A Guide to Building Operation and Maintenance - Part I

Course No: M10-006
Credit: 10 PDH

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This course was adapted from the U.S. Department of Energy Publication, Publication No. PNNL-19634, ''Operations & Maintenance Best Practices: A Guide to Achieving Operational Efficiency'', which is in the public domain.

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Chapter 1 Introduction and Overview

The purpose of this guide is to provide you, the Operations and Maintenance (O&M)/Energy manager and practitioner, with useful information about O&M management, technologies, energy and water efficiency, and cost-reduction approaches. To make this guide useful and to reflect your needs and concerns, the authors met with O&M and Energy managers via Federal Energy Management Program (FEMP) workshops. In addition, the authors conducted extensive literature searches and contacted numerous vendors and industry experts. The information and case studies that appear in this guide resulted from these activities.

It needs to be stated at the outset that this guide is designed to provide information on effective O&M as it applies to systems and equipment typically found at Federal facilities. This guide is not designed to provide the reader with step-by-step procedures for performing O&M on any specific piece of equipment. Rather, this guide first directs the user to the manufacturer's specifications and recommendations. In no way should the recommendations in this guide be used in place of manufacturer's recommendations. The recommendations in this guide 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 guide 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 certified personnel. If such personnel are not available, the actions recommended here should not be initiated.

1.1 About This Guide

This guide is designed to serve as a resource for O&M management and technical staff. It does not try to represent the universe of O&M-related material. Rather, it attempts to:

- Provide needed background information on why O&M is important and the potential for savings from good O&M.
- 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.
- Identify information sources and contacts to assist you in getting your job done.

1.2 Target Audience

O&M/Energy managers, practitioners, and technical staff represent the prime focus of this document. However, 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. It is these staff that are 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.

1.3 Organization and Maintenance of the Document

It is the intention of the authors to update this guide periodically as new O&M procedures and technologies are developed and employed. This guide can be found on the FEMP Web site at **http://www1.eere.energy.gov/femp/operations_maintenance/om_bpguide.html**.

The guide consists of eleven chapters. This chapter provides an introduction and an overview. Chapter 2 provides the rationale for “Why O&M?” Chapter 3 discusses O&M management issues and their importance. Chapter 4 examines Computerized Maintenance Management Systems (CMMS) and their role in an effective O&M program. Chapter 5 looks at the different types of maintenance programs and definitions. Chapter 6 focuses on maintenance technologies, particularly the most accepted predictive technologies. Chapter 7 describes the building commissioning process and how it contributes to effective O&M. Chapter 8 covers the topic of metering and its applications for improved operations and efficiency. Chapter 9 explores O&M procedures for the predominant equipment found at most Federal facilities and, where applicable, provides calculation procedures for estimating energy savings. Chapter 10 describes some of the promising O&M technologies and tools on the horizon to increase O&M efficiency. Chapter 11 provides ten steps to initiating an *operational efficiency* program.

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 Federal contacts for training and assistance. Appendix C includes a list of organizations and trade groups that have interest or are related to O&M. And finally, Appendix D is a form that can be used to submit suggestions or revisions to this guide.

Again, we designed this to be a useful document, and we welcome your input to help us keep it current. Please feel comfortable to make suggestions for changes, additions, or deletions using the form found in Appendix D.

Chapter 2 Why O&M?

2.1 Introduction

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.

2.2 Definitions

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.

2.3 Motivation

In October of 2009, EO 13514 was signed into law. This order directs Federal agencies to further address energy, water, and operational efficiency beyond E.O. 13423.

The key energy- and operational-efficiency-related provisions in the Executive Order are as follows:

- Federal agencies must enhance efforts toward sustainable buildings and communities. Specific requirements include the implementation of high-performance sustainable Federal building design, construction, operation and management, maintenance, and deconstruction.
- Pursuing cost-effective, innovative strategies (e.g., highly reflective and vegetated roofs) to minimize consumption of energy, water, and materials.
- Managing existing building systems to reduce the consumption of energy, water, and materials, and identifying alternatives to renovation that reduce existing asset-deferred maintenance costs.
- Reducing potable water consumption intensity 2% annually through FY 2020, or 26% by the end of FY 2020, relative to a FY 2007 baseline.
- Reducing agency industrial, landscaping, and agricultural water consumption 2% annually, or 20% by the end of FY 2020, relative to a FY 2010 baseline.
- Identifying, promoting, and implementing water reuse strategies consistent with state law that reduce potable water consumption.

While applicable only to Department of Energy facilities, DOE Order 430.2B was issued in February 2008 clearly outlining the requirements and responsibilities for managing DOE facilities. The relevance of this Order lies in forward-thinking and highlights DOE's commitment to energy and resource efficiency.

The key energy- and operational-efficiency-related provisions in the DOE Order are as follows:

- By FY 2015, reduce energy intensity by no less than 30% on average across the entire Department, relative to the Department's energy use in FY 2003. Energy intensity means energy consumption per gross square foot of building space, including industrial and laboratory facilities.
- By FY 2015, reduce potable water use by no less than 16%, relative to the Department's potable water use in FY 2007.
- Install advanced electric metering systems at all Department sites in accordance with the DOE metering plan for site monitoring of electric energy. Standard metering systems for steam, natural gas, and water must also be installed and centrally monitored at all Department sites for steam, natural gas, and water consumption. Advanced meters are defined as having the capability to measure and record interval data (at least hourly for electricity) and communicate the data to a remote location in a format that can be easily integrated into an advanced metering system.
- Use standardized operations and maintenance (O&M) and measurement and verification (M&V) protocols coupled with real-time information collection and centralized reporting capabilities.

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.

Is an Energy Savings Performance Contract Being Considered?
(Haasl and Sharp 1999)

Some level of retrocommissioning (i.e., O&M best practices) is usually appropriate if you are considering any type of energy savings agreement such as an energy savings performance contract. There are two primary reasons for performing retrocommissioning before obtaining an energy-savings agreement. First, the low-cost energy savings gained from retrocommissioning remains with the building (the owner gets all of the savings) and does not become part of the financial agreement; second, retrocommissioning optimizes the existing equipment so the most appropriate capital measures are selected and financed through the agreement.

A good reason for doing retrocommissioning as part of an energy-savings agreement is to ensure that the performance of new equipment is not hindered because it interfaces with older equipment, components, or systems that are malfunctioning. Even when commissioning is specified for the new equipment, it often stops short of looking at the systems with which the new equipment interfaces or examining how it integrates with other systems or equipment that may affect its performance. This is especially true for energy management control systems. Because controls are an area where many difficulties and misunderstandings occur between building owners and performance contractors, it is a good idea to specify commissioning for both the new and existing equipment that may affect the performance of the new equipment.

When retrocommissioning is performed before the energy-savings agreement or energy savings performance contract is finalized, it is important to inform the contractor about the retrocommissioning activities and give him or her a copy of the final report. If the contractor is not informed and energy bills from prior years are used to help determine the energy baseline, the baseline may be inaccurate. This may cause the cost savings upon which the financing is based to be significantly less than expected, leading to disagreements and even legal battles.

Retrocommissioning performed up front to capture the low-cost savings may not be a wise choice if the savings from the retrocommissioning do not remain with the building but, instead, go into a general fund. In this case, the "low-cost/no-cost" improvements should be part of the performance contract. In this way, a portion of the savings stays with the building as part of the financial arrangement. Integrating the retrocommissioning measures into the energy-savings agreement is a way to capture the savings as part of the investment repayment. The amount invested can be increased when the savings estimates are higher. Moreover, the savings gained from bundling these measures with the capital upgrades—especially if some of the upgrades are marginally cost-effective (i.e., good value but with long paybacks)—help to increase the overall viability and attractiveness of the energy savings performance contract funding.

2.4 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.

The need for effective building O&M is illustrated in Figure 2.4.1, which shows how, over time, the performance of a building (and its components) will eventually degrade in two scenarios – one with and one without "normal" maintenance. Of interest in the figure is the prolonged service life achieved through effective O&M. Not shown in this figure is the additional benefit of reduced building (energy) operating costs resulting from effectively maintaining mechanical and electrical equipment (e.g., lighting; heating, ventilation, and air conditioning [HVAC]; controls; and on-site generation).

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

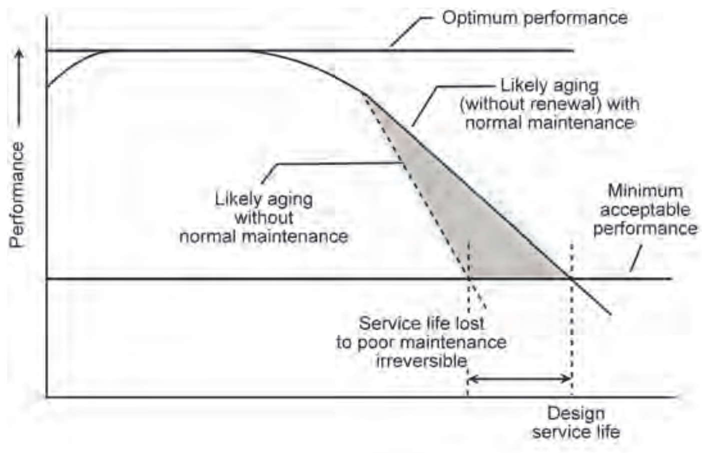

Figure 2.4.1. Effect of adequate and timely maintenance and repairs on the service life of a building (National Research Council 1998).

- 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 Federal buildings, the O&M staff are responsible for not only the comfort, but also the health and safety of the occupants. Of increasing productivity (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.

When Marion County, Florida, officials realized their new county courthouse was making hundreds of employees sick, they did more than send the workers to the doctor, they sued the builder/operator of the building for bad air and won a $14.2 million judgment (Ewell 1996).

- 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* as well as expected carbon management legislation.

O&M measures cost approximately 20 times less and achieve roughly the same energy savings as retrofit measures.

- 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. This model minimizes callbacks and keeps occupants satisfied while allowing more time for scheduled maintenance.

Two recent DOE/FEMP-sponsored programs have highlighted both the opportunity and the cost effectiveness of O&M/low-cost energy efficiency measures; these programs were the Energy Savings Expert Teams (ESET) and Energy Efficiency Expert Evaluations (E4). Both programs were designed to respond to the need for immediate, cost-effective energy savings. From the post evaluations, the following findings were highlighted:

A demonstration focused on O&M-based energy efficiency was conducted at the U.S. Department of Energy Forrestal Building in Washington, D.C. (Claridge and Haberl 1994). A significant component to this demonstration was metering and the tracking of steam use in the building. Within several months, $250,000 per year in steam leaks were found and corrected. These included leaks in a steam converter and steam traps. Because the building was not metered for steam and there was not a proactive O&M program, these leaks were not detected earlier, nor would they have been detected without the demonstration. The key lessons learned from this case study were:

- O&M opportunities in large buildings do not have to involve complex engineering analysis.
- Many O&M opportunities exist because building operators may not have proper documentation that hindered day-to-day actions.
- Involvement and commitment by building administrators is a key ingredient for a successful O&M program.

Energy Savings Expert Teams - ESET (Hunt 2007):

- To realize the same benefits (energy savings), equipment retrofits cost approximately 20-times more than low-cost O&M measures
- Dollars saved per dollars invested (calculated values):
  - *O&M projects:* 3.83 (simple payback 0.26 years)
  - *Retrofit projects:* 0.19 (simple payback 5.26 years)
- Overall program cost-effectiveness for measures implemented (as of May 2007) - includes retrofit, O&M measures and program administration/delivery
  - *Annual energy savings:* 202,512 MMBtu
  - *Annual cost savings:* $1,731,780
  - *Total program cost:* $1,795,000
  - *Simple payback:* 1.0 years

Energy Efficiency Expert Evaluations - E4 (Hail 2008):

- Calculated savings range from 3% to over 40%, average savings 15%.
- Dollars saved per dollars invested (calculated values):
  - *O&M projects (defined as <$5,000):* 14.9 (simple payback 0.07 years)
  - *Retrofit projects (defined as >$5,000):* 0.7 (simple payback 1.5 years)
- Overall program cost effectiveness for measures implemented (as of December 2008), includes retrofit, O&M measures and program administration/delivery
  - *Annual cost savings:* $584,000
  - *Total program cost:* $800,000
  - *Simple payback:* 1.4 years

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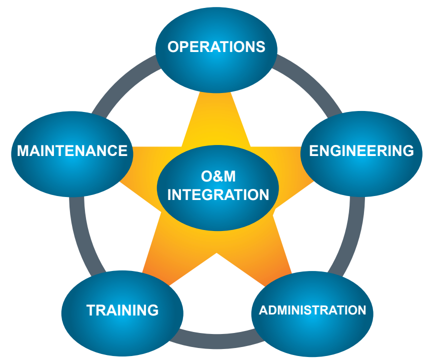
Chapter 3 O&M Management

3.1 Introduction



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: **O**perations, **M**aintenance, **E**ngineering, **T**raining, and **A**dministration—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.

3.2 Developing the Structure

Five well-defined elements of an effective O&M program include those presented above in the OMETA concept (Meador 1995). While these elements, Operations, Maintenance, Engineering, Training, and Administration, 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.

3.3 Obtain Management Support

Federal 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.

Management reports should not assign blame for poor maintenance and inefficient systems, but rather to motivate efficiency improvement through improved maintenance.

When designing management reports, the critical metrics used by each system should be compared to a base period. For example, compare monthly energy use against the same month for the prior year, or against the same month in a particular base year (for example, 1985). If efficiency standards for a particular system are available, compare your system's performance against that standard as well. Management reports should not assign blame for poor maintenance and inefficient systems, but rather to motivate efficiency improvement through improved maintenance.

3.3.1 The O&M Mission Statement

Another useful approach in soliciting management buy-in and support is the development an O&M mission statement. The mission statement does not have to be elaborate or detailed. The main objective is to align the program goals with those of site management and to seek approval, recognition, and continued support. Typical mission statements set out to answer critical questions – a sample is provided below:

- *Who are we as an organization* – specifically, the internal relationship?
- *Whom do we serve* – specifically, who are the customers?
- *What do we do* – specifically, what activities make up day-to-day actions?
- *How do we do it* – specifically, what are the beliefs and values by which we operate?
- *Finally, how do we measure success* – what metrics do we use, (e.g., energy/water efficiency, safety, dollar savings, etc.?)

A critical element in mission statement development is involvement of upper management and facility staff alike. Once involved with the development, there will be "ownership" which can lead to compliance (facility staff) and support (management).

3.4 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, this metric 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 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 of 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.

While some metrics are easier to quantify than others, Table 3.1.1 below can serve as a guide for tracking and trending metrics against industry benchmarks (NASA 2000).

Table 3.1.1. Industry O&M metrics and benchmarks

Metric	Variables and Equation	Benchmark
Equipment Availability	% = Hours each unit is avaialbe to run at capacity / Total hours during the reporting time period	> 95%
Schedule Compliance	% = Total hours worked on scheduled jobs / Total hours scheduled	> 90%
Emergency Maintenance Percentage	% = Total hours worked on emergency jobs / Total hours worked	< 10%
Maintenance Overtime Percentage	% = Total maintenance overtime during period / Total regular maintenance hour during period	< 5%
Preventive Maintenance Completion Percentage	% = Preventive maintenance actions completed / Preventive maintenance actions scheduled	> 90%
Preventive Maintenance Budget/Cost	% = Preventive maintenance cost / Total maintenance cost	15% – 18%
Predictive Maintenance Budget/Cost	% = Preventive maintenance cost / Total maintenance cost	10% – 12%

3.5 Selling O&M to Management

To successfully interest management in O&M activities, O&M managers need to be fluent in the language spoken by management. Projects and proposals brought forth to management need to stand on their own merits and be competitive with other funding requests. While evaluation criteria may differ, generally some level of economic criteria will be used. O&M managers need to have a working knowledge of economic metrics such as:

- **Simple payback** – The ratio of total installed cost to first-year savings.
- **Return on investment** – The ratio of the income or savings generated to the overall investment.
- **Net present value** – Represents the present worth of future cash flows minus the initial cost of the project.
- **Life-cycle cost** – The present worth of all costs associated with a project.

Life-Cycle Cost Training

Take advantage of LCC workshops offered by FEMP. Each year, FEMP conducts a 2-hour televised workshop on life-cycle cost methods and the use of BLCC (Building Life-Cycle Cost) software programs. In some years, two-day classroom workshops are offered at various U.S. locations.

More information can be found at: **http://www1.eere.energy.gov/femp/program/lifecycle.html**

FEMP offers life-cycle cost training along with its Building Life-Cycle Cost (BLCC) computer program at various locations during the year – see Appendix B for the FEMP training contacts.

3.6 Program Implementation

Developing or enhancing an O&M program requires patience and persistence. Guidelines for initiating a new O&M project will vary with agency and management situation; however, some steps to consider are presented below:

- **Start small** – Choose a project that is manageable and can be completed in a short period of time, 6 months to 1 year.
- **Select troubled equipment** – Choose a project that has visibility because of a problematic history.
- **Minimize risk** – Choose a project that will provide immediate and positive results. This project needs to be successful, and therefore, the risk of failure should be minimal.
- **Keep accurate records** – This project needs to stand on its own merits. Accurate, if not conservative, records are critical to compare before and after results.
- **Tout the success** – When you are successful, this needs to be shared with those involved and with management. Consider developing a "wall of accomplishment" and locate it in a place where management will take notice.
- **Build off this success** – Generate the success, acknowledge those involved, publicize it, and then request more money/time/resources for the next project.

3.7 Program Persistence

A healthy O&M program is growing, not always in staff but in responsibility, capability, and accomplishment. O&M management must be vigilant in highlighting the capabilities and accomplishments of their O&M staff.

Finally, 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.

3.8 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 Federal building mangers and organizations indicate this value is significantly higher in the Federal sector, and 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 Federal sector 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 Federal 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, titled *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 are provided below.

Steps to Think About When Considering an O&M 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 Federal agencies 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.

3.8.1 O&M Contract Types

There are four predominant types of O&M contracts. These are: **full coverage** contracts, **full-labor** contracts, **preventive-maintenance** contracts, and **inspection** contracts. Each type of contract is discussed below (PECI 1997).

Full-Coverage Service Contract. A full-coverage service contract provides 100% coverage of labor, parts, and materials as well as emergency service. Owners may purchase this type of contract for all of their building equipment or for only the most critical equipment, depending on their needs. This type of contract should always include comprehensive preventive maintenance for the covered equipment and systems. If it is not already included in the contract, for an additional fee the owner can purchase repair and replacement coverage (sometimes called a "breakdown" insurance policy) for the covered equipment. This makes the contractor completely responsible for the equipment. When repair and replacement coverage is part of the agreement, it is to the contractor's advantage to perform rigorous preventive maintenance on schedule, since he or she must replace the equipment if it fails prematurely.

Full-coverage contracts are usually the most comprehensive and the most expensive type of agreement in the short term. In the long term, however, such a contract may prove to be the most cost-effective, depending on the owner's overall O&M objectives. Major advantages of full-coverage contracts are ease of budgeting and the fact that most if not all of the risk is carried by the contractor. However, if the contractor is not reputable or underestimates the requirements of the equipment to be insured, the contractor may do only enough preventive maintenance to keep the equipment barely running until the end of the contract period. Also, if a company underbids the work in order to win the contract, the company may attempt to break the contract early if it foresees a high probability of one or more catastrophic failures occurring before the end of the contract.

Full-Labor Service Contract. A full-labor service contract covers 100% of the labor to repair, replace, and maintain most mechanical equipment. The owner is required to purchase all equipment and parts. Although preventive maintenance and operation may be part of the agreement, actual installation of major plant equipment such as a centrifugal chillers, boilers, and large air compressors is typically excluded from the contract. Risk and warranty issues usually preclude anyone but the manufacturer installing these types of equipment. Methods of dealing with emergency calls may also vary. The cost of emergency calls may be factored into the original contract, or the contractor may agree to respond to an emergency within a set number of hours with the owner paying for the emergency labor as a separate item. Some preventive maintenance services are often included in the agreement along with minor materials such as belts, grease, and filters.

This is the second most expensive contract regarding short-term impact on the maintenance budget. This type of contract is usually advantageous only for owners of very large buildings or multiple properties who can buy in bulk and therefore obtain equipment, parts, and materials at reduced cost. For owners of small to medium-size buildings, cost control and budgeting becomes more complicated with this type of contract, in which labor is the only constant. Because they are responsible only for providing labor, the contractor's risk is less with this type of contract than with a full-coverage contract.

Preventive-Maintenance Service Contract. The preventive-maintenance (PM) contract is generally purchased for a fixed fee and includes a number of scheduled and rigorous activities such as changing belts and filters, cleaning indoor and outdoor coils, lubricating motors and bearings, cleaning and maintaining cooling towers, testing control functions and calibration, and painting for corrosion control. Generally the contractor provides the materials as part of the contract. This type contract is popular with owners and is widely sold. The contract may or may not include arrangements regarding repairs or emergency calls.

The main advantage of this type of contract is that it is initially less expensive than either the full-service or full-labor contract and provides the owner with an agreement that focuses on quality preventive maintenance. However, budgeting and cost control regarding emergencies, repairs, and replacements is more difficult because these activities are often done on a time-and-materials basis. With this type of contract the owner takes on most of the risk. Without a clear understanding of PM requirements, an owner could end up with a contract that provides either too much or too little. For example, if the building is in a particularly dirty environment, the outdoor cooling coils may need to be cleaned two or three times during the cooling season instead of just once at the beginning of the season. It is important to understand how much preventive maintenance is enough to realize the full benefit of this type of contract.

Inspection Service Contract. An inspection contract, also known in the industry as a “fly-by” contract, is purchased by the owner for a fixed annual fee and includes a fixed number of periodic inspections. Inspection activities are much less rigorous than preventive maintenance. Simple tasks such as changing a dirty filter or replacing a broken belt are performed routinely, but for the most part inspection means looking to see if anything is broken or is about to break and reporting it to the owner. The contract may or may not require that a limited number of materials (belts, grease, filters, etc.) be provided by the contractor, and it may or may not include an agreement regarding other service or emergency calls.

In the short-term perspective, this is the least expensive type of contract. It may also be the least effective—it’s not always a moneymaker for the contractor but is viewed as a way to maintain a relationship with the customer. A contractor who has this “foot in the door” arrangement is more likely to be called when a breakdown or emergency occurs. The contractor can then bill on a time-and-materials basis. Low cost is the main advantage to this contract, which is most appropriate for smaller buildings with simple mechanical systems.

3.8.2 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 Federal 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.

In the past, The General Services Administration (GSA) has inserted into some 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.
- 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.

Since the contract incentives approach is best suited for low cost, quick-payback measures, O&M contractors should consider recommissioning/value recommissioning actions as discussed in Chapter 7.

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

3.9 O&M: The ESPC Perspective

With the prevalence of Energy Savings Performance Contracts (ESPCs) in the Federal sector, some guidance should be offered from the O&M perspective. This guidance takes two forms. First, the need for high-quality and persistent O&M for ESPC projects to assure savings are met. Second, the opportunities O&M provides for enhanced efficiency of new and existing equipment and systems.

3.9.1 O&M Needs for Verified and Persistent Savings (LBNL 2005)

In Federal ESPCs, proper O&M is critical to the maintaining the performance of the installed equipment and to the achievement (and persistence) of the guaranteed energy savings for the term of the ESPC.

Inadequate O&M of energy-using systems is a major cause of energy waste, often affects system reliability and can shorten equipment life. Proper O&M practices are a key component in maintaining the desired energy savings from an ESPC and minimizing the chance of unexpected repair and replacement issues arising during the ESPC contract term. Further, to ensure long-term energy and cost savings, unambiguous allocation of responsibility for O&M and repair and replacement (R&R) issues, including reciprocal reporting requirements for responsible parties, are vital to the success of an ESPC.

