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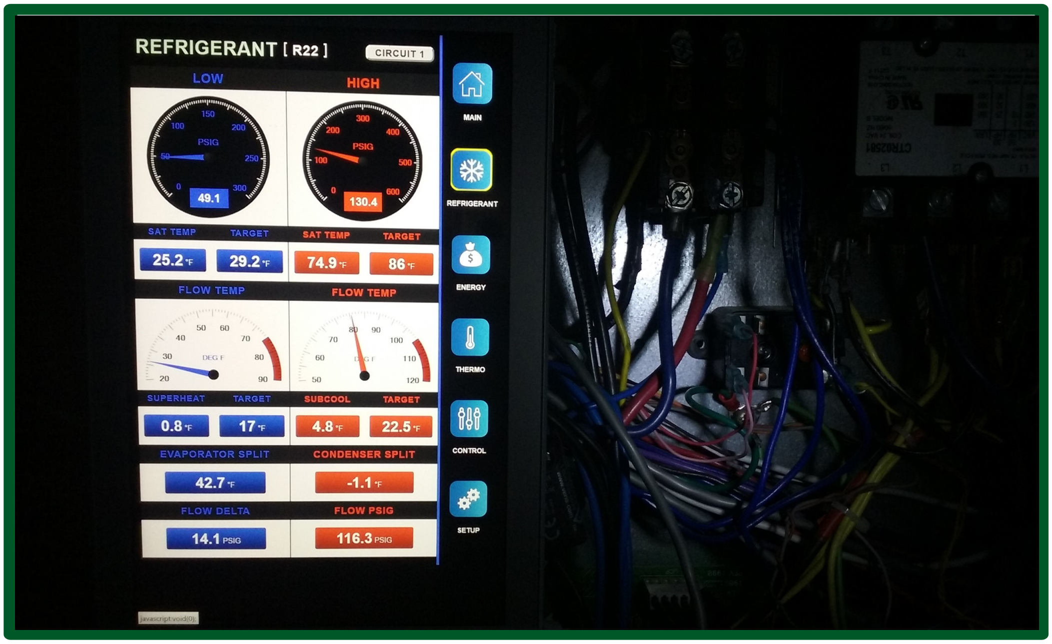

Demonstration & Testing of an EER Optimizer System for DX Air-conditioners

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14. ABSTRACT
Three demonstration sites provided a full range of conditions for the EER Optimizer technology to evaluate the flexibility and efficacy needed for the varying climates of DoD installations. The demonstrations included onboard controls installed on operating package air conditioners at sites in SC, FL, and CA, as well as use of handheld EER Optimizer technology to demonstrate effectiveness when used as an operations & maintenance tool by HVAC technicians. The following were the major objectives: 1. Establish the cost effectiveness of the technology in both onboard & portable versions. 2. Document reliable operation of onboard EER Optimizer technology. 3. Document practicality, usefulness, and simplicity of diagnostics.

15. SUBJECT TERMS
EER Optimizer System, DX Air-conditioners, Bubble Fraction Sensor, Compressor Contactor, Condenser Fan, Charge Solenoid, Evaporator Fan, Energy Management & Control System, HVAC, Power Current Sensor, Relative Humidty

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ACRONYMS AND ABBREVIATIONS

AHRI	American Heating and Refrigeration Institute
ANSI	American National Standards Institute
AROR	Adjusted Rate of Return
ASHRAE	American Society of Heating, Refrigeration and Air conditioning Engineers
BTUH	British Thermal Units per Hour
CCAFS	Cape Canaveral Air Force Station at Patrick Air Force Base
CF	Condenser Fan
CFR	Code of Federal Regulations
DoD	Department of Defense
DX	Direct Expansion as applied to refrigerant in air-conditioning equipment
ECU	Environmental Control Unit
EER	Energy Efficiency Ratio, the ratio of cooling provided to power consumed in Btuh/ Watt
ESCO	Energy Service Company
ESTCP	Environmental Security Technology Certification Program
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEER	Integrated Energy Efficiency Ratio
MBH	1,000 British Thermal Units per Hour
MCAS	Marine Corps Air Station
MCASB	Marine Corps Air Station Beaufort
NOTU	Naval Ordnance Test Unit
OEM	Original Equipment Manufacturer, such as Carrier, Trane, Lennox, York, McQuay
ORNL	Oak Ridge National Laboratory/U.S. Department of Energy
PBM	Performance-Based Maintenance
PMV	Predicted Mean Vote
RH	Relative Humidity
ROI	Return on Investment
RTU	RoofTop Unit
RTUCC	RoofTop Unit Comparison Calculation
SBC	Single Board Computer
SIR	Savings to Investment Ratio

SME	Subject Matter Experts
TXV	Thermal Expansion Valve

EXECUTIVE SUMMARY

Technology Description

The EER Optimizer® minimizes direct expansion (DX) air conditioner energy use by measuring real-time operational efficiency. It is a versatile diagnostic and control technology that measures the Energy Efficiency Ratio (EER) of operating direct expansion air-conditioner and heat pump systems. The EER Optimizer provides easy web access for monitoring and reporting EER, Integrated EER (IEER), and Tons Capacity, and detects faults such as low refrigerant, stuck Thermostatic Expansion Valve (TXV), restricted airflow, broken economizer and fouled coil, all viewable at EERoptimizer.com The portable version is web connected for remote technical assistance, storing readings on a cloud server for later retrieval and analysis, and to support evaluation of historical trends, reporting, and documentation.

Incorporating the results of this demonstration into policy, training, and Heating, Ventilation and Air Conditioning (HVAC) management, design and procurement standards would contribute significantly to addressing the potential for efficiency improvement in unitary HVAC equipment. Implementation of the technology is straightforward and the cost is low enough to meet payback period and return on investment thresholds for Energy Saving Performance Contract (ESPC) and Utility Energy Saving Contract (UESC)-funded projects.

Objectives of the Demonstration

Three demonstration sites provided a full range of conditions for the EER Optimizer technology to evaluate the flexibility and efficacy needed for the widely varying climates of U.S. Department of Defense (DoD) installations. The demonstrations included onboard controls installed on operating package air conditioners at sites in South Carolina, Florida, and California, as well as use of handheld EER Optimizer technology to demonstrate effectiveness when used as an Operations and Maintenance (O&M) tool by HVAC technicians. The demonstration had the following major objectives:

- Establish the cost effectiveness of the technology in both onboard and portable versions.
- Document the reliable operation of onboard EER Optimizer technology.
- Document practicality, usefulness, and simplicity of diagnostics.

Demonstration Results

The reduction in normalized air-conditioner energy usage averaged 28% among the three demonstration sites. Reduction at Fort Irwin was 30%, reduction at Marine Corps Air Station Beaufort (MCASB) was 24%, and reduction at Cape Canaveral Air Force Station (CCAFS) was 30%. All three units exhibited a significant increase in IEER and commensurate decrease in weather normalized energy use for a cooling season, relative to baseline IEER measurements. The average improvement in measured energy efficiency as IEER was 19.7%.

There was a wide variation in cost effectiveness across the three demonstration sites, and the payback period ranged from 3.2 to 5.8 years. Larger air conditioners in warmer climates using more energy will provide shorter payback period. The portable EER Optimizer's fault detection and diagnostics provided energy savings averaging 22% over groups of 10 package air conditioners at each site.

The equipment service needs indicated by the portable unit produced payback periods ranging from 0.4 to 1.1 years, with savings-to-investment ratio (SIR) ranging from 1.0 to 2.4 for the thirty-packaged air-conditioners.

