Measuring and Verifying Savings From Improvements in Operation and Maintenance of Energy-Consuming Systems in Commercial and Institutional Buildings

Discussion Paper Prepared By:

Steven R. Schiller, P.E. and Gale Corsen, P.E.
Schiller Associates
Oakland, CA

Prepared For:

Dale Sartor
Lawrence Berkeley National Laboratory

and

Mark Bailey
U.S. Department of Energy's Rebuild America Program

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1.0 Executive Summary

Losses associated with poor operation and maintenance (O&M) cost industry and government billions of dollars each year[1]. Improved O&M offers an opportunity to lower costs and increase profits by using existing systems and equipment more effectively. For example, a recent California Energy Commission report indicates that improved preventative maintenance techniques can result in energy savings ranging from six to nineteen percent of a typical community college's energy bill[2]. Furthermore, reducing O&M costs may be attainable when energy-using systems and equipment are replaced or upgraded to save energy. In either

[1] "Enhancing Productivity through Improved O&M", Pacific Northwest National Laboratory, http://www.pnl.gov/energy/om/om.htm, 10/13/97
[2] "Study: HVAC Maintenance and Training Does Pay", Barry Abramson and Michael MaGee, Energy User News, April, 1998, page 16.

instance, the decision to make needed improvements may hinge on the ability to quantify or place a value on the savings.

This paper identifies issues and approaches for measuring and verifying (M&V) savings associated with improvements in operations and maintenance (O&M) of commercial and institutional buildings. Background information is provided on O&M techniques and O&M methods that can reduce energy (and other) costs, such as labor and equipment replacement costs. In addition, outlines of M&V Options are provided, following the format of the International Performance Measurement and Verification Protocol (IPMVP), as a starting point for future development. By providing information on O&M practices and methods, and defining requirements for further efforts in this area we hope to encourage more O&M savings by eliminating the market barrier associated with not being able to quantify benefits.

At this time there are no specific M&V protocols for assessing O&M measures. We believe that there will be more O&M projects, performance based and conventional self-financed projects, if M&V protocols did exist because there would be more confidence in the savings if projects could be evaluated under common standards. In addition, performance-based contracts would be more prevalent if there were agreed to methods for determining savings.

2.0 Background

With performance contracting projects the contractor is paid from total savings actually produced by the project.[3] Projects typically involve equipment retrofits to produce energy savings. However, energy savings and operational cost savings can also be achieved through measures that involve operations and maintenance of a facility. For example, for projects in Federal facilities the term "energy savings" is defined as a reduction in the cost of energy resulting from the lease or purchase of operating equipment, improvements, altered operation and maintenance, or technical services.[4] In addition to energy savings, there also can be reductions in costs for O&M, equipment and labor as well as improvements in a building's environment – such as improved lighting or indoor air quality – that can lead to productivity benefits.

Operations and maintenance improvement measures offer many opportunities for energy cost savings. Buildings often are not used and/or do not perform in the manner they were designed. For example, common problems include malfunctioning or non-optimized controls.

Indicators of the need for O&M improvements include:[5]:

- Deferred maintenance activities;
- Excessive operations, maintenance, and/or energy costs; and
- Equipment or systems that require substantial maintenance attention and/or early failure of equipment.

[3] The Energy Efficiency Project Manual, National Association of Energy Service Companies, sponsored by U.S. Department of Energy, October, 1997.
[4] Federal Regulation Section § 8287c.
[5] The Energy Efficiency Project Manual, National Association of Energy Service Companies, sponsored by U.S. Department of Energy, October, 1997.

O&M measures can include repairs of defective equipment or equipment that is not operating as efficiently as possible (e.g. broken HVAC economizer systems), commissioning, improved maintenance procedures (including computerized tracking systems), training, or the installation of computerized systems that monitor system performance and report warnings when systems are not operating properly. In some cases O&M measures can include staffing level changes (either reductions or increases) and/or the out-sourcing of facility O&M staffing. O&M measures do not necessarily involve the installation of new equipment.

