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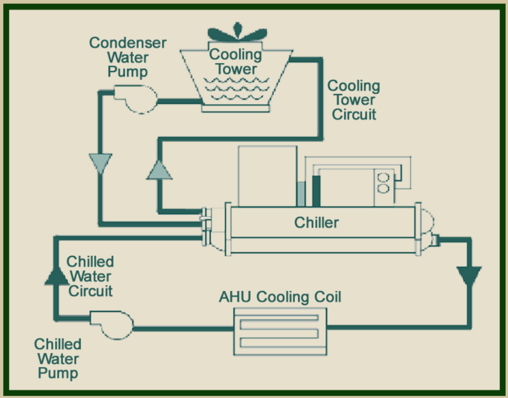
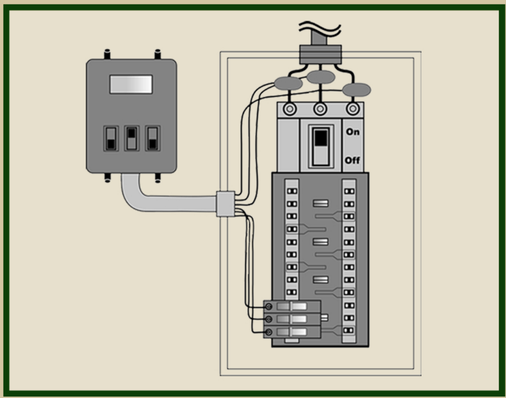
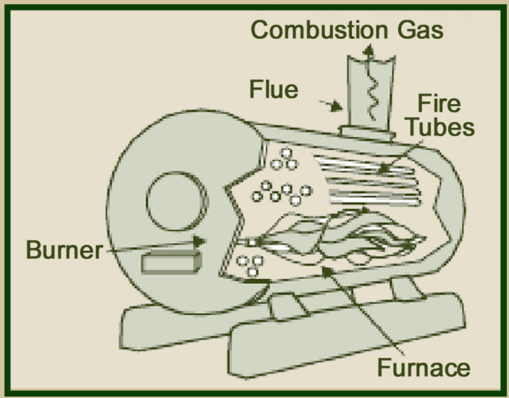
Energy Engineering Analysis Program (EEAP)

Top Operations and Maintenance (O&M) Efficiency Opportunities at DoD/Army Sites

A Guide for O&M/Energy Managers and Practitioners







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Energy Engineering Analysis Program (EEAP)

Top Operations and Maintenance (O&M) Efficiency Opportunities at DoD/Army Sites

A Guide for O&M/Energy Managers and Practitioners

G. P. Sullivan
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May 2007

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Executive Summary

The purpose of this report is to provide the Operations and Maintenance (O&M)/Energy manager and practitioner with useful information about the top O&M opportunities consistently found across the U.S. Department of Defense (DoD)/Army sector. To make this report useful and relevant, the authors have made use of various work completed across the DoD/Army sector, including the Federal Energy Management Program's O&M Best Practices Guide and numerous O&M and energy audits of DoD/Army facilities completed as part of the U.S. Department of Energy's (DOE's) Assessment of Load and Energy Reduction Techniques (ALERT) and Energy Savings Expert Team (ESET) programs. In addition, the authors conducted literature searches and contacted vendors and industry experts to gather pertinent information for this report.

This report consists of five chapters and two appendixes; Chapters 1 and 2 provide an introduction, overview, and a description of how this activity is expected to integrate into the larger Energy Engineering Analysis Program (EEAP) activity. Chapter 3 discusses the fundamental building blocks of any O&M program including general definitions and descriptions of the major types of O&M. Chapter 4 presents the top O&M opportunities organized by equipment or system type and developed with a common format focused on:

- Opportunity identification
- Diagnostic equipment used
- Energy savings and economics
- O&M persistence
- Rules of thumb
- System-specific O&M checklists
- References

Each opportunity described in Chapter 4 was developed to be useful as a stand-alone section relevant to the equipment type.

The top O&M opportunities presented in this report start with *Effective Maintenance Program Structure*. This opportunity highlights the need for a functional O&M organizational structure as a necessary starting point for a practical O&M program. The second opportunity, *Metering for Tracking, Trending, and Operational Efficiency*, presents the need for metering as a critical feedback mechanism of equipment, system and building operation. The third opportunity highlights O&M measures related to *Boilers and Boiler Systems*. This opportunity has an operational focus on O&M needs. The fourth opportunity presents actions related to *Chillers* and also highlights the key operational and maintenance needs and resulting efficiency impacts. The fifth opportunity, *Heating, Ventilation and Air Conditioning (HVAC) Operational Efficiency*, focuses on control system opportunities that are easily affected but often overlooked. *Energy System Leakage* is presented as the sixth opportunity and has a focus on losses in steam, air, and natural gas systems. The seventh opportunity highlights *Distribution System Conditional Assessment* and examines energy losses through poorly insulated equipment and systems. Eighth on the list are opportunities related to *Electric Motors and Motor Systems*, followed by the ninth opportunity presenting opportunities related to *Lighting and Lighting System Control*. The final opportunity ties all the opportunities together in the critical step of *Project Implementation*.

Chapter 5 presents the conclusions and next steps to developing a well-structured and organized O&M program in the DoD/Army sector.

Finally, a glossary of common terms and O&M resources are presented in Appendixes A and B, respectively.

The authors intend to update this guide periodically as the EEAP program moves from initiation to maturity. We fully anticipate, as a function of the program, to identify new opportunities in equipment and systems, and the inclusion of these will increase the value of this document to the DoD/Army sector.

Acknowledgments

This report is the result of numerous people working to achieve a common goal of researching, analyzing, and promoting energy efficiency through Operations and Maintenance (O&M). The authors wish to acknowledge the contribution and valuable assistance provided by the staff at multiple Department of Defense (DoD)/Army sites who participated in a variety of Energy, O&M, Assessment of Load and Energy Reduction Techniques (ALERT), and Energy Savings Expert Team (ESET) programs; we greatly appreciate their patience and willingness to help in our furthering of this concept.

Appreciation is extended to the Pacific Northwest National Laboratory team of Doug Dixon, Dave Payson, Kathy Neiderhiser, Theresa Koehler, Steve Hultman, and Ron Underhill for the conscientious, team-oriented, and high quality assistance they brought to this project.

Finally, we wish to recognize Paul Volkman of the Installation Management Command and Curt Murdock and Dave Shockley of the Huntsville Corps of Engineers for their vision, commitment, and support in helping create and fund this project.

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Chapter 1 Introduction

The purpose of this report is to provide the Operations and Maintenance (O&M)/Energy manager and practitioner with useful information about the top O&M opportunities consistently found across the U.S. Department of Defense (DoD)/Army sector. To make this report useful and relevant, the authors have made use of various work completed across the DoD/Army sector including the Federal Energy Management Program's O&M Best Practices Guide (Sullivan et al. 2004) and numerous O&M and energy audits of DoD/ Army facilities completed as part of the U.S. Department of Energy's (DOE's) Assessment of Load and Energy Reduction Techniques (ALERT) and Energy Savings Expert Team (ESET) programs. In addition, the authors conducted literature searches and contacted vendors and industry experts to gather pertinent information for this report.

It needs to be stated at the outset that this report is designed to provide information on effective O&M as it applies to systems and equipment typically found at DoD/Army facilities. This report is not designed to provide the reader with step-by-step procedures for performing O&M on any specific piece of equipment; rather, it first directs the reader to the manufacturer's specifications and recommendations. In no way should the recommendations in this report be used in place of manufacturer's recommendations. The recommendations in this report are designed to supplement those of the manufacturer, or, as is all too often the case, provide guidance for systems and equipment for which all technical documentation has been lost. As a rule, this report will first defer to the manufacturer's recommendations on equipment operation and maintenance.

Actions and activities recommended in this guide should only be attempted by trained and qualified personnel. If such personnel are not available, then the actions recommended here should not be initiated.

About This Report

This report is designed to serve as a resource for O&M management and technical staff. The objectives of this report are to:

- Provide needed background information on why O&M is important and the potential for savings from practicing good O&M on a specific set of mechanical systems and equipment.
- Define the major O&M program types and provide guidance on the structure of a good O&M program.
- Provide information on state-of-the-art maintenance technologies and procedures for key equipment; in this case the equipment and systems consistently found to be in need of O&M across the DoD/Army sector.
- Identify information sources and contacts to assist the energy/facility manager in getting the job done.

Target Audience

O&M/Energy managers, practitioners, and technical staff represent the prime target audience of this document. Beyond this audience, a competent O&M program requires the participation of staff from five well-defined areas: Operations, Maintenance, Engineering, Training, and Administration. While a given site may not have all five of these areas as separate entities, these functions are provided for within the organization in some capacity by staff; it is these staff that are also targeted.

A successful O&M program requires cooperation, dedication, and participation at all levels and cannot succeed without everyone involved understanding the basic principles and supporting the cause.

Organization and Maintenance of the Document

The report consists of five chapters and two appendixes. This chapter, Chapter 1, provides an introduction and an overview. Chapter 2 provides the background of the program and how this activity is expected to integrate into the larger EEAP activity. Chapter 3 discusses the fundamental building blocks of any O&M program, including general definitions and descriptions of the major types of O&M. Chapter 4 presents the top O&M opportunities. These are organized by equipment or system type and were developed to be useful as stand-alone sections. The top O&M opportunities presented start with *Effective Maintenance Program Structure*. This opportunity highlights the need for a functional O&M organizational structure as a necessary starting point for a practical O&M program. The second opportunity, *Metering for Tracking, Trending, and Operational Efficiency*, presents the need for metering as a critical feedback mechanism of equipment, system and building operation. The third opportunity highlights O&M measures related to *Boilers and Boiler Systems*. This opportunity has an operational focus on O&M needs. The fourth opportunity presents actions related to *Chillers* and also highlights the key operational and maintenance needs and resulting efficiency impacts. The fifth opportunity, *Heating, Ventilation and Air Conditioning (HVAC) Operational Efficiency*, focuses on control system opportunities that are easily affected but often overlooked. *Energy System Leakage* is presented as the sixth opportunity and has a focus on losses in steam, air and natural gas systems. The seventh opportunity highlights *Distribution System Conditional Assessment* and examines energy losses through poorly insulated equipment and systems. Eighth on the list are opportunities related to *Electric Motors and Motor Systems* followed by the ninth opportunity presenting opportunities related to *Lighting and Lighting System Control*. The final opportunity ties all the opportunities together in the critical step of *Project Implementation*.

The O&M environment is in a constant state of evolution and the technologies and vocabularies are ever-expanding. Therefore, a glossary of terms is presented in Appendix A. Appendix B provides a list of organizations and trade groups that have interest or are related to O&M.

The authors intend to update this guide periodically as the EEAP program moves from initiation to maturity. We fully anticipate, as a function of the program, to identify new opportunities in equipment and systems and the inclusion of these will increase the value of this document to the DoD/Army sector.

Reference

Sullivan GP, R Pugh, AP Melendez, and WD Hunt. 2004. *O&M Best Practices: A Guide to Achieving Operational Efficiency, Release 2.0*. PNNL-14788, prepared by Pacific Northwest National Laboratory for the Federal Energy Management Program, U.S. Department of Energy, Washington, D.C. Available URL: http://www1.eere.energy.gov/femp/operations_maintenance/om_bpguide.html

Chapter 2 Background

Operations and maintenance efficiency opportunities on most DoD/Army sites are plentiful. These opportunities stem from the deferred maintenance practices endemic to many sites. Due to budgetary and other constraints, many of these sites operate in a ***reactive maintenance*** mode – that is, systems and equipment are fixed only when broken. This is not a sustainable mode of maintenance and is usually not reflective of the wishes and capabilities of the maintenance staff; the decisions to operate in this manner are usually made far above the maintenance management and practitioner level. The result of this mode of operation is equipment is operated inefficiently and will not achieve its expected life. In short, this mode of operation costs the site both in the short-run with higher energy bills and in the long-run with early equipment failure and shortened economic life.

The genesis of this report is based on the finding that after conducting energy and O&M-related audits on numerous DoD/Army sites, there was a consistent set of O&M opportunities identified. These opportunities, mostly related to the major systems found on these sites (e.g., boiler, chiller, HVAC), could be categorized and highlighted as being most prevalent and returning the greatest potential savings.

The data set used for this prioritization was based largely on the U.S. Department of Energy's Assessment of Load and Energy Reduction Techniques (ALERT) and Energy Savings Expert Team (ESET) programs. Both of these programs were developed to help federal agencies identify and implement low-cost/no-cost O&M opportunities. It is these opportunities that were categorized by equipment/system type, screened for appropriateness, and included in this report.

The goal of this activity is two-fold. First, to present information on the recommended structure and framework of a functioning O&M program. Second, acknowledging the financial realities of most DoD/Army O&M programs, to provide a proven and streamlined path to achieving cost-effective energy savings through low-cost/no-cost O&M recommendations.

It should be stated that given appropriate funding levels, the recommendations presented in this report would be supplemented with other activities to move a program from a reactive mode of maintenance to a goal of preventive and predictive maintenance. However, given the current O&M construct and funding challenges, this activity will focus on getting back some of the inefficiency that the prevalent reactive maintenance programs foster.

Chapter 3 O&M Fundamentals, Motivation, and Savings Potential

Effective O&M is one of the most cost-effective methods for ensuring reliability, safety, and energy efficiency. Inadequate maintenance of energy-using systems is a major cause of energy waste in both the federal government and the private sector. Energy losses from steam, water and air leaks, uninsulated lines, maladjusted or inoperable controls, and other losses from poor maintenance are often considerable. Good maintenance practices can generate substantial energy savings and should be considered a resource. Moreover, improvements to facility maintenance programs can often be accomplished immediately and at a relatively low cost.

Definitions and Motivation

Operations and Maintenance are the decisions and actions regarding the control and upkeep of property and equipment. These are inclusive, but not limited to, the following: 1) actions focused on scheduling, procedures, and work/systems control and optimization, and 2) performance of routine, preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety.

Operational Efficiency represents the life-cycle, cost-effective mix of preventive, predictive, and reliability-centered maintenance technologies, coupled with equipment calibration, tracking, and computerized maintenance management capabilities – all targeting reliability, safety, occupant comfort, and system efficiency.

Major O&M Types

What is maintenance and why is it performed? Past and current maintenance practices in both the private and DoD/Army sectors would imply that maintenance is the actions associated with equipment repair after it is broken. The dictionary defines maintenance as follows: "the work of keeping something in proper condition; upkeep." This would imply that maintenance should be actions taken to prevent a device or component from failing or to repair normal equipment degradation experienced with the operation of the device to keep it in proper working order. Unfortunately, data obtained in many studies over the past decade indicates that DoD/Army facilities do not expend the necessary resources to maintain equipment in proper working order. Rather, they wait for equipment failure to occur and then take whatever actions are necessary to repair or replace the equipment.

Nothing lasts forever and all equipment has associated with it some predefined life expectancy or operational life. The design life of most equipment requires periodic maintenance. Belts need adjustment, alignment needs to be maintained, proper lubrication on rotating equipment is required, and so on. In some cases, certain components need replacement (e.g., a wheel-bearing on a motor vehicle) to ensure the main piece of equipment (in this case perhaps a troop carrier) last for its design life. Anytime we fail to perform maintenance activities intended by the equipment's designer, we shorten the operating life of the equipment. But what options do we have? Over the last 30 years, different approaches to how maintenance can be performed to help ensure that equipment reaches or exceeds its design life have been developed in the United States. In addition to waiting for a piece of equipment to fail (reactive maintenance), we can utilize preventive maintenance (scheduled maintenance), or predictive maintenance (maintenance targeting failure just before it occurs).

Reactive Maintenance. Reactive maintenance is basically the "run it till it breaks" maintenance mode. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached. One study as recent as the winter of 2006 (Schultz 2005) indicates this is still the predominant mode of maintenance in the United States.

The advantages to reactive maintenance can be viewed as a double-edged sword. If we are dealing with new equipment, then we can expect minimal incidents of failure. If our maintenance program is purely reactive, then we will not expend manpower dollars or incur capital cost until something breaks. Since we do not see any associated maintenance cost, we could view this period as saving money. The downside is reality. In reality, during the time we believe we are saving maintenance and capital cost, we are really spending more dollars than we would have under a different maintenance approach. We are spending more dollars associated with capital cost because, while waiting for the equipment to break, we are shortening the life of the equipment, resulting in more frequent replacement. We may incur cost upon failure of the primary device associated with its failure causing the failure of a secondary device. This is an increased cost we would not have experienced if our maintenance program was more proactive. Our labor cost associated with repair will probably be higher than normal because the failure will most likely require more extensive repairs than would have been required if the piece of equipment had not been run to failure. Chances are the piece of equipment will fail during off hours or close to the end of the normal workday. If it is a critical piece of equipment that needs to be back on-line quickly, then we will have to pay maintenance overtime cost. Since we expect to run equipment to failure, we will require a large material inventory of repair parts. This is a cost we could minimize under a different maintenance strategy.

Preventive Maintenance. Preventive maintenance can be defined as follows: Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.

By simply expending the necessary resources to conduct maintenance activities intended by the equipment designer, equipment life is extended and its reliability is increased. In addition to an increase in reliability, dollars are saved over that of a program just using reactive maintenance. Depending on a facility's current maintenance practices, present equipment reliability, and facility downtime, there is little doubt that many facilities purely reliant on reactive maintenance could save much more than 18% by instituting a proper preventive maintenance program.

Preventive maintenance programs have several advantages over purely reactive programs. By performing the preventive maintenance as the equipment designer envisioned, we will extend the life of the equipment closer to design. This translates into dollar savings. Preventive maintenance (e.g., lubrication, filter change) will generally run the equipment more efficiently, resulting in dollar savings. While we will not prevent equipment catastrophic failures, we will decrease the number of failures. Minimizing failures translate into maintenance and capital cost savings.

Predictive Maintenance. Predictive maintenance can be defined as follows: Measurements that detect the onset of a degradation mechanism, thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state. Results indicate current and future functional capability.

Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule. You will recall that preventive maintenance is time-based. Activities such as changing lubricant are based on time, like calendar time or equipment run-time. For example, most people change the oil in their vehicles every 3,000 to 5,000 miles traveled. This is effectively basing the oil change needs on equipment run-time. No concern is given to the actual condition and performance capability of the oil. It is changed because it is time. This methodology would be analogous to a preventive maintenance task. If, on the other hand, the operator of the car discounted the vehicle run-time and had the oil analyzed at some periodicity to determine its actual condition and lubrication properties, then he/she may be able to extend the oil change until the vehicle had traveled 10,000 miles. This is the fundamental difference between predictive maintenance and preventive maintenance, whereby predictive maintenance is used to define a needed maintenance task based on quantified material/equipment condition.

The advantages of predictive maintenance are many. A well-orchestrated predictive maintenance program will all but eliminate catastrophic equipment failures. We will be able to schedule maintenance activities to minimize or delete overtime cost. We will be able to minimize inventory and order parts, as required, well ahead of time to support the downstream maintenance needs. We can optimize the operation of the equipment, saving energy cost and increasing plant reliability. Past studies have estimated that a properly functioning predictive maintenance program can provide a savings of 8% to 12% over a program utilizing preventive maintenance alone. Depending on a facility's reliance on reactive maintenance and material condition, it could easily recognize savings opportunities exceeding 30% to 40%. In fact, independent surveys indicate the following industrial average savings resultant from initiation of a functional predictive maintenance program:

- Return on investment: 10 times
- Reduction in maintenance costs: 25% to 30%
- Elimination of breakdowns: 70% to 75%
- Reduction in downtime: 35% to 45%
- Increase in production: 20% to 25%.

Although it is expensive to begin a predictive maintenance program, the rewards are obvious. Program development will require an understanding of predictive maintenance and a firm commitment to make the program work by all facility organizations and management. An investment will be required for the equipment required, and a training program will need to be developed to train in-plant personnel to effectively use predictive maintenance technologies.

Motivation

The *Energy Policy Act of 2005* (EPAct 2005) and the recently enacted Executive Order 13423 (EO 13423) detail the new energy reduction goals for the federal government. Among others, EPAct 2005 and EO 13423 legislates the following:

- Annual energy reduction goal of 3% from FY 2006 to FY 2015
- Reporting baseline changed from 1985 to 2003
- Annual energy reporting, via DOE, to the President and Congress
- DOE recommends new requirements for FY 2016 to FY 2025 by 2014

Clearly, these are aggressive targets and many federal facilities have been working hard to achieve them. In many cases, the approach to achieving these goals has focused on capital-intensive upgrades of existing equipment and making use of a variety of financing options including Energy Savings Performance Contracts (ESPCs), local utility financing programs, and other third-party financing options.

While effective, some feel that capital upgrades are not always the most cost-effective solution. Indeed, the authors of this guide contend that low-cost/no-cost O&M measures (including activities referred to as retrocommissioning or retuning) should be the first energy savings measure considered. O&M measures should be considered prior to the installation of energy conservation measures for the following reasons:

- Typically, O&M measures are low-cost or no-cost in nature.

- Many O&M measures are easily installed by in-house personnel.

- O&M measures can have immediate payback.

- These measures rarely require the design time, bid preparation, evaluation, and response compared to capital projects that can take up to a year to implement.

O&M Potential, Energy Savings, and Beyond

It has been estimated that O&M programs targeting energy efficiency can save 5% to 20% on energy bills without a significant capital investment (PECI 1999). From small to large sites, these savings can represent thousands to hundreds-of-thousands of dollars each year, and many can be achieved with minimal cash outlays.

Beyond the potential for significant cost and energy/resource savings, an O&M program operating at its peak *operational efficiency* has other important implications:

- A well-functioning O&M program is a safe O&M program. Equipment is maintained properly, mitigating any potential hazard arising from deferred maintenance.

- In most DoD/Army buildings, the O&M staff are responsible for not only the comfort, but also the health and safety of the occupants. Of increasing occurrence and legal concern are indoor air quality (IAQ) issues within these buildings. Proper O&M reduces the risks associated with the development of dangerous and costly IAQ situations.

- Properly performed O&M ensures that the design life expectancy of equipment will be achieved, and in some cases, exceeded. Conversely, the costs associated with early equipment failure are usually not budgeted for and often come at the expense of other planned O&M activities.

- An effective O&M program more easily complies with federal legislation such as the *Clean Air Act* and the *Clean Water Act*.

- A well-functioning O&M program is not always answering complaints; rather, it is proactive in its response and corrects situations before they become problems. Using this model minimizes callbacks and keeps occupants satisfied while allowing more time for scheduled maintenance.

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Chapter 4 Top Operations and Maintenance Efficiency Opportunities

The ten O&M opportunities presented in this chapter represent a small subset of the total potential O&M opportunities at DoD/Army sites. Those selected were chosen for their prevalence and representation as opportunities identified as outcomes of numerous O&M and energy audits completed at DoD/Army facilities.

Each opportunity was written to be stand-alone and useful to site energy and O&M staff. Each opportunity was designed to give those staff the ideas, the necessary technical background, and the savings potential to determine the validity of the opportunity for their specific site and systems.

As stated, the opportunities presented here represent a subset of the total potential for any given site. It is ***not*** the intent of the authors to imply that after completion of these specific activities a site is optimally efficient. On the contrary, the actions and recommendations made here serve as a starting point from where the site will move toward *operational efficiency*.

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Opportunity #1: Effective Maintenance Program Structure, Organization, and Tools

The most-effective O&M programs start with a solid organizational foundation. Successful O&M facility/energy managers learned that while you can have the very best/efficient equipment, staff, and software, if you do not have a well-organized and functioning O&M structure, then you will not achieve your operational-efficiency potential.

O&M management is a critical component of the overall program. The management function should bind the distinct parts of the program into a cohesive entity. From our experience, the overall program should contain five very distinct functions making up the organization: Operations, Maintenance, Engineering, Training, and Administration—OMETA.

Beyond establishing and facilitating the OMETA links, O&M managers have the responsibility of interfacing with other department managers and making their case for ever-shrinking budgets. Their roles also include project implementation functions as well as the need to maintain persistence of the program and its goals. It should be noted that while in larger O&M organizations these five distinct areas (OMETA) will be handled by well-defined departments with dedicated staff, in smaller organizations these functions may be handled by a few staff. If the latter case represents your organization, then the activities presented below still need attention; however, necessary prioritization is required.

Developing the Structure

Five well-defined elements of an effective O&M program include those presented above in the OMETA concept (Meador 1995). While the OMETA elements form the basis for a solid O&M organization, the key lies in the well-defined functions each brings and the linkages between organizations. A subset of the roles and responsibilities for each of the elements is presented below; further information is found in Meador (1995).

Operations

- **Administration** – To ensure effective implementation and control of operation activities.
- **Conduct of Operations** – To ensure efficient, safe, and reliable process operations.
- **Equipment Status Control** – To be cognizant of status of all equipment.
- **Operator Knowledge and Performance** – To ensure that operator knowledge and performance will support safe and reliable plant operation.

Maintenance

- **Administration** – To ensure effective implementation and control of maintenance activities.
- **Work Control System** – To control the performance of maintenance in an efficient and safe manner such that economical, safe, and reliable plant operation is optimized.

- **Conduct of Maintenance** – To conduct maintenance in a safe and efficient manner.
- **Preventive Maintenance** – To contribute to optimum performance and reliability of plant systems and equipment.
- **Maintenance Procedures and Documentation** – To provide directions, when appropriate, for the performance of work and to ensure that maintenance is performed safely and efficiently.

Engineering Support

- **Engineering Support Organization and Administration** – To ensure effective implementation and control of technical support.
- **Equipment Modifications** – To ensure proper design, review, control, implementation, and documentation of equipment-design changes in a timely manner.
- **Equipment Performance Monitoring** – To perform monitoring activities that optimize equipment reliability and efficiency.
- **Engineering Support Procedures and Documentation** – To ensure that engineer support procedures and documents provide appropriate direction and that they support the efficiency and safe operations of the equipment.

Training

- **Administration** – To ensure effective implementation and control of training activities.
- **General Employee Training** – To ensure that plant personnel have a basic understanding of their responsibilities and safe work practices and have the knowledge and practical abilities necessary to operate the plant safely and reliably.
- **Training Facilities and Equipment** – To ensure the training facilities, equipment, and materials effectively support training activities.
- **Operator Training** – To develop and improve the knowledge and skills necessary to perform assigned job functions.
- **Maintenance Training** – To develop and improve the knowledge and skills necessary to perform assigned job functions.

Administration

- **Organization and Administration** – To establish and ensure effective implementation of policies and the planning and control of equipment activities.
- **Management Objectives** – To formulate and utilize formal management objectives to improve equipment performance.

- **Management Assessment** – To monitor and assess station activities to improve all aspects of equipment performance.
- **Personnel Planning and Qualification** – To ensure that positions are filled with highly qualified individuals.
- **Industrial Safety** – To achieve a high degree of personnel and public safety.

Obtain Management Support

DoD/Army O&M managers need to obtain full support from their management structure in order to carry out an effective maintenance program. A good way to start is by establishing a written maintenance plan and obtaining upper-management approval. Such a management-supported program is very important because it allows necessary activities to be scheduled with the same priority as other management actions. Approaching O&M by equating it with increased productivity, energy efficiency, safety, and customer satisfaction is one way to gain management attention and support.

Another consideration for a functional O&M program is the development of a "mission statement." This statement should be carefully designed to capture the goals and challenges of the program and present well-defined outcomes (e.g., a responsive, safe, and energy-efficient organization). The ultimate goal of the O&M mission statement should be to receive management buy-in at the highest level. A clear understanding of program objectives and goals is necessary before management puts their trust in and promotes some level of ownership in the program.

Measuring the Quality of Your O&M Program

Traditional thinking in the O&M field focused on a single metric—reliability—for program evaluation. Every O&M manager wants a reliable facility; however, reliability alone is not enough to evaluate or build a successful O&M program.

Beyond reliability, O&M managers need to be responsible for controlling costs, evaluating and implementing new technologies, tracking and reporting on health and safety issues, and expanding their program. To support these activities, the O&M manager must be aware of the various indicators that can be used to measure the quality or effectiveness of the O&M program. Not only are these metrics useful in assessing effectiveness, but they are also useful in cost justification of equipment purchases, program modifications, and staff hiring.

Below are a number of metrics that can be used to evaluate an O&M program. Not all these metrics can be used in all situations; however, a program should use of as many metrics as possible to better define deficiencies and, most importantly, publicize successes.

- **Capacity factor** – Relates actual plant or equipment operation to the full-capacity operation of the plant or equipment. This is a measure of actual operation compared to full-utilization operation.
- **Work orders generated/closed out** – Tracking of work orders generated and completed (closed out) over time allows the manager to better understand workloads and better schedule staff.

- **Backlog of corrective maintenance** – An indicator of workload issues and effectiveness of preventive/predictive maintenance programs.
- **Safety record** – Commonly tracked either by number of loss-of-time incidents or total number of reportable incidents. Useful in getting an overall safety picture.
- **Energy use** – A key indicator of equipment performance, level of efficiency achieved, and possible degradation.
- **Inventory control** – An accurate accounting of spare parts can be an important element in controlling costs. A monthly reconciliation of inventory "on the books" and "on the shelves" can provide a good measure of your cost-control practices.
- **Overtime worked** – Weekly or monthly hours of overtime worked has workload, scheduling, and economic implications.
- **Environmental record** – Tracking of discharge levels (air and water) and non-compliance situations.
- **Absentee rate** – A high or varying absentee rate can be a signal of low worker morale and should be tracked. In addition, a high absentee rate can have a significant economic impact.
- **Staff turnover** – High turnover rates are also a sign of low worker morale. Significant costs are incurred in the hiring and training of new staff. Other costs include those associated with errors made by newly hired personnel that normally would not have been made by experienced staff.

