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Highlights and Lessons Learned from Army Re-Tuning^{TM} Pilot Demonstrations

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Highlights and Lessons Learned from Army Re-tuning™ Pilot Demonstrations

Overview

The Army has aggressively pursued policy and energy efficiency projects and programs in recent years to meet Federal mandates and reduction goals organizationally [EISA 2007, AR 420-1, 42 U.S.C. § 8253 (Energy Management Requirements)], resulting in a 9.6% reduction in energy use intensity (EUI) from FY2015 to FY2017. Despite these successes, the Army remains the largest consumer of electricity in the Federal government and spent approximately $1.15 billion in energy-related costs in FY2018. Many of the low-cost/no-cost conservation measures have been deployed, so finding additional savings and projects that either (a) are cost effective or (b) can be bundled with more costly capital improvement projects to improve life cycle cost effectiveness, is imperative for the Army. Leveraging building control systems (BCS) and optimizing building performance through re-tuning represents a great opportunity for the Army.

In 2016, the Pacific Northwest National Laboratory (PNNL), in support of the Assistant Secretary of the Army (Installations, Energy and Environment), i.e., ASA (IE&E), was tasked with a multi-year study and pilot demonstration to develop a business case for the potential energy and cost reduction benefits from re-tuning efforts for the Army.

Army Re-tuning Pilot Highlights:

- The pilot re-tuning demonstration yielded roughly $700,000 in annual cost savings ($268 per 1,000 square feet), which was measured and validated from building-specific electricity and natural gas interval-metered data.
- For each installation, annual cost savings ranged from $67,000 to $247,000, with simple paybacks ranging from 1 to 3.7 years.
- The overall simple payback for the demonstration was 1.4 years.

Background

The Army is a large, geographically dispersed organization with 156 installations and over 980 million square feet of building space to operate and maintain. The building stock spans a wide range of vintages and missions, with many serving cross-cutting functions and purposes. Operating and maintaining these buildings efficiently is an ongoing challenge for Energy and Resource Efficiency Managers.

Re-tuning is a systematic process aimed at minimizing building energy consumption by identifying and correcting operational problems that plague buildings. Re-tuning relies on building automation/control system (BAS/BCS) data to identify and implement control improvements at no cost other than the time to program the changes. These low-cost/no-cost operational improvements improve energy efficiency and occupant comfort, and reduce operating costs. Figure 1 shows a typical degradation curve for buildings over time. This degradation can be attributed to several factors, including equipment wear and tear, lack of corrective maintenance practices, building envelope degradation, dynamic occupancy (mission) requirements, resource challenges, and lack of optimal control sequences. Periodic re-tuning or retro-commissioning can recover much of this degradation (as shown by the blue section in Figure 1, but will not persist over time. Continuous re-tuning, shown by the green sawtooth profile, can help maintain a building's operational efficiency at its design efficiency by continuously optimizing equipment control strategies and performance. Continuous re-tuning requires proactive maintenance and control practices to preserve equipment life and maintain peak operational performance.

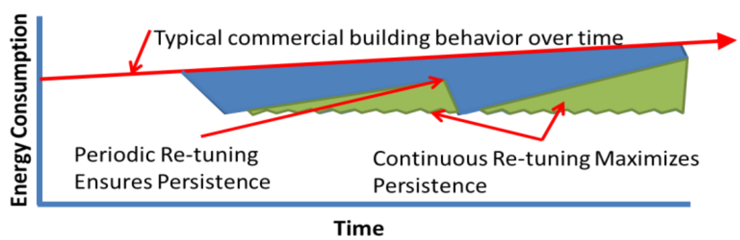

Figure 1. Typical Energy Consumption vs. Time Profile for Buildings

Pilot Results

A total of 19 buildings covering over 2.6 million square feet in floor area were selected to pilot the re-tuning methodology at four Army installations—Fort Bragg, Fort Riley, Redstone Arsenal, and Aberdeen Proving Ground. A variety of building types were selected for the pilot demonstration to determine the energy savings and economic benefit from re-tuning in a variety of buildings at Army installations. An overview of the buildings included in the pilot demonstration for each installation is provided in Table 1. Results of the re-tuning pilot demonstrations are provided in Table 2, and show the annual energy and cost savings by resource, as well as the overall cost savings and simple payback for each installation.