The "pay for performance" aspect of performance contracting requires that the project's benefits be quantified. Therefore, the measurement and verification (M&V) process, in which savings from projects are documented, is one of the most important activities associated with implementing performance contracts. It also is the second most crucial negotiation issue after pricing—and it is usually the basis for disputes when they do occur between contractors and users. How to document savings is a barrier to implementation of O&M measures as many owners are not sure of how either (a) savings will be achieved and (b) savings can be quantified. Thus, M&V can be defined as risk mitigation—for contractors and energy users.

At first glance, the basics of M&V for O&M are no different than they are for other measures – savings are the difference between what happens and what "would have been" had the measures not been implemented. However, several important issues arise when we seek to measure and value these O&M benefits. Those issues include concerns about: valuation of savings, determining and adjusting baselines, persistence of savings and time period for analysis, and O&M measure's indirect effects.

Risk may be the most difficult O&M issue to address. Somehow, decision makers seem more reticent to tackle risk in the O&M context than they are when deciding on a new piece of equipment or redundant additions to a system. Risk, as defined here, refers to the possibility that some event could occur if one or more systems do not function correctly – if a production line has to be shut down, or a critical health care item malfunctions. Risk also refers to the managerial disfavor attached to too many complaints. The costs of lost productivity (for example, due to poor lighting or improperly operating ventilation systems), tarnished images, and outright liability claims may potentially dwarf any O&M savings.

Thus, energy savings program developers and facility owners have tended to concentrate on improvements to specific systems and equipment that have easy to quantify benefits and to shy away from programs that achieve savings through more hard to define and quantify O&M improvements. Overcoming barriers to more O&M savings measures requires (a) improvements in information management and management of perceptions about what savings can be achieved through O&M measures and (b) improvements in the methods for measuring and verifying O&M project savings.

Methods for measuring and verifying the savings from O&M measures are not nearly as developed or tested as methods for M&V of energy or water retrofit projects[6]. There are

[6] See International Performance Measurement and Verification Protocol (IPMVP), U.S. DOE, DOE/EE-0157, 1997 and U.S. DOE Federal Energy Management Program M&V Guideline, 1996. www.ipmvp.org

numerous characteristics of O&M measures that make quantifying baseline conditions, post-installation conditions and savings very difficult. The purpose of this discussion paper is to look at the issues inherent in the M&V of O&M measures and thus begin the process of defining M&V mechanisms that can reduce a barrier to the implementation of more O&M measures.

3.0 Overview of O&M Practices

3.1 O&M Options

Building operations and maintenance options include:

- Reactive or Corrective Maintenance,
- Preventive (or Preventative) Maintenance,
- Predictive Maintenance, and
- Proactive Operations and Maintenance.

Reactive Maintenance is epitomized by the old "if it ain't broke don't fix it" saying and run-to-failure philosophy. It is simple, requires no forethought, and, up to the point of machinery failure, requires the least support from the O&M crew and infrastructure.

In a reactive mode, little, if any, effort is made to ensure that operating conditions are within the design envelope. Consequently, the actual service performance and life span of the equipment are substantially below the estimates of the manufacturer. The equipment is simply run until it either fails catastrophically or it no longer provides its intended function. At that time, often with an emergency call, the equipment must be overhauled or replaced.

Although reactive maintenance may make economic sense in some instances (replacing a light bulb, for instance), in a vast majority of process applications it is by far the most expensive life-cycle cost mode. It is still, surprisingly, the predominant method of plant operation in the U.S. despite the high product loss, capital equipment loss, total manpower expenditure, and accident rate that results from its use. [7]

Preventive Maintenance (PM) is the art of (a) regularly performing certain maintenance procedures (e.g. cleaning filters, lubricating rotating parts, adjusting fan belts, etc.) and (b) periodically checking key operating parameters to determine if the operating conditions and resulting degradation rate are within the expected limits. Preventative maintenance is instrumental in preventing an energy system from using more energy than necessary.