Consideration of Computerized Maintenance Management Systems (CMMS)

A computerized maintenance management system (CMMS) is a type of management software that performs functions in support of management and tracking of O&M activities. These systems automate most of the logistical functions performed by maintenance staff and management. The CMMS comes with many options and has many advantages over manual maintenance tracking systems. Depending on the complexity of the system chosen, typical CMMS functions may include the following:

- Work-order generation, prioritization, and tracking by equipment/component.
- Historical tracking of all work orders generated that become sortable by equipment, date, person responding, etc.
- Tracking of scheduled and unscheduled maintenance activities.
- Storing of maintenance procedures as well as all warranty information by component.
- Storing of all technical documentation or procedures by component.
- Real-time reports of ongoing work activity.

- Calendar- or run-time-based preventive maintenance work-order generation.
- Capital and labor cost tracking by component as well as shortest, median, and longest times to close a work order by component.
- Complete parts and materials inventory control with automated reorder capability.
- PDA interface to streamline input and work-order generation.
- Outside service call/dispatch capabilities.

Many CMMS programs can now interface with existing energy management and control systems (EMCS) as well as property management systems. Coupling these capabilities allows for condition-based monitoring and component energy use profiles.

CMMS Benefits

One of the greatest benefits of the CMMS is the elimination of paperwork and manual tracking activities, thus enabling the building staff to become more productive. It should be noted that the functionality of a CMMS lies in its ability to collect and store information in an easily retrievable format. A CMMS does not make decisions, rather it provides the O&M manager with the best information to affect the *operational efficiency* of a facility.

Benefits to implement a CMMS include the following:

- Detection of impending problems before a failure occurs, resulting in fewer failures and customer complaints.
- Achieving a higher level of planned maintenance activities that enables a more efficient use of staff resources.
- Affecting inventory control, enabling better spare-parts forecasting to eliminate shortages and minimize existing inventory.
- Maintaining optimal equipment performance that reduces downtime and results in longer equipment life.

CMMS Pitfalls

While CMMS can go a long way toward automating and improving the efficiency of most O&M programs, there are some common pitfalls. These include the following:

- Improper selection of a CMMS vendor. This is a site-specific decision. Time should be taken to evaluate initial needs and look for the proper match of system and service provider.

- Inadequate training of the O&M administrative staff on proper use of the CMMS. These staff need dedicated training on input, function, and maintenance of the CMMS. Typically, this training takes place at the customer's site after the system has been installed.

- Lack of commitment to properly implement the CMMS. A commitment needs to be in place for the start up/implementation of the CMMS. Most vendors provide this as a service, and it is usually worth the expense.

- Lack of commitment to persist in CMMS use and integration. While the CMMS provides significant advantages, it needs to be maintained. Most successful CMMS installations have a "champion" who ushers and encourages its use.

O&M Contracting

Approximately 40% of all non-residential buildings contract maintenance service for heating, ventilation, and air conditioning (HVAC) equipment (PECI 1997). Discussions with DoD/Army facility mangers and organizations indicate the trend is toward increased reliance on contracted services.

In the O&M service industry, there is a wide variety of service contract types ranging from full-coverage contracts to individual equipment contracts to simple inspection contracts. In a relatively new type of O&M contract, called End-Use or End-Result contracting, the O&M contractor not only takes over all operation of the equipment, but also all operational risk. In this case, the contractor agrees to provide a certain level of comfort (space temperature, for instance) and then is compensated based on how well this is achieved.

From discussions with DoD/Army O&M personnel, the predominant contract type is the full-coverage contract (also referred to as the whole-building contract). Typical full-coverage contract terms vary between 1 and 5 years and usually include options for out-years.

Upon review of several sample O&M contracts used in the DoD/Army sector, it is clear that some degree of standardization has taken place. For better or worse, some of these contracts contain a high degree of "boiler plate." While this can make the contract very easy to implement, and somewhat uniform across government agencies, the lack of site specificity can make the contract ambiguous and open to contractor interpretation often to the government's disadvantage.

When considering the use of an O&M contract, it is important that a plan be developed to select, contract with, and manage this contract. In its guide, *Operation and Maintenance Service Contracts* (PECI 1997), Portland Energy Conservation, Inc. did a particularly good job in presenting steps and actions to think about when considering an O&M contract. A summary of these steps is provided below:

Steps to consider when developing an O&M service contract:

- *Develop objectives for an O&M service contract, such as:*
  - *Provide maximum comfort for building occupants.*
  - *Improve operating efficiency of mechanical plant (boilers, chillers, cooling towers, etc.).*
  - *Apply preventive maintenance procedures to reduce chances of premature equipment failures.*
  - *Provide for periodic inspection of building systems to avoid emergency breakdown situations.*

- *Develop and apply a screening process. The screening process involves developing a series of questions specific to your site and expectations. The same set of questions should be asked to perspective contractors and their responses should be rated.*

- *Select two to four potential contractors and obtain initial proposals based on each contractor's building assessments. During the contractors' assessment process, communicate the objectives and expectations for the O&M service contract and allow each contractor to study the building documentation.*

- *Develop the major contract requirements using the contractors' initial proposals. Make sure to include the requirements for documentation and reporting. Contract requirements may also be developed by competent in-house staff or a third party.*

- *Obtain final bids from the potential contractors based on the owner-developed requirements.*

- *Select the contractor and develop the final contract language and service plan.*

- *Manage and oversee the contracts and documentation.*
  - *Periodically review the entire contract. Build in a feedback process.*

The ability of DoD/Army sites to adopt the PECI-recommended steps will vary. Still, these steps do provide a number of good ideas that should be considered for incorporation into federal maintenance contracts procurements.

O&M Contract Incentives

An approach targeting energy savings through mechanical/electrical (energy-consuming) O&M contracts is called ***contract incentives***. This approach rewards contractors for energy savings realized for completing actions that are over and above the stated contract requirements.

Many contracts for O&M of DoD/Army building mechanical/electrical (energy consuming) systems are written in a prescriptive format where the contractor is required to complete specifically noted actions in order to satisfy the contract terms. There are two significant shortcomings to this approach:

- The contractor is required to complete only those actions specifically called out, but is not responsible for actions not included in the contract even if these actions can save energy, improve building operations, extend equipment life, and be accomplished with minimal additional effort. Also, this approach assumes that the building equipment and maintenance lists are complete.

- The burden to verifying successful completion of work under the contract rests with the contracting officer. While contracts typically contain contractor reporting requirements and methods to randomly verify work completion, building O&M contracts tend to be very large, complex, and difficult to enforce.

One possible method to address these shortcomings is to apply a provision of the Federal Acquisition Regulations (FAR), Subpart 16.404 – Fixed-Price with Award Fees, which allows for contractors to receive a portion of the savings realized from actions initiated on their part that are seen as additional to the original contract:

Subpart 16.404 — Fixed-Price Contracts With Award Fees.

(a) Award-fee provisions may be used in fixed-price contracts when the Government wishes to motivate a contractor and other incentives cannot be used because contractor performance cannot be measured objectively. Such contracts shall —

  (1) Establish a fixed price (including normal profit) for the effort. This price will be paid for satisfactory contract performance. Award fee earned (if any) will be paid in addition to that fixed price; and

  (2) Provide for periodic evaluation of the contractor's performance against an award-fee plan.

(b) A solicitation contemplating award of a fixed-price contract with award fee shall not be issued unless the following conditions exist:

  (1) The administrative costs of conducting award-fee evaluations are not expected to exceed the expected benefits;

  (2) Procedures have been established for conducting the award-fee evaluation;

  (3) The award-fee board has been established; and

  (4) An individual above the level of the contracting officer approved the fixed-price-award-fee incentive.

Applying this approach to building mechanical systems O&M contracts, contractor-initiated measures would be limited to those that

- require little or no capital investment,
- can recoup implementation costs over the remaining current term, and
- allow results to be verified or agreed upon by the government and the contractor.

Under this approach, the contractor bears the risk associated with recovering any investment and a portion of the savings.

The General Services Administration (GSA) has inserted into many of its mechanical services contracts a voluntary provision titled Energy Conservation Award Fee (ECAF), which allows contractors and sites to pursue such an approach for O&M savings incentives. The ECAF model language provides for the following:

An energy use baseline will be furnished upon request and be provided by the Government to the contractor. The baseline will show the 3-year rolling monthly average electric and natural gas use prior to contract award.

- The Government will calculate the monthly electric savings as the difference between the monthly energy bill and the corresponding baseline period.
- The ECAF will be calculated by multiplying the energy savings by the monthly average cost per kilowatt-hour of electricity (kWh).
- All other contract provisions must be satisfied to qualify for award.
- The Government can adjust the ECAF for operational factors affecting energy use such as fluctuations in occupant density, building use changes, and when major equipment is not operational.

Individual sites are able to adapt the model GSA language to best suit their needs (e.g., including natural gas savings incentives). Other agencies are free to adopt this approach as well since the provisions of the FAR apply across the federal government.

Energy savings opportunities will vary by building and by the structure of the contract incentives arrangement. Some questions to address when developing a site specific incentives plan are:

- Will metered data be required or can energy savings be stipulated?
- Are buildings metered individually for energy use or do multiple buildings share a master meter?
- Will the baseline be fixed for the duration of the contract or will the baseline reset during the contract period?
- What energy savings are eligible for performance incentives? Are water savings also eligible for performance incentives?
- What administrative process will be used to monitor work and determine savings? Note that overly rigorous submittal, approval, justification, and calculation processes will discourage contractor participation.

An added benefit from the contract incentives process is that resulting operations and energy-efficiency improvements can be incorporated into the O&M service contract during the next contract renewal or recompetition since (a) the needed actions are now identified, and (b) the value of the actions is known to the Government.

Model Contract Language

Contracts being recompeted offer an opportunity to replace dated and often ambiguous boilerplate maintenance contract clauses with model contract clauses that make use of current best practices including predictive maintenance technologies such as infrared thermography, ultrasonics, and vibration analysis. These increased and updated requirements will result in increased award fees as current boilerplate clauses tend to emphasize only a preventive maintenance approach.

Examples of model contract language in the federal facilities sector are difficult to locate. The National Aeronautics and Space Administration (NASA) has developed a series of Guide Performance

Work Statements that allow for the incorporation of many of the current O&M best practices, including the use of predictive testing and inspection. The NASA O&M contracting approach has become more outcome-based with an emphasis on results and outcomes instead of relying on the traditional performance-based approach where work requirements are specified. The family of NASA documents for these performance-based contracts is available at http://www.hq.nasa.gov/office/codej/codejx/, under the section heading "NASA Guide Performance Work Statements (GPWS)":

- (NASA 1997a) *The Guide Performance Work Statement for Center/Installation Operation Support Services*, Section C, contains the complete (unedited) GPWS. Of particular interest are the following subsections:
  - C.12, General Requirements and Procedures for Recurring Work,
  - C.15, Heating, Ventilation, Air Conditioning, Refrigeration, and Compressed Air Systems Maintenance and Repair,
  - C.16, High and Low Voltage Electrical Distribution Systems Maintenance and Repair,
  - C.17, Central Heating Plant Generation and Distribution Systems Operation, Maintenance and Repair, and
  - C.23, Potable and Industrial Water Systems Operation, Maintenance, and Repair.

- The *User's Guide for Preparing Performance Guide Work Statements for Center Operations Support Services* states that predictive testing and inspection is treated just like preventive maintenance in that it is performed and inspected on a regular basis (NASA 1997b).

- "Guide Performance Work Statement for Subsection 32 – Energy/Water Conservation Management Services" calls for contractors to serve as the site energy and water conservation program managers. Included in this section are various O&M functions including meter reading, audits, utility bill verification, leak detection, EMCS operation and repair, and commissioning (NASA 1999).

Program Development

The road from a purely reactive O&M program to an effective and efficient program is not an easy one. The following is a list of some basic steps that will help to get moving down this path.

1. Develop a master equipment list identifying the equipment in your facility.
2. Prioritize the listed components based on importance to process.
3. Assign components into logical groupings.
4. Determine the type and number of maintenance activities required and periodicity using:
   a. Manufacturer technical manuals
   b. Machinery history
   c. Root cause analysis findings – Why did it fail?
   d. Good engineering judgment
5. Assess the size of maintenance staff.
6. Identify tasks that may be performed by operations maintenance personnel.
7. Analyze equipment failure modes and effects.
8. Identify effective maintenance tasks or mitigation strategies.

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Opportunity #2: Metering for Tracking, Trending, and Operational Efficiency

Introduction

One of the most critical functions of any O&M program is an ability to understand equipment/system performance. Without some ability to evaluate performance you are unlikely to make the best decisions. Metering and sub-metering of energy and resource use is a critical component of a comprehensive O&M program. Metering for O&M and energy efficiency refers to the measurement of quantities of energy delivered, for example, kilowatt-hours of electricity, cubic feet of natural gas, pounds of steam. Metering may also involve identifying times-of-use for the various energy sources, the instantaneous demand for energy, as well as identifying energy use for a collection of buildings, individual buildings, rooms, or specific equipment, such as a boiler, a chiller, or a motor.

In addition to the general *business sense* of metering, the federal government has now mandated some level of metering throughout the federal sector. The *Energy Policy Act of 2005* (EPAct 2005), Section 103, requires all federal agencies to install metering and advanced metering, wherever practicable, by October 1, 2012. DOE has developed a set of guidelines for agencies to apply to their own policies to meet the EPAct 2005 metering requirement. The DOE guidelines (www1.eere.energy.gov/femp) require electric metering to be installed on all buildings where feasible, where energy cost savings are possible, and where cost-effective, based on a 10-year simple payback and an annual savings of at least 2%. At the agency level, implementation plans were due by August 3, 2006. Furthermore, agencies are required to establish plan deadlines and progress reporting guidelines for individual installations.

Facility resource metering has a variety of applications for the DoD/Army facility/energy manager. The necessity to control costs, diagnose equipment malfunction, allocate usage, and set resource efficiency goals are all increasingly important reasons for energy and water metering. Furthermore, with the escalating volatility of energy and water rates, these needs are becoming more important.

> The importance of metering can be summed up by the Energy Manager's Maxim: If you do not collect it… you cannot measure it. If you do not measure it… you cannot manage it.

Historically, the federal sector has lagged the private sector in metering applications. To this day at DoD/Army sites, it is common to find one "master" meter serving loads representing a few buildings to well in excess of 500 buildings. These master- metered accounts make it very difficult to manage energy use and was one of the primary drivers for the EPAct legislation requiring at least building-level metering, where cost effective, for federal-sector buildings.

Importance of Metering

Metering provides the information that *when analyzed* allows the building operations staff to make informed decisions on how to best operate mechanical/electrical systems and equipment. These decisions will ultimately affect energy costs, equipment costs, and overall building performance. Reasons for metering vary by site; listed below are some rational to consider for sub-metering at your site.

- Monitor existing utility usage
- Verify utility bills
- Identify the best utility rate plans
- Measure, verify, and optimize equipment performance
- Isolate energy use and costs
- Measure, not estimate, tenant energy use
- Diagnose equipment and systems operations
- Manage energy use.

Metering Applications

The uses for metered data vary from site-to-site and while not all sites have the same uses, some of the more common applications are presented below (Sydlowski 1993).

- **Data Recording**. Advanced meters can duplicate the conventional metering function of recording total consumption, plus offer enhanced functions such as time-of-use, peak demand, load survey, and power outage recording. For electric metering, advanced meters may also include recording of other electric characteristics, such as voltage, current, and power factor.

- **Total Consumption**. This is the most basic data-recording function, which duplicates the standard kilowatt-hour of electricity (kWh), hundred cubic feet volume (CCF) of gas, or gallons (gal) of water consumed between meter readings.

- **Time-of-Use Metering**. Different rates can be charged for on-peak and off-peak time periods by accumulating the total consumption during operator-defined time windows. The time windows may vary during both time of day and weekday/weekend/holiday.

- **Peak Demand Metering**. Billing of many larger commercial and industrial customers is based on total consumption and the highest 15-, 30-, or 60-minute demand during the billing period. The peak demand may be reported as a single highest value, highest four values, or highest value during each hour (all peak demand values must be accompanied by an associated time stamp).

- **Load Survey (Profile or Time-Series Data)**. Energy consumption and conservation impact studies, as well as more complex analysis of system loading, require more detailed demand data. A load survey provides periodic consumption or demand data (in time increments of 1, 5, 15, 30, or 60 minutes).

- **Monitoring and Control**. A two-way communication link between a central station and customer site provides the opportunity for integrating some other utility functions into the metering functions. Meters can be programmed to detect and report by exception (e.g., report only when a fault is detected) for power outage, leak detection, and tamper detection. The meter can also dispatch control functions, such as remote service disconnect/reconnect, demand-side management (DSM) load control, and load scheduling.

- **Load Control**. Load control includes DSM control functions such as air conditioner and water heater load-shedding. The DSM load control could be triggered by a fixed algorithm operating independently or real-time central station control.

- **Load Scheduling**. This includes scheduled start and stop of equipment to minimize or shift load to take maximum advantage of the demand and time-of-use billing rate structures.

- **Leak Detection**. Continuous monitoring of gas or water usage or pressure can be used to detect leaks.

Metering Approaches

The four predominant levels of resource metering (EPRI 1996) are:

- One-time/spot measurement
- Run-time measurement
- Short-term monitoring
- Long-term monitoring

Each level has its own unique characteristics – no one monitoring approach is useful for all projects. A short description of each monitoring level is provided below.

One-Time/Spot Measurements

One-time measurements are useful in many "baseline" activities to understand instantaneous energy use, equipment performance, or loading. These measurements become particularly useful in trending equipment performance over time. For example, a spot measurement of a boiler-stack exhaust temperature, trended over time, can be very diagnostic of boiler efficiency.

Related to energy performance, one-time measurements are useful when an energy-efficiency project has resulted in a finite change in system performance. The amperage of an electric motor or lighting system taken before and after a retrofit can be useful to quantify system savings – assuming similar usage (hours of operation) before and after.

Equipment useful in making one-time/spot measurements include clamp-on amp probes, contact and non-contact temperature devices, non-intrusive flow measurement devices, and a variety of combustion-efficiency devices. Most of these measurements are obtained and recorded in the field by the analyst.

Run-Time Measurements

Run-time measurements are made in situations where hours-of-operation are the critical variable. These measurements are prevalent where an energy efficiency project has impacted the use (i.e., hours of operation) of a device. Appropriate applications for run-time measurements include the run-times of fans and pumps, or the operational characteristics of heating, cooling, or lighting systems.

Because run-time measurements do not capture the energy-use component of the system, these measurements are typically used in conjunction with one-time/spot measurements. Equipment useful in making run-time measurements includes a variety of stand-alone (battery-operated) data loggers providing time-series record on run-time. Most of these devices are non-intrusive (i.e., the process or system is not impacted by their use or set-up) and are either optically triggered or take advantage of the electromagnetic characteristics of electrical devices. Run-time measurements are usually obtained in the field by the device, recorded to memory, and then downloaded by the analyst at a later date.

Short-Term Measurements/Monitoring

Short-term monitoring combines both elements of the previous two levels into a time-series record of energy or resource use: magnitude and duration. Typically, short-term monitoring is used to verify performance, initiate trending, or validate energy efficiency improvement. In this level, the term of the monitoring is usually less than one year, and in most cases on the order of weeks to months. In the case of energy efficiency improvement validation, also known as *measurement and verification*, these measurements may be made for two-weeks prior and post installation of an efficiency improvement project. These data are then, using engineering and statistical methods, extrapolated over the year to report the annual impact.

Equipment useful in short-term monitoring includes a host of portable, stand-alone data loggers capable of multivariate time-series data collection and storage. Most of these data loggers accept a host of sensors including temperature, pressure, voltage, current flow, etc., and have standardized on input communications (e.g., 4 to 20 milliamperes or 0 to 5 volts). These loggers are capable of recording at user-selected intervals from fractions of a second, to hourly, to daily recordings. These systems usually rely on in-field manual downloading or, if available, modem and/or network connections.

Long-Term Measurements/Monitoring

Long-term monitoring also makes use of time-series recording of energy or resource use, but over a longer duration. Different from short-term use, this level focuses on measurements used in long-term trending or performance verification. The term is typically more than a year and quite often the installation is permanent.

Useful applications for this level of monitoring include situations where system use is influenced by variances in weather, occupant behavior, or other operating conditions. Other applications include reimbursable resource allocation, tenant billing activities, or in cases where the persistence of energy or resource savings over time is at issue.

Equipment useful in long-term monitoring included a variety of data loggers, utility-grade meters, or fixed-data acquisition systems. In most cases, these systems communicate via a network connection/ phone modem to a host computer and/or over the internet.

Metering System Components

There are four necessary components to a viable building-level metering system: the meters, the data-collection system, the data storage/retrieval system, and the analysis system/capability (AEC 2003; EPRI 1996). Each component is described below.

Meters

At the most basic level, all meters provide some output related to resource use – energy, water, natural gas, etc. Beyond this basic level, more sophisticated meters take advantage of additional capabilities including electrical demand tracking, power quality measurements, and multiple-meter communication for leak-detection applications. A typical electrical sub-meter is shown in Figure 1.

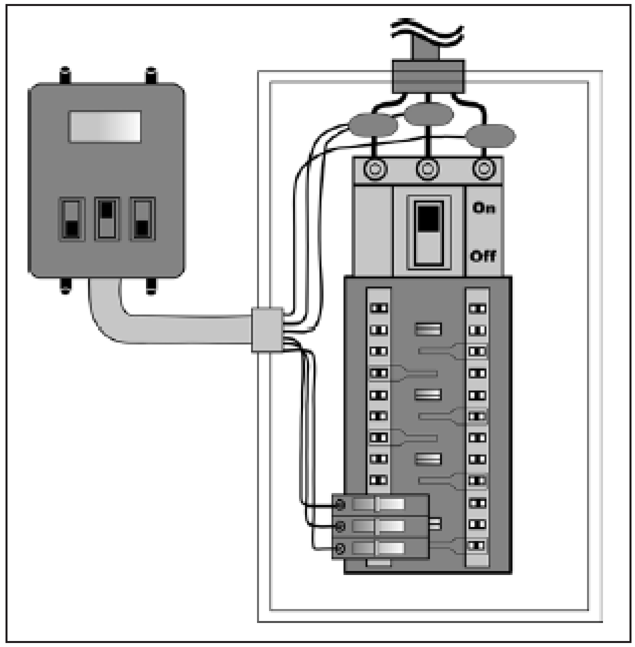

Figure 1. Typical Electrical Sub-Meter (box on left) Used in Long-Term Monitoring

For electrical systems, meters can be installed to track whole-building energy use (e.g., utility meters), sub-panel energy use (e.g., a lighting or process circuit), or a specific end use (e.g., a motor or a chiller). For water, natural gas, and other flow-related applications, meters are typically in-line installations using positive displacement, insertion turbine, or pressure-related techniques. Depending on the need, any of these meters will vary in size, type, output configuration, accuracy, and price.

To better understand portable meters or data loggers and their vendors, the report titled *Portable Data Loggers Diagnostic Tools for Energy-Efficient Building Operations* (PECI 1999) is particularly good. A list of vendors of larger, dedicated, whole-building meters can be found in the report titled *Advanced Utility Metering* (AEC 2003).

Data Collection

Modern metering data-collection systems take advantage of recent developments in communications technologies. Over the past 15 years, Automated Meter reading (AMR) systems have increased in sophistication and reliability, and now represent a very economic means of data collection. Available technologies include radio frequency, phone modem (including wireless/cellular), local area networks, and Internet solutions.

Data Storage

The need for, and the duration of, data storage should be carefully considered in the design and implementation of a metering system. A clear understanding of data needs and applications will drive storage decisions. At the most basic level, metered data is easily stored in one of many available database systems. The duration of data storage is a function of data use; long-term end-use studies require longer-duration storage, short-term daily comparisons require less. There are a variety of application service providers (ASPs) that can provide data storage and retrieval services on a fee-based service.

Data Analysis

Large-scale analysis of energy data can be time-consuming and expensive. In many cases, the manufacturers of metering equipment also provide off-the-shelf or custom software applications to assist these functions. In addition to the meter manufacturers, third-party software vendors, including some ASPs can provide data capture, collection/storage, and analysis services. Analytical services can range from simple use-reporting and tenant billing, to more sophisticated activities of energy use diagnostics and system performance indicators.

Metering Economics

The economic value of metering is directly proportional to the use of the resulting data. The range of potential resource savings related to metering varies with the building, equipment, and the use of the metered data. Economic savings attributed to metering can be as high as 20%, the higher savings percentages requiring a very proactive use of the metered data.

Metering system installed costs will vary with system, existing infrastructure, meter type, communication needs, number purchased, etc. On average, installation of long-term, whole-building-type meters costs between $1,000 to $10,000 per point or meter. An average per-meter installed cost may be in the range of $3,000 to $5,000. Metering at the end-use level with temporary or portable data loggers has a much lower installed cost – usually on the order of $300 to $1,000, depending on the equipment used.

Steps in Metering Planning

The development of a federal metering program is highly dependent on a site's needs, existing metering equipment, and available infrastructure. When it comes to metering, *one size does not fit all*. Below are some very general guidelines identifying the steps and actions necessary for a quality metering program. These guidelines summarize information found in AEC (2003), EPRI (1996), and Sydlowski (1993) where more detailed information can be found. Figure 2 presents these steps in a flow chart format.

- Formalize objectives and goals of metering program.
  - identify and confirm goals of stakeholders/users
  - prioritize goals as near-term, mid-term, and long-term
  - formalize necessary/expected outcomes

- Develop program structure. Identify data needs, equipment needs, analysis methodologies, and responsible staff.
  - develop data and analysis needs based on necessary outcomes
  - develop equipment needs based on data needs
  - take advantage of existing infrastructure
  - identify responsible staff, preferably a metering "champion"

- Develop criteria for evaluation metering costs, benefits, and impacts to existing systems, infrastructure, and staff.
  - determine relative economics of proposal
  - justify with cost/benefit, return on investment, or payback metric

- Develop a prioritized implementation plan targeting manageable successes.
  - screen opportunities based on success potential
  - start small/manageable – build off success

- Develop a sustainable plan, targeting use, updates, calibration, maintenance, and program reinvestment.
  - maintain your investment
  - make this success visible
  - plan for future implementation/ reinvestment

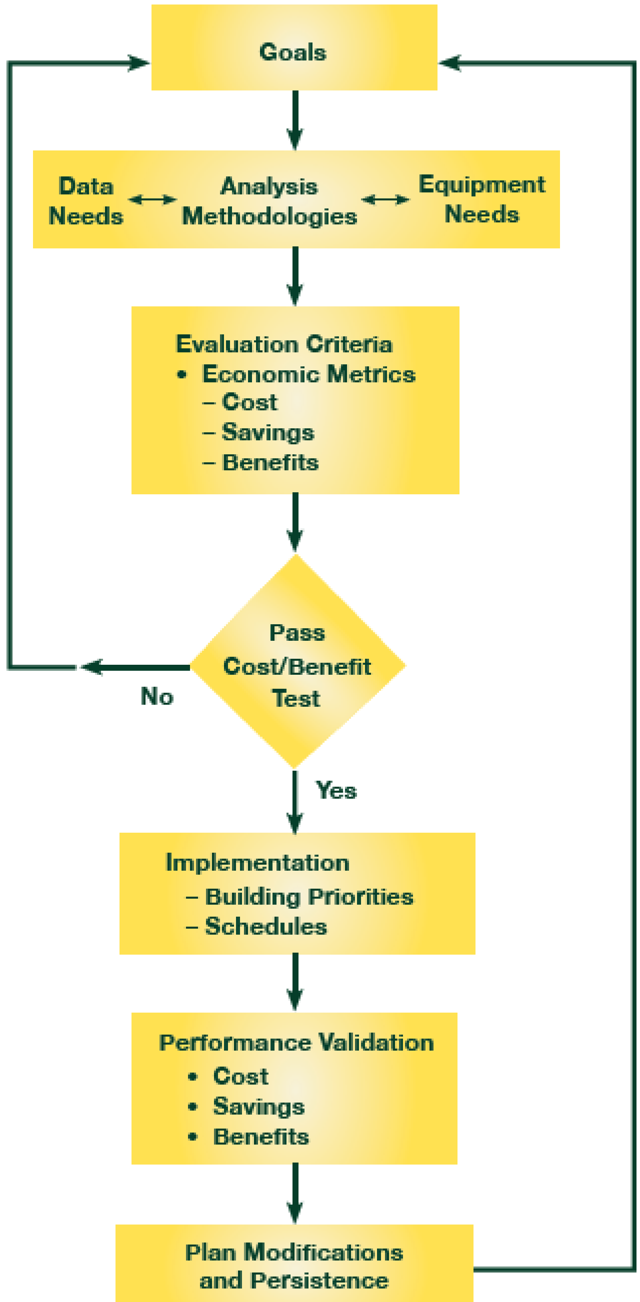

Figure 2. Metering Plan Development Process

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Opportunity #3: Boiler Operational Efficiency

Introduction

Put simply, boilers are fuel-burning systems that produce either hot water or steam that is circulated through piping for heating or process uses. This section addresses boilers, their relevance to the DoD/Army sector, their potential for savings, and the more common inefficiencies found with these systems. Figure 3 presents a typical boiler highlighting the components of the burner, fire tubes, and flue (EPA 2006).

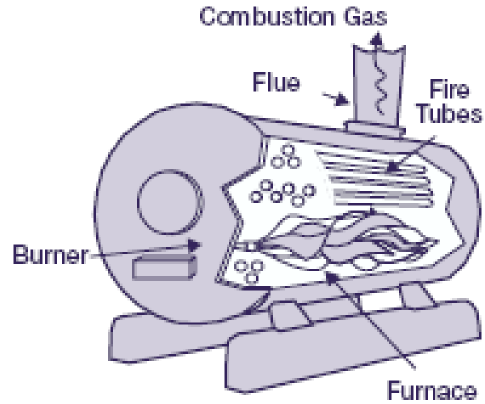

Figure 3. Typical Fire-Tube Boiler

Typical Energy Impacts

According to *2005 Buildings Energy Data Book* (DOE 2005), space heating and water heating energy use in commercial buildings is estimated at over 45% of a commercial building's total energy use. This is an average for all building types, measured on a Btu/ft^2 basis. This large percentage of energy use highlights the importance of maintaining, and the potential for reducing, heating system energy consumption.