Implementation Issues

Overall, indoor air quality and thermal comfort were unchanged or improved, and temperature and humidity were more tightly controlled. There was reduction in the level and severity of unplanned and/or emergency repairs. The EER Optimizer system allowed project engineers to identify performance issues sooner and prevent more severe failures. Technicians using EER Optimizer stated that the remote fault detection and diagnostics feature is a key benefit for them. Overall, the occupant comfort perception survey responses were more positive for the test period than they were for the baseline period.

A key lesson learned centers around the condition of the air conditioner units selected for field retrofit. It is critical that equipment be well-maintained and in good operating condition. The applicable capacity range of DX Air conditioners for this technology is 10 to 100 tons (120,000 to 1,200,000 Btuh). Units that do not have the original factory compressors are not good candidates for retrofit. If unavoidable, the cost of refurbishing or making repairs to equipment in poor condition should be included in the project economic evaluation. In addition, EER Optimizer-enhanced Rooftop Units (RTUs) may be a viable and cost-effective replacement for aging chilled water cooling systems, especially if the reduction of water consumption is desired. Project buy-in from the installation HVAC maintenance shop and/or base maintenance contractor as well as the contracting officer is essential to successful implementation.

Project and procurement justification can be based on one or more of the following benefits:

- Continuously optimizes operational parameters to minimize energy costs while improving occupant comfort and productivity.
- Slows performance deterioration and potentially adds years of service life before replacement is needed.
- Provides a realistic and objective assessment of in-situ equipment operating condition to guide the repair vs. replace decision process.
- Detects and diagnoses faults for performing targeted preventive maintenance or supporting Performance-based Maintenance (PBM) to maximize cost effectiveness.
- Provides remote connection to identify issues before they become problematic, for faster response to an occupant complaint, and to enhance technician productivity.

Factory installations typically provide more attractive project economics than field retrofits. Specified DX package unit(s) are shipped to ClimaTek HVAC LLC from the Original Equipment Manufacturer (OEM) and then to the project site. Allow 8 weeks in the project schedule for installation, testing and shipping. For full functionality an internet connection will be needed. This can be provided by, in order of preference, (a) facilities Local Area Network (LAN), (b) installation VLAN, (c) Virtual Private Network (VPN) over dedicated Wide Area Network-Internet Service Provider (WAN-ISP), or (d) self-contained cellular. Cybersecurity features of the system include data encryption, layered credentials, two-factor authentication, and intrusion detection.

1.0 INTRODUCTION

Commercial unitary HVAC systems, or rooftop air conditioners, are used to cool over 60% of U.S. commercial floor area.[1] Military installations utilize unitary HVAC technology for space conditioning in buildings such as commissaries, schools, and theaters, and in Environmental Control Units (ECUs) used for mobile operations. In addition, many public buildings, such as schools and libraries, employ rooftop air conditioners for cooling. Rooftop units are also available in heat pump models as an alternative to fuel gas or electric resistance heating.

EER Optimizer® is a versatile diagnostic and control technology that measures the Energy Efficiency Ratio (EER) of operating RTUs and provides a basis for optimizing equipment energy use by directly measuring real-time, in-situ operational efficiency, a capability not available with competing technology. The patented [2] technology is analogous to the feedback control of central plant HVAC systems, which provide much more efficient cooling than RTUs. The demonstrations of the EER Optimizer technology included onboard controls installed on operating RTUs at three demonstration sites, as well as use of handheld EER Optimizer technology to demonstrate effectiveness when used as an Operations and Maintenance (O&M) tool by HVAC technicians.

1.1 BACKGROUND

Unitary DX split-system and package air conditioners and heat pumps are ubiquitous in the Department of Defense (DoD) facilities and mobile units (ECUs). The large potential for improvement makes unitary systems an outstanding target for DoD facility energy efficiency upgrades. The energy efficiency of current unitary HVAC systems is much less than that of distributed chilled water systems and few cost-effective choices exist for increasing their energy efficiency. Although DoD facilities utilize central chilled / hot water plants for large building heating and cooling, facilities such as commissaries, base exchanges, theaters and schools are often located remotely from chilled/hot water distribution piping and are therefore served by stand-alone unitary-DX HVAC systems.

Unitary HVAC systems are readily available in a range of capacities from 5 to 100 tons, have a relatively low first cost, and are easily serviced. However, even new best-in-class EER-14 commercial unitary[3] equipment does not give the 30% increase in efficiency over the American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE) Standard 90.1 desired to meet Federal energy reduction goals. Current recommended energy efficiency specifications published by the Consortium for Energy Efficiency (CEEE) for new unitary air conditioning and heat pump systems[4] establish Energy Efficiency Ratios (EERs) of 10.3 to 11.7 and Integrated Energy Efficiency Ratios (IEER) of 11.4 to 12.9, depending on system capacity.

[1] U.S. Dept. of Energy, Better Buildings program, June 17, 2013 webinar, *Advanced RTU Campaign*, https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/AdvancedRTUCampaignWebinar6-17-2013.pdf.

[2] US Patent numbers 6,427,454; 9,261,542; 9,574,810

[3] Commercial unitary equipment is understood to mean equipment over 5 tons capacity utilizing 3-phase electric power. EER-14 means an Energy Efficiency Rating of 14 Btuh of cooling per Watt of electric usage.

[4] The Consortium for Energy Efficiency (CEE), a North American non-profit organization with members including utilities, state energy offices, research organizations, and environmental groups, developed specifications for unitary systems in 2016 – see https://library.cee1.org/system/files/library/7559/CEE_ComACHP_UnitarySpec2016.pdf

Current models must meet the energy conservation standards specified in the Code of Federal Regulations[5] 10 CFR 431.97 of EER 9.8 to 11.2, depending on capacity. Upcoming Department of Energy requirements are a 13% increase in minimum efficiency (2018) and then a 28% (2023) increase[6]. However, the substantial base of installed unitary systems has an EER of 9.0 or less, dependent on system condition and maintenance history.[7]

EER is defined as the quantity of cooling provided per unit of electric power consumed, in units of 10^3BTU/hr per kW, sometimes notated as MBH/kW (MBtuH/kW), or simply Btuh per Watt. EER varies greatly with cooling load, refrigerant level, maintenance condition and airflow, age and wear and tear, among other factors. The energy efficiency of operating DX-packaged and split cooling units is not directly and continuously measured, as with large campus chilled water HVAC plants, using current technology. Instead, energy engineers and service technicians use indirect indicators of equipment performance to subjectively assess efficiency. Technicians adjust operating parameters according to manufacturer guidelines and standard field practice, which varies with technicians' level of experience. Current practice does not maximize the operating EER of unitary DX equipment, rather, the general goal is to avoid comfort complaints.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overarching performance objective is to increase energy efficiency and reduce energy consumption of the target unitary DoD air-conditioning equipment with EER metering and feedback control technology.

1.3 REGULATORY DRIVERS

- Installations Energy Instruction DODI 4170.11
- Energy Policy Act of 1992
- Energy Policy Act of 2005
- Executive Order 16393
- GSA 2010 Facilities Standards (P100)
- ASHRAE Energy Efficiency Standard 90.1
- ASHRAE Green Standard 189.1
- ASHRAE IAQ Standard 62.1 (2013 § 5.9)

[5] https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec431-97.pdf

[6] https://www.ecfr.gov/cgi-bin/text-idx?SID=8a5b57743b0296e02d26b410d48df7d0&mc=true&node=se10.3.431_197&rgn=div8

[7] *Efficiency Maine* suggests assuming EER of 9.0 for systems 5-10 years old and 8.0 for systems 10-15 years old - http://www.efficiencymaine.com/pdfs/EM_SAW_Rooftop.pdf

2.0 TECHNOLOGY DESCRIPTION

EER Optimizer technology is embodied in two versions. The “onboard” version is installed into a unitary system, such as a rooftop package unit, and can automatically change the refrigerant charge level, cooling coil temperature and airflow, and fan speeds to continuously maximize energy efficiency. The applicable capacity range of DX Air conditioners for this technology is 10 to 100 tons (120,000 to 1,200,000 Btuh). The “portable” hand-held version is carried by service technicians and energy engineers, who use the values displayed on the touchscreen to tune refrigerant charge, fan speeds, and other parameters; to identify underperforming components such as a fouled condenser coil, to maximize energy efficiency, and to identify systems that are justified for replacement. EER Optimizer technology is well suited to DoD Performance Contracting efforts (ESPC and UESC) to reduce facility operating costs.

