensor issues and verify control parameter calibration. Performance testing proceeded in each of three operational control modes:

1) *Manual* mode operates without any automatic or variable speed control functions
2) *Automatic* mode provides automatic blower speed control and damper adjustment to best meet space temperature set point, similar to a conventional VAV package unit.
3) *Optimize* mode continuously adjusts all operational parameters to achieve the maximum possible energy efficiency while meeting space temperature, humidity, and ventilation needs.

Figure 9. Advanced NexGen Heat-pump Package Unit Being Installed at Fort Irwin OSJA Building.

Operational modes were cycled during the demonstration period with approximately 1 to 2-week periods on *Manual* or *Automatic*, with most operation being in *Optimize* mode. Analog backup control mode was also tested for extended periods, which operates the unit conventionally from the wall thermostat in case of digital controller failure. RAFDD was active in all modes, with faults and diagnostics continuously logged to a web page hosted on a cybersecure cloud server. Operational testing continued from completion of commissioning until the end of the cooling and heating seasons of the second year of the project, to obtain 12 full months of performance, fault, and energy data.

Figure 10. Advanced NexGen Cooling Package Unit Being Installed at CCSFS NOTU Support Building.

5.4.2 Modeling and Simulation

The project team performed two major modeling and simulation tasks: (1) development of heat exchanger and system models, and (2) comparative analysis of simulation with field data. Computer models for the baseline and NexGen units were developed using proprietary software tools CoilDesigner® and VapCyc®. Modeling was based primarily on first principles with a minimum of tuning from field data. Each circuit of the dual circuit system was modeled independently. Model results were compared to baseline unit manufacturer data and NexGen unit field performance to form a conservative performance baseline. To identify the factors which most strongly drove EER improvement, a response surface model for EER was fit from Optimize mode field test data.

Additionally, the baseline model proved valuable for validating field data derived performance, such as EER, IEER and system capacity. System capacity was derived from field measurement of temperatures and refrigerant mass flow along with appropriate thermophysical calculations. In particular, the mass flow rate of refrigerant obtained from field sensor measurements was validated using compressor maps and the full VCS model.

5.5 SAMPLING PROTOCOL

Baseline data was sampled once per minute by 45-channel data logging systems from June 2017 through March 2019, see Figure 12. NexGen advanced package unit demonstration data were collected continuously from the end of the baseline period through the end of the demonstration data period on the last day of February 2021. NexGen data was collected via the EEROptimizer website (https://eeroptimizer.com) over sequential time periods starting with *Manual* mode, followed by *Auto* mode, and lastly by *Optimize* mode. Data sampling rate is twice per minute and at least 12 full months of baseline and NexGen data was collected from each site. (Note that the EEROptimizer website has continued to log data beyond the end of the demonstration, as logging is a normal controller function.) Field data selected for analysis was filtered to remove data which did not meet clearance criteria, such as data with outside air RH greater than 100%, or negative values for subcooling, that are not physically or thermodynamically possible and are most likely signal or processing error artifacts.

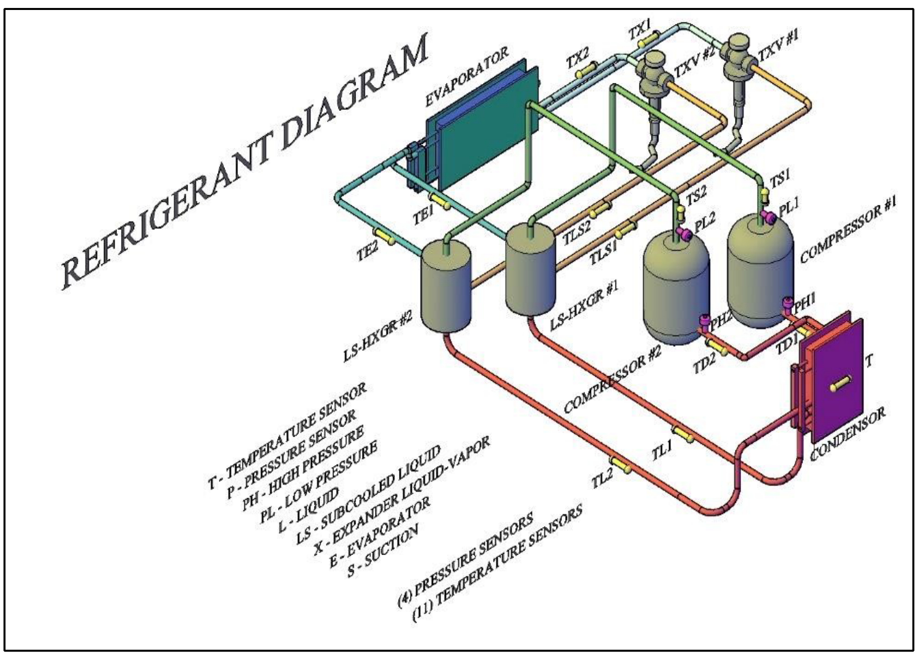

Figure 11. Location of Sensors on Refrigerant Circuits of Package Air-conditioner.

Baseline unit sensor points listed in the table below were sampled at 60 second intervals by the data logging system, and every sample was recorded every 1 minute in a comma delimited text file. There were a total of 45 sensor channels at each site. Text files were automatically uploaded to a cloud server once each day, and in turn the server data is backed up on a local server in the Advantek IT room, which is backed up to a different cloud server and an external hard drive.

The sampling rate was at times of interest temporarily increased to 15 seconds when more detail was desired. Data were made available in near-real-time (within 10 minutes) to all project personnel by secure connection via any standard web browser. CSV[20] files containing the most recent data were uploaded at approximately 10 to 14-day intervals into Excel files for review by the PI and project team.

Figure 12. HOBO Dataloggers Installed in Baseline Unit at CCSFS-NOTU.

[20] Comma Separated Value files are text content that can be read / imported by MS-Excel and nearly every data analysis software.

Table 4. Listing of Data Samples Collected by Logger System Installed on the Baseline Equipment.

LOGGER	TYPE/CH	SENSOR	TRANS	MEASUREMENT	UNITS	ACC ±	DESCRIPTION
LOGGER #1	ANALOG 1	0-5 Vdc	SENSATA	HI-P-1	PSIG	6	Refrigerant pressure, high side, circuit 1
	ANALOG 2	0-5 Vdc	SENSATA	LO-P-1	PSIG	6	Refrigerant pressure, low side, circuit 1
	DIGITAL 1	T	ONSET	COMP-OUT-1	F	0.36	Refrigerant temperature, compressor out, circuit 1
	DIGITAL 2	T		COND-OUT-1	F	0.36	Refrigerant temperature, condenser out, circuit 1
	DIGITAL 3	T		LIQHX-OUT-1	F	0.36	Refrigerant temperature, heat exchanger out, circuit 1
	DIGITAL 4	T		TXV-OUT-1	F	0.36	Refrigerant temperature, TXV out, circuit 1
	DIGITAL 5	T		EVAP-OUT-1	F	0.36	Refrigerant temperature, evaporator out, circuit 1
	DIGITAL 6	T		SUCHX-OUT-1	F	0.36	Refrigerant temperature, heat exchanger out, circuit 1
	DIGITAL 7	T		COMP-OUT-2	F	0.36	Refrigerant temperature, compressor out, circuit 2
	DIGITAL 8	T		COND-OUT-2	F	0.36	Refrigerant temperature, condenser out, circuit 2
	DIGITAL 9	T		LIQHX-OUT-2	F	0.36	Refrigerant temperature, heat exchanger out, circuit 2
	DIGITAL 10A	T		TXV-OUT-2	F	0.36	Refrigerant temperature, TXV out, circuit 2
	DIGITAL 10B	T		EVAP-OUT-2	F	0.36	Refrigerant temperature, evaporator out, circuit 2
	DIGITAL 10C	T		SUCHX-OUT-2	F	0.36	Refrigerant temperature, heat exchanger out, circuit 2
	DIGITAL 10D	T		COND-AIR-OUT	F	0.36	Air temperature, condenser out
LOGGER #2	ANALOG 1	0-5 Vdc	SENSATA	HI-P-2	PSIG	6	Refrigerant pressure, high side, circuit 2
	ANALOG 2	0-5 Vdc	SENSATA	LO-P-2	PSIG	6	Refrigerant pressure, low side, circuit 2
	DIGITAL 1A	4-20mA	BLANCET	LIQ-FLOW-1	GPM	1%	Liquid flow, circuit 1
	DIGITAL 1B	4-20mA	BLANCET	LIQ-FLOW-2	GPM	1%	Liquid flow, circuit 2
	DIGITAL 2	T	ONSET	COIL-LEFT	F	0.36	Air temperature, evaporator coil out, left side
	DIGITAL 3	T		COIL-RIGHT	F	0.36	Air temperature, evaporator coil out, right side
	DIGITAL 4	F	MEAS	RES-LEVEL-1	%	5%	Reservoir level, circuit 1
	DIGITAL 5	F	SPEC	RES-LEVEL-2	%	5%	Reservoir level, circuit 2
	DIGITAL 6	T	ONSET	RES-TEMP	F	0.36	Temperature, reservoir
	DIGITAL 1C	4-20mA	ONSET	COIL-DELTA-P	IN-WC	0.01	Air pressure differential across package unit
	DIGITAL 1D	4-20mA	VERIS	UNIT-TOT-POWER	KW	1%	Total power demand of package unit
	DIGITAL 7	T-RH	ONSET	RA-T/RH	F/%	0.21 / 2.5%	Temperature and Humidity, return air from space
	DIGITAL 8	T-RH		SA-T/RH	F/%	0.21 / 2.5%	Temperature and Humidity, supply air to space
LOGGER #3	ANALOG 1	0-10 VDC	signal	VFD-SPEED	%	1%	Variable Frequency Drive speed signal, % of full
	ANALOG 2	0-10 VDC	signal	COND-FAN-SPEED	%	1%	Condenser fan speed signal, % of full
	DIGITAL 1A	0-5 Vdc	ONSET	COIL-VELOCITY	FPM	10%	Air velocity, evaporator coil inlet face
	DIGITAL 1B	0-5 Vdc	SENSATA	RES-PRESSURE-1	PSIG	6	Pressure, reservoir circuit-1
	DIGITAL 1C	0-5 Vdc	SENSATA	RES-PRESSURE-2	PSIG	6	Pressure, reservoir circuit-2
	DIGITAL 2	5-512 mVdc	ONSET	COMP1-AMPS	AMPS	1%	Amps, compressor 1
			ONSET	COMP2-AMPS	AMPS	1%	Amps, compressor 2
	DIGITAL 1D	0-5 Vdc	CE-Trans	COND-FAN-kW	Watts	1.5%	Power, Watts, condenser fans
	DIGITAL 1E	0-5 Vdc	CE-Trans	BLOWER-kW	Watts	1.5%	Power, Watts, evaporator blower
	DIGITAL 2A	4-20mA	VERIS	ROOM-T/RH/CO2	F/%/PPM	1 / 2% / 2%	Temperature, Humidity and Carbon Dioxide level, room
	DIGITAL 2B	4-20mA					
	DIGITAL 2C	4-20mA					
	DIGITAL 3	T-RH	ONSET	OA-T/RH	F/%	0.21 / 2.5%	Temperature and Humidity, outdoor air
	DIGITAL 2D	4-20mA	VERIS	OA-CO2	ppm	2%	Carbon Dioxide, outdoor air

5.6 SAMPLING RESULTS

This subsection presents a summary of sampling results and charts of processed data gathered during the demonstration. Full data sets are archived as sets of CSV files which contain from approximately 44,000 (baseline) to 90,000 (technology demonstration) data points per month for 14 to 21 months (baseline) and 13 months (technology demonstration).

5.6.1 Baseline Data

Before the standard unit was replaced with the advanced NexGen unit, measured baseline energy efficiency data as EER in units Btuh per Watt (equal to MBH/kW), and measured unit power demand in units kW were analyzed, example data shown below. From the CCSFS-NOTU baseline unit, Figure 13 shows Stage-1 efficiency (1 compressor energized) cycles between about EER 7 to 8 Btuh/Watt as outdoor temperature rises and falls over the course of three days, with electric power demand ranging from about 10 to 12 kW. Data for Stage-2 (both compressors energized) are shown in Figure 15, EER cycles from about 9 to 10 Btuh/Watt, with electric power demand ranging from about 13 to 15 kW.

From the Army Fort Irwin (AFI) OSJA baseline unit, Figure 14 shows Stage-1 efficiency (1 compressor energized) cycles between EER 6.2 to 7.2 Btuh/Watt as outdoor temperature rises and falls over the course of three days, with electric power demand ranging from about 4.2 to 4.8 kW. Data for Stage-2 (both compressors energized) are shown in Figure 16; EER cycles from about 7 to 9 Btuh/Watt, with electric power demand ranging from about 8 to 9.6 kW.

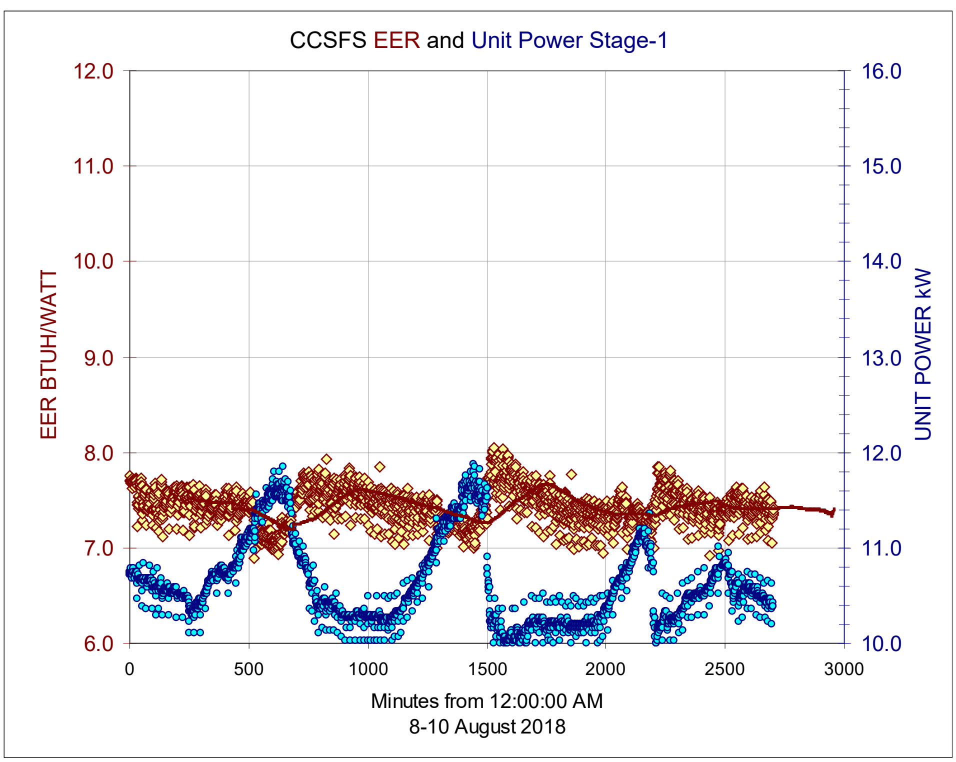

Figure 13. CCSFS-NOTU Baseline Measured Stage-1 Efficiency EER and kW Data 8-10 August 2018.

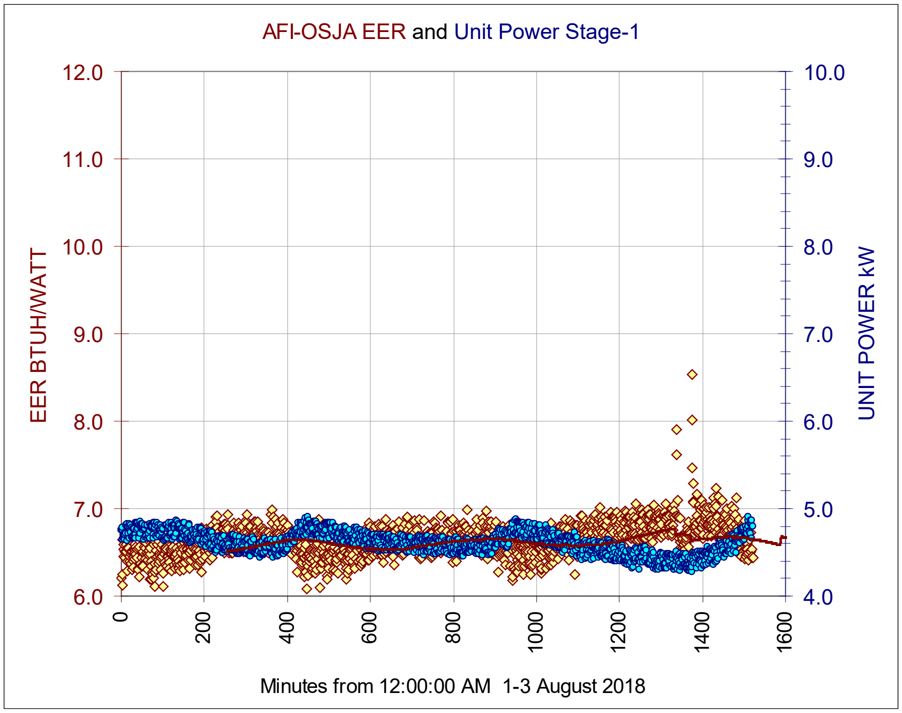

Figure 14. Fort Irwin OSJA Baseline Measured Stage-1 Efficiency EER and kW Data 1-3 August 2018.

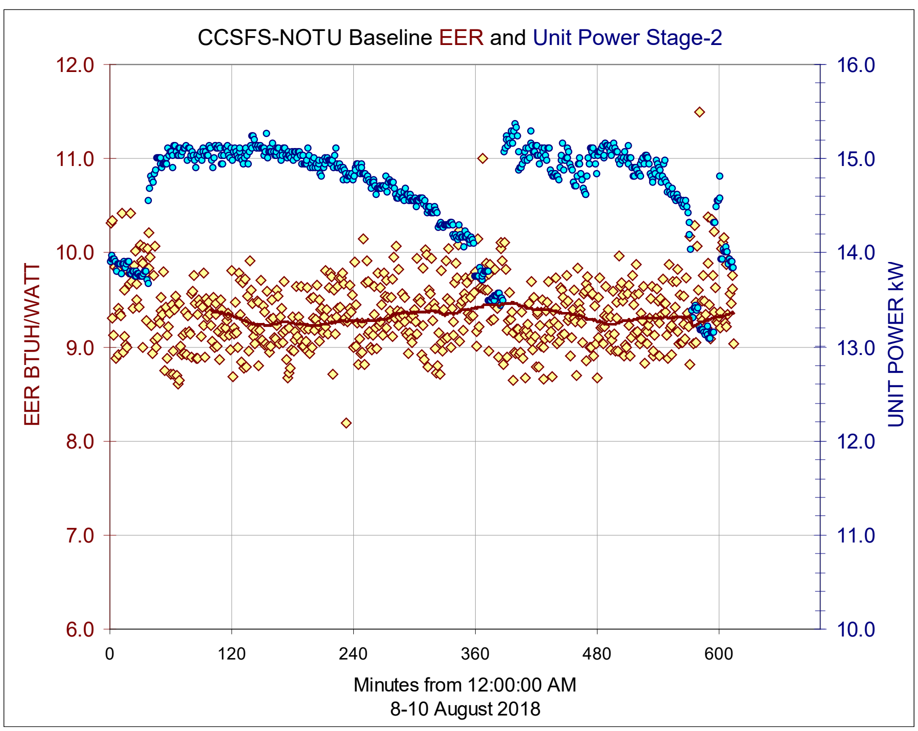

Figure 15. CCSFS-NOTU Baseline Measured Stage-2 Efficiency EER and kW Data 8-10 August 2018.