Potential Savings

Depending on the condition of the existing boiler, savings potential resulting from boiler system improvements range from 5% to 20%. O&M-related boiler opportunities are typically functions of combustion efficiency, boiler control, and overall system maintenance (e.g., tube cleaning, insulation maintenance).

Figure 4 breaks down the typical cost categories for a boiler plant, as a percentage of total operating costs (Eckerlin 2006).

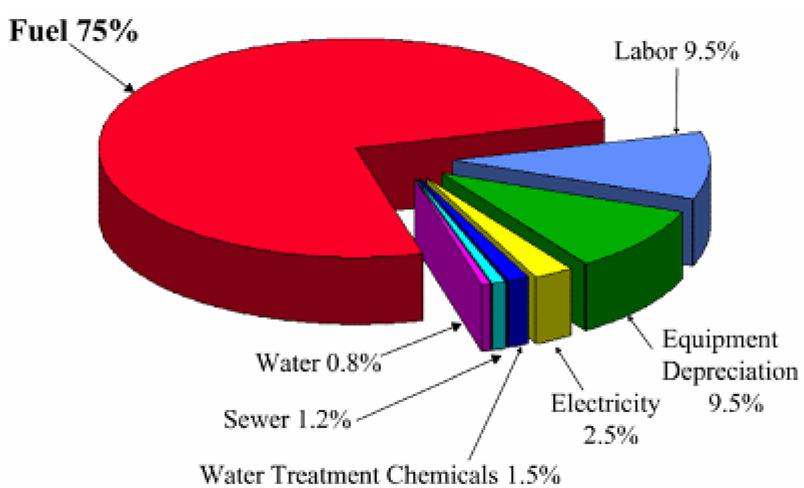

Figure 4. Typical Boiler Plant Cost Factors

It is interesting to note the relative percentages of total cost allocated to fuel cost. This fuel cost, 75% of the total cost, should become the #1 target when looking to affect cost reduction.

Operational/Energy Efficiency Measures

There are many operational/energy efficiency measures that could be presented for proper boiler operation and control. The following section focuses on the most prevalent O&M recommendations having the greatest energy impacts at DoD/Army facilities. These recommendations are also some of the most easily implemented for boiler operators and O&M contractors.

Boiler Measure #1: Boiler Loading, Sequencing, Scheduling, and Control

The degree to which a boiler is loaded can be determined by the boiler's firing rate. Some boiler manufacturers produce boilers that operate at a single firing rate, but most manufacturers' boilers can operate over a wide range of firing rates. The firing rate dictates the amount of heat that is produced by the boiler and, consequently, modulates to meet the heating requirements of a given system or process. In traditional commercial buildings, the hot water or steam demands will be considerably greater in the winter months, gradually decreasing in the spring/fall months, and finally hitting its low point during the summer. A boiler will handle this changing demand by increasing or decreasing the boiler's firing rate. Meeting these changing loads introduces challenges to boiler operators to meet the given loads while loading, sequencing, and scheduling the boilers properly.

Any gas-fired boiler that cycles on and off regularly or has a firing rate that continually changes over short periods can be altered to improve the boiler's efficiency. Frequent boiler cycling is usually a sign of insufficient building and/or process loading. Possible solutions to this problem (Dyer 1991) include adjusting the boiler's high- and low-pressure limits (or differential) farther apart and thus keeping the boiler on and off for longer periods of time. The second option is replacement with a properly sized boiler.

The efficiency penalty associated with low-firing stems from the operational characteristic of the boiler. Typically, a boiler has its highest efficiency at high fire and near full load. This efficiency usually decreases with decreasing load.

O&M Tip: Load management measures, including optimal matching of boiler size and boiler load, can save as much as 50% of a *boiler's* fuel use.

The efficiency penalty related to the boiler cycle consists of a pre-purge, a firing interval, and a post-purge, followed by an idle (off) period. While necessary to ensure a safe burn cycle, the pre- and post-purge cycles result in heat loss up the exhaust stack. Short cycling results in excessive heat loss. Table 1 indicates the energy loss resulting from this type of cycling (Dyer 1991).

Table 1. Boiler Cycling Energy Loss

Number of Cycles/Hour	Percentage of Energy Loss
2	2
5	8
10	30

"Based on equal time between on and off, purge 1 minute, stack temp = 400°F, flow air through boiler with fan off = 10% of fan forced air flow." (Dyer 1991)

Opportunity Identification

Boiler operators should record in the daily log if the boiler is cycling frequently. If excessive cycling is observed, then operators should consider the options given above to correct the problem.

Boiler operators should also record in the daily log the firing rate to meet the given hot water or steam load. If the boiler's firing rate continuously cycles over short periods of time and with fairly small variations in load, then this should be noted. Seasonal variations in firing rate should be noted with an eye for sporadic firing over time. Corrections in firing rates require knowledge of boiler controls and should only be made by qualified staff.

Diagnostic Equipment

Data Loggers. The diagnostic test equipment to consider for assessing boiler cycling includes many types of electric data logging equipment. These data loggers can be configured to record the time-series electrical energy delivered to the boiler's purge fan as either an amperage or wattage measurement. These data could then be used to identify cycling frequency and hours of operation.

Other data-logging options include a variety of stand-alone data loggers that record run-time of electric devices and are activated by sensing the magnetic field generated during electric motor operation. As above, these loggers develop a times-series record of on-time that is then used to identify cycling frequency and hours of operation.

Energy Savings and Economics

Estimated Annual Energy Savings. Using Table 1, the annual energy savings that could be realized by eliminating or reducing cycling losses can be estimated as follows:

$$Energy\ Savings = \left[\left(\frac{BL \times RFC}{EFF \times \left(1 - \frac{EL_1}{100}\right)} \right) - \left(\frac{BL \times RFC}{EFF \times \left(1 - \frac{EL_2}{100}\right)} \right) \right] \times H$$

$$Annual\ Energy\ Savings = \sum_{i=1}^{n} Energy\ Savings$$

where BL = current boiler load or firing rate, %/100
RFC = rated fuel consumption at full load, MMBtu/hr
EFF = boiler efficiency, %/100
EL_1 = current energy loss due to cycling, %
EL_2 = tuned energy loss due to cycling, %
H = hours the boiler operates at the given cycling rate, hours

Estimated Annual Cost Savings. The annual cost savings that could be realized by eliminating or reducing cycling losses can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times FC$$

where FC = fuel cost, \$/MMBtu

Boiler Loading Energy Savings and Economics Example

Example Synopsis

A boiler's high-pressure setpoint was increased to reduce the cycling losses of a given boiler. Before the change was implemented, the boiler cycled on and off 5 times/hour, during low load conditions. With the new setpoint, the boiler only cycles on and off 2 times/hour. The boiler operates at this low load condition approximately 2,500 hours/year, and has a firing rate at this reduced loading of 20%. The rated fuel consumption at full load is 10 MMBtu/hr, with an efficiency of 82%. The average fuel cost for the boiler is \$9.00/MMbtu.

The annual energy savings can be estimated as:

$$Energy\ Savings = \left[\left(\frac{0.2 \times 10}{0.82 \times \left(1 - \frac{8}{100}\right)} \right) - \left(\frac{0.2 \times 10}{0.82 \times \left(1 - \frac{2}{100}\right)} \right) \right] \times 2{,}500$$

$$Energy\ Savings = 405.78 MMBtu / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (405.78 MMBtu / yr) \times (\$9.00 / MMBtu)$$

$$Annual\ Cost\ Savings = \$3{,}652 / yr$$

An associated energy conservation measure that should be considered, in relation to boiler sequencing and control, relates to the number of boilers that operate to meet a given process or building load. The more boilers that operate to meet a given load, results in lower firing rates for each boiler. Boiler manufacturers should be contacted to acquire information on how well each boiler performs at a given firing rate, and the boilers should be operated accordingly to load the boilers as efficiently as possible. The site should also make every possible effort to reduce the number of boilers operating at a given time.

Operation and Maintenance – Persistence

Most boilers require daily attention including aspects of logging boiler functions, temperatures, and pressures. Boiler operators need to continuously monitor the boiler's operation to ensure proper operation, efficiency, and safety. For ideas on persistence actions see the Boiler Operations and Maintenance Checklist and Sample Boiler Logs at the end of this section.

Boiler Measure #2: Boiler Combustion Efficiency

The boiler combustion process is affected by many variables including the temperature, pressure, and humidity of ambient air; the composition of the fuel and the rate of fuel and air supply to the process. It is important to note that the theoretical representation of the combustion process is just that – theoretical. It is important to consider all the real-world inefficiencies and how the fuel and air actually come together when making combustion efficiency estimates.

Opportunity Identification

The efficiency of the combustion process is typically measured through the percent oxygen (O_2) in the exhaust gas. The amount of oxygen (or excess air as it is often referred to) in the exhaust gas is defined as the amount of air, above that which is theoretically required for complete combustion. It is imperative that boilers are operated with some excess air to ensure complete and safe combustion. Yet, the amount of excess air needs to be controlled so to minimize the losses associated with the heat that is expelled in the exhaust gases. Table 2 summarizes the typical optimum excess air requirements of conventional boilers (Turner 2004).

> **O&M Tip**: A comprehensive tune-up with precision testing equipment to detect and correct excess air losses, smoking, unburned fuel losses, sooting, and high stack temperatures can result in *boiler* fuel savings of 2% to 20%.

The tuned combustion efficiency values specific to the subject boiler are typically published by the manufacturer. These values, usually published as easy to use charts, will display the optimum combustion efficiency compared to the boiler load or firing rate. Using this information, site personnel can determine the maximum combustion efficiency at the average load of the subject boiler.

Table 2. Optimum Excess Air

Fuel Type	Firing Method	Optimum Excess Air (%)	Equivalent O_2 (by volume)
Natural gas	Natural draft	20 to 30	4 to 5
Natural gas	Forced draft	5 to 10	1 to 2
Natural gas	Low excess air	0.4 to 0.2	0.1 to 0.5
No. 2 oil	Rotary cup	15 to 20	3 to 4
No. 2 oil	Air-atomized	10 to 15	2 to 3
No. 2 oil	Steam-atomized	10 to 15	2 to 3
No. 6 oil	Steam-atomized	10 to 15	2 to 3

"To maintain safe unit output conditions, excess-air requirements may be greater than the optimum levels indicated. This condition may arise when operating loads are substantially less than the design rating. Where possible, check vendors' predicted performance curves. If unavailable, reduce excess-air operation to minimum levels consistent with satisfactory output." (Turner 2004)

If the boiler has large variances in load (firing rate) throughout the year, and the given boiler combustion efficiency varies significantly with load (firing rate), then the equation referenced below can be calculated for each season, with the appropriate efficiency and fuel consumption for the given season.

Tuning the Boiler. The boiler can be tuned by adjusting the air to fuel ratio linkages feeding the boiler burner. Experienced boiler operators will need to adjust the air to fuel linkages accordingly to increase or decrease the given ratios to achieve the optimum excess air and resulting combustion efficiency.

Diagnostic Equipment

To accurately measure combustion efficiency, excess air and a host of other diagnostic parameters, a combustion analyzer is recommended. These devices, made by a number of different manufacturers, are typically portable, hand-held devices that are quick and easy to use. Most modern combustion analyzers will measure and calculate the following:

- Combustion air ambient temperature, T_a
- Stack temperature of the boiler, T_s
- Percent excess air, %
- Percent O_2, %
- Percent CO_2, %
- Percent CO, %
- Nitric Oxide, NX ppm
- Combustion efficiency, EF

A typical combustion analyzer is shown in Figure 5. The probe seen in the picture is inserted in a hole in the exhaust stack of the boiler. If the boiler has a heat recovery system in the boiler exhaust stack, such as an economizer, then the probe should be inserted above the heat recovery system. Figure 6 provides example locations for measurement of stack temperature and combustion air temperature readings (Combustion Analysis Basics 2004).

Energy Savings and Economics

Estimated Annual Energy Savings. The annual energy savings that could be realized by improving combustion efficiency can be estimated as follows:

$$Annual\ Energy\ Savings = \left[1 - \left(\frac{EFF_1}{EFF_2}\right)\right] \times AFC$$

where EFF_1 = current combustion efficiency, %
EFF_2 = tuned combustion efficiency, %
AFC = annual fuel consumption, MMBtu/yr

Figure 5. Combustion Analyzer

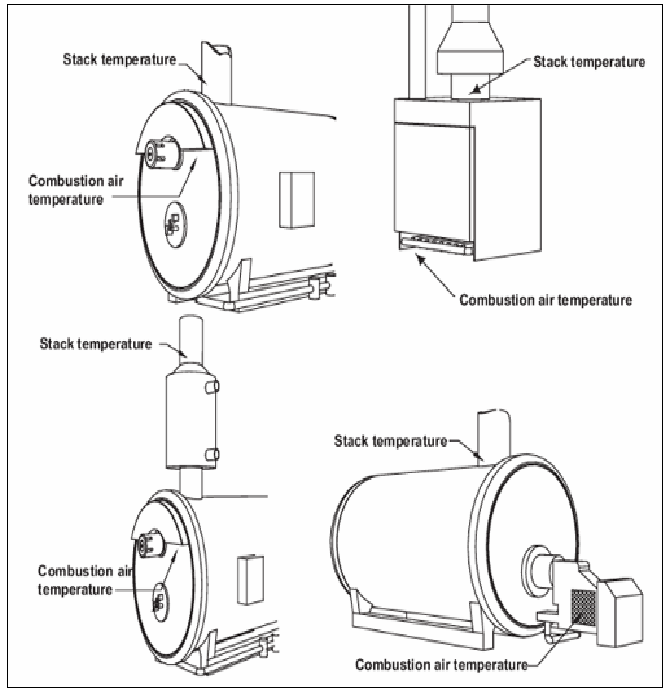

Figure 6. Example Locations – Combustion Analysis

Estimated Annual Cost Savings. The annual cost savings that could be realized by improving combustion efficiency can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times FC$$

where FC = fuel cost, \$/MMBtu

Combustion Efficiency Energy Savings and Economics Example

Example Synopsis

A boiler has an annual fuel consumption of 5,000 MMBtu/yr. A combustion efficiency test reveals an excess air ratio of 28.1%, an excess oxygen ratio of 5%, a flue gas temperature of 400°F, and a 79.5% combustion efficiency. The boiler manufacturer's specification sheets indicate that the boiler can safely operate at a 9.5% excess air ratio, which would reduce the flue gas temperature to 300°F and increase the combustion efficiency to 83.1%. The average fuel cost for the boiler is $9.00/MMbtu.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \left[1 - \left(\frac{79.5}{83.1}\right)\right] \times 5,000$$

$$Annual\ Energy\ Savings = 216.61 MMBtu / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (216.61 MMBtu / yr)(\$9.00 / MMBtu)$$

$$Annual\ Cost\ Savings = \$1,949 / yr$$

Operation and Maintenance – Persistence

Combustion analysis measurements should be taken regularly to ensure efficient boiler operation all year. Depending on use, boilers should be tuned at least annually, high-use boilers at least twice annually.

Boilers that have highly variable loads throughout the year should consider the installation of online oxygen analyzers. These analyzers will monitor the O_2 in the exhaust gas and provide feedback to the linkages controlling the air to fuel ratios into the boilers burner (DOE 2002). This type of control usually offers significant savings by continuously changing the air to fuel linkages and maintaining optimum combustion efficiencies at all times. It should be noted that even if the boiler has an oxygen “trim” system, the boiler operators should periodically test the boilers with hand-held combustion analyzers to ensure the automated controls are calibrated and operating properly.

Boiler Measure #3: Trending Boiler Stack Temperature

Trending the boiler stack temperature ensures the minimum amount of heat is expelled with the boiler’s exhaust gases. This essentially minimizes the total thermal mass flowing with the exhaust air out of the boiler. A lower boiler stack temperature means more of the heat is going into the water or steam serving the process load or HVAC system in the building.

The stack temperature of the boiler can be optimized and maintained by making sure all heat transfer surfaces (both on the fire-side and on the water-side) are clean. This is accomplished through an effective water-treatment program (water-side affect) and a fire-side cleaning program.

A final method of stack-gas temperature optimization can be accomplished through the use of a heat-recovery system such as an economizer. An economizer places an air-to-water heat exchanger in the exhaust stack that uses the heat in the exhaust gases to preheat the feed water into the boiler.

Opportunity Identification

This section will focus on maintaining an effective water-side maintenance/cleaning, and fire-side cleaning program, as these are no-low cost measures to implement, that should be part of the O&M program for the building.

Fire-Side Cleaning and Maintenance Program. Fire-side cleaning consists of manually cleaning the particulates that accumulate on the fire-side of the boiler. Reducing the residue on the fire-side of the boiler increases the amount of heat that gets absorbed into the water, and helps maintain proper emissions from the boiler. Some particulate accumulation is normal for continuously operating boilers, but excessive fire-side residue can be an indication of failed internal components that are expelling unburned fuel into the combustion chamber, causing excess sooting. Excess sooting can also be the result of incomplete combustion due to inadequate excess air.

Water-Side Cleaning and Maintenance Program. Hot water boilers are usually closed-loop systems; therefore, the boiler water is treated before it enters the boiler and piping, and does not require any additional chemicals or daily water-treatment tests. Steam boilers, on the other hand, lose steam due to a variety of circumstances and therefore require additional water to maintain consistent water levels. Boiler water-side maintenance for steam boilers consists of maintaining “soft water” for the feed-water and eliminating as much dissolved oxygen as possible. The first requires daily chemical monitoring and treatment of the feed-water. The presence of “hard-water” can create a “scale” buildup on the pipes. Once built up, the scale acts as an insulator and inhibits heat transfer into the boiler water. This creates excess heat in the combustion chamber that gets vented with the exhaust gases rather than absorbing into the process water.

Scale formation on the waterside of the boiler is due to poor water quality, as such, water must be treated before it enters the boiler. Table 3 presents the chemical limits recommended for Boiler-Water Concentrations (Turner 2004).

The table columns highlight the limits according to the American Boiler Manufacturers Association (ABMA) for ***total solids, alkalinity, suspended solids,*** and ***silica***. For each column heading the ABMA value represents the target limit, while the column headed “Possible” represents the upper limit.

O&M Tip: Every 40°F reduction in net stack temperature (outlet temperature minus inlet combustion air temperature) is estimated to save 1% to 2% of a boiler’s fuel use.

Table 3. Recommended Limits for Boiler-Water Concentrations

Drum Pressure (psig)	Total Solids		Alkalinity		Suspended Solids		Silica
	ABMA	Possible	ABMA	Possible	ABMA	Possible	ABMA
0 to 300	3,500	6,000	700	1,000	300	250	125
301 to 450	3,000	5,000	600	900	250	200	90
451 to 600	2,500	4,000	500	500	150	100	50
601 to 750	2,000	2,500	400	400	100	50	35
751 to 900	1,500	--	300	300	60	--	20
901 to 1,000	1,250	--	250	250	40	--	8
1,001 to 1,500	1,000	--	200	200	20	--	2

The second water-side maintenance activity requires an operational de-aerator to remove excess oxygen. Excess oxygen in the feed-water piping can lead to oxygen pitting and ultimately corrosion that can cause pipe failure. As seen in Figures 7 through 12, proper de-aerator operation is essential to prevent oxygen pitting that can cause catastrophic failures in steam systems (Eckerlin 2006).

Figure 7. Boiler Tube – Scale Deposit

Figure 8. Boiler Tube – Failure (Rupture)

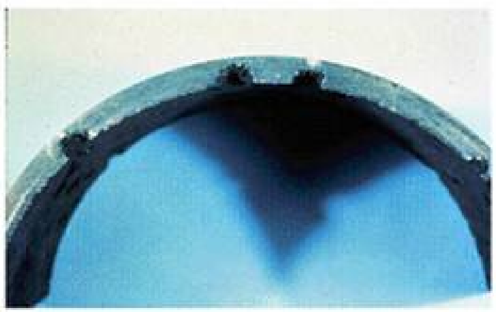

Figure 9. Feed-Water Pipe – Oxygen Pitting

Figure 10. Boiler Tube – Failure (Rupture)

Figure 11. Condensate Pipe – Oxygen Pitting

Figure 12. Condensate Pipe – Acidic Corrosion

Diagnostic Equipment

Diagnostic equipment consists of a boiler-stack thermometer and water-treatment test equipment necessary to properly analyze the boiler water. Local water-treatment companies should be contacted to determine the appropriate additives and controlling agents needed for the particular water compositions that are unique to the given community or region.

Energy Savings and Economics

Figure 13 presents energy loss percentage as a function of scale thickness. This information is very useful in estimating the resulting energy loss from scale build-up.

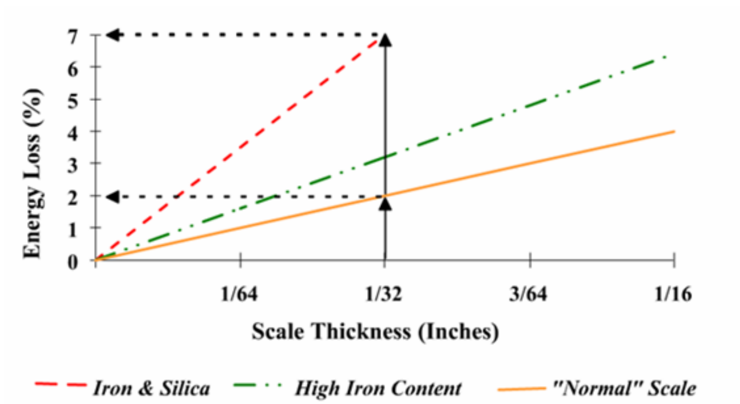

Figure 13. Boiler Energy Losses vs. Scale Thickness

Estimated Annual Energy Savings

The annual energy savings that could be realized by removing scale from the water side of the boiler can be estimated as follows:

$$Annual\ Energy\ Savings = \left[\left(\frac{BL \times RFC}{EFF \times \left(1 - \frac{EL_1}{100}\right)} \right) - \left(\frac{BL \times RFC}{EFF \times \left(1 - \frac{EL_2}{100}\right)} \right) \right] \times H$$

where BL = current boiler load or firing rate, %/100
RFC = rated fuel consumption at full load, MMBtu/hr
EFF = boiler efficiency, %/100
EL_1 = current energy loss due to scale buildup, %
EL_2 = tuned energy loss with out scale buildup, %
H = hours the boiler operates at the given cycling rate, hours

Estimated Annual Cost Savings

The annual cost savings that could be realized by removing scale from the water side of the boiler can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times FC$$

where FC = fuel cost, \$/MMBtu

Boiler Tube Cleaning Energy Savings and Economics Example

Example Synopsis

After visually inspecting the water side of a water tube boiler, normal scale, 3/64 inch thick, was found on the inner surface of the tubes – from Figure 13, this translates into a 3% energy loss. Onsite O&M personnel are going to manually remove the scale. The boiler currently operates 4,000 hrs/yr, at an average firing rate of 50%, with a boiler efficiency of 82% and a rated fuel consumption at full load of 10 MMBtu/hr. The average fuel cost for the boiler is \$9.00/MMbtu.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \left[\left(\frac{0.5\times 10}{0.82\times\left(1-\frac{3}{100}\right)}\right)-\left(\frac{0.5\times 10}{0.82\times\left(1-\frac{0}{100}\right)}\right)\right]\times 2,000$$

$$Annual\ Energy\ Savings = 377.17\,MMBtu/yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = \left(377.17\,MMBtu/yr\right)\left(\$9.00/MMBtu\right)$$

$$Annual\ Cost\ Savings = \$3,394/yr$$

Operation and Maintenance – Persistence

- Boiler operators should record the results of the boiler water-chemistry tests daily. The water-chemistry tests should be recorded and benchmarked to determine the necessary treatment.
- Boiler operators should complete daily records of the de-aerator's operation to ensure continuous and proper operation.
- Boiler operators should take daily logs of stack temperature for trending purposes as this is a highly diagnostic indication of boiler heat-transfer-surface condition. An increasing stack temperature can be indicative of reduced heat transfer.

- The fire side of the boiler should be cleaned once a year, and is usually mandated by local emission regulatory comities.

The Boiler Operations and Maintenance Checklist, sample boiler maintenance log, and water quality test report form are provided at the end of this section for review and consideration.

Boiler Rules of Thumb

In the report, *Wise Rules for Industrial Energy Efficiency,* the EPA develops a comprehensive list of rules of thumb relating to boiler efficiency improvements. Some of these rules are presented below (EPA 2003):

- **Boiler Rule 1**. Effective boiler load management techniques, such as operating on high fire settings or installing smaller boilers, can save over 7% of a typical *facility's* total energy use with an average simple payback of less than 2 years.

- **Boiler Rule 2**. Load management measures, including optimal matching of boiler size and boiler load, can save as much as 50% of a *boiler's* fuel use.

- **Boiler Rule 3**. An upgraded boiler maintenance program, including optimizing air-to-fuel ratio, burner maintenance, and tube cleaning, can save about 2% of a *facility's* total energy use with an average simply payback of 5 months.

- **Boiler Rule 4**. A comprehensive tune-up with precision testing equipment to detect and correct excess air losses, smoking, unburned fuel losses, sooting, and high stack temperatures can result in *boiler* fuel savings of 2% to 20%.

- **Boiler Rule 5**. A 3% decrease in flue gas O_2 typically produces *boiler* fuel savings of 2%.

- **Boiler Rule 6**. Every 40 deg F reduction in net stack temperature (outlet temperature minus inlet combustion air temperature is estimated to save 1% to 2% of a boiler's fuel use.

- **Boiler Rule 7**. Removing a 1/32-inch deposit on boiler heat transfer surfaces can decrease a boiler's fuel use by 2%; removal of a 1/8-inch deposit can decrease boiler fuel use by over 8%.

- **Boiler Rule 8**. For every 11 deg F that the entering feedwater temperature is increased, the boiler's fuel use is reduced by 1%.

Boiler Operations and Maintenance Checklist (Sullivan et al. 2004)

Description	Comments	Maintenance Frequency			
		Daily	Weekly	Monthly	Annually
Boiler use/sequencing	Turn off/sequence unnecessary boilers	X			
Check steam pressure	Is variation in steam pressure as expected under different loads? Wet steam may be produced if the pressure drops too fast	X			
Check burner	Check for proper control and cleanliness	X			
Check air temperatures in boiler room	Temperatures should not exceed or drop Below design limits	X			
Boiler blow-down	Verify the bottom, surface and water column blow-downs are occurring and are effective	X			
Boiler logs	Keep daily logs on: • Type and amount of fuel used • Flue gas temperature • Makeup water volume • Steam pressure, temperature, and amount generated Look for variations as a method of fault Detection	X			
Check boiler water treatment	Confirm water-treatment system is functioning properly	X			
Check flue gas temperatures and composition	Measure flue gas composition and temperatures at selected firing positions - recommended O_2% and CO_2% Fuel — O_2% — CO_2% Natural gas — 1.5 — 10 No. 2 fuel oil — 2.0 — 11.5 No. 6 fuel oil — 2.5 — 12.5 Note: percentages may vary due to fuel composition variations		X		
Check pilot and burner assemblies	Clean pilot and burner following manufacturer's guidelines. Examine for mineral or corrosion buildup.		X		
Check boiler operating characteristics	Stop fuel flow and observe flame failure. Start boiler and observe characteristics of flame.		X		
Inspect all linkages on combustion air dampers and fuel valves	Check for proper setting and tightness		X		
Check blow-down and water-treatment procedures	Determine if blow-down is adequate to prevent solids buildup			X	
Flue gases	Measure and compare last month's readings flue gas composition over entire firing range			X	
Inspect boiler insulation	Inspect all boiler insulation and casings for hot spots			X	

Sample Hot Water and Steam Boiler Operations Log

STEAM HEATING BOILERS

Maintenance • Testing • Inspection Log

BUILDING	ADDRESS	MONTH	YEAR	FUEL TYPE	BOILER NO.

PERSONS TO BE NOTIFIED IN CASE OF EMERGENCY (INCLUDE NAME AND PHONE NUMBER)

DAILY MAINTENANCE INSPECTION CHECKS

DATES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Checked by (please initial):																															
1. Observe Water Level																															
2. Record Boiler Pressure																															
3. Record Flue Gas Temp.																															

WEEKLY MAINTENANCE INSPECTION CHECKS

WEEKS	WEEK 1	WEEK 2	WEEK 3	WEEK 4
Checked by (please initial):				
1. Test Low Water Cut-off				
2. Test Gage Glass				
3. Observe Flame Condition				

MONTHLY MAINTENANCE INSPECTION CHECKS (Enter Date Checked)

1. Manual Lift Relief Valves	Relief Valve Check Date:	Date Checked		Date Checked
2. Review Condition of each item and/or Test each item	A. Linkages		F. Floor Drains	
	B. Damper Controls		G. Flame Detection Device	
	C. Stop Valves		H. Limit Controls	
	D. Refractory		I. Operating Controls	
	E. Flue-Chimney Breeching			
3. Observe Gage Glass on Expansion Tank			Weekly and Monthly Checks Performed by:	
4. Combustion Air Adequate/Unobstructed				

HOT WATER HEATING BOILERS **Maintenance • Testing • Inspection Log**

BUILDING	ADDRESS	MONTH	YEAR	FUEL TYPE	BOILER NO.
PERSONS TO BE NOTIFIED IN CASE OF EMERGENCY (INCLUDE NAME AND PHONE NUMBER)					

DAILY MAINTENANCE INSPECTION CHECKS

DATES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Checked by (please initial):																															
1. Record Boiler Pressure																															
2. Record Boiler Water Temp																															
3. Record Flue Gas Temp.																															