2.1 TECHNOLOGY OVERVIEW

2.1.1 Onboard Unit

The onboard efficiency controller version can be factory-installed in new equipment, as well as retrofitted to existing equipment to improve energy efficiency and cooling / dehumidification performance, reliability / uptime, and reduce energy costs. The onboard controller processor output corresponds to EER, which is maximized by continuously adjust fan speeds, refrigerant level and flow, and any/all other operating parameters in an operating unit, as cooling load and operating conditions vary. In contrast, the best competing technology can only select a high or low Condenser Fan (CF) speed based on temperature or pressure; and refrigerant level is fixed by the factory initially and adjusted after installation by a service technician.

2.1.2 Hand-held Unit

The portable service tool version can be deployed as an enhancement of, in addition to or instead of standard refrigerant system analyzers, which virtually every service technician is adept at using. The technology can be the centerpiece of a Performance-based Maintenance (PBM) system whereby service actions are targeted according to return on investment. The hand-held instrument enables a field service technician to directly evaluate the energy efficiency performance of any operating unit, adjust refrigerant level and fan speed, and perform other indicated service actions as needed to maximize IEER. The hand-held unit also enables faster and more accurate evaluation of potential energy savings from equipment replacement. The instrument uses familiar Schrader refrigerant pressure connections and clamp-on temperature sensors; a clamp-on refrigerant velocity sensor; and clamp-on electric voltage and current sensors. In all other respects, operation of the portable hand-held version is like the operation of refrigerant analyzers that service technicians currently use, requiring minimal training.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

There is no competing technology that continuously seeks the unique combination of operating parameters that minimizes electric usage per unit of cooling delivered. There is no competing technology that accurately measures the energy efficiency of an operating unit in the field, using the industry standard EER and IEER efficiency metrics.

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3.0 PERFORMANCE OBJECTIVES

The EER Optimizer demonstration had the following major objectives:

- Verify significant improvement in operating IEER using the portable version, including 5% improvement for well-maintained, properly charged DX equipment, and 20% improvement in equipment in need of curative maintenance actions, such as coil cleaning and/or refrigerant leak detection and repair.
- Establish the cost effectiveness of the technology in both onboard and portable versions.
- Document reliable operation of onboard EER Optimizer technology.
- Document practicality, usefulness, and simplicity of diagnostics for portable EER Optimizer technology.

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4.0 DEMONSTRATION SITE DESCRIPTION

Demonstration sites for both handheld and onboard versions of EER Optimizer are:

1. Cape Canaveral AFS (CCAFS) / Naval Ordnance Test Unit (NOTU), located within a mile of the seacoast in Cape Canaveral, Florida.
2. Marine Corps Air Station Beaufort (MCASB), located in coastal South Carolina.
3. Army Fort Irwin (AFI)National Training Center (NTC), located in the Mojave Desert near the Nevada - California border.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The EER Optimizer demonstration site at Marine Corps Air Station Beaufort, South Carolina, is Building 1283, the Base Exchange facility, which has 11 unitary air conditioning units located on the roof. One of these units, RTU-2, a 2003 20-ton Trane package unit utilizing R-22 refrigerant, was the demonstration platform for retrofit with Advantek's ClimaStat® technology in 2011 – 2013 [8]. The demonstration site at Cape Canaveral Air Force Station, Florida, is NOTU Building 1115 at CCAFS. This was also the site of a previous Environmental Security Technology Certification Program (ESTCP) project demonstrating ClimaStat® in a new Carrier 7½ -ton packaged air-conditioning package unit installed in 2012. The EER Optimizer demonstration site at Fort Irwin, California, is building 606, Public Works / Environmental. A 2010 12½-ton dual-compressor Carrier R410a package heat pump was retrofitted with the on-board version. The building and its air-conditioning system is typical of many at Fort Irwin.

4.2 FACILITY / SITE CONDITIONS

Three demonstration sites provided a full range of test conditions for the EER Optimizer technology to demonstrate the flexibility and efficacy needed for the widely varying climates of DoD installations.

The Florida and South Carolina sites are located at humid and temperate ends of the ASHRAE hot and humid climate region and both installations have several buildings served by candidate unitary-DX equipment with considerable cooling load. The Florida site is in ASHRAE Climate Zone 2A, with a winter heating season limited to a few days of below normal temperatures when heating is needed, and cooling / dehumidification is needed almost year-round. CCAFS experiences 3290 cooling degree-days per year on average. The South Carolina site is in ASHRAE Climate Zone 3A with a 4-month heating season, during which no cooling is needed and heat is provided by a gas burner. MCASB experiences 2650 cooling degree-days per year on average.

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[8] ESTCP project EW-201144 final report, *Demonstration and Testing of ClimaStat® for Improved DX Air-Conditioning Efficiency*, April 2013, Advantek Consulting, Inc.

Fort Irwin, California, has the high ambient temperatures and low humidity of the hot and arid Mojave Desert, needing much different optimal refrigerant levels than the Florida and South Carolina sites, especially due to the low critical temperature of R-410A as compared with legacy R-22 equipment. The California site is in ASHRAE Climate Zone 3B and experiences 2600 cooling degree-days per year on average. The DX units at Fort Irwin are heat pumps, which provide winter heat during the 4-month heating season, which can be severe at times.

5.0 TEST DESIGN

Fundamental Problem: *Unitary cooling and heat pump equipment rarely operates at peak EER. Operating conditions vary daily and seasonally with weather, and occupant loading and set points. And, equipment condition declines over years as components wear, foul and degrade, and due to minute refrigerant leaks.*

5.1 CONCEPTUAL TEST DESIGN

The testing aims to validate the assertions that EER Optimizer technology increases the operating energy efficiency level of DX package systems and reduces annual energy consumption and costs; results in no degradation of indoor air quality; operates reliably without adverse maintenance effects; and is cost effective. Three demonstration air conditioners field-equipped with the onboard EER Optimizer system were fully instrumented on both the airflow process and refrigerant cycle with dedicated data loggers and 45 sensors. The portable EER Optimizer technology was evaluated using measurements of the energy efficiency performance of ten air conditioner units at each demonstration site made to establish baseline and serviced performance levels.

Demonstration comparisons were conducted by way of two methodologies: (1) on same units using 'with / before' versus 'without / after' for the onboard version and (2) on several DX units using 'before' versus 'after' for the portable version. Metrics used to measure success were field-measured EER (Energy Efficiency Ratio = Btu/hr cooling / total unit Watts][9] and IEER (Integrated Energy Efficiency Ratio)[10]; cooling season electric kWh consumed – both calculated and normalized to cooling degree-day and heating degree-day (CDD and HDD) weather data for adaptation to other climate locations; actual tracked materials and labor costs versus realized electric savings; Indoor Air Quality (IAQ) via space relative humidity, temperature, and carbon dioxide levels and the fraction of occupied hours which these levels are deemed acceptable; and maintenance costs and the number and severity of unplanned or emergency maintenance interventions, if any.