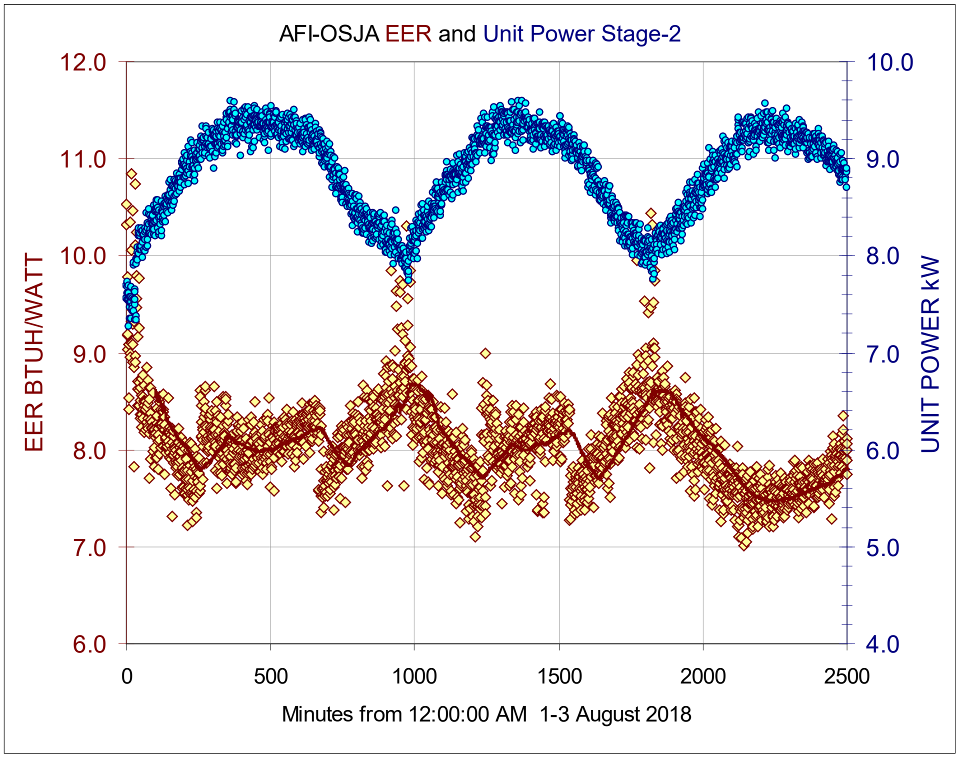

Figure 16. Fort Irwin OSJA Baseline Measured Stage-2 Efficiency EER and kW Data 1-3 August 2018.

5.6.1.1 CCSFS-NOTU baseline unit performance data

The CCSFS-NOTU Trane 15-ton two-stage cooling unit shown in Figure 17 was thoroughly serviced in July 2018 to maximize its performance and provide a true baseline. Service actions included coil cleaning, belt adjustment, cabinet repairs, and adjusting refrigerant charge. Performance pre-service in August 2017 and one-year later in August 2018 was compared to assess servicing effect and data consistency. The occupied space was significantly less comfortable in August 2018 than August 2017, with the fraction of hours in the ASHRAE-defined comfort zone dropping from 18.2% to 1.9%. This was due to small but significant increases in both space temperature and humidity. Predicted percentage dissatisfied (PPV) rose from 11.2% to 15.5%. Possible causes could be an increase in thermostat setpoint by 1-degree F, reduced compressor run time and dehumidification, and/or increased infiltration air leakage through the many loose-fitting windows and doors in the building.

Conditioned supply air from the AC unit was slightly warmer in August 2018 than August 2017, likely due to shorter run cycles, as listed below in Table 6. Although airflow was slightly less, available cooling capacity increased significantly, possibly due to servicing in July 2018. (However, cooling capacity was 23% less than factory rating.) An increase in external static pressure is likely due to filters being loaded, which would account for the reduced airflow as well. While median SHR (sensible heat ratio) indicates a significant increase in Stage I dehumidification capability, space humidity and dew point were higher in August 2018 than August 2017.

Compressor parameters were largely unchanged in August 2018 compared against August 2017, with some considerable exceptions. Stage II compressor operation decreased from 6.3 run hours per day to 3.4 hours. Compressor 2 discharge temperature increased from 183 F to 210 F and superheat increased from 80.3 deg-F to 112.2 deg-F. Compressor 2 pressure ratio and mass flow also increased considerably, yet Amps decreased slightly. Condenser parameters were also largely unchanged in August 2018 compared against August 2017, with a few exceptions. There was a slight 3.1 deg-F increase in Stage I discharge air temperature. Subcooling on circuit-2 decreased significantly from 5.0 to 1.9 deg-F. Fan motor amps and power increased slightly.

Efficiency parameters were virtually all improved from August 2017 to August 2018 as can be seen in Table 5, likely due to the recent servicing. System COP, EER, IEER, and Capacity are all increased slightly, while SHR decreased, showing an overall small but significant performance improvement of 4%. Performance of the baseline unit was markedly deteriorated as compared with its factory ratings. Energy efficiency of IEER 7.6 is 26% worse than the factory rated IEER 10.2. Total cooling capacity of 11.8 tons is 23% less than the factory rated 15.2 tons, and dehumidification capacity is 21% reduced from factory rating.

Figure 17. CCSFS-NOTU Baseline Unit that Was Replaced.

Table 5. CCSFS-NOTU Baseline Performance Comparison Before versus After Servicing.

System	Energy Efficiency Parameters					Sensible Heat
Stage 1	Cycle COP	System COP	EER	**IEER****	Capacity [Tons]*	Ratio [SHR]
Aug 2017	3.9	2.1	7.3	7.1	6.8	0.86
Aug 2018	4.3	2.2	7.4	7.3	7.0	0.61
Difference	0.4	0.1	0.1	0.2	0.2	-0.25
Stage 2						
Aug 2017	3.4	2.2	7.8	7.7	10.1	0.78
Aug 2018	3.1	2.7	9.4	8.8	11.8	0.74
Difference	-0.3	0.5	1.5	1.1	1.6	-0.04

Manufacturer nominal rating is 10.1 Tons Stage I and 15.2 Tons Stage II at IEER 10.2

Energy	Max Demand Power [kW]	Usage per Day [kWh/day]	Usage per CDD [kWh/CDD]	Efficiency **IEER**	Balance Temp [°F]	Energy Signature [kWh/°F]
Aug 2017	16.0	261.1	44.5	7.3	60.8	29.4
Aug 2018	15.4	209.5	32.1	7.6	62.2	26.5
Difference	-0.7	-51.5	-12.4	0.3	1.5	-2.91
%Difference	-4%	-20%	-28%	4%		

Peak power demand was reduced to 15.4 kW in August 2018 compared against 16.0 kW in August 2017. Energy consumption per day, and per cooling degree-day were both considerably reduced in August 2018 vs 2017. Reduced normalized energy consumption is likely a result of slightly increased efficiency combined with a reduction in space load. Slightly reduced cooling load is indicated by the increase in balance temperature from 60.8 to 62.2 F. It was noted that median outdoor air temperature was about 1 to 2 degrees F warmer in August 2018 than August 2017, and cooling degree-days per day were 19.6 vs 17.6. Even though the weather was warmer, cooling demand was less and unit operation was slightly more efficient.

Table 6. CCSFS-NOTU Baseline Comparison of Operating Parameters Before versus after Servicing.

Trane Model TCH181C400AA Horizontal, 15 Ton High Efficiency, no factory options
Serial P46104116D

Comfort	Median Occupied Space Conditions				Comfort Parameters	
	Temperature [°F]	Humidity [%rh]	Dew Pt [*F]	CO2 [ppm]	PPV Dissatisified	In Comfort Zone
Aug 2017	72.8	71.6	62.8	426	11.2%	18.2%
Aug 2018	73.9	74.3	65.1	422	15.4%	1.9%
Difference	1.2	2.7	2.2	-4.9	4%	-16%

Cooling Coil	Median Supply Air Conditions		Blower	External Static	Cooling	Sensible Heat
Stage I	Temperature [°F]	Dew Pt [*F]	CFM	Pressure [in-wc]	[Tons]	Ratio [SHR]
Aug 2017	65.0	64.0	4182	0.53	6.2	0.86
Aug 2018	65.5	64.3	3889	0.68	6.7	0.61
Difference	0.5	0.3	-293	0.15	0.5	-0.25
Stage II						
Aug 2017	62.4	60.8	4189	0.54	9.5	0.78
Aug 2018	63.5	61.8	3906	0.68	11.4	0.74
Difference	1.1	1.1	-283	0.13	1.9	-0.04

Compressor 1	Average Discharge				Mass Flow	Run Hours
Stage I	Temperature [°F]	Superheat [degF]	Amps	Pressure Ratio	[lb/hr]	[hrs/day]
Aug 2017	177	80.0	12.4	3.39	934	16.0
Aug 2018	169	71.8	12.8	3.17	1021	15.0
Difference	-7.2	-8.2	0.4	-0.2	87	-1.0
Stage II						
Aug 2017	186	78.9	13.5	3.53	1029	6.3
Aug 2018	182	74.5	13.8	3.30	1112	3.4
Difference	-3.7	-4.4	0.3	-0.2	83	-2.9

Compressor 2	Average Discharge				Mass Flow	Run Hours
Stage II	Temperature [°F]	Superheat [degF]	Amps	Pressure Ratio	[lb/hr]	[hrs/day]
Aug 2017	183	80.3	7.5	3.40	477	6.3
Aug 2018	210	112.2	7.0	4.84	682	3.4
Difference	27.8	31.9	-0.5	1.4	204	-2.9

Condenser	Median Temperatures [°F]				Fan Power	
C1 Stage I	Ambient	Discharge Air	Condensing	Subcool	Amps	Watts
Aug 2017	80.5	90.0	95.9	15.7	2.35	450
Aug 2018	81.4	93.0	96.5	15.2	2.50	478
Difference	0.8	3.1	0.6	-0.4	0.15	29
C1 Stage II						
Aug 2017	88.6	106.8	108.0	18.3	2.33	445
Aug 2018	90.7	108.5	109.6	17.2	2.45	469
Difference	2.1	1.7	1.6	-1.0	0.12	24
C2 Stage II						
Aug 2017	88.6	106.8	103.5	5.0	2.33	445
Aug 2018	90.7	108.5	100.1	1.9	2.45	469
Difference	2.1	1.7	-3.4	-3.1	0.12	24

5.6.1.2 Fort Irwin OSJA baseline unit performance data

The Fort Irwin OSJA 7.5-ton two-stage heat-pump unit shown in Figure 18 was thoroughly serviced in July 2018 to maximize its performance and provide a true baseline. Service actions included coil cleaning, belt replacement, control system repairs, and adjusting refrigerant charge. Performance pre-service in August 2017 and one-year later in August 2018 was compared to assess servicing effect and data consistency. The occupied space was more comfortable in August 2018 than August 2017, with the fraction of hours in the ASHRAE-defined comfort zone rising from 0% to 28.9%. This was due mostly to significant decrease in both space temperature and humidity. Predicted percentage dissatisfied (PPV) dropped from 87.9% to 63.7%. Possible causes could be a decrease in thermostat setpoint and increased compressor run hours.

Conditioned supply air from the AC unit was slightly warmer in August 2018 than August 2017, likely because of increased blower efficiency due to belt replacement. Although airflow was slightly more, available cooling capacity decreased slightly. Cooling capacity was 19% less than factory rating.

Compressor parameters were largely unchanged in August 2018 compared against August 2017, with considerable exceptions. Compressor 1 discharge temperature increased from 167 F to 189 F and superheat increased from 60 deg-F to 82 deg-F. Compressor 2 discharge temperature increased from 175 F to 193 F and superheat increased from 50 deg-F to 64 deg-F. Condenser parameters were also largely unchanged in August 2018 compared against August 2017, with a few exceptions. There was a 5.8 deg-F increase in Stage I discharge air temperature, likely because of dirt and feathers found on the coil. Stage II condensing temperature increased by 5.5 and 6.1 degrees on circuit 1 and circuit 2, respectively.

Efficiency parameters are virtually all deteriorated from August 2017 to August 2018, likely due to coil fouling. System COP, EER, IEER, and Capacity are all decreased slightly as listed in Table 7, showing an overall small but significant performance decline of 5.2%. Performance is markedly deteriorated as compared with the factory ratings. Energy efficiency of IEER 7.4 is 21% worse than the factory rated IEER 9.3. Total cooling capacity of 5.8 tons is 19% less than the factory rated 7.2 tons. Peak power demand was 9.6 kW in August 2018 compared against 9.8 kW in August 2017. There was little change in energy consumption per day, and per cooling degree-day August 2018 vs 2017. Reduced load is indicated by the slight increase in balance temperature from 62.8 to 64.7 F. Median outdoor air temperature while Stage II cooling was energized was about 6 degrees warmer in August 2018 than August 2017, and cooling degree-days per day were 29.5 in 2018 vs 27.9 in 2017.

Table 7. Fort Irwin OSJA Baseline Performance Comparison Before versus After Servicing.

System	Energy Efficiency Parameters					Sensible Heat
Stage 1	Cycle COP	System COP	EER	**IEER****	Capacity [Tons]*	Ratio [SHR]
Aug 2017	3.6	2.0	6.9	6.9	2.7	0.62
Aug 2018	2.6	1.9	6.6	6.6	2.7	0.62
Difference	-1.0	-0.1	-0.3	-0.3	0.0	-0.01
Stage 2						
Aug 2017	2.8	2.5	8.7	8.7	5.9	0.74
Aug 2018	2.3	2.3	8.1	8.2	5.8	0.71
Difference	-0.5	-0.2	-0.7	-0.5	0.0	-0.03

Manufacturer nominal rating is 3.6 Tons Stage I and 7.2 Tons Stage II at IEER 9.3

Energy	Max Demand Power [kW]	Usage per Day [kWh/day]	Usage per CDD [kWh/CDD]	Efficiency **IEER**	Balance Temp [°F]	Energy Signature [kWh/°F]
Aug 2017	9.2	171.5	16.3	8.0	62.8	14.4
Aug 2018	9.6	181.9	16.5	7.6	64.7	14.9
Difference	0.4	10.4	0.2	-0.4	1.8	0.54
%Difference	4%	6%	1%	-5.2%		

Figure 18. Fort Irwin OSJA Heat Pump Unit that Was Replaced.

Table 8. Fort Irwin OSJA Baseline Comparison of Operating Parameters Before versus After Servicing.

Carrier — Model 50TJQ008 - - - 501GA — Serial 2299G30449 — Heat pump, 7-/12 ton

Comfort	Median Occupied Space Conditions				Comfort Parameters	
	Temperature [°F]	Humidity [%rh]	Dew Pt [*F]	CO2 [ppm]	PPV Dissatisified	In Comfort Zone
Aug 2017	78.9	31.0	48.2	415	51.3%	10.7%
Aug 2018	66.8	46.6	47.0	403	63.7%	28.9%
Difference	-12.2	15.6	-1.2	-11.7	na	18%

Cooling Coil Stage I	Median Supply Air Conditions Temperature [°F]	Dew Pt [*F]	Blower CFM	External Static Pressure [in-wc]	Cooling [Tons]	Sensible Heat Ratio [SHR]
Aug 2017	66.9	48.9	1197	0.41	2.6	0.62
Aug 2018	68.0	45.8	1310	0.40	2.5	0.62
Difference	1.1	-3.1	113	-0.01	-0.1	-0.01
Stage II						
Aug 2017	64.0	47.4	1212	0.40	5.8	0.74
Aug 2018	68.1	47.9	1467	0.25	5.8	0.71
Difference	4.1	0.5	255	-0.15	-0.1	-0.03

Compressor 1 Stage I	Average Discharge Temperature [°F]	Superheat [degF]	Amps	Pressure Ratio	Mass Flow [lb/hr]	Run Hours [hrs/day]
Aug 2017	168	60.8	10.4	2.51	442	8.5
Aug 2018	189	81.8	10.4	2.49	432	8.7
Difference	21.4	20.9	0.0	0.0	-10	0.3
Stage II						
Aug 2017	203	83.9	11.8	2.65	477	14.0
Aug 2018	215	92.7	12.2	2.65	472	14.9
Difference	12.3	8.9	0.4	0.0	-5	0.9

Compressor 2 Stage II	Average Discharge Temperature [°F]	Superheat [degF]	Amps	Pressure Ratio	Mass Flow [lb/hr]	Run Hours [hrs/day]
Aug 2017	175	50.4	11.8	3.42	594	14.0
Aug 2018	193	64.2	12.2	3.47	607	14.9
Difference	18.1	13.8	0.4	0.1	12	0.9

Condenser	Median Temperatures [°F]				Fan Power	
C1 Stage I	Ambient	Discharge Air	Condensing	Subcool	Watts	Amps
Aug 2017	84.1	85.6	106.5	9.7	42	0.2
Aug 2018	85.0	86.2	107.4	9.6	44	0.2
Difference	0.9	0.6	0.9	-0.1	2	0.0
C1 Stage II						
Aug 2017	95.7	112.3	119.0	3.0	447	2.3
Aug 2018	101.8	118.1	124.6	1.5	437	2.3
Difference	6.2	5.8	5.5	-1.5	-10	-0.1
C2 Stage II						
Aug 2017	95.7	112.3	124.6	9.2	447	2.3
Aug 2018	101.8	118.1	130.8	8.1	437	2.3
Difference	6.2	5.8	6.1	-1.0	-10	-0.1

5.6.2 NexGen Technology Demonstration Data

Each advanced NexGen unit's EERoptimizer® controller logs 54 datapoints and calculates energy usage and efficiency in the standard EER metric units of Btuh per Watt (MBH/kW). Examples of charted logged data are described below. Refrigerant high pressure and low pressure charted in Figures 19 and 20 for July 3-12, 2021 generally follows the rise and fall of outdoor temperature, which ranged from 75.5 to 93.6 F at CCSFS and from 69.7 to 108.4 at Fort Irwin.

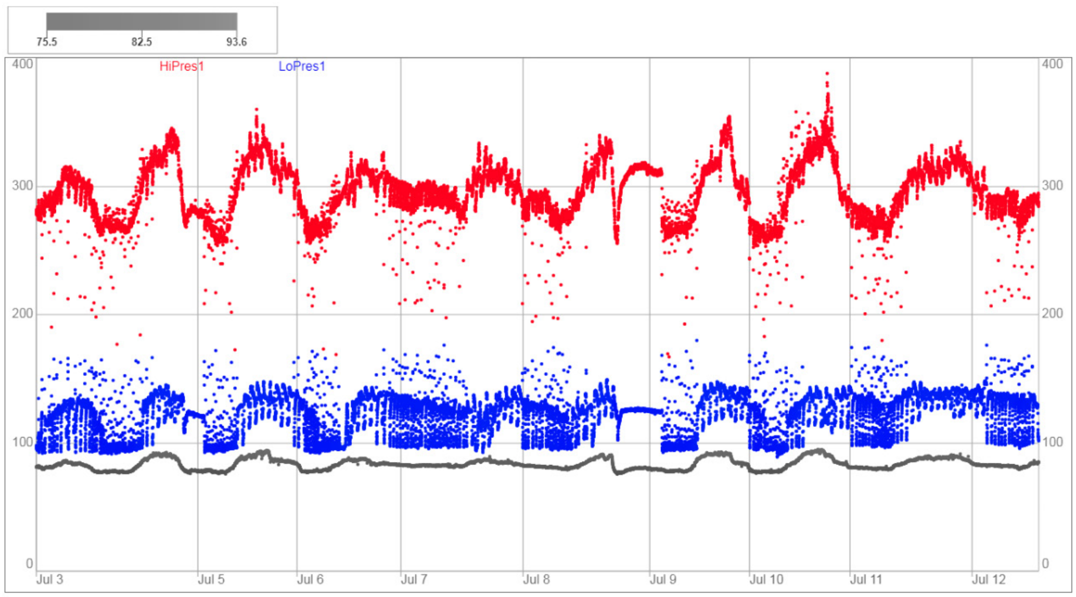

Figure 19. Logged Refrigerant High Pressure (Red) and Low Pressure (Blue) from NOTU NexGen Unit.

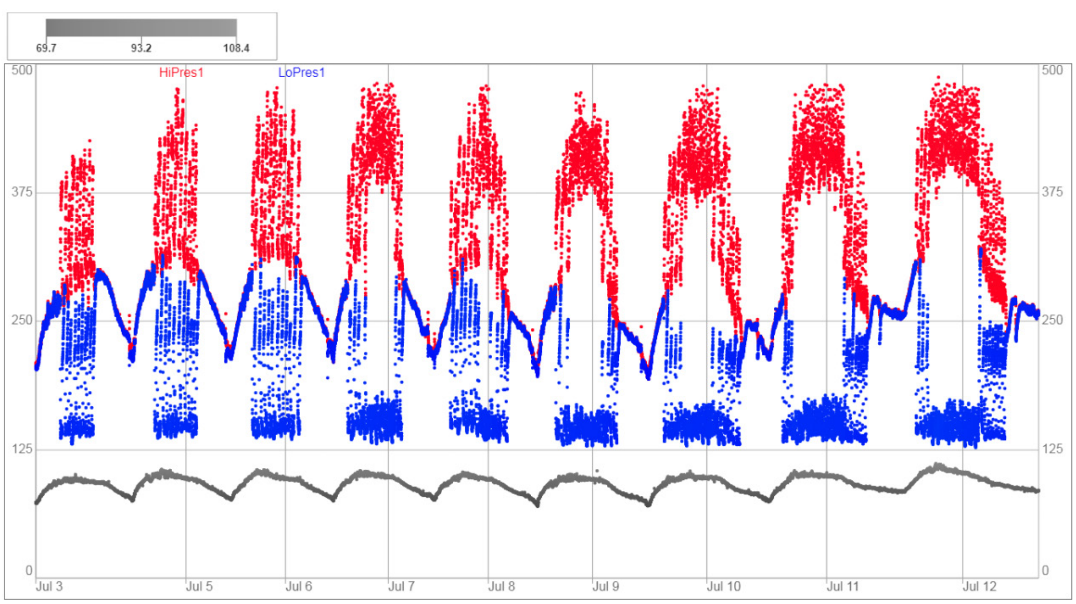

Figure 20. Logged Refrigerant High Pressure (Red) and Low Pressure (Blue) from OSJA NexGen Unit.