Either the ESCO or the government (or the government's representative) may perform O&M activities on equipment installed as part of an ESPC. However, the ESCO is ultimately responsible for ensuring the performance of new equipment installed as part of the ESPC throughout the duration of the ESPC contract term. The government is typically responsible for existing equipment.

One Illustrative Scenario: Why O&M reporting is important for ESPC Projects

At one ESPC site, a disagreement during the performance period was seriously exacerbated due to the allocation of O&M responsibilities and the lack of reporting required on O&M conducted.

The primary cost saving measure implemented by the ESCO was an upgrade to the central chiller plant. The ESCO installed one new chiller (out of two), and two new distribution pumps (out of four). The ECM did not upgrade the existing cooling tower and distribution system. Due to project economics, the site elected to operate and maintain the entire chilled water system, including the new equipment. The ESPC contract did not require the site to document or report O&M activities to the ESCO.

After project acceptance, several problems with the chiller plant arose. In one instance, both chillers went out of service due to high head pressure. The ESCO asserted that the event was due to improper operations and lack of adequate maintenance by site personnel, and had voided the warranty for the new chiller. The site contended that the system was not properly commissioned and had design problems.

Since the site had not maintained any O&M records, they had no foundation to win the dispute. The site's contracting officer was obligated to continue full payments to the ESCO even though systems were not operating properly. After much contention, the ESCO eventually got the system working properly.

Lessons Learned:

- O&M documentation on ECMs is essential to minimizing disputes.
- If feasible, have ESCO accept O&M responsibilities.
- Proper commissioning is essential prior to project acceptance.

In an ideal scenario, the ESCO will both operate and perform all maintenance activities on equipment installed in an ESPC project. In many cases, however, it is not practical for the ESCO to carry out these activities. Often, the site is accustomed to performing O&M and the cost of reallocating these responsibilities may not be feasible within the ESPC contract term, since services must be paid from savings. In other instances, limited site access or other issues may make government O&M preferable.

A critical factor in the success of an ESPC is to ensure that the O&M plan for new equipment relates well to the O&M approach for existing equipment. This is especially true when new and existing equipment are located in the same facility or when existing equipment has a potential effect on the operation or savings achieved by new equipment. Clear definition of roles and responsibilities for O&M contribute toward proper coordination of O&M activities for new and existing equipment. In doing so, the chance of customer dissatisfaction, accusations and potential litigation during the ESPC contract term are minimized.

From the ESPC perspective, Table 3.2.2 below presents an overview of the key O&M issues, the timing or stage in the process which it needs to be addressed and the relevant supporting documents for more information. All listed documents can be found on the FEMP ESPC web site at: **http://www1.eere.energy.gov/femp/financing/espcs.html**.

Table 3.2.2. Overview of key O&M issues, timing, and supporting documents

Key O&M Topics	ESPC Stage	Reference Documents
1. Describe overall responsibility for the operation, maintenance, repair, and replacement at the project level	Initial and Final Proposals	Section 3.b, 3.c, 3.d of the Risk/Responsibility Matrix; Sections C.6, C.7, C.8 of IDIQ
2. Describe responsibility for the operation, maintenance, repair, and replacement of each ECM.	Final Proposal	Sections C.6, C.7, C.8 of IDIQ
3. Define different conditions under which Repair and Replacement (R&R) work will be performed, who will be liable, and the source of funds for performing R&R activities.	Final Proposal	Section C.8 of IDIQ
4. Define reporting requirement for O&M activities and its frequency.	Final Proposal	IDIQ; M&V Plan Outline (Sections 2.4.1, 3.8.8)
5. Submission of the ECM-specific O&M checklists by the ESCO.	Final Proposal	Recommended, but not required by IDIQ contract
6. ESCO provides O&M training & submits the Operations and Maintenance Manual for ECMs, including: • New written operations procedures; • Preventive maintenance work procedures and checklists.	Project Acceptance	IDIQ Attachment 2: Sample Checklist/Schedule of Post-Award Reporting Requirements and Submittals Sections C.6.3 and C.7.4 of IDIQ
7. Government (or ESCO) periodically reports on maintenance work performed on ECMs	Performance Period	Section C.7.3 of IDIQ
8. Identification of O&M issues that can adversely affect savings persistence; Steps to be taken to address the issue	Performance Period	Annual Report (Sections 1.5, 2.5.1, 2.5.2, 2.5.3); Project specific O&M checklists

3.9.2 Determination and Verification of O&M Savings in ESPCs

> **10 CFR § 436.31**. Energy cost savings means a reduction in the cost of energy and related operation and maintenance expenses, from a base cost established through a methodology set forth in an energy savings performance contract, utilized in an existing Federally owned building or buildings or other Federally owned facilities as a result of—(1) The lease or purchase of operating equipment, improvements, altered operation and maintenance, or technical services…
>
> **Source: Title 10, Code of Federal regulation part 436 Subpart B – Methods and Procedures for Energy Savings Performance Contracting.**

O&M and other energy-related cost savings are allowable in Federal ESPCs, and are defined as reduction in expenses (other than energy cost savings) related to energy and water consuming equipment. In fact, an analysis of annual measurement and verification (M&V) reports from 100 ongoing Super ESPC projects showed that 21% of the reported savings were due to reductions in O&M costs (LBNL 2007). These energy-related cost savings, which can also include savings on R&R costs, can constitute a substantial portion of a project's savings, yet O&M and R&R cost savings are often not as diligently verified or reviewed as energy savings.

Energy-related cost savings can result from avoided expenditures for operations, maintenance, equipment repair, or equipment replacement due to the ESPC project. This includes capital funds for projects (e.g., equipment replacement) that, because of the ESPC project, will not be necessary. Sources of energy-related savings include:

- Avoided current or planned capital expense,
- Transfer of responsibility for O&M and/or R&R to the ESCO, and
- Avoided renovation, renewal, or repair costs as a result of replacing old and unreliable equipment.

Methods for estimating O&M savings resulting from changes to equipment have not been developed for the FEMP or IPMVP M&V Guidelines. However, the general rule to follow is that any savings claimed from O&M activities must result in a real decrease in expenditures. O&M budget baselines cannot be based on what the agency *should* be spending for proper O&M; baseline expenditures must be based on what the agency is spending. The agency's O&M expenditures after implementation need to decrease for savings to be considered real.

Determining the appropriate level of effort to invest in the M&V of energy-related cost saving is the same as for energy cost savings: The level of M&V rigor will vary according to (a) the value of the project and its expected benefits, and (b) the risk in not achieving the benefits. A graded approach towards measuring and verifying O&M and R&R savings is advised. There is one primary method for calculating O&M savings, which is detailed below.

The most common approach for calculating energy-related cost savings involves the same concepts as those used for determining energy savings: Performance-period labor and equipment costs are subtracted from adjusted baseline values, as shown in the equation below.

O&M Cost Savings = [Adjusted Baseline O&M Costs] – [Actual O&M Costs]

This method is appropriate for most projects, and is especially simple to apply to those that include elimination of a maintenance contract or reduction in government staff. For other projects, costs for replacement parts can often be determined from purchase records and averaged to arrive at an annual baseline value. Labor costs for particular services may be more difficult to quantify since service records may not be representative or may lack sufficient detail. For example, parts costs for replacement light bulbs, ballasts, or steam traps are relatively easy to quantify from purchase records. Labor costs to replace lamps, ballasts, or steam traps are more difficult to quantify because time spent on these specific tasks may not be well documented. In addition, labor reductions on these specific tasks may not qualify as "real savings" if labor expenditures do not decrease. Although the agency receives value in the sense that labor is freed up to perform other useful tasks, this value may not result in cost savings that can be paid to the ESCO.

Baseline O&M costs should be based on actual budgets and expenditures to the greatest extent practical. This essentially "measures" the baseline consumption of these parts or services. Estimated expenditures should be avoided if at all possible. In cases where such information is not available and must be estimated, parts and labor costs can be derived from resources such as R.S. Means or other methods. Estimated expenditures should be adjusted to reflect any site-specific factors that would affect costs.

A more complete discussion of this topic can be found at the main ESPC web site located at: **http://www1.eere.energy.gov/femp/financing/espcs.html.**

3.10 References

LBNL 2005. *Planning and Reporting for Operations & Maintenance in Federal Energy Saving Performance Contracts*. Lawrence Berkeley National Laboratory, Berkeley, California. Available at: **http://ateam.lbl.gov/mv/**.

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Meador, R.J. 1995. *Maintaining the Solution to Operations and Maintenance Efficiency Improvement*. World Energy Engineering Congress, Atlanta, Georgia.

NASA. 2000. Reliability Centered *Maintenance Guide for Facilities and Collateral Equipment*. National Aeronautics and Space Administration, Washington, D.C. February 2000.

PECI. 1997. *Operations and Maintenance Service Contract*. Portland Energy Conservation, Inc., Portland, Oregon.

Chapter 4 Computerized Maintenance Management System

4.1 Introduction

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.

4.2 CMMS Needs Assessment

In determining the need for a CMMS, facility managers should assess their current mode of operation. Key questions to ask include:

- Do you have an effective way to generate and track work orders? How do you verify the work was done efficiently and correctly? What is the notification function upon completion?
- Are you able to access historical information on the last time a system was serviced, by whom, and for what condition?
- How are your spare-parts inventories managed and controlled? Do you have either excess inventories or are you consistently waiting for parts to arrive?
- Do you have an organized system to store documents (electronically) related to O&M procedures, equipment manuals, and warranty information?
- When service staff are in the field what assurances do you have that they are compliant with all life, health and safety issues (e.g., lock and tag) and are using the right tools/equipment for the task?
- How are your assets, i.e., equipment and systems, tracked for reporting and planning?

If the answers to these questions are not well defined or lacking – you may consider investigating the benefits a well implemented CMMS may offer.

4.3 CMMS Capabilities

CMMS systems automate most of the logistical functions performed by maintenance staff and management. CMMS systems come with many options and have 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 which 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.

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.

As reported in A.T. Kearney's and *Industry Week's* survey of 558 companies that are currently using a computerized maintenance management system (DPSI 1994), companies reported an average of:
28.3% increase in maintenance productivity
20.1% reduction in equipment downtime
19.4% savings in lower material costs
17.8% reduction in maintenance, repairs, operation (MRO) inventory
14.5 months average payback time.

- **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 CMMS provides significant advantages, they need to be maintained. Most successful CMMS installations have a "champion" of its use who ushers and encourages its continued use.

Considerations for CMMS Evaluation and Selection

- Have all relevant in-house staff (particularly field staff) been involved with the assessment of need, desired capabilities, and usability of proposed system?
- Does the product meet all of the needs as assessed?
- "Feature overload" is a common complaint of active CMMS users. Are you purchasing more than you need or have the capability to manage?
- Does the product offer module expansion as your system or needs grow?
- If needed, how well does the system integrate with other facility/energy management or accounting systems?
- How long has the vendor been in business? Do they have references for similar installations they could provide?
- How does the vendor provide technical assistance?
- How are product upgrades accomplished, and at what cost?

4.4 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.

4.5 CMMS Resources

The Internet provides a great resource for identifying CMMS vendors. A simple search under "CMMS" provides links to the many vendors and the resources they offer.

CMMS and EMCS (Energy Management and Control System) Integration

As technology improves and both of these systems develop capabilities, opportunities for integration exist. A good example is with air filtration systems. Traditionally, air filters are changed as part of a time-based PM activity – filters may get changed every 3 months, needed or not. Newer filtration systems made use of pressure sensors to calculate a need based filter change out. Many of these systems communicate back though an existing EMCS and notify the system monitor of differential pressure limit/alarm and the need for a filter change.

The opportunity and capability now exists to "port" this same differential pressure limit from the EMCS directly to the CMMS. This development affords a level of real-time maintenance management, whereby the filter change notification becomes an automatically generated work order scheduled based on need. In addition, this particular filter item is removed from inventory and a re-order paced if necessary. While this example highlight a simple air filter integration capability, the same logic applies to many other systems and equipment for which time-based maintenance can be replaced with need-based maintenance.

4.6 Reference

DPSI. 1994. *Uptime for Windows Product Guide, Version 2.1*. DPSI, Greensboro, North Carolina.

Chapter 5 Types of Maintenance Programs

5.1 Introduction

What is maintenance and why is it performed? Past and current maintenance practices in both the private and government 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 most private and government 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. For example, equipment may be designed to operate at full design load for 5,000 hours and may be designed to go through 15,000 start and stop cycles.

The need for maintenance is predicated on actual or impending failure – ideally, maintenance is performed to keep equipment and systems running efficiently for at least design life of the component(s). As such, the practical operation of a component is time-based function. If one were to graph the failure rate a component population versus time, it is likely the graph would take the "bathtub" shape shown in Figure 5.1.1. In the figure the Y axis represents the failure rate and the X axis is time. From its shape, the curve can be divided into three distinct: infant mortality, useful life, and wear-out periods.

The initial infant mortality period of bathtub curve is characterized by high failure rate followed by a period of decreasing failure. Many of the failures associated with this region are linked to poor design, poor installation, or misapplication. The infant mortality period is followed by a nearly constant failure rate period known as useful life. There are many theories on why components fail in this region, most acknowledge that poor O&M often plays significant role. It is also generally agreed

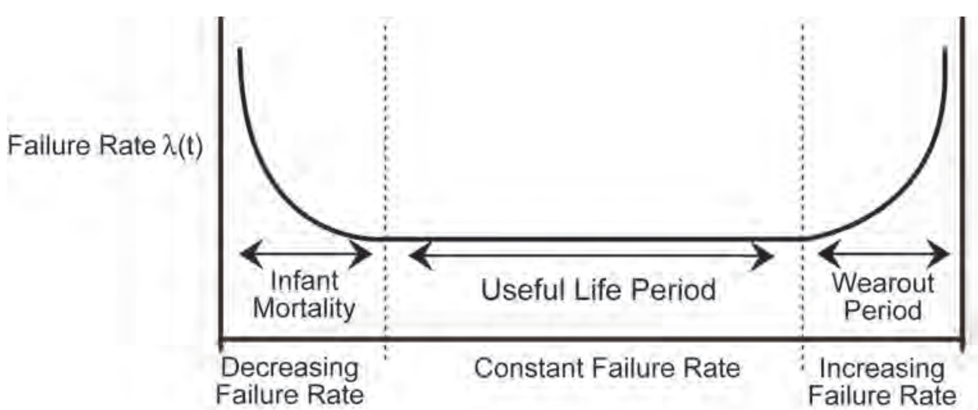


Figure 5.1.1. Component failure rate over time for component population

that exceptional maintenance practices encompassing preventive and predictive elements can extend this period. The wear-out period is characterized by a rapid increasing failure rate with time. In most cases this period encompasses the normal distribution of design life failures.

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 a car) 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 ensure 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, predictive maintenance, or reliability centered maintenance.

5.2 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. Studies as recent as the winter of 2000 indicate this is still the predominant mode of maintenance in the United States. The referenced study breaks down the average maintenance program as follows:

- >55% Reactive
- 31% Preventive
- 12% Predictive
- 2% Other.

Advantages

- Low cost.
- Less staff.

Disadvantages

- Increased cost due to unplanned downtime of equipment.
- Increased labor cost, especially if overtime is needed.
- Cost involved with repair or replacement of equipment.
- Possible secondary equipment or process damage from equipment failure.
- Inefficient use of staff resources.

Note that more than 55% of maintenance resources and activities of an average facility are still reactive.

Advantages to reactive maintenance can be viewed as a double-edged sword. If we are dealing with new equipment, we can expect minimal incidents of failure. If our maintenance program is purely reactive, 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, 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.

5.3 Preventive Maintenance

Advantages

- Cost effective in many capital-intensive processes.
- Flexibility allows for the adjustment of maintenance periodicity.
- Increased component life cycle.
- Energy savings.
- Reduced equipment or process failure.
- Estimated 12% to 18% cost savings over reactive maintenance program.

Disadvantages

- Catastrophic failures still likely to occur.
- Labor intensive.
- Includes performance of unneeded maintenance.
- Potential for incidental damage to components in conducting unneeded 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.

The U.S. Navy pioneered preventive maintenance as a means to increase the reliability of their vessels. 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. Studies indicate that this savings can amount to as much as 12% to 18% on the average. Depending on the facilities 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.

While preventive maintenance is not the optimum maintenance program, it does have several advantages over that of a purely reactive program. 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 (lubrication, filter change, etc.) 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.

5.4 Predictive Maintenance

Predictive maintenance can be defined as follows: Measurements that detect the onset of system degradation (lower functional state), 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.

Advantages

- Increased component operational life/availability.
- Allows for preemptive corrective actions.
- Decrease in equipment or process downtime.
- Decrease in costs for parts and labor.
- Better product quality.
- Improved worker and environmental safety.
- Improved worker morale.
- Energy savings.
- Estimated 8% to 12% cost savings over preventive maintenance program.

Disadvantages

- Increased investment in diagnostic equipment.
- Increased investment in staff training.
- Savings potential not readily seen by management.

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, 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 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%.

On the down side, to initially start into the predictive maintenance world is not inexpensive. Much of the equipment requires cost in excess of $50,000. Training of in-plant personnel to effectively utilize predictive maintenance technologies will require considerable funding. Program development will require an understanding of predictive maintenance and a firm commitment to make the program work by all facility organizations and management.

5.5 Reliability Centered Maintenance

Reliability centered maintenance (RCM) magazine provides the following definition of RCM: "a process used to determine the maintenance requirements of any physical asset in its operating context."

Basically, RCM methodology deals with some key issues not dealt with by other maintenance programs. It recognizes that all equipment in a facility is not of equal importance to either the process or facility safety. It recognizes that equipment design and operation differs and that different equipment will have a higher probability to undergo failures from different degradation mechanisms than others. It also approaches the structuring of a maintenance program recognizing that a facility does not have unlimited financial and personnel resources and that the use of both need to be prioritized and optimized. In a nutshell, RCM is a systematic approach to evaluate a facility's equipment and resources to best mate the two and result in a high degree of facility reliability and cost-effectiveness. RCM is highly reliant on predictive maintenance but also recognizes that maintenance activities on equipment that is inexpensive and unimportant to facility reliability may best be left to a reactive maintenance approach. The following maintenance program breakdowns of continually top-performing facilities would echo the RCM approach to utilize all available maintenance approaches with the predominant methodology being predictive.

Advantages

- Can be the most efficient maintenance program.
- Lower costs by eliminating unnecessary maintenance or overhauls.
- Minimize frequency of overhauls.
- Reduced probability of sudden equipment failures.
- Able to focus maintenance activities on critical components.
- Increased component reliability.
- Incorporates root cause analysis.

Disadvantages

- Can have significant startup cost, training, equipment, etc.
- Savings potential not readily seen by management.

- <10% Reactive
- 25% to 35% Preventive
- 45% to 55% Predictive.

Because RCM is so heavily weighted in utilization of predictive maintenance technologies, its program advantages and disadvantages mirror those of predictive maintenance. In addition to these advantages, RCM will allow a facility to more closely match resources to needs while improving reliability and decreasing cost.

Table 5.5.1 below highlights guidance on RCM development by equipment application (adapted from NASA 2000). It is important to both define the equipment criticality and cost of down-time when determining the optimal mix of maintenance elements. Once defined, the equipment can be prioritized in the developing a functional RCM program.

Table 5.5.1. Reliability centered maintenance element applications

Reliability Centered Maintenance Hierarchy		
Reactive **Element Applications**	***Preventive*** **Element Applications**	***Predictive*** **Element Applications**
Small parts and equipment	Equipment subject to wear	Equipment with random failure patterns
Non-critical equipment	Consumable equipment	Critical equipment
Equipment unlikely to fail	Equipment with known failure patterns	Equipment not subject to wear
Redundant systems	Manufacturer recommendations	Systems which failure may be induced by incorrect preventive maintenance

5.6 How to Initiate Reliability Centered Maintenance

The road from a purely reactive program to a RCM program is not an easy one. The following is a list of some basic steps that will help to get moving down this path (NASA 2000).

1. Develop a Master equipment list identifying the equipment in your facility.
2. Prioritize the listed components based on importance or criticality to operation, process, or mission – see text box highlighting priority scheme.

Maintenance Priority Matrix for RCM Development

Priority Weighting	Description	Application
1	Emergency	Life, health, safety risk-mission criticality
2	Urgent	Continuous operation of facility at risk
3	Priority	Mission support/project deadlines
4	Routine	Prioritized: first come/first served
5	Discretionary	Desired but not essential
6	Deferred	Accomplished only when resources allow

Comparison of Four Maintenance Programs (Piotrowski 2001)

Reactive Maintenance (Breakdown or Run-to-Failure Maintenance)

Basic philosophy

- Allow machinery to run to failure.
- Repair or replace damaged equipment when obvious problems occur.

Cost: $18/hp/yr

This maintenance philosophy allows machinery to run to failure, providing for the repair or replacement of damaged equipment only when obvious problems occur. Studies have shown that the costs to operate in this fashion are about $18 per horsepower (hp) per year. The advantages of this approach are that it works well if equipment shutdowns do not affect production and if labor and material costs do not matter.

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 impacts on components and systems.
8. Identify effective maintenance tasks or mitigation strategies.

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

An Introduction to Reliability and Maintainability Engineering
By: Charles E. Ebeling
Published by: McGraw Hill College Division
Publication date: September 1996

Maintenance Engineering Handbook
By: Lindley R. Higgins, Dale P. Brautigam, and R. Keith Mobley (Editor)
Published by: McGraw Hill Text, 5th Edition
Publication date: September 1994

Condition-Based Maintenance and Machine Diagnostics
By: John H. Williams, Alan Davies, and Paul R. Drake
Published by: Chapman & Hall
Publication date: October 1994

Maintenance Planning and Scheduling Handbook
By: Richard D. (Doc) Palmer
Published by: McGraw Hill
Publication date: March 29, 1999

Maintainability and Maintenance Management
By: Joseph D. Patton, Jr.
Published by: Instrument Society of America, 3rd Revision
Publication date: February 1994

Reliability-Centered Maintenance
By: John Moubray
Published by: Industrial Press, 2nd Edition
Publication date: April 1997

Reliability-Centered Maintenance
By: Anthony M. Smith
Published by: McGraw Hill
Publication date: September 1992.

Preventive Maintenance (Time-Based Maintenance)

Basic philosophy

- Schedule maintenance activities at predetermined time intervals.
- Repair or replace damaged equipment before obvious problems occur.

Cost: $13/hp/yr

This philosophy entails the scheduling of maintenance activities at predetermined time intervals, where damaged equipment is repaired or replaced before obvious problems occur. When it is done correctly, studies have shown the costs of operating in this fashion to be about $13 per hp per year. The advantages of this approach are that it works well for equipment that does not run continuously, and with personnel who have enough knowledge, skills, and time to perform the preventive maintenance work.

Predictive Maintenance (Condition-Based Maintenance)

Basic philosophy

- Schedule maintenance activities when mechanical or operational conditions warrant.
- Repair or replace damaged equipment before obvious problems occur.

Cost: $9/hp/yr

This philosophy consists of scheduling maintenance activities only if and when mechanical or operational conditions warrant-by periodically monitoring the machinery for excessive vibration, temperature and/or lubrication degradation, or by observing any other unhealthy trends that occur over time. When the condition gets to a predetermined unacceptable level, the equipment is shut down to repair or replace damaged components so as to prevent a more costly failure from occurring. In other words, “Don’t fix what is not broke.” Studies have shown that when it is done correctly, the costs to operate in this fashion are about $9 per hp per year. Advantages of this approach are that it works very well if personnel have adequate knowledge, skills, and time to perform the predictive maintenance work, and that it allows equipment repairs to be scheduled in an orderly fashion. It also provides some lead-time to purchase materials for the necessary repairs, reducing the need for a high parts inventory. Since maintenance work is only performed when it is needed, there is likely to be an increase in production capacity.