5.2 BASELINE CHARACTERIZATION

Baseline data were collected before installing the EER Optimizer onboard system on the three demonstration DX units, and before any adjustments or maintenance were carried out on the 30 DX units using the portable instrument. Additional onboard baseline data was collected during the third cooling season during selected benchmark days when the EER Optimizer control functions were disabled to operate the unit in its baseline configuration to obtain a performance benchmark.

[9] ANSI/ASHRAE Standard 37-2009. Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment. Approved by ANSI on 25 June 2009.

[10] ANSI/AHRI Standard 340/360-2007 with Addenda 1 and 2 (Formerly ARI Standard 340/360-2007), 2007 Standard for Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment. Approved by ANSI on 27 October 2011.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

EER Optimizer technology provides an accurate and practical analysis of the energy efficiency of any operating DX Air conditioner or heat pump unit, expressed in standard units by measuring the cooling or heating capacity and the power usage. The cloud linked optimizer system software is easily updated via code changes that are automatically pushed out to all onboard and portable units as a soft update. The technology provides web monitoring and reporting of EER, IEER, and Tons Capacity and detected faults such as low refrigerant, stuck TXV, restricted airflow, broken economizer, compressor wear, or fouled coil, viewable at EERoptimizer.com

The handheld version of the technology is embedded in a portable instrument, which is intended to be connected to various points on an operating air-conditioner or heat pump and removed at the end of a typical 1- to 2-hour service call. The portable unit is web connected for remote technical assistance, storing readings on a cloud server for later retrieval and analysis, and to support evaluation of historical trends, reporting, and documentation. Diagnostics include low refrigerant, stuck TXV, restricted airflow, compressor wear, and fouled coil. The onboard version is embedded in a unitary controller, which is permanently installed into the DX unit. It controls fan and blower speeds, damper position, and refrigerant charge level, as well as performing fault detection and diagnostics via an internet-connected web interface. Sensitive diagnostics detect issues before they become problematic.

The onboard version of the technology makes adjustments for the purpose of maximizing measured energy efficiency in a relational feedback loop utilized to optimize cooling or heating capacity relative to power consumed. The target is maximum EER while precisely meeting sensible and latent loads. Optimum parameter adjustment is a function of the load under which the air conditioner or heat pump is running. In order to demonstrate simultaneous optimization of several parameters, the three demonstration units, if not already equipped, were equipped with commercially available variable speed supply and CFs, a bypass damper with a commercially available actuator, and a refrigerant charge reservoir and commercially available solenoid valves.

At the demonstration sites, cybersecurity was addressed via a VPN on an isolated internet connection. In general, installations are accepting of Ethernet hardwire facility network connections over a VLAN or dedicated WAN; Wi-Fi has been used but is discouraged or not permitted. Dependence on the network for execution of control strategies has been avoided, specifically, basic control functionality is available during a network outage; for example, blower, fan and compressor start/stop and basic speed control algorithms are internal to the Single Board Computer (SBC). For high level optimization, trending, remote monitoring and alarm functions, dependence on the network is unavoidable. A display panel and dedicated Level 2 front end are physically co-located with the equipment. If required, additional steps can be taken to protect critical functions from modification over the network, including barriers to manipulation, security diagnostic software, encryption, and two-factor authentication.

5.4 OPERATIONAL TESTING

The baseline phase was during the 2014 cooling season, when data was collected before installation of the technology, as listed in the table below. The test phase was the 2016 cooling season, when data was collected after the technology was installed and fully operational.

The tables below list for each demonstration site the cooling degree-days for the respective year, the start and end dates of the data collection periods, the number of days and the cooling degree-days in the data collection periods.

Table 1. Baseline and Test Data Period Start and End Dates and Cooling Degree-Days.

DATA PERIOD - Baseline

Site	CDD-2014	Start	End	Days	CDD
MCASB (SC)	2627	7/27/14	10/8/14	73	964
AFI-NTC (CA)	3225	9/2/14	10/4/14	32	529
CCAFS (FL)	3633	6/28/14	10/14/14	108	1804

DATA PERIOD - Test

Site	CDD-2016	Start	End	Days	CDD
MCASB (SC)	2851	6/8/16	9/7/16	91	1715
AFI-NTC (CA)	2788	6/8/16	9/26/16	110	2160
CCAFS (FL)	3588	6/5/16	9/8/16	95	1690

5.4.1 Onboard System Performance Measurements

The 2014 baseline data was supplemented by periodic benchmarking during the 2016 cooling season by setting the technology run mode to “Manual,” which suspends the automatic and optimization control functions. Benchmarking was performed to account for equipment wear and deterioration that occurred between the end of the 2014 baseline period and the start of the 2016 test period, a span of 20 months centered on the 2015 cooling season during which the technology was installed, calibrated, and refined.

Operating data was used to compare performance of systems with and without or before and after EER Optimizer technology implementation. The results were correlated to climatic (outside temperature, relative humidity) and operational variables (setpoint temperature, outside air ventilation, indoor relative humidity and carbon dioxide levels). The reduced and verified data were analyzed to calculate the effect on the performance objective variables; specifically, energy efficiency, energy cost, cooling and dehumidification performance and occupied space indoor air quality.

Space indoor air quality (IAQ) was evaluated by counting the number of data sample intervals during which the indoor space temperature, humidity, and carbon dioxide level are within the comfort parameters defined by ASHRAE Standard 62.1 *aka* “The IAQ Standard” and ASHRAE Standard 55 *aka* “The Comfort Standard.” These parameters were compared ‘with’ versus ‘without’ the EER Optimizer onboard version.

Nearing completion of the respective demonstration projects, each host facility point of contact were asked about their interest in keeping the EER Optimizer system in operation or, alternatively, returning the units to their pre-demonstration condition. All three hosts indicated a preference for keeping the EER Optimizer system in operation if possible.

5.4.2 Handheld Portable Performance Measurements

A total of 30 DX HVAC units were randomly selected at CCAFS, MCASB, and AFI-NTC. The i-Optimize portable system was used to test energy efficiency (EER and IEER), cooling capacity (Tons) and detect issues such as low refrigerant, stuck TXV, restricted airflow, fouled condenser coil, compressor wear and the like. EER and IEER indicate the amount of cooling provided per unit of electrical energy consumed in units of Btuh per Watt.

CCAFS

The average age of the ten tested units was 10.9 years. The as-found energy efficiency degradation versus factory rating averaged 39%. The average factory energy efficiency rating of the units is IEER 11.9, the measured energy efficiencies average IEER 7.2, and the energy efficiency after servicing is IEER 9.3, which is a 22% improvement. The refrigerant circuits averaged 18% undercharged, ranging up to 6.4 lbs. undercharged. Diagnostics included fouled condenser coils on all units except building 1115 and 52003, likely due to the corrosive coastal salt air. With servicing the loss of energy efficiency was reduced from 39% to 14%.

MCASB

The average age of the units was 13.3 years. The as-found energy efficiency degradation versus factory rating averaged a 42% loss of efficiency. The average factory energy efficiency rating of the units is IEER 11.0, the measured energy efficiencies average IEER 6.4, and the energy efficiency after servicing was IEER 8.8, which is a 26% improvement. The refrigerant circuits averaged 18% undercharged. Diagnostics included a control issue on RT-5, fouled condenser coils on RT-6 and RT-9, and a failed CF on RT-7.

AFI-NTC

The average age of the units was 7.8 years. The as-found energy efficiency degradation versus factory rating averaged 25%. The average factory energy efficiency rating of the units is IEER 11.3, the measured energy efficiencies average IEER 8.4, and the energy efficiency after servicing is IEER 10.3, which was a 19% improvement. The refrigerant circuits averaged 16% undercharged, ranging from 0.1 to 9.4 lbs. undercharged. Diagnostics included failed CFs on two units at building 308 and the food court unit at Exchange bldg. 918.