Individual compressor power [kW] is charted below in Figures 21 for CCSFS-NOTU and Figure 22 for Fort Irwin OSJA. The NOTU NexGen second-stage compressor operated only during peak summer afternoon heat, while both OSJA compressors operated nearly continuously to satisfy thermostat setpoint in the extreme desert heat. At NOTU, the 10-ton nominal first-stage compressor had a power demand ranging from about 3 to 7 kW depending on load and speed, and the 5-ton nominal second-stage compressor demand was 1.5 to 3 kW. At OSJA, power demand ranged from 1.6 to 3.2 kW for each of the 4.25-ton nominal compressors.

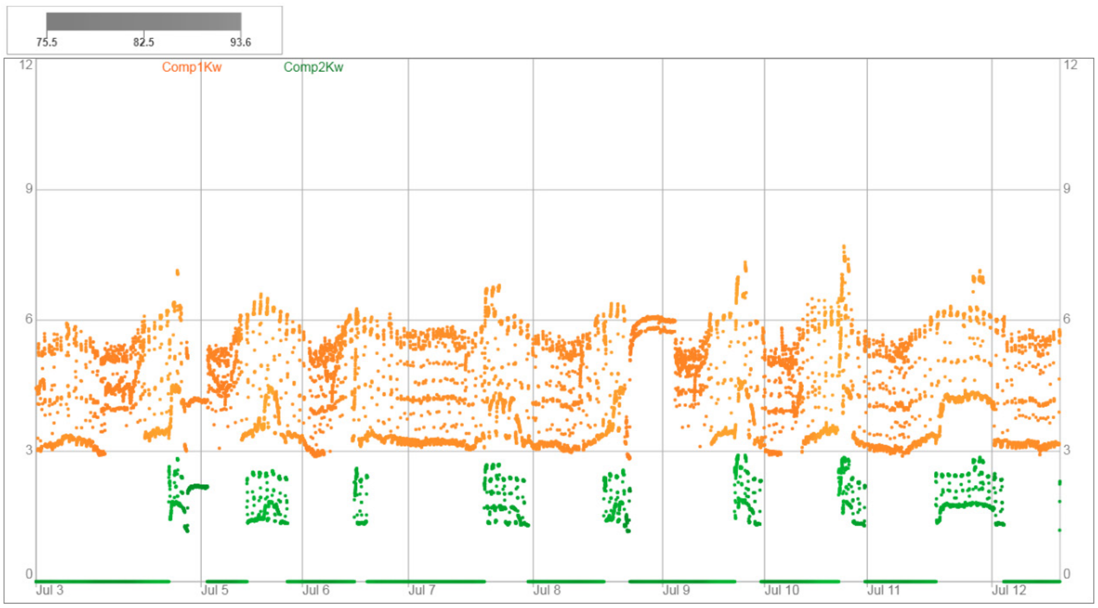

Figure 21. Logged Compressor-1 (Orange) and Compressor-2 (Green) kW from NOTU NexGen Unit.

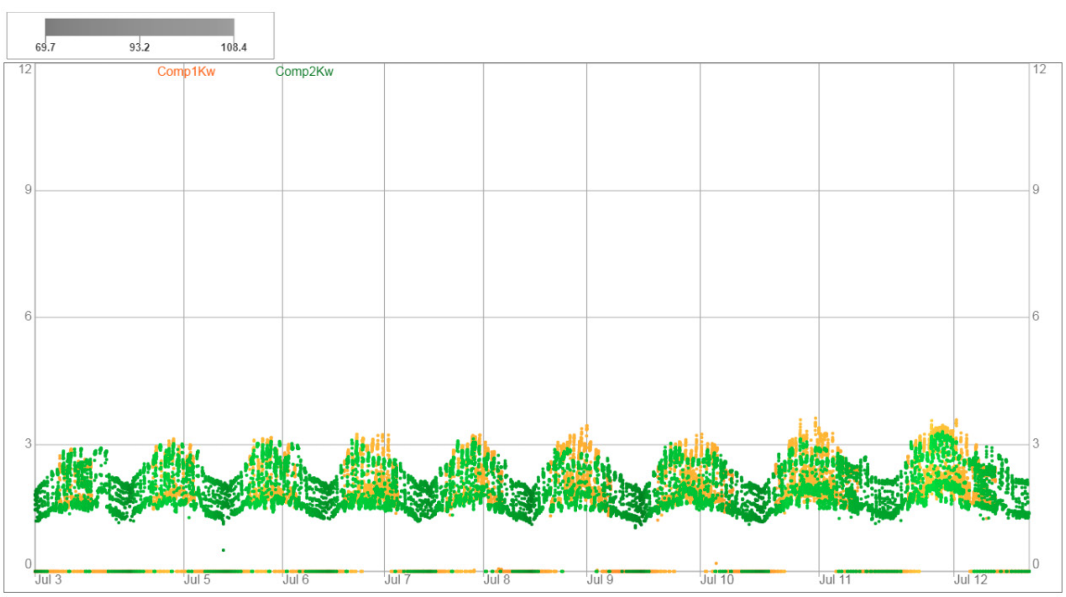

Figure 22. Logged Compressor-1 (Orange) and Compressor-2 (Green) kW from OSJA NexGen Unit.

Total unit power [kW] and real-time EER [Btuh/Watt] are charted in Figures 23 and 24 from the NexGen units installed at CCSFS-NOTU and Fort Irwin OSJA respectively. Each EER data point is the instantaneous ratio of Btuh cooling capacity to kW power demand for a 30-second sampling interval. Both charts show increased efficiency when compressors are energized continuously, rather than short cycles when load is less than the capacity at minimum speed. The lowest EER data points are transients upon compressor energize, when total unit electric usage is large and delivered cooling capacity is low due to thermal / thermodynamic lag. Conversely, EER is highest while cooling is still being delivered after compressor shut off. Power demand varies daily with the rise and fall of outdoor temperature, and as compressor and fan speeds are adjusted to match load and maximize energy efficiency.

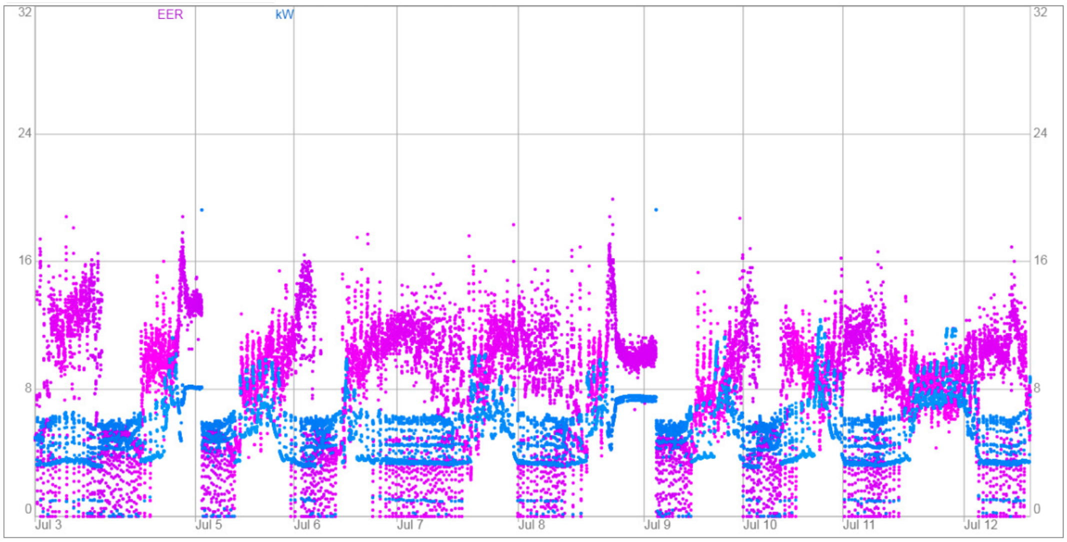

Figure 23. Logged Instantaneous EER (Purple) and Power kW (Blue) from NOTU NexGen Unit.

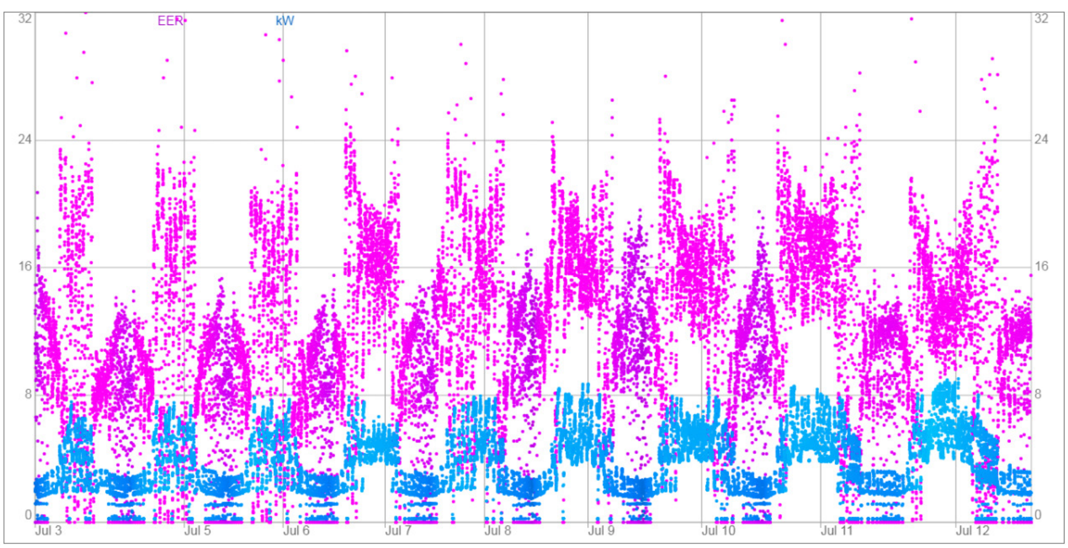

Figure 24. Logged Instantaneous EER (Purple) and Power kW (Blue) from OSJA NexGen Unit.

6.0 PERFORMANCE ASSESSMENT

Table 9. Performance Objectives

Performance Objective	Metric	Success Criteria	Results
Quantitative Performance Objectives			
Increase A/C Unit's Energy Efficiency	Energy used by each A/C unit vs cooling and/or heating provided	At least 35% improvement in field-measured energy use and efficiency as IEER	At CCSFS, HVAC energy use reduced by 48% and IEER improved by 54%. At Fort Irwin, HVAC energy use reduced by 64% and IEER improved by 48%
Improve Facility Indoor Air Quality (IAQ)	Fraction of time that IAQ meets ASHRAE 62.1 criteria	10% increase in fraction of hours IAQ is satisfactory	At CCSFS, average humidity lowered from 71 to 49%$_{rh}$, fraction of hours in comfort zone increased by 94%. At Fort Irwin, no significant change in fraction of hours in comfort zone
Demonstrate Cost Effectiveness	Cost of installed technology relative to energy savings	Overall payback period of 7 years or less	Life-cycle savings $34k on projected incremental first cost $14k, giving a payback period of 6.2 years and an SIR of 2.4
Demonstrate Reliability	Percentage of time the system performs as designed	50% reduction in downtime relative to baseline	At CCSFS, HVAC downtime was reduced by 87%, and at Fort Irwin, downtime was reduced by 91%
Qualitative Performance Objectives			
Manageability using existing facility HVAC staff & resources	Field assessment by HVAC technicians at demonstration sites	Concurrence of HVAC staff supervisors at sites of maintainability	Overall concurrence of maintainability with existing technicians and resources, as long as training is provided
Reliability relative to reliability of base unit	Field assessment by HVAC SME at demonstration sites	Concurrence that advanced unit performs as well or better than baseline unit	General agreement NexGen units were at least as or more reliable than other new package unit equipment
User satisfaction	Likert Scale	No decrease in satisfaction over baseline	Small qualitative increase in satisfaction at CCSFS, no change at Fort Irwin, no statistically significant change

6.1 INCREASE A/C UNITS ENERGY EFFICIENCY

6.1.1 Site 1 Baseline: 15-ton Cooling Unit at CCSFS NOTU

Baseline monthly energy use, cooling load, and comfort parameters were calculated from 21 one-month data sets each consisting of approximately 44,000 data points. The full baseline data analysis period spanned from July 1, 2017 through March 31, 2019.

Monthly maximum power demand of the unit was 14.2 kW, with the peak of 20.1 kW occurring in July 2017 (before the unit was serviced), monthly kW and kWh are listed in Table 10. Energy consumption was 54,457 kWh/year and of that total, cooling energy was 47,994 kWh/year. Monthly energy use generally followed the seasonal variation in climate, as shown in Figure 25. Highest monthly usage was 7,448 kWh in July and minimum was 753 kWh in December. Operation of the blower for ventilation accounted for 12% of annual energy use. Stage I operation (one compressor) accounted for 71% and Stage II (both compressors) accounted for 7% of annual cooling energy. Winter electric resistance heating made up 12% of total energy consumption.

Weather data from NOAA records shows 3538 annual cooling degree days (CDD_{65}) at the nearest weather station, which is 182.5 CDD_{65} per day. Energy use correlates well with the standard 65F base CDD data, though regression of energy use with average outdoor temperature shows the actual building balance point to be 60.2F as can be seen in Figure 26. Energy use correlation with CDD_{65} is $r^2 = 0.93$ with a sensitivity of 11.7 kWh/CDD_{65} minimizing monthly prediction error, as charted in Figure 27. Monthly energy use sensitivity ranges from 5.2 to 20.4 kWh/CDD_{65} and averaged 13.6 kWh/CDD_{65}. Site measured data shows a slightly warmer site microclimate with 193.4 CDD_{65} per day, which is warmer by 5.9% annual and 9.4% monthly average, as shown in Figure 28.

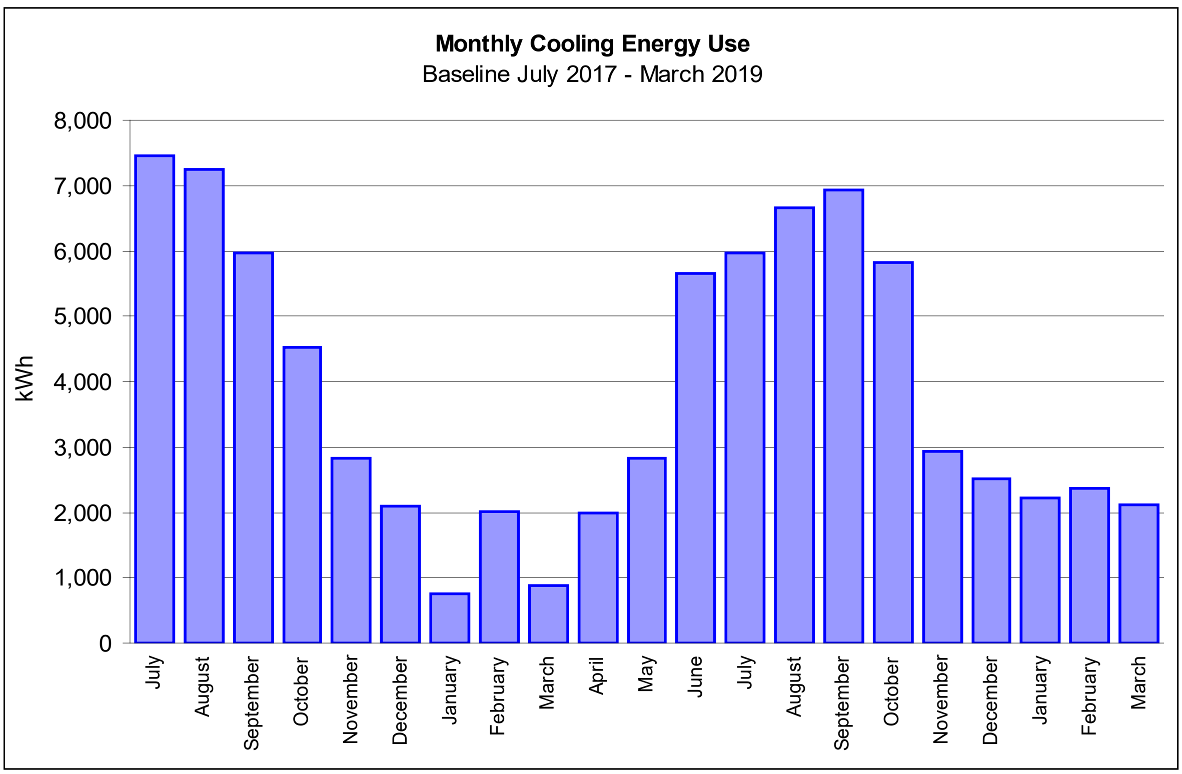

Figure 25. CCSFS Baseline Monthly Cooling & Heating Energy Use kWh.

Table 10. CCSFS Baseline Monthly Energy Use Analysis Summary.

CCAFS-NOTU Baseline Unit Monthly Data Analysis Summary

Trane Model TCH181 Horizontal, 15 Ton High Efficiency, no factory options

Serial P46104116D

Electric Energy		Power kW		Energy Use kWh				Normalized Energy		
		Stage I	Stage II	Blower	Stage I	Stage II	Total	Cooling kWh/Day	kWh/CDD	FLEOH
2017	July	10.7	20.1	3%	95%	3%	7,448	225.4	13.0	371.1
	August	10.6	16.9	1%	92%	8%	7,248	241.7	13.4	428.3
	September	10.8	17.9	3%	87%	9%	5,962	200.7	11.9	333.8
	October	12.0	17.9	0%	96%	4%	4,532	113.4	11.9	252.9
	November	11.6	14.6	12%	86%	2%	2,821	83.0	10.8	193.5
	December	11.4	14.4	51%	48%	1%	2,097	33.2	9.9	145.8
2018	January	10.5	0	18%	10%	*	753	8.6	5.7	47.9
	February	11.1	15.0	7%	91%	2%	2,012	66.8	12.2	134.1
	March	11.5	15.0	2%	98%	1%	871	18.4	5.2	58.2
	April	11.2	0	12%	88%	0%	1,988	58.4	8.2	118.0
	May	11.4	15.1	5%	89%	6%	2,837	87.2	7.9	187.9
	June	11.9	16.1	1%	86%	13%	5,650	186.8	12.5	351.6
	July	12.8	17.3	3%	84%	13%	5,963	196.2	11.8	345.1
	August	12.7	15.6	4%	75%	22%	6,659	216.3	12.6	426.3
	September	13.0	15.7	3%	71%	26%	6,932	223.4	12.9	441.0
	October	13.0	15.3	8%	69%	23%	5,819	173.2	12.7	380.6
	November	13.0	14.7	20%	55%	2%	2,934	72.1	10.0	199.4
	December	11.1	14.4	15%	35%	1%	2,515	57.3	16.1	175.3
2019	January	10.8	14.8	16%	30%	0%	2,218	46.9	20.4	149.8
	February	12.0	14.2	36%	62%	1%	2,357	53.8	12.4	166.5
	March	11.4	13.8	39%	42%	1%	2,122	35.9	8.7	154.1
	Total / Annual	11.6	14.2	12%	71%	7%	47,994	131.5	13.6	3375.6

* January 2018 Resistance Heat 1953.2 kWh accouted for 72.3% of energy use.
November 2018 Resistance Heat 868.3 kWh accouted for 22.8% of energy use.
December 2018 Resistance Heat 2436.3 kWh accouted for 49.2% of energy use.
January 2019 Resistance Heat 2637 kWh accouted for 54.3% of energy use.
February 2019 Resistance Heat 32.9 kWh accouted for 1.4% of energy use.
March 2019 Resistance Heat 488.3 kWh accouted for 18.7% of energy use.
Annual Resistance Heat 6462.8 kWh accouted for 11.9% of energy use.