WEEKLY MAINTENANCE INSPECTION CHECKS

WEEKS	WEEK 1	WEEK 2	WEEK 3	WEEK 4
Checked by (please initial):				
1. Observe Flame Condition				
2. Observe Circulation Pumps				

MONTHLY MAINTENANCE INSPECTION CHECKS (Enter Date Checked)

1. Manual Lift Relief Valves	Relief Valve Check Date:	Date Checked		Date Checked
2. Review Condition of each item and/or Test each item	A. Flame Detection Devices		F. Refractory	
	B. Limit Controls		G. Stop Valves	
	C. Operating Controls		H. Check Valves	
	D. Floor Drains		I. Drain Valves	
	E. Flue Piping		J. Linkages	
3. Observe Gage Glass on Expansion Tank			Weekly and Monthly Checks Performed by:	
4. Combustion Air Adequate/Unobstructed				

Sample Water Quality Test Form

Date	Softener	Feedwater			Boiler Water Test						Condensate		Lbs products fed/day			Operator Initials
	Total Hardness	TDS or Cond.	Total Hardness	pH	Bir. No.	O-Alk	TDS or Cond.	SiO_2	SO_3	Poly or PO_4	pH	TDS or Cond.				
Control Range																

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Opportunity #4: Chiller Operational Efficiency

Introduction

A chiller can be generally classified as a refrigeration system that cools water. Similar to an air conditioner, a chiller uses either a vapor-compression or an absorption cycle to cool. Once cooled, chilled water has a variety of applications from space cooling to process uses (Sullivan et al. 2004). Among other equipment types, chillers are the most commonly used refrigeration device to provide cooling for larger commercial buildings. Figure 14 presents a typical chiller plant highlighting the components of cooling tower, pumps, and cooling application shown as the AHU Cooling Coil (EPA 2006).

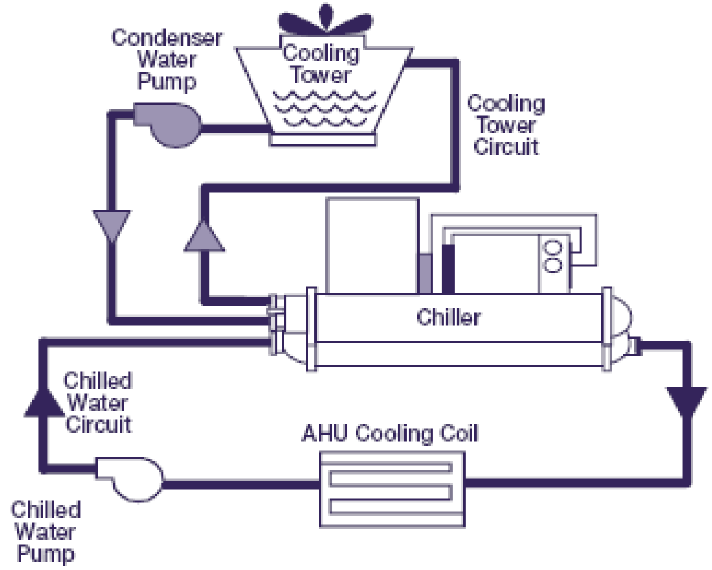

Figure 14. Typical Chiller Plant

Typical Energy Impacts

According to the *2006 Buildings Energy Data Book,* space cooling energy use in commercial buildings is estimated as 6% of a commercial building's total energy use (DOE 2006). This is an average for all building types, measured on a Btu/ft^2 basis. This relatively large percentage of energy use highlights the need to maintain and reduce cooling system energy consumption.

Potential Savings

Depending on the system type, age, and level of maintenance, chiller energy savings as a function of annual energy use can be decreased by as much as 5% to 8% (Sullivan et al. 2004). These savings relate to proper upkeep, ability to capture and trend temperature data, and the performance of all scheduled maintenance tasks.

The annual cost savings that can be achieved by increasing chiller performance by 5% can be estimated as shown in Table 4 (Dyer and Maples 1995). These savings are presented by cooling capacity (chiller size) and cost of electricity.

Table 4. Dollars Saved Annually by Improving Chiller Performance by 5%

Cooling Capacity	Electrical Cost			
	$0.04/kW-hr	$0.06/kW-hr	$0.08/kW-hr	$0.10/kW-hr
100-ton	$1,877	$2,816	$3,755	$4,693
300-ton	$5,631	$8,448	$11,265	$14,079
600-ton	$11,262	$16,896	$22,530	$28,158
900-ton	$16,993	$25,344	$33,795	$42,237
1,000-ton	$18,770	$28,816	$37,550	$46,693
1,500-ton	$28,155	$42,240	$56,325	$70,395

Operational/Energy Efficiency Measures

Although there are numerous energy conservation measures that could be presented for proper chiller operation and control, this section will focus on the most prevalent recommendations. The recommendations presented below are specific to chillers that use microprocessor-based controllers, which are now the standard control mechanism in modern chillers. Some chiller manufacturers produce microprocessor-based controllers that can be retrofit on older chillers. These new controls usually offer more accurate control, allow for temperature reset strategies, and can be integrated into Building Automation Systems (BAS).

Chiller Measure #1: Chilled Water Temperature Control

Chillers are typically set to have a chilled water output temperature in the range of 42°F to 45°F. If the maximum cooling load on the chillers cause the chiller to operate at less than full load, then the chiller operator could possibly increase the chilled water temperature and still meet the cooling loads of the building while saving energy.

Likewise, the energy input required for any chiller (mechanical compression or absorption) increases as the temperature lift between the evaporator and the condenser increases. Raising the chilled water temperature will cause a corresponding increase in the evaporator temperature and thus, decrease the required temperature lift. A decrease in temperature lift equates to a decrease in energy use.

> **O&M Tip**: Increasing chiller water temperature by 1°F reduces chiller energy use by 1.7% and 1.2% for centrifugal and reciprocating compressors, respectively.

Opportunity Identification

The basic chilled water control strategies for chillers using microprocessor-based controllers are presented below:

Return Temperature. A chiller controlled by return-water temperature will rely on preset operational instructions based on the return temperature. For example, if the return water temperature increases, indicating an increasing load, then the chiller is preprogrammed to respond with greater capacity and thereby mitigating the increased load.

Supply Temperature. A chiller controlled by the supply-water temperature functions with a set of water temperatures pre-programmed based on chiller loading. For example, as a space or process calls for greater capacity (i.e., a space temperature is increasing with solar loading), the chiller response is proportional to the call for added capacity.

Constant Return. If the chiller is controlled to have a constant return-water temperature, then the chiller will modulate chilled water supply temperatures to achieve a certain return-water temperature over a range of chiller loads. In this case, the chiller operator specifies the desired chilled return-water temperature, and the chiller modulates the chilled water supply temperature accordingly to meet this temperature.

Outside Air. Water-cooled chillers that are located indoors, usually require an outdoor temperature sensor wired into the chiller's control panel. Most chiller manufacturers provide outside air temperature sensors that are specific to their chillers, and easily be integrated into the chiller control panel. In this case, the chiller reads the outdoor wet-bulb temperatures and modulates the chilled water temperature based on predefined outdoor air temperatures and chilled-water set-points.

Zone Temperature. Some chillers come equipped with temperature sensors that read interior zone temperatures, or they have controls that can be integrated into the BAS. In this case, the operators can apply chilled water reset strategies based on the interior zone temperatures. In each case, the chiller will usually step up the chilled water temperature to that of the reset value, even if the compressor is in the "off" cycle.

Chilled water reset strategies usually reset the chilled water temperature over a range of about 10°F (Webster 2003). Chiller operators should contact their local chiller manufacturers for information on setting appropriate chilled water temperatures. Manufacturers can provide guidance on chilled water modulation at partial loads, and outside air temperatures for the particular chiller.

Regardless of the control strategy used to modulate chilled water temperatures, the operators should always keep in mind the impacts on the entire chilled water system. Care should be taken to optimize the entire system, rather than just applying chilled water reset strategies blindly (Webster 2003).

It is also important to consider the implications on cooling coils and their ability to regulate the indoor relative humidity ratios within the building, at higher chilled water temperatures. As the chilled water temperatures are increased, the energy/facility managers should closely monitor indoor relative humidity (RH) levels to make sure they are staying in the 55% to 60% RH range.

Diagnostic Equipment

Opportunities with chillers rely on the use of the chiller controller and/or the BAS for diagnosis. There are situations where neither the controller nor the BAS are available or programmed properly for use. In these cases, portable data loggers for evaluating temperatures are most appropriate. In addition, chiller and chilled water distribution systems usually have temperature and pressure devices hard-mounted to the system. These devices, provided they are accurate, can be used in system diagnostics.

Energy Savings and Economics

Recognizing that the system efficiency can increase by as much as 3% to 5% by raising the chilled water supply temperature by 2°F to 3°F (Sullivan et al. 2004), the annual energy savings that could be realized can be estimated as follows:

$$Energy\ Savings = (CEU \times H) - \left[CEU \times H\left(1 - \frac{ES}{100}\right)\right]$$

$$Annual\ Energy\ Savings = \sum_{i=1}^{n} Energy\ Savings$$

where CEU = chiller energy use, kW
H = hours of operation at a given load, h
ES = energy savings, %

Estimated Annual Cost Savings

The annual cost savings that could be realized by increasing chilled water temperatures can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times ER$$

where ER = electric energy rate, $/kWh

It should be noted that this cost savings calculation does not account for an electric peak demand reduction. If the facility has a peak demand charge, and the chiller operates every day on an operational schedule that is coincident with the facilities peak demand, then this estimate slightly underestimates the cost savings.

Chilled Water Supply Temperature Energy Savings and Economics Example

Example Synopsis

A water-cooled centrifugal chiller currently has a constant 42°F supply temperature. After inspection it was determined that the temperature controls can allow modulation up to 45°F during low load periods. The operators estimate that the chiller can operate at 45°F for 3,000 hrs/yr, and the chiller has an electrical load of 300 kW when operating at these low load conditions. The average electric rate is $0.10/kWh.

The annual energy savings can be estimated as:

$$Energy\ Savings = (300 \times 3,000) - \left[300 \times 3,000\left(1 - \frac{2.25}{100}\right)\right]$$

$$Annual\ Energy\ Savings = 20,250 kWh / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (20,250 kWh/yr)(\$0.10/kWh)$$

$$Annual\ Cost\ Savings = \$2,025/yr$$

Chiller Measure #2: Condenser Water Temperature Control

The effect of reducing condenser water temperature (water-cooled chillers only) is very similar to that of raising the chilled water temperature on the supply side, namely reducing the temperature lift that must be supplied by the chiller. These temperatures can be reset downward as outdoor wet-bulb temperatures decrease and during low-load conditions (Webster 2003).

It is important to note that the chiller operators need to make sure that the chiller is capable of handling lowered condenser water temperatures. Some chillers are not designed to handle lower condenser water temperatures and can encounter compressor oil return problems. As a default, site personnel should always check with their local chiller manufacturers before lowering the condenser water temperatures.

Opportunity Identification

Most chillers reach their maximum operating efficiency at the designed peak load. However, chillers operate at the part-load condition most of the time. Resetting the condenser water temperature normally decreases the temperature lift between the evaporator and the condenser, thus increasing the chiller operating efficiency. Therefore, to reset the condenser water temperature to the lowest possible temperature will allow the cooling tower to generate cooler condenser water whenever possible. Note that although lowering the condenser water temperature will reduce chiller energy, it may increase cooling tower energy consumption because the tower fan may have to run longer to achieve the lower condenser water temperature. In addition, some older chillers have condensing water temperature limitations. Consult the chiller manufacturer to establish appropriate guidelines for lowering the condenser water temperature.

> **O&M Tip**: For each 1°F decrease in condenser cooling water temperature, until optimal water temperature is reached, there is a decrease in chiller energy use by up to 3.5%.

Figure 15 shows the performance curves for York chillers, with and without condenser water temperature resets (Webster 2003).

The graph in Figure 15 highlights the fact that with fixed-speed systems the energy consumption at part load is at least 80% of the full-load energy use over the entire chiller loading range. With a variable condenser temperature, the energy consumption is reduced at part load. To achieve the greatest savings, the condenser water reset needs to be coupled with a variable-speed drive where the part-load energy use is greatly reduced.

Whatever the strategy, the energy consumption of the chiller and the cooling tower needs to be considered as a system and be appropriately balanced – an increase in one may or may not off-set the decrease in the other.

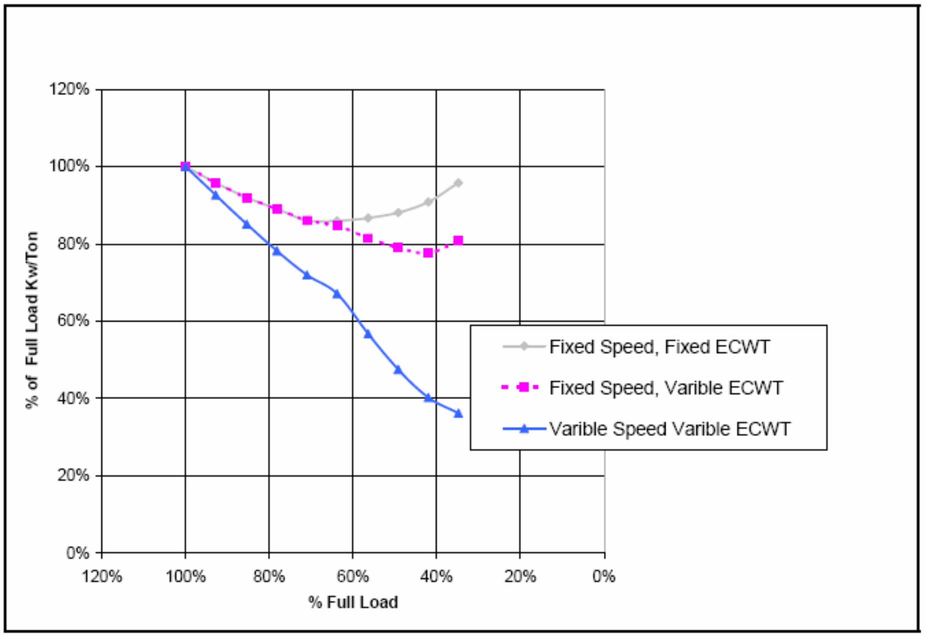

Figure 15.   York Chiller – Performance Curves with Condenser Water Temperature Reset

(Note: ECWT = Entering Condenser Water Temperature, assumes a minimum ECWT of 55°F.)

Diagnostic Equipment

Opportunities with chillers rely on the use of the chiller controller and/or the BAS for diagnosis. There are situations where neither the controller not the BAS are available or programmed properly for use. In these cases, portable data loggers for evaluating temperatures are most appropriate. In addition, chiller and chilled water distribution systems usually have temperature and pressure devices hard-mounted to the system. These devices, provided they are accurate, can be used in system diagnostics.

Estimated Annual Energy Savings

Lowering the condenser water temperature 2°F to 3°F (Sullivan et al. 2004) can increase system efficiency by as much as 2% to 3%. The annual energy savings that could be realized by reducing condenser temperatures can be estimated as follows:

$$Energy\ Savings = (CEU \times H) - \left[CEU \times H \left(1 - \frac{ES}{100} \right) \right]$$

$$Annual\ Energy\ Savings = \sum_{i=1}^{n} Energy\ Savings$$

where CEU = chiller energy use, kW
H = hours of operation at a given load, h
ES = energy savings, %

Estimated Annual Cost Savings

The annual cost savings that could be realized by reducing condenser temperatures can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times ER$$

where ER = electric energy rate, \$/kWh

It should be noted that this cost savings calculation does not account for an electric peak demand reduction. If the facility has a peak demand charge, and the chiller operates every day on an operational schedule that is coincident with the facility's peak demand, then this estimate slightly underestimates the cost savings.

Condenser Temperature Reset Energy Savings and Economics Example

Example Synopsis

A water-cooled centrifugal chiller currently has an entering condenser water temperature of 80°F. After inspection it was determined that the entering condenser water temperature can be reset down to 77°F. The operators estimate that the chiller can operate at 77°F for 3,000 hrs/yr, and the chiller has an electrical load of 300 kW when operating at these low load conditions. The average electric rate is \$0.10/kWh.

The annual energy savings can be estimated as:

$$Energy\ Savings = (300 \times 3,000) - \left[300 \times 3,000\left(1 - \frac{3}{100}\right)\right]$$

$$Annual\ Energy\ Savings = 27,000 kWh/yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (27,000 kWh/yr)(\$0.10/kWh)$$

$$Annual\ Cost\ Savings = \$2,700/yr$$

Chiller Measure #3: Chiller Maintenance and Cleaning

The first step to developing and maintaining an effective chiller maintenance program is to prepare a detailed daily operating log. In its simplest form, the daily log will be written in a notebook, and should be used to identify any trends that develop in relation to chiller's operating conditions. If the chiller operators have access to a laptop or desktop computer, then the operator should take full advantage of this to record their daily logs. Although most sites keep daily and weekly operating logs, they often reside on the operator's desk and are not used to trend and analyze data. For daily and weekly operating logs to be effective, they must be used to properly trend and diagnose maintenance issues.

The second element of effective chiller maintenance is the development of regular chiller inspections. Site staff should contact their local chiller manufacturers to determine what particular components need inspection and the recommended inspection frequency. Nevertheless, there are some basic steps site staff can take to make sure their chillers are being maintained properly. Among them are (Trade Press Publishing Corporation 2001):

- Routine inspection for refrigerant leaks.
- Checking compressor operating pressures.
- Checking all oil levels and pressures.
- Examining all motor voltages and amps.
- Checking all electrical starters, contactors, and relays.
- Checking all hot gas and unloaded operations.
- Using superheat and sub-cooling temperature readings to obtain a chiller's maximum efficiency.
- Taking discharge line temperature readings.

Opportunity Identification

Condenser cleaning. Cleaning the chiller's condenser tubes is one of the most important maintenance activities to ensure efficient chiller performance. The degree to which a condenser tube is fouled can be identified by implementing a daily/weekly chiller log. By using trended data, if operations staff notice that the difference between the refrigerant-condensing temperature and the leaving-water temperature is higher than expected, or if this change-in-temperature starts to rise over time, then it is an indication of fouling or scaling. Condenser tubes can have scale develop due to various mineral and sludge deposits precipitating and accumulating on these surfaces. Any scaling or fouling of these surfaces effectively insulates the surfaces and results in a larger temperature difference between the water and the refrigerant leading to a decrease in chiller efficiency.

These detrimental effects can extend beyond the chiller and to cooling load causing inadequate cooling, longer chiller run-times, and increased cooling energy costs. If this scaling/fouling is left unattended for extended periods of time, then it can lead to condenser-tube failure and/or compressor failure (Simmons 2005). Both of these outcomes are very expensive to fix and can be avoided with proper operations and maintenance practices.

Cleaning condenser tubes takes place using one or both of the following methods – chemical and/or mechanical cleaning. Chemical cleaning is accomplished through the use of powerful chemicals and should only be undertaken by qualified staff. Mechanical cleaning makes use of specially-designed brushes for scale removal and usually takes place during annual maintenance activities. Mechanical cleaning is also done after the chemical cleaning has been completed. In either case, site staff should contact the chiller manufacturer to understand appropriate procedures specific to the chiller.

If condenser tubes are found to be scaled and/or the chiller is old or heavily used, then testing of chiller tube integrity and potential for failure should be considered. This type of testing, called eddy-current testing, makes use of circulating electromagnetic currents (eddies) that get interrupted and detected near surface irregularities like cracks or corrosion. This very diagnostic procedure is useful to locate maintenance issues before they become problems.

Evaporator cleaning. The evaporator, part of the closed-loop portion of the chiller, typically has chemicals added to the loop before the chiller is operated. Thus, evaporators usually do not require yearly cleaning. Yet, if subject to external contaminants or treated incorrectly, the same cleaning procedure implemented for the condenser tubes should be implemented on the evaporator.

Water chemistry. Water-treatment programs are initiated in chilled water systems to inhibit scale buildup, microorganism growth, and corrosion, and to clear the sand, dirt, and other debris from the system. The water chemistry at a given facility is primarily a function of the local water quality and varies from one region of the country to another. Accordingly, a local water-treatment company should be contacted to determine what chemical treatments are needed and how often they should be applied. These companies can also provide information on the most cost-effective treatments, and specifics on how they should be handled.

In closed-loop chilled water systems, the water should have been treated when the system was initially commissioned or at any subsequent filling. In this configuration, water-chemistry tests only need to be conducted periodically to ensure that the appropriate water chemistry is maintained. In open-loop systems, such as the case with cooling towers, some water is lost due to evaporation and the water is exposed to the ambient atmosphere. As water evaporates, dissolved minerals precipitate into the water, resulting in increased concentrations of these elements over time. In these situations, an effective water-chemistry program must be implemented and monitored daily.

The water chemistry is usually regulated through the use of an equation that determines the cycles of concentration of the system water and the makeup water (Meitz 1999).

$$Cycles\ of\ Concentration = \frac{Cl^{-}{}_{system}}{Cl^{-}{}_{makeup}}$$

The cycles of concentration is usually calculated by monitoring the chloride concentrations in the system water and in the makeup water. The only reason chloride would not be used to measure cycles of concentration is if chlorine is used as a biocide in the cooling system. In this case, the concentration of another parameter would be chosen (Meitz 1999).

The cycles of concentration will indicate how many times the water can cycle through the system before chemical treatments are needed. Cooling towers usually control cycles of concentration by measuring the conductivity of the water within the system. As water evaporates and the conductivity of the water increases, a bleed valve will open and bleed some of the water to a drain. A float valve within the cooling tower will then allow treated makeup water to enter the system and maintain the given water levels.

The ratio of chloride in the process water to the ratio of chloride in the makeup water is usually about the same as the ratio of “hardness.” Hard water or “hardness” is the primary cause of scale buildup. The chemical treatments that are used are usually designed to reduce the hardness of the water and to inhibit corrosion.

Biocides can also be used in cooling systems to prevent fouling from microbial growth. Microbial growth results from bacterial and algal growth. Similar to scale formation, microbial growth acts as an insulator, reducing the heat transfer from the fluid to the piping system.

Finally, dirt and debris that build up in the cooling tower water should be periodically removed. If all these issues are continuously regulated, and the cooling tower fan controls are working properly, then the cooling tower will be able to better cool makeup water, and increase the efficiency of the entire chilled water system.

Diagnostic Equipment

Electric data loggers. For an accurate chiller load characterization and run-time profile, portable data loggers can be installed to measure the chiller electrical energy use over time. The data loggers can be set to record energy use over time (e.g., an average week), taking amperage and voltage (to generate kW) measurements at least every 15 minutes. This type of analysis is useful in understand chiller kW loading and run-time characterizations.

In addition to the kW measurement, having the ability to assess cooling capacity over time is very diagnostic. Cooling capacity can be assessed through the use of a flow-meter coupled with temperature measurements – typically referred to as a "Btu flow-meter." This type of meter captures chilled water flow and the change in temperature across the chiller. If both kW and Btu (Btus are usually converted to "tons" of cooling) measurements are captured in a time-series format, then the above-mentioned kW/ton can be generated and trended over time. This value becomes extremely diagnostic in understanding chiller performance and efficiency.

Operation and Maintenance – Persistence

To create an effective operation and maintenance program it is imperative that the site develops an efficient and effective chiller training program. Chiller operators should be trained on the various inspection items listed above, and given guidance on what should be included in daily operating logs. Guidance should also be provided on how this information should be used to trend and diagnose maintenance tasks. For specific information on maintenance tasks and their correlating frequency, see the chillers operations and maintenance checklist at the end of this section.

The following excerpt (Piper 2006) highlights the importance of developing and maintaining an effective chiller maintenance program.

> *"Most new, highly-efficient centrifugal chillers carry a full-load efficiency rating of approximately 0.50 kW per ton. If that chiller is well maintained, in five years it can be expected to have a full-load efficiency of 0.55-60 kW/ton. If maintenance has been ignored for that same chiller, it would not be surprising to find that the full-load efficiency had decreased to 0.90 to 1.0 kW per ton. On an annual basis, this means that a poorly maintained chiller will use 20-25% more energy annually to produce the same cooling."*

Site personnel should use the daily/weekly chiller logs to monitor the chilled water temperatures and condenser water temperatures over a wide range of cooling loads. If the site deems it appropriate to adjust the chilled water or condenser water temperatures, then the operators should monitor the relative humidity levels of the building to ensure the appropriate RH levels are met, even at partial loads.

Diagnostic tools for treating the process water consist of water-treatment equipment necessary to properly analyze and treat the process water. Local water-treatment companies should be contacted to determine the appropriate additives and controlling agents needed for the particular water compositions that are unique to a given community or region.

Chiller Rules of Thumb

- **Chiller Rule 1**. Free cooling can reduce cooling system energy use by up to 40%, depending on location and load profile.
- **Chiller Rule 2**. Increasing chiller water temperature by 1 deg F reduces chiller energy use by 1.7% and 1.2% for centrifugal and reciprocating compressors, respectively.
- **Chiller Rule 3**. For each 1 deg F decrease in condenser cooling water temperature, until optimal water temperature is reached, there is a decrease in chiller energy use by up to 3.5%.
- **Chiller Rule 4**. Installing variable-speed drives in place of constant speed systems can reduce cooling system energy use by 30% to 50%, depending on load profile.

The energy savings achievable by resetting chilled water and condenser water temperatures can be estimated as shown in Table 5 (Webster 2003).

Table 5. Chiller Energy Savings Per Degree (°F) of Reset

Chiller (kW/ton) Percentage Savings per Degree (°F) of Reset		
	Fixed Speed	**Variable-Frequency Drive (VFD)**
Chilled Water Reset	0.5% to 0.75%	2.0% to 3.0%
Condenser Water Reset	0.75% to 1.25%	1.5% to 2.0%

Chiller Operations and Maintenance Checklist (Sullivan et al. 2004)

Description	Comments	Maintenance Frequency			
		Daily	Weekly	Semi-Annually	Annually
Chiller use/sequencing	Turn off/sequence unnecessary chillers	X			
Overall visual inspection	Complete overall visual inspection to be sure all equipment is operating and safety systems are in place	X			
Check setpoints	Check all setpoints for proper setting and function	X			
Evaporator and condenser coil fouling	Assess evaporator and condenser coil fouling as required		X		
Compressor motor temperature	Check temperature per manufacturer's specifications		X		
Perform water quality test	Check water quality for proper chemical balance		X		
Leak testing	Conduct leak testing on all compressor fittings, oil pump joints and fittings, and relief valves		X		
Check all insulation	Check insulation for condition and appropriateness		X		
Control operation	Verify proper control function including: • Hot gas bypass • Liquid injection		X		
Check vane control settings	Check settings per manufacturer's specification			X	
Verify motor load limit control	Check settings per manufacturer's specification			X	
Verify load balance operation	Check settings per manufacturer's specification			X	
Check chilled water reset settings and function	Check settings per manufacturer's specification			X	
Check chiller lockout setpoint	Check settings per manufacturer's specification				X
Clean condenser tubes	Clean tubes at least annually as part of shutdown procedure				X
Eddy current test condenser tubes	As required, conduct eddy current test to assess tube wall thickness				X
Clean evaporator tubes	Clean tubes at least annually as part of shutdown procedure				X
Eddy current test evaporator tubes	As required, conduct eddy current test to assess tube wall thickness				X
Compressor motor and assembly	• Check all alignments to specification • Check all seals, provide lubrication where necessary				X
Compressor oil system	• Conduct analysis on oil and filter • Change as required • Check oil pump and seals • Check oil heater and thermostat • Check all strainers, valves, etc.				X
Electrical connections	Check all electrical connections/terminals for contact and tightness				X
Water flows	Assess proper water flow in evaporator and condenser				X
Check refrigerant level and condition	Add refrigerant as required. Record amounts and address leakage issues.				X

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Opportunity #5: Heating, Ventilation, and Air Conditioning (HVAC) Operational Efficiency

Introduction

Commercial building HVAC systems have many variables that can positively and negatively affect system efficiency. Some of these parameters include HVAC control of setback times and temperatures, HVAC sensor calibration, building use, building occupancy, and general maintenance of components such as filters and valves. These factors and many others contribute to overall building performance.

Typical Energy Impacts

Energy use for space heating and space cooling in a typical commercial building accounts for greater than 35% of the building's total energy use (DOE 2005a). This is an average for all building types, measured on a Btu/ft^2 basis. This large percentage of energy use presents a great opportunity to reduce HVAC energy consumption.

Potential Savings

In facilities that operate on a daily preset schedule, the proper operation and scheduling of air-handling units can save 10% to 70% of the air-handling unit total energy use (Wulfinghoff 1999).

Retrocommissioning is a systematic process for improving the current conditions and operations of an existing building, to ensure the functionality of equipment and systems and also to optimize how they operate together to reduce energy waste and improve building operation and comfort (Lundstrom 2006). Many retrocommissioning activities focus on HVAC systems and controls. Retrocommissioning an existing building can usually save 5% to 20% of the building's total energy use.

Operational/Energy Efficiency Measures

There are multiple energy conservation measures that could be presented for proper HVAC operation and control. The following section focuses on the most prevalent recommendations and those having the greatest energy impacts made at DoD/Army facilities. These recommendations are also some of easiest to implement, with a focus on low-cost/no-cost actions.

Commercial buildings use a wide range of heating, cooling, and mechanical ventilation systems. This section focuses on the control of such systems. The energy conservation measures are developed with respect to direct digital control (DDC), pneumatic, and electromechanical control systems.

The energy conservation recommendations are presented in a generalized manner, and, although some recommendations address some specifics in relation to the type of air-handling unit or heating/cooling system, the specifics of the system are not addressed. This section begins with an overview of some key components.

Direct Digital Control (DDC) Systems. DDC systems use microprocessor-based controllers and their internal software programs to execute the control logic. DDC systems are usually tied into a central computer where operators can monitor the building's operation, record alarms, and make changes to the control algorithms. DDC systems allow for more complex operational schedules, allow for trending, and can usually be integrated into Energy Management Control Systems. DDC systems also use electronic controls that are more accurate than older-style pneumatic controls. All of these benefits offer potential energy savings and more accurate control of interior spaces (DDC Online 2006a).

DDC systems use a basic control loop with various sensors, controllers, and controlled devices. The sensor will measure temperature, pressure, relative humidity, etc., and, based on the preset code, the sensor will send a signal to a controller. Based on this information, the controller will determine the appropriate action and send a signal to the controlled device to achieve a given temperature, relative humidity, etc. The controlled devices include such elements as valves, damper actuators, and fans (DDC Online 2006a).