6.0 PERFORMANCE ASSESSMENT

6.1 PERFORMANCE OBJECTIVES FOR ONBOARD TECHNOLOGY

6.1.1 Increase AC Units Energy Efficiency

Cooling season electric demand and consumption – both actual and adjusted to cooling degree-day (CDD) weather data for straightforward adaptation to other climate locations – is listed in the tables below. The reduction in normalized energy usage averaged 28% among the three demonstration sites. Reduction at Fort Irwin (AFI) was 30%, reduction at MCASB was 24%, and reduction at CCAFS was 30%. There was no significant change in peak electric demand between the baseline and test periods.

Field-measured IEER (Integrated Energy Efficiency Ratio – weighted Btuh/Watt) was calculated for each demonstration unit. All three units exhibited a significant increase in IEER and commensurate decrease in normalized energy use for a cooling season, relative to baseline IEER measurements. The average improvement in measured IEER was 19.7%. Improvement at Fort Irwin (AFI) was 34%, improvement at MCASB was 13%, and improvement at CCAFS was 12%. Propagation of error analysis shows IEER measurement accuracy of ±0.6 Btuh/Watt which is about 4% of the measured test values.

A comparison of field measured IEER versus a test period benchmark is shown in the table below. The benchmark values account for equipment deterioration that occurred in the 20 months from the 2014 baseline period to the 2016 test period, especially at CCAFS where the benchmark IEER 12.8 was significantly degraded from the baseline IEER 13.9. The average improvement in measured IEER was 21.7%. Improvement at Fort Irwin (AFI) was 30%, improvement at MCASB was 13%, and improvement at CCAFS was 22%. Reduction in energy use averaged 25%.

Table 2. Energy Efficiency Comparison and Savings of Optimized Operation with Test Period Benchmark.

ENERGY EFFICIENCY - Test versus Benchmark

	Site	CCAFS	MCASB	AFI-NTC	**Average**
IEER	Factory Rated	13.2	11.2	10.7	**11.7**
	Baseline (2014)	13.9	11.8	9.5	**11.7**
	Benchmark (2016)	12.8	11.9	9.8	**11.5**
	Optimized	15.5	13.4	12.8	**13.9**
Results	Point Increase	2.7	1.6	3.0	**2.4**
	Efficiency Gain	22%	13%	30%	**21.7%**
	Energy Savings	30%	24%	22%	**25.2%**
Stats	*Confidence Anova*	*0.997*	*0.998*	*0.965*	***0.965***
	Confidence t-Test	*0.99886*	*0.99997*	*0.99878*	***0.9988***

6.1.2 Maintain or Improve Facility Indoor Air Quality (IAQ)

Overall, indoor air quality and thermal comfort was improved or unchanged. Temperature, Relative Humidity (RH) and carbon dioxide (CO_2) data was collected in the zones served by the demonstration DX units to establish a performance baseline. Data collection continued during EER Optimizer use, providing a basis for comparison between "before" and "after". A comfort level metric was computed 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.

CCAFS

Temperature, humidity, number of people dissatisfied, and PMV were significantly improved in the test data set relative to the baseline data as shown in Table 5. There was no change in ventilation level, which was adequate 100% of the time. The temperature was 1.1 degrees-F cooler, corresponding to the aforementioned change in set point. The RH was slightly improved on average and the temperature and humidity were more tightly controlled relative to the baseline period.

MCASB

While there was no significant change in humidity or ventilation for the test period relative to the baseline data, space temperature was about 2 degrees-F warmer during the test period much of the time. The warmer temperatures on average are accounted for by the increase in space set point from 73F to 75F to comply with energy management policy. Because of the wide BAS control dead band and slow unit response, space temperature was more often pushed beyond the ASHRAE comfort zone limit.

AFI-NTC

Temperature control was improved in the test period relative to the baseline period, with the percentage of hours classified as "warm" dropping from 65% to 10%. Although there was no change in setpoint, median temperature dropped from 80.4F to 74.2F. Building 606 is small and has an exposed metal-frame metal roof. The building's low thermal mass and insulation level present a dynamically challenging load to conventional air conditioner controllers because space temperature rises quickly when the compressors cycle off. There was no significant change in humidity or ventilation. Time in the comfort zone was not improved because the extremely dry conditions were below the comfort zone limit most of the time. Temperature was more tightly controlled relative to the baseline period.

6.1.3 Demonstrate Cost Effectiveness of EER Optimizer Technology

Energy savings values shown in § 6.1.1 show a reduction in normalized energy usage averaging 28% among the three demonstration sites. Reduction at AFI was 30%, reduction at MCASB was 24%, and reduction at CCAFS was 30% relative to baseline energy consumption. The electric usage of each unit is shown in the table below; note MCASB usage is over twice that of AFI and CCAFS because the air conditioner unit is twice as large: 20 tons at MCASB versus 12½ tons at AFI and 8¼ tons at CCAFS. Payback period averages 4.8 years and annual return on investment averages 22% for the demonstration units.

Table 3. Energy Savings and Life Cycle Cost Values from the Three Demonstration Sites.

LIFE-CYCLE COST - Test Units

	Electric	Energy Saved		Economics	
Site	2016	kWh	Annual	Payback	Annual ROI
MCASB (SC)	$4,495	13,972	$1,397	3.2	31%
AFI-NTC (CA)	$1,783	5,551	$777	5.8	17%
CCAFS (FL)	$1,944	5,998	$840	5.4	19%

Economics cost basis is $4,538 as a factory installed system.

There is a wide variation in cost effectiveness across the three demonstration sites, payback period ranges from 3.2 to 5.8 years. In general, larger units having more energy usage will provide more energy savings. Because the cost of the technology is insensitive to equipment size, it follows that more energy savings at the same cost will result in better project economics.

Installation of the technology on larger units gives a shorter the payback period, along with higher return on investment (ROI) and savings to investment ratio (SIR). Similarly, higher cooling loads, longer cooling seasons, and/or higher outdoor temperatures tend to provide more energy savings and better project economics. A secondary savings factor is load profile: cooling load that is steady over the day will provide more savings than a load that rapidly rises to a peak at mid-day and then quickly subsides by late afternoon.

6.1.4 Maintain or Improve Reliability of the AC unit

Repair needs of the demonstration units were compared between the baseline, transition, and test periods. There was a reduction in the level and severity of unplanned and/or emergency repairs, from baseline season to test season. The EER Optimizer system allowed project engineers to identify performance issues sooner and prevent more severe failures. The types of service actions needed in the test period had a lower cost associated with them, indicating that the 57% average reduction in total service costs is at least partially attributable to the EER Optimizer technology. The demonstration units were continuously functional and comfort conditions were maintained at all times during the demonstration, except when powered down for service.

6.1.5 Manageability Using Existing Facility HVAC Staff and Resources

At each demonstration site during the transition period cooling season 2015, a presentation and technology walk-through was held for the HVAC shop supervisor and technicians assigned to work on DX equipment. The following cooling season 2016, a follow up technology review and Q&A session was held with the Facility Manager, shop supervisor, subject matter expert, and technicians to address any concerns and solicit feedback. HVAC technicians at all three demonstration sites agreed the technology can be serviced and maintained with existing staff. Some technicians stated, and most others agreed that the remote fault detection and diagnostics feature of the EER Optimizer system is a key benefit for them.