Reliability Centered Maintenance (Pro-Active or Prevention Maintenance)

Basic philosophy

- Utilizes predictive/preventive maintenance techniques with root cause failure analysis to detect and pinpoint the precise problems, combined with advanced installation and repair techniques, including potential equipment redesign or modification to avoid or eliminate problems from occurring.

Cost: $6/hp/yr

This philosophy utilizes all of the previously discussed predictive/preventive maintenance techniques, in concert with root cause failure analysis. This not only detects and pinpoints precise problems that occur, but ensures that advanced installation and repair techniques are performed, including potential equipment redesign or modification, thus helping to avoid problems or keep them from occurring. According to studies, when it is done correctly, operating in this fashion costs about $6 per hp per year. One advantage to this approach is that it works extremely well if personnel have the knowledge, skills, and time to perform all of the required activities. As with the predictive-based program, equipment repairs can be scheduled in an orderly fashion, but additional improvement efforts also can be undertaken to reduce or eliminate potential problems from repeatedly occurring. Furthermore, it allows lead-time to purchase materials for necessary repairs, thus reducing the need for a high parts inventory. Since maintenance work is performed only when it is needed, and extra efforts are put forth to thoroughly investigate the cause of the failure and determine ways to improve machinery reliability, there can be a substantial increase in production capacity.

5.7 References

NASA. 2000. *Reliability Centered Maintenance Guide for Facilities and Collateral Equipment*. National Aeronautics and Space Administration, Washington, D.C.

Piotrowski, J. April 2, 2001. *Pro-Active Maintenance for Pumps, Archives, February 2001*, **Pump-Zone.com** [Report online]. Available URL: **http://www.pump-zone.com**. Reprinted with permission of Pump-Zone.com.

Chapter 6 Predictive Maintenance Technologies

6.1 Introduction

Predictive maintenance attempts to detect the onset of a degradation mechanism with the goal of correcting that degradation prior to significant deterioration in the component or equipment. The diagnostic capabilities of predictive maintenance technologies have increased in recent years with advances made in sensor technologies. These advances, breakthroughs in component sensitivities, size reductions, and most importantly, cost, have opened up an entirely new area of diagnostics to the O&M practitioner.

As with the introduction of any new technology, proper application and **TRAINING** is of critical importance. This need is particularly true in the field of predictive maintenance technology that has become increasingly sophisticated and technology-driven. Most industry experts would agree (as well as most reputable equipment vendors) that this equipment should not be purchased for in-house use if there is not a serious commitment to proper implementation, operator training, and equipment monitoring and repair. If such a commitment cannot be made, a site is well advised to seek other methods of program implementation—a preferable option may be to contract for these services with an outside vendor and rely on their equipment and expertise.

Table 6.1.1 below highlights typical applications for some of the more common predictive maintenance technologies. Of course, proper application begins with system knowledge and predictive technology capability – before any of these technologies are applied to live systems.

Table 6.1.1. Common predictive technology applications (NASA 2000)

Technologies	Applications	Pumps	Electric Motors	Diesel Generators	Condensers	Heavy Equipment/ Cranes	Circuit Breakers	Valves	Heat Exchangers	Electrical Systems	Transformers	Tanks, Piping
Vibration Monitoring/Analysis		X	X	X		X						
Lubricant, Fuel Analysis		X	X	X		X					X	
Wear Particle Analysis		X	X	X		X						
Bearing, Temperature/Analysis		X	X	X		X						
Performance Monitoring		X	X	X	X				X		X	
Ultrasonic Noise Detection		X	X	X	X			X	X		X	
Ultrasonic Flow		X			X			X	X			
Infrared Thermography		X	X	X	X	X	X	X	X	X	X	
Non-destructive Testing (Thickness)					X				X			X
Visual Inspection		X	X	X	X	X	X	X	X	X	X	X
Insulation Resistance			X	X			X			X	X	
Motor Current Signature Analysis			X									
Motor Circuit Analysis			X				X			X		
Polarization Index			X	X						X		
Electrical Monitoring										X	X	

6.2 Thermography

6.2.1 Introduction

Infrared (IR) thermography can be defined as the process of generating visual images that represent variations in IR radiance of surfaces of objects. Similar to the way objects of different materials and colors absorb and reflect electromagnetic radiation in the visible light spectrum (0.4 to 0.7 microns), any object at temperatures greater than absolute zero emits IR energy (radiation) proportional to its existing temperature. The IR radiation spectrum is generally agreed to exist between 2.0 and 15 microns. By using an instrument that contains detectors sensitive to IR electromagnetic radiation, a two-dimensional visual image reflective of the IR radiance from the surface of an object can be generated. Even though the detectors and electronics are different, the process itself is similar to that a video camera uses to detect a scene reflecting electromagnetic energy in the visible light spectrum, interpreting that information, and displaying what it detects on a liquid crystal display (LCD) screen that can then be viewed by the device operator.

Because IR radiation falls outside that of visible light (the radiation spectrum to which our eyes are sensitive), it is invisible to the naked eye. An IR camera or similar device allows us to escape the visible light spectrum and view an object based on its temperature and its proportional emittance of IR radiation. How and why is this ability to detect and visualize an object's temperature profile important in maintaining systems or components? Like all predictive maintenance technologies, IR tries to detect the presence of conditions or stressors that act to decrease a component's useful or design life. Many of these conditions result in changes to a component's temperature. For example, a loose or corroded electrical connection results in abnormally elevated connection temperatures due to increased electrical resistance. Before the connection is hot enough to result in equipment failure or possible fire, the patterns are easily seen through an IR imaging camera, the condition identified and corrected. Rotating equipment problems will normally result in some form of frictional change that will be seen as an increase in the component's temperature. Faulty or complete loss of refractory material will be readily seen as a change in the components thermal profile. Loss of a roof's membrane integrity will result in moisture that can be readily detected as differences in the roof thermal profile. These are just a few general examples of the hundreds of possible applications of this technology and how it might be used to detect problems that would otherwise go unnoticed until a component failed and resulted in excessive repair or downtime cost.

6.2.2 Types of Equipment

Many types of IR detection devices exist, varying in capability, design, and cost. In addition, simple temperature measurement devices that detect IR emissions but do not produce a visual image or IR profile are also manufactured. The following text and pictures provide an overview of each general instrument type.

Figure 6.2.1. Typical IR spot thermometer

Spot Radiometer (Infrared Thermometer) – Although not generally thought of in the world of thermography, IR thermometers use the same basic principles as higher end equipment to define an object's temperature based on IR emissions. These devices do not provide any image representative of an object's thermal profile, but rather a value representative of the temperature of the object or area of interest.

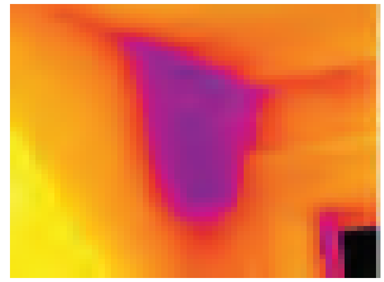


Figure 6.2.2. Internal house wall. Note dark area indicating cooler temperatures because of heat loss.

Infrared Imager – As indicated earlier, equipment capabilities, design, cost, and functionality vary greatly. Differences exist in IR detector material, operation, and design. At the fundamental level, IR detection devices can be broken down into two main groups – imagers and cameras with radiometric capability. A simple IR imager has the ability to detect an object's IR emissions and translate this information into a visual image. It does not have the capability to analyze and quantify specific temperature values. This type of IR detection device can be of use when temperature values are unimportant and the object's temperature profile (represented by the image) is all that is needed to define a problem. An example of such an application would be in detecting missing or inadequate insulation in a structure's envelope. Such an application merely requires an image representative of the differences in the thermal profile due to absence of adequate insulation. Exact temperature values are unimportant.

IR cameras with full radiometric capability detect the IR emissions from an object and translate this information into a visible format as in the case of an imager. In addition, these devices have the capability to analyze the image and provide a temperature value corresponding to the area of interest. This capability is useful in applications where a temperature value is important in defining a problem or condition. For example, if an image indicated a difference between a pulley belt temperature and an ambient temperature, the belt may have worn, be the wrong size, or indicate a misalignment condition. Knowing the approximate temperature differences would be important in determining if a problem existed.

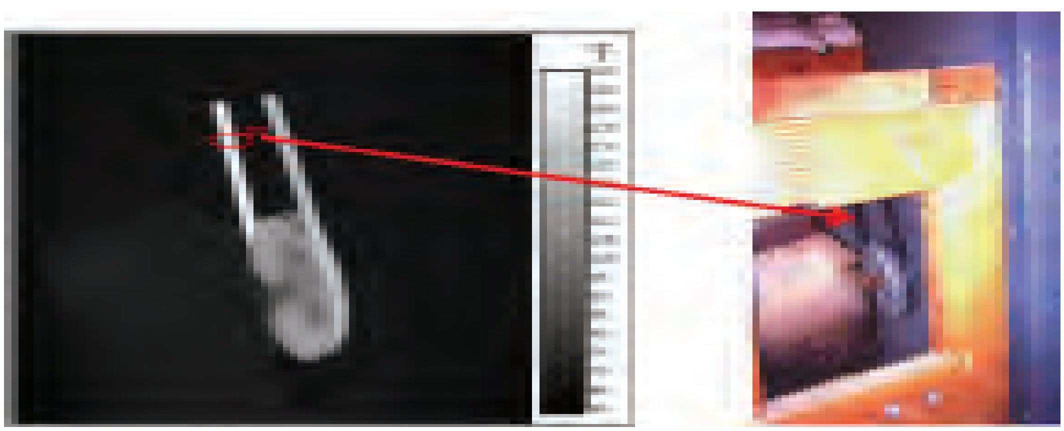


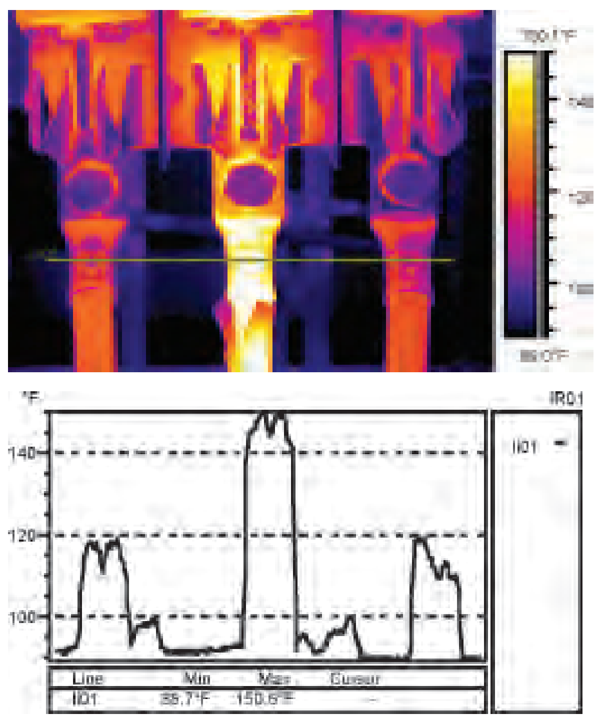
Figure 6.2.3. Temperature is used in defining belt problems. Figure shows a belt temperature of 149°F, and ambient temperature of 67°F for a difference of 82°F. The difference should be trended over time to determine slippage that would be indicated by a higher temperature difference.

6.2.3 System Applications

6.2.3.1 Electrical System Applications

The primary value of thermographic inspections of electrical systems is locating problems so that they can be diagnosed and repaired. "How hot is it?" is usually of far less importance. Once the problem is located, thermography and other test methods, as well as experience and common sense, are used to diagnose the nature of the problem. The following list contains just a few of the possible electrical system-related survey applications:

- Transmission lines
  - Splices
  - Shoes/end bells
    - Inductive heating problems
  - Insulators
    - Cracked or damaged/tracking
- Distribution lines/systems
  - Splices
  - Line clamps
  - Disconnects
  - Oil switches/breakers
  - Capacitors
  - Pole-mounted transformers
  - Lightning arrestors
  - Imbalances
- Substations
  - Disconnects, cutouts, air switches
  - Oil-filled switches/breakers (external and internal faults)
  - Capacitors
  - Transformers
    - Internal problems
    - Bushings
    - Oil levels
    - Cooling tubes
    - Lightning arrestors
  - Bus connections
- Generator Facilities
  - Generator
    - Bearings
    - Brushes
    - Windings
    - Coolant/oil lines: blockage
  - Motors
    - Connections
    - Bearings
    - Winding/cooling patterns
    - Motor Control Center
    - Imbalances
- In-Plant Electrical Systems
  - Switchgear
  - Motor Control Center
  - Bus
  - Cable trays
  - Batteries and charging circuits
  - Power/Lighting distribution panels



Software analysis tools can quantify and graphically display temperature data. As shown above, the middle conductor/connection is a much higher temperature indicating a loose connection.

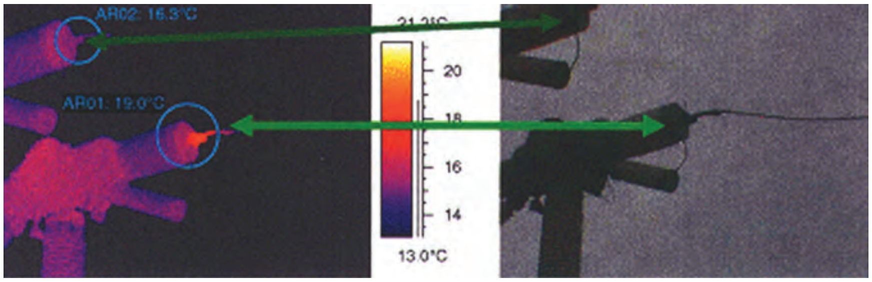


Figure 6.2.4. Air breaker problem. Highlighted by temperature difference between two different breakers. Likely caused by poor connection.

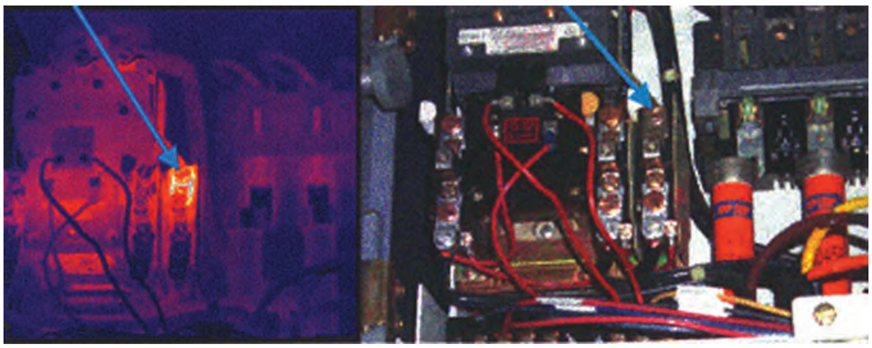


Figure 6.2.5. Overloaded contacts show different temperature profiles indicating one contact seeing much greater load, a potentially unsafe situation.

6.2.3.2 Mechanical System Applications

Rotating equipment applications are only a small subset of the possible areas where thermography can be used in a mechanical predictive maintenance program. In addition to the ability to detect problems associated with bearing failure, alignment, balance, and looseness, thermography can be used to define many temperature profiles indicative of equipment operational faults or failure. The following list provides a few application examples and is not all inclusive:

- Steam Systems
  - Boilers
    - Refractory
    - Tubes
  - Traps
  - Valves
  - Lines
- Heaters and furnaces
  - Refractory inspections
  - Tube restrictions
- Fluids
  - Vessel levels
  - Pipeline blockages
- Environmental
  - Water discharge patterns
  - Air discharge patterns
- Motors and rotating equipment
  - Bearings
    - Mechanical failure
    - Improper lubrication
  - Coupling and alignment problems
  - Electrical connections on motors
  - Air cooling of motors

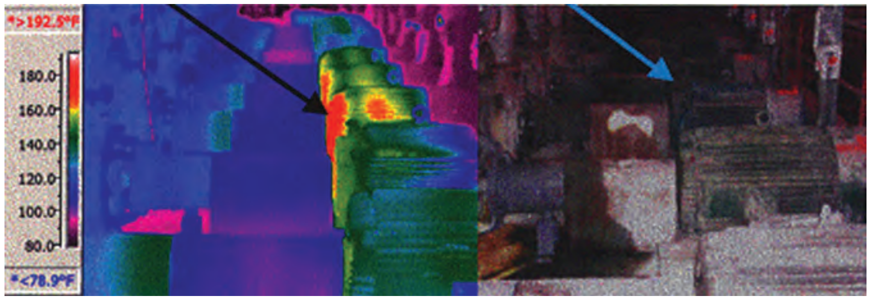


Figure 6.2.6. IR scans of multiple electric motors can highlight those with hot bearings indicting an imbalance or wear problem.

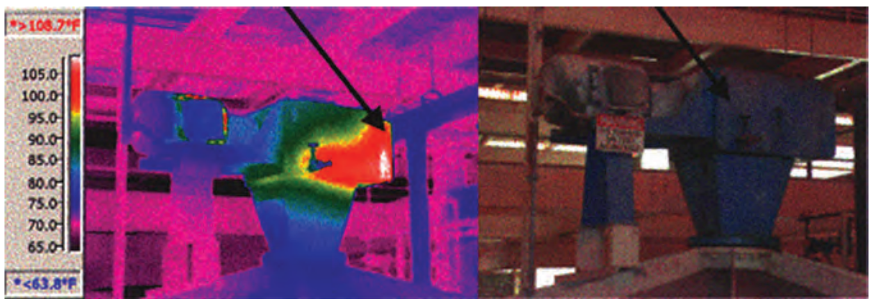


Figure 6.2.7. Possible gearbox problem indicated by white area defined by arrow. Design drawings of gearbox should be examined to define possible cause of elevated temperatures.

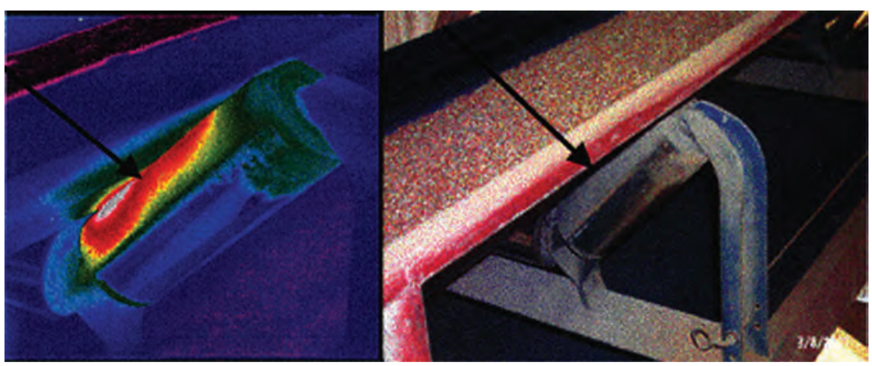


Figure 6.2.8. Seized conveyer belt roller as indicated by elevated temperatures in belt/roller contact area.

Figure 6.2.9. Inoperable steam heaters seen by cooler blue areas when compared to the operating heaters warmer red or orange colors.

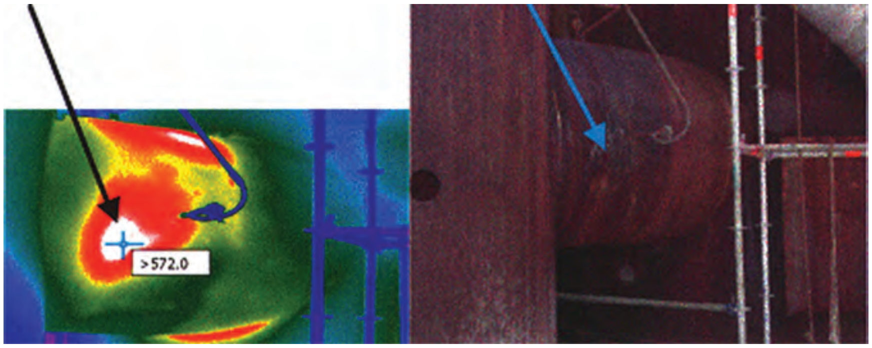


Figure 6.2.10. IR scans of boiler can highlight those areas where the refractory has broken down leading to costly heat loss.

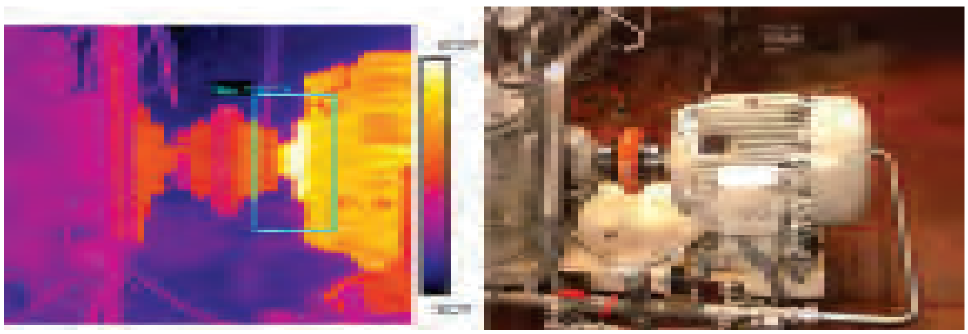


Figure 6.2.11. When trended, IR scans of single bearings provide a useful indicator of wear and eventual need for replacement.

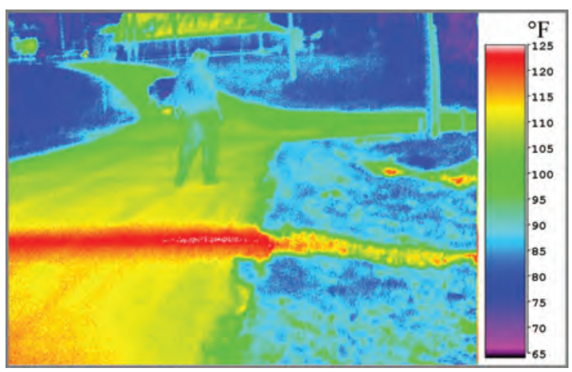
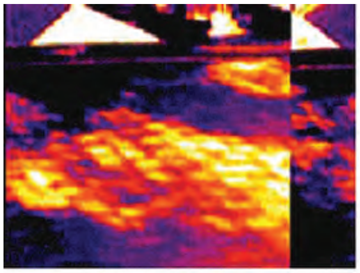
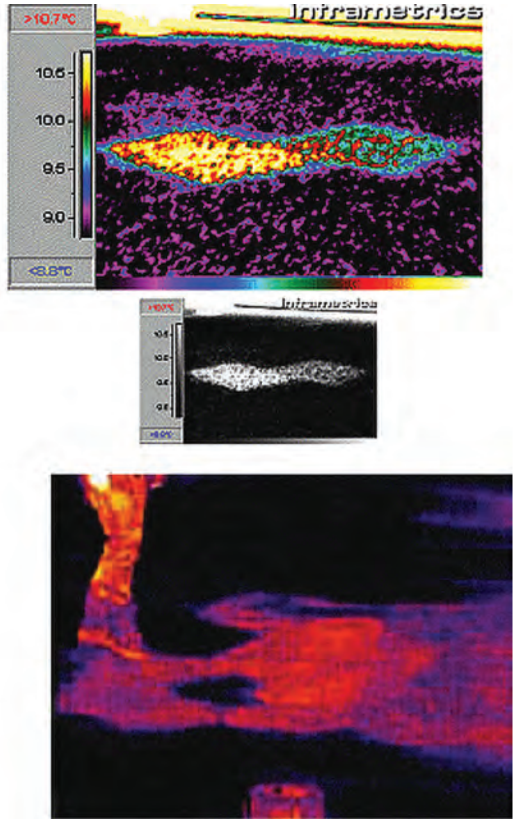


Figure 6.2.12. Steam or hot water distribution system leaks and/or underground line location can be defined with IR.