Table 1. Buildings Selected for Re-tuning at each Installation

Installation	Building Number	Building Type	Year Built	Floor Area (ft^2)
Bragg	8-1808	Administrative/Office	2010	647,000
Bragg	1-1326	Administrative/Office	1932	61,000
Bragg	3-1606	Ice Rink (MWR)	1975	33,000
Bragg	H-3014	Administrative/Office	2002	75,000
Riley	863A	Company Headquarters	2009	38,000
Riley	2560	Worship Center/Chapel	2014	23,000
Riley	4012	Child Development Center	2009	26,000
Riley	7006	Company Headquarters	2005	16,000
Riley	8632	Company Headquarters	2008	64,000
Riley	77680	Training Support Center	2011	72,000
Redstone	4400 & 4402	Administrative/Office	2011	436,000
Redstone	3495	Classrooms/Continuing Education	1967	50,000
Redstone	3713	Band Training Building	2010	16,000
Redstone	5405	Prototype Integration Facility	2002	64,000
Redstone	5678	Administrative/Office	1942	50,000
APG	2202	Administrative/Office	2011	147,000
APG	6001	Administrative/Lab	2010	248,000
APG	6002	Administrative/Lab	2010	276,000
APG	6006	Administrative/Lab	2010	262,000
			Total	**2,604,000**

MWR = morale, welfare and recreation; APG = Aberdeen Proving Ground.

Table 2. Annual Energy Savings, Cost Savings, and Simple Payback by Installation for the Re-tuning Pilot

Installation		Electricity		Natural Gas		Steam[a]		Overall	
	Square Footage Re-tuned	Energy Savings (kWh)	Cost Savings ($)	Energy Savings (kcf)	Cost Savings ($)	Energy Savings (MLB)	Cost Savings ($)	Cost Savings ($)	Simple Payback
Ft. Riley	239,000	892,000	$66,000	400	$1,600	NA	NA	$67,000	3.7
Ft. Bragg	816,000	3,822,000	$206,000	6,800	$41,000	NA	NA	$247,000	1.0
Redstone Arsenal	616,000	1,622,000	$106,000	1,000	$4,000	3,600	$110,000	$221,000	1.1
APG	934,000	1,652,000	$107,000	10,000	$56,000	NA	NA	$163,000	1.5
Total	2,605,000	7,988,000	$485,000	18,200	$102,600	3,600	$110,000	$698,000	1.4

(a) Redstone Arsenal was the only pilot installation that included buildings that used steam for heating

Leveraging EnergyPlus and lessons learned from the pilot demonstration, a modeling and simulation effort analyzed five primary Army building types for re-tuning potential: large offices/admin (LO), company operations facilities (COF), brigade headquarters (BdeHQ), tactical equipment maintenance facilities (TEMF), and unaccompanied enlisted personnel housing (UEPH). The average cost savings and total cost savings potential for re-tuning across the Army's building portfolio for the building types included in this analysis are summarized in Table 3. Table 3 also includes the minimum square footage at which re-tuning is economically attractive for each respective building type and climate region. Individual installations should evaluate the feasibility of re-tuning at their garrisons and buildings using the analysis provided in the business case for re-tuning. In general, re-tuning should be implemented in the following building types:

- All LO buildings greater than 70,000 square feet in floor area
- All BdeHQs greater than 30,000 square feet in floor area
- All COFs greater than 60,000 square feet in floor area
- All UEPHs greater than 100,000 square feet in floor area
- All TEMFs greater than 200,000 square feet in floor area

Table 3. Average and Total Cost Savings by Building Type, and Minimum Square Footage Required for Re-tuning to be Economical

Building Type	Average Savings Across Portfolio ($/1,000 sf)	Total Cost Savings Potential for Re-tuning ($M)	Minimum Square Footage Required in Each Climate Zone			
			Hot	Hot/Cold	Mild	Cold
LO	$184	$14	56,000	54,000	64,000	71,000
COF	$353	$9.2	22,000	29,000	62,000	31,000
BdeHQ	$468	$37.4	23,000	22,000	30,000	13,000
TEMF	$75	$1.7	132,000	124,000	200,000	113,000
UEPH	$138	$14.6	95,000	63,000	71,000	101,000
All Buildings	**$204**	**$77**				

LO = large office; COF = company operations facility; BdeHQ = brigade headquarters; TEMF = tactical equipment maintenance facility; UEPH = unaccompanied enlisted personnel housing.

