ESTCP

EXECUTIVE SUMMARY

Performance-Based Maintenance Pilot for Unitary DX HVAC Equipment

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ESTCP Project EW18-5363

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ACRONYMS AND ABBREVIATIONS

BTU	British thermal unit
CCSFS	Cape Canaveral Space Force Station
DoD	U.S. Department of Defense
DX	direct expansion of refrigerant
ECM	energy conservation measure
EER	energy efficiency ratio
EFLHC	equivalent full load cooling hour
ESPC	energy saving performance contract
HVAC	heating, ventilation, and air-conditioning
IEER	integrated energy efficiency ratio
kW	kilowatt
kWh	kilowatt hour
NASKW	Naval Air Station Key West
O&M	operation and maintenance
PBM	performance-based maintenance
RTUCC	rooftop unit comparison calculator
SIR	savings-to-investment ratio
TAB	testing, adjusting & balancing
UESC	utility energy service contract

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1.0 INTRODUCTION

This performance-based maintenance (PBM) pilot demonstration addressed reductions in unitary direct expansion of refrigerant (DX) heating, ventilation, and air-conditioning (HVAC) energy use concurrent with routine periodic servicing, which has been shown to improve lifetime HVAC energy efficiency. Successfully piloting the energy saving technology with installation energy manager and technicians demonstrated to Department of Defense (DoD), energy service companies, and utilities the value of using PBM for unitary DX HVAC equipment.

Consistent and detailed monitoring of equipment performance relative to the baseline of a common energy-consuming system, such as unitary DX HVAC equipment, based on accurately measured energy efficiency, can show energy savings when installation energy managers incorporate monitoring results into their planning and decision-making over the service life of unitary DX HVAC equipment. This successful demonstration offers DoD a piloted basis and implementation guidance for including PBM in routine maintenance guidelines for unitary DX equipment and supports DoD's goals for energy savings and operating cost reduction.

This pilot was carried out via partnering with the installation energy manager, public works director and onsite HVAC maintenance technicians at Naval Air Station Key (NASKW). This approach offered an expeditious demonstration of deploying a new energy-saving technology with installation-level guidance and participation, rather than relying long-term on outsourced or utility contractors to implement and monitor energy savings and technology effectiveness.

2.0 OBJECTIVES

This pilot focused on demonstrating PBM as an effective protocol for maintaining optimum unitary DX HVAC performance *when implemented by the Energy Manager and the installation HVAC operation and maintenance (O&M) Team*. The overarching goal was integration of PBM into existing HVAC O&M by the DoD facilities personnel at the demonstration site. One objective of this pilot project was to expand the use of proven i-Optimize analyzer technology to demonstrate benefits and economics of accurate diagnostics and energy efficiency measurement of unitary DX HVAC systems that are used by all DoD installations. Primary objectives were realizing a measurable improvement in energy efficiency and demonstration of cost effectiveness when implemented at scale.

3.0 TECHNOLOGY DESCRIPTION

This pilot project focused on incorporating a newly demonstrated technology, *i-Optimize*, into a performance assurance protocol that could be utilized by DoD as an installation O&M requirement, or as a utility energy service contract (UESC) or energy saving performance contract (ESPC) energy conservation measure (ECM).

Improving and sustaining operational energy efficiency of unitary DX HVAC equipment via performance-based O&M and identifying poorly performing equipment to be replaced.

Figure ES-1. An i-Optimize Diagnostic Analyzer Being Used to Measure Performance of a Package AC Unit.

Figure ES-2. Clamps and Sensors Used with i-Optimize Diagnostic Analyzer.

i-Optimize is a portable diagnostic analyzer tool that a technician carries from one DX unit to another, temporarily affixing 12 clamp-on sensors (refrigerant pressures; refrigerant temperatures; ambient, entering and supply air temperature & humidity; static pressure; power leads) for comprehensive data collection and to guide servicing. One i-Optimize tool was used for servicing multiple units in succession. Use of the diagnostic analyzer can replace the use of conventional tools such as pressure gauges, ammeter, temperature sensors, and voltage meter, if desired.

i-Optimize technology provides an accurate and practical evaluation of the energy efficiency of any operating DX air-conditioner or heat pump unit, displayed on screen in standard units of British thermal units (BTU) per hour per watt (or thousand BTU per hour per kilowatt [kW]), by measuring the cooling or heating capacity and the power usage. Integrated energy efficiency ratio (IEER) is the standard metric used to measure and report unitary DX HVAC equipment performance by all manufacturers. The technology provides web monitoring & reporting of energy efficiency ratio (EER), IEER, tons capacity and detection and suggested diagnosis of faults such as low refrigerant, stuck thermal expansion valve, restricted airflow, broken economizer, compressor wear, or fouled coil.