These images show elevated temperatures of roof insulation due to difference in thermal capacitance of moisture-laden insulation.



IR thermography is a powerful tool for locating roof leaks. As shown in the images, lighter colored regions indicate areas of potential leakage.

6.2.3.3 Roof Thermography

The old adage "out of sight, out of mind" is particularly true when it applies to flat roof maintenance. We generally forget about the roof until it leaks on our computers, switchgear, tables, etc. Roof replacement can be very expensive and at a standard industrial complex easily run into the hundreds of thousands of dollars. Depending on construction, length of time the roof has leaked, etc., actual building structural components can be damaged from inleakage and years of neglect that drive up repair cost further. Utilization of thermography to detect loss of a flat roof's membrane integrity is an application that can provide substantial return by minimizing area of repair/replacement. Roof reconditioning cost can be expected to run less than half of new roof cost per square foot. Add to this the savings to be gained from reconditioning a small percentage of the total roof surface, instead of replacement of the total roof, and the savings can easily pay for roof surveys and occasional repair for the life of the building with change left over.

6.2.4 Equipment Cost/Payback

As indicated earlier, the cost of thermography equipment varies widely depending on the capabilities of the equipment. A simple spot radiometer can cost from $500 to $2,500. An IR imager without radiometric capability can range from $7,000 to $20,000. A camera with full functionality can cost from $18,000 to $65,000. Besides the camera hardware, other program costs are involved.

Computer hardware, personnel training, manpower, etc., needs to be accounted for in the budget. Below is a listing of equipment and program needs recommended by a company recognized as a leader in the world of IR program development:

- Level I thermographic training
- Level II thermographic training
- Ongoing professional development
- IR camera and accessories
- Report software
- Laptop computer
- Color printer
- Digital visual camera
- Personal Protective Equipment (PPE) for arc flash protection

Payback can vary widely depending on the type of facility and use of the equipment. A production facility whose downtime equates to several thousands of dollars per hour can realize savings much faster than a small facility with minimal roof area, electrical distribution network, etc. On average, a facility can expect a payback in 12 months or less. A small facility may consider using the services of an IR survey contractor. Such services are widely available and costs range from $600 to $1,200 per day. Contracted services are generally the most cost-effective approach for smaller, less maintenance-intensive facilities.

6.2.5 Training Availability

Training for infrared thermography is available through a variety of system manufacturers and vendors. In addition, the American Society of Non-destructive Testing (ASNT) has established guidelines for non-destructive testing (NDT) (Level I, II, or III) certification (NASA 2000). These three levels are designed to take the student from Level I - where the student is competent with equipment function and use, to Level II – where the student is fully capable and experienced and can complete diagnostics and recommendations, to Level III – where the student is fully experienced to supervise and teach Level I and II students.

6.2.6 Case Studies

IR Diagnostics of Pump

A facility was having continual problems with some to its motor and pump combinations. Pump bearings repeatedly failed. An IR inspection confirmed that the lower thrust bearing was warmer than the other bearing in the pump. Further investigation revealed that the motor-pump combination was designed to operate in the horizontal position. In order to save floor space, the pump was mounted vertically below the motor. As a result, the lower thrust bearing was overloaded leading to premature failure. The failures resulted in a $15,000 repair cost, not including lost production time ($30,000 per minute production loss and in excess of $600 per minute labor).

IR Diagnostics of Steam Traps

Steam trap failure detection can be difficult by other forms of detection in many hard to reach and inconvenient places. Without a good trap maintenance program, it can be expected that 15% to 60% of a facility's traps will be failed open. At $3/1,000 lb (very conservative), a ¼-in. orifice trap failed open will cost approximately $7,800 per year. If the system had 100 traps and 20% were failed, the loss would be in excess of $156,000. An oil refinery identified 14% of its traps were malfunctioning and realized a savings of $600,000 a year after repair.

IR Diagnostics of Roof

A state agency in the northeast operated a facility with a 360,000 square foot roof area. The roof was over 22 years old and experiencing several leaks. Cost estimates to replace the roof ranged between $2.5 and $3 million. An initial IR inspection identified 1,208 square feet of roof requiring replacement at a total cost of $20,705. The following year another IR inspection was performed that found 1,399 square feet of roof requiring replacement at a cost of $18,217. A roof IR inspection program was started and the roof surveyed each year. The survey resulted in less than 200 square feet of roof identified needing replacement in any one of the following 4 years (one year results were as low as 30 square feet). The total cost for roof repair and upkeep for the 6 years was less than $60,000. If the facility would have been privately owned, interest on the initial $3 million at 10% would have amounted to $300,000 for the first year alone. Discounting interest on $3 million over the 5-year period, simple savings resulting from survey and repair versus initial replacement cost ($3 million to $60,000) amount to $2,940,000. This figure does not take into account interest on the $3 million, which would result in savings in excess of another $500,000 to $800,000, depending on loan interest paid.

6.2.7 Resources

The resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

FLIR Systems
Boston, MA
Telephone: 1-800-464-6372
Web address: www.flirthermography.com

Raytek
Santa Cruz, CA
Telephone: 1-800-227-8074
Web address: www.raytek-northamerica.com

Mikron Instrument Company, Inc.
Oakland, NJ
Telephone: (201) 405-0900
Web address: www.irimaging.com

Electrophysics
Fairfield, NJ
Telephone: (973) 882-0211
Web address: www.electrophysics.com

6.2.7.1 Infrared Service Companies

Hartford Steam Boiler
Engineering Services
Telephone: (703) 739-0350
Web address: www.hsb.com/infrared/

American Thermal Imaging
Red Wing, MN
Telephone: (877) 385-0051
Web address: www.americanthermalimaging.com

Infrared Services, Inc.
5899 S. Broadway Blvd.
Littleton, CO 80121
Voice: (303) 734-1746
Web address: www.infrared-thermography.com

Snell Thermal Inspections
U.S. wide
Telephone: 1-800-636-9820
Web address: www.snellinspections.com

6.2.7.2 Infrared Internet Resource Sites

Academy of Infrared Thermography
(www.infraredtraining.net)

- Level I, II, and III certification information and training schedule
- Online store (books, software, videos)
- Online resources (links, image gallery, message board)
- Communication (classifieds, news, industry-related information
- Company profile and contact information

Snell Infrared (Snellinfrared.com)

- Training and course information
- Industry links
- IR library
- Newsletter
- Classifieds
- IR application information

6.3.1 Introduction

One of the oldest predictive maintenance technologies still in use today is that of oil analysis. Oil analysis is used to define three basic machine conditions related to the machine's lubrication or lubrication system. First is the condition of the oil, that is, will its current condition lubricate per design? Testing is performed to determine lubricant viscosity, acidity, etc., as well as other chemical analysis to quantify the condition of oil additives like corrosion inhibitors. Second is the lubrication system condition, that is, have any physical boundaries been violated causing lubricant contamination? By testing for water content, silicon, or other contaminants (depending on the system design), lubrication system integrity can be evaluated. Third is the machine condition itself. By analyzing wear particles existing in the lubricant, machine wear can be evaluated and quantified.

In addition to system degradation, oil analysis performed and trended over time can provide indication of improperly performed maintenance or operational practices. Introduction of contamination during lubricant change-out, improper system flush-out after repairs, addition of improper lubricant, and improper equipment operation are all conditions that have been found by the trending and evaluation of oil analysis data.

Several companies provide oil analysis services. These services are relatively inexpensive and some analysis laboratories can provide analysis results within 24 hours. Some services are currently using the Internet to provide quick and easy access to the analysis reports. Analysis equipment is also available should a facility wish to establish its own oil analysis laboratory. Regardless of whether the analysis is performed by an independent laboratory or by in-house forces, accurate results require proper sampling techniques. Samples should be taken from an active, low-pressure line, ahead of any filtration devices. For consistent results and accurate trending, samples should be taken from the same place in the system each time (using a permanently installed sample valve is highly recommended). Most independent laboratories supply sample containers, labels, and mailing cartons. If the oil analysis is to be done by a laboratory, all that is required is to take the sample, fill in information such as the machine number, machine type, and sample date, and send it to the laboratory. If the analysis is to be done on-site, analytical equipment must be purchased, installed, and standardized. Sample containers must be purchased, and a sample information form created and printed.

The most common oil analysis tests are used to determine the condition of the lubricant, excessive wearing of oil-wetted parts, and the presence of contamination. Oil condition is most easily determined by measuring viscosity, acid number, and base number. Additional tests can determine the presence and/or effectiveness of oil additives such as anti-wear additives, antioxidants, corrosion inhibitors, and anti-foam agents. Component wear can be determined by measuring the amount of wear metals such as iron, copper, chromium, aluminum, lead, tin, and nickel. Increases in specific wear metals can mean a particular part is wearing, or wear is taking place in a particular part of the machine. Contamination is determined by measuring water content, specific gravity, and the level of silicon. Often, changes in specific gravity mean that the fluid or lubricant has been contaminated with another type of oil or fuel. The presence of silicon (usually from sand) is an indication of contamination from dirt.

6.3.2 Test Types

- **Karl Fischer Water Test** – The Karl Fischer Test quantifies the amount of water in the lubricant.

  Significance: Water seriously damages the lubricating properties of oil and promotes component corrosion. Increased water concentrations indicate possible condensation, coolant leaks, or process leaks around the seals.

- **ICP Spectroscopy** – Measures the concentration of wear metals, contaminant metals, and additive metals in a lubricant.

  Significance: Measures and quantifies the elements associated with wear, contamination, and additives. This information assists in determining the oil and machine condition.

The following guide highlights the elements that may be identified by this test procedure. Also provided are brief descriptions explaining where the particles came from for engines, transmissions, gears, and hydraulic systems.

Spectrometer Metals Guide				
Metal	**Engines**	**Transmissions**	**Gears**	**Hydraulics**
Iron	Cylinder liners, rings, gears, crankshaft, camshaft, valve train, oil pump gear, wrist pins	Gears, disks, housing, bearings, brake bands, shaft	Gears, bearings, shaft, housing	Rods, cylinders, gears
Chrome	Rings, liners, exhaust valves, shaft plating, stainless steel alloy	Roller bearings	Roller bearings	Shaft
Aluminum	Pistons, thrust bearings, turbo bearings, main bearings (cat)	Pumps, thrust washers	Pumps, thrust washers	Bearings, thrust plates
Nickel	Valve plating, steel alloy from crankshaft, camshaft, gears from heavy bunker-type diesel fuels	Steel alloy from roller bearings and shaft	Steel alloy from roller bearings and shaft	
Copper	Lube coolers, main and rod bearings, bushings, turbo bearings, lube additive	Bushings, clutch plates (auto/ powershift), lube coolers	Bushings, thrust plates	Bushings, thrust plates, lube coolers
Lead	Main and rod bearings, bushings, lead solder	Bushings (bronze alloy), lube additive supplement	Bushings (bronze alloy), grease contamination	Bushing (bronze alloy)
Tin	Piston flashing, bearing over-lay, bronze alloy, babbit metal along with copper and lead	Bearing cage metal	Bearing cage metal, lube additive	
Cadmium	N/A	N/A	N/A	N/A
Silver	Wrist pin bushings (EMDs), silver solder (from lube coolers)	Torrington needle bearings (Allison transmission)	N/A	Silver solder (from lube coolers)
Titanium	Gas turbine bearings/hub/ blades, paint (white lead)	N/A	N/A	N/A
Vanadium	From heavy bunker-type diesel fuels	N/A	N/A	N/A

Spectrometer Metals Guide (contd)

Contaminant Metals				
Silicon	Dirt, seals and sealants, coolant inhibitor, lube additive (15 ppm or less)	Dirt, seals and sealants, coolant inhibitor, lube additive (15 ppm or less)	Dirt, seals and sealants, coolant additive, lube additive (15 ppm or less)	Dirt, seals and sealant, coolant additive, lube additive (15 ppm or less)
Sodium	Lube additive, coolant inhibitor, salt water contamination, wash detergents	Lube additive, coolant inhibitor, salt water contamination, wash detergents	Lube additive, saltwater contamination, airborne contaminate	Lube additive, coolant inhibitor, saltwater contamination, airborne contaminate
Multi-Source Metals				
Molybdexznum	Ring plating, lube additive, coolant inhibitor	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor, coolant inhibitor, grease additive	Lube additive, coolant inhibitor
Antimony	Lube additive	Lube additive	Lube additive	Lube additive
Manganese	Steel alloy	Steel alloy	Steel alloy	Steel alloy
Lithium	N/A	Lithium complex grease	Lithium complex grease	Lithium complex grease
Boron	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor
Additive Metals				
Magnesium	Detergent dispersant additive, airborne contaminant at some sites	Detergent dispersant additive, airborne contaminant at some sites	Detergent dispersant additive, airborne contaminant at some sites	Detergent dispersant additive, airborne contaminant at some sites
Calcium	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water
Barium	Usually an additive from synthetic lubricants	Usually an additive from synthetic lubricants	Usually an additive from synthetic lubricants	Usually an additive from synthetic lubricants
Phosphorus	Anti-wear additive (ZDP)	Anti-wear additive (ZDP)	Anti-wear additive (ZPD), EP additive (extreme pressure)	Anti-wear additive (ZDP)
Zinc	Anti-wear additive (ZDP)	Anti-wear additive (ZDP)	Anti-wear additive (ZPD)	Anti-wear additive (ZDP)

Test Types (contd)

- **Particle Count** – Measures the size and quantity of particles in a lubricant.

  Significance: Oil cleanliness and performance. An increase in particle size and gravity is an indication of a need for oil service.

- **Viscosity Test** – Measure of a lubricant's resistance to flow at a specific temperature.

  Significance: Viscosity is the most important physical property of oil. Viscosity determination provides a specific number to compare to the recommended oil in service. An abnormal viscosity (±15%) is usually indicative that lubricant replacement is required.

- **Fourier transform (FT)-IR Spectroscopy** – Measures the chemical composition of a lubricant.

  Significance: Molecular analysis of lubricants and hydraulic fluids by FT-IR spectroscopy produces direct information on molecular species of interest, including additives, fluid breakdown products, and external contamination.

- **Direct Read Ferrography** – Measures the relative amount of ferrous wear in a lubricant.

  Significance: The direct read gives a direct measure of the amount of ferrous wear metals of different size present in a sample. If trending of this information reveals changes in the wear mode of the system, then action is required.

- **Analytical Ferrography** – Allows analyst to visually examine wear particles present in a sample.

  Significance: A trained analyst visually determines the type and severity of wear deposited onto the substrate by using a high magnification microscope. The particles are readily identified and classified according to size, shape, and metallurgy.

- **Total Acid Number** – Measures the acidity of a lubricant.

  Description: Organic acids, a by-product of oil oxidation, degrade oil properties and lead to corrosion of the internal components. High acid levels are typically caused by oil oxidation.

6.3.3 Types of Equipment

Although independent laboratories generally perform oil analysis, some vendors do provide analysis equipment that can be used on-site to characterize oil condition, wear particles, and contamination. These devices are generally composed of several different types of test equipment and standards including viscometers, spectrometers, oil analyzers, particle counters, and microscopes. On-site testing can provide quick verification of a suspected oil problem associated with critical components such as water contamination. It can also provide a means to quickly define lubricant condition to determine when to change the lubricant medium. For the most part, detailed analysis will still require the services of an independent laboratory.

Typical oil analysis equipment available from several different vendors.

6.3.4 System Applications

All machines with motors 7.5 hp or larger, and critical or high-cost machines should be evaluated for routine lubricating oil analysis (NASA 2000) from monthly to quarterly. All hydraulic systems, except mobile systems, should be analyzed on a quarterly basis. Mobile systems should be considered for analysis based upon the machine size and the cost effectiveness of performing the analysis. Generally speaking, it is more cost effective in mobile equipment to maintain the hydraulic fluid based on the fluid condition. However, for small systems, the cost to flush and replace the hydraulic fluid on a time basis may be lower than the cost to analyze the fluid on a routine basis. Typical equipment applications include:

- Turbines
- Boiler feed pumps
- Electrohydraulic control (EHC) systems
- Hydraulics
- Servo valves
- Gearboxes
- Roller bearings
- Anti-friction bearings
- Any system where oil cleanliness is directly related to longer lubricant life, decreased equipment wear, or improved equipment performance

6.3.5 Equipment Cost/Payback

For facilities utilizing a large number of rotating machines that employ circulating lubricant, or for facilities with high dollar equipment using circulating lubricant, few predictive maintenance technologies can offer the opportunity of such a high return for dollars spent. Analysis for a single sample can run from $15 to $100 depending on the level of analysis requested – samples are typically sent through the mail to the testing center. Given the high equipment replacement cost, labor cost, and downtime cost involved with a bearing or gearbox failure, a single failure prevented by the performance of oil analysis can easily pay for a program for several years.

6.3.6 Training Availability

Training for lubricant and wear particle analysis typically takes place via vendors. Because the analysis is usually conducted by outside vendors at their location, training consists of proper sampling techniques (location and frequency) as well as requisite sample handling guidance.

6.3.7 Case Studies

Reduced Gear Box Failure

Through oil analysis, a company determined that each time oil was added to a gear reducer, contamination levels increased and this was accompanied by an increase in bearing and gear failures. Further examination determined that removing the cover plate to add oil allowed contamination from the process to fall into the sump. Based on this, the system was redesigned to prevent the introduction of contamination during oil addition. The result was a reduction in bearing/gearbox failure rates.

Oil Changes When Needed

A major northeast manufacturer switched from a preventive maintenance approach of changing oil in 400 machines using a time-based methodology to a condition-based method using in-house oil analysis. The oil is now being changed based on its actual condition and has resulted in a savings in excess of $54,000 per year.

Oil Changes and Equipment Scheduling

A northeast industrial facility gained an average of 0.5 years between oil changes when it changed oil change requirements from a preventive maintenance time-based approach to changing oil based on actual conditions. This resulted in greater than a $20,000 consumable cost in less than 9 months.

A large chemical manufacturing firm saved more than $55,000 in maintenance and lost production cost avoidance by scheduling repair of a centrifugal compressor when oil analysis indicated water contamination and the presence of high ferrous and non-ferrous particle counts.

6.3.8 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.3.8.1 Analysis Equipment Resources

Computational Systems, Inc./
Emerson Process Management
Knoxville, TN
Telephone: (865) 675-2400
Fax: (865) 218-1401
Web address: **www.compsys.com**

Reliability Direct, Inc.
League City, TX
Telephone: 1-888-710-6786
Fax: (281) 334-4255
Web address: **www.reliabilitydirect.com**

Spectro, Inc.
Industrial Tribology Systems
Littleton, MA
Telephone: (978) 486-0123
Fax: (978) 486-0030
E-Mail: Info@SpectroInc.com
Web address: **www.spectroinc.com**

6.3.8.2 Oil Analysis Laboratories

Computational Systems, Inc./
Emerson Process Management
Knoxville, TN
Telephone: (865) 675-2400
Fax: (865) 218-1401
Web address: **www.comsys.com**

Polaris Laboratories
Indianapolis, IN
Telephone: (877) 808-3750
Fax: (317) 808-3751
Web address: **www.polarislabs1.com**

Analysts, Inc.
Locations throughout the U.S.
Telephone: (800) 336-3637
Fax: (310) 370-6637
Web address: **www.analystsinc.com**

LubeTrak
Sandy, UT
Telephone: 1-866-582-3872 (Toll Free)
Web address: **www.lubetrak.com**

6.3.8.3 Internet Resource Sites

www.testoil.com

- Sample report
- Free oil analysis
- Industry-related articles
- Test overview
- Laboratory services
- Training services

www.compsys.com

- Laboratory service
- Technical articles
- Application papers
- Sample report
- Training services
- Technical notes

www.natrib.com

- Technical articles
- Case studies
- Newsletters
- Application notes

6.4 Ultrasonic Analysis

6.4.1 Introduction

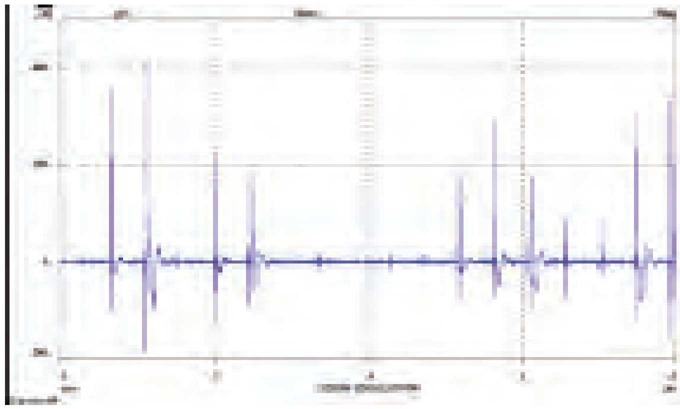
Ultrasonic, or ultrasounds, are defined as sound waves that have a frequency level above 20 kHz. Sound waves in this frequency spectrum are higher than what can normally be heard by humans. Non-contact ultrasonic detectors used in predictive maintenance detect airborne ultrasound. The frequency spectrums of these ultrasounds fall within a range of 20 to 100 kHz. In contrast to IR emissions, ultrasounds travel a relatively short distance from their source. Like IR emissions, ultrasounds travel in a straight line and will not penetrate solid surfaces. Most rotating equipment and many fluid system conditions will emit sound patterns in the ultrasonic frequency spectrum. Changes in these ultrasonic wave emissions are reflective of equipment condition. Ultrasonic detectors can be used to identify problems related to component wear as well as fluid leaks, vacuum leaks, and steam trap failures. A compressed gas or fluid forced through a small opening creates turbulence with strong ultrasonic components on the downstream side of the opening. Even though such a leak may not be audible to the human ear, the ultrasound will still be detectable with a scanning ultrasound device.

Ultrasounds generated in vacuum systems are generated within the system. A small percentage of these ultrasonic waves escape from the vacuum leak and are detectable, provided the monitoring is performed close to the source or the detector gain is properly adjusted to increase detection performance. In addition to system vacuum or fluid leaks, ultrasonic wave detection is also useful in defining abnormal conditions generated within a system or component. Poorly seated valves (as in the case of a failed steam trap) emit ultrasounds within the system boundaries as the fluid leaks past the valve seat (similar to the sonic signature generated if the fluid was leaking through the pipe or fitting walls). These ultrasounds can be detected using a contact-type ultrasonic probe.

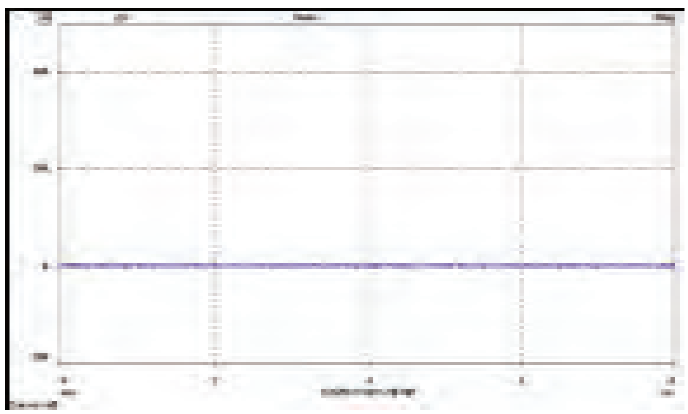
Ultrasonic detection devices can also be used for bearing condition monitoring. According to National Aeronautics and Space Administration (NASA) research, a 12-50x increase in the amplitude of a monitored ultrasonic frequency (28 to 32 kHz) can provide an early indication of bearing deterioration.