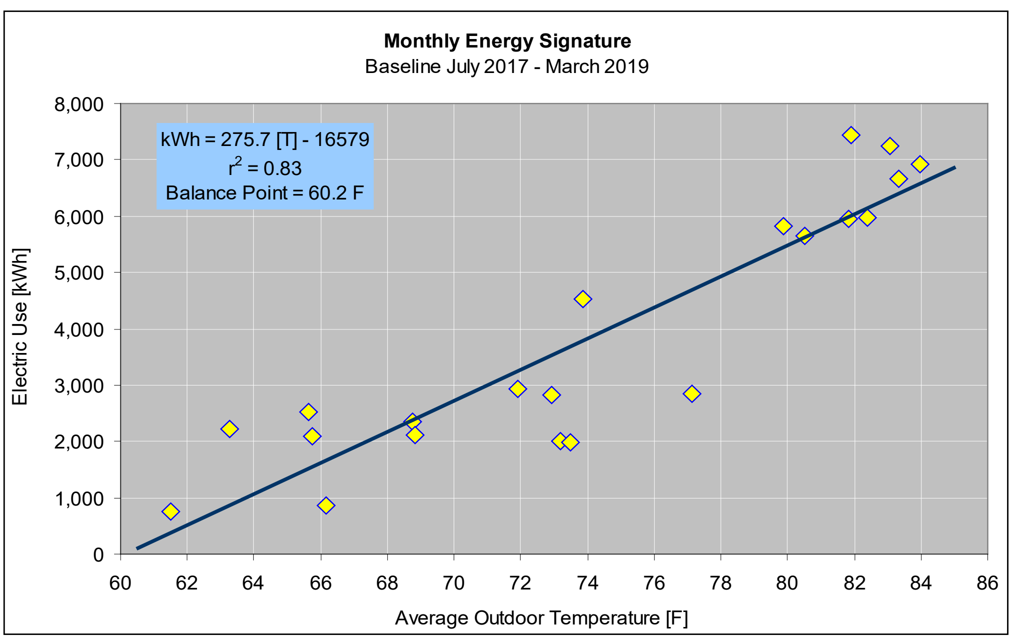

Figure 26. CCSFS Baseline Monthly Energy Signature kWh vs Outdoor Temperature.

Table 11. CCSFS Baseline Monthly Space & Outdoor Temperature, Humidity, and Cooling Degree-days.

Psychrometrics		Space Temperature [°F]			Space Humidity [%rh]			Outdoor Temperature [°F]			Cooling Deg-Day	
		High	Median	Low	High	Median	Low	High	Average	Low	Monthly	per Day
2017	July	79	72.4	70	86	72.0	60	94	81.9	72	559	17.7
	August	83	73.1	71	88	72.6	59	95	83.1	74	538	17.6
	September	94	73.9	70	91	76.3	53	92	81.8	73	481	16.0
	October	95	75.4	61	96	61.2	24	90	73.9	52	380	12.3
	November	75	72.9	68	91	74.9	49	86	72.9	58	202	6.7
	December	79	71.2	58	94	72.7	31	85	65.7	40	101	3.4
2018	January	81	63.0	50	98	65.4	28	84	61.5	30	46	1.5
	February	-	-	-	101	72.6	35	88	73.2	50	165	5.5
	March	-	-	-	101	60.0	21	88	66.2	55	106	3.5
	April	-	-	-	94	68.0	27	90	73.5	51	214	7.1
	May	82	73.4	70	94	66.4	50	90	77.1	68	342	11.0
	June	78	73.8	72	92	68.8	58	93	80.5	68	448	14.9
	July	80	73.7	71	100	69.5	59	96	82.4	71	497	16.6
	August	81	74.0	72	100	75.6	61	95	83.3	73	515	17.2
	September	77	74.1	72	89	75.1	60	96	84.0	73	522	17.4
	October	79	73.3	69	100	74.1	54	93	79.9	55	421	13.6
	November	79	73.0	61	101	75.5	28	90	71.9	42	223	7.2
	December	83	73.1	63	100	67.7	36	87	65.6	43	110	3.6
2019	January	80	71.5	62	100	58.7	33	85	63.3	42	71	2.3
	February	85	72.1	64	94	69.8	42	89	68.7	52	121	4.3
	March	-	-	-	-	-	-	86	68.8	46	129	4.1
Total / Annual		80	73.1	69	95	70.9	46	96	74.3	30	3538	9.7

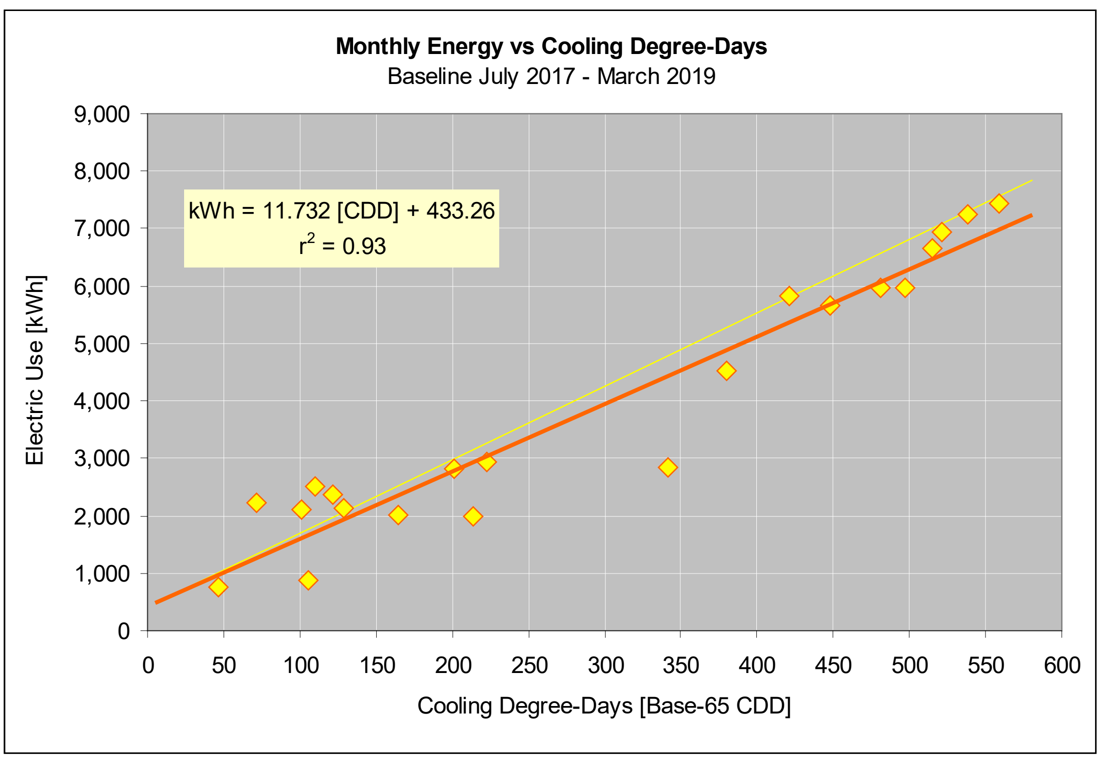

Figure 27. CCSFS Baseline Monthly Energy Signature kWh versus CDD.

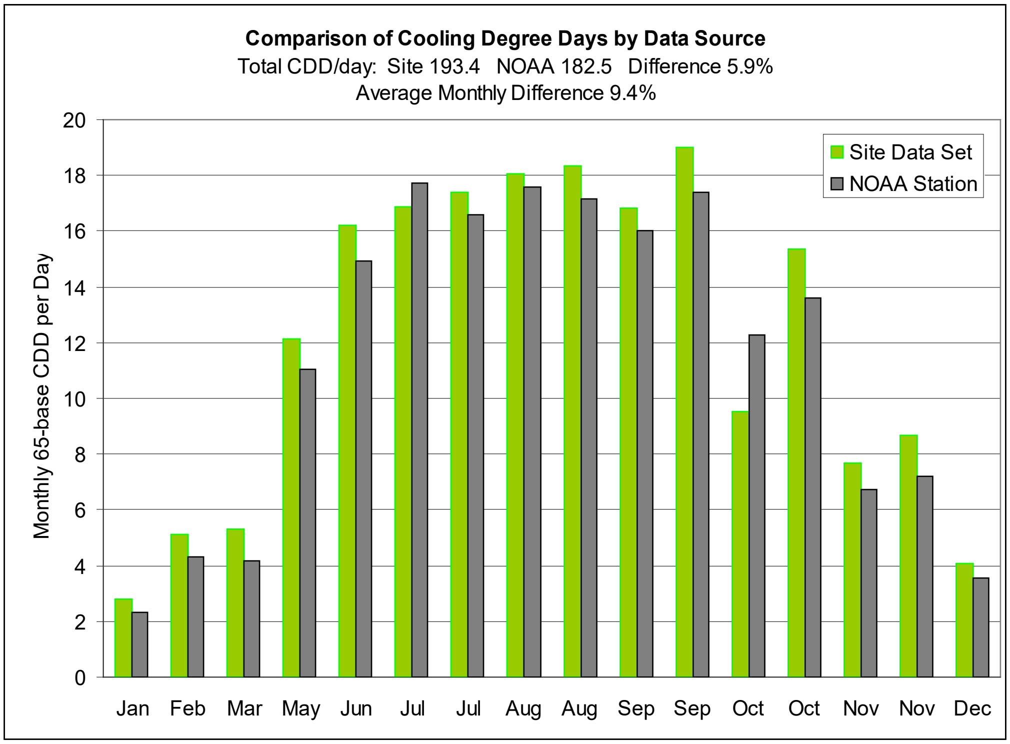

Figure 28. CCSFS Baseline Period Comparison of Degree Days by Data Source.

6.1.2 Site 2 Baseline: 7.5-ton Heat-Pump Unit at Fort Irwin NTC

Monthly energy use, cooling load, and comfort parameters were calculated from 14 one-month data sets each consisting of approximately 44,000 data points using data loggers shown in Figure 30. The baseline data analysis period spanned from June 1, 2017 through July 31, 2018.

Monthly maximum power demand was 7.7 kW, with the peak of 8.8 kW occurring in July 2017 (before the unit was serviced), monthly values are listed in Table 12. Energy consumption was 35,870 kWh/year and of that total, cooling energy was 22,899 kWh/year (64%) and heating energy use was 12,971 kWh (36%). Monthly energy use generally followed the seasonal variation in climate, with higher usage during summer cooling and winter heating, and lower usage in spring and fall, as charted in Figure 29. Highest monthly usage was 5133 kWh in July and minimum was 1788 kWh in April. Operation of the blower for ventilation accounts for 12% of annual energy use. Operation in Stage I (one compressor) accounts for 31% and Stage II (both compressors) accounts for 57% of annual cooling and heating energy.

Outdoor sensor data from the demonstration site was used to calculate 3619 annual cooling degree-days (CDD_{65}) and 2043 annual heating degree-days (HDD_{65}), which calculates to 216.9 total degree-days (TDD_{65}) per day. Energy use correlated well with the standard 65 F base degree-day data, though regression of energy use with average outdoor temperature shows the actual building balance point was 54.5 F, see Figure 31. Energy use correlation with TDD_{65} is r^2=0.85 with a sensitivity of 4.8 kWh/TDD_{65} minimizing monthly prediction error as charted in Figure 32, and a sensitivity of 6.3 kWh/TDD_{65} minimizing annual prediction error. Monthly energy use sensitivity ranges from 3.6 to 10.7 kWh/TDD_{65} and averaged 5.7 kWh/TDD_{65}.

NOAA weather data from the nearest site indicates a slightly more severe site microclimate with 235.9 TDD_{65} per day, which is more severe by 8.1% annual and 9.3% monthly average (3% warmer summer and 21% cooler winter) as shown in Figure 33.

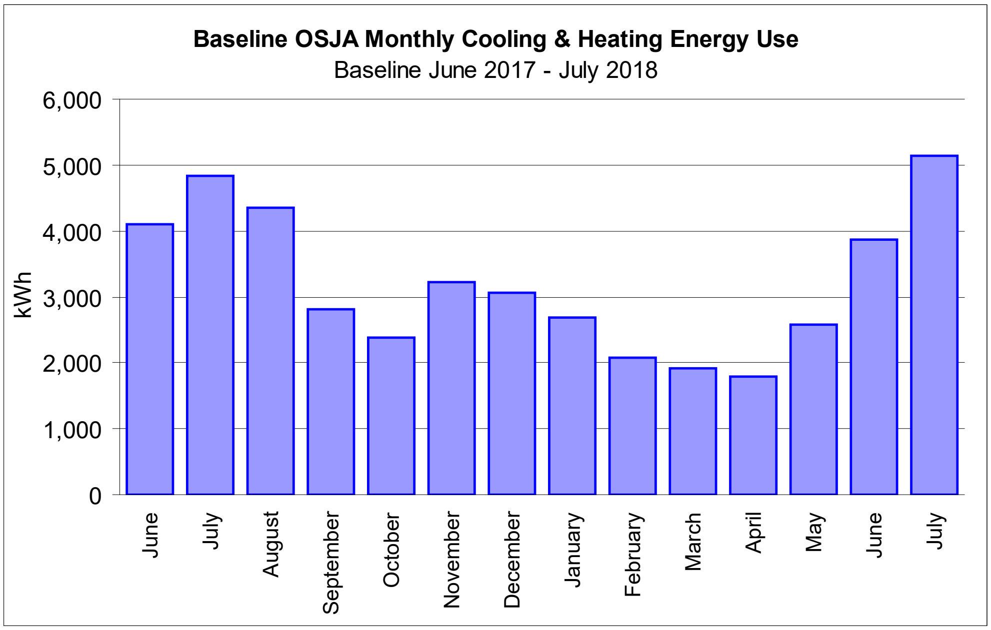

Figure 29. Fort Irwin OSJA Baseline Monthly Cooling & Heating Energy Use kWh.

Figure 30. HOBO Dataloggers Installed in Baseline Unit at Fort Irwin OSJA.

Table 12. Fort Irwin OSJA Baseline Unit Monthly Energy Use Analysis Summary.

AFI Baseline Unit Monthly Data Analysis Summary

Carrier Model 50TJQ008 - - - 501GA Heat pump, 7-/12 ton

Serial 2299G30449

Electric Energy		Power kW		Energy Use kWh				Normalized Energy		
		Stage I	Stage II	Blower	Stage I	Stage II	Total	Total kWh/Day	kWh/CDD	FLEOH
2017	June	4.3	8.7	4%	27%	69%	4,101	131.1	5.9	473.4
	July	4.3	8.8	1%	31%	68%	4,831	155.0	5.6	549.4
	August	4.2	8.5	2%	35%	64%	4,348	138.1	5.8	510.3
	September	4.1	8.3	9%	55%	36%	2,803	85.1	5.9	337.9
	October	4.0	7.3	11%	64%	23%	2,386	67.1	7.1	327.0
2018	April	4.1	7.6	30%	40%	28%	1,788	40.9	4.3	234.0
	May	4.1	7.9	15%	42%	42%	2,573	70.2	6.0	327.1
	June	4.2	8.3	4%	28%	67%	3,867	123.7	6.0	466.7
	July	4.3	8.7	0%	23%	77%	5,133	164.9	5.8	588.6
2017	November	3.7	7.1	5%	39%	57%	3,232	102.7	10.7	453.2
	December	3.8	6.8	12%	15%	73%	3,068	87.0	5.2	448.6
2018	January	3.8	6.9	18%	13%	70%	2,686	71.3	4.9	387.4
	February	4.0	6.7	25%	7%	68%	2,076	55.6	3.6	309.4
	March	4.1	6.8	33%	13%	54%	1,909	41.1	3.7	281.8
	Total / Annual	4.1	7.7	12%	31%	57%	35,870	98.3	6.3	4629
	Cooling	4.2	8.2	9%	38%	53%	22,899	62.7	6.3	2782
	Heating	3.9	6.9	19%	17%	64%	12,971	35.5	6.3	1886

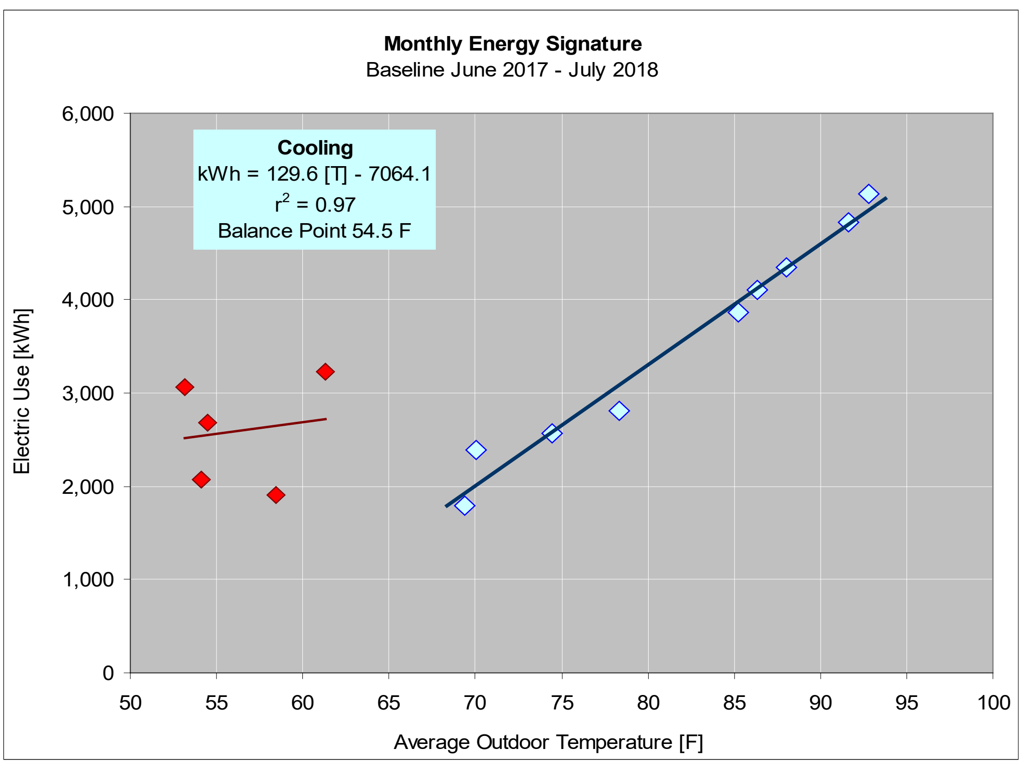

Figure 31. Fort Irwin OSJA Baseline Monthly Energy Signature kWh versus Outdoor Temperature.

Table 13. Fort Irwin Baseline Monthly Space & Outdoor Temperature, Humidity, and Cooling Degree-days.

Psychrometrics		Space Temperature [°F]			Space Humidity [%rh]			Outdoor Temperature [°F]			Degree-Day	
		High	Median	Low	High	Median	Low	High	Average	Low	Monthly	per Day
2017	June	79	66.0	59	63	32.4	14	116	86.4	52	666	22.2
	July	83	66.9	64	87	42.0	11	112	91.6	72	859	27.7
	August	82	66.7	63	95	48.7	18	110	88.0	68	737	23.8
	September	78	66.3	64	92	63.5	24	106	78.3	51	436	14.5
	October	84	66.9	62	53	22.1	10	94	70.0	49	293	9.5
	November	83	66.7	61	56	27.9	8	82	61.3	40	289	9.6
	December	76	66.4	53	32	11.2	4	75	53.2	35	523	16.9
2018	January	74	66.4	54	57	25.9	9	75	54.5	36	454	14.7
	February	82	67.3	49	42	18.1	6	80	54.1	29	431	15.4
	March	77	66.4	51	65	25.5	7	88	58.5	38	346	11.2
	April	85	65.5	52	69	26.1	11	96	69.4	42	288	9.6
	May	74	66.0	58	55	33.8	14	104	74.5	51	360	11.6
	June	85	66.1	62	52	31.4	12	112	85.2	58	619	20.7
	July	87	66.6	64	79	52.1	11	117	92.8	72	886	28.6
Total / Annual		82	66.4	60	60	29.6	11	117	72.7	29	5663	15.5
Cooling											3619	
Heating											2043	

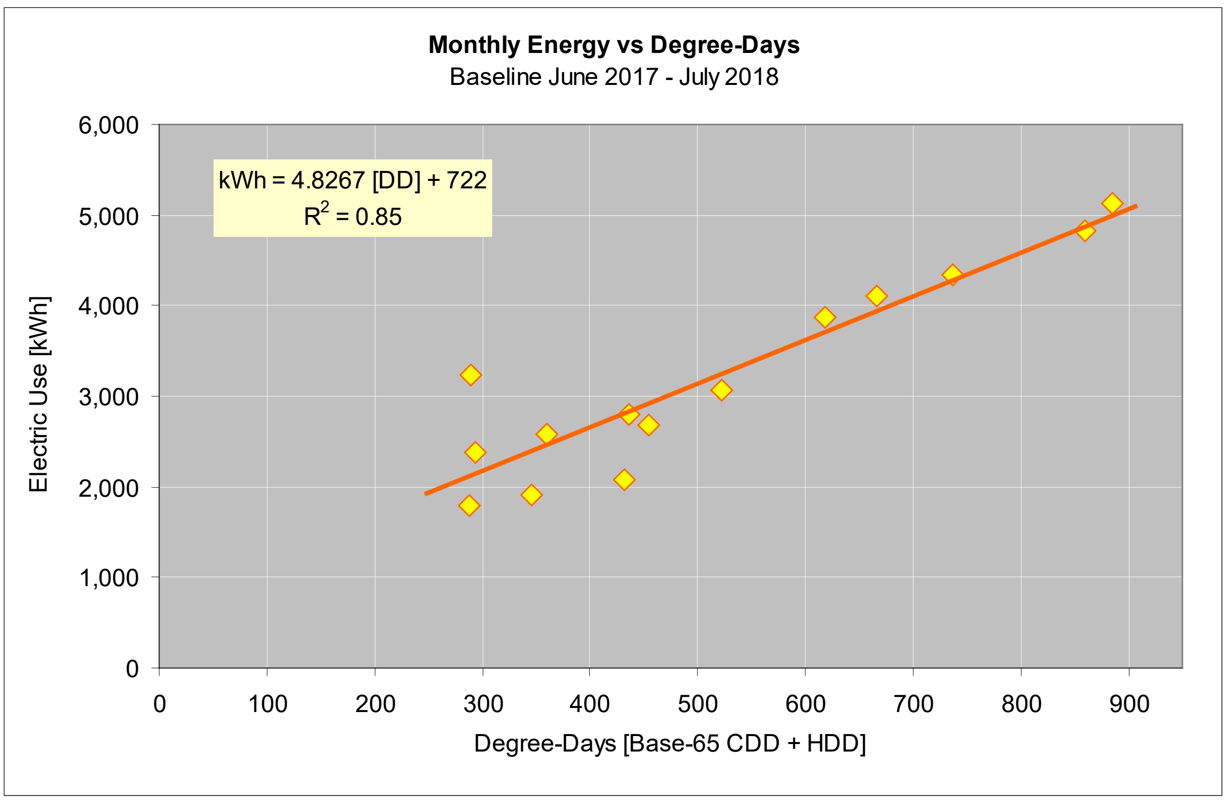

Figure 32. Fort Irwin OSJA Baseline Monthly Energy Signature kWh versus TDD.