6.1.6 Reliability of AC Unit Relative to Reliability of Baseline Unit

The reliability of the demonstration equipment is largely related to the initial system design, including unit sizing, ductwork, and controls; the operating environment, maintenance practices, occupant interventions, as well as manufacturer-determined robustness of technology. To evaluate reliability, we qualitatively assessed reliability of the baseline demonstration units using maintenance data collected prior to using EER Optimizer being installed. The service log entries from the three demonstration units are summarized below.

MCASB

Overall, it appears this unit during the test period was as or more reliable than during the baseline and transition periods. The demonstration unit was originally installed in 2003 and is nearing the end of its service life. Maintenance needs during the test period were reduced overall, however, there were new service needs related to the technology.

AFI-NTC

Overall, it appears this unit during the test period was as reliable as during the baseline and transition periods. Maintenance needs during the test period were reduced overall, however, there were new service needs related to the technology. The blower belt needed replacement because of rapid wear due to the blower drive settings.

CCAFS

Overall, it appears this unit during the test period was as reliable as during the baseline and transition periods. Maintenance needs during the test period were slightly less overall, however, there were new service needs related to the technology.

6.1.7 User Satisfaction

Occupants at the demonstration sites were surveyed regarding their perceived performance of the air conditioning system using a Likert-type survey instrument. The survey was designed to measure changes in satisfaction with the perceived thermal and ventilation comfort provided by the subject technology. The survey questions and response scales are presented in § 5.5 and repeated below for convenience. See Appendix E for response data. There was a 0.20 increase in calibration responses from baseline to test at AFI and CCAFS; survey results were adjusted accordingly. There was a consensus that energy was being used more efficiently.

Overall, the survey responses were more positive for the test period than they were for the baseline period. The largest improvement was at Fort Irwin, presumably because of the cooler and more consistent temperature and improved air circulation provided by the EER Optimizer technology. This was reflected by the improved responses to all questions. Most of the improvement at CCAFS was to questions 3 and 5 indicating improved ventilation air flow. There was no significant improvement in the MCASB responses; however, there was complete staff turnover between the baseline and the test periods and responses were mostly neutral.

ANONYMOUS AIR CONDITIONING SURVEY

scale for questions 1, 2 and 3. 1-very unsatisfied 2-unsatisfied 3-neutral 4-satisfied 5-very satisfied

1. How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?
   [note: calibration question]
2. How satisfied are you with the temperature in your workspace?
3. How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?

scale for question 4 and 5. 1-interferes 2-somewhat interferes 3-neither 4-somewhat enhances 5-enhances

4. Does your thermal comfort in your workspace interfere with or enhance your ability to get your job done?
5. Does the air quality in your workspace interfere with or enhance your ability to get your job done?

scale for question 6. 1-inefficient 2-somewhat inefficient 3-average 4-somewhat efficient 5-efficient

6. Considering energy use, how efficiently is this building performing in your opinion?

6.2 PERFORMANCE OBJECTIVES FOR PORTABLE TECHNOLOGY

6.2.1 Increase AC Units Energy Efficiency

Overall across the three DoD installations included in the demonstration, the energy efficiency of the 30 tested DX HVAC units was measured to have deteriorated by 35% from the factory IEER rating using the portable EER Optimizer (*i*-Optimize) unit. Average unit age was 10.6 years. Refrigerant loss averaged 17% and totaled 104 lbs., while correcting under / over charge was estimated to provide energy savings of 10%. Partial restoration of energy efficiency via targeted servicing indicated by the portable EER Optimizer unit fault detection and diagnostics, which were deemed cost effective, including coil cleaning, repairs, and correcting refrigerant charge provided energy savings averaging 22% including the refrigerant charge corrections.

6.2.2 Demonstrate Cost Effectiveness of EER Optimizer Technology

Annual energy savings estimates were computed using the measured IEER improvement of the demonstration DX units, the site cooling degree-days, and the site total cost per kWh rate. Implementation costs include the *i*-Optimize portable unit at $3,000, about 8 hours/year labor on average per HVAC unit, and approximately $1,000 parts and $550 refrigerant at each site.

Average implementation cost per site for 10 packaged HVAC units was $11,748, or $102 to $188 per nominal ton. Annual predicted energy savings ranged from $11,310 to $26,573 per year for the 10 units evaluated, which is $181 to $231 savings per nominal ton per year. Economics of the *i-Optimize* technology and subsequent equipment servicing produced payback periods ranging from 0.4 to 1.1 years overall, with SIR ranging from 1.0 to 2.4 for the groups of 10 packaged HVAC units at the three DoD installations.

CCAFS experienced the largest savings, due to the combination of larger ton unit sizes combined with greater potential for improvement. Accordingly, payback period was the shortest at 0.4 year and savings to investment ratio was the highest at 2.4.

MCASB

Annual energy savings from servicing the 10 units is predicted to be $11,310 with a payback period of 1.1 years. Economic justification for annual servicing based on energy savings would be justifiable if reliability benefits, reduced potential for unit failure, and potentially extended service life were also considered.

AFI-NTC

Annual energy savings from servicing the 10 units is predicted to be $19,206 with a payback period of 0.6 years. Annual performance-based maintenance would be cost effective and the savings to investment ratio of 1.7 could meet Energy Service Company (ESCO) performance contract and ESIP funding thresholds.

CCAFS

Annual energy savings from servicing the 10 units is predicted to be $26,573 with a payback period of 0.4 years. Annual performance-based maintenance would be cost effective and the savings to investment ratio of 2.4 is well above ESCO performance contract and ESIP funding thresholds.

A white paper summarizing the results of the portable demonstration was shared with ESCO points of contact (Southern Company Energy Services, EMCOR, FPL Energy Services, and NORESCO) with a follow up phone discussion. All were interested in the technology and intend to look for application opportunities as an energy conservation measure.

7.0 COST ASSESSMENT

This section provides cost information so that an engineering professional can reasonably estimate costs for implementation at a given site.

7.1 COST MODEL FOR ONBOARD SYSTEM

Estimates are listed for each cost element as described in the table below. Equipment includes incremental cost of the EER Optimizer control unit and all sensors, not the air conditioner package unit. Installation costs for retrofit of an existing unit are considerably higher than a factory retrofit. The need for a temporary cooling unit at the site for use while equipment is being installed will depend on the weather and cooling load at the time of the project and is at the discretion of the facility manager. Estimation of annual energy savings requires input data including electric rates, geographic location, building usage, and cooling load. If the current cooling energy usage of an existing system is known, energy savings can be estimated at 25 to 28% as discussed in § 6.1.1. The range of measured savings among the three demonstration sites was 24% to 30%. It is recommended that Advantek Consulting Engineering be contacted to perform a Rooftop Unit Comparison Calculation (RTUCC) hourly energy usage model to obtain an accurate dollar savings prediction for a specific installation. Maintenance savings is the average of the tracked differential between baseline maintenance costs versus maintenance costs during the test period. Turnover is the cost for a training session for the Facility Manager, Subject Matter Expert (SME), HVAC Shop Supervisor and Technicians (factory cost includes travel to site). Remote monitoring of DX unit performance and diagnostics includes weekly interpretation of operating parameter trends, forwarding fault detection alerts and alarms to appropriate facility and/or maintenance personnel as they occur.

Table 4. Cost Model for Application of Onboard Technology to New or Existing DX Package Units.