PM tests, inspections, servicing, parts replacements, etc. are based on service life (for example, hours of operation) or purely on time-in-service. The PM method can be labor intensive, some unneeded maintenance is performed, and incidental damage to equipment as a consequence of the intrusions will often occur. A PM system can, however, be a cost effective strategy when the life span of the equipment is well understood and consistent. Studies in the utility industry report

[7] "Completing the Last Step in O&M Cost Reduction", O&M Evolution – from Reactive to Proactive, Don Jarrell, Pacific Northwest National Laboratory, http://www.pnl.gov/energy/energy/fmcpap3.htm, 10/13/97

a reactive to preventive life-cycle cost savings in the 12% to 18% range[8]. This methodology, while it significantly reduces the O&M cost over reactive maintenance, and is successful in making equipment last longer, still allows abrupt failures.

Predictive Maintenance advocates measurements aimed at the detection of degradation mechanisms themselves, thereby allowing the degradation to be understood and eliminated or controlled prior to significant physical deterioration of the equipment.

These usually non-intrusive measurement methods allow early detection and correction, reducing the potential for degradation considerably earlier in its progression. Advanced technologies, such as vibration analysis, oil analysis, thermography, and condition monitoring, move the problem recognition capability to the leading edge of the degradation envelope.

The application of this technology results in marked increased equipment life, earlier corrective actions, decreased process downtime, decreases in maintenance parts and labor, better product quality, decreased environmental impact, and more energy savings.[9]

Proactive Operations and Maintenance takes predictive maintenance a step further in that ideally the detection and diagnosis of off-normal equipment operation is used to identify the root causes of system conditions. This approach is a step towards optimizing the O&M process. With proactive O&M, operations are integrated into the maintenance process, and the primary effort is to identify and redress parameters outside the design envelope, responsible for the off-design condition.

The use of computers and low cost sensors allows O&M managers to automate recognition of problems (what went out of specification), to run degradation mechanistic diagnostics (what's going wrong), and to effect a root cause solution (what needs to be done to really correct the situation). Ideally, the result is that a complete picture of the problem and its solution is presented to both the operations and maintenance staff. Asset managers can proceed using informed decisions based on known degradation rates and better estimates of equipment remaining life. Predicting and planning now become the hallmark of maintenance. The approach helps eliminate both system downtime and unnecessary maintenance.[10]

3.2 Effective O&M

An effective maintenance management program is detail oriented. Extensive records are typically needed for equipment inventories, work orders, detailed cost accounting, and logs of system operation, performance, and failures. Administrative costs can be considerable and difficult to justify compared to potential savings.

The most effective tool in any O&M improvement is the right kind of staff: motivated, well informed, and experienced. However, the staff can be greatly assisted with appropriate tools

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[8] *op cit*

[9] see also "Predictive Operation and Maintenance Technologies", Pacific Northwest National Laboratory, http://www.pnl.gov/energy/energy/poamt.htm, 10/13/97

[10] "Completing the Last Step in O&M Cost Reduction", Evolution of the Proactive Approach", Don Jarrell, Pacific Northwest National Laboratory http://www.pnl.gov/energy/energy/fmcpap3.htm, 10/13/97

such as a building management system. In recent years, competent computer-based O&M management tools have become available at relatively favorable prices, facilitating record keeping, scheduling, and other functions that provide important information to the O&M manager.[11]

Modern software can relate materials and labor costs to work orders and types of work orders, link them to parts and materials inventories, initiate purchase orders for stock replacement, and print monthly summary reports. No longer is it necessary to make repetitive entries for the same transaction so it can be recorded several different ways. The O&M manager has been granted a cost-effective tool not only for tracking costs against budgets, but also for monitoring the operating and maintenance history of each system and piece of equipment and predicting their future requirements.