Overall, the energy and modeling simulation results showed a total cost savings potential for re-tuning the five building types across the Army was $204 per 1,000 square feet, and as much as $77M annually (7% of the energy-related expenditures by the Army annually). While evaluating pilot sites for re-tuning, several common issues were identified that made the re-tuning process less efficient and more expensive for sites. Evaluating and addressing these critical issues prior to and after the re-tuning process will improve the economics and effectiveness of re-tuning, and ensure the persistence of savings through the re-tuning process. The remainder of this document outlines these common issues observed throughout the re-tuning pilot.

Critical Issues of Re-tuning at Army Installations

Baseline conditions were established for the buildings selected at each installation prior to implementing any re-tuning measures so that the resulting savings could be accurately measured and verified. After implementing the re-tuning measures, PNNL monitored the operation of the buildings remotely and returned to each installation to provide technical assistance to the site staff to ensure that the modified control strategies operated as intended. The pilot data and baseline observations highlighted three primary areas that have significant impacts on re-tuning and overall building performance in Army facilities. These areas include operations and maintenance (O&M), BAS infrastructure, and metering.

Operations and Maintenance

Proper O&M of building heating, ventilation, and air conditioning (HVAC) equipment is vital for maintaining equipment efficiency and avoiding increased energy use over time and premature mechanical system failures. Effective maintenance requires adequate resources and systematic routines that are designed to properly maintain, repair and replace equipment as needed. Best practice maintenance activities should be prioritized by building and system type to optimize critical equipment efficiency and extend overall operating life.

O&M of BAS/BCS Controls and Equipment Infrastructure

A BAS/BCS is the central control system that operates the various systems, components and equipment in a building. The control system receives input from various sensors across building systems and, leveraging programmed logic, makes decisions on how the systems should operate at any given point in time. Components (sensors and actuators) in the control system should be continuously monitored for functionality through BAS graphics, physical evaluation, or real-time fault detection and diagnostics (FDD). Sensors in the BAS must be calibrated and installed in a proper location to provide accurate data. Actuators, dampers, and valves must be working with no air or water leaks.

Below are some observed conditions and examples of how a BAS may respond to failed sensors or failed valve or damper actuators. Keeping a control system operating properly requires a systematic process of identifying and calibrating, repairing or replacing failed sensors or actuators, and ensuring that communications are reliable (95-99% uptime).

- **Poorly located outdoor-air temperature (OAT) sensor**. The OAT sensor is calibrated correctly but is not placed in a location that allows the sensor to be effective. It should be properly shielded on the north face of the building away from any thermal energy sources. Poor location may expose the OAT sensor to false readings which could influence economizer operation, cause boilers to shut off prematurely, or cause chillers to start prematurely.

- **Failed duct static pressure sensors**. Airflow and pressure sensors are prevalent in most BASs. They provide direct or indirect feedback to control loops that direct the speed of variable frequency drive (VFD)-equipped fan and pump motors. Failure of these sensors often results in a motor operating at its maximum or minimum frequency. Subsequent comfort complaints are common due to insufficient or inadequate air or water flow. At one of the pilot installations, one building was found to have five failed duct static pressure sensors for the largest six air-handling units (AHUs) in the building, resulting in supply fans operating at 100% speed. Identifying and correcting this issue resulted in significant energy savings, extended the life of the AHU supply fans, and enabled the implementation of a re-tuning measure (static pressure reset). This example highlights the need for periodic system observations by O&M staff as a regular part of day-to-day building operations.

- **Excess or insufficient outdoor air**. Some AHU airflow sensors are utilized to perform volumetric matching of a building's outdoor and exhaust flow rates to ensure proper indoor-air quality (IAQ) and building pressurization. When not working properly, these sensors can impact building pressure and the volume of outdoor air entering the building. Too little volume may lead to negative building pressure as well as potential IAQ problems. Too much volume may lead to the need for excess energy consumption to condition the outdoor air (when conditions are not conducive to economizing), and an overly positive building pressure.