Traditional HVAC field servicing technology used at DoD installations consisted of separate tools such as thermometers, analog pressure gauges, and voltage & current meters. Traditional procedures for HVAC service technicians consisted of using these instruments to diagnose a "no cooling" or "no heating" problem by taking readings of refrigerant pressures, temperatures and air flow, and voltage and/or current readings on electric motors used for fans, compressor and thermostat controls. The *i-Optimize* analyzer technology has been demonstrated to DoD installations as a superior diagnostic fault-detection and analytical tool, compared to the traditional HVAC field instrumentation and practices traditionally used for servicing and repairs. When used in a PBM program, it helped avoid future occupant complaints, excessive energy use, performance degradation, component failures, and reactive service calls. PBM could be integrated into existing O&M protocols or implemented as an ECM for UESCs and ESPCs. This pilot project demonstrated the following key features and benefits of the technology:

1. Detailed Diagnostics
   The *i-Optimize* diagnostic tool analyzes real-time energy efficiency and amount of cooling delivered, along with comparison to factory-rated performance. This real-time analysis quickly pinpointed operational parameters that were reducing the energy efficiency and performance of the equipment.

2. Interpretation & Documentation
   The *i-Optimize* diagnostic analyzer stores detailed operational readings and basic artificial intelligence interpretations. The installation energy manager or HVAC supervisor can download data at any location via a web browser. The *i-Optimize* cloud database supports detailed, consistent documentation of service action results; degradation of system performance over time; continuous commissioning / retro-commissioning and measuring & verifying; and comparative analysis of energy efficiency and cooling / heating performance at each service call.

3. <u>Connectivity & Communication</u>
   The advanced *i-Optimize* diagnostic tool connects field technicians via internet screen (Figure ES-1) sharing with a remote subject matter expert, such as the HVAC supervisor or energy engineer, for deeper evaluation when needed. This capability to leverage master technician's and HVAC engineer's experience to field service teams via screen sharing, data streaming, and documentation helps to quickly identify, diagnose, and remedy inefficient operation and operational issues that might be difficult for the servicing technician to identify and understand.

   Incorporating *i-Optimize* instrumentation into HVAC servicing required training of field technicians responsible for service and maintenance of unitary DX HVAC systems at NASKW. This training required four hours of classroom instruction and eight hours of field practice for each technician and facilities manager involved in HVAC servicing. Data collected by *i-Optimize* instruments used in the field were available in real time by connection to a web-based cloud server. The data was used to determine HVAC system energy efficiency and performance relative to baseline.

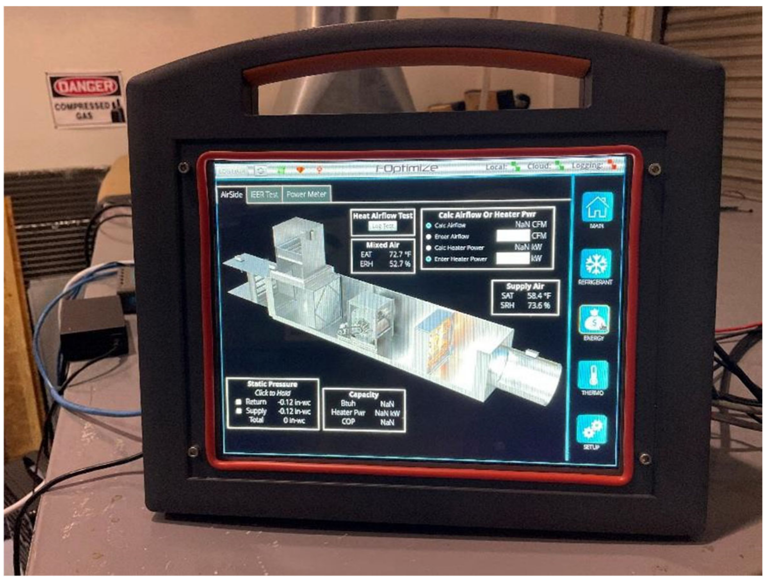

Figure ES-3. i-Optimize Diagnostic Analyzer Airside Energy Screen.