COST MODEL FOR ONBOARD EER OPTIMIZER TECHNOLOGY

Cost Element	Data Collected During Demonstration	Factory New Unit	Retrofit Existing Unit
EQUIPMENT - Capital cost to purchase technology product and components	Paid invoices from vendors & suppliers. This is incremental cost of technology, does not include air conditioner package unit cost.	$4,689	$4,689
INSTALLATION - Labor and Materials	Labor & materials costs provided by subcontractors and accepted by prime, does not include prime / general contractor fees and markup	$3,368	$11,688
TEMPORARY HVAC - service during unit downtime	IF NEEDED depending on cooling load and time of year, service & equipment costs provided by subcontractors and accepted by prime, oes not include prime / general contractor markup	$420	$640
ENERGY SAVINGS - Facility annual operational cost differential	Costs assigned to specific HVAC units being modified, both before & after modifications, including energy and IAQ.	Depends on Unit Size and Climate	Depends on Size, Load and Climate
MAINTENANCE SAVINGS - Maintenance & servicing annual cost differential	Costs determined by facility maintenance managers for before & after modification, and for HVAC staff costs for training and use of EER Optimizer	$737	$737
TURNOVER - Training and monthly monitoring costs	Costs associated with Advantek providing training to maintenance & operational personnel at facility to maintain equipment, and remote monitoring, alerts and alarms	$570 + $80/mo	$235 + $80/mo

7.2 COST MODEL FOR PORTABLE UNIT

Estimates are listed for each cost element as described in the table below. Equipment includes the *i*-Optimize portable unit and a set of clamp-on sensors. Usage is the cost for two performance checks per year per DX unit plus a labor and small parts allowance based on an average of the amounts expended for servicing 30 demonstration units as indicated by *i*-Optimize fault detection and diagnostics. Estimation of annual energy savings requires input data including electric rates, geographic location, building usage, and cooling load. If the current energy usage of a DX unit is known, energy savings can be estimated at 22% as discussed in § 6.2.1. The range of measured savings among the 30 DX units was 4% to 40%. It is recommended that Advantek Consulting Engineering be contacted to perform an RTUCC hourly energy usage model to obtain an accurate dollar savings prediction for a specific installation. Maintenance savings is based on the tracked reduction of needed repairs. Turnover is the cost of a training session for the Facility Manager, SME, HVAC Shop Supervisor and Technicians.

Table 5. Cost Model for Application of Portable *i*-Optimze Technology.

COST MODEL FOR PORTABLE EER OPTIMIZER TECHNOLOGY

Cost Element	Data Collected During Demonstration	Estimated Cost
EQUIPMENT - Capital cost to purchase technology product	Paid invoices from vendors & suppliers	$3,000
USAGE - Annual Labor and Materials per DX Unit	Labor & materials costs by subcontractors and accepted by prime, does not include prime / general contractor fees and markup. Includes technician time, refrigerant, small parts.	$1,175
ENERGY SAVINGS - Facility annual operational cost differential	Costs assigned to specific HVAC units being modified, both before & after modifications, including energy and IAQ	Depends on Tons, Load and Climate
MAINTENANCE SAVINGS - Annual maintenance cost differential per DX unit	Costs determined by facility maintenance managers for before & after modification, and for HVAC staff costs for training and use of EER Optimizer, both handheld & onboard versions	$438
TURNOVER - Training	Costs associated with Advantek providing training to maintenance & operational personnel at facility to use handheld version and maintain equipment	$435

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8.0 IMPLEMENTATION ISSUES

Information that will aid in the implementation of the technology is explained below.

1. A key lesson learned from implementation of the technology at the demonstration sites centers around the condition of the air conditioner unit(s) selected for field retrofit. It is critical that equipment be well-maintained and in good operating condition. The applicable capacity range of DX Air conditioners for this technology is 10 to 100 tons (120,000 to 1,200,000 Btuh). Units that do not have the original factory compressors are not good candidates for retrofit. If unavoidable, the cost of refurbishing or making repairs to equipment in poor condition should be included in the project economic evaluation.

2. EER Optimizer enhanced RTUs may be a viable and cost-effective replacement for aging chilled water cooling systems, especially if reduction of water consumption is desired.

3. Project buy-in from the installation HVAC maintenance shop and/or base maintenance contractor and the contracting officer is essential to successful implementation.

4. Project justification can be based on one or more of the following benefits:

    a. *Continuously optimizes operational parameters to minimize energy costs while improving occupant comfort and productivity.*
    b. *Slows performance deterioration and potentially add years of service life before replacement is needed.*
    c. *Provides a realistic and objective assessment of in-situ equipment operating condition to guide the repair or replace decision process.*
    d. *Detects and diagnoses faults for performing targeted preventive maintenance or supporting performance-based maintenance to maximize cost effectiveness.*
    e. *Provides remote connection to identify issues before they become problematic, for faster response to an occupant complaint, and to enhance technician productivity.*

5. Cooling load, climate and electric rates are key drivers of project economics. Higher cooling load, longer cooling season, larger equipment size, and higher electric rate tends to mean shorter payback period and higher Adjusted Rate of Return (AROR) and SIR.

6. Factory installation will provide the best project economics. Specified DX package unit(s) are shipped to ClimaTek HVAC LLC from the OEM and then to the project site. Allow 8 weeks in the project schedule for installation, testing and shipping.

For full functionality an internet connection will be needed. This can be provided by, in order of preference, (a) facilities LAN, (b) installation VLAN, (c) VPN over dedicated WAN-ISP, or (d) self-contained cellular. Cybersecurity features of the system include data encryption, layered credentials, two-factor authentication, and intrusion detection.

7. Field retrofit costs are largely driven by mobilization and travel, so retrofit projects including at least two to four DX systems have an economy of scale and are easier to justify.

8. Unitary equipment older than one year are usually past the warranty period unless an extended warranty was purchased. Installation of the on-board EER Optimizer system requires adding components to the refrigeration circuit, which could result in a factory compressor warranty claim being denied. Typically, the EER Optimizer installer assumes responsibility for a compressor warranty claim if the manufacturer will not. Note that compressor operating temperature will be reduced, and compressors will be protected by the liquid-vapor separator installed upstream of the compressor, tending to reduce compressor stress.

9. Please reference the following peer reviewed publications for additional technical details.

West, Michael and Richard Combes, "Continuous Tuning of Refrigerant Charge to Improve DX Equipment Performance." ASHRAE Transactions, 2017 Winter Meeting.

West, Michael and Richard Combes, "Unitary HVAC Equipment: Performance Optimization Strategy and Field Tests." ASHRAE Transactions, 2016 Winter Meeting.

West, Michael and Richard Combes, "What Owners Need to Know About Rooftop Unit Maintenance." HPAC Engineering, Vol. 86, No. 10, pp. 18-23. October 2014. hpac.com/october-2014-digital-edition#5

West, Michael and Thomas Brooke. "Improvement of IEER Rating and Dehumidification Capability in Unitary DX Equipment." ASHRAE Transactions, 2013 Annual Meeting.

West, Michael and Richard Combes. "Improvement of Integrated Energy Efficiency and Latent Cooling Capability by Refrigeration Cycle Variation with Evaporator Coil Optimization in R-410a Unitary Equipment." ASHRAE Transactions, 2013 Annual Meeting.

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APPENDIX A POINTS OF CONTACT

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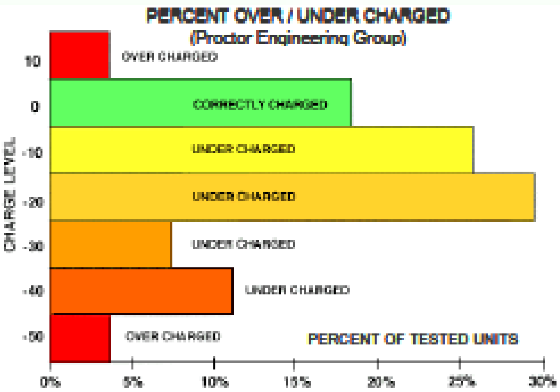
APPENDIX B TECHNOLOGY FACTSHEET

EER Optimizer Technology

The EER Optimizer provides an accurate and practical measurement of the EER of any DX cooling unit, expressed in the standard units of cooling capacity per unit of energy use (Btuh per Watt, MBH per kW, or COP) or as a 4-20mA control signal. Having the actual operating EER is key to improving efficiency, because it provides a realistic assessment of current equipment condition with feedback so operating parameters can be optimized.