- **Leaking heating hot water and chilled water coils**. Most buildings observed at Army installations were observed to have leaking heating and cooling coils. When a building operates both heating and cooling systems simultaneously (as observed at many installations), the leaks are difficult to identify because the temperature setpoints may be met even in the presence of faulty control strategies and leaks. This often results in simultaneous heating and cooling that goes unnoticed. To help mitigate simultaneous heating and cooling, most control systems provide lockouts at either the plant (hot or chilled water) or at the AHU to ensure that only one coil can operate (for systems with both heating and cooling coils). These lockouts are typically based on the OAT. If properly configured, the heating lockout setpoint should be less than the cooling lockout setpoint (typically 50-55°F for heating and 55-60°F for cooling). However, if chilled water or hot water plants are required to operate continuously, the control system cannot eliminate simultaneous heating and cooling through lockouts if hot or chilled water coils are leaking. Leaking hot or chilled water coils can also negatively impact chilled water or hot water plant performance, by adding loads to the plant and causing increased staging of equipment and potential short cycling of chillers and/or boilers.

Recommendations for BAS Controls Improvements. The PNNL team observed many building and control system deficiencies that could have been avoided by routine maintenance. To account for these deficiencies, a scouting site visit was required as part of the re-tuning pilot to identify issues and allow the installation to correct them, prior to any re-tuning implementation. Repairing communication failures between BAS controllers is a maintenance task that will have an overall positive impact on building efficiency, operations, and resilience. Many of these problems were identified early on during the re-tuning process at the pilot installations, but required significant time to repair prior to implementing any re-tuning measures. Systematic and timely O&M for building systems (including the BAS controls) should be a high priority for the Army to ensure resilience, readiness, and optimal performance in their buildings. There are automatic fault detection and diagnostic (AFDD) tools that can be used to automate part of this process (identifying failed sensors, failed control valves, and failed economizer dampers). The Army should consider the added benefits of installing AFDD tools to enable more proactive maintenance. Otherwise, training on retro-commissioning (RCx) and re-tuning methods should be considered as short and long-term investments by the Army to aid their workforce in identifying these common issues that were prevalent in the baseline condition of many of the buildings selected for the pilot.

BAS Infrastructure

Documentation

Accurately maintained building HVAC and control system documentation is an important part of maintenance, modifications and upgrades. It assists the reader (O&M staff, commissioning agents, control contractors, engineers, building mangers, etc.) in coordinating how the building systems should be operated and maintained. Keeping these documents updated as projects (RCx or re-tuning) are implemented is critical to persistence of savings and continuity in operations.

The documentation should include a full set of the original building prints, including mechanical, electrical, plumbing and architectural as well as controls, lighting and other related documents. A set of the original testing and balancing (TAB) reports should be saved for each air side device and system and every hydronic loop and coil. All notes provided by the commissioning agent and a list of deficiencies, resolutions and suggestions should be saved and compiled into a systems manual for the building and included as part of the building's documentation library.

Recommendations for Documentation Improvements. The installations that participated in the re-tuning pilot were missing all or some portions of the documentation outlined above for many of the buildings selected for re-tuning. The documentation is critical for deciphering building characteristics and baseline operations before data analysis and onsite investigations are conducted to identify improvements. Many advanced control systems create links to some or all of this data from the graphical user interface (GUI). The Army should consider this as a requirement for future BAS upgrades/additions and all future projects in existing buildings.

Supervisory Controllers

The primary function of the supervisory controllers in each building is to facilitate communication between a central user interface and the various building field controllers. Additionally, complex programming that takes many different inputs from different building-level field controllers can be implemented in the supervisory controller. Implementing programming at this level allows for greater visibility and flexibility to the end user. This programming can often be done through a web-browser connection to the supervisory controller.

Several installations had buildings with overloaded or near-capacity supervisory controllers. This is due to undersized building supervisory controllers that do not have the bandwidth for the level of alarming, trending, and object point count that the installation is requiring for their buildings. Overburdened controllers can and will lead to slow communication bus speeds, which in turn contribute to intermittent connections to the field controllers and slow control processes that affect normal day-to-day building comfort and equipment level performance.