4.0 PERFORMANCE ASSESSMENT

Energy efficiency metrics for the DX air-conditioning systems included in this pilot were calculated for two PBM pilot phases: phase-1: *Baseline* and phase-3: *Evaluation*. First, phase-1: baseline measurements were gathered, followed by implementing the indicated service actions during phase-2: *Servicing,* and then post-service measurements were gathered during phase-3: *Evaluation.* Results showed measured energy efficiency as EER and IEER were both improved by about 30% on average in the group of selected systems that were serviced, compared with a measured 7% EER increase / 9% IEER *decrease* in the systems that were not serviced. The 30% efficiency improvement equated to restoration of 61% and 66% of the efficiency lost to degradation in EER and IEER, respectively. Degradation measured by the baseline evaluation indicated a loss of 27% of factory-rated efficiency.

Energy efficiencies of each DX system were also expressed as a percentage of factory rated efficiency. Calculated this way, servicing the DX systems improved energy efficiency by 20% of the factory rating, while there was an overall loss of 1% of efficiency in the systems that were not serviced. For comparison, the one DX system that was replaced provided a 57% measured efficiency improvement over the baseline factory rating. A wide range of improvement percentages were noted during this pilot, which emphasized the importance of PBM implementation across a large number of DX systems in order to realize consistent results.

The IEER energy efficiency measurement was used along with equipment and weather data to project the energy savings per year realized by carrying out PBM servicing. Metrics were compared to determine how PBM servicing affected energy efficiency, energy usage, and, to the limited extent that installation service records were available, reliability. Economics were calculated using the actual electric rate billed to the pilot site. Annual savings due to servicing the DX systems selected for this pilot was calculated to be 21%, which was about $33,000 per year at the NASKW electric rate of $0.1062 per kWh. One DX system was replaced giving a projected savings of 39%. See Figure ES-2.

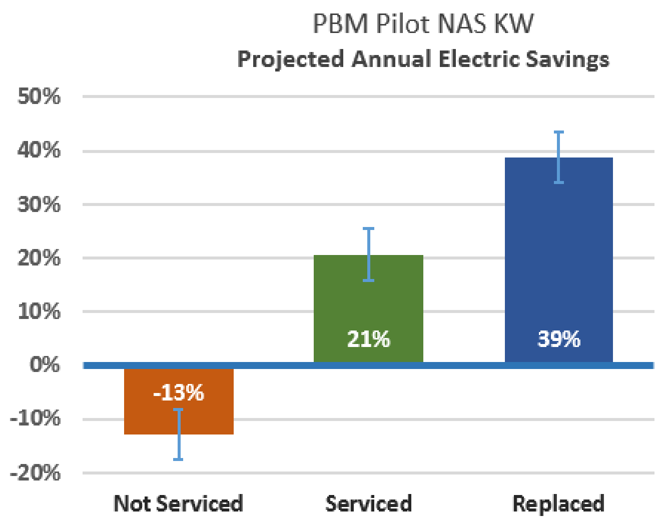

Figure ES-4. Projected Annual Electric Savings from the PBM Pilot.

Of the seven air-conditioning units that were designated to *not* be serviced, three of these failed entirely during the pilot project period, and one required unplanned emergency repair.

None of the 16 units that were serviced using the PBM protocol failed, and none required emergency repairs. Service notes for the failed units indicate “Compressor fail, motor winding bad” [unit asset number KWT-A350-PDR-01], “Condemned - bad compressor” [KWT-A350-PDR-03], and “One compressor failed” [KWT-N00213-PDR-010]. Package DX unit KWT-N00213-PDR-01, a 3-year old 15-ton American Standard / Trane unit experienced a compressor failure early in the pilot project due to compressor overheat from low refrigerant charge – an exceptionally rare failure mode in well-maintained units. During phase-1 baseline, measured superheat averaged 40.1 degrees-F and subcool was about 0 degrees-F, confirming failure could have been avoided by PBM servicing.