Ultrasonic detection devices are becoming more widely used in detection of certain electrical system anomalies. Arcing/tracking or corona all produce some form of ionization that disturbs the air molecules around the equipment being diagnosed and produces some level of ultrasonic signature. An ultrasonic device can detect the high-frequency noise produced by this effect and translate it, via heterodyning, down into the audible ranges. The specific sound quality of each type of emission is heard in headphones while the intensity of the signal can be observed on a meter to allow quantification of the signal.

In addition to translating ultrasonic sound waves into frequencies heard by the human ear or seen on a meter face, many ultrasonic sound wave detectors provide the capability to capture and store the detectors output. Utilizing display and analysis software, a time waveform of the ultrasonic signature can then be visually displayed. This functionality increases the technology's capability to capture and store quantifiable data related to a components operating condition. Ultrasonic signature information can then be used to baseline, analyze, and trend a component's condition. In contrast to a technician's subjective analysis of a component's condition using an audio signal, many ultrasonic anomalies indicative of component problems are more easily defined using a signature profile. The following images of ultrasonic time waveforms from two identical gearboxes illustrate how ultrasonic signature data storage and analysis can be used to quantify machine condition. Gearbox "1" waveform shows an ultrasonic signature anomaly that may be attributable to missing or worn gear teeth, while Gearbox "2" signature shows a flat profile.



Gearbox 1



Gearbox 2

Generally, this type of diagnosis can be performed on a standard personal computer (PC). The programs not only provide the spectral and time series views of the ultrasonic signature but enable users to hear the translated sound samples simultaneously as they are viewing them on the PC monitor.

6.4.2 Types of Equipment

Ultrasonic analysis is one of the less complex and less expensive predictive maintenance technologies. The equipment is relatively small, light, and easy to use. Measurement data are presented in a straightforward manner using meters or digital readouts. The cost of the equipment is moderate and the amount of training is minimal when compared to other predictive maintenance technologies. The picture to the right shows a typical ultrasonic detection device.

Typical hand-held ultrasonic detector

Since ultrasounds travel only a short distance, some scanning applications could present a safety hazard to the technician or the area of interest may not be easily accessible. In these applications, the scanning device is generally designed with a gain adjust to increase its sensitivity, thereby allowing scanning from a greater distance than normal. Some ultrasonic detectors are designed to allow connection of a special parabolic dish-type sensing device (shown at right) that greatly extends the normal scanning distance.

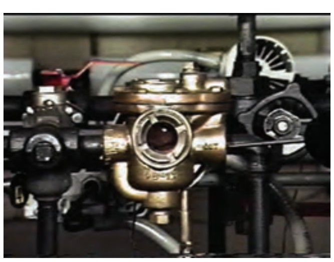
Parabolic dish used with ultrasonic detector greatly extends detection range abilities.

6.4.3 System Applications

6.4.3.1 Pressure/Vacuum Leaks

- Compressed air
- Oxygen
- Hydrogen
- Heat exchangers
- Boilers
- Condensers
- Tanks
- Pipes
- Valves
- Steam traps.

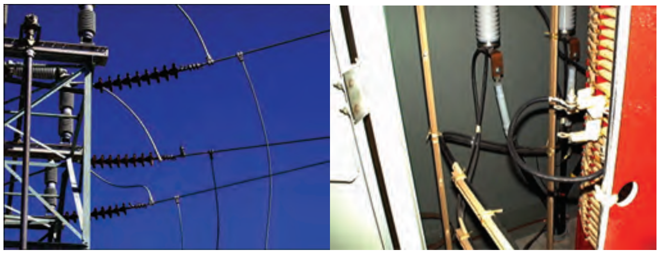
Ultrasonic detection can be used to locate underground system leaks and detect heat exchanger tube leakage.



From steam trap faults and valve leakage to compressor problems, ultrasonic detection can be used to find a variety of problems that generate ultrasonic signatures.

6.4.3.2 Mechanical Applications

- Mechanical inspection
- Bearings
- Lack of lubrication
- Pumps
- Motors
- Gears/Gearboxes
- Fans
- Compressors
- Conveyers.



Mechanical devices are not the only sources of ultrasonic emission. Electrical equipment will also generate ultrasonic waves if arcing/tracking or corona are present.

6.4.3.3 Electrical Applications

- Arcing/tracking/corona
- Switchgear
- Transformers
- Insulators
- Seals/Potheads
- Junction boxes
- Circuit breakers.

6.4.4 Equipment Cost/Payback

As indicated earlier, ultrasonic analysis equipment cost is minimal when compared to other predictive maintenance technologies. A typical handheld scanner, software, probes, will cost from $750 to $10,000 – depending on the type, accuracy and features. The minimal expense combined with the large savings opportunities will most often result in an equipment payback period of 6 months or less.

6.4.5 Training Availability

Training for ultrasonic analysis is available through a variety of system manufacturers and vendors. Depending on your needs, consider training that will qualify you for the American Society of Non-destructive Testing (ASNT) various levels of certification. Generically, these levels take the following form:
Level I – the student is competent with equipment function and use; Level II – the student is fully capable and experienced and can complete diagnostics and recommendations; Level III – the student is fully experienced to supervise and teach Level I and II student.

Steam Trap Applications
(NASA 2000):

Steam traps should be monitored on the down-stream side of the trap using the test equipment's contact mode. Each type of steam trap produces a distinct sound as briefly described below. It is recommended that users receive training and then gain experience in a controlled environment before diagnosing operating systems.

Typical ultrasonic signatures will include and opening and closing sound characterized by steam rushing sound followed by a period of relative quiet. Many types of traps fail in the open position, producing a continuous, rushing sound. Common trap types and their diagnostic signatures include:

Inverted Bucket: A normal trap sounds as if it is floating; a failed trap sinks, producing a continuous flow noise.

Float and Thermostatic (Continuous Load): Flow and noise associated with these traps are usually modulated as the trap opens and closes. Failed traps are normally cold and silent.

Thermostatic: Ultrasonic testing results of this type of trap vary. The signatures produced by these traps can be continuous or intermittent depending on the type. It is best to reference a properly functioning trap for a baseline signature for comparison.

6.4.6 Case Studies

Ultrasound Detects Compressed Air Leaks

A northeast industrial plant was experiencing some air problems. The facility's two compressors were in the on mode for an inordinate amount of time, and plant management assumed a third compressor was needed, at a cost of $50,000. Instead, the foundry invested less than $1,000 in contracting an outside firm to perform an ultrasound inspection of its air system. In a single day, the ultrasound technician detected 64 air leaks accounting for an estimated total air loss of 295.8 cfm (26% of total system capacity). Considering it cost approximately $50,014 per year (calculated at $.04/kilowatt/hour) to operate the two air compressors, at a total of 1,120 cfm, correcting this air loss saved the plant $13,000 per year. In addition, the plant avoided having to spend another $50,000 on another air compressor, because after the leaks were found and repaired, the existing compressors were adequate to supply demand.

A Midwest manufacturer saved an estimated $75,900 in annual energy costs as a result of an ultrasound survey of its air system. A total of 107 air leaks were detected and tagged for repair. These leaks accounted for an air loss of 1,031 cfm, equal to 16% of the total 6,400 cfm produced by the air compressors that supply the facility.

Steam Trap Monitoring (NASA 2000)

Implementation of a steam trap monitoring program often has significant financial benefit. Initial steam trap surveys in the petrochemical industry revealed that 34% of the steam traps inspected had failed, mostly in the open position. For facilities with a periodic steam trap monitoring program, the following distribution of degradations were discovered during each survey:

- Five steam leaks (other than traps) per 150 traps
- Two leaking valves per 150 traps
- Twenty of the 150 traps leak

Building off these findings – one trap (failed open) with a ¼ inch orifice will lose roughly 500 MBtu/year (at 25 psi) if undiscovered. With a cost of steam at $7.50 per MBtu, a boiler efficiency of 75% and a system energized for 50% of the year, the annual cost savings of detecting this leak is $2,500. This one leak could justify the purchase of an ultrasonic detector – and this is likely one of many leaks to be found.

6.4.7 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.4.7.1 Equipment Resources

UE Systems
Elmsford, NY
Telephone: (914) 592-1220 or
1-800-223-1325
Fax: (914) 347-2181
Web address: **www.uesystems.com**

CTRL Systems, Inc.
Westminster, MD
Telephone: (877) 287-5797
Web address: **www.ctrlsys.com**

Specialized Diagnostic Technologies, Inc.
SDT North America
Cobourg, Ontario
Canada
Telephone: 1-800-667-5325
Web address: www.sdtnorthamerica.com

Superior Signal Company
Spotswood, NJ
Telephone: 1-800-945-TEST(8378) or
(732) 251-0800
Fax: (732) 251-9442
Web address: www.superiorsignal.com

6.4.7.2 Service Companies

Mid-Atlantic Infrared Services, Inc.
Bethesda, MD
Telephone: (301) 320-2870
Web address: www.midatlanticinfrared.com

UE Systems, Inc.
Telephone: (914) 592-1220 or
1-800-223-1325 (Toll Free)
Fax: (914) 347-2181
Web address: www.uesystems.com

Leek Seek
Telephone: TX: (512) 246-2071
CA: (909) 786-0795
FL: (727) 866-8118
Web address: www.leekseek.com

6.4.7.3 Internet Resource Sites

www.uesystems.com
- Technology overview
- Training
- Links
- Sound demos

www.superiorsignal.com
- Technology overview
- Ultrasonic sound bites (examples)
- Ultrasonic spectral graphs

6.5 Vibration Analysis

6.5.1 Introduction

As all of us who ride or drive an automobile with some regularity know, certain mechanical faults or problems produce symptoms that can be detected by our sense of feel. Vibrations felt in the steering wheel can be an indicator of an out-of-balance wheel or looseness in the steering linkage. Transmission gear problems can be felt on the shift linkage. Looseness in exhaust system components can sometimes be felt as vibrations in the floorboard. The common thread with all these problems is that degeneration of some mechanical device beyond permissible operational design limitations has manifested itself by the generation of abnormal levels of vibration. What is vibration and what do we mean by levels of vibration? The dictionary defines vibration as "a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed or the state of being vibrated or in vibratory motion as in (1) oscillation or (2) a quivering or trembling motion."

The key elements to take away from this definition are vibration is motion, and this motion is cyclic around a position of equilibrium. How many times have you touched a machine to see if it was running? You are able to tell by touch if the motor is running because of vibration generated by motion of rotational machine components and the transmittal of these forces to the machine housing. Many parts of the machine are rotating and each one of these parts is generating its own distinctive pattern and level of vibration. The level and frequency of these vibrations are different and the human touch is not sensitive enough to discern these differences. This is where vibration detection instrumentation and signature analysis software can provide us the necessary sensitivity. Sensors are used to quantify the magnitude of vibration or how rough or smooth the machine is running. This is expressed as vibration amplitude. This magnitude of vibration is expressed as:

- **Displacement** – The total distance traveled by the vibrating part from one extreme limit of travel to the other extreme limit of travel. This distance is also called the "peak-to-peak displacement."
- **Velocity** – A measurement of the speed at which a machine or machine component is moving as it undergoes oscillating motion.
- **Acceleration** – The rate of change of velocity. Recognizing that vibrational forces are cyclic, both the magnitude of displacement and velocity change from a neutral or minimum value to some maximum. Acceleration is a value representing the maximum rate that velocity (speed of the displacement) is increasing.

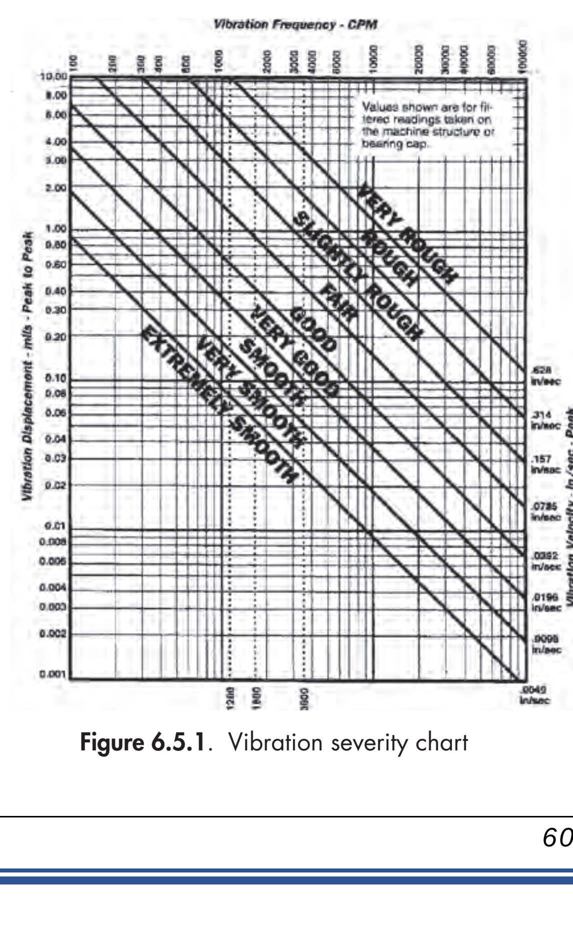


Figure 6.5.1. Vibration severity chart

Various transducers are available that will sense and provide an electrical output reflective of the vibrational displacement, velocity, or acceleration. The specific unit of measure to best evaluate the machine condition will be dependent on the machine speed and design. Several guidelines have been published to provide assistance in determination of the relative running condition of a machine. An example is seen in Figure 6.5.1. It should be said that the values defined in this guideline, or similar guidelines, are not absolute vibration limits above which the machine will fail and below which the machine will run indefinitely. It is impossible to establish absolute vibration limits. However, in setting up a predictive maintenance program, it is necessary to establish some severity criteria or limits above which action will be taken. Such charts are not intended to be used for establishing vibration acceptance criteria for rebuilt or newly installed machines. They are to be used to evaluate the general or overall condition of machines that are already installed and operating in service. For those, setting up a predictive maintenance program, lacking experience or historical data, similar charts can serve as an excellent guide to get started.

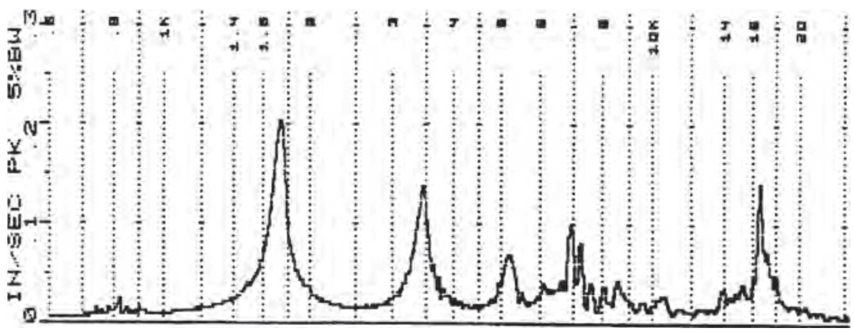


Figure 6.5.2. FFT – Example of graph breaking down vibration level at different frequencies

As indicated earlier, many vibration signals are generated at one time. Once a magnitude of vibration exceeds some predetermined value, vibration signature analysis can be used in defining the machine location that is the source of the vibration and in need of repair or replacement. By using analysis equipment and software, the individual vibration signals are separated and displayed in a manner that defines the magnitude of vibration and frequency (Figure 6.5.2). With the understanding of machine design and operation, an individual schooled in vibration signature analysis can interpret this information to define the machine problem to a component level.

6.5.2 Types of Equipment

Depending on the application, a wide variety of hardware options exist in the world of vibration. Although not complicated, actual hardware requirements depend on several factors. The speed of the machine, on-line monitoring versus off-line data collection, analysis needs, signal output requirements, etc., will affect the type of equipment options available. Regardless of the approach, any vibration program will require a sensing device (transducer) to measure the existing vibration and translate this information into some electronic signal. Transducers are relatively small in size (see Figure 6.5.3) and can be permanently mounted or affixed to the monitoring location periodically during data collection.

Figure 6.5.3. Typical vibration transducers

In some cases, the actual translation of the vibration to an electrical signal occurs in a handheld monitoring device. A metal probe attached to a handheld instrument is held against a point of interest and the instrument translates the motions felt on the probe to some sort of electrical signal. Other portable devices use a transducer and handheld data-collection device. Both styles will provide

Examples of typical hand-held vibration sensing meters. Note readout providing immediate level indication.

Typical Vibration Analyzer – Note liquid crystal display providing actual vibration waveform information in addition to machine condition analytical capabilities.

some sort of display where the vibration magnitude is defined. Styles and equipment size vary greatly, but equipment is designed to be portable.

Some signal acquisition and analysis equipment interface a PC directly with the sensors.

In addition to instruments designed to measure vibration magnitude, many manufacturers provide instrumentation that will perform signal analysis as well. Some equipment is a stand-alone design and performs analysis in the field independent of computer interface while other equipment designs interface tranducers directly with a PC where analysis software is utilized to interpret the signal data.

6.5.3 System Applications

Vibration monitoring and analysis can be used to discover and diagnose a wide variety of problems related to rotating equipment. The following list provides some generally accepted abnormal equipment conditions/faults where this predictive maintenance technology can be of use in defining existing problems:

- Unbalance
- Eccentric rotors
- Misalignment
- Resonance problems
- Mechanical looseness/weakness
- Rotor rub
- Sleeve-bearing problems
- Rolling element bearing problems

- Flow-induced vibration problems
- Gear problems
- Electrical problems
- Belt drive problems.

Analyzing equipment to determine the presence of these problems is not a simple and easily performed procedure. Properly performed and evaluated vibration signature analysis requires highly trained and skilled individuals, knowledgeable in both the technology and the equipment being tested. Determination of some of the problems listed is less straightforward than other problems and may require many hours of experience by the technician to properly diagnosis the condition.

6.5.4 Equipment Cost/Payback

As indicated earlier, the styles, types, and capabilities of vibration monitoring equipment vary greatly. Naturally, equipment cost follows this variance. Transducers can cost under $100. The expected cost for vibration metering devices capable of defining magnitude with no analysis capability is approximately $1,000. The cost goes up from there. A high-end vibration analyzer with software and all the accessories can exceed $30,000. A typical industrial site can expect to recover the cost of the high-end equipment investment within 2 years. Sites with a minimal number of rotating equipment, low-cost equipment installations, and/or no production-related concerns may find it uneconomically advantageous to purchase a $30,000 vibration analysis system. These facilities may be wise to establish an internal program of vibration monitoring using a low-cost vibration-metering device and then employ the services of an outside contractor to conduct periodic surveys. These services generally range in cost from $600 to $1,200 per day.

6.5.5 Training Availability

Training for vibration analysis is available through a variety of system manufacturers and vendors. Additional training and certification is available through the Vibration Institute (see Resources section for contact information) from where certification for Levels I – IV is available.

6.5.6 Case Studies

Vibration Analysis on Pump

Vibration analysis on a 200-hp motor/pump combination resulted in determination of improperly sized shaft bearings on both the pump end and the motor end. Repair costs were less than $2,700. Continued operation would have led to failure and a replacement cost exceeding $10,000.

6.5.7 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.5.7.1 Training Equipment Resources

Wilcoxon Research, Inc.
Gaithersburg, MD
Telephone: (301) 330-8811 or 1-800-945-2696
Web site: www.wilcoxon.com

Computational Systems, Inc./ Emerson Process Management
Web address: www.compsys.com

DLI Engineering Corporation
U.S. wide
Telephone: 1-800-654-2844 or (206) 842-7656
Web address: www.dliengineering.com

Commtest, Inc.
Knoxville, TN
Telephone: 1-877-582-2946
Web address: www.commtest.com

6.5.7.2 Service Companies

Industrial Research Technology
Bethlehem, PA - Pittsburgh, PA - Cleveland, OH - Detroit, MI - Chicago, IL - Charleston, SC
Telephone: (610) 867-0101 or 1-800-360-3594
Fax: (610) 867-2341

Computational Systems, Inc./ Emerson Process Management
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

6.5.7.3 Training/Internet Resource Sites

Vibration Institute
www.vibinst.org
6262 S. Kingery Highway
Suite 212, Willowbrook, IL 60527
Telephone: (630)654-2254
Fax: (630)654-2271

www.plant-maintenance.com
- Training material
- Industry links
- Free software
  - FFT/CMMS/Inventory control
- Technical articles
- Maintenance-related articles

www.reliabilityweb.com
- Training material
- Industry links
- Free software
  - FFT/CMMS/Inventory control
- Technical articles
- Maintenance-related articles

www.maintenance-news.com
- Industry links
- Technical articles
- Maintenance-related articles

6.6 Motor Analysis

6.6.1 Introduction

When it comes to motor condition analysis, infrared (IR) and vibration will not provide all the answers required to properly characterize motor condition. Over the past several years, motor condition analysis techniques have evolved from simple testing into testing techniques that more accurately define a motor's condition. Motor faults or conditions like winding short-circuits, open coils, improper torque settings, as well as many mechanically-related problems can be diagnosed using motor analysis techniques. Use of these predictive maintenance techniques and technologies to evaluate winding insulation and motor condition has not grown as rapidly as other predictive techniques. Motor analysis equipment remains fairly expensive and proper analysis requires a high degree of skill and knowledge. Recent advances in equipment portability and an increase in the number of vendors providing contracted testing services continue to advance predictive motor analysis techniques. Currently, more than 20 different types of motor tests exist, depending on how the individual tests are defined and grouped. The section below provides an overview of two commonly used tests.

6.6.2 Motor Analysis Test

6.6.2.1 Electrical Surge Comparison

In addition to ground wall insulation resistance, one of the primary concerns related to motor condition is winding insulation. Surge comparison testing can be used to identify turn-to-turn and phase-to-phase insulation deterioration, as well as a reversal or open circuit in the connection of one or more coils or coil groups. Recent advances in the portability of test devices now allow this test technique to be used in troubleshooting and predictive maintenance. Because of differences in insulation thickness, motor winding insulation tends to be more susceptible to failure from the inherent stresses existing within the motor environment than ground wall insulation. Surge comparison testing identifies insulation deterioration by applying a high frequency transient surge to equal parts of a winding and comparing the resulting voltage waveforms. Differences seen in the resulting waveforms are indicative insulation or coil deterioration. A properly trained test technician can use these differences to properly diagnose the type and severity of the fault. In addition to utilization of this motor analysis technique in a predictive maintenance program, it can also be used to identify improper motor repair practices or improper operating conditions (speeds, temperature, load).

Surge comparison testing is a moderately complex and expensive predictive maintenance technique. As with most predictive maintenance techniques, the greatest saving opportunities do not come directly from preventing a catastrophic failure of a component (i.e., motor) but rather the less tangible cost saving benefits. Reduced downtimes, ability to schedule maintenance, increased production, decreased overtime, and decreased inventory cost are just a few of the advantages of being able to predict an upcoming motor failure.

6.6.2.2 Motor Current Signature Analysis

Another useful tool in the motor predictive maintenance arsenal is motor current signature analysis (MCSA). MCSA provides a non-intrusive method for detecting mechanical and electrical problems in motor-driven rotating equipment. The technology is based on the principle that a conventional electric motor driving a mechanical load acts as a transducer. The motor (acting as a transducer) senses mechanical load variations and converts them into electric current variations that are transmitted along the motor power cables. These current signatures are reflective of a machine's condition and closely resemble signatures produced using vibration monitoring. These current signals are recorded and processed by software to produce a visual representation of the existing frequencies against current amplitude. Analysis of these variations can provide an indication of machine condition, which may be trended over time to provide an early warning of machine deterioration or process alteration.