Field Controllers

Field controllers typically interface with HVAC equipment hardware (relays, sensors, VFDs, etc.) via dedicated inputs and outputs. The field controller actively controls the physical HVAC equipment with embedded logic that is focused on each of the individual HVAC components that the controller is connected to. Each field controller feeds information up to the supervisory controller via a communication protocol (e.g., BACnet, Lon, Modbus, etc.). Most, if not all, of the software tools to program field level controllers are vendor specific and require additional time and training to properly utilize the configuration inside the controller.

Recommendations for Supervisory and Field Controllers Improvements. Installations must work to maintain integration capability both between building field controllers and supervisory controllers and between supervisory controllers and the central server. This includes the software, hardware, and staff knowledge to maintain the interconnectivity of the various parts of the BAS/BCS. In addition, processes need to be put in place to keep tools updated on the system that meet the current security requirements, and training plans in place so staff know how to use the tools effectively. Trend and historical data is critical for the ongoing success of re-tuning and related efforts. Without this capability, data analysis is limited to snap shots in time that cannot be relied on for baseline or current performance trends of building systems.

Equipment Integration

Equipment integration issues were frequently identified in the buildings selected for the re-tuning pilot. Examples are listed below for several equipment types based on the experience of the re-tuning team, and potential operational improvements (including re-tuning measures) available when fully integrated.

Lighting

Integrating a lighting control system with the BAS allows for shared occupancy sensors and for occupancy-based control (OBC) strategies. A lighting control system can perform a scheduled lighting sweep (turning off lights that were overridden on, at a designated time) and also provide true occupancy patterns to optimize HVAC schedules. In some cases, the occupancy status can be used to automate HVAC systems at the zone level (fan coils, zone terminal boxes, etc.) so that systems operate in “vacancy” mode when the space is operating on an occupied schedule. Vacancy mode widens the zone temperature setpoints by 2-3°F. For example, a zone may have occupied setpoints of 72°F (heating) and 75°F (cooling). If the lighting occupancy sensor turns off lights in a zone due to vacancy, the occupancy status can be used by the BAS to widen the temperature setpoints to 70°F (heating) and 77°F (cooling). The space continues to ventilate (ideally, at a reduced rate), but the energy input is reduced as the temperature relaxes during vacancy mode. Once occupancy resumes, the zone can typically recover the 2°F temperature offset in 30 minutes to 1 hour.

Boilers

Boiler integration, even if the boiler system has its own intelligent management system, is vital to uncovering energy savings through implementation of re-tuning measures. While packaged boiler controls typically operate internal boiler sequences such as firing rate and gas purge controls, most will still accept certain commands from an integrated BAS. Typical measures include demand-based runtime, hot water temperature reset/optimization, and intelligent scheduling/setback. Newer high efficiency condensing boilers also provide excellent turn down capabilities that can be leveraged during low-load conditions.

Chillers

Newer air-cooled and water-cooled chillers have excellent turn down capabilities and offer good energy savings during part-load conditions. Integration of chilled water systems enables the implementation of re-tuning measures such as chilled water temperature reset and optimized equipment staging. This allows for reduced equipment runtimes and overall improvement of chilled water plant efficiency. Full integration also allows for chilled water plant metrics (e.g., kW/ton) to be monitored over time to identify potential issues with plant operations.

Variable Frequency Drivers (VFDs)

Many VFDs are not fully integrated with the BAS. In addition to the speed/frequency command, there are several additional internal VFD parameters (e.g., the VFD’s internal power consumption and demand usage) available to integrate to the control system. Having this level of integration supports data analytics and demand limiting strategies. VFD power data can serve as a sub-meter and be used to help calculate performance metrics for AHUs or chilled/hot water plants.

Thermostats

Properly integrated thermostats can be utilized for smart scheduling and increased setback optimization. Integrating thermostats also allows for the use of a common global space temperature setpoint in the BAS that can help optimize building temperature control and develop automated seasonal strategies. Implementing a global setpoint strategy can also decrease the potential for occupants to make large adjustments to space temperature setpoints which can place HVAC systems serving adjacent zones in simultaneous heating and cooling modes. Occupant control of thermostats should be limited to be within ±2°F of a global setpoint. A common setpoint also helps eliminate large variances in space temperatures that negatively impact re-tuning measures that leverage zone-level feedback for control reset strategies.