Pneumatic and Electromechanical Control Systems. Historically pneumatic and electromechanical controllers were the standard control mechanism in HVAC systems, and many DoD/Army facilities are just now starting to retrofit the existing controls with DDC controls. For pneumatic and electromechanical controllers, the controller is a separate piece of hardware, contrary to DDC systems that use an internal software program as the controller. These pneumatic and electromechanical controllers control temperature setpoints in a building based on preset setpoints and time clocks. For example, if a building has 10 heat pumps, each of which is used to heat and cool discrete zones within a building, then each heat pump might be controlled with a wall-mounted electromechanical controller that has a digital display. Each one of the zones operates as its own zone, and does not coordinate operational characteristics with the other zones. The system allows the user to enter in temperature setpoints and operational schedules, but the system has limited intelligent control.

HVAC Measure #1: HVAC Scheduling, Temperature/Pressure Setpoints

Site energy/facility managers should have a goal of matching HVAC scheduling to the actual tenant schedules within all buildings. The building operators should closely monitor tenant schedules and adjust the HVAC schedules accordingly to meet changing schedules throughout the year.

The construction of the building, including the types of windows, insulation, and overall orientation, contributes to its ability to retain conditioned air. This coupled with the internal heating and cooling loads in the building will dictate when the HVAC system should be cycled during the day.

DDC Optimal Start/Stop

Most DDC systems have optimal start-stop programs with software algorithms that assess indoor and outdoor temperatures and, based on adaptive learning, the DDC system will activate the building's HVAC system at different times each day. This technology is one of the most energy-efficient HVAC control programs available and should be used whenever possible. Other DDC systems have the ability to program preset start-stop times for the building's HVAC system. In this case, the building operators should try to start the HVAC system as close to the tenants' arrival as possible. The operators should also consider applying different start times based on average outdoor air temperatures versus times of extreme outdoor air temperatures.

DDC Holiday Scheduling

If the building has a DDC control system, then it will typically come equipped with a holiday scheduling feature. Building operators should use this feature to turn off the building's HVAC system during unoccupied periods and holidays. In addition to unoccupied periods and holidays, many Army/DoD facilities, such as barracks, training facilities, and mess halls, will go unoccupied for periods of time when troops are deployed. These deployments can leave buildings unoccupied for long periods and therefore should have scheduling adjusted accordingly. It should be noted that if the building is located in a humid climate, then the HVAC system should be put into standby mode and turned on to maintain the humidity limits and unoccupied setback temperatures within the facility.

Building operators should periodically review their DDC codes to make sure the HVAC schedules matches the tenant schedules as closely as possible. If the building operators have to implement overrides to handle extreme weather conditions or special occupancy circumstances, then these overrides should be recorded and removed as soon as possible.

In buildings with electromechanical and pneumatic controls, the building operators should at a minimum apply a start-stop schedule based on historic data relating to the amount of time it takes to condition the building. In general, when the HVAC system is turned off, the building operators need to ensure that all the HVAC fans and pumps are turned off. Although it might be necessary to continuously operate the building chillers and boilers, the building's fans and pumps can be turned off when the HVAC system is not operating.

Temperature and Pressure Setpoints

Temperature setpoints in buildings can typically be programmed using the proportional integral (PI) control loop. If the PI control loop is used, then the site must ensure that the throttling range is not too small (DDC Online 2006b). The throttling range relates to the gap between the heating setpoint and cooling setpoint. The larger this gap is, the less energy the site will use to condition the interior air. Currently, federal law mandates that federal facilities have a heating setpoint of 68°F and a cooling setpoint of 78°F (WMU News 2001). This means that when the interior temperatures drop below 68°F, the building heating coils will activate to raise the temperature, and when the temperatures get above 78°F the building cooling coils will activate to cool the space. In humid climates, the system is usually operated so that the cooling coil first reduces the incoming air temperature to 55°F to remove moisture, and then the heating coil heats the air to the given temperature setpoints.

Although the 68°F and 78°F setpoint temperatures are federally mandated, many facilities are not operated at these temperatures because of occupant complaints. In some cases, if the site has a strong energy awareness campaign, and/or site personnel are encouraged to abide by the federally mandated setpoints, then these setpoints are honored. Yet there are many sites that opt for cooling setpoints on the order of 74°F to 76°F, and heating setpoints on the order of 70°F to 72°F. In either case, the site should strive to have the largest throttling range (or dead-band gap) between the two setpoints. This ensures that the HVAC system will not slightly overcool the building, causing the building to immediately go into heating mode, and then slightly overheat the building, causing it to go back into cooling mode. This type of constant cycling is inefficient, hard on equipment, and causes the building to constantly "hunt" for the right temperature.

As previously mentioned, the building operators should also implement a nighttime or unoccupied setback temperature. The unoccupied setback for heating should be 5°F to 10°F cooler than the occupied setpoint, and the unoccupied setback for cooling should be 5°F to 10°F warmer than the occupied setpoint. In humid climates, the underlying activator of the system should be the relative humidity ratios. As long as these ratios are met, the interior temperatures should be allowed to float over the preset unoccupied setpoints.

The temperature setpoint methodology is also valid for electromechanical and pneumatic controls. The only difference may be in the allowable control points – two are typical with electromechanical systems.

Pressure Setpoints

Based on energy and O&M audits of DoD/Army installations, many air-side static pressure setpoints fall in range of the 1.9” water column (w.c.) to 2.6” w.c. This is far higher than necessary where most variable air volume (VAV) systems are intended to operate in the 1” to 1.5” w.c. range (Lundstrom 2006). If this type of operation is encountered, then the site should investigate the system to make sure the VAV fans are operating and controlling properly. These high static pressure readings can sometimes be caused by site staff looking to make a quick fix when one of the fans is not operating or controlling properly. This could also be caused by a failed static pressure sensor, failed inlet vane controls, slipping belts or breached ductwork. In any case, the building operator should determine the design air-side static pressure setpoint for the particular air-handling unit to ensure the current operation is as close to this value as possible. The operator should identify the location of the static pressure gauges – they should be installed about 2/3 of the way down the longest stretch of ductwork.

Setting and Setpoint: Questions to Ask

A key element of any effective HVAC O&M program is the proper setting and the persistence of all HVAC control parameters. Below is a set of questions site staff should be asking when assessing how settings and setpoints may have changed over time (PECI 1999 –“putting the O back in O&M…”).

- Have occupancy patterns or space layouts changed? Are HVAC and lighting still zoned to efficiently serve the spaces?
- Have temporary occupancy schedules been returned to original settings?
- Have altered equipment schedules or lockouts been returned to original settings?
- Is equipment short-cycling?
- Are time-clocks checked monthly to ensure proper operation?
- Are seasonally changed setpoints regularly examined to ensure proper adjustment?
- Have any changes in room furniture or equipment adversely affected thermostat function? (Check thermostat settings or other controls that occupants can access.)
- Are new tenants educated in the proper use and function of thermostats and lighting controls?

In DDC control systems, some HVAC operators encourage unoccupied pressure setpoint reductions to be implemented in conjunction with the unoccupied temperature setpoint changes. This offers greater energy savings in VAV systems by allowing for a larger dead-band temperature range and less air to be circulated through the building.

As staff perform certain maintenance tasks to prepare equipment for heating or cooling seasons, they should also review and adjust operational strategies seasonally.

HVAC Measure #2: HVAC Tune-Up and Maintenance

Some of the most important HVAC tune-up and maintenance activities a site should consider are related to the following: valves, filters, coil cleanings, sensor calibration, damper operation, belt system checks, system override correction, and air/water-flow analysis.

Valves

Control valves in HVAC systems are used to control the amount of hot or chilled water that circulates through heating or cooling coils. While a necessary component, control valves are notorious for failing. Unfortunately, when a control valve failure occurs, it often goes unnoticed by site staff because it is difficult to assess visually. Common control valve problems/malfunctions include valves that have been manually overridden in the open position, valves stuck in a fixed position, valves that are leaking, and valves that are incorrectly wired – usually backwards.

One method of valve diagnosis starts with the DDC system. Through the DDC system, an operator will determine if a particular heating coil is hot (i.e., is being supplied with hot water). This will be evident through the system reported as a temperature at the coil. Next, the operator will make sure the zone served by this coil is actually calling for heat; this is represented in the system as a request for service. If the zone is not calling for heat, yet the coil is hot, then the operator should examine the control valve for either leakage or manual override. This same procedure holds true for cooling coils.

Another method of valve diagnosis again makes use of the DDC system. In this scenario, the operator uses the system to fully close both the heating and cooling valves or he can manually override them. Once done, the operator then reviews the air temperatures on either side of the heating/cooling coils for which there should not be more than a 2°F to 4°F temperature difference between the two temperature sensors. If the temperature difference exceeds this range, then the operator should consider either control valve or temperature sensor malfunction.

Filters

Air filters play a critical role in maintaining indoor air quality and protecting the downstream components of an air-handling system from dirt that reduces equipment efficiency. In the worse case, dirty filters can result in supply air bypassing the filter and depositing dirt on the heating/cooling coils rather than on the filter. This results in dirty coils, poor heat transfer, and general inefficiency. Furthermore, cleaning a dirty coil is far more difficult and labor intensive than replacing filters (DOE 2005b).

As a rule, sites should routinely change filters based on either the pressure drop across the filter, calendar scheduling, or visual inspection. Scheduled intervals should be between 1 and 6 months, depending on the dirt loading from indoor and outdoor air. Measuring the pressure drop across the filter is the most reliable way to assess filter condition. In facilities with regular and predictable dirt loading, measuring the pressure drop across the filter can be used to establish the proper filter-changing interval; thereafter, filter changes can be routinely scheduled. Refer to manufacturer's data for the recommendations of pressure drop across specific filters (DOE 2005b).

Coil Cleaning

Hot water and chilled-water coils in HVAC systems tend to accumulate dirt and debris, similarly to HVAC filters. As dirt and debris accumulates, it inhibits the heat transferred from the working fluid to the air stream, thus reducing the efficiency of the HVAC system. Much like HVAC filters, the scheduled intervals between cleanings is a function of the dirt loading across the coil and is primarily a function of how much dirt is in the ambient air and what has bypassed the filter. Based on the site's periodic inspections, the given facility should develop appropriate cleaning schedules for all the hot water and chilled-water coils. Figure 16 presents a cooling coil in great need of maintenance.

Sensor Calibration

The HVAC temperature, pressure, relative humidity and CO_2 sensors within a building have certain calibration limits that they operate within. The accuracy of a given sensor is primarily a function of the sensor type, with accuracy of all sensors usually degrading over time. Accordingly, as a general maintenance function, sensor assessment and calibration should be a routine function. Refer to manufacturer's data for the recommendations of assessment and calibration.

Damper Operation

There are a number of potential faults HVAC dampers may be subject to. These include dampers stuck open or closed, dampers manually positioned (i.e., mechanically fixed in a position using wire, boards, etc.), dampers with missing vanes, or dampers operating with poor seals. Figure 17 shows one all-too-common solution to a damper issue – something not recommended by this guide's authors.

Figure 16. Cooling Coil Requiring Maintenance (DOE 2005b)

Figure 17. Damper "Quick-Fix" – Not Recommended!

As with valves, damper operation can be verified using a DDC control system. Through this system, a facility manager can activate the damper to the fully-open and then fully-closed position while a colleague in the field verifies this function. If a particular damper is not actuating as it should, then the linkages and actuator should be examined for proper connection and operation. During this process, field staff should also verify that all moving parts are properly lubricated and seals are in good shape.

Because economizers are dampers that interact with outside air, buildings using these should receive special attention. In addition to the above procedure, economizer dampers should be checked at a higher frequency to ensure proper modulation, sealing, and sensor calibration. The temperature and/or humidity (i.e., enthalpy) sensor used to control the economizers should be part of a routine calibration schedule.

Belt-Driven System

Belt-driven systems are common in HVAC fan systems. Belt drives are common because they are simple and allow for driven equipment speed control, which is accomplished through the adjustment of pulley size. While belt-drive systems are generally considered to be efficient, certain belts are more efficient than others. Standard belt drives typically use V-belts that have a trapezoidal cross section, and operate by wedging themselves into the pulley. These V-belts have initial efficiencies on the order of 95% to 98%, which can degrade by as much as 5% over the life of the system if the belts are not periodically re-tensioned (DOE 2005c).

If the fans currently have standard V-belts, then retrofit options for consideration include cogged-V-belts or synchronous belts and drives. In both cases, efficiency gains on the order of 2% to 5% are possible, depending on the existing belt and its condition. It should be noted that cogged-V-belts do not require a pulley change as part of the retrofit, while the synchronous belt retrofit does.

System Overrides

System overrides that are programmed into the buildings DDC systems should be periodically checked. System overrides are sometimes necessary to handle extreme weather conditions, occupancy conditions, or special events. As these are programmed, a special note should be made of what was overridden, for what purpose, and when it can be reset. The site should implement a continuous override inspection program to look at all the overrides that have been programmed into the DDC system and to make sure they are removed as soon as possible.

Simultaneous Heating and Cooling

In dry climates that do not have a need to simultaneously heat and cool the air to control the relative humidity, it is generally advised that the heating should be disabled whenever the cooling system is activated and vice versa. In pneumatic and electromechanical systems, the building operator may have to manually override the heating and cooling system to accomplish this.

With DDC systems installed in areas not requiring dehumidification, the system should be programmed to lock out the hot-water pumps during high ambient conditions (e.g., outdoor air temperatures above 70°F) and lock out the chilled water pumps during low ambient conditions (e.g., outdoor air temperatures below 60°F to 55°F). This will ensure that only the necessary service is provided and eliminate the wasteful practice of unnecessary simultaneous heating and cooling.

Where simultaneous heating and cooling are required (e.g., in humid climatic regions) to remove the moisture from the conditioned air, and then to heat the air back up to the required setpoint temperatures, building operators should check for proper operation. As noted above, checks should be made to ensure temperature dead-band setting is far enough apart that it does not cause the HVAC system to continuously "hunt."

General Findings

The following list of generalized actions related to HVAC systems was put together based on recommendations that have been made at various DoD/Army facilities:

- Verify heating/cooling coil has no water flowing through it when the fan feeding the system is off.
- Control exhaust fans based on room temperatures through the DDC system rather than having the fans run continuously – have to address building air balance issues.
- Examine the chilled water and hot water pumps to determine if one or two can be shut off over certain temperature ranges.
- Upgrade controls to allow the VAV zone controllers to know if the fan is in heat or cool modes – let VAV zone controllers drive the fan system to provide heat or cool on a demand calculation basis.
- Incorporate a hot water reset function into the DDC control algorithms, rather than operating at a constant hot water supply temperature. This will save energy by decreasing the boiler's hot water temperature or steam pressure when the boiler is operating at a part-load condition. In order to avoid possible boiler damage, as a result of acid formation in the boiler's exhaust stack, a minimum reset temperature of 140°F should be implemented (Hatley et al. 2005).

Diagnostic Equipment

Electric Data Loggers

Electric data loggers can be implemented to determine how much energy a given piece of equipment is using, and to determine if the equipment is turning on and off with the correct schedule. Electric data loggers can be installed on any piece of electrical equipment used to operate the HVAC systems.

Portable Multi-Use Data Loggers

There are a variety of small, portable, battery-operated, multi-use data loggers available from an assortment of vendors. The loggers are programmable and typically store weeks-to-months of data. Sensors types and measurements recorded include temperature, humidity, pressure, amperage, voltage, lighting intensity, run-time for motor-driven devices, and contact closures/pulses. These devices are extremely useful in diagnosing system operation and very economic – typically less than $100.

CO_2 Sensors

CO_2 sensors are useful to validate existing outside air fractions and as a control point for modern demand-control ventilation systems.

Operation and Maintenance – Persistence

To appropriately address all the maintenance issues listed above, the site needs to have a fully functional O&M program. This program would ideally use a Computerized Maintenance Management System (CMMS) to develop work orders for the various tasks described above. As noted above, once the site establishes trends on the frequency at which maintenance tasks should be carried out, this information should be programmed into the CMMS.

Energy/facility managers should initiate programs to periodically verify the building setpoint temperatures are maintained consistently throughout the base. These managers should implement regular inspections of various buildings to make sure they are all operating according to the protocol the site has developed.

HVAC Operations and Maintenance Checklist (Sullivan et al. 2004)

Description	Comments	Maintenance Frequency			
		Daily	Weekly	Semi-Annually	Annually
Overall visual inspection	Complete overall visual inspection to be sure all equipment is operating and safety systems are in place	X			
Verify control schedules	Verify in control software that schedules are accurate for season, occupancy, etc.	X			
Verify setpoints	Verify in control software that setpoints are accurate for season, occupancy, etc.	X			
Time clocks	Reset after every power outage	X			
Check all gauges	Check all gauges to make sure readings are as expected		X		
Control tubing (pneumatic system)	Check all control tubing for leaks		X		
Check outside air volumes	Calculate the amount of outside air introduced and compare to requirements		X		
Check setpoints	Check setpoints and review rationale for setting		X		
Check schedules	Check schedules and review rationale for setting		X		
Check deadbands	Assure that all deadbands are accurate and the only simultaneous heating and cooling is by design		X		
Check sensors	Conduct thorough check of all sensors – temperature, pressure, humidity, flow, etc. – for expected values			X	
Time clocks	Check for accuracy and clean			X	
Calibrate sensors	Calibrate all sensors: temperature, pressure, humidity, flow, etc.				X

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Opportunity #6: Energy System Leakage

Introduction

Distributed utilities (e.g., water, steam, compressed air, natural gas) are commonly found on many DoD/Army sites. Often, these systems are buried underground or located in difficult-to-access sub-structures and frequently considered out-of-site/out-of-mind. Unfortunately, because these systems are not always visible they are often improperly maintained, resulting in leakage and significant loss of energy and resource. Additional ramifications include potential safety hazards of leakage of high-temperature fluids (water and/or steam) as well as combustion issues with natural gas.

Typical Energy Impacts

Leakage of any utility is a wasteful, unnecessary occurrence, and results in excessive operating costs incurred by the facility. The energy impacts of leakage are directly related to the lost utility, its value and duration without detection. The most common leaks on DoD/Army sites include steam, water, natural gas, and compressed air.

Potential Savings

The economic implications of leakage can be minimal (a few dollars per year) for small water leaks to considerable (many thousands of dollars per year) for steam, compressed air, or natural gas leaks. Regardless of size, leakage detection and correction should be a priority because of the economics, the safety, and potential for damage to surrounding systems from leakage.

Operational/Energy Efficiency Measures

Leaks in commercial buildings have a range of causes, from initial design and construction flaws, to operations-related leaks. Most of the operations-related leaks are a result of vibration, misalignment, and abrasion in operating equipment causing fittings and connections to wear or loosen over time.

The sections below, which are specific to certain types of leaks, address the common cause of the leaks, the types of connections, fittings/equipment that usually have leaks, the energy impacts of the leak, and the proper diagnostic equipment used to locate, identify, and repair the leak. The types of leaks are addressed in a generalized manner to cover a wide range of typical leak types and their energy impacts, and will provide background information to the energy and facility manager on where and what to look for.

System Leakage Measure #1: Steam Leaks

Steam leaks are a continuous source of wasted thermal energy, water, and the chemicals used to treat the water. Some steam leaks will be obvious, as the site personnel will be able to see steam discharging from the leak source, while others are hidden within process equipment, heat exchanges, or steam traps.

> **O&M Tip**: Repairing steam system leaks can save 1% of a *facility's* total energy use with an average simple payback of 3 months.

Steam leaks and their energy impacts correlate with the size of the leak and the pressure of the steam. Thus, the higher the steam system pressure, the higher the steam leak discharge rate and consequently the higher the energy implications to the site. Steam leaks in pressurized systems can come from various sources and have a wide range of causes. Some of the more common locations for steam leaks include pipes, valves, fittings, connections, washers, flanges, steam traps, and excessive system bleeding, including boiler blow-downs. Figure 18 highlights some of steam-leak locations typical of DoD/Army sites.

Figure 18. Steam Leakage as Found on DoD/Army Installations

A typical steam system that is lacking a regular maintenance program can expect that 15% to 30% of the installed steam traps have failed (DOE 2006). Every steam trap that is "failed open" is wasting energy by allowing steam to pass through the device, condense, and drain into the condensate system.

In addition to the wasted energy of the steam leak itself, these leaks can have detrimental effects on the heating system as a whole. For example:

- Steam leaks are a dangerous safety hazard to site personnel working in the vicinity of the leak.
- Steam leaks increase the amount of heat required for the steam system, which may necessitate the startup and operation of extra boilers.
- Additional water (make-up water) is needed to compensate for the water lost with the steam.
- Additional water-treatment chemicals are needed to treat required make-up water.
- Though not a steam leak, when failed closed, steam traps can cause a condition known as water hammer within the steam system. Water hammer is the result of excessive condensate built up in the steam line, which should have drained through the steam trap. Once enough of the condensate has built up in the system, it will form a "slug" of water, which travels at a high rate of speed and can damage process and other distribution equipment upon impact.

Opportunity Identification

The entire steam-distribution system should be inspected when the scheduled system audit is performed. For steam leaks that are visible, the site energy/facility manager should record the location and approximate the size of the leak in his notes. Leak sizes should be estimated with an approximate orifice diameter and recorded in audit notes for prioritization and eventual correction. The energy/ facility manager should also attempt to assess the cause of the leak and relay that information to the maintenance department. The entire steam system piping network should be analyzed, including all the interactions with the process equipment.

Diagnostic equipment used to assess failed steam traps are discussed below. Steam trap leaks are more difficult to properly locate and identify, and should only be identified by qualified personnel.

Once the leaks have been identified and the possible causes have been determined, site personnel should determine an appropriate time for correction. If the particular section of piping has isolation valves, and the section can be isolated with the steam system still operational, then the leak should be fixed as soon as possible. If the steam system needs to be operational continuously, then the operators should plan on fixing the leaks the next time the steam system is scheduled to be off line, such as shutdowns, holidays, or weekends.

Diagnostic Equipment

Ultrasonic Leak Detector. Ultrasonic leak detectors translate sounds inaudible to the human ear into frequencies that can be detected. These devices can both amplify the sound as well as present it visually on a screen or meter. Either way, the operator of the detector will be alerted to leakage location and in some cases can make an assessment of the leakage rate. In addition, because these devices are typically used with headphones, they are easily operated in often loud industrial/process settings.

The majority of the ultrasonic detectors on the market are unaffected by audible noise, and will translate the ultrasonic sound wave produced by the steam flowing through the steam trap into frequencies heard by the human ear or seen on a meter face. In either case, the detector gives the operator the ability to analyze the steam traps for proper operation. Once properly trained, the operator can use the detector to determine if the steam trap has "failed open" (blowing live steam to the condensate system) or "failed closed" (steam is not passing through but is condensing in the trap and backing up into the steam distribution system). As noted above, using an ultrasonic detector to assess steam-trap function requires training on the proper use of the device. If there are no trained steam-trap inspectors onsite, then the site should consider an external contractor to conduct the audit.

Visual Inspection. The steam leaks discharging to atmospheric conditions will usually be visible. Accordingly, site personnel should periodically walk down the entire steam system, visually checking for steam leaks. In addition to the steam distribution system, valve pits and vaults should also be opened for inspection.

Thermal Imaging Camera. Thermal imaging cameras can be very useful in identifying steam leaks within process equipment and steam traps. Thermal imaging cameras have a visual display that transforms the infrared, electromagnetic radiation signatures of the object into a visual picture. The camera usually shows the picture and the correlating thermal temperature gradients of the object being analyzed. Accordingly, these cameras are capable of showing steam traps failed open and discharging live steam to the condensate drain – where the entire trap will appear the relative color of live steam. As with ultrasonic detectors, this type of assessment should only be performed by certified thermographers. If there are not certified thermographers onsite, then the site should consider an external contractor to conduct the steam-trap assessment.

> **O&M Tip**: An effective steam-trap maintenance program can save 3% of a *facility's* total energy use with an average simple payback of 2 months.

Energy Savings and Economics

Table 6 can be used to approximate the energy loss from steam leakage (IAC 2006).

Table 6. Annual Energy Loss from a Steam Leak

Steam Pressure					
Hole Size (in.)	Annual Heat Loss (MMBtu/yr)				
	20 psig	50 psig	100 psig	200 psig	400 psig
0.05	20	25	100	150	375
0.1	100	200	500	800	1,500
0.25	250	1,000	2,025	4,000	>4,000
0.5	1,600	3,250	4,000	>4,000	>4,000

Estimated Annual Energy Savings. The annual energy savings that could be realized by repairing a steam leak can be estimated as follows (IAC 2006).

$$Annual\ Energy\ Savings = \frac{EL \times H}{\eta \times 8,760}$$

where EL = energy loss-steam leak, MMBtu/yr (from table above)
H = annual hours of operation, hours
η = boiler efficiency (%/100)

Estimated Annual Cost Savings. The annual cost savings, which could be realized by repairing a steam leak, can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times FC$$

where FC = average heating system fuel cost, $/MMBtu

Steam Leaks Energy Savings and Economics Example

Example Synopsis

A steam system audit reveals a steam leak in a pressurized steam line. The leak has an estimated orifice diameter of 0.10 inches, and is located in a section of line that has a steam pressure of 100 psig. The line is energized 8,000 hrs/yr, the heating system efficiency is estimated at 75%, and the current fuel costs are $9/MMBtu.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \frac{500 \times 8,000}{0.75 \times 8,760}$$

$$Annual\ Energy\ Savings = 608.83 MMBtu / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (608.83 MMBtu / yr)(\$9.00 / MMBtu)$$

$$Annual\ Cost\ Savings = \$5,479 / yr$$

Energy Savings and Economics – Failed Steam Traps

Table 7 can be used to approximate the energy loss from a failed-open steam trap (DOE 2006).

Table 7. Steam Trap Discharge Rate

Trap Orifice Diameter (in.)	Steam Loss (lb/hr)			
	Steam Pressure (psig)			
	15	100	150	300
1/32	0.85	3.3	4.8	--
1/16	3.40	13.2	18.9	36.2
1/8	13.7	52.8	75.8	145
3/16	30.7	119	170	326
1/4	54.7	211	303	579
3/8	123	475	682	1,303

"Steam is discharging to atmospheric pressure through re-entrant orifice with a coefficient of discharge equal to 0.72" (DOE 2006).

Estimated Annual Energy Savings. The annual energy savings that could be realized by repairing a failed steam trap can be estimated as follows (DOE 2006).

$$Annual\ Energy\ Savings = \frac{DR \times H}{1,000}$$

where DR = discharge rate of steam, lb/hr
H = annual hours of operation, hours

Estimated Annual Cost Savings. The annual cost savings that could be realized by repairing a failed steam trap can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times FCS$$

where FCS = average fuel cost of steam, \$/1,000 lb of steam

It should be noted that this cost savings calculation assumes onsite personnel have benchmarked the fuel cost of steam production. This will display how much the site is paying to produce steam, on a \$/1,000 lb of steam basis.

Steam Trap Replacement Energy Savings and Economics Example

Example Synopsis

A steam system audit reveals a failed steam trap in a steam line pressurized to 100 psig. The steam trap has an orifice diameter of 1/8 of an inch. The line is energized 8,000 hrs/yr and the current fuel costs are \$10/1,000 lb of steam.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \frac{52.8 \times 8,000}{1,000}$$

$$Annual\ Energy\ Savings = 422.4\left(1,000 lb / yr\right)$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = \left(422.4\left(1,000 lb / yr\right)\right)\left(\$10.00 / 1,000 lb\right)$$

$$Annual\ Cost\ Savings = \$4,224 / yr$$

Operation and Maintenance – Persistence

Steam leak identification should be part of a continuous steam system maintenance program. The entire steam system should be audited at least annually to find and correct steam leaks.

The maintenance program for steam traps should include the periodic testing of the facility steam traps based on the following testing intervals (Bell 2000).

- System Pressure of 0 to 30 psig: Annually
- System Pressure of 30 to 100 psig: Semi-annually
- System Pressure of 100 to 250 psig: Quarterly or Monthly
- System Pressure over 250 psig: Monthly or Weekly

Once all the major leaks in the steam system have been fixed, the plant should consider hiring a steam system specialist to assess the entire steam system.

System Leakage Measure #2: Compressed Air Leaks

Compressed air leaks are common in compressed air systems and are usually a continuous source of wasted electric energy. The leaks often go unnoticed by site personnel because they are difficult for the human ear to hear and can occur in difficult-to-access locations in the distribution system.

In addition to the wasted energy of the leak itself, the leaks can have detrimental effects on the compressed air system as a whole by causing (DOE 2000):

- System pressure reduction, resulting in lower productivity of systems and staff.
- System pressure fluctuations, resulting in improper operation of processes and systems.
- Lowered pressure requiring excess compressor capacity to achieve a given task or function.
- Lowered pressure requiring longer compressor runtimes leading to shortened compressor life and increased O&M costs.

Opportunity Identification

Although there is a countless number of potential leak sources, the fact sheet titled *Minimize Compressed Air Leaks* identifies the most common as couplings, hoses, tubes, fittings, pipe joints, quick disconnects, FRLs (filter, regulator, and lubricator), condensate traps, valves, flanges, packing, thread sealants and point of use devices (DOE 2000).

A common source of compressed air leaks is the lack of use of thread sealants. It is very important that all pipe and connection threads have properly implemented thread sealant. This is one of the easiest, low-cost preventive maintenance activities the site can engage in.

> **O&M Tip**: Repairing air leaks can reduce *compressed air system* energy use by 30% or more.

Diagnostic Equipment

Ultrasonic Leak Detector. Ultrasonic leak detectors translate sounds inaudible to the human ear into frequencies that can be detected. These devices can both amplify the sound as well as present the sound visually on a screen or meter. Either way, the operator of the detector will be alerted to leakage location and in some cases can make an assessment of the leakage rate. These devices are extremely useful in tracing compressed air lines in a quick and efficient manner. In addition, because these devices are typically used with headphones, they are easily operated in often loud industrial/process settings.

Soap and Water. One of the traditional methods of compressed air leak detection makes use of the simplest of technology – a container of soapy water. This detection method is usually conducted with a paint brush and manual application of the soapy water to suspect leakage locations and then checking for bubbles. Clearly this method is not as “high-tech” nor as quick as using the ultrasonic detector; however, done properly, it is very effective.