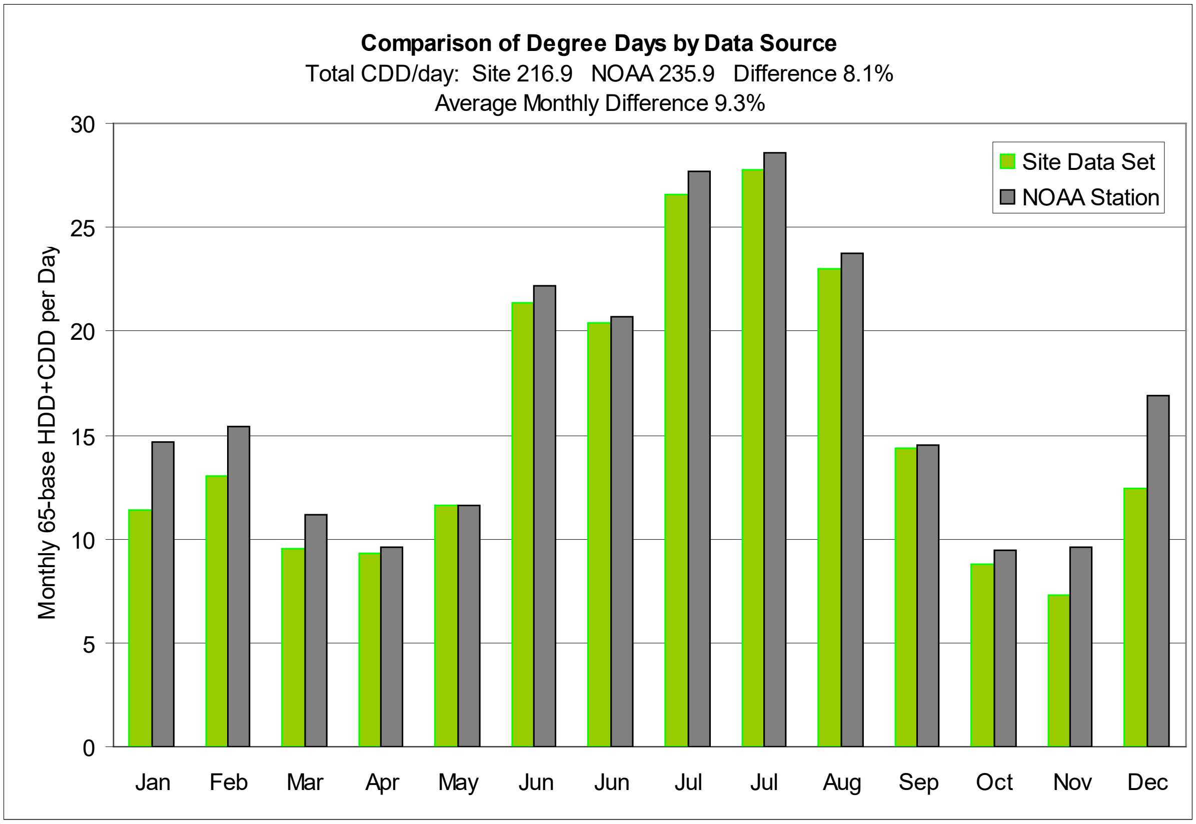

Figure 33.Fort Irwin OSJA Baseline Period Comparison of Degree Days by Data Source.

6.1.3 Demonstration Results

Changing from the existing to the advanced air-conditioners reduced HVAC energy use by more than 45%, with no sacrifice of comfort or reliability, as compared with the standard technology they replaced. Energy efficiency metrics for the HVAC equipment were calculated for the baseline and advanced phases of the package air-conditioner demonstration.

Analysis followed *ANSI/AHRI Standard 340/360-2007 with Addenda 1 and 2*, which is the standard for performance testing of unitary DX equipment used by all manufacturers. EER is calculated at 95F outdoor temperature, and IEER is a weighted average of four adjusted EERs measured at 95F, 81.5F, 68F, and 65F so that IEER value is a better predictor of actual installed energy use over a typical cooling season than EER alone. Similarly, HSPF is calculated at 47F and 17F outdoor temperature for heating energy efficiency, and heating IEER is weighted for 62F, 47F, 35F, and 17F outdoor temperature.

Metrics were compared to determine how the change from the standard air conditioner to the advanced NexGen air conditioner affected energy efficiency, overall energy usage, comfort, indoor air quality, and reliability. Time series charts for values of interest were plotted for visual comparison, as shown in Section 5.6.2, such as temperatures, power usage, cooling or heating delivered, and efficiency. The energy use per cooling or heating degree-day (kWh/DD) provides a straightforward adaptation to other climates, since CDD and HDD data is readily available for nearly any location.

Climate sensitivity comparisons were performed to gauge suitability across a range of cooling and heating season severity. Economics were calculated using the actual electric rates paid by each demonstration site and the projected fully commercialized costs, and results are presented in a format that can be easily adapted to electric rates for other locations.

Findings caused by the demonstration process itself, which do not represent true steady-state performance, were addressed by examining the raw data. Outlier data points, such as transients and spikes occurring immediately after a compressor is energized, were filtered using Chauvenet's criterion based 3.48 standard deviations from the mean. A two-sample t-Test[21] analysis was employed for the baseline versus advanced observations (paired two sample for means). Data verifications were performed every few days during test periods by charting the reduced data to visually locate significant outlying points that may indicate erroneous data collection or operational problems, such a loss of sensor calibration or a DX unit component failure.

At site 1, NOTU Support Building at Cape Canaveral Space Force Station in Florida, the NexGen package unit is 15-ton cooling with electric heat. At site 2, OSJA Building at Fort Irwin National Training Center in the California high desert, the NexGen unit is 8½-ton heat pump providing cooling in summer and heating in winter. The replaced units were nearing the end of their service life and defined two baseline performance levels: factory ratings and field-measured energy efficiency. Baseline unit energy use was measured using Veris kW meters ±1%, and advanced unit energy use was measured by Invertek motor drives ±2%. The advanced units' IoT control systems continuously log 54 sensor and operating parameters every 30 seconds.

Advanced unit performance data was compared with baseline unit performance measured for one year pre- and post-installation. Comparison of energy usage by the advanced unit against the baseline unit is presented by month in the charts below. Measured monthly kWh energy consumed by the NexGen unit is compared against the baseline in Figure 34 for CCSFS-NOTU and Figure 35 for Fort Irwin OSJA. At CCSFS-NOTU, cooling energy use was reduced by 48%. At Fort Irwin OSJA, cooling + heating energy use was reduced by 64%.

Oddly, the CCSFS-NOTU NexGen unit used more energy in February, but less energy in all other months. The baseline unit used less energy in February because it did not provide active dehumidification, which accounts for most of the compressor run hours when the weather is cool but humid. The CCSFS-NOTU NexGen unit provided substantial active dehumidification, and the baseline unit provided very little dehumidification. Median space humidity was reduced from around $70\%_{rh}$ with the baseline unit to around $50\%_{rh}$ with the NexGen unit, and active dehumidify mode increased compressor and electric heat demand in February accordingly. However, even while providing active dehumidification, there was an overall 48% annual energy use reduction.

The Fort Irwin OSJA NexGen unit used less energy than baseline every month of the demonstration period. It made maximum use of fresh and dry desert air for cooling when outdoor temperature was cooler than space temperature. The Fort Irwin NexGen provided more advantageous economizer and ventilation control compared with the baseline unit, accounting for nearly one-third of measured energy savings by optimally utilizing dry outdoor air for cooling and ventilation.

[21] A t-test is a statistical hypothesis test in which the test statistic is used to determine if two sets of data are significantly different from each other by comparing results before and after installation of the technology.

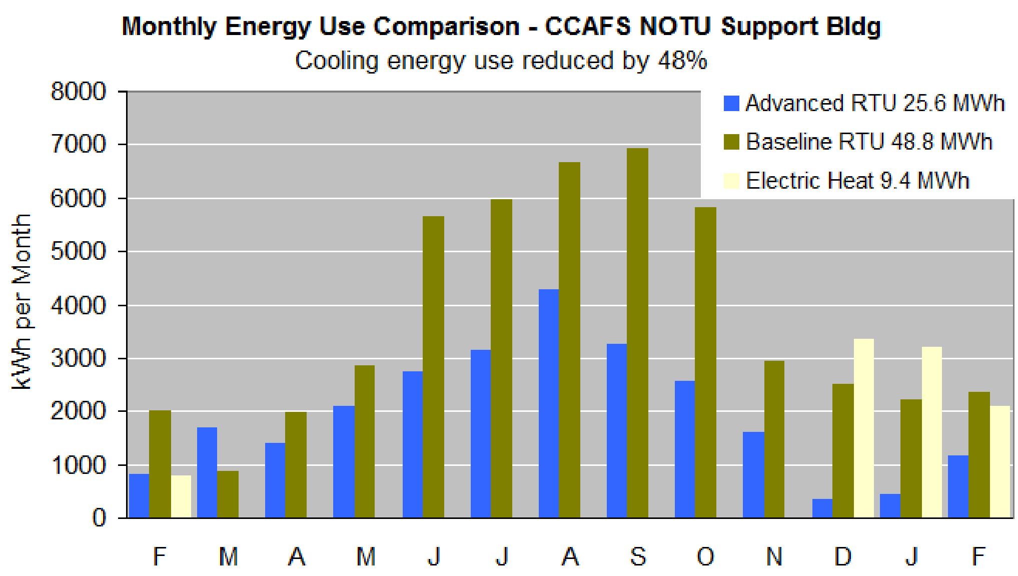

Figure 34. CCSFS-NOTU Comparison of Monthly kWh Energy Use NexGen versus Baseline.

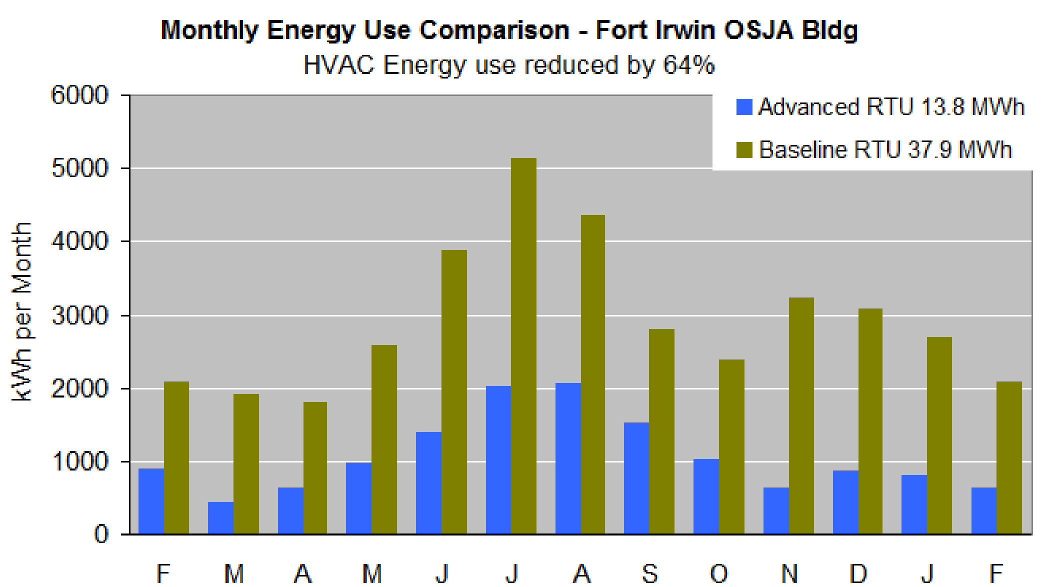

Figure 35. Fort Irwin OSJA Comparison of Monthly kWh Energy Use NexGen versus Baseline.

Comparison of weather-normalized energy usage by the advanced unit against the baseline unit is presented by month in the charts below. Measured monthly kWh energy consumed per degree-day by the NexGen unit is compared with the baseline in Figure 36 for CCSFS-NOTU and Figure 37 for Fort Irwin OSJA. At CCSFS-NOTU, weather-normalized cooling energy use was reduced by 51%.

At Fort Irwin OSJA, weather-normalized cooling + heating energy use was reduced by 61%. Baseline data from both sites show atypically high weather-normalized energy use in months when weather was mild because standard package units consume energy for ventilation regardless of the need for cooling or heating. The NexGen unit controller minimized this consumption by use of an advanced demand-controlled ventilation algorithm.

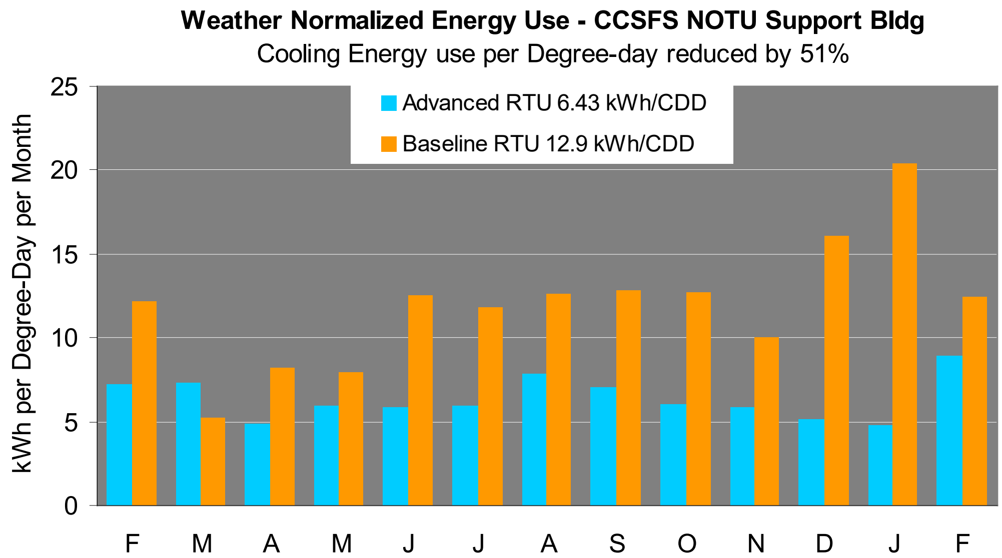

Figure 36. CCSFS-NOTU Weather Normalized kWh Energy Use NexGen versus Baseline.

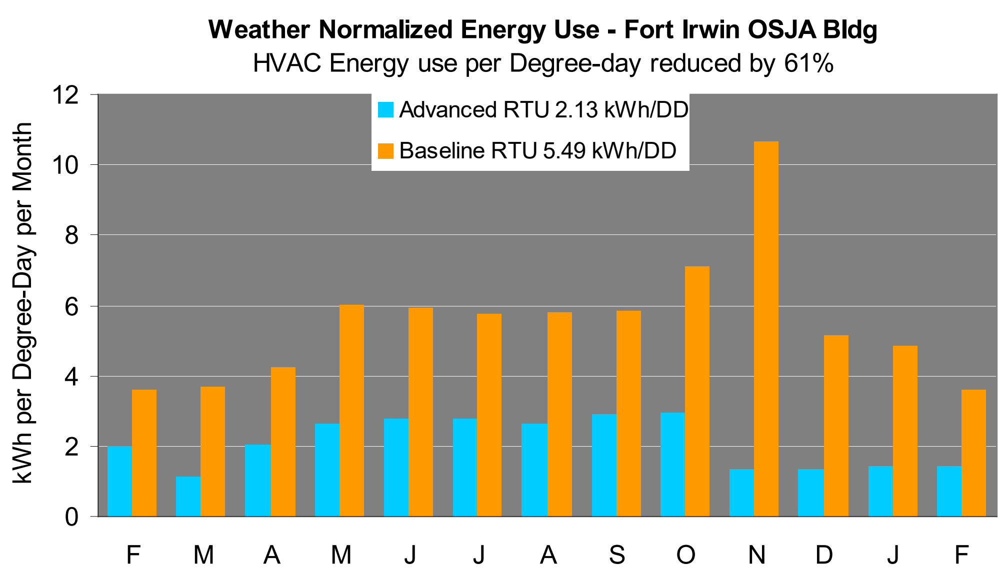

Figure 37. Fort Irwin OSJA Weather Normalized kWh Energy Use NexGen versus Baseline.

The quantity of heating and cooling delivered to the space is presented in Figures 38 and 39 by month in kTHs (kiloTon-Hours, one ton-hour is equal to 12,000 Btuh for one hour.) Peak cooling month was August at both sites, though peak power baseline month was July at OSJA and September at NOTU. Both units used a small amount of heating needed to maintain the 74F / 50%rh space condition requirement at CCSFS and the 70.5 F space temperature setpoint at Fort Irwin. 41% of the heating by the advanced unit at CCSFS was for dehumidification when the weather was cool and humid. The CCSFS baseline did not provide heat because the occupants set the thermostat for cooling only, and because the baseline unit had no active dehumidification capability.

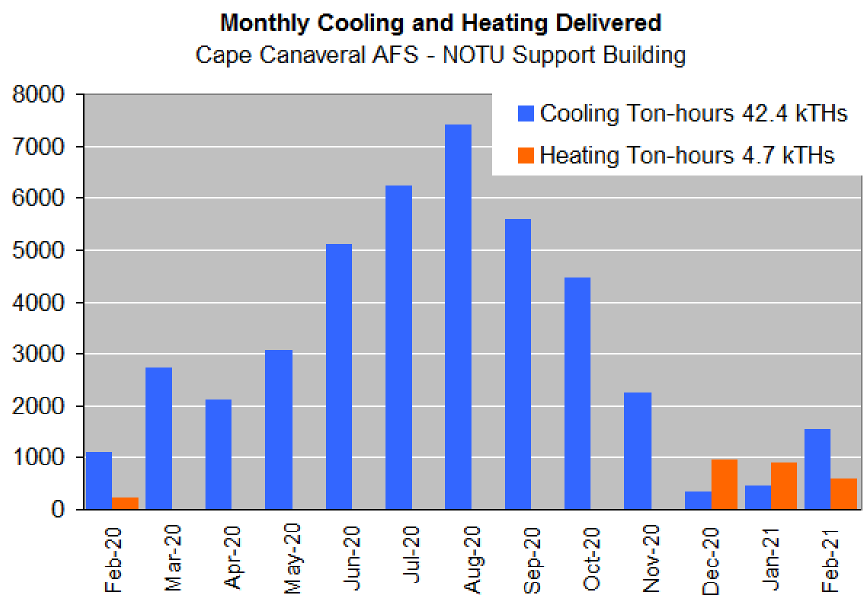

Figure 38. CCSFS-NOTU Monthly Total Cooling & Heating Delivered by NexGen Unit.

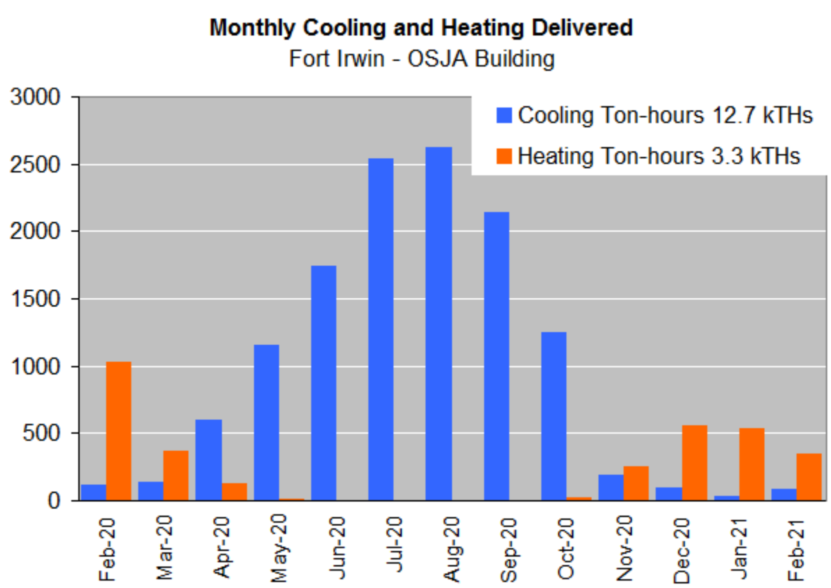

Figure 39.Fort Irwin OSJA Monthly Total Cooling & Heating Delivered by NexGen Unit.