Motor current signature analysis is one of the moderately complex and expensive predictive techniques. The complexity stems in large part from the relatively subjective nature of interpreting the spectra, and the limited number of industry-wide historical or comparative spectra available for specific applications. This type of analysis is typically limited to mission critical applications and/or those with life/health/safety implications.

6.6.3 System Applications

- Stem packing degradation
- Incorrect torque switch settings
- Degraded stem or gear case lubrication
- Worn gear tooth wear
- Restricted valve stem travel
- Obstructions in the valve seat area
- Disengagement of the motor pinion gear
- Improper seal/packing installation
- Improper bearing or gear installation
- Inaccurate shaft alignment or rotor balancing
- Insulation deterioration
- Turn-to-turn shorting
- Phase-to-phase shorting
- Short circuits
- Reversed or open coils.

6.6.4 Equipment Cost/Payback

As indicated earlier, motor analysis equipment is still costly and generally requires a high degree of training and experience to properly diagnosis equipment problems. A facility with a large number of motors critical to process throughput may find that ownership of this technology and adequately trained personnel more than pays for itself in reduced downtime, overtime cost, and motor inventory needs. Smaller facilities may find utilization of one of the many contracted service providers valuable in defining and maintaining the health of the motors within their facility. As with most predictive maintenance contract services, cost will range from $600 to $1,200 per day for on-site support. Finding a single motor problem whose failure would result in facility downtime can quickly offset the cost of these services.

6.6.5 Training Availability

Training for motor analysis is usually highly specialized and typically available through a variety of system manufacturers and vendors.

6.6.6 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.6.6.1 Equipment Resources

Computational Systems, Inc./
Emerson ProcessManagement
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

Chauvin Arnoux®, Inc.
d.b.a. AEMC® Instruments
200 Foxborough Boulevard
Foxborough, MA 02035
Telephone: (508) 698-2115
or (800) 343-1391
Fax: (508) 698-2118
Email: sales@aemc.com

AVO International
4651 S. Westmoreland Road
Dallas, TX 75237-1017
Telephone: (800) 723-2861
Fax: (214) 333-3533

Baker Instrument Company
4812 McMurry Avenue
Fort Collins, CO 80525
Telephone: (970) 282-1200 or (800) 752-8272
Fax: (970) 282-1010

6.6.6.2 Service Companies

Industrial Technology Research
Bethlehem, PA - Pittsburgh, PA -
Cleveland, OH - Detroit, MI - Chicago, IL -
Charleston, SC - Hamilton, ONT
Telephone: (610) 867-0101 or (800) 360-3594
Fax: (610) 867-2341

6.6.6.3 Internet Site Resources

www.mt-online.com
- Technology overview
- Technology vendors
- Industry articles

www.reliabilityweb.com
- Service companies
- Training services
- Software links (including Motor Master)

6.7 Performance Trending

6.7.1 Introduction

In addition to the general preventive maintenance we perform, or have performed on our vehicles, many of us log and trend important parametric information related to the health of our vehicles and use this information to determine maintenance needs. We calculate and trend our cars mileage per gallon of gas. We track engine temperature and oil pressure. We track oil usage. This information is then used to define when vehicle maintenance is required. Maintenance activities such as tune-ups, thermostat replacement, cooling system flushes, belt replacements, oil seal replacements, etc., may all be originally stimulated by vehicle parametric information we trend.

Using this performance trending approach can also be a valuable tool in maintaining the health and operational performance of the components in our facilities/plants. By logging and trending the differential pressure across a supply or discharge filter in the HVAC system, we can determine when filter replacement is required, rather than changing the filter out at some pre-defined interval (preventive maintenance). Logging and trending temperature data can monitor the performance of many heat exchangers. This information can be used to assist in the scheduling of tube cleaning. It may also serve as an indication that flow control valves are not working properly or chemical control measures are inadequate. Perhaps a decrease in heat exchanger performance, as seen by a change in delta-temperature, is due to biological fouling at our cooling loop pump suction. An increase in boiler stack temperature might be an indication of tube scaling. We may need to perform tube cleaning and adjust our chemistry control measures. Changes in combustion efficiency may be indicative of improperly operating oxygen trim control, fuel flow control, air box leakage, or tube scaling.

The key idea of performance trending is that much of the equipment installed in our facilities is already provided with instrumentation that can be used to assist in determination of the health/condition of the related component. Where the instruments are not present, installation of a pressure, temperature, or current sensing data loggers can be relatively straight forward and rather inexpensive. A particular good resource to better understand portable meters or data loggers and their vendors is the report titled *Portable Data Loggers Diagnostic Tools for Energy-Efficient Building Operations* (PECI 1999).

6.7.2 How to Establish a Performance Trending Program

One of the first steps of any predictive maintenance program is to know what equipment exists in your facility. First, generate a master equipment list, then prioritize the equipment on the list to define which pieces of equipment are critical to your facility's operation, important to personnel safety, or can have a significant budget impact (either through failure or inefficient operation).

Evaluate what parametric data should/could be easily collected from installed or portable instrumentation to provide information related to the condition/performance of the equipment on the master list based on your equipment prioritization.

Determine what, if any, of the defined data are already collected. Evaluate if any related parametric information is currently being tracked and if that information provides information regarding the condition or efficiency of a component or system. Terminate the collection of information not useful in the evaluation of a component's condition/efficiency unless required by other administrative requirements.

Define and install instrumentation not currently available to monitor a critical component's condition/efficiency.

Log the information at some frequency defined by plant engineering or operational staff. For example, the frequency may be every 4 hours while operating or may simply be a single reading after reaching steady-state conditions, depending on the data evaluation needs.

Provide collected data to individual with knowledge and background necessary to properly trend and evaluate it.

6.7.3 System Applications

Generally, any plant component with installed, or easily installed, instrumentation useful in evaluating the components condition, operation, or efficiency can be trended. Information can also be obtained using portable instrumentation, (e.g., an infrared thermometer or a variety of stand-alone data logging devices). Some general applications might be:

- Heat exchangers
- Filters
- Pumps
- HVAC equipment
- Compressors
- Diesel/gasoline engines
- Boilers.

6.7.4 Equipment Cost/Payback

The cost to establish an effective trending program is minimal and can provide one of the largest returns on dollars expended. Most plants have much of the instrumentation needed to gain the parametric information already installed. Today's instrumentation offers many cost-effective opportunities to gather information without having to incur the expense of running conduit with power and signal cabling. The information gatherers are generally already on the payroll and in many cases, already gathering the needed information to be trended. For the most part, establishing a trending program would require little more than using the information already gathered and currently collecting dust. When portable data-logging systems are purchased, the payback for the little extra money spent is quickly recovered in increased machine efficiency and decreased energy cost.

6.7.5 Training Availability

Training for performance trending is very application-specific. Most trending is done via pre-installed system sensors, an existing building automation system and/or the use of portable data loggers. All of these systems will function differently with education and training typically available through equipment vendors or distributors.

6.7.6 Case Studies

Operational Efficiency Opportunity Using Data Logger Data to Validate Boiler Operation (FEMP 2007)

Objective: Use data logger (5-minute run-time, time-series data) to validate proper boiler operation.

Situation: Federal facility with boiler heating/process loads. End-use run-time data logger installed. Data reported are from peak-season loading conditions.

Findings: Reviewing the 5-minute run-time data (data collected with stand-alone magnetic field enabled logger placed near boiler combustion-air blower motor) reveals excessive cycling of boiler; Figure 6.7.1 presents these data. A bar in the figure rising from 0 to 1 indicates the boiler cycling "on," the bar returning from 1 to 0 indicates the boiler cycling "off." Therefore, each bar in the graph represents one on/off cycle.

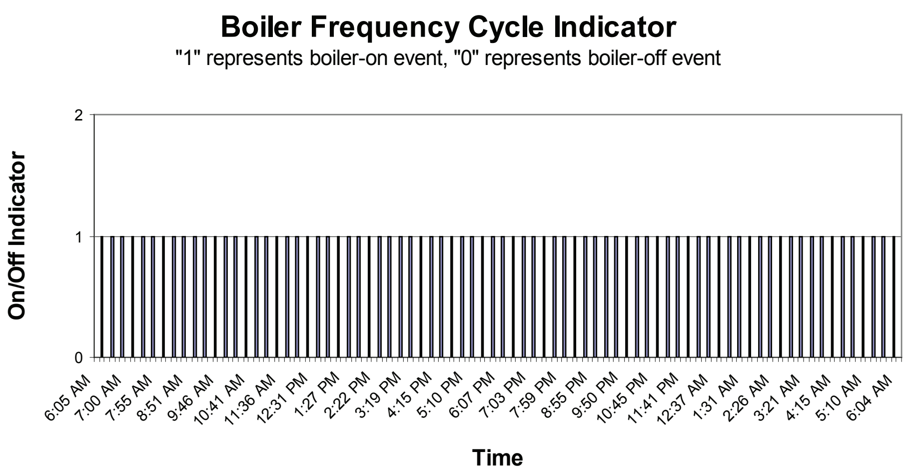


Figure 6.7.1. Boiler Cycling Frequency Data

Outcome: Processing these data reveals an average of 6.5 on/off cycles per hour – far in excess of the recommended 1-2, depending on load conditions. Further exploration uncovered gross boiler over-sizing due to partial decommissioning of building/process loads. The outcome recommendation includes installation of smaller, properly sized, and more efficient boiler to carry load.

6.8 References

FEMP. 2007. *Metering Best Practices Guide: A Guide to Achieving Utility Resource Efficiency*. DOE/EE-0323. U.S. Department of Energy, Federal Energy Management Program, Washington, D.C.

NASA. 2000. Reliability Centered Maintenance Guide for Facilities and Collateral Equipment. National Aeronautics and Space Administration, Washington, D.C.

PECI. 1999. *Portable Data Loggers Diagnostic Tools for Energy-Efficient Building Operations*. Prepared for the U.S. EPA and U.S. DOE by Portland Energy Conservation, Incorporated, Portland, Oregon.

Chapter 7 Commissioning Existing Buildings

7.1 Introduction

Commissioning of existing buildings is quickly becoming one of the most important topics in the building management arena. In the Federal Sector, commissioning has taken on new importance with the enactment of EISA 2007, whereby Federal facilities are required to be assessed for commissioning measures. In general, commissioning is the process of ensuring that a building performs according to its design intent and the needs of its owners and occupants (Anderson 1997). While additional research is needed to further pinpoint the costs and resulting benefits of commissioning new and existing buildings, numerous case studies have demonstrated resulting O&M-related energy efficiency improvements on the order of 5% to 30% covering a wide range of building uses. The resulting simple payback periods are typically less than 2 years and often less than 0.5 year.

Ideally, the building commissioning process begins during the planning stages of a new building design or new equipment installation. The fact is that the vast majority of buildings have never been commissioned. Even today, with mounting evidence of resulting expected benefits, very few new buildings undergo a complete commissioning process. Instead, new buildings are typically turned over to the building operating staff with operating problems in place, incomplete documentation, and minimal operator training for building-specific equipment. These same problems occur with major equipment installations. Then, during building and equipment operations phases, the overall efficiency of mechanical systems degrades as sensors drift, short-term adjustments are made, tenant needs change, and so on. Even after adjustments are made, perhaps through a one-time recommissioning effort, performance degradation is continuous.

Commissioning of existing buildings (and more specifically the energy-consuming mechanical/electrical systems within them and control systems that monitor them) is critical to ensure energy-efficient operation. Additional benefits include extended equipment life, increased tenant satisfaction through improved space comfort, improved indoor air quality, and fewer O&M emergency calls.

Table 7.1.1 below (adapted from FEMP 2006) provides guidance on commissioning types and their suitability for different facility situations.

Table 7.1.1. Commissioning type consideration by facility condition

What Type of Commissioning Should I Choose?	
My Building is…	***Consider…***
…new or going to be undergoing major renovation.	**Commissioning** – ideal for new construction or major renovation, and best implemented through all phases of the construction project.
…old and expensive to operate and experiencing a lot of equipment failures.	**Retro-commissioning** – ideal for older facilities that have never been through a commissioning process.
…relatively new and was commissioned during construction, but energy use has been increasing.	**Re-commissioning** – ideal to "tune-up" buildings that have already been commissioned, bring them back to their original design intent and operational efficiency.
…large and complex, has a metering system and a preventive maintenance program, but still has high energy use and tenant complaints.	**Continuous Commissioning** – ideal for facilities with building automation system (BAS), advanced metering systems, and well-run O&M organizations.

7.2 Definitions

There are a number of commissioning approaches that can be applied to building mechanical/ electrical equipment and systems.

New Building Commissioning: New building commissioning (Cx) is a means to ensuring through design reviews, functional testing, system documentation, and operator training that systems and equipment in new buildings are operating properly.

Recommissioning: Recommissioning (RCx), which is sometimes referred to as "retrocommissioning," is the practice of commissioning existing buildings – testing and adjusting the building systems to meet the original design intent and/or optimize the systems to satisfy current operational needs. RCx relies on building and equipment documentation, along with functional testing to optimize performance.

Continuous Commissioning™: Continuous commissioning™ refers to a commissioning approach that is integrated into a facility's standard O&M program. As such, activities in support of the continuous commissioning™ effort are completed on a regular basis, compared to recommissioning approaches that tend to be distinct events. The continuous commissioning™ (CC) approach developed by the Energy Sciences Laboratory at Texas A&M University is a formalized continuous commissioning™ approach and is defined as "an ongoing process to resolve operating problems, improve comfort, optimize energy use and to identify retrofits for existing commercial and institutional buildings and central plant facilities" (Texas A&M 2002). Continuous commissioning™ is the most costly existing building commissioning approach due to necessary allocations of staff and equipment; however, the higher costs can work to identify equipment inefficiencies as they occur, allowing for quick remediation, greater energy and cost savings, and better building services. By definition, continuous commissioning™ works to ensure more stable building operations over time than the recommissioning approaches.

Value Recommissioning: Value recommissioning (VCx) is the lowest cost option that focuses on the most common opportunities, ideally incorporating them into daily operating procedures. VCx is the least comprehensive and requires the least specialized skill set. VCx concentrates on the most common opportunities that typically carry the shortest payback periods. Therefore, VCx is best applied in buildings where resources for structured recommissioning or continuous commissioning™ programs are not available. In addition to realizing highly cost-effective energy savings, tracking benefits (i.e., energy savings, cost savings, and reduced occupant complaints) of VCx activities can be helpful in developing justifications for funding requests of the more robust commissioning approaches.

Summary of Commissioning Approaches				
Commissioning Approach	**Primary Objectives**	**Relative Costs**	**Benefits**	**Best Applications**
New building or new equipment commissioning	Ensure new equipment is correctly installed and operating correctly.	Costs vary by size of building and complexity of systems: $0.50 to $3.00 per square foot (Welker 2003).	Owners know equipment operates correctly and as intended at acceptance. Resulting documentation and training helps establish correct building operations and are useful to future recommissioning activities.	The commissioning process should be applied to new buildings and equipment at the beginning of the project-planning phase.
Recommissioning (RCx)	Adjust equipment to provide services within equipment specifications while also meeting current mission/tenant operating requirements.	$0.05 to $0.40 per square foot. Additional data are needed to help pinpoint costs based on specific building features and the scope of the RCx effort.	Verifies and restores equipment operation in accordance with original accordance with original design intent and/or to meet current operating requirements.	Since RCx is a point-in-time event, best applications are for buildings/systems that have not been adequately maintained (recommissioned) for some period of time, especially those systems that have not been adapted to accommodate changing space/tenant needs.
Continuous Commissioning™	Integrate comprehensive commissioning approach into on-going facility O&M program.	Highest cost option for existing buildings and systems.	Identifies and addresses problems as they occur. Energy savings persist. Should generate greatest energy savings.	Continuous commissioning™ is the preferred approach when resources (staffing and equipment) are available.
Value Recommissioning (VCx)	Focus on the most frequently available-recommissioning/retrocommissioning opportunities with highest payback as part of daily O&M.	Lowest cost option for existing buildings and systems.	Can be completed by in-house staff. Minimal up-front or on-going investment required.	VCx can be applied in virtually any building. Can be used to demonstrate benefits of larger, more aggressive existing building commissioning program.

7.3 Typical Findings from Existing Building Commissioning

Many case studies of existing building commissioning efforts have been published over the years. A review of case studies for multiple buildings published by Portland Energy Conservation, Inc. (PECI), Texas A&M University, proceedings from National Building Commissioning Conferences, and FEMP Assessments of Load and Energy Reduction Techniques (ALERT) is useful in identifying measures most typically available in commercial building spaces. The most frequently cited measures/opportunities are:

- Adjust reset and set-back temperatures and temperature settings – Settings are often adjusted over time based on personal preferences, to compensate for inadequate system operation, or to achieve energy savings. In addition, sensors require periodic recalibration.
- Staging/sequencing of boilers, chillers, and air handling units – Equipment should be operated in the most efficient combination of chillers, boilers, and fans at varying load conditions.
- Adjust and repair dampers and economizers – Malfunctioning or poorly tuned dampers (including seals, actuators, and linkages) and economizers result in (1) increased supply air fan energy in the closed position or require additional air heating and cooling when open too much, (2) undesired building operating conditions due to lack of outside air, and (3) premature equipment degradation and replacement.
- Modify control strategies for standard hours of operation – Motors, pumps, fans, and air handlers often operate on a 24/7 schedule even though not required by either the building tenants or the building operating plan.
- Eliminate simultaneous heating and cooling – Heating and cooling systems for the same space can compete against each other due to improper setpoints.
- Air and water distribution balancing and adjustments – Systems require rebalancing due to drift and changing building/workspace mission and/or tenant requirements.
- Verify controls and control sequencing including enabling and re-enabling automatic controls for setpoints, weekends, and holidays. Verify that overrides are released.

7.4 Costs and Benefits

While there are many case studies available on various building commissioning approaches, these case studies do not present costs and measured savings in a uniform way. In addition, there are very few assessments of existing building commissioning efforts containing a "large" building sample from which generalized cost and benefit conclusions can be drawn. This prevents us from being able to pinpoint costs for the various commissioning approaches, especially in 2004 dollars. We are, however, able to draw from the case studies trends in the costs and, in the case of existing building commissioning, the realized energy and/or cost savings.

7.4.1 New Building Commissioning Costs and Benefits

(Welker 2003)

While O&M is typically thought of as being limited to existing buildings, it is important for building planners, designers, and O&M managers to consider O&M throughout the new building process. One important action is ensuring adequate resources are lined up for the building once it is operating. Another highly important action is commissioning the new building. New building commissioning begins during the planning process and runs through final acceptance. The primary goals of new building commissioning efforts are to

- ensure design intent criteria and the owner's requirements are documented and met
- ensure systems and equipment are fully functional and operate in an integrated manner
- provide documentation on systems and equipment that will be
- verify O&M staff training needs are met.

The cost of new building commissioning varies based on several factors including the building's use, which determines complexity of mechanical systems and size. Typical new building commissioning provider's fees range from $0.50 per square foot (/ft^2) for "simple" buildings (such as some spaces and classrooms) to $3.00/ft^2 for complex buildings such as hospitals and laboratories. Economies-of-scale do apply. These cost ranges are summarized in Figure 7.4.1.

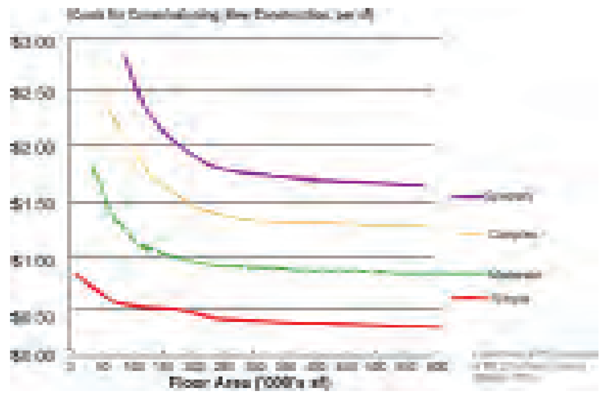


Figure 7.4.1. Construction Phase CX costs

7.4.2 Existing Building Commissioning Costs and Benefits

Of the numerous publications reporting or assessing existing building commissioning efforts, three contain significant building samples (see "Summary of Recommissioning Case Study Publications"). These publications, all of which rely on recommissioning efforts from the 1990s, show a range of resulting costs and savings. The reported average cost to recommission is usually in the range of $0.05/ft^2 to $0.40/ft^2. The simple payback period on these efforts is usually less than 2 years and quite frequently less than 0.5 year. Additional reported benefits include reports of improved office comfort, reduced occupant complaints, improved indoor air quality, extended equipment life, reductions in equipment failure, and improved building documentation.

The Cost Effectiveness of Commercial Building Commissioning: A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States

A comprehensive study completed in late 2004 (LBNL 2004) was designed as a "meta-analysis" to compile and synthesize extensive published and unpublished data from buildings commissioning projects undertaken across the United States over the past two decades, establishing the largest available collection of standardized information on commissioning experience. Data were analyzed from 224 buildings across 21 states, representing 30.4 million square feet of commissioned floor area (73 percent in existing buildings and 27 percent in new construction). The goal of this program was to develop a detailed and uniform methodology for characterizing, analyzing, and synthesizing the results. For existing buildings, the analysis found median commissioning costs of $0.27/ft^2, whole-building energy savings of 15 percent, and payback times of 0.7 years. For new construction, median commissioning costs were $1.00/ft^2 (0.6 percent of total construction costs), yielding a median payback time of 4.8 years (excluding quantified non-energy impacts). with an average simple payback period of 0.7 year. Average savings varied significantly for the building use types – $1.26/ft^2/yr for medical research buildings down to $0.17 ft^2/yr for school buildings.

7.5 Tracking Commissioning Benefits

As with any investment, it is important to develop metrics for tracking and persistence. In the case of building commissioning, these metrics need to be implemented and tracked on a regular basis for assurance of performance savings. Below is a compilation of commissioning metrics (LBNL 2004) useful for persistence tracking.

Building Characteristics and Demographics

- Building type (using DOE/CBECS definitions), vintage, location
- Year building commissioned
- Reasons for commissioning, deficiencies identified, measures recommended

Energy utilization intensity (use or savings)

- *Electricity:* kWh/building-year,12 kWh/ft^2-year
- *Peak electrical power:* kW/building; W/ft^2
- *Fuel:* MMBtu/building; kBtu/ft^2-year
- *Purchased thermal energy:* MMBtu/building-year; kBtu/ft^2-year
- *Total energy:* MMBtu/building-year; kBtu/ft^2-year13
- *Energy cost:* $/building-year; $/ft^2-year (based on local or standardized energy prices; nominal [not corrected for inflation] and inflation-corrected to a uniform year's currency)
- Percent energy use savings (total and by fuel)
- Percent total energy cost savings
- *Persistence index:* Post-commissioning energy use in a given year/pre-commissioning energy use (unit-less ratio)

Commissioning cost

- $/building; $/ ft^2 (based on nominal costs or, preferably, inflation-corrected to a uniform year's currency levels. Can be gross value or net, adjusting for the quantified value of non-energy impacts)
- Commissioning cost ratio, for new construction (commissioning cost/total building or renovation construction cost, %)
- Costs are tabulated separately for the commissioning agent and other parties
- Allocation of costs by source of funds (building owner, utility, research grant, other)
- Total building construction cost (denominator for commissioning cost ratio)

Cost effectiveness

- Undiscounted payback time (commissioning cost/annualized energy bill savings). This indicator is preferably normalized to standard energy prices; costs and benefits are inflation corrected to a uniform year's currency levels

Deficiencies and measures

- Deficiencies/building; Deficiencies/100 kft^2
- Measures/building; Measures/100 kft^2
- Unique codes to identify combinations of deficiencies and measures (described in more depth below) [see Measures Matrix]

Commissioning scope

- Presence of pre-defined "steps" (yes/no), with different criteria for existing buildings and new construction

Non-energy impacts

- Type
- Quantified (when possible), $/building-year; $/$ft^2$-year [can be positive or negative] – one time or recurring

7.6 The Commissioning Process

A four-step process for existing building commissioning is often recommended (Haasl and Sharp 1999).