Setting and maintaining refrigerant charge level is the most basic of service procedures, yet it is the most error prone.



Manufacturer-specified refrigerant level is often not set or maintained properly, which results in less than rated performance. In addition to leakage, even an adequately charged system will have too much refrigerant for some operating conditions and not enough for others. An air-conditioner's nameplate charge level is necessarily a manufacturer compromise to assure ample capacity/protection under all foreseeable operating conditions in all climates, yet it does not ensure optimal annual energy efficiency. The current refrigerant of choice (R-410a) is a mixture of two refrigerants (50% R-32 and R-125) that have differing thermodynamic properties and thus fractionalize, which further complicates determination and adjustment of the proper refrigerant level.

Maximize Energy Efficiency without having to rely on frequent service calls.

"…the air conditioning system can be performing below its capacity because of poor maintenance and maintain comfort while energy use increases."

"I don't see anyone really checking charge right, most technicians only do a touch method."

"I have even found 8 ounces overcharge on brand new units." [total charge is 5 to 8 pounds]

EER Optimizer technology has been incorporated into a prototype (1) hand-held service technician tool, and (2) on board refrigerant level and fan speed /airflow controller. For the service instrument, the EER measurement is clearly displayed, allowing a technician to immediately appraise the operating efficiency of any unit. The on-board controller continuously seeks to maximize EER via adjusting the coil airflow, refrigerant level, condenser fan speed, and other parameters as needed.

Measure, display, and feedback the actual operating EER of any unit.

Accurate and quick measurement of air-conditioner energy efficiency enables facility managers to economically justify major service or replacement of low-performing equipment. These air-conditioning units would otherwise unknowingly be operated at dismal efficiency levels. Cost is estimated at $1000 for a mass produced on-board controller version, and around $2000 for a commercial instrument.

"In general, service calls and annual tune-ups are not profit makers [for AC service contractors]."

"The bulk of the contractor's profits come from selling replacement parts and from selling a replacement air conditioner when the current unit fails."

"… it would be hard to implement [proper service] under the pressure of having several 'no cool' calls waiting for their arrival."

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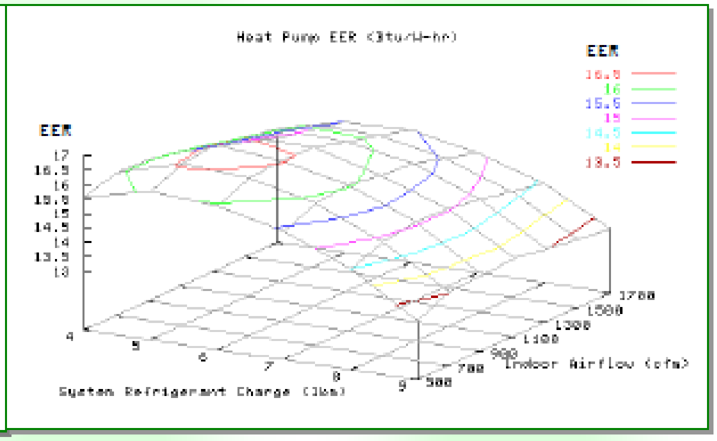
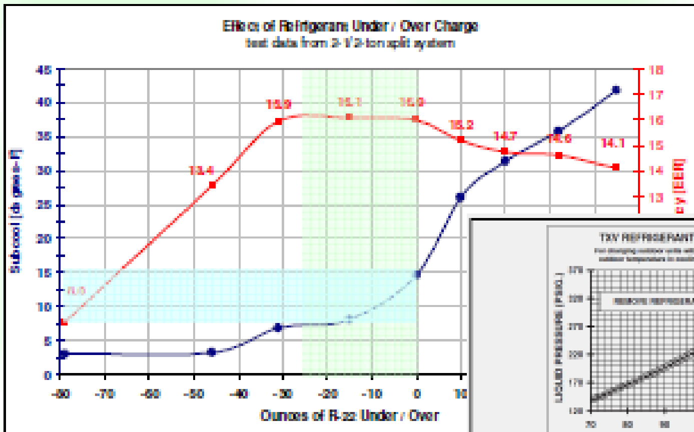
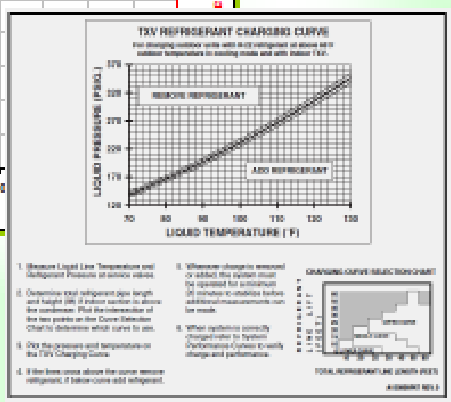
Heat Pump EER varies with Indoor Airflow over the cooling coil. The optimal System Refrigerant Charge in turn varies with Indoor Airflow in order to maximize the operating EER.

Consider a nominal system charge of 7.9 lbm for example: Maximum obtainable EER from the map is 15.0 at 1100 cfm. At low load, adjusting the charge to 4.7 lbm and decreasing coil airflow to 900 cfm increased EER to 16.7 - an 11% improvement at this low-load condition.







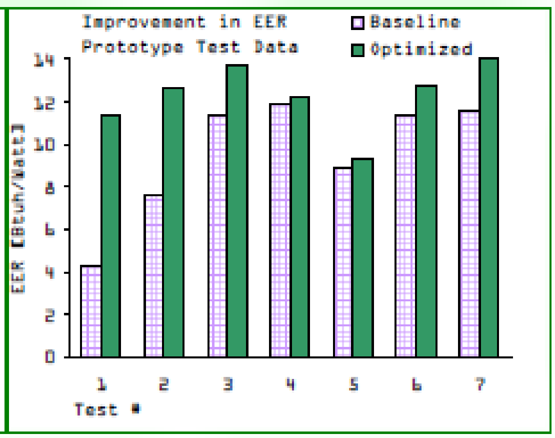
Ideally, technicians use the charging curve charts provided by the equipment manufacturer for each model they service. Followed closely, the charts guide charge adjustment to a nominal level. However, the resulting charge is not necessarily optimal for all operating conditions. The red line in the data chart shows how EER can degrade substantially from just a few ounces of under or over charge.

78% of units tested by Proctor Engineering Group were in the under-charged regime where EER drop-off is exceedingly steep.

[Downey, T. and Proctor, J. *What Can 13,000 Air Conditioners Tell Us?* Proceedings of the ACEEE 2002 Summer Study on Energy Efficiency in Buildings, 1:53-68.

Checks of 4,385 commercial DX units by Proctor Engineering Group indentified 60% of the units needed charge adjustment.

EER Optimizer Test Data demonstrates a significant EER increase averaging 42%. For example Test #6: The optimal charge at 1700 cfm and 84F ambient was 7.9 lbm. As outdoor temperature drops to 76F, airflow was adjusted to 1100 cfm to maximize EER and charge was adjusted to 8.4 lbm to maximize cooling capacity. This is because EER varies with outdoor air inlet temperature at the condenser coil. The required system refrigerant charge in turn varies in order to maximize cooling capacity. Current technology cannot make this adjustment.



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