Whichever the detection method, as the leaks are identified, site staff should note the location and estimate the size of the leak. Leak sizes should be estimated with an approximate orifice diameter and recorded in audit notes for prioritization and correction.

Energy Savings and Economics

The amount of compressed air lost in the leak can be estimated as a function of orifice diameter and line pressure with Table 8 (DOE 2000).

Table 8. Compressed Air Leakage Rates

Leakage Rates for Different Supply Pressures and Approximate Orifice Sizes (cfm)						
Pressure (psig)	Orifice Diameter (in.)					
	1/64	1/32	1/16	1/8	1/4	3/8
70	0.29	1.16	4.66	18.62	74.40	167.80
80	0.32	1.26	5.24	20.76	83.10	187.20
90	0.36	1.46	5.72	23.10	92.00	206.60
100	0.40	1.55	6.31	25.22	100.90	227.00
125	0.48	1.94	7.66	30.65	122.20	275.50

"For well-rounded orifices, multiply the values by 0.97, and for sharp-edged orifices, multiply the values by 0.61." (DOE 2000)

Estimated Annual Energy Savings. The annual energy savings that could be realized by fixing a compressed air leak can be estimated as follows:

$$Annual\ Energy\ Savings = N \times LR \times EU \times H \times C$$

where N = number of leaks, no units
LR = leakage rate, cfm (from the table above)
EU = compressor energy use, kW/cfm
H = annual hours of operation, hours
C = orifice edge coefficient, no units

Estimated Annual Cost Savings. The annual cost savings that could be realized by fixing a compressed air leak can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times ER$$

where ER = average annual electricity rate, \$/kWh

It should be noted that this cost savings calculation does not account for an electric peak demand reduction. If the facility has a peak demand charge, and the compressor operates every day on an operational schedule that is coincident with the facilities peak demand, then this estimate slightly underestimates the cost savings.

Compressed Air Leaks Energy Savings and Economics Example

Example Synopsis

A compressed air system audit reveals 5 air leaks, all with an estimated orifice diameter of 1/16 of an inch. The leaks are located in a line pressurized to 100 psig. The energy use of the compressor is 18 kW/100 cfm, and is operated 8,760 hrs/yr. The electrical rate is approximately $0.10/kWh. (Assumed sharp edged orifice coefficient equals 0.61)

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = 5 \times 6.31 \times 0.18 \times 0.61 \times 8,760$$

$$Annual\ Energy\ Savings = 30,346.30 kWh / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (30,346.30 kWh / yr)(\$0.10 / kWh)$$

$$Annual\ Cost\ Savings = \$3,034 / yr$$

Operation and Maintenance – Persistence

Any site with distributed compressed air systems should implement an ongoing compressed-air leak-detection program. After the compressed air system is audited, one should not assume that the problem is fixed for good. On the contrary, the tests and procedures developed above should be carried out on a regular basis – no less than quarterly. This would ensure the implementation of a complete and persistent leak detection and repair program.

Fixing the leak can be as simple as tightening connections or applying thread sealants to a pipe connection and re-tightening the connection. Or, in some cases new fittings, valves or connection equipment must be retrofit to correct the leak.

Once all the leaks in the compressed air system have been fixed, the site should consider engaging a qualified compressed air specialist to adjust the compressor controls. The site should also consider a full compressed air system audit, as fixing compressed air leaks is only one of the multiple types of energy conservation measures that can be implemented on a compressed air system.

> **O&M Tip**: It takes approximately 2.5 to 5.0 kWh to compress 1,000 ft^3 of air to 100 psi. Each psi reduction in compressed air loss from the distribution system (at 100 psi), reduces a *compressor's* energy use by more than one-half percent.

System Leakage Measure #3: Natural Gas Leaks

Similar to compressed air leaks, natural gas leaks can represent a large source of wasted energy. Different from compressed air leaks, natural gas leakage has the additional component of the commodity cost – the actual cost of the gas – greatly increasing the value of the leakage. Because of this added cost and relevant safety issues, natural gas system design, layout, and materials are usually of high quality and receive greater scrutiny than standard compressed air systems. However, all these elements are subject to the same degradation mechanisms as in compressed air systems and should be part of any comprehensive leak detection program.

Opportunity Identification

Similar to compressed air, natural gas leakage most often occurs at couplings, fittings, pipe joints, regulators, meters, and flanges. Consistent with compressed air systems all connections need to have proper thread sealant applied and checked for proper function.

Diagnostic Equipment

Because natural gas is comprised mostly of methane, it does not have any smell in its natural state. Therefore, the producers of the gas add a very pungent "rotten egg" smell (usually a sulfur compound known as mercaptan) that is easily detected by most people. This smell provides for one of the most diagnostic methods of leak detection – if you smell rotten eggs, then there is a good chance you have a gas leak.

In areas of high ventilation or as a confirmation of leak location, both the ultrasonic leak detection and the soap-and-water detection methods discussed above apply. In addition, there are a variety of combustible-gas leak detection products designed for this specific application. Most are portable hand-held devices that sense a variety of combustible gases – including methane.

Energy Savings and Economics

Because of the commodity value, it is highly economic to locate and repair any and all natural gas leaks.

Operation and Maintenance – Persistence

Any site with distributed natural gas should implement an ongoing leak-detection program. This particularly holds true for aging distribution systems, systems exposed to the elements, and process-related systems where vibration is a factor.

Rules of Thumb

Steam Leakage Rules of Thumb

- **Steam Rule 1**. An effective steam trap maintenance program can save 3% of a *facility's* total energy use with an average simple payback of 2 months.

- **Steam Rule 2**. An effective steam trap maintenance program can reduce a boiler's fuel use by 10% to 20%.

- **Steam Rule 3**. Repairing steam system leaks can save 1% of a *facility's* total energy use with an average simple payback of 3 months.

In the absence of calculating the cost of a failed steam trap or a steam leak, Figure 19 can be used as a rough cost estimate for steam leaks and steam traps failed open (The Natural Gas Boiler Burner 2006).

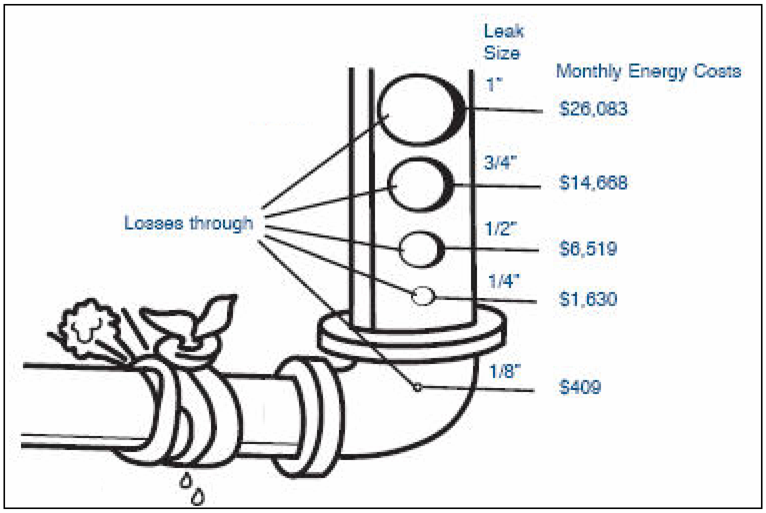

Figure 19. Steam Leak Monthly Energy Costs

"Assumptions: Calculated using a compressible flow analysis, for a sharp edged orifice. Heating system cost of $9.50/1,000 lbs, at a steam pressure of 150 psig" (The Natural Gas Boiler Burner 2006).

In its report, *Wise Rules for Industrial Energy Efficiency,* the U.S. Environmental Protection Agency develops a comprehensive list of rules of thumb relating to compressed air. These rules of thumb are presented below (EPA 2003).

Compressed Air Systems Rules of Thumb

- **Compressed Air Rule 1**. Efficiency improvements can reduce *compressed air system* energy use by 20% to 50%.
- **Compressed Air Rule 2**. Efficiency improvements to compressed air systems can save approximately one-half percent of a *facility's* total energy use.
- **Compressed Air Rule 3**. Repairing air leaks can reduce *compressed air system* energy use by 30% or more.
- **Compressed Air Rule 4**. Repairing air leaks can reduce a *facility's* total energy use by about one-half percent, with an average simple payback of 3 months.
- **Compressed Air Rule 5**. It takes approximately 2.5 to 5.0 kWh to compress 1,000 ft^3 of air to 100 psi. Each psi reduction in compressed air loss from the distribution system (at 100 psi), reduces a *compressor's* energy use by more than one-half percent.

In the absence of calculating the cost of a compressed air leak, Table 9 can be used as a rough cost estimate for compressed air leakage cost (DOE 2003).

Table 9. Compressed Air Leaks – Cost Per Year

Size (in.)	Cost Per Year ($/yr)
• 1/16	$523
● 1/8	$2,095
⬤ 1/4	$8,382

"Costs calculated using electricity rate of $0.05 per kWh, assuming constant operation and an efficient compressor" (DOE 2003).

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Opportunity #7: Distribution System Conditional Assessment

Introduction

Distribution systems both internal and external to DoD/Army buildings have enormous potential for excess energy use. This excess use is usually tied to missing or compromised insulation and resulting heat loss on distribution lines, valve bodies, and steam traps. Given these missing sections are not always noticed, or in areas of easy access, the resulting heat loss can be significant in both magnitude and duration.

Typical Energy Impacts

Given the age of many of the DoD/Army distribution systems and the noted condition of some, an Army-wide distribution system assessment would undoubtedly net significant savings gains – in some cases on the order of 20% to 30% of system use.

Potential Savings

The energy impact of compromised and/or missing insulation is related to the affected surface area, the surface temperature, and the system use. In a simple 8-inch steam line with missing insulation, the annual energy cost can be as high as $500 for every 10 feet of piping – assuming $5/million Btu steam cost. This factor, multiplied over what could be many hundreds of feet of piping, could add up to a significant savings potential.

Operational/Energy Efficiency Measures

This section focuses on the installation of the appropriate insulation for distribution piping and associated equipment. It addresses the proper insulation for a given use and is structured to be specific to building distribution applications.

Buildings have many components that are crucial to proper heating and cooling system distribution functionality. Although all these components are important, installing the proper insulation on piping and relevant equipment is relatively easy and should be considered one of the first measures to implement in existing buildings.

As a general rule, thermal insulation should be installed on the following types of piping systems and equipment:

- HVAC chilled water pipes/valves/fittings
- HVAC hot water pipes/valves/fittings
- HVAC steam pipes/valves/fittings, steam traps
- Domestic hot water pipes/valves/fittings
- Domestic chilled water pipes/valves/fittings

Distribution System Measure: Ensuring Proper Insulation

Uninsulated steam, hot water, and chilled water lines are a continuous source of wasted thermal energy. When compared to the thermal heat losses of bare surfaces, insulating pipes and valves reduces energy losses by at least 90% (Turner 2004). This wasted thermal energy has a direct effect on the energy requirements of the entire system, and this thermal energy loss is the primary economic driver for installing insulation on commercial building distribution systems.

Opportunity Identification

In general, all steam, high-temperature hot water, chilled water, and domestic hot water piping should be insulated. In addition, all valves, valve bodies, storage tanks, and other ancillary distribution-system equipment should be insulated. As one author states it … all piping networks and appropriate equipment with operating temperatures above 105°F and below 55°F should be insulated (Bell 2000).

> **O&M Tip**: If the surface is too hot to hold with your bare hand, then it will likely be cost-effective to add insulation.

Diagnostic Equipment

Temperature Measurement Devices. Temperature measurement devices are used to measure the surface temperature of the piping network or system. The most common types of devices are thermal imaging cameras, hand-held contact thermometers, and hand-held infrared temperature devices.

As with most measurement technology, some level of training is recommended for proper and accurate operation. Clearly, the use of a thermal imaging camera would require some level of training depending on the application. It should also be noted that simple hand-held infrared temperature devices can lead to erroneous conclusions if the spot-size-to-distance ratio is not well understood or applied.

Energy Savings and Economics

Table 10 can be used to approximate the energy loss from horizontal bare steel pipe and flat surfaces to still air at 80°F, measured in Btu/hr-ft (EPA 2003). To use this table, identify the nominal pipe size on the left column and then locate the pipe temperature (i.e., fluid temperature) on the top row. Where these two intersect represents the hourly heat loss per lineal foot of bare pipe, given in Btu/hour/foot.

Energy Savings Calculation for Pipe Insulation

To estimate the energy savings that is achievable through insulating pipes, use Table 10 and the assumption that, given the appropriate type and amount, the insulation will reduce the heat losses by 90% (DOE 2004).

Table 10. Energy Loss from Steel Pipes and Flat Surfaces to Still Air (ASHRAE 1993)

Horizontal Bare Steel Pipe and Flat Surface Heat Loss (Btu/hr/ft)										
Nominal Pipe Size (in.)	**Pipe Inside Temperature (°F)**									
	180	**280**	**380**	**480**	**580**	**680**	**780**	**880**	**980**	**1,080**
0.5	59.3	147.2	263.2	412.3	600.9	836.8	1,128.6	1,458.6	1,918	2,436.8
0.75	72.5	180.1	332.6	506.2	739.2	1,031.2	1,392.9	1,836	2,373.5	3,018.8
1	88.8	220.8	396.1	622.7	910.9	1,272.6	1,721.2	2,271.5	2,939.4	3,741.6
1.25	109.7	272.8	490.4	772.3	1,131.7	1,583.8	2,145.6	2,835.4	3,673.4	4,680.9
1.5	123.9	308.5	555.1	875.1	1,283.8	1,798.3	2,438.2	3,224.6	4,180.5	5,330
2	151.8	378.1	681.4	1,076.3	1,581.5	2,218.9	3,012.6	3,989.2	5,177.2	6,606.3
2.5	180.5	450	811.9	1,284	1,888.8	2,652.6	3,604.3	4,775.3	6,199.5	7,912.5
3	215.9	538.8	973.5	1,541.8	2,271.4	3,194	4,344.9	5,762.2	7,486.9	9,562.3
3.5	243.9	609	1,101.4	1,746.1	2,574.7	3,623.6	4,933	6,546.4	8,510.4	10,874.3
4	271.6	678.6	1,228.2	1,948.7	2,875.9	4,050.5	5,517.5	7,326	9,528.1	12,178.9
4.5	299.2	747.7	1,354.4	2,150.9	3,176.8	4,477.7	6,103.8	8,109.5	10,553.2	13,496.2
5	329.8	824.7	1,494.8	2,375.4	3,510.6	4,950.7	6,751.3	8,972.5	11,678.4	14,936.3
6	387.1	968.7	1,757.8	2,796.8	4,138	5,841.4	7,972.7	10,603.1	13,808.2	17,667.6
7	440.5	1,102.8	2,003	3,189.9	4,723.9	6,673.5	9,114.2	12,127.4	15,799.4	20,220.8
8	493.3	1,235.7	2,246.1	3,580	5,305.5	7,500	10,248.4	13,642.2	17,778.2	22,758
9	545.9	1,368.1	2,488.8	3,970.2	5,888.7	8,331	11,392.1	15,174.5	19,787.1	25,323
10	604.3	1,514.8	2,757.2	4,400.7	6,530.1	9,241.1	12,638.6	16,835.1	21,949.2	28,104.9
11	656	1,644.8	2,995.5	4,783.8	7,102.1	10,054.9	13,756.2	18,328.4	23,900.3	30,606.1
12	704	1,762.3	3,203.8	5,104.9	7,557.3	10,661.8	14,524.9	19,256.7	24,967.6	31,766.8
14	771	1,934.2	3,525.9	5,636	8,373.9	11,862.4	16,235.5	21,635.6	28,212.3	36,120.3
16	872.2	2,189	3,993.2	6,387.4	9,495.9	13,458	18,424.8	24,556.6	32,021.1	40,990.7
18	972.5	2,441.7	4,456.7	7,132.9	10,609.4	15,041.3	20,596.7	27,453.2	35,795.6	45,813.1
20	1,072.1	2,692.4	4,916.8	7,873.2	11,715.1	16,613.4	22,752.5	30,326.8	39,537.6	50,590
24	1,269.3	3,188.9	5,828.3	9,339.9	13,905.5	19,726.9	27,019.7	36,010.1	46,930.3	60,014.7
	Surface Inside Temperature (°F)									
	180	**280**	**380**	**480**	**580**	**680**	**780**	**880**	**980**	**1,080**
Vertical Surface	212.2	533.1	973.3	1,558.6	2,321.2	3,298	4,530.1	6,062.8	7,945.5	10,231.5
Horizontal Surface										
Facing Up	234.7	586.4	1,061.1	1,683.5	2,484.9	3,501.9	4,775.4	6,350.4	8,276.3	10,606.1
Facing Down	183.6	465.3	861.4	1,399.6	2,122.8	3,038.4	4,217.8	5,696.7	7,524.5	9,754.7

*"Calculations from ASTM C680-82; steel: k = 314.4 Btu*in/h*ft^2*°F; ε=0.94."*
"Losses per square foot of pipe for pipes larger than 24 in. can be considered the same as losses per square foot for 24-in. pipe" (ASHRAE 1993).

Estimated Annual Energy Savings

The annual energy savings that could be realized by insulating piping can be estimated as follows:

$$Annual\ Energy\ Savings = \frac{\left[EL - (EL \times 0.1)\right] \times L \times H}{C_1 \times EFF}$$

where EL = energy loss, Btu/hr/ft
L = length of pipe, ft
H = annual hours of operation, hrs
C_1 = conversion constant, 1,000,000 Btu/MMBtu
EFF = heating or cooling system efficiency (%/100)

Estimated Annual Cost Savings

The annual cost savings that could be realized by insulating piping can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times FC$$

where FC = fuel cost, $/MMBtu

Pipe Insulation Energy Savings and Economics Example

Example Synopsis

A mechanical room has 40 ft of un-insulated piping. The pipes are made of steel, 4 inches in diameter, and heated to 280°F. The lines are energized 8,760 hrs/yr and the average fuel cost is $9.00 MMbtu. The pipes will be insulated with fiberglass insulation, with an all-service jacket. The insulation is assumed to reduce the heat loss by 90%. The heating system efficiency is estimated as 75%.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \frac{\left[678.6 - (678.6 \times 0.1)\right] \times 40 \times 8,760}{1,000,000 \times 0.75}$$

$$Annual\ Energy\ Savings = 285.34 MMbtu / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (285.337 MMbtu / yr)(\$9.00 / MMbtu)$$

$$Annual\ Cost\ Savings = \$2,568 / yr$$

An additional resource for calculating energy savings through insulation is the 3E Plus software program. This program can be downloaded for free from the following website: http://www.pipeinsulation.org/

Energy Savings Calculation – Valve and Fitting Insulation

Table 11 presents information that can be used to determine the energy savings associated with installing removable insulation on valves (DOE 2004). To use this table, identify the system operating temperature on the left-hand column and then locate the valve size on the top row. Where these two intersect represents the hourly heat loss given in Btu/hour.

Table 11. Energy Savings (Btu/hr) from Installing Removable Insulated Valve Covers

Operating Temperature, °F	Valve Size, inches					
	3	**4**	**6**	**8**	**10**	**12**
200	800	1,090	1,560	2,200	2,900	3,300
300	1,710	2,300	3,300	4,800	6,200	7,200
400	2,900	3,400	5,800	8,300	10,800	12,500
500	4,500	6,200	9,000	13,000	16,900	19,700
600	6,700	9,100	13,300	19,200	25,200	29,300

"Based on 2 inches of insulation on 150-pound class flanged valves with an ambient temperature of 65°F" (DOE 2004).

Estimated Annual Energy Savings

The annual energy savings that could be realized by insulating valves or fittings can be estimated as follows:

$$Annual\ Energy\ Savings = \frac{ES \times H}{C_1 \times EFF}$$

where ES = energy savings, Btu/hr
H = annual hours of operation, hrs
C_1 = conversion constant, 1,000,000 Btu/MMBtu
EFF = heating or cooling system efficiency (%/100)

Estimated Annual Cost Savings

The annual cost savings that could be realized by insulating valves or fittings can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times FC$$

where FC = fuel cost, $/MMBtu

Valve Insulation Energy Savings and Economics Example

Example Synopsis

A mechanical room has one heated valve that is uninsulated. The valve is a steel valve, with 10-inch pipes entering both sides of the valve. The valve is heated to 300°F. The valve is energized 8,760 hrs/yr and the average fuel cost is $9.00 MMbtu. The heating system efficiency is estimated as 75%.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \frac{6,200 \times 8,760}{1,000,000 \times 0.75}$$

$$Annual\ Energy\ Savings = 72.42 MMbtu / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (72.42 MMbtu / yr)(\$9.00 / MMbtu)$$

$$Annual\ Cost\ Savings = \$652 / yr$$

Operation and Maintenance – Persistence

Energy and facility managers should perform an initial facility audit to check for missing insulation. After this initial audit has been conducted and the various locations requiring insulation have been insulated, building operators should periodically check the piping network for fundamental repairs, including missing insulation. Before site personnel remove any insulation, they should check with OSHA regulations to make sure the activity is conducted in accordance with its regulations. This is done to ensure plant personnel are not exposed to the asbestos that is potentially in the existing insulation (DOE 2004).

Site personnel and contractors performing any maintenance on piping networks should be required to report any removal of insulation that could not/was not replaced. Personnel should also be given mandatory instructions to replace all removable insulation, whether it was removed as part of their activity or not.

Insulation Rules of Thumb

- **Insulation Rule #1**: Insulating steam lines can save 1% of a *facility's* total energy use with an average simple payback of 10 months.
- **Insulation Rule #2**: If the surface is too hot to hold with your bare hand, then it will likely be cost-effective to add insulation.

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Opportunity #8: Electric Motors

Introduction

Electric motors are used in buildings to drive a variety of pumps, fans, and process loads. The types of motor control systems can differ from building to building and present a challenge for the energy/ facility managers to address in an efficient and cost-effective manner.

Typical Energy Impacts

According to the DOE fact sheet *Buying An Energy-Efficient Electric Motor*, over half of all electrical energy consumed in the United States is used by electric motors (DOE 1996). This large percentage of energy use provides a great opportunity for various efficiency improvements. Likewise on DoD/Army sites, motors make up a significant percent of total energy use and should be considered a resource of energy savings.

Potential Savings

Replacing a standard motor with an energy-efficient motor can result in 5% energy savings (IAC 1996). Depending on the motor size and loading, these savings can translate from hundreds to thousands of dollars per year.

Operational/Energy Efficiency Measures

The vast majority of motor-driven systems in buildings are driven by alternating current (AC) electric motors. Accordingly, this section develops energy conservation measures related to AC motors.

Electric Motors Measure #1: Energy-Efficient Motors

Recent advancements in electric motors have lead to the development of electric motors that are considerably more efficient than standard electric motors. In addition to the electric energy savings that can result from energy-efficient motors, some of the other potential benefits include (CDA 2006):

- Improved equipment reliability
- Reduced downtime
- Reduced operation and maintenance costs.

The National Electrical Manufacturers Association (NEMA) has developed the most recent motor efficiency standards. This new set of standards, developed in 2001, is entitled *NEMA Premium Energy Efficiency Motor Standard*. Developed as a voluntary program, motor manufacturers can voluntarily have their motors certified as NEMA Premium Motors. If the motor is certified in this way, then it has been tested to either meet or exceed a set of NEMA minimum full-load efficiency levels (DOE 2005). These new standards, developed under the new NEMA Premium Efficiency Program, set higher full-load efficiency standards than those previously set by EPAct of 1992 (DOE 2005).

Since this NEMA premium efficiency standard was developed, recent advancements in the rotor portion of certain motors have led to even more efficient motors. These new “ultra-efficient” motors come equipped with copper rotors instead of aluminum rotors. These new rotors increase the efficiency of the system and decreased the rotor losses (I^2R losses) of the motor. Ultra-efficient motors are showing increased efficiency over high-efficiency motors of between 3% to 5%.

The NEMA premium-efficiency and the ultra-efficient motors discussed above are usually cost-effective when annual operation exceeds 2,000 hrs/yr, or use of about 7.5 hours a day, Monday through Friday (DOE 2005). The electric energy rates of the region will also dictate the savings and cost-effectiveness of the retrofit.

These premium or ultra-efficient motors should be considered for implementation in all new construction projects requiring motor-driven systems and for replacement of old-standard efficiency motors requiring repair or rewinding.

Opportunity Identification

Energy/facility managers should survey and categorize all the electric motors at the facility – starting with the largest motors. This categorization should include a record of all information on the motor name plate and make a note of the particular application. Site staff can contact the equipment manufacturer to get information on the efficiency of the motor in relation to the motor’s load and application, or they can use the Motor Master Software package discussed below.

After the initial survey is complete, site personnel should perform an economic analysis of the various motors to determine the most economic retrofit options. This analysis usually requires the use of electric metering equipment, and should only be conducted by trained personnel. If the site is lacking trained personnel, then it should consider hiring a specialist familiar with motor-system analysis.

If the analysis discovers motors that should be retrofit with energy-efficient motors, then site personnel should tag all motors that are identified for retrofit. These tags should indicate if the motor should be retrofit immediately or when the motor has failed.

To assist in making good economic decisions on which motors to replace and when, DOE and its partners have developed a free software program titled Motor Master. This software program helps the building operators analyze existing motors based on size, efficiency, loading characteristics, and provides an output of life-cycle, cost-effective retrofit options for the specific motor analyzed. This software program is available through DOE and can be downloaded for free at the following website: http://www1.eere.energy.gov/industry/bestpractices/software.html#mm.

Energy-Efficient Motor Design Criteria

While energy-efficient motors have many benefits, there are some fundamental design questions or criteria that should be addressed. The following presents some of the most important design criteria to think about when considering the installation of an energy-efficient motor (ACEEE 2006).

Motor Speed. There can be a significant variance in motor speed based on motor type; energy-efficient motors usually have higher full-load operating speeds than standard motors (ACEEE 2006).

This becomes a factor when retrofitting to energy-efficient motors. If the current motor is properly sized, then it is very important that the retrofit options have as close to the same "rated" operating speeds as possible. In certain applications, such as motors operating a centrifugal pump or fan, a higher operating speed could change the system operating characteristics and have a detrimental effect on the system as a whole. Prior to retrofit, site personnel should talk to the particular motor manufacturer to understand a motor's rated speed (rpm) to ensure its retrofit application is appropriate.

Rated Efficiency. In conducting economic analyses for motor retrofit, it is suggested that the *nominal efficiency* ratings given by the various manufacturers should be used instead of *minimum guaranteed efficiency* or other such ratings. The nominal efficiency rating is a standardized rating and should be accurate for existing and retrofit motors.

Electric Power System. The NEMA Premium Efficiency motors discussed above have a higher in-rush current than standard-efficiency motors (ACEEE 2006). This current can cause certain types of magnetic circuit-breakers to trip – depending on their size. If a facility has breaker-tripping issues after premium-efficiency motors are installed, then a review of breaker limits is suggested. Another option is consideration of new hybrid or thermal breakers, which do not trip at higher in-rush currents.

Operating Characteristics. The last consideration that needs to be made when selecting an energy-efficient motor is the torque requirements of the motor. NEMA Design B motors have lower starting torque specifications than the NEMA Design A motors. Accordingly, the site should try to accurately categorize the torque characteristics of the motor to choose the correct motor retrofit. In general, energy-efficient motors used for HVAC purposes should not require a high starting torque and should not have to operate in a configuration that requires more torque than the motor is specified to produce (ACEEE 2006).

Motors to Retrofit

The following is a list of motors used in commercial buildings that should be considered for retrofit with energy-efficient motors:

- Boilers – forced draft fan motors
- Chillers – compressor motors
- Air-Handling Units – fan motors
- Exhaust Fan – fan motors
- Cooling Tower – fan motors
- HVAC Pump – pump motors

Note: This list is intended to highlight some of the major motor systems. All AC motors in the facility should be considered for the implementation of energy-efficient motors.

Diagnostic Equipment

Electric Data Loggers. For an accurate motor-load characterization and run-time profile, portable data loggers can be installed to measure the motor energy use over time. The data loggers can be set to record energy use over time (e.g., an average week), taking amperage and voltage (to generate kW) measurements at least every 15 minutes. This type of analysis is useful in understanding motor loading and run-time characterizations, both of which are useful in determining proper motor application.

Strobe Meter. Another practical tool to determine motor loading is a strobe meter. Strobe meters are useful way to establish the rpm of the motor. This test should be conducted at different times and under different loading conditions to develop an accurate rpm versus load profile. Once developed, this profile can be compared to the manufacturer's specifications to estimate motor loading.

Energy Savings and Economics

The fundamental equation for calculating electric motor energy use is given by the following equation:

$$Energy\ Use = \frac{S \times L}{EFF} \times H$$

where

where	Energy Use	=	energy consumed by the motor, kWh
	S	=	size of the motor, kW
	L	=	motor loading factor (%/100)
	H	=	hours the motor operates at this load, hours
	EFF	=	efficiency of the motor (%/100)

If the motor operates at approximately the same load all year, then this equation can be used, with the correlating hours of operation for the year to calculate the yearly energy consumption. If the motor has a loading factor that changes over the year, then the equation needs to be calculated for a given load and a given number of hours the motor operates at this load. By doing this multiple times and summing the results, the approximate energy use for the year can be calculated.

Estimated Annual Energy Savings. The annual energy savings that could be realized by installing an energy-efficient motor can be estimated as follows:

$$Annual\ Energy\ Savings = \left(\frac{S_1 \times L_1}{EFF_1} - \frac{S_2 \times L_2}{EFF_2} \right) \times H$$

where	S_1	=	size of the current motor, kW
	L_1	=	current motor loading factor, (%/100)
	EFF_1	=	efficiency of the current motor, (%/100)
	S_2	=	size of the new motor, kW
	L_2	=	new motor loading factor, (%/100)
	EFF_2	=	efficiency of the new motor, (%/100)
	H	=	hours the motor operates at this load, hours

Note: To convert the rated hp of the motor to kW, multiply the hp by 0.746. For example, 20 hp = 20 hp(0.746) = 14.92 kW.*

Estimated Annual Cost Savings. The annual cost savings that could be realized by installing an energy-efficient motor can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times ER$$

where ER = average annual electricity rate, *\$/kWh*

It should be noted that this cost savings calculation does not account for an electric peak demand reduction. If the facility has a peak demand charge, and the motor operates every day on an operational schedule that is coincident with the facilities peak demand, then this estimate slightly underestimates the cost savings.