Step 1: Planning. The planning step includes developing and agreeing upon the overall commissioning objectives and strategies, assembling the project team, and compiling and perusing building and equipment documentation. Examples of objectives could be a desire to optimize building operations to reduce operating costs, address complaints from occupants regarding air quality or comforts, create a model facility, and improve facility O&M including reducing emergency trouble calls. Regarding the commissioning team formation, considerations in forming the team could include contracted or in-house staff, level of effort required, desired and necessary qualifications, availability and use of resident knowledge, and available funding resources.

Step 2: Investigation. During this step the site assessment is completed, monitoring and functional test plans are developed and executed, test results are analyzed, a master list of deficiencies is compiled, and recommendations for improvements, including estimates of energy and cost savings, are generated and presented for consideration.

Step 3: Implementation. Accepted recommendations from the investigation step are put into place in the implementation step. Actions include making repairs and improvements, retesting and re-monitoring for results, fine-tuning improvements as needed, and revising estimates energy and cost savings.

Step 4: Hand-off and Integration. Final documentation of the commissioning effort describing the process, individuals, systems information, and actions taken is developed in this step. Also developed is a plan for future commissioning efforts. Items addressed by the commissioning plan should include recommended procedures for specific building equipment, frequency of testing, analysis of results, periodic reporting, identification of key players, and budget requirements.

7.7 Commissioning Provider Qualifications

The question of who should complete the recommissioning effort can be addressed once the recommissioning objectives and budget have been established. Some facilities have the in-house capability to successfully recommission their own equipment, but most do not. Here are some qualifications to consider when selecting a commissioning provider:

- Experience in recommissioning similar types of buildings by use and/or by design
- Experience in recommissioning similar types of building systems
- Experience in providing O&M training
- Specialized skills to consider include
    - Air/water testing and balancing
    - Design, installation, and/or troubleshooting of DDCs, pneumatic, and EMCSs
    - Demonstrated skills in working with metering and testing equipment/instrumentation.
- Relevant professional licenses and certifications (e.g., professional engineer)

7.8 The Future of Building Commissioning

The building commissioning field has grown markedly in the last five years. The data to date have shown tremendous benefits across the board when commissioning has been performed. While much more data are needed in order to fully verify and promote the energy and cost benefits, commissioning intuitively makes great business sense. As the awareness to the energy, cost and operational benefits is raised, we should expect to see the way commissioning is completed to become more effective and reliable and working toward becoming a regular part of the building operations process. Expect some of the following to help move the commissioning process forward.

- Chronicled experiences will lead to better estimates of costs and potential savings.
- Statements of work will become more standardized.
- New functional testing protocols will be developed and made widely available.
- New automated diagnostic technologies will become critical components in establishing continuous commissioning™ programs.
- Certified commissioning providers.

7.9 Case Studies

7.9.1 System Shutdown During Unoccupied Periods

(Texas A&M 2002)

The Figure 7.9.1 presents the measured building electricity consumption, excluding chiller consumption, before and after implementation of air-handling units (AHUs) and office equipment turn-off on nights and weekends in the Stephen F. Austin Building in Austin, Texas.

The Stephen F. Austin Building has 470,000 square feet of floor area with 22 dual duct AHUs. During the first phase of implementation, 16 AHUs were turned off from midnight to 4 a.m. weekdays and weekends. During the second phase, 22 AHUs were turned off from 11:00 p.m. to 5 a.m. during weekdays and weekends. During the second phase, all occupants were asked to turn off office equipment when they leave their office. The measured results show that the nighttime whole building electricity use decreased from 1,250 kW to 900 kW during the first phase. During the second phase, the nighttime minimum electricity decreased to 800 kW. It was observed that the daily peak electricity consumption after night shutdowns began is significantly lower than the base peak. For example, the lowest peak during the second phase is 1,833 kW, which is 8% lower than the base peak. The lower electricity peak indicates that some office equipment remained off during the daytime or employees were more conscientious in turning off lights and equipment when they left the office. The annual energy cost saving, including electricity, heating and cooling, was determined to be $100,000/yr using measured hourly data.

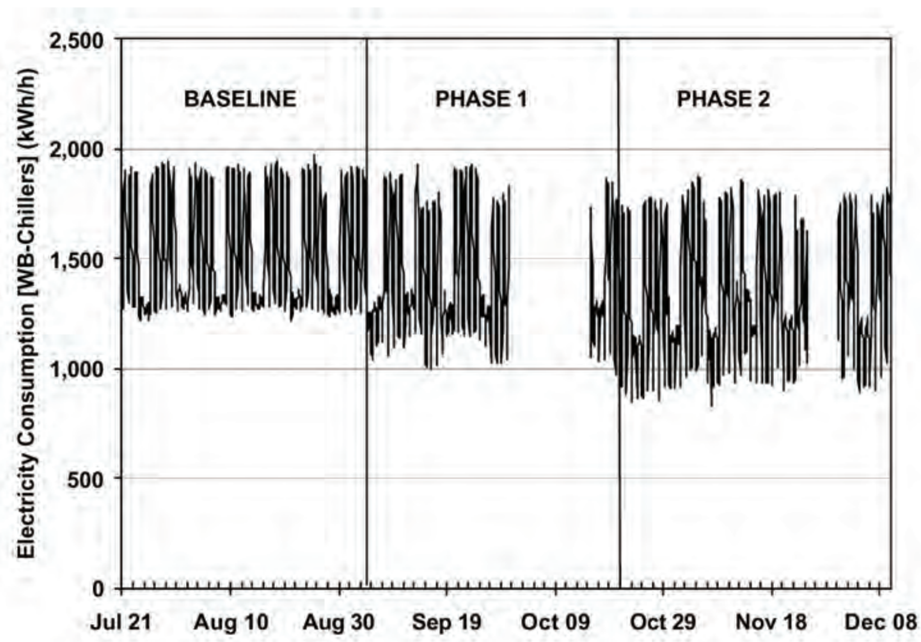


Figure 7.9.1. Whole-building electricity use before and after night shutdown program. Data gaps were periods when data were not available. Average nightime savings is 350 kW (1,250 kW – 900 kW).

7.9.2 In-House Recommissioning at a DOE National Laboratory

The William R. Wiley Environmental Molecular Sciences Laboratory (EMSL) at the Pacific Northwest National Laboratory (PNNL) in Richland, Washington, is a 200,000-square-foot national scientific user facility. In fiscal year (FY) 2000, the energy management team at PNNL recognized an opportunity to improve the performance of the laboratory and reduce energy use and costs through recommissioning. Results: In FY 2002, the estimated resulting annual energy savings of 27% and annual energy cost savings (avoidance) of 35%, or $173,735, versus expected consumption and cost. With a total investment of approximately $125,000, this retrocommissioning effort had a simple payback of well less than 1 year.

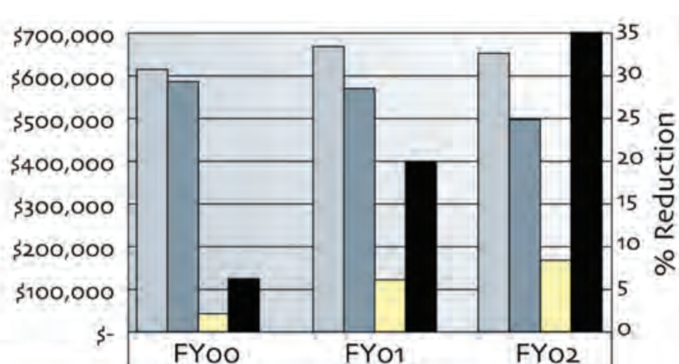
The energy performance for PNNL's EMSL building is shown in Figure 7.9.2.

The PNNL team followed the basic four-step commissioning approach. During the planning step, the team of in-house staff with experience in equipment operation, energy management, and engineering was assembled and overall objectives and strategies were agreed upon.

In the investigation step, a list of potential energy efficiency measures (EEMs) for the building was developed, the building systems were evaluated, cost estimates for corrective actions were generated, and opportunities prioritized. In developing the list of potential EEMs, the DOE Industrial Assessment Center (**www.iac.rutgers.edu/database**) served as a starting point.

During the implementation step, the implementation budget was finalized and occupant approvals obtained before changes were put into effect. EEMs deemed easy to complete, measure, and most likely to succeed were the first to be addressed. Results of these initial actions were then used to build-up credibility for the recommissioning approach and gain support to accomplish the full range of EEMs. Completed EEMs were monitored for results with readjustments made as necessary.

For the hand-off and integration step, PNNL has continued the recommissioning effort with activities such as monitoring building energy data, periodic review of operational changes, occupant and operator feedback, and monthly update reports. On-going monitoring of building performance helps to ensure that retrocommissioned building systems continue to operate in their optimized state and energy savings continue to be realized.



	FY00	FY01	FY02
Expected Energy Cost	$624,713	$689,444	$668,741
Actual Energy Cost	$582,864	$571,365	$495,016
Avoided Cost	$41,849	$118,079	$173,725
Avoided Cost (%)	7.2%	20.7%	35.1%

Figure 7.9.2. PNNL EMSL building energy performance by fiscal year (FY)

Roughly 200 low- and no-cost EEMs were put into place at EMSL. Examples of completed EEMs include

- HVAC systems tuning including modifying chilled water temperature setpoints, ensuring correct operation of heating and cooling valves, optimizing chiller operations, checking and correcting supply fan return dampers, optimizing selected fan heating/cooling strategies, reducing dead band limits on digital controls, and resetting building air flows as appropriate.
- Adjusting temperatures by modifying heat recovery system operational temperatures, modifying supply fan air discharge temperatures, resetting zonal thermostats to better match the conditions of the space (occupied or unoccupied), and applying additional night setbacks.
- Adding holiday schedules to building controls.
- Designating staff members to review operational strategies for facility systems for operational efficiency improvement opportunities.

While the energy and cost savings of the EMSL recommissioning effort are on the high-end, reported benefits of retrocommissioning efforts at other buildings are also impressive. Commissioning of existing buildings is an option that needs to be considered for inclusion in any O&M program.

Summary of Recommissioning Case Study Publications

"What Can Commissioning Do for Your Building" (PECI 1997) compiled a database of 175 buildings commissioned between 1993 and 1997. Commissioned buildings were located in the United States and Canada, ranged in size from 12,500 to 2.2 million square feet, ranged in age from 1 (new) to 74 years with a median age of 6 years, and covered a range of end uses including office buildings, retail facilities, hospitals, schools, and laboratories. Data in the case study are compiled by building use and provide the following general findings: costs to commission ranged from $0.02 to $2.88 per square foot with a median cost per square foot ranging from $0.09 to $0.31 per square foot. Reported benefits include energy use and energy cost savings, extended equipment life, improved documentation, reduced equipment failure, increased staff training, improved temperature control, improved relative humidity control, reduced occupant complaints, air balancing, and improved indoor air quality (i.e., contaminant control, improved ventilation, and reduced carbon dioxide).

"Commissioning Existing Buildings" (Gregerson 1997) looks at the recommissioning of 44 existing buildings. Commissioning efforts occurred primarily between 1993 and 1996 ran from $0.05 to $0.40 per square foot with energy savings usually ranging from 5% to 15% and paybacks of less than 2 years. This analysis also reports that significant opportunities are often found in buildings with large deferred maintenance, energy intensive buildings, and medical and research facilities.

The "FEMP Continuous Commissioning Guidebook for Federal Energy Managers" (Texas A&M 2002) provides a summary of results at 28 buildings continuously commissioned as part of the Texas LoanSTAR program. Building uses included hospitals, offices, and dual-use buildings with laboratories and offices or classrooms and offices. Measured annual energy savings averaged $0.64 per square foot per year (/ft^2/yr) with an average simple payback period of 0.7 year. Average savings varied significantly for the building use types – $1.26/ft^2/yr for medical research buildings down to $0.17 ft^2/yr for school buildings.

7.10 Additional Resources

In addition to the references listed at the end of this chapter, there are many sources of information on existing and new building commissioning via the Internet.

The Portland Energy Conservation, Inc. website (**http://www.peci.org**) should be your first stop when searching for additional information on existing and new building commissioning. This website offers a wide variety of materials including guidance on the commissioning process, case studies, functional testing guides, links to other websites supporting commissioning activities, and more.

Other potential sources include your state energy office (some offer additional guidance, case studies, and possibly even funding/grants) and your servicing utilities as recommissioning is an excellent way to help meet demand side management initiative goals.

7.11 References

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Chapter 8 Metering for Operations and Maintenance

8.1 Introduction

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/resource efficiency refers to the measurement of quantities of energy delivered, for example, kilowatt-hours of electricity, cubic feet of natural gas, pounds of steam, and gallons of water. Metering may also involve identifying times-of-use for the various energy sources, the instantaneous demand for energy, as well as identify energy use for a collection of buildings, individual buildings, rooms, or specific equipment (e.g., a boiler, chiller, or motor).

Facility resource metering has a variety of applications for the Federal 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.

Historically, the Federal sector has lagged the private sector in metering applications. To this day at Federal 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 are the primary driver for the legislation below.

Energy Policy Act of 2005, Public Law 109-58, Section 103

By October 1, 2012, in accordance with guidelines established by the Secretary under paragraph (2) all Federal buildings shall, for the purposes of efficient use of energy and reduction in the cost of electricity used in such buildings, be metered. Each agency shall use, to the maximum extent practicable, **advanced meters** or advanced metering devices that provide data at least daily and that measure at least hourly consumption of electricity in the Federal buildings of the agency. Such data shall be incorporated into existing Federal energy tracking systems and made available to Federal facility managers.

Energy Policy Act 2005 (EPAct 2005): Section 103 of EPAct 2005 requires that "all Federal buildings shall, for the purposes of efficient use of energy and reduction in the cost of electricity used in such buildings, be metered … to the maximum extent practicable." This requirement of law is the driving force behind the ongoing efforts of Federal agencies to meter their electric use. The primary metering requirements established in Section 103 of EPAct 2005, Energy Use Management and Accountability,[1] are summarized by these key points:

Figure 8.1.1. Typical utility socket-type meter

- By October 1, 2012, all Federal buildings will be metered for electricity if practicable.
- Installed meters will support the efficient use of energy and reduction in cost of electricity used.
- Advanced metering devices that provide interval data on at least a daily basis will be used subject to practicability.

[1] The metering requirements of EPAct 2005 amended Section 543 of the National Energy Conservation Policy Act (42 U.S.C. 8253).

- Metered data will be used made available to Federal facility managers.
- Requires Federal agencies to submit to the Department of Energy (DOE) an implementation plan identifying personnel responsible for achieving metering requirements, and any determination by the agency that advanced meters or metering systems are not practicable in their specific situation.

Energy Independence and Security Act of 2007 (EISA 2007): Among other requirements EISA 2007 further strengthens the metering requirements of EPAct 2005 with the following language:

- Not later than October 1, 2016, each agency shall provide for equivalent metering of natural gas and steam, in accordance with guidelines established by the Secretary under paragraph (2).

In addition to energy, gas, and steam metering of water is encouraged to obtain data to support the water intensity reduction goals outlined in EISA 2007.

8.2 Importance of Metering and the Business Case

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.

Outside of single-building sites, there is limited building or equipment sub-metering within the Federal sector. Single building sites are metered for total use by their servicing utility providers, while multi-building sites usually rely on a master meter provided by the utilities at the utilities' points of entry to the site. Sites are billed by their utility providers based on the cumulative usage readings obtained from these utility, or revenue, meters over the billing period, usually about one month. But now consider the application of meters to individual buildings and even energy-intensive equipment that provides facility managers and operators real-time information on how much energy has been or is being used. This type of information can be used to assist in optimizing building and equipment operations, in utility procurements, in building energy budget planning and tracking, and so on.

It is important to keep in mind that meters are not an energy efficiency/energy conservation technology per se; instead, meters and their supporting systems are devices that provide building owners and operators data that can be used to:

- Reduce energy/utility use
- Reduce energy/utility costs
- Improve overall building operations
- Improve equipment operations.

How the metered data are used is critical to a successful metering program. Depending on the type of data collected, it can enable the following practices and functions:

- Verification of utility bills
- Comparison of utility rates
- Proper allocation of costs or billing of reimbursable tenants

- Demand response or load shedding when purchasing electricity under time-based rates
- Measurement and verification of energy project performance
- Benchmarking building energy use
- Identifying operational efficiency improvement opportunities and retrofit project opportunities
- Usage reporting and tracking in support of establishing and monitoring utility budgets and costs, and in developing annual agency energy reports.

Ultimately, the business case for metering energy/utility use is based on the anticipated benefits to the site. Most of the metered data uses listed above will result in energy cost savings that can be used to justify the cost to purchase, install, and operate the metering system. The degree of cost savings realized depends on the unit cost of the energy/utility being saved and on the effectiveness with which the site analyzes the data and acts upon its findings/recommendations. But other potential benefits should also be considered as part of the metering business case. Examples can include

- Supporting efforts to attain Energy Star and/or LEED-EB (Leadership in Energy and Environmental Design – Existing Buildings) certifications
- Promoting tenant satisfaction by providing information that tenants find useful in managing their operations
- Prolonging equipment life (and reducing capital investment requirements) and improving its reliability by verifying the efficient operation of equipment
- Assessing the impact of utility price fluctuations prior to or as they happen, allowing sites/agencies to address budget shortfalls on a proactive basis.

8.3 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, pounds (lb) of steam, 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.

8.4 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. Only long-term monitoring meets requirements set forth in EPAct 2005. A short description of each monitoring level is provided below.

8.4.1 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.

One-time/Spot Measurement Advantages

- Lowest cost
- Ease of use
- Non-intrusive
- Fast results

One-time/Spot Measurement Disadvantages

- Low accuracy
- Limited application
- Measures single operating parameter

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.

8.4.2 Run-Time Measurements

Run-Time Measurement Advantages

- Low cost
- Relatively easy of use
- Non-intrusive
- Useful for constant-load devices

Run-Time Measurement Disadvantages

- Limited application
- Measures single operating parameter
- Requires additional calculations/ assumptions

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 include 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.

8.4.3 Short-Term Measurements/ Monitoring

Short-Term Measurement Advantages

- Mid-level cost
- Can quantify magnitude and duration
- Relatively fast results

Short-Term Measurement Disadvantages

- Mid-level accuracy
- Limited application
- Seasonal or occupancy variance deficient
- More difficult to install/monitor

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.

8.4.4 Long-Term Measurements/ Monitoring

Long-Term Measurement Advantages

- Highest accuracy
- Can quantify magnitude and duration
- Captures most variance

Long-Term Measurement Disadvantages

- High cost
- Most difficult to install/monitor
- Time duration for result availability

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.

8.4.5 The Metering Hierarchy

Given the above described metering approaches, there is a logical order, or hierarchy, to consider as you look to maximize your metering value while minimizing your metering cost. Figure 8.4.1 presents this concept as a function of level of effort and diagnostic capability that applies to electric metering. This proposed hierarchy starts at the most aggregate level of data collection and processing – the *whole-building* meter. Assuming access to interval electric data (these are data collected usually at 15-minute intervals), this meter and resulting data can be diagnostic in identifying trends and variance in whole-building performance. In addition, these data can useful in understanding the operation and efficiency of major building systems (e.g., chillers, boilers, air handlers). While the resolution of whole-building data may not be fine enough to identify specific operational or efficiency issues, it can often be used to "frame the question" of what equipment/system is performing inconsistently and in need of further exploration.

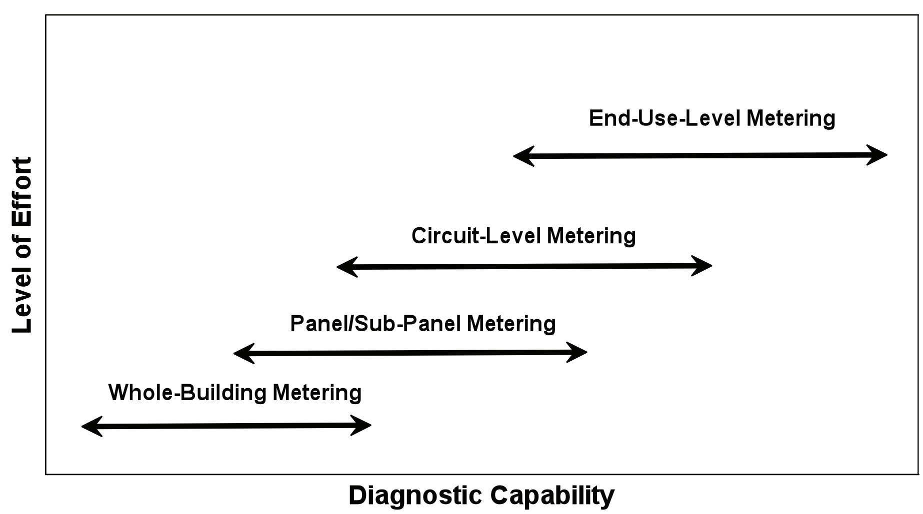


Figure 8.4.1. Electric metering hierarchy

If the whole-building meter represents the most aggregate level, the next finer level is at the *electrical panel/sub-panel*. This second tier in the metering hierarchy focuses on loads connected at a panel (or sub-panel) level as aggregations of specific loads. Examples of panel-level monitoring include lighting panels or motor panels (i.e., motor control centers – MCCs) where hours of operation or efficiency project validation are of interest.

Moving up one more level in the hierarchy, we examine *circuit-level* monitoring. The focus of metering at this level is within the panel or sub-panel and the monitoring of a specific circuit of interest. This circuit may have specific plug loads of interest such as computers or other peripherals, or may be of interest for power quality or harmonics studies.

The final level in the hierarchy, having the finest data resolution, is the end-use level. End-use monitoring serves to isolate a particular system or equipment type for detailed study. In many cases, the objective of end-use monitoring is equipment performance, whether to identify inefficiency or validate savings estimates. Chillers, boilers, cooling towers, pumps and motors are often end-use metered for performance metrics.

While the above hierarchy presents a step-wise approach to metering and efficiency diagnostics, by no means are we suggesting that all hierarchy steps need be followed sequentially when moving from whole-building to end-use metering. In fact, in some cases there should be enough information to move from the whole-building level directly to end-use level when diagnosing or trending efficiency opportunities. In cases where inefficiency by specific equipment is not so apparent, the additional steps may be beneficial to properly identify the poorly operating equipment.

8.5 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.