Breakdown of energy use by package unit functional component is compared in the pie graphs below; Figure 40 for the baseline and advanced units at CCSFS-NOTU, and Figure 41 for Fort Irwin OSJA. The overall size of the pies is proportional to total annual energy consumption. Stage I energy consumption kWh is the subtotal of the first stage compressor and outdoor condenser fan. Stage II adds the second compressor. Supply air and ventilation to the space is provided by the blower. At both sites, baseline blower energy use was a larger portion of total energy use than advanced blower energy use due to the no-slip synchronous belt drive and optimized variable speed control. At CCFSF, use of Stage II increased while Stage I proportionally decreased as the optimizing controller seeks the most efficient combination of stages and compressor speeds. CCSFS Stage I energy use decreased by 56% and at Fort Irwin, Stage II energy use decreased by 75.3%.

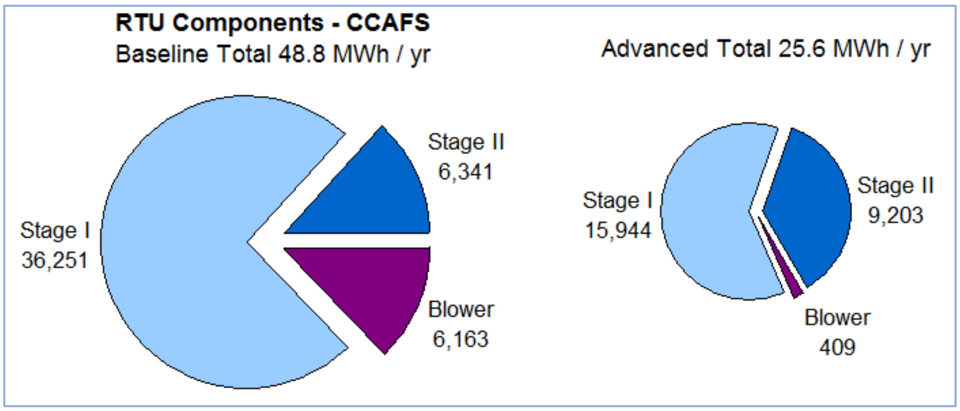

Figure 40. CSFS-NOTU Comparison of Annual kWh Breakdown by Function - Baseline versus NexGen.

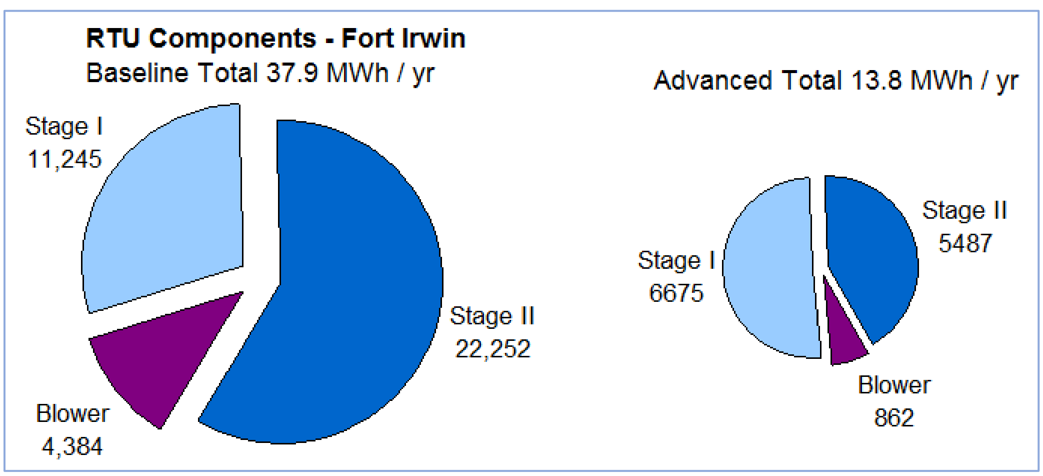

Figure 41. Fort Irwin OSJA Comparison of Annual kWh Breakdown by Function - Baseline versus NexGen.

Operational energy efficiency of the advanced NexGen package units was measured and compared with standard factory ratings and the field-measured energy efficiency of baseline units. Standard metrics are EER (Energy Efficiency Ratio) and IEER (Integrated Energy Efficiency Ratio).

EER is simply the rate of cooling or heating provided in units of MBH (thousands of Btuh) per kW of power used, also the quantity of heating or cooling provided in units of Btu per Watt-hour power consumed. Advanced unit efficiency calculations were performed merging two sets of formulas based on air or refrigerant sensors, and IEER calculations followed ANSI/AHRI Standard 340/360-2007 equations for rating of unitary equipment. The EERoptimizer® controller continuously calculates EER using both air and refrigerant sensors. Advanced unit monthly and weighted average annual energy efficiency are presented in Figure 42 for CCSFS-NOTU and Figure 43 for Fort Irwin OSJA.

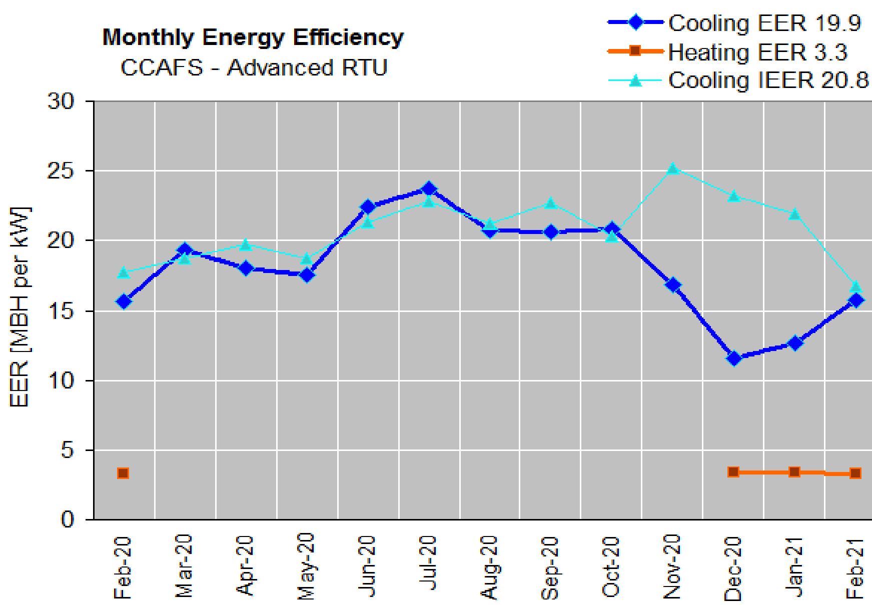

Figure 42. CCSFS-NOTU NexGen Unit Measured Monthly Energy Efficiency.

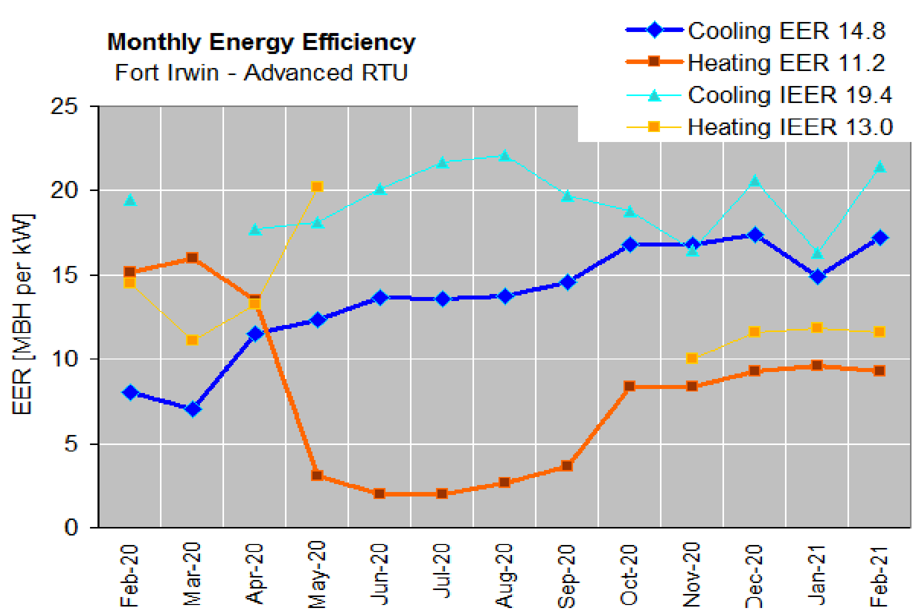

Figure 43. Fort Irwin OSJA NexGen Unit Measured Monthly Energy Efficiency.

In the monthly energy efficiency charts above, EER is the monthly total cooling delivered divided by the monthly total power consumed, and IEER is the monthly calculation of energy efficiency according to the equations in ANSI/AHRI Standard 340/360-2007. In these charts, EER represents the actual measured energy efficiency as operated at each site, while IEER is based on the typical load profile defined in the Standard to facilitate apples-to-apples comparison among various brands and models of equipment.

The measured annual cooling efficiency of the NexGen unit at CCSFS-NOTU is EER 19.9 and IEER 20.8, which is 54% improved over the factory rated IEER of 14.0. Improvement over the baseline unit's factory rated IEER 10.2 is 112%, and over the baseline unit's measured operational efficiency IEER 6.7 is 222% improved. This large improvement was realized concurrent with a near doubling of the delivered latent cooling (dehumidification) capacity and reduction of average space humidity from around $70\%_{rh}$ to $50\%_{rh}$. Electric heat energy efficiency was measured at EER 3.3, which is 12% lower than the nameplate rating – expected as electric heat is notoriously inefficient. However, heating load at CCSFS is too low to justify use of heat-pump heating.

The measured annual cooling efficiency of the NexGen unit at Fort Iwin OSJA is EER 14.8 and IEER 19.4, which is 46% improved over the factory rated IEER of 12.5. Improvement over the baseline unit's factory rated IEER 9.3 is 96%, and over the baseline unit's measured operational efficiency IEER 7.4 is 147% improved. The measured annual heat-pump heating efficiency of the NexGen unit at Fort Iwin OSJA is EER 11.2 and IEER 13.0, which is 22% improved over the factory rated IEER of 10.6. Operational heating efficiency was lower than expected because of frequent compressor cycling due to the low building heating load relative to cooling load, where the larger cooling load was the basis for heat pump capacity selection.

6.2 IMPROVE FACILITY INDOOR AIR QUALITY (IAQ)

During the baseline period, monthly median space temperatures at CCSFS-NOTU varied within 2 degrees of the 73.1 F overall median, apart from several days in January 2018 when heating was not turned on (heat switched off by occupants). However, space temperature peaks averaging 80.5 F occurred regularly, such as when the rollup door was opened to load equipment via forklift. Baseline median space humidity levels were consistently excessive at 70.9% rh. Relative humidity ranged from a low of 21% to fully saturated 100% rh. Plotted on the ASHRAE defined comfort zone, Figure 44, space conditions were rarely comfortable. The data clearly shows the baseline HVAC system does not adequately dehumidify.

Monthly median space temperatures at Fort Iwin OSJA during the baseline period were within 1 degree of the 66.4 F annual median. Space temperature peaks as high at 87F (averaging 82F) or drops as low as 49 F (averaging 60 F) occurred at least monthly while the unit was awaiting service after a fault or trip. Space humidity levels were very dry most of the year, except July-September, with the median for the baseline period at 29.6% rh being typically acceptable for this desert climate. Monthly median relative humidity ranged from a low of 11% to a high 63% rh. Plotted on the ASHRAE comfort zone, Figure 45, these space conditions would be defined as uncomfortable. Data clearly shows that the baseline HVAC system does not humidify (add moisture to the air), however, humidification is not desired by the occupants or facility management and is rarely provided in this climate zone, as dry conditions are considered normal. Occupant survey results indicated mostly too cool or cold, rather than too dry.

Space temperature and humidity were logged during the entire two-year test period. Monthly median values are plotted on the comfort zone charts below. The CCSFS graph highlights the much stronger dehumidification performance of the advanced unit, which maintained monthly average space humidity of around 50%rh, lower than the 70%rh baseline average. Little or no dehumidification is needed in Fort Irwin's desert climate. The advanced unit at CCSFS provides substantial active dehumidification, but the baseline unit provided very little dehumidification, complicating energy usage comparisons. Median space humidity was reduced from around 70%rh with the baseline unit to around 50%rh with the NexGen unit – a keenly perceptible improvement. Active dehumidify mode increased compressor and electric heat demand, and absorbed 41% of the cooling efficiency savings, giving a net savings including energy use for active dehumidification of 28%. This accounts for much of the electric heat energy use in December, January and February, and increased cooling energy use in March.

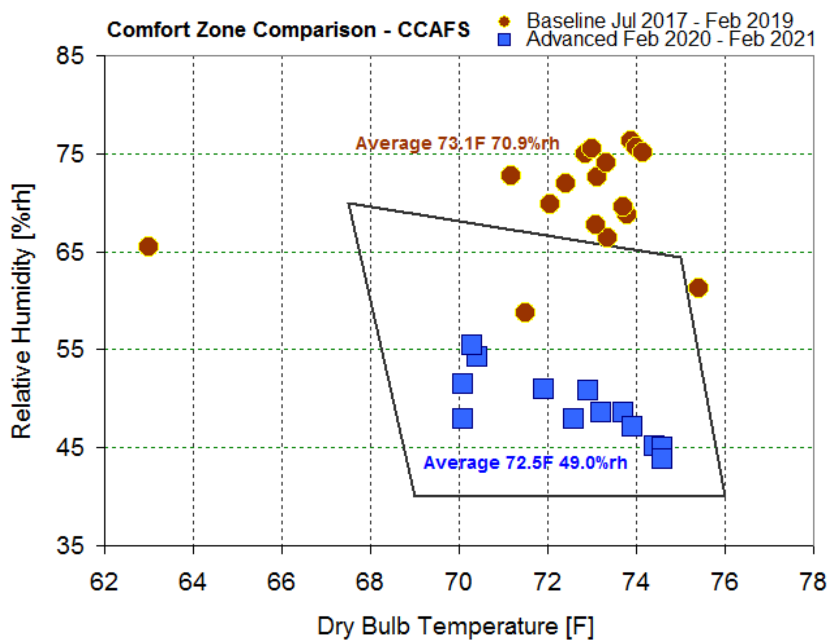

Figure 44. CCSFS-NOTU Comparison of Space Comfort Zone Conditions Advanced NexGen versus Baseline.

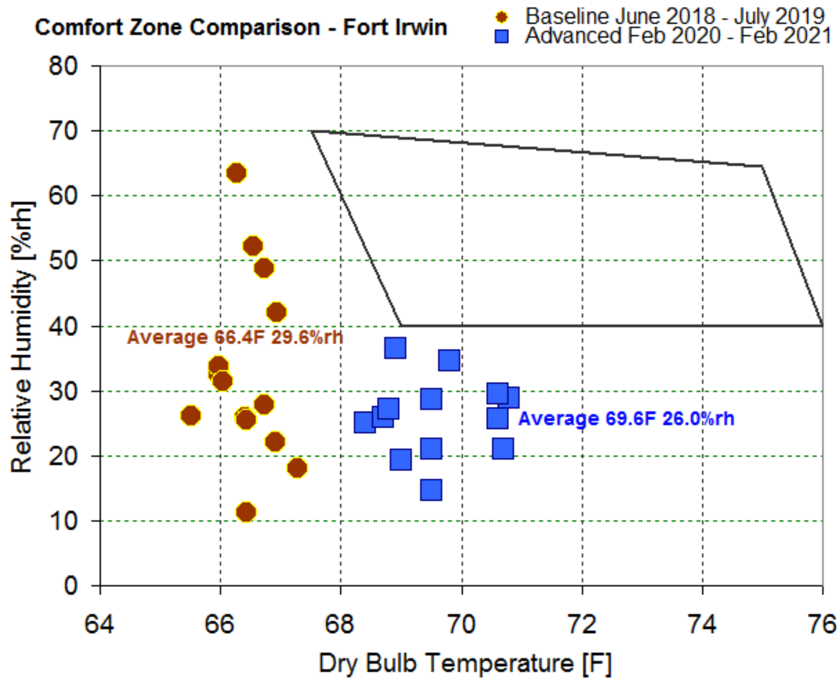

Figure 45. Fort Irwin OSJA Space Comfort Zone Conditions Advanced NexGen versus Baseline.

IAQ[22] of the space conditioned by the DX units was monitored and recorded as described in Section 5. Temperature, relative humidity and carbon dioxide levels of outside air and within the conditioned space were continuously measured. Occupancy and activities in the conditioned space were noted on collected data, for example, working hours at the Fort Irwin OSJA building are clearly posted, and working hours at CCSFS-NOTU are well defined.

It was found that the baseline DX package units over-ventilated the spaces much of the time, presenting an energy savings opportunity that the NexGen units successfully realized. Analysis of indoor versus outdoor carbon dioxide concentration were used to help characterize IAQ compared against the baselines. Ventilation was more than adequate during the baseline period, as evaluated by the space carbon dioxide level averaging 424 ppm at CCSFS-NOTU and 408 ppm the Fort Irwin OSJA building. The advanced NexGen integrated VAV-Economizer-DCV control algorithm maintained space carbon dioxide levels still well below the ASHRAE 700 ppm guideline[23], providing a monthly average of 500 ppm at CCSFS-NOTU and 486 ppm at Fort Irwin OSJA, while allowing levels to drift upward for energy savings during period of higher than usual occupancy.

[22] Indoor Air Quality generally refers to specific space air parameters: temperature, humidity, carbon dioxide, volatile organic compounds (VOCs), and particulates. For this demonstration, only temperature, humidity and carbon dioxide were tracked because accurate VOC and particulate sensors are exceedingly costly.

[23] ANSI/ASHRAE Addendum d to ANSI/ASHRAE Standard 62.1-201. CO_2 concentrations in acceptable outdoor air typically range from 300 to 500 ppm. Maintaining a steady-state CO_2 concentration in a space no greater than about 700 ppm above outdoor air levels will indicate that a substantial majority of visitors entering a space will be satisfied.

Table 14. Ventilation During Advanced NexGen Period Evaluated as CO_2 ppm.

Feb 2020 thru Feb 2021	Ventilation as CO_2 ppm		
Building	**Minimum**	**Average**	**Maximum**
CCSFS-NOTU	357	500	950
Fort Irwin NTC OSJA	387	486	908

CCSFS-NOTU baseline indoor space conditions were within the ASHRAE-defined comfort zone only 5.9% of the time on average, with humidity and/or temperature being excessive 92.9% and 15.9% of the time, respectively. With the advanced NexGen unit, CCSFS-NOTU baseline indoor space conditions were within the ASHRAE-defined comfort zone 98.2% of the time on average.

Fort Irwin OSJA baseline indoor space conditions were within the ASHRAE-defined comfort zone 0.0% of the time on average, with humidity and/or temperature being too dry and/or too cool 65.6% and 17.2% of the time, respectively. With the advanced NexGen unit, Fort Irwin OSJA baseline indoor space conditions were within the ASHRAE-defined comfort zone 68.4% of the time on average, significantly less than the theoretically perfect 100% due to a combination of the normally dry desert conditions and the occupant activity-required low thermostat setpoint.

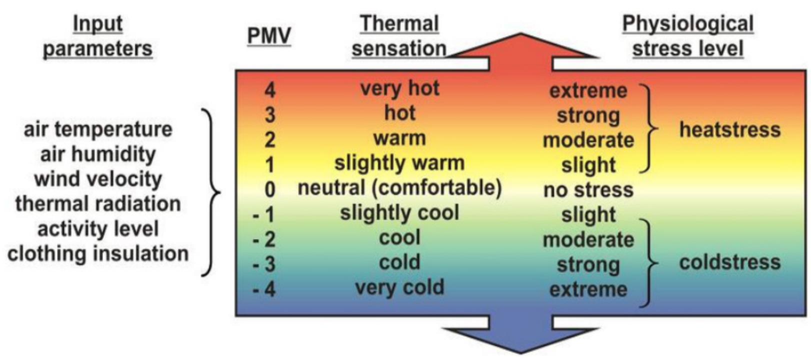

Figure 46. PMV (Predicted Mean Vote) Scale for Human Thermal Sensation.