Metering

Interval-metered data can be leveraged to help track building energy performance, identify performance issues or re-tuning opportunities, and validate (through measurement and verification) any commissioning or re-tuning projects. Through continuous tracking of an installation’s energy use intensity (EUI) by building, opportunities can quickly be identified by decision makers for project implementation (e.g., HVAC renovation, equipment replacement, RCx, re-tuning). Advanced analytical tools are available that generate useful interpretation of interval-metered data. Large quantities of data can be quickly processed to show daily, seasonal, or annual operational changes and their effect on building energy performance.

The Army has invested heavily in installation of smart meters and integration of meters to the meter data management system (MDMS). However, the re-tuning team observed that installations were missing interval electricity and natural gas data for most of the candidate buildings. This was typically a function of physical meter infrastructure failures, meter installation failures (e.g., current transducers connected backwards), or communication failures with MDMS. As a result, many good candidate buildings were dropped from the list during the building screening process.

Recommendations for Metering Improvements. The Army should prioritize the modernization of the metering program, and dedicate resources to make sure meters are functional and data is reporting and usable for energy and water tracking. This will require procurement of appropriate metering technologies, oversight during installation and testing of communication protocols, and ongoing data collection and analysis to identify meter failures when they occur.

Summary and Suggestions for Path Forward

The cumulative cost savings potential across the Army's portfolio of the five selected building types is $204 per 1,000 square feet, and the total cost savings potential is $77M, or roughly 7% of all energy-related expenditures for the Army annually. The pilot effort, which covered over 2.6M square feet of building floor area at four installations, validated $700,000 in annual cost savings and a simple payback of 1.4 years. Overall, the pilot and business case confirmed that there is great potential to implement re-tuning across the Army's building stock. However, many issues were identified during the pilot that limit the potential for re-tuning at Army installations. While this document outlines many of the deficiencies identified during the pilot, it is critical that installations review their buildings to ensure systems are in working order prior to implementing re-tuning. The following issues should be prioritized by the Army to fully realize the benefits of re-tuning:

1. Operations and Maintenance (O&M): Proper O&M of building HVAC systems and controls is critical when implementing re-tuning measures.
2. BAS/BCS Infrastructure: The BAS/BCS must be integrated and communicating effectively to implement re-tuning measures.

Once the above items are addressed, re-tuning can be an effective way to improve efficiency, occupant comfort, and installation readiness and resilience. If a full re-tuning cannot be accomplished, the business case identifies measures that are most effective for achieving energy savings. In order to reap the most energy savings, the following four measures should be prioritized for implementation across the Army building stock:

1. Widen deadbands and night setback – 8.7% cumulative savings potential,
2. Discharge-air temperature reset – 5.7% cumulative savings potential,
3. Reduce minimum airflow setpoints – 5.2% cumulative savings potential, and
4. Shorten HVAC schedules – 5.2% cumulative savings potential.

About The Re-tuning Pilot

The re-tuning pilot was sponsored by the Office of the Deputy Assistant Secretary of the Army for Energy and Sustainability and coordinated with the U.S. Army Installation Management Command, with the goal of demonstrating the applicability of implementing re-tuning measures in Army buildings. A team of re-tuning practitioners (mechanical engineers and BAS control experts) from the U.S. Department of Energy's Pacific Northwest National Laboratory performed the re-tuning assessments, identified opportunities for energy efficiency measures, and implemented and validated the measures with the pilot installation's energy and controls teams support.

The pilot focused on adapting and applying the re-tuning methodology on 4-8 building types at 4 installations in the Army. PNNL assessed and implemented a series of re-tuning measures in each building and monitored the buildings for 12 months to ensure persistence of savings. Energy and cost savings was determined using Army metered data. A modeling and simulation effort that leveraged lessons learned from the pilot was undertaken to develop a business case for the potential energy and cost reduction benefits from implementing re-tuning across the Army. In addition, re-tuning implementation guides were developed to assist the Army with implementing new or troubleshooting existing re-tuning measures that have been implemented. For more details about the business case or findings and recommendations for each site, please refer to the business case report or reach out to the pilot participants for the individual installation reports.

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