8.5.1 Meters

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

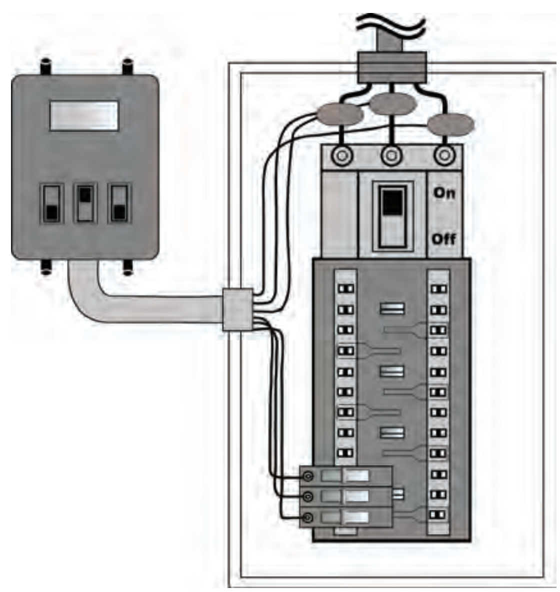


Figure 8.5.1. Typical electrical sub panel (box on left) used in long-term monitoring

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 chiller). See Figure 8.5.1 for sub-panel. For water, steam, 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. A more complete treatment of utility meters, applications, and evaluation criteria can be found in the FEMP Metering Best Practices Guide (FEMP 2007).

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).

8.5.2 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. When developing the communications portion of your metering program, it is important to consider what existing communications infrastructure you can take advantage of (e.g., building automation system, local area network) to potentially lower the cost of AMR. In addition, if you have a large site with distributed buildings you may find benefit in considering multiple communications technologies (e.g., networks in one area, phone lines in another, and wireless in a third) to gain the necessary communications coverage. Available technologies include:

- *Traditional or cellular phone modem:* Considered a proven technology, generally available and secure. This mode can be expensive and one needs to be connected to access to real-time data
- *Local area networks:* A proven technology with increasing availability and always connected. This mode can have IT security concerns/issues.
- *Building automation systems:* When present provides advantage of accessibility and fast communication. Some systems can have compatibility or data availability issues.
- *Radio frequency/wireless networks:* With no wires to install, this mode has great logistical and cost advantage. Issues do arise with potential for electrical interference and hardware costs.
- *Power line carriers:* Excellent use of existing infrastructure and connect-ability. Overall system cost and data transfer rates need to be researched before implementation.

8.5.3 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 are 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.

The specific requirements of the data storage/database system should be decided with assistance from site IT staff or others knowledgeable, or those who will be using the system. Below are concepts and specifications based on work done for the California Energy Commission Public Interest Energy Research Program (PIER) and the Building Technologies Program of the U.S. Department of Energy

(CEC 2007). A more complete list of data storage software and hardware considerations can be found in the FEMP Metering Best Practices Guide (FEMP 2007).

- Data shall be stored in a structured query language (SQL)-compliant database format or time series format. Minimum requirements are a SQL server or equivalent.
- The database shall allow other application programs to read and access the data with appropriate password protection while the database is running. The database shall not require shutting down in order to access or have data added.
- Trend data shall be archived in a database from field equipment in time intervals no less than once per day.
- All data shall be stored in database file format for direct use by third-party application programs.
- Sufficient data storage capacity will be able to store at least two years of data for all data points. In addition, storage capacity will also allow for compression of one year of data for historic trends and archiving.
- Time stamps shall be collected on all data. The time stamp, depending on system architecture, will be captured at the field controller or system controller and directed to the database archive.

8.5.4 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.

8.6 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 vary 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, and meter type. On average, long-term whole-building type meter installed cost runs between $1,000 to $5,000 per point or meter. This range is so large because some buildings require extensive rewiring and additional activities related to bringing existing systems up to code. Assuming limited requirements and code issues, an average per meter (electric) installed cost is roughly $1,500.

As Federal agencies move toward increased metering, decisions need to be made on the optimal level of metering. In the extreme case, one would have difficulty justifying a meter installation on a small, seldom used, remote storage building. On the other hand, a large, continuously occupied administrative building would make a better case. At issue is where to draw the line, that is, below some set of criteria the economic case for metering becomes marginal.

EPAct 2005 requires that Federal buildings be metered for electricity "where practicable." The following formula to cost-justify an electric meter (or other utility meters) was presented in DOE (2006):

$$\frac{\left[\left(\dfrac{\text{Installed Cost}}{\text{Desired Simple Payback}}\right) + \text{Annual Cost}\right]}{\%\ \text{Annual Savings}} = \text{Minimum Annual Electric Bill}$$

Where:

- *Installed Cost* refers to the total cost to purchase, install, and commission the meter. As previously noted, the cost of a meter application will vary based on a number of factors. Building electric meters are often in the range of $1,000 to $5,000 completely installed. This broad range reflects the uncertainty of system upgrades that may be associated with electrical code compliance issues.
- *Desired Simple Payback* represents the number of years it will take the metering system to produce (lead to) cost savings equal to the installed cost. Most agencies prefer a simple payback period of 10 years or less.
- *Annual Cost* is the total annual cost of the fees and expenses to cover communications, data collection and storage, and data analysis, as well as meter operations and maintenance. The annual cost will vary based on several factors and is typically in the range of $120/year ($10/month) to $600/year ($50/month).
- *% Annual Savings* is the estimated cost savings benefits to be realized from the productive use of the metered data. Federal sites are advised to use a minimum of 2 percent annual savings when considering meters for EPAct 2005 compliance.

Using the above formula also requires that there be a reasonable way to estimate the current annual electricity (utility) costs for the building being considered. Except in cases where the buildings already have standard meters, actual usage data to estimate the annual costs will not be available. In these cases, one of the following accepted methods of estimating building energy use should be applied (FEMP 2007):

- Square footage
- Energy-use intensity
- Calibrated software
- Short-term metering

To demonstrate how the metering cost justification formula is used, the following values will be used:

- Installed cost = $5,000
- Desired simple payback = 10 years
- Annual cost = $25/month = $300/year
- % annual savings = 2 percent

Sample calculation: **(NOTE: The values in this sample are for demonstration purposes only. Sites considering metering applications should use values specific to their site.)**

$$\frac{\left[\left(\dfrac{\text{Installed Cost}}{\text{Desired Simple Payback}}\right) + \text{Annual Cost}\right]}{\%\ \text{Annual Savings}} = \text{Minimum Annual Electric Bill}$$

= [($5,000) ÷ (10 years) + $300/year] ÷ (0.02)

= $40,000 minimum annual electric bill

In this *example*, an electric meter application will be cost-justified if the building's annual electricity use is more than $40,000.

As previously mentioned, the results from this equation are sensitive to the input variables.

8.7 Metering Financing Options

There are a number of potential financing alternatives available to Federal sites. Factors affecting the financing alternatives available include estimated system cost, agency policies, and utility company support offerings, to name a few. In some cases, sites will be able to finance their metering systems through a combination of approaches, while in other cases they may be limited to single options.

8.7.1 Metering Financing Hierarchy

As a way for sites to begin their initial considerations of financing alternatives, the metering financing hierarchy has been developed (Figure 8.7.1). This hierarchy is based on life-cycle costs to the site's facility, utility, or energy management program as many consider life-cycle costs to be the most significant factor in selecting their financing approach. Additional hierarchies may be developed based on factors such as speed of implementation or lowest first/up-front cost. Note that a lowest first cost approach may allow for faster implementation or a metering program with expanded capabilities.

The Metering Financing Hierarchy

"No-Cost" Options:

Policy-directed approaches

- Include in construction and renovation projects
- Assess tenant fees
- Reinvest energy savings

Utility provided (for time-based rates customers)

Appropriations Options:

- Line item appropriations
- Locally managed appropriations

Alternative Financing:

- Utility company financing
- Energy savings performance contracts (ESPCs)

Figure 8.7.1. The metering financing hierarchy

The approaches addressed at the top of the hierarchy are the so-called "no cost" options. This is not to imply that the meters are free: instead, the costs to purchase and install the meters are covered in part or in total by programs other than the site facilities, utilities, or energy program.

The appropriations approaches are next in this hierarchy's order. While the costs for the metering system are now being incurred by the site or agency facilities programs, agency appropriations are a familiar approach where the total costs of the meters are paid at the time of purchase and installation.

Alternatively financed approaches appear at the bottom of this hierarchy since the overall life-cycle costs are higher than the appropriations approaches due to added financing charges. This is not to imply that these approaches are any less likely to succeed than the other options. Site metering opportunities at some sites may benefit from alternative financing as a way expand the metering system or add capabilities beyond the EPAct 2005 requirements.

Specific to alternatively financed approaches and as described in the document titled: *Approaches for the Application of Advanced Meters and Metering Systems at Federal Facilities through Alternatively Financed Contracts* (LBNL 2005), there are at least five potential approaches to using alternatively financed projects to achieve the benefits of advanced meters and metering systems. Each of these approaches is briefly described below with more detail provided in the above mentioned report:

1. **Install as part of other energy conservation measures (ECMs) or the M&V effort of the project** – the meters installed as part of other ECMs (such as peak load management) or the M&V plan of an ESPC or the performance assurance plan of a UESC (either as required for M&V or augmented by additional facility funds) can be used to achieve the benefits of advanced metering.

2. **Install using project savings** – a portion of savings from other ECMs can be used to install and use advanced metering. This approach has been used in a relatively large, complex facility with significant potential for additional supply side savings opportunities.

3. **Install as ECM with stipulated savings** – This approach has also been used in a relatively large facility with significant potential for follow-on savings.

4. **Install as an ECM with stipulated initial savings and follow-on share of savings** – This approach is an extension of approach 3 with the application of the Award Fee Plan incentive concept, which allows a sharing of subsequent savings from actions taken on opportunities identified by the metering system.

5. **Install in support of retro-commissioning ECM** – the cost-effective use of retro-commissioning of relatively large and complex buildings has been repeatedly demonstrated by Texas A&M University.

Advanced metering technologies are unique energy conservation measures because their primary benefit is to help identify energy saving opportunities. The problem is resulting energy savings are often difficult to quantify prior to installation and use. Thus, installation through alternative financing for several of the identified approaches does rely on stipulating savings, which is contrary to FEMP M&V guidance.

Critical to the success of advanced metering technologies is the availability of staff that are motivated and trained to use the data. This includes the ability to gather, analyze, direct, and implement changes that work to optimize performance and energy efficiency. *Remember, metering by itself does not save energy; instead, metering should be viewed as a technology that enables optimized performance and energy efficiency.* The strategies summarized all require dedicated staff capable of affecting changes as a result of the analysis of metered data. These staff can be in-house, with an energy services company, or even a Resource Efficiency Manager.[2]

[2] See **http://www.energy.wsu.edu/projects/rem/** for information on Resource Efficiency Managers.

8.8 Steps in Meter Planning

The development of a metering plan is highly dependent on a site's needs, its mission, 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 FEMP (2006), AEC (2002), EPRI (1996), and Sydlowski (1993) where more detailed information can be found.

Whichever approach a site uses in its planning effort, there are key elements that should be addressed for all utility metering programs (FEMP 2006):

- Establish program goals and objectives
- Identify needs to support selected analysis approaches
- Develop and apply evaluation criteria
- Implementation, design, and installation
- Performance validation and persistence

Figure 8.8.1 provides a more detailed overview of the planning process.

8.8.1 Establish Program Goals and Objectives

The critical first step for all metering programs is to establish the site's overall metering objective. While the ultimate goal of the metering program is to reduce utility use and/or costs, how this is done will depend on how the metered data are used. Some of the more typical uses include cost allocation among tenants, bill verification, demand management, and energy use diagnostics. Examples of possible objectives might be:

- To fully enable energy bill allocation throughout an entire facility.
- To effectively manage electric loads to minimize costs under a time-based rate schedule.
- To identify system-specific operational efficiency opportunities.

8.8.2 Identify Needs to Support Selected Analysis Approaches

The information obtained in this step is used to ensure that the necessary data are obtained and its analysis is supported. Inclusive is the survey of any existing metering components that are operational and in use as they may support the new program's goals and objectives.

- *Data needs serves as the starting point for this portion of the plan's development*. What specific types of data are needed to support the program's goals and objectives. For example, allocation electricity costs based on actual use will require (at a minimum) kWh and kW data at the building level or for portions of the buildings occupied by different tenants.
- *Analysis methodologies are a critical component of a site's metering program*. Data by itself is not of much use without some analysis to determine what it means.

- *Equipment needs are based on the data requirements and the analysis methodologies identified*, and should identify what types of metering/monitoring equipment and hardware/software tools would be most appropriate to provide that data and its communication and storage.
- *Survey existing metering systems*. Many multiple building sites have some level of building metering or sub-metering in place.
- *Staffing resources* needed to operate the metering system when in place are also critical to a successful metering program.

Some Questions to Consider in Developing Your Objectives

- What are the annual utility costs for your facility?
- Who are the primary energy users and why?
- What operations actions can help reduce utility costs?
- Where is the poorly designed or operating equipment?
- What equipment should be replaced and when?
- Do like buildings use similar amounts of energy?
- Do buildings have similar operating schedules?
- Do buildings have unique operating requirements?
- By building, how much energy do you use daily? Weekly? Monthly?
- Are your energy savings strategies/projects producing results?
- What utility rate opportunities can you take advantages of?
- Are there regional or national/agency initiatives to address specific utility usage issues (e.g., water management)
- Has utility price volatility been, or could it be, an issue at your site?

- *Security requirements vary widely across the Federal sector*. In general, information technology (IT) staff should be asked to participate in the development of the metering program planning efforts at the very beginning of the process.

8.8.3 Develop and Apply Evaluation Criteria

Meters should be applied where they will lead to a cost-effective reduction in utility use and/or costs. Determining which buildings can be metered cost-effectively requires that criteria be established and applied that take into account the life-cycle costs to meter and the benefits to be realized. The primary variables that impact the cost-effectiveness of meters are:

- The annual utility cost of the building being metered
- The cost to purchase and install the meter and associated hardware
- Expected savings resulting from the productive use of data, typically in the range of 2 percent to 10 percent, but sometimes higher depending on how the metered data are used
- Site economic criteria – usually payback period.

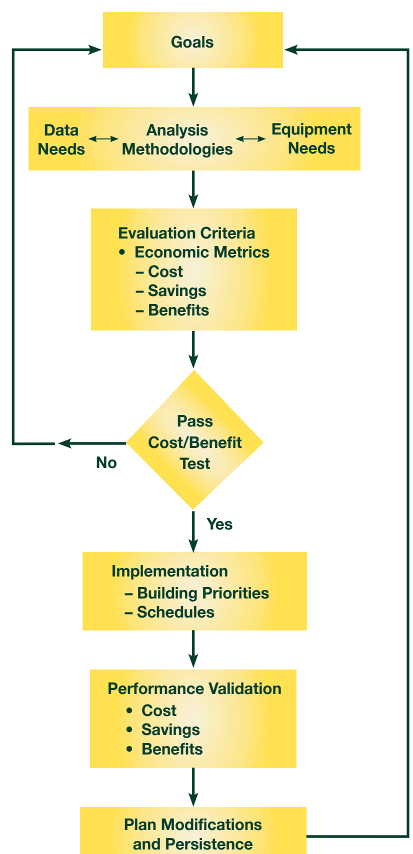


Figure 8.8.1. Development process for meter system planning

8.8.4 Implementation, Design, and Installation

The planning process up to this point has been largely analytical. Based on the goals, objectives, analysis needs, and application of evaluation criteria, there is now enough information to design the actual metering system. Elements of the implementation, design, and installation steps include the following sub-elements discussed below:

- System financing, or how much funds are available and how will these funds be obtained, needs to be addressed early in the design process and revisited once cost estimates based on actual designs are completed.
- Prioritization of buildings and/or utilities to be metered. There may be a need or a greater benefit to metering some buildings and/or some utilities before others.
- The design of the metering system hardware application needs to:
  - Satisfy functional requirements
  - Define a system architecture
  - Develop equipment specifications
  - Review and refine the cost estimate to purchase and install the metering system.

8.8.5 Performance Validation and Persistence

Once the metering system is up and running, the overall program focus shifts to making sure:

- Accurate data are obtained and put to timely productive use
- The metering system continues to operate effectively and reliably.

8.9 Case Study – General Services Administration's Kastenmeier Federal Courthouse

In 2005, the operations staff at the Kastenmeier Federal Courthouse in Madison, Wisconsin, agreed to serve as a pilot site for the demonstration of the newly developed web-enabled Whole-Building Energy Diagnostician (WBE). The WBE was originally developed by the Pacific Northwest National Laboratory (PNNL) with funding from the Department of Energy's Building Technologies Program. In an effort to make the tool more affordable and more widely available to the Federal sector, DOE's Federal Energy Management Program (FEMP) funded the development of a web-enabled version of the WBE. The WBE module installed at the Kastenmeier Federal Courthouse was a commercialized version of the tool.

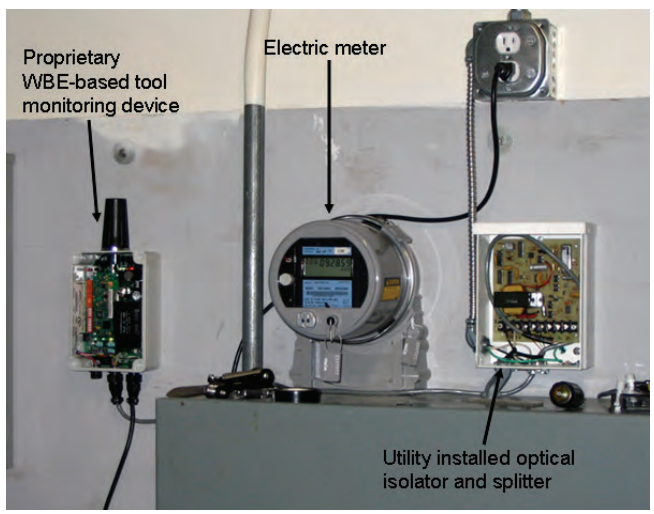


Figure 8.9.1. Installed wireless monitoring system for WBE-based system

Photo courtesy of NorthWrite, Inc., Minneapolis, MN.

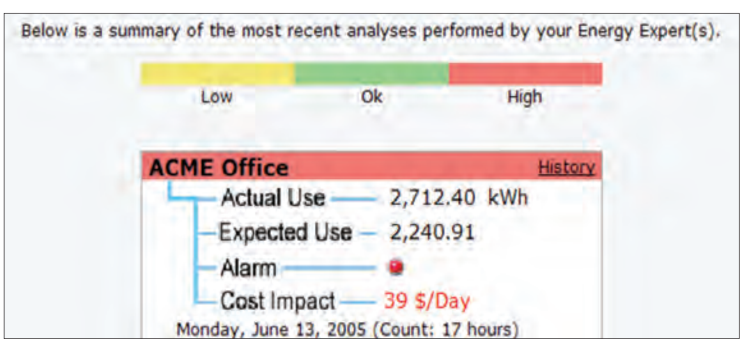
The WBE module tracks energy uses at the building level – in this case, the total electric and natural gas use. The values of expected energy consumption are generated by empirical models of the building, which are automatically developed by the WBE. In general, the model uses time of week, outdoor air dry-bulb temperature, and relative humidity as independent variables. The WBE then graphically provides building operators alarms for unexpected usage to identify major changes in energy consumption (PNNL 2005).

As part of the demonstration project, NorthWrite, Inc., partnered with FEMP to make the web-enabled WBE module available to the Madison Courthouse as part of an overall suite of operations and management tools. The Madison Courthouse is a 100,000-square-foot building in Madison, Wisconsin. The building spaces include court rooms, chambers for the judges, jury rooms, holding cells, and offices for the Clerk of Courts, Bankruptcy Courts and U.S. marshals. Daily building occupancy includes approximately 120 full-time employees plus daily visitors.

The one-year demonstration started in May 2005 with the installation of the electric pulse meter and a monitor device, which reads pulse outputs from the meter and sends them wirelessly to a network operations center, needed to support the web-enabled WBE (Figure 8.9.1). A gas pulse meter was installed in July 2005. Summary of costs to purchase, install, and operate the metering system at the Kastenmeier Federal Courthouse is as follows:

- $1,000 to purchase and install the electric and gas meters (approximately $500 each)
- $3,500 to install the proprietary WBE-based tool hardware
- $2,500 to train agency staff on the use of the commercial web-based suite of tools (which included the WBE-based tool as well as additional site maintenance management functionality)
- $100 per month for the monitor service
- $250 per month to subscribe to the WBE-based tool and commercial maintenance management services suite of tools.

The reports and graphics generated by the WBE module are reviewed daily by the building mechanic as part of the morning startup, with an emphasis on verifying that peak usages do not vary unexpectedly (Figures 8.9.2 and 8.9.3). These daily reviews of the data have been helpful in diagnosing:



Screenshots courtesy of NorthWrite, Inc., Minneapolis, MN.

Figure 8.9.2. Sample screen capture for a generic building showing an alarm or high-energy using condition. Included is an estimated cost impact associated with the higher than expected electricity use.

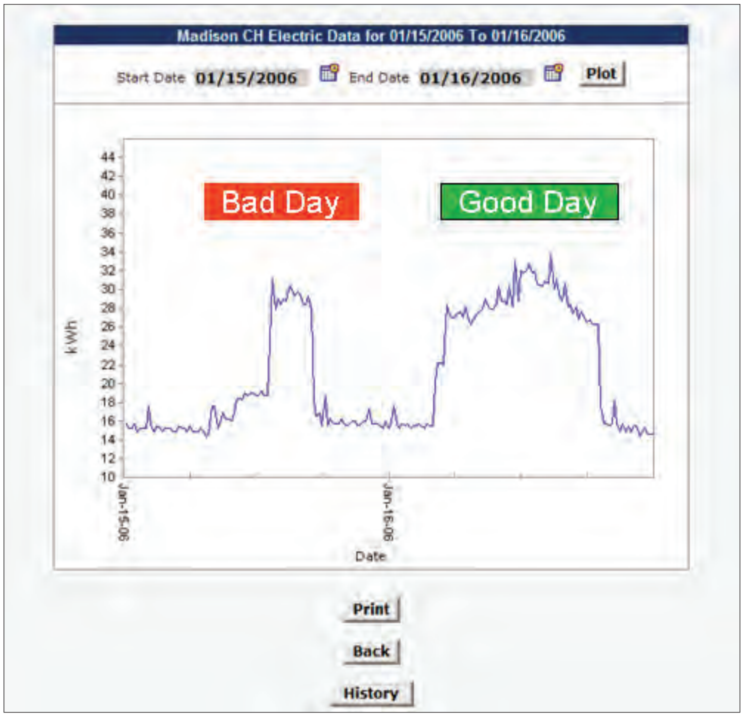


Figure 8.9.3. Data from the monitoring device provides a comparison of 2 days of electricity use for Sunday, January 15, 2006, and Monday, January 16, 2006. Figure shows unexpected off-hour usage on the 15th, while electricity consumption on the 16th was as expected.

- Incomplete reprogramming of schedules on the building automation system (BAS) following a time change
- Improper boiler sequencing operations
- An air-handler operating 24/7 instead of on the schedule as programmed by the BAS
- Belt slippage due to wear on a large horsepower motor
- Refrigerant leaks in rooftop compressors.

The WBE module also lets the General Services Administration (GSA) staff observe the effects of variable-speed drives and direct-expansion cooling operations, including occasional spikes in electrical consumption, and verify that energy-intensive IT downloads are completed during off-hours.

Since this is a web-based system, the GSA regional energy office in Chicago is able to access and review the system data. This second set of eyes works to alert the Madison staff of other possible emerging trends.

Lessons Learned:

- Metered data were instrumental in identifying high or abnormal energy use, and assisted in diagnosing inefficient equipment and systems operations at the Kastenmeier Federal Courthouse.
- The ability to view data at multiple, including remote, locations allowed for expanded assessment capabilities.
- Metering natural gas consumption, while not required by EPAct 2005, proved beneficial. Metering natural gas consumption is now required by EISA 2007.

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