Estimated DoD maintenance cost for this unit since new was $132 labor, plus the compressor replacement cost of $1940 for a total cost of $2,072. PBM servicing cost would have been about $400, while the $1940 compressor failure, equipment downtime, and occupant and technician inconvenience would have been avoided entirely. Consensus comments by the HVAC technicians indicated much improved reliability of equipment serviced by PBM.

5.0 COST ASSESSMENT

Cost effectiveness of PBM was analyzed in terms of payback period and savings-to-investment ratio (SIR). Economics supports installation wide PBM as an ECM for HVAC O&M contracts, as an ECM for proposed UESC and ESPC projects, and for integration into existing O&M servicing.

Raw economic values were calculated based on the tracked actual implementation cost of this pilot project at the demonstration site, and on estimated hard implementation costs depending on the number of DX systems to be serviced in a PBM program. Tracked pilot site costs including training, labor, and materials totaled $73,000, which yielded a 2.1-year simple payback period for this pilot.

Anticipated cost for future implementation is somewhat less. Estimated hard implementation costs are based on 40 person-hours of training & follow-up, two diagnostic analyzers, two technicians and four hours per DX system. Projected savings for a future program at NASKW encompassing 60 DX systems is $249,000 over the two-year service cycle, giving a payback period of 6.5 months and an SIR of 1.9 on the $134,000 implementation cost. Payback period at Marine Corps Air Station Beaufort and Cape Canaveral Space Force Station (CCSFS) would be 7.6 months and 7.5 months, respectively.

Energy use per cooling degree-day and equivalent full load cooling hour (EFLH$_C$) analysis provides a straightforward adaptation to other DoD installation locations. A weather sensitivity analysis was performed using Pacific Northwest National Laboratory's rooftop unit comparison calculator (RTUCC) HVAC hourly modeling software to provide guidance on suitability across a range of cooling and heating season severity across the continental U.S. climate zones. Analysis using RTUCC and EFLH$_C$ modeling showed PBM is well-justified where there is a moderate to high electric cooling and/or heat-pump load. Economics are less favorable for cold regions locations with a mild / short summer cooling season and/or primary reliance on gas or electric resistance heating. Projected payback period for a PBM program encompassing 60 DX systems with an average size of 12-tons and assuming an electric rate of $0.10 per kWh ranges from about 6 to 8 months (Figure ES-3). Modeling suggested a PBM program would produce energy savings of about $81,000 to $116,000 per year on an estimated hard implementation cost of $114,000 per service cycle of two-years for 60 DX systems of average size 12-tons at $0.10/kWh electric rate.