Data at 1-minute intervals of space temperature and humidity were used to calculate comfort level via predicted mean vote (PMV) analysis. The PMV is the average comfort vote, using a seven-point thermal sensation scale from cold (-3) to hot (+3). Zero is the ideal value, representing thermal neutrality. The comfort zone is defined by combinations of the six key factors for thermal comfort for which the PMV is within the recommended limits ($-0.5<PMV<+0.5$), as illustrated in Figure 45. After calculating the PMV, the predicted percent dissatisfied (PPD) can be estimated[24]. This PMV-PPD calculation is widely used and accepted for design and field assessment of comfort conditions by ISO Standard 7730[25]. The CCSFS-NOTU baseline was PMV 1.0 / PPD 27% dissatisfied, which improved to PMV 0.39 / PPD 8.8% dissatisfied with the advanced NexGen unit.

[24] ASHRAE Handbook of Fundamentals, CHAPTER 9 THERMAL COMFORT. https://courses.washington.edu/me333afe/ASHRAE_Comfort.pdf

[25] ISO 7730:2005 Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. https://www.iso.org/standard/39155.html

The Fort Irwin baseline was PMV -0.6 / PMV 13% dissatisfied, which improved to PPD 0.0 / PMV 5.2% dissatisfied with the advanced NexGen unit.

6.3 DEMONSTRATE COST EFFECTIVENESS

The advanced units provided a much more comfortable workspace while also saving considerable energy. Efficiency comparisons were made between the combined advanced unit result against (1) the OEM factory rating of a similar currently available high-efficiency model, (2) the OEM efficiency rating of the baseline unit, and (3) the weighted average annual measured efficiency of the baseline unit. The advanced unit at CCSFS NOTU Support Building is 54% more efficient than the high-efficiency model, and over twice the efficiency level of the baseline unit's OEM rating. The advanced unit at Fort Irwin OSJA Building is 46% more energy efficient than a current high-efficiency model, and nearly twice as efficient at the baseline unit's OEM rating.

For the CCSFS unit, measured EER 19.9 is close to IEER 20.8, indicating the operational load profile is similar to the defined standard profile. The CCSFS unit has an electric resistance heat coil, which directly converts electricity to heat at the rate of 3.3 Btuh per Watt. For the Fort Irwin unit, measured EER 14.8 is much lower than IEER 19.4, indicating the operational load profile is much harsher than the standard defined profile, this is expected because summer afternoon temperatures at Fort Irwin climb well above 110 F while the highest standard load profile temperature is 95 F. The Fort Irwin unit is a heat pump, the measured heating EER 11.2 is lower than IEER 13.0 because of frequent compressor cycling due to a relatively small heating load at OSJA Building.

In addition to the above two energy efficiency determination methods, performance testing was carried out targeting discrete test points and conditions as listed in ANSI/AHRI Standard 340/360-2007. Monthly EER and IEER are listed with the results of the discrete tests in the tables below. The efficiency of the advanced units for comparison purposes was designated to be the average of the three methods.

Table 15. Measured Energy Efficiency Values by Method and Type Compared with Baseline Values.

CCAFS AC Units Efficiency Comparison

Method	Type	MBH/kWh
Monthly	EER	19.9
Continuous	IEER	20.8
Discrete	IEER	24.1
Combined	IEER	**21.6**
OEM Factory	IEER	14.0
Improvement		54%
Baseline OEM	IEER	10.2
Improvement		112%
Baseline	IEER	6.7
Improvement		222%

Fort Irwin AC Units Efficiency Comparison

Cooling

Method	Type	MBH/kWh
Monthly	EER	14.8
Continuous	IEER	18.7
Discrete	IEER	21.3
Combined	IEER	**18.3**
OEM Factory	IEER	12.5
Improvement		46%
Baseline OEM	IEER	9.3
Improvement		96%
Baseline	IEER	7.4
Improvement		147%

Performance was predicted using weather data and electric rates for the two demonstration sites, Army Fort Irwin National Training Center (AFINTC) and Naval Ordnance Test Unit (NOTU), and an additional DoD site with a moderate climate, Marine Corps Air Station Beaufort (MCASB). Energy savings estimates along with payback periods for 17½-ton models are compared in the chart below. Payback period is the key criterion used by ESCOs in consideration and application of new technologies, the *ClimaTek NexGen* unit has the fastest payback. Results of a BLCC MilCon ECIP analysis are summarized in the tables below for the 10-year period typically used for ESPC projects.

Table 16. Comparison of BLCC MilCon Economic Analysis for Three DoD Scenarios.

BLCC 5.3-15 MilCon Analysis ECIP Results

	ClimaTek Foundation		
	MCASB	AFINTC	NOTU
Payback Period (years)	4.5	2.3	4.8
Savings to Investment Ratio (SIR)	2.0	3.9	1.9
Adjusted Internal Rate of Return (AIRR)	10%	18%	10%

Analysis of 17½-ton unit at 3 DoD sites.
Electric $/kWh: MCASB 0.102, AFINTC 0.165, NOTU 0.069
No maintenance savings, 3.0% dicsount rate, standard DOE utility escalation rates

Table 17. Comparison of Cost and Economics of Advanced Technology versus Standard and Mid-line Models.

	ClimaTek Incremental		**Annual Energy Savings**				**Payback Period (years)**		
	Price/Ton	**Cost/Ton[2]**	**MCASB**	**AFINTC**	**NOTU**	**Percent**	**MCASB**	**AFINTC**	**NOTU**
vs. Standard-Line	$1,661	$574	$2,573	$5,098	$2,385	42%	3.9	2.0	4.2
vs. Mid-Line	$1,661	$366	$1,964	$3,891	$1,821	36%	3.3	1.6	3.5

*Analysis of 17½-ton unit at 3 DoD sites. Electric $/kWh: MCASB 0.102, AFINTC 0.165, NOTU 0.069
² ClimaTek Foundation vs Mid-line median price $1295/ton, Standard-line median price $1087/ton

Pricing and data were obtained for 11 commercially available systems for cost and performance comparisons, including four Carrier models, four Trane models, and three Daikin models. Analyses using weather data and electric rates from the three demonstration sites show the *ClimaTek Foundation* model having the shortest payback period for all three installations, and the *ClimaTek Expert* model having the highest energy savings. A simple payback analysis was performed on the ClimaTek next generation advanced high-efficiency DX models using the incremental cost over median cost and performance of standard- and mid-line models from three manufacturers (Carrier, Daikin, and Trane). The analysis was carried out using weather data and electric rates from the three proposed demonstration sites. The results are summarized in the table below. Energy savings ranges from 36% to 52% and payback period is from 1.3 to 5.1 years.

Table 18. Comparison of Cost and Economics of Advanced Technology versus Lowest Price Units.

Cost and Performance Comparisons*

		Incremental	Annual energy Savings				Payback Period [years]		
vs Standard-Line	Price/Ton	Cost/Ton²	MCASB	AFINTC	NOTU	Percent	MCASB	AFINTC	NOTU
ClimaTek Expert	$1,681	$845	$3,161	$6,263	$2,930	52%	4.7	2.4	5.0
ClimaTek Foundation	$1,277	$442	$2,573	$5,098	$2,385	42%	3.0	1.5	3.2
vs Mid-Line									
ClimaTek Expert	$1,681	$685	$2,552	$5,056	$2,366	47%	4.7	2.4	5.1
ClimaTek Foundation	$1,277	$281	$1,964	$3,891	$1,821	36%	2.5	1.3	2.7

*Analysis of 17½-ton unit at 3 demonstration sites. Electric $/kWh: MCASB 0.102, AFINTC 0.165, NOTU 0.069

² Mid-line median price $996/ton, Standard-line median price $836/ton

6.4 DEMONSTRATE RELIABILITY

This quantitative performance objective evaluated the reliability of the *NextGen* units relative to reliability of baseline existing units according to the percentage of time the unit performed as designed. However, in general, reliability comparison of new equipment in its first year of operation against old equipment at or near end of serviceable life isn't necessarily conclusive.

Non-performance of the unit "as designed" included time the unit was non-operational, non-functional, or not responsive to occupant / user controls / commands, and time the occupied space comfort conditions exceeded 2x-sigma (two standard deviations) from acceptable conditions or were far outside of the average comfort and IAQ zone conditions, as defined by ASHRAE Standards 55 and 62.1, respectively for a continuous period longer than 90 minutes. Reliability was assessed via calculation of the reduction in downtime relative to baseline as tracked by unit power usage and space conditions logged at one-minute intervals. For example, data showing zero power usage and space temperature more than about 5 degrees-F from thermostat setpoint was deemed to indicate the unit was non-operational for that one-minute log interval. The reduction in downtime hours at the CCSFS demonstration site was 87% from 72.2 hours to 9.4 hours, and downtime was reduced by 91% at AFINTC from 96.1 hours to 8.2 hours, over a 12-month period, which exceeds the success criteria of a 50% downtime reduction.

The total cost of servicing the NexGen units was returned via energy savings and anticipated longer equipment life. There is unlikely to be direct accountable maintenance savings because service labor is in short supply: time & materials not used on a NexGen unit were utilized to service other HVAC equipment. The advised service budget for the Next Generation units is $50 to $75 per ton per year.

Baseline comparisons can be made versus (a) existing DoD units and (b) comparable high-performance models. Estimated service costs for existing units averages $71 per ton per year, however, some maintenance is deferred or simply not done, so actual DoD service costs are likely less and energy use and equipment life suffer accordingly. Service cost for comparable high-performance models is estimated at $89 per ton per year. *NexGen* required service actions aim to sustain energy efficiency and increase equipment life to provide a payback period on service cost of 0.4 to 1.1 years, while service actions on existing and comparable high-performance units aim simply to maintain unit operation and prevent emergency repairs.

Table 19. Comparison of Maintenance Cost Estimates.

MAINTENANCE COST ESTIMATES	
Cost per Ton per Year	
Minimal / deferred maintenance	$40
Repair existing DoD units	$71
Comparable high-performance units	$89
ClimaTek service budget	$50 to 75

6.5 MANAGEABILITY USING EXISTING FACILITY HVAC STAFF & RESOURCES

In addition to increased energy efficiency and cost-effectiveness, the project demonstrated how automated fault detection & diagnostics contributes to ease of maintenance by addressing challenging issues that cause decline in operational energy efficiency and equipment service life. The demonstration site buildings have special conditions associated with reliability and maintenance response that were successfully addressed at each demonstration site. The staff and contractors usually responsible for HVAC maintenance were briefed, involved in and sometimes solely carried out maintenance of the demonstration units. These maintenance staff were surveyed via interview to identify concerns and recommendations for maintenance of NexGen equipment and responses were compiled over the course of the demonstration. Questions addressed whether additional or special skills or training is / was needed to maintain the equipment; whether more, same, or less maintenance is / was required; and the relative difficulty of performing preventative maintenance tasks. Typical technician comments below characterize demonstration findings at both sites.

"Techs will need a day or two training on the different components and control use."

"The control panel screen is great, you can really pinpoint how well a unit is running."

"The fault detection is something every HVAC unit should have, that's been very helpful."

"Regarding future installation of these units, yes eventually when servicing catches up. In the meanwhile, would be good to have training."

"A good way to track performance and spot degradation of new units from the day they are installed."

Overall, there was concurrence of HVAC shop staff at CCSFS and contracted staff at Fort Irwin of maintainability using existing technicians and resources, as long as classroom and field training is provided. Most technicians were generally interested and enthusiastic about the NexGen unit and welcomed the opportunity to learn advanced operation and service procedures as a way of easing their future workload and keeping their skills up to date. Comments generally indicated less maintenance was needed, and servicing required a higher skill and knowledge level to perform.

6.6 RELIABILITY RELATIVE TO RELIABILITY OF BASE UNIT

Reliability relative to the base unit was gauged according to field assessment by the HVAC SME and/or Energy Manger at both demonstration sites based on operational observations and occupant reports, along with technician comments. There was overall concurrence that the advanced NexGen units perform better than base unit or typical package units and provide space conditions closer to requirements. There was general agreement that the NexGen units had fewer outages and downtime than the units they replaced and are easier to service as long as training is provided to interested technicians, although in general, reliability comparison of new equipment in its first year of operation against old equipment at or near end of serviceable life isn't necessarily conclusive. There was concern expressed about the availability of replacement parts. The DoD personnel asked about the demonstration generally agreed that the NexGen units were at least as or more reliable than other new package unit equipment at their respective installations.

6.7 USER SATISFACTION

User satisfaction was gauged by comparing building occupant responses to statements regarding environmental comfort on a Likert scale where respondents indicated their level of agreement or disagreement on a symmetric agree-disagree scale as summarized in Figure 47. An overall score of 0 (zero) is ideal and corresponds to comfortable neutral conditions causing no perceptible discomfort, distraction or negative productivity affect. Survey qualitative and numerical results indicate a small increase in user satisfaction at CCSFS-NOTU from baseline C=1.59 to C=0.74 with the change to the NexGen unit, apparently due primarily to lower humidity along with secondary perception of fresher air and a positive productivity affect. Numerical results from Fort Irwin NTC indicate a slight decrease in user satisfaction, however, there appears to be little or no qualitative difference in user satisfaction between baseline and NexGen.

Environmental Comfort Survey Results

	CCSFS-NOTU		Fort Irwin NTC	
	Baseline	NexGen	Baseline	NexGen
n=	6	5	6	6
Thermal Sensation	1.2	-0.6	-0.6	-0.7
Humid or Dry	2.4	0.1	-0.7	-0.6
Fresh or Tainted	2.4	1.3	1.2	1.9
Productivity Affect	-0.6	1.4	0.0	0.1
Breezy or Still	1.3	0.2	0.2	0.1
Overall Score C=	1.59	0.74	0.56	0.68

Much too hot	Much too humid	Much too breezy	Very fresh	Greatly enhances
Too hot	Too humid	Too breezy	Fresh	Somewhat enhances
Warm but comfortable	Humid but comfortable	Breezy but comfortable	Somewhat fresh	Neither enhances nor interferes
Comfortable	Neither humid nor dry	Neither breezy nor still	Neither fresh nor tainted	Somewhat interferes with
Cool but comfortable	Dry but comfortable	Still but comfortable	Somewhat tainted	Greatly interferes with
Too cold	Too dry	Too still	Tainted	
Much too cold	Much too dry	Much too still	Very tainted	

Figure 47. Environmental Comfort Survey Results and Response Scale.

Post-processing statistical confidence T-tests were used to determine if the perceived environmental comfort changes between baseline and NexGen are real and not due to randomness. Although the confidence interval of overall scores C is precise to about ±0.04, P-values indicate the difference between the overall scores of baseline versus NexGen is less than statistically significant for CCSFS (tStat=1.69, tCritical=2.13, P=0.083) and less so for Fort Irwin NTC (tStat=-0.706, tCritical=2.13, P=0.26). These statistics taken alone indicate there is no significant statistical difference between the baseline and NexGen overall numerical scores.

7.0 COST ASSESSMENT

Elements of the demonstration project cost assessment are presented in the table below. Costs were documented from actual expenditures tracked as the project progressed, and projected estimates were developed for fully commercialized availability.

Table 20. Cost Assessment Elements of the New Technology.

Cost Element	Data Collected During Demonstration
Capital cost of equipment	Paid invoices from suppliers
Installation costs and consumables	Labor & materials costs provided by Advantek and subcontractors
Facility operational costs	Costs assigned to the specific HVAC unit being installed, both before & after installation, including energy and IAQ
Maintenance & servicing costs	Costs before & after installation, and for HVAC staff costs for operation overview meeting
Training costs	Costs associated with Advantek providing training to O&M personnel at facility

Installation costs for the two demonstration sites were tracked and used to characterize costs for replacing an existing standard HVAC unit with an advanced NexGen system. Training needs and costs were documented and projected. Design costs associated with selecting equipment size, components, configuration and features at both demonstration sites were documented and assigned as a cost to be allocated incrementally to similar future projects at a particular installation.

Energy savings were compiled based on the "before" and "after" comparisons of space cooling and heating kWh energy at the demonstration sites using the actual $/kWh rates of the installations hosting the advanced NexGen air-conditioner demonstrations. Additional savings related to improved Indoor Air Quality, i.e., humidity control and CO_2 levels in the conditioned space, and for costs of providing stand-alone dehumidification to achieve similar relative humidity and fresh air ventilation levels are not included in the life cycle cost projection because of the wide variability of these factors.

Because HVAC equipment duty cycle is primarily a function of onsite ambient weather conditions, maintenance intervals and costs were specific to each host installation. Actual and projected costs to maintain the advanced units were compared to maintenance costs documented for standard baseline equipment. Maintenance costs and training costs for facility HVAC staff were compiled by project personnel, and operational data were collected during the study period for evaluating the relative reliability of the advanced units and compared with baseline data. OEM reliability data were used for estimating equipment life and expected maintenance costs during the lifetime, as well as unit replacement costs.

A major consideration in cost assessment of NexGen air-conditioner technology is the cost differential between installation and operation of air-conditioning units with remote automated fault detection & diagnostics (RAFDD) technology versus the equipment, staff, and productivity cost of operating and maintaining standard units. This assessment provides a basis for DoD installations to make financial decisions on whether to deploy RAFDD, or to pay HVAC maintenance staff to continue with standard maintenance practices and untimely equipment replacements.

7.1 COST MODEL

A straight-line economic calculation based on demonstration results was performed. ESCO projects sometimes look at incremental cost of a NexGen unit versus a standard unit, and then compare that against the energy savings the ECM would generate, using an example of $1060 incremental initial cost per ton and 55.6% energy savings, the simple payback period would be 3.9 years. This simple calculation method can be utilized for various installations by substitution of the appropriate energy cost per kWh.

$$\text{Simple Payback Years} = \mathbf{3.9} = \frac{\left(\text{Incremental Initial Cost of Proposed Technology at Scale } \mathbf{\$1{,}060 \text{ per Ton}}\right)}{\left(\text{Unit Energy Consumed by Typical Baseline Unit } \mathbf{3856 \text{ kWh/Year per Ton}}\right) \times \left(\text{Energy Cost } \mathbf{0.1264 \text{ \$/kWh}}\right) \times \left(\mathbf{55.56\%} \text{ Savings Over Typical Existing Technology}\right)}$$

In other project scenarios, savings would be compared against the total cost of the NexGen unit:

$$\text{Simple Payback Years} = \mathbf{7.4} = \frac{\left(\text{Cost of Proposed Technology at Scale } \mathbf{\$2{,}000 \text{ per Ton}}\right)}{\left(\text{Unit Energy Consumed by Typical Baseline Unit } \mathbf{3856 \text{ kWh/Year per Ton}}\right) \times \left(\text{Energy Cost } \mathbf{0.1264 \text{ \$/kWh}}\right) \times \left(\mathbf{55.56\%} \text{ Savings Over Typical Existing Technology}\right)}$$

Package unit equipment life is typically 10 to 15 years; 10 to 12 years is typical for baseline models with uncoated coil and standard maintenance practices, while the projected NexGen unit life is anticipated to be 15 years because of a coated coil, soft motor start, cooler compressor operation, and RAFDD supported maintenance. The NexGen unit provides an SIR as high as 2.6, which is high enough to garner ESCO attention for inclusion in financed projects. Energy and O&M savings versus current standard and mid-line equipment is 42% and 36% respectively.

7.2 COST DRIVERS

The major economic drivers for a project to install a NexGen package AC unit or heat pump will be capital cost; local climate; and maintenance, service & training costs.

7.2.1 Capital Cost

The capital cost at the time of consideration for a project will be a function of commercial availability and price competition among manufacturers. Market research was completed in August 2022 to determine what commercial products and services are available by collecting and analyzing product information on the technical capabilities within the marketplace. There are relatively few US-based manufacturers of commercial HVAC package units offering advanced models suitable for industrial / military grade applications.

ClimaTek uniquely offers the "CFS 3.0" model NexGen package unit with IEER above 20, with the following features and benefits. The unit's active high-performance humidity control does not rely on reheat of any type. A graphic touchscreen control panel is remotely viewable from any web browser via a cybersecure, encrypted cloud server. System operation is continuously monitored, and operation is analyzed to diagnose faults, which are mitigated to the extent possible without technician intervention. There are over 50 RAFDD parameters, including energy efficiency, tons, kW, Amps, humidity, refrigerant pressures and temperatures, airflow, and ventilation; and an alert is sent if operation is abnormal. A wall touch panel for occupants displays status, temperatures, humidity, and carbon dioxide. The units come with variable air volume demand-controlled ventilation (VAV-DCV), which is integrated with a dew-point economizer and space pressurization control. High intensity UVC germicidal emitters, ASTM-B117 10,000-hour salt-spray-tested coil and cabinet coating, and MODBUS communication with BAS / EMCS are standard features.