Energy-Efficient Motor Energy Savings and Economics Example

Example Synopsis

A standard 460-volt, three-phase, 50-hp motor has reached the end of its useful life and will be replaced with an energy-efficient motor. The motor has an average loading factor of 80%, and has an operational efficiency at this loading of 93.2%. The new motor has an efficiency rating of 96.4% at a loading factor of 80% and will operate at this loading for 8,760 hrs/yr. The electrical rate is approximately \$0.10/kWh.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \left(\frac{50 \times 0.80}{0.932} - \frac{50 \times 0.80}{0.964}\right) \times 8,760$$

$$Annual\ Energy\ Savings = 12,480.19 kWh / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (12,480.19 kWh / yr)(\$0.10 / kWh)$$

$$Annual\ Cost\ Savings = \$1,248 / yr$$

Electric Motors Measure #2: Dual- and Multiple-Speed Motors

Dual- or multiple-speed motors are manufactured in one of two possible configurations. In the first configuration, the motor has a single set of windings and the motor comes equipped with a switch that energizes or de-energizes an additional set of poles (DOE 2003). The second configuration has multiple windings, and each set of windings energizes a different number of poles (DOE 2003). In either case, the motor can be operated at different speeds (e.g., a three-speed motor can operate at high, medium, and low setting).

Dual- or multiple-speed motors can offer significant cost savings in buildings when installed on HVAC fan systems. The greatest potential savings are with fans that operate at a predetermined setpoint continuously (i.e., 24 hours-per-day, 7 days-per-week), while the load or occupancy of the building varies. This type of continuous operation is common place in many DoD/Army facilities. In many cases, the installation of dual-speed motors offers a simple, cost-effective solution to this deficiency.

Opportunity Identification

All constant-air-volume (CAV) or dual-duct HVAC fan systems that operate continuously at a pre-determined setpoint should be analyzed to determine if the building load actually requires such operation. While some climate regions require the HVAC system to operate continuously to control the indoor moisture or relative humidity, they can unusually operate at a lower fan setpoint during the unoccupied hours of the day or night. The building operators should conduct an analysis of the building to determine the outdoor air requirements on an average day. This would look at changes in occupancy over the course of the day, and determine if certain periods of time could have reduced outdoor air. If so, then dual- or multiple-speed fans could be implemented and run on the lower setting(s) during low or unoccupied periods.

Dual- and Multiple-Speed Motor Design Criteria

Although dual-speed or multiple-speed motors can offer significant cost savings, there are some fundamental design questions or criteria that should be addressed. Presented below are some of the most important design criteria when considering the installation of a dual- or multiple-speed motor:

Motor Speed and Efficiency. Multiple-speed motors allow for operation at various preset driven speeds. Although they allow for speed control, they are usually less efficient than standard or energy-efficient motors. They are also considerably more expensive and should only be used in installations allowing for operation on the low-speed settings for considerable periods of time.

The significant savings in HVAC fan system installations can be developed from the fan affinity laws, which govern the relationship between fan speed and power use. For example, if a motor is operated on its low setting, then the system will be circulating approximately 1/2 of the air it would at the high setting, which correlates to fan affinity law 1, yet the motor will be using 1/8 of the power it uses at the high setting, correlating to fan affinity law 3. Thus, if the air flow is reduced by 1/2 with a dual-speed motor, then the motor will be using 1/8 of the full load power.

To develop this example further, if a facility could operate on the low setting at night, then the building fans would be consuming 1/8 of the power that they consume during the day when they are operated on high speeds. Depending on the motor size and energy cost, this retrofit can save a facility from hundreds of dollars to thousands of dollars per year.

It should be noted that while these motors offer significant cost savings potential, variable-frequency-drive (VFD) motors will offer even greater savings in applications with variable loads and should also be considered if the site is considering installing a dual- or multiple-speed motor.

Operating Characteristics. Dual-speed motors that are retrofit in the place of standard motors in HVAC fan systems will cause significant pressure drops in HVAC ductwork when operated on the lower settings. This interaction should be considered when retrofitting with dual- or multiple-speed motors. Accordingly, an HVAC specialist should assist in the initial design.

Motors to Retrofit

The following are some of the more common systems for which this retrofit should be considered; other systems and equipment may well be good candidates and should be considered.

- Air-Handling Unit – fan motor
- Exhaust Fan – fan motor

Diagnostic Equipment

The electric energy based diagnostic equipment used to analyze fan systems for implementation of multiple- or dual-speed motors is the same as that presented for energy-efficient motors listed above.

In relation to HVAC fan systems, an additional piece of diagnostic equipment used to estimate savings potential is the carbon dioxide (CO_2) sensor. These sensors are used to make accurate measurements of CO_2 in the return-air system. This measurement can then be used to adjust the amount of outside-air necessary to meet CO_2 maximum requirements as presented by ASHRAE. Once characterized, the HVAC fan systems can be reset (or controlled continuously) to operate at only the speed necessary to meet the requirements.

Energy Savings and Economics

If standard motors are retrofit with dual- or multiple-speed motors, then the savings would result from two areas. First, there would be a reduction in the energy required to condition, the now reduced quantity, of air in the building. The second energy savings element results from the reduction in fan energy use. While the reduction in heating/cooling energy use is dependant on the climate region of the building and is specific to the heating and cooling system configurations, the electric energy savings resulting from the new motors can be calculated with the fan affinity laws presented below.

Estimated Annual Energy Savings. The annual energy savings that could be realized by installing a dual-speed motor can be estimated as follows:

$$Annual\ Energy\ Savings = (MC_1 \times H) - \left[(MC_2 \times H_1) + (Power_f \times H_2)\right]$$

where

where	MC_1	=	rated motor size (current motor), kW
	H	=	hours the motor operates, hrs/yr
	MC_2	=	rated energy consumption on high speed (new motor), kW
	H_1	=	hours the motor operates on high speed, hrs/yr
	$Power_f$	=	motor energy consumption on low speed (new motor), kW
	H_2	=	hours the motor operates on low speed, hrs/yr

The $Power_f$ can be estimated as follows:

$$Power_f = Power_i \left(\frac{RPM_f}{RPM_i} \right)^3$$

where RPM_i = initial fan rotational speed, *rpm*
RPM_f = final fan rotational speed, *rpm*
$Power_f$ = initial power, *(units of power)*
$Power_i$ = final power, *(units of power)*

Estimated Annual Cost Savings. The annual cost savings that could be realized by installing a dual-speed motor can be estimated as follows:

$$Annual\ Cost\ Savings = Annual\ Energy\ Savings \times ER$$

where ER = average annual electricity rate, $/kWh

It should be noted that this cost savings calculation does not account for any electric peak demand reduction or HVAC heating and cooling savings, and consequently underestimates the savings potential.

Dual-Speed Motor Energy Savings and Economics Example

Example Synopsis

A standard 460-volt, three-phase, 3600-rpm, 20-hp (14.72-kW) motor has reached the end of its useful life and will be replaced with a dual-speed motor. The existing motor operated continuously, 8,760 hrs/yr, has an average loading factor of 80%, and has an operational efficiency at this loading of 90.7%. The new dual-speed motor has an efficiency rating of 88.2% at a loading factor of 80% and will operate at 3,600 rpm (high speed) for 4,000 hrs/yr and then will operate at 1800 rpm, at an 80% loading factor for 4,760 hrs/yr, with the same efficiency rating at this loading of 88.2%. The electrical rate is approximately $0.10/kWh.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = \left(\frac{14.72 \times 0.80}{0.907} \times 8,760 \right) - \left[\left(\frac{14.72 \times 0.80}{0.882} \times 4,000 \right) + \left(\frac{14.72 \times 0.80}{0.882} \left(\frac{1,800}{3,600} \right)^3 \times 4,760 \right) \right]$$

$$Annual\ Energy\ Savings = 52,385.10 kWh / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (52,385.10 kWh / yr)(\$0.10 / kWh)$$

$$Annual\ Cost\ Savings = \$5,238 / yr$$

Operation and Maintenance – Persistence

Site personnel should conduct an initial motor assessment as described above. Once the results of the analysis are developed, the site should then determine an appropriate procedure for replacing or rewinding existing motors and set up a system to trend motor life and performance. This will provide information on actual motor life in relation to their expected or rated life. If the motors are continuously failing prematurely, then the site should hire a specialist to diagnose the problem.

It should be noted that the recommendations presented here are generalized, and licensed professionals should be contacted for the analysis specification of motors used in building HVAC fan systems. Finally, in electric motor systems with variable loads, VFD motors are another option that often proves economic and should be considered in retrofit opportunities.

Electric Motors Rules of Thumb

Table 12 illustrates the savings from using NEMA Premium motors versus EPAct energy-efficient motors (DOE 2005). It should be noted that the savings shown in the table are the difference between an *energy-efficient* motor and a *NEMA premium-efficiency* motor; the savings would be greater comparing a standard efficiency motor with either of the above.

Table 12. Annual Savings from Specifying NEMA Premium Motors

Horsepower (hp)	Full-Load Motor Efficiency (%)		Annual Savings from Use of a NEMA Premium Motor	
	Energy-Efficient Motor	NEMA Premium Efficient Motor	Annual Energy Savings, kWh	Dollar Savings ($/yr)
10	89.5	91.7	1,200	60
25	92.4	93.6	1,553	78
50	93.0	94.5	3,820	191
100	94.5	95.4	4,470	223
200	95.0	96.2	11,755	588

"Based on purchase of a 1,800 rpm totally enclosed fan-cooled motor with 8,000 hours per year of operation, 75% load, and an electric rate of $0.05/kWh" (DOE 2005).

Electric Motors Operations and Maintenance Checklist (Sullivan et al. 2004)

Description	Comments	Maintenance Frequency			
		Daily	Weekly	Monthly	Annually
Motor use/sequencing	Turn off/sequence unnecessary motors	X			
Overall visual inspection	Complete overall visual inspection to be sure all equipment is operating and safety systems are in place	X			
Motor condition	Check the condition of the motor through temperature or vibration analysis and compare to baseline values		X		
Check lubrication	Assure that all bearings are lubricated per the manufacturer's recommendation			X	
Check packing	Check packing for wear and repack as necessary. Consider replacing packing with mechanical seals.			X	
Motor alignment	Aligning the motor coupling allows for efficient torque transfer to the pump			X	
Check mountings	Check and secure all motor mountings			X	
Check terminal tightness	Tighten connection terminals as necessary			X	
Cleaning	Remove dust and dirt from motor to facilitate cooling			X	
Check bearings	Inspect bearings and drive belts for wear. Adjust, repair, or replace as necessary.				X
Motor condition	Checking the condition of the motor through temperature or vibration analysis helps assure long life				X
Check for balanced three-phase power	Unbalanced power can shorten the motor life through excessive heat buildup				X
Check for over-voltage or under-voltage conditions	Over- or under-voltage situations can shorten the motor life through excessive heat buildup				X

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Opportunity #9: Lighting and Lighting System Control

Introduction

Recent studies reveal that over 20% of the nation's electricity consumption is related to various types of lighting products and systems. Advanced energy saving technologies are readily available to reduce both the connected load and energy consumption, but are only effective if they are properly installed, calibrated, and maintained. Improvements in lighting efficiencies are so rapid that it can be cost-effective to implement upgrades, retrofits, or redesigns to lighting systems that are less than 5 years old.

Typical Energy Impacts

According to the *2006 Buildings Energy Data Book,* lighting energy use in commercial buildings is estimated as 23% of a commercial building's total energy use (DOE 2006). This is an average for all building types, measured on a Btu/ft^2 basis. This large percentage of energy use highlights the need to maintain and reduce lighting system energy consumption.

Potential Savings

Significant improvements in energy efficiency can be made by implementing currently available and cost-effective lighting technologies. Numerous studies highlight energy and cost savings of 20% to 50% realized through the proper application of lighting technologies.

Operational/Energy Efficiency Measures

This section is structured differently than the other sections in this report. Due to the large variety of lighting system types and configurations, there a countless number of retrofit options and considerations that needs to be addressed at DoD/Army facilities. Thus, this section develops some of the fundamental relationships between lights, ballasts, fixtures, controls, and their interaction with the building as a whole. It also develops specific recommendations relating to lighting maintenance and considerations for retrofit versus redesign options. This information can then be used to determine if certain lighting retrofits are appropriate for a given application or facility. The energy savings calculations are very straightforward for lighting and will be developed in a generalized manner, so that they can be applied to any lighting retrofit.

Lighting Measure #1: High-Efficiency Lamps

A lighting system consists of light sources, the ballasts or other devices that regulate the power that drives electric lights, the luminaire housing with components that hold the sources and direct and shield the light, and lighting controls that manipulate the time or intensity of lighting systems.

Natural light sources include the sun and daylight (light from the sky). The electric light sources most common to DoD/Army buildings include incandescent/halogen, fluorescent, high intensity discharge, and light emitting diodes. Characteristics common to light sources include their output, efficiency, life, color, and distribution.

The lamp is the source of electric light, the device that converts electric power into visible light. Selecting the lamp types is at the heart of a high-quality lighting plan, and central to visual performance, energy conservation, and the appearance of a space. Various light sources have different characteristics, but the basic performance principles include the following:

- Lumen output – the amount of light emitted by a lamp
- Efficacy – the efficiency of lamps in producing light, measured in lumens of light per watt of energy
- Rated lamp life – expected lamp life typically reported in hours
- Lamp lumen depreciation – the loss of light output over time, usually reported as a percentage
- Color temperature (CCT) and color rendering (CRI) – a numerical value related to the appearance of the light and the objects illuminated.

Opportunity Identification

In identifying lighting opportunities, it is critical to fully understand existing lighting type, age, and control. Presented below are the characteristics of the most common lamp types found across the DoD/Army sector.

Fluorescent Lamps. Fluorescent lamps generate their light by using electricity to excite a conductive vapor of mercury and an inert gas. The resultant ultraviolet light strikes a phosphor coating on the inside of the tube, causing it to glow. The elements used in the phosphor coating control the lamp's color.

T12 lamps are linear fluorescent lamps with a 1-1/2 inch diameter (12/8 of an inch). They are now considered obsolete for most new applications. These were the standard fluorescent lamps until T8 lamps came on the market in the 1980s.

T8 lamps are linear fluorescent lamps with a 1 inch diameter (8/8 of an inch). These are the workhorse of the commercial lighting industry and have become the standard for offices and general applications. Since they are 22% more efficient than T12s, it is generally always cost-effective to retrofit or replace fixtures that use T12 lamps in existing applications even before the existing T12 lamps burn out.

High performance T8 lamps provide higher efficacy, higher maintained lumens, and are available in extended life versions with a 20% increase in lamp life. Premium T8s have a higher initial cost, but the increased energy efficiency and life make them the recommended light source for most commercial fluorescent installations including federal projects.

T5 lamps are linear fluorescent lamps with a diameter of 5/8 of an inch. These cannot replace T8 lamps because they have different characteristics and different lengths (metric), socket configurations and ballasts. T5s are smaller lamps than T8s, but have similar efficacy (lumens per watts). Their smaller diameter allows for shallower fixtures and greater reflector control, but also increases the brightness, limiting their use to heavily shielded or indirect fixtures.

T5HO (high output) are T5 lamps with approximately the same maintained lumens as two standard T8 lamps but less efficient, with about 7% to 10% fewer lumens per watt. This development allows the designer to potentially reduce the number of fixtures, lamps, and ballasts in an application, making it less expensive to maintain. However, the intense brightness of T5HOs limits their use to primarily indirect luminaries to avoid glare. Also, using one-lamp rather than two-lamp luminaries eliminates the potential for two-level switching. Analysis is required to demonstrate the benefits of using T5HO lamps to offset their lower efficacy and higher cost.

Compact fluorescent lamps (CFLs) are fluorescent lamps with a single base and bent-tube construction. Originally designed for the retrofitting of standard incandescents, the first CFLs had a screw-type base. While screw base lamps are still available, commercial applications typically use lamps with a 4-pin base. This prevents the future replacement of a screw-based CFL with a much less efficient incandescent lamp. CFL lamps have a wide range of sizes and attractive colors, and can be used in most federal applications that formerly used incandescent.

High Intensity Discharge (HID). High intensity discharge lamps also use a gas-filled tube to generate light, but use an arc current and vaporized metals at relatively high temperatures and pressures. There are two main types in current use – metal halide (MH) and high-pressure sodium (HPS) – and their characteristics are determined by the gas. MH provides a white light with a CRI of 65 to 95, while HPS emits a yellowish light with a CRI of 22 to 65. Historically, HID lamps were relegated to outdoor or service areas, but advances in color, configurations, and efficacy have made them more attractive for commercial and interior use.

Electrodeless Lamps (also called induction lamps). Electrodeless lamps (also called induction lamps) most commonly use radio frequency to ionize mercury vapor at low pressures, resulting in exciting the phosphors inside the envelope to create a glow, similar to fluorescent technology.

Incandescent/Halogen Lamps. Incandescent/halogen lamps generate their light by heating a tungsten filament until it glows, in the presence of an inert gas such as argon or nitrogen. A halogen lamp is a form of incandescent lamp that introduces traces of halogen gas and a quartz envelope to burn hotter and prolong the filament life. Consequently, they are whiter (3,000K rather than 2,700K) and are slightly more energy efficient than a standard incandescent. Halogen should be used in lieu of standard incandescent, and low voltage should be considered for the tighter, more focused beam. However, whenever possible, the use of more efficient CFL or ceramic metal halide sources should be explored. Since incandescent/halogen lamp types are very inefficient (roughly five times less efficient than fluorescent), they should be used sparingly, or the project will not meet the energy code. See the suggested uses below.

Diagnostic Equipment

Generally, the diagnostics of lamps involves the evaluation of the basic characteristics of lighting including the quality and quantity of light, the equipment types, efficiency, condition, and cleanliness. For some of these characteristics, visual inspection and physical testing is appropriate and requires no special tools. For others, some basic tools can be helpful.

Illuminance (light) Meter. Illuminance meters are often referred to as a “light meters.” Illuminance meters come in many forms but all perform the same basic function, they record the light level in lumens or foot-candles. Light levels should be taken at the spaces where the specific tasks are to be performed such as desktops for office work, hallway floors for egress, etc.

As lamps age, light levels will change over time. However, with modern equipment this is a relatively slight effect and is not typically considered a metric used to make changes to equipment or replace lamps. The most important measurement of light levels is an evaluation when systems are initially installed, equipment changes are made, or an O&M program is initiated. Light levels that are higher than necessary to provide appropriate lighting or higher than designed are an opportunity for energy savings as light level and kWh usage are directly related.

The required light levels (illuminance) for building areas will depend on the expected tasks. The widely accepted and referenced quality and illuminance recommendations are developed by the Illuminating Engineering Society of North America (IESNA), and can be found in Chapter 10 of the IESNA Handbook, Ninth Edition. The building tenants or other regulatory organizations may also have specific requirements for the activities to be performed in the building.

High-Efficiency Lamp Energy Savings and Economics

The energy saving calculations developed below assume the facility has a standard electric rate structure; with an electric rate ($/kWh) and a peak demand charge ($/kW). If the site has an electric rate that varies by season, or is based on time-of-day rates, then the Energy and Facility Manager should consider the use of the following tool to estimate energy savings: US DOE – Building Life Cycle Cost (BLCC5) tool. This tool is used for advanced economic analysis and can be downloaded from the following website: http://www1.eere.energy.gov/femp/information/download_blcc.html

If the current electric rate ($/kWh) has little variance throughout the year, then an average, conservative, rate should be chosen and used in the equations presented below. The peak demand charge is billed as the highest kW reading recorded on the electric meter for a given month. Thus, if the lighting system has a schedule coincident with the peak demand, then the retrofit options will offer a reduction in peak demand costs. Again, if the peak demand charge ($/kW) changes throughout the year, then an average, conservative, demand charge should be chosen.

The first energy savings calculation is developed to display the energy savings associated with installing more efficient lamps. Lighting retrofit activities may fall into one or more of the following categories.

De-Lamping and Reduced Wattage

- Replace lamps with lower-wattage options in over-lit spaces
- De-lamp fixtures in over-lit spaces
- Implement reflectors to concentrate light and replace existing lamps with lower-wattage options

Retrofit Options

- Replace incandescent lamps with lower-wattage CFLs
- Replace mercury vapor lamps and ballasts with HPS or MH lamps and ballasts
- Replace T-12 lamps and magnetic ballasts with T8 lamps and low-power electronic ballasts

- Replace T-12 lamps and magnetic ballasts with Super T8 lamps and low-power electronic ballasts
- Install occupancy sensors in hallways, meeting rooms, etc. (All sporadically occupied spaces.)
- Install day-lighting controls in rooms with sufficient natural lighting
- Install photocells on exterior lights

Note: This is a generalized list of recommendations and is not intended to be a comprehensive list. Also, experienced lighting professionals should be contacted to for particular lighting retrofits.

Estimated Annual Energy Savings. The annual energy savings that could be realized by installing more efficient lamps can be estimated as follows:

$$Annual\ Energy\ Savings = N \times \frac{(RPL_1 - RPL_2)}{1,000} \times H$$

where N = number of lamps, no units
RPL_1 = rated power of the current lamp, watts
RPL_2 = rated power of the new lamp, watts
H = annual hours of operation, hours

Estimated Annual Cost Savings. The annual cost savings that could be realized by installing more efficient lamps can be estimated as follows:

$$Annual\ Cost\ Savings = (AES \times ER) + \left[\frac{(RPL_1 - RPL_2)}{1,000} \times N \times PD\right]$$

where ER = average annual electricity rate, \$/kWh
PD = average annual peak demand charge, \$/kW

It should be noted that this cost savings calculation does not account for a peak demand reduction. If the lights have an operational schedule that is coincident with the peak demand that is set each month, then the peak demand savings should be added to this cost savings calculation.

Lamp Replacement Energy Savings and Economics Example

Example Synopsis

A facility has 100 incandescent bulbs, rated at 100 watts, which operate 4,000 hrs/yr. The facility has chosen to replace the lamps with compact fluorescent lamps, which are rated at 26 watts. The electrical rate is approximately \$0.10/kWh.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = 100 \times \frac{(100 - 26)}{1,000} \times 4,000$$

$$Annual\ Energy\ Savings = 29,600 kWh / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = (29,600 kWh/yr)(\$0.10/kWh)$$

$$Annual\ Cost\ Savings = \$2,960/yr$$

Lighting Measure #2: Lighting Control Devices

There is seldom just one way to accomplish the desired control of lighting, and a variety of equipment is available to the lighting designer. A comprehensive strategy uses several of these control devices in concert, responding to project-specific usage patterns:

- Manual controls
  - Switches and switching patterns
  - Manual dimmers
- Automatic controls
  - Occupancy sensors
  - Daylight sensors
  - Pre-set controls
  - Time controls
  - Centralized control management

Manual Controls. Manual controls allow the users to select the lighting levels best suited to their immediate needs. Task lights located in workstations should have manual controls. Spaces with variable activities, such as training rooms, multi-purpose rooms, or conference centers generally require manual controls to enable the users to tailor the light for each different activity. Allowing the users to select a "pre-set" lighting scene will generally reduce consumption. With manual controls, occupancy satisfaction is achieved, but the reduction in energy use is unpredictable since it requires individuals to turn off their lights. For effective use, the controls need to be intuitive and labeled. Note that even with manual controls, the energy standard still requires automatic shutoff when spaces are not occupied.

Switches. Switching strategies can be used in combinations to offer multiple levels of illumination and multiple mixes of available light sources. In its simplest application, open work areas can have several zones of luminaires, so partially occupied rooms do not need to burn all the lights. Three-way switches are typically used in multi-entry and multi-zoned rooms to facilitate people moving from zone to zone. Automatic switches (or sentry-type switches that reset to the off position) are appropriate for use with manual-on/automatic-off occupancy sensors. Another strategy is bi-level switching – two (or more) light levels within a space can be attained with multi-lamp luminaires, factory pre-wired for easy connection to separate switches, which allows one lamp in each fixture to be turned off, effectively "dimming" the lights. When several light sources – e.g., overhead luminaries, wall washers, down lights – are present, each type should be switched separately.

Manual Dimmers. Manual dimming is most useful to respond to specific user needs – dimming the conference room lights for AV presentations, raising the light level for the cleaning crew, changing the mood in a cultural space. Manual dimmers can be wall box sliders or hand-held remote controls. Both incandescent and fluorescent light sources are dimmable, and both use less energy when dimmed, although the energy saved is not always proportional to the decrease in light. Incandescent lamps can be readily dimmed, but fluorescents need specialized electronic dimming ballasts.

Automatic Controls. Automatic controls provide benefits in user comfort and energy conservation. Automatic controls can deliver reliable energy savings without occupant participation, and when well designed, without their notice. In addition, they can make adjustments to light levels throughout the day, or in response to specific needs. For safety reasons, lighting controls should be specified to default to full-on when control equipment fails. Recommissioning is valuable for determining that all the controls operate and save energy as intended.

Occupancy Sensors. Occupancy sensors turn off the lights when they detect that no occupants are present. The occupancy sensor includes a motion sensor, a control unit, and a relay for switching the lights. The sensor and control unit are connected to the luminaire by low voltage wiring, with a transformer stepping down the current. There are three commonly used types of occupancy sensors, defined by how they detect motion: ultrasonic, passive infrared, and dual-technology.

Daylight Controls. Daylight controls are photoelectric devices that turn off or dim the lights in response to the natural illumination available. Depending on the availability of daylight, the hours of operation, and the space function, photoelectrically controlled lighting can save 10% to 60% of a building's lighting energy. This can translate into even more savings since daylight availability coincides with the hours of the day when peak demand charges apply.

Smooth and continuous dimming is the preferred strategy for automated day-lighting controls in offices or other work areas, since it is not distracting to the workers. The photosensor adjusts the light level based on the amount of natural light sensed by sending a signal to the dimming ballast. The less expensive dimming ballasts with minimum settings of 20% of full output are appropriate for daylight dimming (EPRI 1997). The two strategies – "closed-loop" and "open loop" – are based on photo-sensor locations, and the correct sensor location is essential. In a "closed loop" system, the sensor is located above a horizontal surface to detect the light reflecting off that surface from both electric and daylight sources. Since the sensor is reading reflected light, the reflective characteristics of the surface should remain constant. Consequently, sensors are located over a circulation area, rather than a workstation where the reflectivity of the worker's clothes or desktop contents might change. In an "open-loop" system, the sensor is located near the window in such a way to only detect daylight. In both systems, the sensor must not pick up the direct illumination from the electric lights. Sensors can control more than one dimming ballast but the luminaires being controlled must all have a similar orientation to the natural light. For example, trees in front of several windows define a separate lighting "zone." Time-delay settings are used to slow down the response to rapid changes in natural lighting conditions, providing more steady lighting.

Switching the lights off when sufficient natural lighting is present is a less expensive strategy, but not as acceptable to the occupants. This approach is most commonly found in outdoor applications – controlling parking lot lighting for example. In buildings, a stepped approach to daylight switching is sometimes employed, in which only some lamps are switched off in multi-lamp luminaires. Alternately, daylight switching is used in rooms where continuous occupancy is not common, such as corridors, cafeterias, atria, or copy rooms.

Pre-Set Controls. Switching, dimming, or a combination of the two functions can be automatically preprogrammed so that the user can select an appropriate lighting environment ("scene") at the touch of a button. Each scene uses a different combination of the luminaires in the room (sometimes dimmed) to provide the most appropriate light for one of several planned activities in that room. A “pre-set controller” and wiring plan organizes this. For example, the occupant of a conference room could select one pre-set scene from a five-button “scene selector” wall-mounted in the room, labeled “Conference,” “Presentation,” “Slide Viewing,” “Cleaning,” and “Off.” This allows multiple lighting systems to be installed to meet the varying needs of separate activities, but prevents them from all being used at full intensity for every activity. A pre-set scene should be included for the cleaning crew, which should use the most energy-efficient lights that will allow them to do their work.

Time Clocks. Time clocks are devices that can be programmed to turn lights on or off at designated times. These are a useful alternative to photoelectric sensors in applications with very predictable usage, such as in parking lots. Simple timers are another option, turning the lights on for a specified period of time, although there are limited applications where this is appropriate, e.g., library stacks. A time-controlled “sweep” strategy is sometimes effective. After normal hours of occupancy, most of the lighting is turned off (swept off), but if any occupants remain, then they can override the command in just their space. Override controls can be wall switches located within the space or be activated by telephone or computer. These systems typically flash the lights prior to turnoff, to give any remaining occupants ample time to take action. There is usually more than one sweep operation scheduled after hours until all lights are turned off.

Centralized Control/Management. Automated Building Management Systems (BMS) are becoming more common in medium- and large-sized facilities to control HVAC, electrical, water, and fire systems. Incorporating lighting controls is a natural step in efficient management, and centralized lighting control systems are available that can interface with building maintenance systems while providing data on lighting operation. However, in some cases, centralized systems are not appropriate for some functions, such as managing the dimming controls. The technological advance that may change this is DALI (digital addressable lighting interface), a communication protocol that allows an entire lighting system to be managed with computer software. This is promising for situations that require sophisticated control and flexibility for lighting reconfiguration. The DALI system is being designed based on an international standard so that various system components are compatible.

Energy Savings and Economics

The energy savings and economics below will develop ways to maintain performance and improve system efficiency through planned maintenance, retrofit, and redesign.

Diagnostic Equipment

Generally, the diagnostics of lighting systems involves the evaluation of the basic characteristics of lighting:

- Quality and quantity of light.
- Equipment types and efficiency, condition, and cleanliness.
- Control condition/settings.
- Energy usage.

For some of these characteristics, visual inspection and physical testing is appropriate and requires no special tools. For others, some basic tools can be helpful.