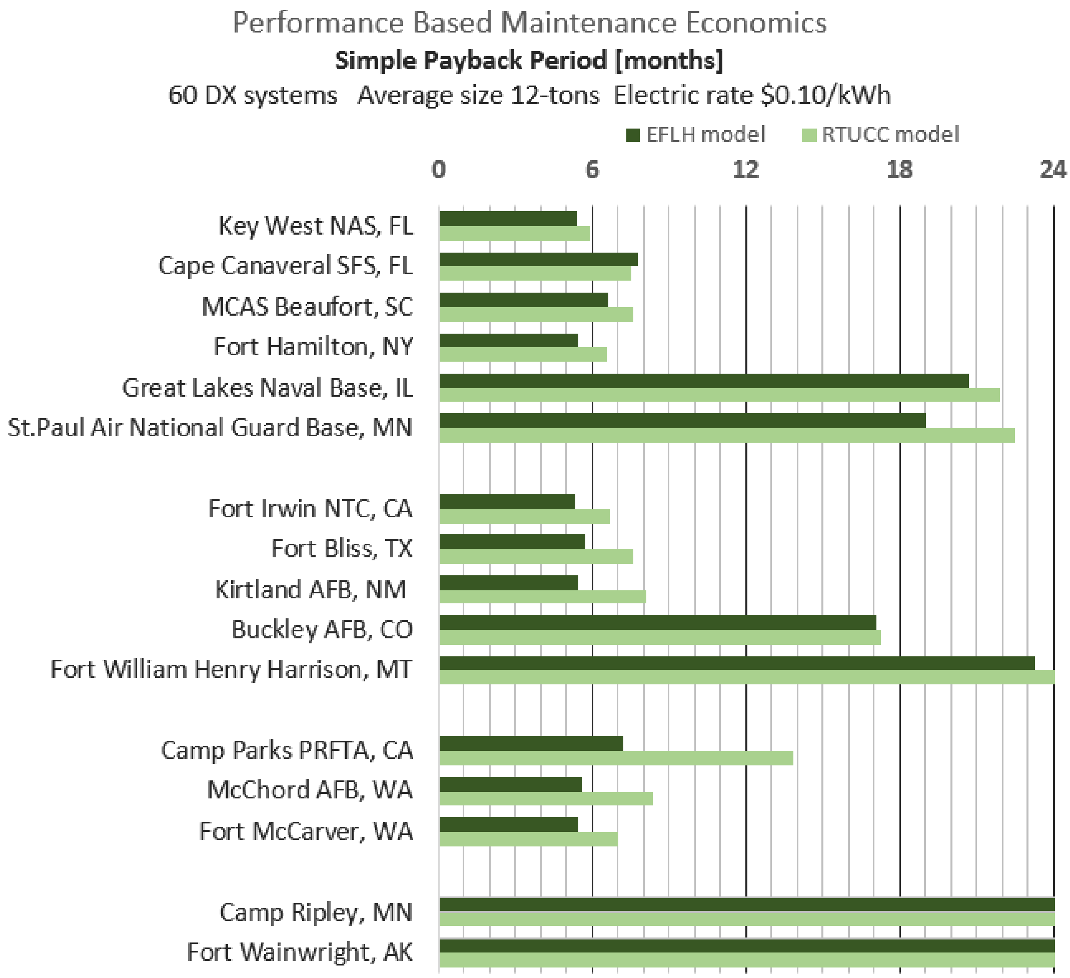

Figure ES-5. Modeled PBM Program Payback Period for Various DoD Locations.

6.0 IMPLEMENTATION ISSUES

One memorable technician comment well captures the biggest implementation issue:

"PBM would be great if our equipment PMs were up to date, but we aren't tuning a well-serviced 2019 Ford F150 that's been cared for, we are just trying to keep grandpa's '85 Chevy truck running down the road."

The chief lesson learned during this pilot project period was the HVAC Shops at NASKW, CCSFS and Patrick Space Force Base, and the public works departments in general, are allocated insufficient resources. The project team observed that O&M budget needs are funded at only about 50% to 60% of what is agreed to be a minimal level.

Severely understaffed and lacking adequate tools, parts and materials, HVAC technicians are scarcely able to keep up with basic maintenance tasks. Furthermore, about half of the DX systems they were responsible for were well past their lifespan and in poor condition due to years of deferred maintenance, resulting in a pervasive need for unbudgeted emergency repairs and hurried replacements, which perpetuated the cycle. As such, the project team found it challenging to implement an advanced, forward-thinking O&M protocol in a setting that had difficulty meeting even the most basic O&M principles and operated day-to-day with uncertainty.

A second issue identified during this pilot was the incomplete installation of new / replacement DX equipment, which was first-hand observed by the project team. Normally the installing HVAC contractor should be held responsible for proper startup and checkout of new systems, to ensure all operating parameters were set as specified by the engineer of record. The commissioning consultant and/or testing, adjusting, and balancing (TAB) contractor carries out a commissioning protocol or checklist, which typically includes TAB. Some or all these critical quality control / performance assurance steps were skipped on some DoD HVAC projects.

Broad implementation of PBM could be accomplished at the installation, region, service, or DoD level. One pathway is alternative funding via inclusion of PBM as an ECM in a large UESC or ESPC project. DoD-funded implementation hinges on justification for additional O&M funding; verifiable energy savings alone offers a good value proposition and competitive SIR, with improved reliability being an additional benefit.