While a few manufacturers offer units that partially meet some requirements, only the ClimaTek units provides truly advanced NexGen performance and features. Therefore, at the time of this report, procurement would likely be on a basis of other than full and open competition. A source justification template is available by request to the project PI at mwest@advantekinc.com. A justification requests authorization to procure specialized HVAC package units that are peculiar to one manufacturer, ClimaTek HVAC LLC, on an other than full and open competition basis. The proposed procurement would be a sole source action from Advantek Consulting Engineering, Inc. (CAGE code 6B1S4, SAM MQN8MMTB3NW7) by firm fixed price purchase order. Current design, equipment, material, and installation costs at the time of this report total $106,026 per unit.

7.2.2 Local Climate

Facility energy costs and savings were projected from the demonstration field-measured data to one location in each ASHRAE climate zone using RTUCC and EFLH models, as shown in Figure 48. The Rooftop Unit Comparison Calculator (RTUCC) was developed by PNNL[26] to compare high-efficiency rooftop air conditioners to standard equipment in terms of life-cycle cost. RTUCC is simpler to use than complicated building simulation models, while offering more detail than simplified estimating tools. While simplified tools are typically based on full-load efficiencies and full-load equivalent operating hours, RTUCC accounts for local climate and part-load as well as full-load efficiencies.

Equivalent full-load cooling hours ($EFLH_C$), also known as Full Load Equivalent Operating Hours (FLEOH), are the number of hours an air conditioner would operate at full load to equal the amount of cooling delivered by the system at a constant thermostat setting over a cooling season. Equivalent full load heating ($EFLH_H$) hours are the winter analogue to $EFLH_C$. Standard $EFLH_C$ values are published in a number of locations, including on the Energy Star site as part of their calculators (EPA 2016)[27], in the Code of Federal Regulations (USFTC 2013)[28], and in various standard or generic TRMs (Technical Reference Manual)[29].

[26] U.S. DOE's Pacific Northwest National Laboratory, https://rtucc.pnnl.gov/#/

[27] Savings Calculator https://www.energystar.gov/products/heating_cooling/guide/savings-calculator

[28] 16 C.F.R. Part 305: Energy and Water Use Labeling Under the Energy Policy and Conservation Act (Energy Labeling Rule) https://www.ftc.gov/legal-library/browse/federal-register-notices/16-cfr-part-305-energy-water-use-labeling-under-energy-policy-conservation-act-energy-labeling-rule

[29] Equivalent Full Load Cooling Hours/Year https://watermgt.com/solutions/cooling.html

The climate data weather station ID, 5-year average cooling degree-days (base 63F), heating degree-days (base 65F), total degree days, and the fraction of heating provided via heat-pump before auxiliary heat is needed are listed in Table 20 for each climate zone location and nearest major city. Only cooling was modeled for zones 1A and 2A because a heat pump is not needed.

DoD Site & Location			Cooling & Heating Load Parameters				
Zone	**DoD Location**	**Nearest Major City**	**Climate Station [ID]**	**CDD 63**	**HDD 65**	**TDD**	**Heat-pump fraction**
1A	Key West NAS, FL	Miami, FL	KNQX	6171	48	6219	-
2A	Cape Canaveral SFS, FL	Orlando, FL	KXMR	4298	464	4762	-
3A	MCAS Beaufort, SC	Beaufort, SC	KNBC	3412	1606	5018	0.76
4A	Fort Hamilton, NY	New York, NY	KNYC	1577	4505	6082	0.52
5A	Great Lakes Naval Base, IL	Chicago, IL	KUGN	1072	6546	7618	0.30
6A	St.Paul Air National Guard Base, MN	Minneapolis, MN	KSGS	1171	7446	8617	0.36
2B	Davis-Monthan AFB	Tucson, AZ	KDMA	4285	1705	5990	1.0
3B	Fort Bliss, TX	El Paso, TX	KBIF	3465	2386	5852	0.70
4B	Kirtland AFB, NM	Albuquerque, NM	KABQ	2082	4019	6101	0.72
5B	Buckley AFB, CO	Denver, CO	KBKF	1304	6128	7432	0.51
6B	Fort William Henry Harrison, MT	Helena, MT	KHLN	958	7866	8824	0.40
3C	Camp Parks PRFTA, CA	San Francisco, CA	KLVK	1476	3142	4618	1
4C	McChord AFB, WA	Seattle, WA	KTCM	587	5370	5957	1
5C	Fort McCarver, WA	Port Angeles, WA	KCLM	180	5964	6144	1
7	Camp Ripley, MN	International Falls, MN	KBRD	914	8645	9559	0.36
8	Fort Wainwright, AK	Fairbanks, AK	PAFB	271	13169	13440	0.13

RTUCC and EFLH models were developed for a 15-ton standard package unit and a 15-ton NexGen advanced package unit. The models were calibrated against field data from the demonstration sites. The RTUCC model includes auxiliary heat energy while the EFLH model does not, however, there is no difference in auxiliary heat energy efficiency between the baseline and NexGen units, so there is no effect on savings. Agreement between the models is good except for the Marine (C) zones where the RTUCC calculations oddly diverge to irrational values.

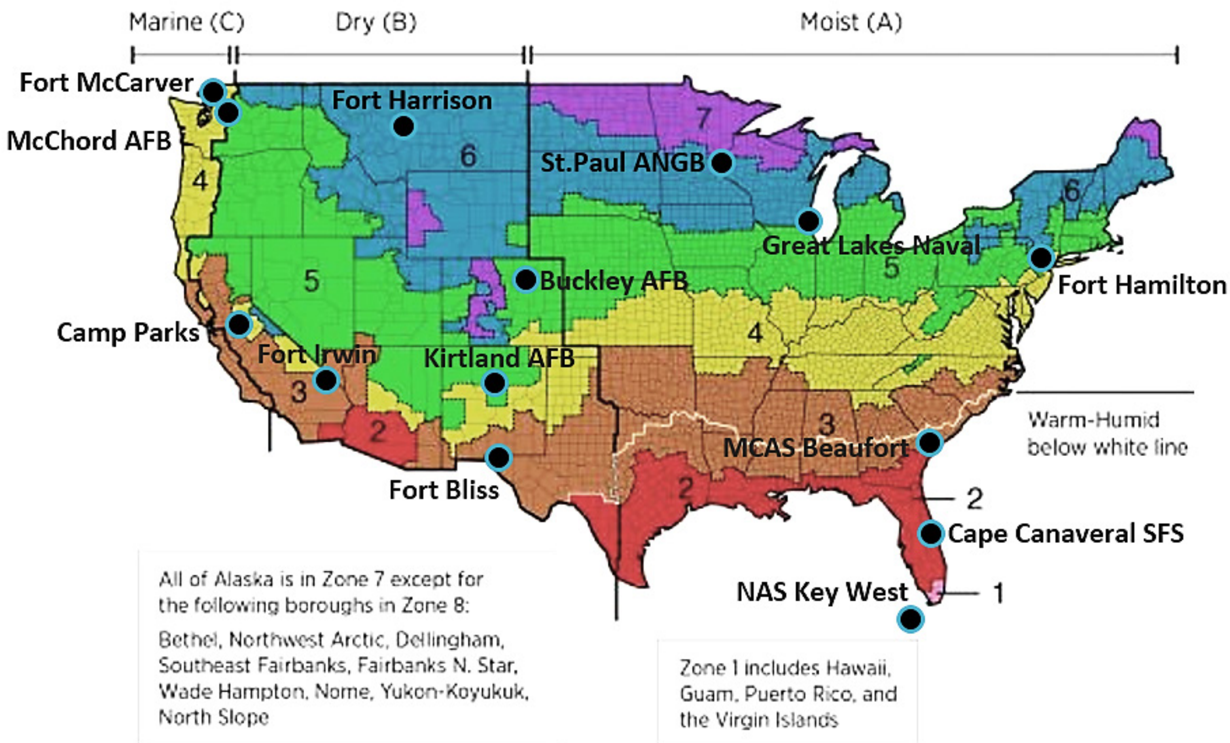

Figure 48. CONUS Map Showing Climate Zone of the 16 Modeled DoD Installation Locations.

Modeling results were computed using an electric rate of $0.062 (6.2 cents) per kWh for one unit of size 15-tons with an incremental capital cost of $9,116 between a standard unit and a NexGen unit, see Table 22 Cost Model. No credit was taken for kW demand savings, if any, or maintenance savings. Dollar savings can be scaled up or down using a ratio of the actual electric rate to $0.062 and the actual unit size to 15-tons. Higher electric rate and/or larger unit size will provide more savings, shorter payback period, and higher SIR.

In general, the results show that longer and/or hotter cooling seasons give better NexGen installation economics. Predicted payback periods by the EFLH model average 6.7 years across the 16 DoD locations, with a minimum 4.6 years (Key West NAS, FL) and maximum 14.5 years (Fort Wainwright, AK). RTUCC predicted payback periods average 7.3 years, minimum 3.6 years (Key West NAS, FL) and maximum 11.4 years (Camp Ripley, MN).

Predicted savings-to-investment ratios (SIR) by the EFLH model average 2.4 across the 16 locations, with a maximum 3.3 (Key West NAS, FL) and minimum 1.0 (Fort Wainwright, AK). RTUCC predicted SIRs average 1.7, maximum 3.5 (Key West NAS, FL) and minimum 0.2 (McChord AFB, WA).

Table 21. Energy Use, Savings, and Economics for One 15-ton Unit by DoD Site Climate Zone.

Zone	Energy Use: EFLH Model Baseline Energy [kWh]	Energy Use: EFLH Model NexGen Energy [kWh]	Energy Use: RTUCC Model Baseline Energy [kWh]	Energy Use: RTUCC Model NexGen Energy [kWh]	Savings & Economics: EFLH Model Annual Electric Savings	Savings & Economics: EFLH Model Simple Payback [years]	Savings & Economics: EFLH Model SIR^{+}	Savings & Economics: RTUCC Model Annual Electric Savings	Savings & Economics: RTUCC Model Simple Payback [years]	Savings & Economics: RTUCC Model SIR^{+}
1A	68,902	36,688	66,779	24,169	$2,000	4.6	3.3	$2,641	3.6	3.5
2A	47,994	25,555	55,041	28,865	$1,390	6.6	2.3	$1,623	6.5	2.0
3A	51,725	27,542	59,170	34,994	$1,500	6.1	2.5	$1,499	6.7	2.0
4A	43,761	23,301	74,229	53,798	$1,270	7.2	2.1	$1,267	8.1	1.7
5A	33,895	18,048	104,742	88,993	$980	9.3	1.6	$976	10.9	1.3
6A	43,011	22,902	137,068	116,866	$1,250	7.3	2.1	$1,252	8.2	1.6
2B	66,883	35,612	60,411	28,938	$1,940	4.7	3.2	$1,951	5.0	2.6
3B	57,344	30,534	57,559	30,800	$1,660	5.5	2.7	$1,659	6.0	2.2
4B	55,556	29,582	60,847	34,819	$1,610	5.7	2.6	$1,614	6.2	2.1
5B	49,459	26,335	84,254	61,078	$1,430	6.4	2.4	$1,437	7.0	1.9
6B	46,160	24,579	110,764	89,152	$1,340	6.8	2.2	$1,340	7.6	1.8
3C	51,567	27,458	39,069	27,615	$1,490	6.1	2.5	$710	-	0.93
4C	66,515	35,417	61,022	58,026	$1,930	4.7	3.2	$185	-	0.24
5C	68,600	36,527	71,592	75,982	$1,990	4.6	3.3	-$272	-	-
7	44,953	23,936	178,155	162,898	$1,300	7.0	2.1	$946	11.4	1.2
8	21,765	11,589	248,727	238,486	$630	14.5	1.0	$635	-	0.8

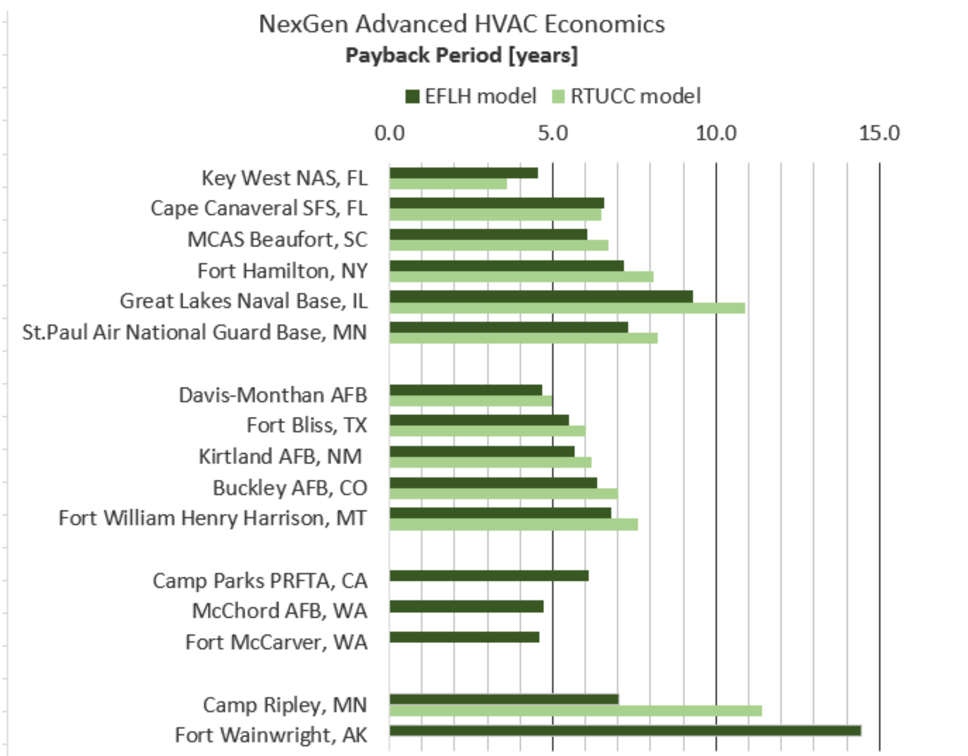

Figure 49. NexGen Advanced Economics for One 15-ton Unit by Location.

7.2.3 Maintenance, Service & Training

Maintenance & servicing costs will vary between an onsite DoD-employed HVAC shop, versus an onsite private-employed contractor, versus an offsite HVAC contracting firm.

Training costs will depend on the level of knowledge and experience possessed by the designated HVAC technicians. Typical training required is one half-day classroom session, followed by one half-day field session at an operational NexGen system. Initial training follow-up includes engineer availability to answer questions and provide field assistance, followed by remote assist via live cloud connection as needed.

7.3 COST ANALYSIS AND COMPARISON

Cost elements associated with purchasing and installing an advanced NexGen air conditioner were factored into a Life Cycle Cost (LCC) model. LCC calculations were run comparing installation and operation of new baseline versus new NexGen equipment. The demonstration units are hand-built prototypes having a higher engineering and assembly labor cost than baseline models, which are manufactured on a high-volume production line. The model output costs for two scenarios were compared to give an assessment of cost impacts to the installation, as listed in Table 22.

Facility operational costs will be dependent on the local electric rate at the time of the project and the severity of the climate at the installation location. The economics presented below are computed using an electric rate of $0.062 (6.2 cents) per kWh on a unit size of 15-tons, with no credit taken for kW demand savings, if any. Savings can be scaled up or down using a ratio of the actual electric rate to $0.062 and the actual unit size to 15-tons.

Projected costs are based on large-quantity pricing versus actual energy cost reduction relative to baseline. Costs tracked during the demonstration include additional installation and consumables costs than would be expended for a commercial installation. As broken down in Table 22 right, the total projected cost of ownership of a NexGen unit estimated at $81,744 is 29% less than the $114,763 cost of ownership of a baseline unit over 15 years. Utilized as an ECM, each NexGen unit would produce a life cycle savings of about $34k for an additional first cost of about $14k, giving a payback period of 6.2 years and an SIR of 2.4.

Table 22 Cost Model Comparison for Quantity-1 15-ton Package Unit.

	Baseline	ClimaTek NexGen	
Cost Element	Estimated Costs	Data Tracked During Demonstration	Projected Costs
Hardware capital cost	$17,223	$22,821	$21,575
Installation & assembly costs	10,288	31,466	13,496
Consumables & materials costs	3,853	34,426	5,409
Facility energy cost $0.062/kWh	44,635	22,269	22,269
Maintenance & service costs	24,975	16,875	14,625
Hardware lifetime	10 years	15 years	15 years
Technician training costs	-	13,200	4,400
Total Ownership Cost (15 years)	$114,730	$141,057	$81,774
Total Ownership $ per Ton	$7,649	$9,404	$5,452

8.0 IMPLEMENTATION ISSUES

Implementation of this technology at a specific site / building will need to include consideration of certain issues during each step of the project. Lessons learned during each step, including selection of units to be replaced, procurement, connectivity, commissioning, and technical support, are discussed below.

1. Unit Selection

Best economics will be ensured by judiciously examining package units that will soon be due for replacement. Good candidates should be screened by size, condition, and application.

By far the best applications are those requiring space humidity control in hot- and warm-humid climate zones 1A, 2A, 3A and portions of 4A. Typically, these applications are laboratories, assembly shops, clean rooms, meeting and conference facilities, libraries, medical buildings, food service spaces, schools, auditoriums, theatres, gymnasiums, and multi-tenant housing. The ideal candidates for replacement are package units utilizing reheat for humidity control. Look for a hot-gas or warm-liquid reheat coil downstream of the cooling coil in the existing unit, and/or electric resistance heating elements located downstream of the supply blower, in the supply ductwork, or in terminal boxes. Some buildings have a humidistat located on the wall near the thermostat, or a combination thermostat-humidistat.

A general rule is the larger the unit, the shorter the payback period and the higher the savings-to-investment ratio will be. Package units sizes 15-tons to 30-tons are ideal, with savings potential for units in the full application range of 7½-tons to 60-tons being evaluated on a case by case basis. Good candidates are units nearing the end of their useful economic and/or service life, which is commonly 10 to 12 years in most locations, 7-10 years near the seacoast, and 12 to 15 or more years in desert climate locations.

2. Procurement

Market research was completed in August 2022 to determine what advanced unitary DX products are available by collecting and analyzing information on the technical capabilities within the marketplace. There are relatively few US-based manufacturers of commercial HVAC package units offering ultra-high efficiency models suitable for industrial / military grade applications, hence a sole-source procurement is likely to be desirable.

Procurement of DX equipment to meet specified air temperature, relative humidity, and air quality requirements is challenging and energy intensive to satisfy with standard HVAC package units while also complying with Unified Facilities Criteria (UFC) commissioning, life-cycle cost, energy performance, humidity control, and corrosion protection requirements. A sole-source justification template (justification for use of other than full and open competition), is available by contacting the PI directly (mikewest@adantekinc.com). See 7.2.1 Capital Cost for details. This procurement process can take as long as 12 months, sometimes spanning across an entire fiscal year, so initiating the process well before candidate units' expected end of life is advisable.

3. Connectivity

The EERoptimizer unitary DX controller needs a connection to the ClimaTek cloud server for full functionality, which includes setpoint optimization, fault logging, trend charting, and remote user interface viewing. The connection is via a closed isolated network (CIN) which avoids the need for any physical connection to the military or facility LAN, thereby minimizing cybersecurity concerns. The proven capability of the system to achieve a Risk Management Framework (RMF) Cybersecurity Authorization as outlined in the ESTCP Cybersecurity Guidance document for a closed restricted network physically separate from the installation network(s) is essential to achieving full functionality and realizing all of the benefits the technology is capable of providing.

The CIN is a data communications enclave that operates in a single security domain, implements a security policy administered by a single authority, does not connect to any other network and has a single, common, continuous security perimeter[30]. The only devices on the EERoptimizer CIN are internal to the cybersecure EERoptimizer controller embedded in the NexGen package HVAC unit. Typically, implementing this connection is accomplished via a commercial internet service provider (e.g., CenturyLink, Google Fiber, Xfinity, Frontier) either by cable modem or DSL, or cellular data service provided by AT&T, with a dedicated firewall.

4. Commissioning

NexGen units are fully tested in all modes of operation when assembled according to a quality control / quality assurance protocol. These procedures are continued at the field site by a ClimaTek engineer at the time of package unit installation. Onsite commissioning tasks include checking sensor calibrations, communication verification, and testing and documenting all operating modes; cooling, heating and ventilation capacity; and EER and IEER. Continuous ongoing commissioning is provided remotely via monitoring of diagnostic fault and sensor alerts and alarms, and periodic trend charting to visually identify unusual trends or other behaviors that might indicate a developing issue. Continuous commissioning maintains the unit in as close to like-new operational condition as is physically possible, while detecting and correcting small issues before they grow and become problematic.

5. Technical Support

A training session for onsite HVAC technicians is scheduled after installation and commissioning. ClimaTek engineers supported by offsite contracted technicians are available to provide backing to onsite technicians as needed.

[30] NIST Risk Management Framework https://csrc.nist.gov/Projects/risk-management/sp800-53-controls/overlay-repository/government-wide-overlay-submissions/closed-isolated-network

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APPENDIX A POINTS OF CONTACT

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