Illuminance (light) Meter. Illuminance meters are often referred to as a “light meters.” Illuminance meters come in many forms but all perform the same basic function, they record the light level in lumens or foot-candles. Light levels should be taken at the spaces where the specific tasks are to be performed such as desktops for office work, hallway floors for egress, etc.

Light levels will change over time as lamps age. However, with modern equipment this is a relatively slight effect and is not typically considered a metric used to make changes to equipment or replace lamps. The most important measurement of light levels is an evaluation when systems are initially installed, equipment changes are made, or an O&M program is initiated. Light levels that are higher than necessary to provide appropriate lighting or higher than designed are an opportunity for energy savings, as light level and kWh usage are directly related.

The required light levels (illuminance) for building areas will depend on the expected tasks. The widely accepted and referenced quality and illuminance recommendations are developed by the Illuminating Engineering Society of North America (IESNA), and can be found in Chapter 10 of the IESNA Handbook, Ninth Edition. The building tenants or other regulatory organizations may also have specific requirements for the activities to be performed in the building.

Energy/Lighting/Occupancy Loggers. Lighting loggers can be installed that measure lighting on/off schedules for long periods of time with the capability to download the data to any computer for analysis. This kind of data can identify areas where lighting is left on after hours. Similar occupancy-based loggers can specifically identify lighting that remains on when spaces are unoccupied. This information can be used to identify overlit spaces as well as good applications for occupancy sensor controls. These loggers are available from a variety of sources. These can be found on the world-wide web or in the report, *Portable Data Loggers Diagnostic Tools for Energy-Efficient Building Operations* (PECI 1999).

Flicker Checker. For hard-to-reach areas (high ceilings), it is often difficult to determine the type of lighting installed (electronic, magnetic ballast). There is a simple tool available to help determine the characteristics of ballast type (and therefore often lamp type) installed. A common version of this tool is a “flicker checker” used to determine electronic versus electromagnetic ballasts. It operates like a simple toy top and will indicate whether the operating ballast above is a 60 Hz type or electronic high-frequency type. Typically, the 60 Hz type will be operating T12 technology lamps. The high frequency may be operating T12 or T8 technology.

Solar Data. When considering the application of daylighting into building spaces, it is important to understand the potential of the building space and the capability of the sun in your area to provide adequate daylight. This involves evaluating the tasks in the space, characterizing the configuration of the space including size and shape of windows or skylights, and assessment of the solar availability in your location. Solar availability data is maintained by the National Oceanographic and Atmospheric Association (NOAA) at www.noaa.gov. Available data includes number of hours of sunshine, number of clear, overcast, and partially cloudy days in a number of cities across the United States based on weather charts. Exterior illumination of sun and daylight can be found for any U.S. latitude through the IESNA daylight availability publication or the ASHRAE handbook. Sun angles can be determined by the Pilkington LOF Sun Angle Calculator, available from www.sbse.org/resources/sac/.

The third energy savings calculation is developed to display the energy savings associated with installing occupancy sensors.

Estimated Annual Energy Savings. The annual energy savings that could be realized by installing occupancy sensors can be estimated as follows:

$$Annual\ Energy\ Savings = N \times F \times \frac{RPF}{1,000}(H_1 - H_2)$$

where	N	=	number of rooms, no units
	F	=	number of fixtures per room, no units
	RPF	=	rated input power per fixture, watts/fixture
	H_1	=	current annual hours of operation, hours
	H_2	=	control-based -annual hours of operation, hours

It should be noted that this calculation requires onsite personnel calculate or estimate the amount of time the lights will operate at the new setting, in relation to the amount of time they operate at the current setting.

Estimated Annual Cost Savings. The annual cost savings that could be realized by installing new occupancy sensors can be estimated as follows:

$$Annual\ Cost\ Savings = \left(AES \times ER\right)$$

where	ER	=	average annual electricity rate, \$/kWh

Lamp Replacement Energy Savings and Economics Example

Example Synopsis

A facility has chosen to install occupancy sensors in 15 conference rooms. Each room has 10 lighting fixtures, with a rated input power per fixture of 150 watts/fixture. The conference rooms are currently illuminated 4,000 hrs/yr. With the new occupancy sensors, the rooms are expected to be illuminated 1,000 hrs/yr. The electrical rate is approximately $0.10/kWh.

The annual energy savings can be estimated as:

$$Annual\ Energy\ Savings = 15 \times 10 \times \frac{150}{1,000}(4,000 - 1,000)$$

$$Annual\ Energy\ Savings = 67,500 kWh / yr$$

The annual cost savings can be estimated as:

$$Annual\ Cost\ Savings = \left(67,500 kWh / yr\right)\left(\$0.10 / kWh\right)$$

$$Annual\ Cost\ Savings = \$6,750 / yr$$

Lighting Operations and Maintenance Checklist (Sullivan et al. 2004)

Description	Comments	Maintenance Frequency
Visual inspection	Inspect fixtures to identify inoperable or faulty lamps or ballasts. Burned out lamps may damage ballasts if not replaced.	Weekly to monthly
Visual inspection	Inspect fixtures and controls to identify excessive dirt, degrades lenses, inoperable or ineffective controls.	Semi-annually
Clean lamps and fixtures	Lamps and fixture reflective surfaces should be cleaned periodically for maximum efficient delivery of light to the space	6 to 30 months, depending on space and luminaire type
Clean walls and ceilings	Clean surfaces allow maximum distribution of light within the space	1 to 3 years, depending on dirtiness of environment
Replace degraded lenses or louvers	Replace yellowed, stained, or broken lenses or louvers	As identified
Repaint walls and replace ceilings	Lighter colored surfaces will increase light distribution efficiency within the space	As identified or at tenant change
Replace burned out lamps	For larger facilities consider group relamping	As needed or on group schedule
Evaluate lamps and ballasts for potential upgrade	Rapid change in technology may result in significant savings through relamping or simple retrofit.	Every five years or on group relamping schedule
Survey lighting use/illumination levels	Measure light levels compared to tasks needs in typical spaces. Identify areas for reduction or increase in illuminance	Initially and at task/tenant change
Survey for daylighting capability	Identify areas where daylighting controls could be used	One-time analysis or at tenant change
Survey for local controls capability	Identify areas where local automatic controls could be used	Initially and at tasks/tenant change

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Opportunity #10: Project Implementation

Introduction

Well-planned and implemented O&M projects can lead to some of the quickest returns-on-investment of any energy-related project; in fact, it is not unusual to have O&M projects show simple paybacks measured in days rather than years. As previously mentioned, O&M projects should be considered the first energy conservation measure for the following reasons:

- O&M measures are usually low cost/no cost in nature.
- O&M measures can often be affected or completed using in-house staff.
- O&M measures result in some of the quickest economic paybacks of any activity.
- O&M measures are usually quick to complete and rarely require the design and bid activities necessary for capital-related projects.

Implementation

Developing or enhancing an O&M program requires patience and persistence. Guidelines for enhancing an O&M program and implementing projects will vary from site-to-site; however, some steps to consider are presented below.

Step 1: Identifying the Opportunities. Whether you use the information in this document or not, opportunity identification is a critical first step. Beyond this report there are many resources available to the federal sector and the DoD to assist with opportunity identification – the Federal Energy Management Program (FEMP) website (http://www1.eere.energy.gov/femp/) is an excellent place to start. The key to this step is to identify multiple opportunities to pursue as part of a larger action plan.

Step 2: Developing an Action Plan. Subsequent to opportunity identification is the exercise of opportunity assessment, prioritization, and selection. The output of Step 1 should be multiple opportunities – some of these may be mutually exclusive, others not. Whichever the case, the action plan should take all the identified opportunities, screen them for appropriateness, prioritize the remaining opportunities, and develop an implementation time-line. The action plan should also address opportunities for partnerships for project implementation and the economics and finance paths to be considered.

Step 3: Feasibility and Project Blueprint. This step is focused on the economic and technical details of the opportunities. It usually includes estimates on energy and resource savings and the associated costs to make the final go/no-go decisions. Where applicable, life-cycle costs analysis is recommended. Because many O&M projects are low-cost/no-cost, this step may be more focused on the scheduling of system outages, staff time, and necessary changes to procedural documents.

Step 4: Implementation, Evaluation, and Verification. Once identified, planned, and validated, project implementation comes next. For typical O&M projects, this requires coordination with building managers and occupants and may require service outages and other disconnections. Once implemented, the project moves to the evaluation and verification phase, making use of pre-defined evaluation protocols aimed at opportunity function and verified performance. Elements of this step should be ongoing over the life of the project as a means of continued performance and savings persistence.

Step 5: Project Highlighting and Recognition. By nature, O&M programs operate behind-the-scenes and their visibility is usually tied to calls for service or other “complaint-related” events. The paradigm of O&M’s association with only “problems” and not “successes” needs to change. These programs need to focus on the day-to-day successes that often go unrecognized – this requires good tracking and trending of savings and expense as well as accurate accounting of utility use. To be sustainable, an O&M program must be visible beyond the O&M management. Persistence in facilitating the OMETA linkages and relationships enables heightened visibility of the O&M program within other organizations. A healthy O&M program is growing in responsibility, capability, and accomplishment. O&M management must be vigilant in highlighting the capabilities and accomplishments of their O&M staff. The most successful O&M programs are those that are visible throughout the entire organization.

This five-step process should be considered an ongoing effort with new projects always being identified and moving through the process.

Chapter 5 Conclusions and Next Steps

The goal of this report is to provide the Operations and Maintenance (O&M)/Energy manager and practitioner with useful information about the top O&M opportunities consistently found across the DoD/Army sector. This work was based on numerous O&M and energy audits of DoD/Army facilities completed as part of the U.S. Department of Energy's Assessment of Load and Energy Reduction Techniques (ALERT) and Energy Savings Expert Team (ESET) programs, as well as the Federal Energy Management Program's O&M Best Practices Guide, referenced throughout this report.

It should be reiterated that while this report was designed to provide information on effective O&M as it applies to systems and equipment typically found at DoD/Army facilities, the report was not designed to provide the reader with step-by-step procedures for performing O&M on any specific piece of equipment. This report first directs the reader to the manufacturer's specifications and recommendations for O&M specific to their equipment. The recommendations in this report are designed to supplement those of the manufacturer, or, as is all too often the case, provide guidance for systems and equipment for which all technical documentation has been lost. Actions and activities recommended in this guide should only be attempted by trained and qualified personnel. If such personnel are not available, then the actions recommended in this report should not be initiated.

As presented, the persistence mechanism of any efficiency program starts with good O&M. Having a well-structured and organized O&M program is critical to the program sustainability, success, and achieving of operational efficiency. If there were only one O&M opportunity a site could adopt, then the authors of this document would recommend the development of a well-structured O&M organization. Once developed, this organization can begin all the recommended actions and activities within this and other documents. It has been our experience that without a well-developed and functioning O&M organization, all other elements of efficiency and action will be short-lived and unsustaining.

The second critical element of operational efficiency is an understanding of energy and resource use by equipment and systems; thus the need for good metering, monitoring and trending. Without information, the facility/energy manager has little insight to operations, performance, or efficiency.

Given these first two elements, a working O&M structure and a method of assessing performance via metering and trending, a facility/energy manager can begin to prioritize systems and equipment (e.g., boilers, chillers, HVAC, motors) for conditional assessment, predictive/preventive/corrective action, and ultimately achieving operational efficiency.

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Appendix A

Glossary of Common Terms

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Appendix A

Glossary of Common Terms

Absorption chiller – A refrigeration machine using heat as the power input to generate chilled water.

Adjustable-speed drive – A means of changing the speed of a motor in a step-less manner. In the case of an AC motor, this is accomplished by varying the frequency.

Aerator – A device installed in a faucet or showerhead that adds air to the water flow, thereby maintaining an effective water spray while reducing overall water consumption.

Air changes – Replacement of the total volume of air in a room over a period of time (e.g., 6 air changes per hour).

Ambient temperature – The temperature of the air surrounding an object.

Ballast – A device used to supply the proper voltage and limit the current to operate one or more fluorescent or high-intensity discharge lamps.

Base – A selected period of time with consumption levels or dollar amounts, to which all future usage or costs are compared.

Blackwater – Water discharged from toilets, urinals, and kitchen sinks.

BLCC – Building Life Cycle Costing.

Blowdown – The discharge of water from a boiler or a cooling tower sump that contains a high proportion of total dissolved solids.

British thermal unit (Btu) – The amount of heat required to raise the temperature of one pound of water 1 degree Fahrenheit at or near 39.2 degrees Fahrenheit.

Building commissioning – A systematic process of assuring that a building facility performs in accordance with design intent and the owner's operational needs. Verification and documentation that all building facility systems perform interactively in an efficient manner and that operations and maintenance personnel are well trained.

Building envelope – The exterior surfaces of a building that are exposed to the weather, i.e., walls, roof, windows, doors, etc.

Celsius (Centigrade) – The temperature at which the freezing point of water is 0 degrees and the boiling point is 100 degrees at sea level.

Centrifugal fan – A device for propelling air by centrifugal action.

cfm – Cubic feet per minute usually refers to the volume of air being moved through an air duct.

Chiller – A refrigeration machine using mechanical energy input to drive a centrifugal compressor to generate chilled water.

Coefficient of performance – Ratio of tons of refrigeration produced to energy required to operate equipment.

Coefficient of utilization – Ratio of lumens on the work surface to total lumens emitted by the lamps.

Cold deck – A cold air chamber forming a part of an air conditioning system.

Combined wastewater – A facility's total wastewater, both graywater and blackwater.

Color rendering index (CRI) – The color appearance of an object under a light source as compared to a reference source.

Condensate – Water obtained by charging the state of water vapor (i.e., steam or moisture in air) from a gas to a liquid, usually by cooling.

Condenser – A heat exchanger that removes heat from vapor, changing it to its liquid state. In refrigeration systems, this is the component that rejects heat.

Conduction – Method of heat transfer in which heat moves through a solid.

Convection – Method of heat transfer in which heat moves by motion of a fluid or gas, usually air.

Cooling tower – A device that cools water directly by evaporation.

Damper – A device used to limit the volume of air passing through an air outlet, inlet, or duct.

Degree days – The degree day for any given day is the difference between 65 degrees and the average daily temperature. For example, if the average temperature is 50 degrees, then the degree days is 65 – 50 = 15 degrees days. When accumulated for a season, degree days measure the severity of the entire season.

Demand load – The maximum continuous requirement for electricity measured during a specified amount of time, usually 15 minutes.

Demand factor – The ratio of the maximum demand of a system to the total connected load on the system.

Double bundle chiller – A condenser usually in a refrigeration machine that contains two separate tube bundles allowing the option of rejecting heat to the cooling tower or to another building system requiring heat input.

Dry bulb temperature – The measure of the sensible temperature of air.

Economizer cycle – A method of operating a ventilation system to reduce refrigeration load. Whenever the outside air conditions are more favorable (lower heat content) than return air conditions, outdoor air quantity is increased.

Efficacy – Ratio of usable light to energy input for a lighting fixture or system (lumens per watt)

Energy management system – A microprocessor-based system for controlling equipment and monitoring energy and other operating parameters in a building.

Energy requirement – The total yearly energy used by a building to maintain the selected inside design conditions under the dynamic impact of a typical year's climate. It includes raw fossil fuel consumed in the building and all electricity used for lighting and power. Efficiencies of utilization are applied and all energy is expressed in the common unit of Btu.

Energy utilization index – A reference that expresses the total energy (fossil fuel and electricity) used by a building in a given period (month, year) in terms of Btu's/gross conditioned square feet.

Enthalpy – The total heat content of air expressed in units of Btu/pound. It is the sum of the sensible and latent heat.

Evaporator – A heat exchanger in which a liquid evaporates while absorbing heat.

Evaporation – The act of water or other liquids dissipating or becoming vapor or steam.

Faucet aerator – Either a device inserted into a faucet head or a type of faucet head that reduces water flow by adding air to the water steam through a series of screens and/or small holes through a disk. An aerator produces a low-flow, non-splashing stream of water.

Flow restrictors – Washer-like disks that fit inside faucet or shower heads to restrict water flow.

Flushometer valve toilet – Also known as a pressure assisted or pressurized tank toilet, a toilet with the flush valve attached to a pressurized water supply tank. When activated, the flush valve supplies the water to the toilet at the higher flow rate necessary to flush all the waste through the toilet trap and into the sewer.

Foot candle – Illumination at a distance of one foot from a standard candle.

Gravity flush toilet – A toilet designed with a rubber stopper that releases stored water from the toilet's tank. Gravity flow water then fills the bowl and carries the waste out of the bowl, through the trap and into the sewer.

Graywater – Used water discharged by sinks, showers, bathtubs, clothes washing machines, and the like.

Gross square feet – The total number of square feet contained in a building envelope using the floors as area to be measured.

Heat gain – As applied to HVAC calculations, it is that amount of heat gained by space from all sources including people, lights, machines, sunshine, etc. The total heat gain represents the amount of heat that must be removed from a space to maintain indoor comfort conditions. This is usually expressed in Btu's per hour.

Heat loss – The heat loss from a building when the outdoor temperature is lower than the desired indoor temperature it represents the amount of heat that must be provided to a space to maintain indoor comfort conditions. This is usually expressed in Btu/hour.

Heat pump – A refrigeration machine possessing the capability of reversing the flow so that its output can be either heating or cooling. When used for heating, it extracts heat from a low-temperature source.

Heat transmission coefficient – Any one of a number of coefficients used in the calculation of heat transmission by conduction, convection, and radiation through various materials and structures.

Horsepower (hp) – British unit of power, 1 hp = 746 watts or 42,408 Btu's per minute.

Hot deck – A hot air chamber forming part of a multi-zone or dual duct air-handling unit.

Humidity, relative – A measurement indicating the moisture content of the air.

IAQ – Indoor Air Quality.

IEQ – Indoor Environmental Quality.

Infiltration – The process by which outdoor air leaks into a building by natural forces through cracks around doors and windows.

Latent heat – The quantity of heat required to effect a change in state of a substance.

Life-cycle cost – The cost of the equipment over its entire life including operating costs, maintenance costs, and initial cost.

Low flow toilet – A toilet that uses 3.5 gallons of water per flush.

Load profile – Time distribution of building heating, cooling, and electrical load.

Lumen – Unit of measurement of rate of light flow.

Luminaire – Light fixture designed to produce a specific effect.

Makeup – Water supplied to a system to replace that lost by blowdown, leakage, evaporation, etc. Air supplied to a system to provide for combustion and/or ventilation.

Modular – System arrangement whereby the demand for energy (heating, cooling) is met by a series of units sized to meet a portion of the load.

Orifice plate – Device inserted in a pipe or duct that causes a pressure drop across it. Depending on orifice size, it can be used to restrict flow or form part of a measuring device.

ORSAT apparatus – A device for measuring the combustion components of boiler or furnace flue gases.

Piggyback operation – Arrangement of chilled water generation equipment whereby exhaust steam from a steam turbine driven centrifugal chiller is used as the heat source of an absorption chiller.

Plenum – A large duct used as a distributor of air from a furnace.

Potable water – Clean, drinkable water; also known as "white" water.

Power factor – Relationship between kVA and kW. The power factor is one when the kVA equals the kW.

Pressurized tank toilet – A toilet that uses a facility's waterline pressure by pressurizing water held in a vessel within the tank; compressing a pocket of trapped air. The water releases at a force 500 times greater than a conventional gravity toilet.

Pressure reducing valve – A valve designed to reduce a facility's water consumption by lowering supply-line pressure.

Radiation – The transfer of heat from one body to another by heat waves without heating the air between them.

R Value – The resistance to heat flow of insulation.

Seasonal efficiency – Ratio of useful output to energy input for a piece of equipment over an entire heating or cooling season. It can be derived by integrating part load efficiencies against time.

Sensible heat – Heat that results in a temperature change, but no change in state.

Siphonic jet urinal – A urinal that automatically flushes when water, which flows continuously to its tank, reaches a specified preset level.

Source meter – A water meter that records the total waterflow into a facility.

Sub meter – A meter that record energy or water usage by a specific process, a specific part of a building, or a building within a larger facility.

Therm – A unit of gas fuel containing 100,000 Btu's.

Ton (of refrigeration) – A means of expressing cooling capacity: 1 ton = 12,000 Btu/hour cooling (removal of heat).

U Value – A coefficient expressing the thermal conductance of a composite structure in Btu's per (square foot) (hour) (degree Fahrenheit difference).

Ultra low flow toilet – A toilet that uses 1.6 gallons or less of water per flush.

Variable-speed drive – See "Adjustable-speed drive."

Variable-frequency drive – See "Adjustable-speed drive."

Veiling reflection – Reflection of light from a task or work surface into the viewer's eyes.

Vapor barrier – A moisture impervious layer designed to prevent moisture migration.

Wet bulb temperature – The lowest temperature attainable by evaporating water in the air without the addition or subtraction of energy.

Xeriscaping – The selection, placement, and care of water-conserving and low-water-demand ground covers, plants, shrubs, and trees in landscaping.

Appendix B

Resources and Backup Data

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Appendix B

Resources and Backup Data

The references and resources provided in this appendix are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided here for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

O&M Professional/Trade Associations

EFCOG
Energy Facility Contractors Group
http://www.efcog.org/

International Maintenance Institute (IMI)
http://www.imionline.org

Society for Maintenance & Reliability Professionals (SMRP)
Operates an emailing/discussion function. Anyone can join by simply sending an email message with the word SUBSCRIBE in the body of the message to: network - request@mailserv.tenagra.com
http://www.smrp.org/

Washington Association of Maintenance and Operations Administrators (WAMOA)
Educational Facilities Maintenance Professionals in Washington State
Contact Kathy Vega, Seattle Regional Support Office

World Federation of Building Service Contractors
Fairfax, VA
(703) 359-7090

Organizations with Some O&M Interests

American Society of Mechanical Engineers (ASME)
Founded in 1880, today ASME International is a nonprofit educational and technical organization serving a world-wide membership of 125,000 and conducts one of the world's largest technical publishing operations, holds some 30 technical conferences and 200 professional development courses each year, and sets many industrial and manufacturing standards. The work of ASME is performed by its member-elected Board of Governors and through its 5 councils, 44 boards, and hundreds of committees in 13 regions throughout the world. There are a combined 400 sections and student sections serving ASME's world-wide membership. ASME's vision is to be the premier organization for promoting the art, science, and practice of mechanical engineering throughout the world.
http://www.asme.org/

Association for Facilities Engineering (AFE)
Formerly the American Institute of Plant Engineers. AFE Facilities Engineering Journal
http://www.afe.org/journal.html

Association for Facilities Engineering (AFE)
Provides education, certification, technical information, and other relevant resources for plant and facility engineering, operations, and maintenance professionals worldwide.
http://www.afe.org/

Association of Energy Engineers (AEE)
The role of today's facility manager spans a cross-section of job responsibilities including: energy procurement, security, building performance, maintenance scheduling, equipment upgrades, multi-site portfolio management, budget planning, energy efficiency, communications technology, environmental compliance, and employee productivity. The FMI division of AEE is dedicated to providing its members industry information, conference and seminar programs, reference books, and marketplace surveys to enhance your knowledge base and job effectiveness.
http://www.aeecenter.org/divisions/

Association of Higher Education Facilities Officers
http://www.appa.org/

Boiler Efficiency Institute, LLC
P.O. Box 2255
Auburn, AL 36831-2255
(334) 821-3095
www.boilerinstitute.com

Building Owners and Managers Association
Publish: "How to Design and Manage your Preventive Maintenance Program"
http://www.boma.org/

Condition-Based Maintenance (CBM)
Becoming more widespread within U.S. industry and military. A complete CBM system comprises a number of functional capabilities and the implementation of a CBM system requires the integration of a variety of hardware and software components. There exists a need for an Open System Architecture to facilitate the integration and interchangeability these components from a variety of sources. OSA-CBM is striving to build a de-facto standard to encompass the entire range of functions from data collection through the recommendation of specific maintenance actions.
http://www.mimosa.org/

Facilities Net
For professionals in facility design, construction, and maintenance related to or product of Tradelines who arranges executive level conference on facility programs for corporations and universities.
http://www.facilitiesnet.com/

Institute of Asset Management (IAM)
The independent organization for professionals dedicated to furthering our knowledge and understanding of Asset Management. In particular, the institute seeks to spread good practice and develop decision support tools and techniques.
http://www.iam-uk.org/

Institute of Electrical and Electronics Engineers (IEEE)
IEEE's Reliability Society is the world's largest technical professional society.
http://www.ewh.ieee.org/soc/rs/Useful_Information/Links.htm

Institute of Industrial Engineers (IIE)
http://www.iienet2.org/Default.aspx

International Council for Machinery Lubrication (ICML)
A vendor-neutral, not-for-profit organization founded to facilitate growth and development of machine lubrication as a technical field of endeavor. Among its various activities, ICML offers skills-based certification testing for individuals in the fields of machine condition monitoring, lubrication, and oil analysis.
http://www.lubecouncil.org/

International Facilities Management Association (IFMA)
http://www.ifma.org/

Machinery Information Management Open Systems Alliance (MIMOSA)
Advocates open exchange of equipment condition-related information between condition assessment, process control, and maintenance information systems through published, consensus, conventions and to gain greatest value by combining vital condition information from multiple sources for collective evaluation, reaching accurate determinations of current condition, and projected lifetime and communicating results in a useful, understandable form. MIMOSA is committed to preserving the advantages, effectiveness, and rich detail contained in specialized applications such as vibration, temperature, lubricating oil, and electric motor monitoring and analysis systems within an integrated enterprise information structure.
http://www.mimosa.org/

Maintenance and Reliability Center (MRC)
A premier institution, headquartered at the University of Tennessee, for education, research, development, information exchange and application of maintenance and reliability engineering. Maintenance and reliability engineering focuses on the use of analysis techniques, advanced predictive and preventive technologies and management systems to identify, manage, and eliminate failures that lead to losses in system function.
http://www.engr.utk.edu/mrc/

Motor Decisions Matter
A national campaign encouraging the use of sound motor management and planning as a tool to cut motor energy costs and increase productivity. The campaign is sponsored by a consortium of motor industry manufacturers and service centers, trade associations, electric utilities, and government agencies.
DOE Office of Industrial Technologies Clearinghouse
1-800-862-2086
http://www.motorsmatter.org/

National Association of Energy Service Companies (NAESCO)
1615 M Street, NW, Suite 800
Washington, D.C. 20036
(202) 822-0955
http://www.naesco.org

National Association of State Energy Officials (NASEO)
14141 Prince Street, Suite 200
Alexandria, VA 22314
(703) 299-8800
http://www.naseo.org

National Association of State Procurement Officials (NASPO)
http://www.naspo.org

National School Plant Management Association (NSPMA)
Chartered in 1995, NSPMA was formed in the interest on enhancing and promoting the educational process. Its purpose is to provide for the exchange of information that improves school plant management, maintenance, and care through the promotion of acceptable policies, standards, and practices and to promote the professional advancement of school plant management personnel.
http://nspma.org/

Oklahoma Predictive Maintenance User's Group (OPMUG)
Established in 1992 to provide maintenance professionals throughout Oklahoma, and the surrounding states, an opportunity to share and obtain first hand knowledge about predictive maintenance.
http://www.opmug.net/

Plant Engineering and Maintenance Association of Canada (PEMAC)
The national technical association devoted to plant engineering and maintenance, created by and for plant engineering and maintenance people.
http://www.pemac.org

Professional Thermographers Association
http://www.prothermographer.com

Reliability Division American Society for Quality
http://www.asq.org/

Society for Machinery Failure Prevention Technology (MFPT)
A Division of the Vibration Institute, MFPT acts as a focal point for technological developments that contribute to mechanical failure reduction or prevention.
http://www.mfpt.org/

Society for Maintenance & Reliability Professionals (SMRP)
An independent, nonprofit society by and for practitioners in the Maintenance & Reliability Profession with nearly 2,000 members strong with global penetration.
http://www.smrp.org

Society of Reliability Engineers (SRE)
We hope you will find our Web site interesting and useful. Here, you may contact the Society Officers, become better acquainted with other SRE Chapters, and discover other links of interest to the Reliability Engineer.
http://www.sre.org/

University of Maryland - Reliability Engineering Program
http://www.enre.umd.edu/

O&M Publications

Chilton's Industrial Maintenance and Plant Operation
http://www.impomag.com

HPAC Engineering
1300 E Ninth Street
Cleveland, OH 44114-1503
(216) 696-7000
http://www.hpac.com

Industrial Maintenance and Plant Operation
http://www.impomag.com

Maintenance Solutions
P.O. Box 5268
Pittsfield, MA 01203-5268
http://www.facilitiesnet.com

Maintenance Technology
(847) 382-8100/Fax: (847) 304-8603
http://www.mt-online.com

P/PM Technology
SC Publishing
P.O. Box 2770
Minden, NV 89423-2770
(702) 267-3970

Plant & Facilities Engineering Digest
Adams/Huecore Publishing, Inc.
29100 Aurora Road, Suite 200
Cleveland, OH 44139
(708) 291-5222

Preventative Maintenance Magazine
Reliability Magazine
http://www.reliability-magazine.com/

Events Related to O&M

Association of Energy Engineers
World Energy and Engineering Conference held every November in Atlanta.
AEE, 700 Indian Trail
Lilburn, GA 30247

Machinery Reliability Conference
Reliability Magazine
http://www.reliability-magazine.com

Maintenance Engineering-98
Annual conference sponsored by The Maintenance Engineering Society of Australia Inc. (MESA).
Contact ME-98
P.O. Box 5142
Clayton, Victoria, 3168, Australia
+61 3 9544 0066, Fax +61 3 9543 5906.

National Association of State Procurement Officials (NASPO)
Contact: Katie Kroehle (202) 586-4858

National Predictive Maintenance Technology Conference
P/PM Magazine
Phone: (702) 267-3970; Fax: (702) 367-3941

Portland Energy Conservation, Inc. (PECI)
Resource library website for case studies and tuning procedures.
http://www.peci.org/library.htm

Government Energy-Efficiency Organizations

Federal Energy Management Program (FEMP)
U.S. Department of Energy
http://www1.eere.energy.gov/femp