An emerging addition to the O&M management toolkit is Automated Diagnostics. These are expert tools that automate the process of diagnosing faults and performance degradation in equipment and systems. The systems serve as intelligent advisors to operators, engineers, maintenance personnel, administrators and management. Some diagnostic tools provide only alarms when conditions exceed acceptable ranges, while others identify improperly operating equipment and the root causes of performance degradation.[12,13]

The concept involves diagnostics that can be applied to many components such as motors, valves, heat exchangers, compressors, filters, generators, boilers and electrical equipment to provide automated, integrated degradation and fault diagnoses in real time. The technology is also being extended to validation of sensor performance. Sensor failure is pervasive across industries and results in performance losses associated with not knowing the true operating state of equipment or a process. Researchers are developing a capability to automatically identify and locate sensor degradation and failure. When a failure is found, this system will provide virtual sensor data until the failed sensor can be re-calibrated or replaced.[14]

Realizing savings from O&M measures depends in part on the ease with which procedures can be executed and the availability and use of adequate engineering documentation. Typical O&M documentation includes systems O&M manuals, functional concept manuals, maintenance master equipment lists and real property installed equipment inventories. O&M management plans include O&M staffing plans, training plans, preventive maintenance plans, budget estimates, contract maintenance plans and a Service Contract Procurement Document.

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[11] For example, the Maximo and Maximo/Advantage systems from PSDI (617-661-1444), an Oracle based maintenance DBM tool. The systems also facilitate work orders, inventory, and preventive maintenance. Lawrence Berkeley National Laboratory / University of California, Berkeley is among the users of the software. The university has recently switched from a prescriptive to performance based maintenance program, including performance metrics.

[12] University of California, Department of Facilities Administration, Facilities Manual Vol. 6 Operation and Maintenance of a Plant, http://www.ucop.edu/facil/facilman/volume6/ch1.html, February 22, 1996. The university distinguishes (Section 1.4) between Planned, Preventive, and Emergency maintenance.Page: 6

[13] "Small-Scale On-Line Diagnostics for an HVAC System" by Robert H. Dodier, Curtiss, and Kreider, ASHRAE paper 4148 (RP-883), presented January 1998

[14] "Automated Diagnostics", Pacific Northwest National Laboratory, http://www.pnl.gov/energy/energy/ad.htm, 10/13/97

3.3 O&M Cost Categories

The total cost of any building facility, system, or equipment item is the sum of its:

- Capital costs
- Operating costs (including utility costs)
- Maintenance costs
- Consequential costs

Although simplified approaches may be used for limited purposes, it is well established that the total cost of a property and its operation must ultimately relate to its entire lifetime. Differences in life spans, the timing of various component costs, and indeed the availability and cost of money, make anything less than full life cycle costing an incomplete picture.

Capital costs arise from acquiring and replacing facilities, including financing costs. In the context of life cycle costing, the total cost is usually defined by an initial cost, final cost (removal), salvage, expected lifetime, and applicable discount rate. Effective O&M practices can minimize capital costs by extending equipment lifetimes and facilitating orderly replacements (allowing time for least-cost procurement and other requisite activities). Capital investment efficiency looks closely at the maintenance or degradation of capital HVAC equipment. To accomplish this in the field it may be necessary to establish quantitative measures for capital equipment condition, degradation, and lifetime – measures such as tube wall thickness and keeping track of repetitive stresses.

In a reciprocal manner, effective capital investments should minimize the need for operating and maintenance staff and their associated O&M costs. Capital improvements raise productivity, provide for effective performance and improved services, and meet increasing demand. Such productivity improvements are not always reflected in O&M funding projections, thereby overstating the O&M funds required. If this leads to under-funding of capital investment in order to sustain existing operations, the practice is shortsighted. Budgets, including O&M budgets, should be consistent with optimized life cycle costing, which will anticipate the full implication of all cost elements, including lower O&M funding requirements resulting from investments in modernization. Careful planning will therefore show if a more aggressive timetable for investment in modernization offers further reductions in proposed O&M funding.[15]

Operating costs consist of utilities, supplies, and wages and salaries for operating staff. Operating costs may include "continuous commissioning" to extend the benefits of an initial commissioning. Many authorities urge that the commissioning process should not be a one-time activity. Initial commissioning or re-commissioning can be an important starting point, but the process needs to continue with ongoing re-evaluations, because operations are not static.

The further comments about maintenance costs apply equally to most operating supplies and labor costs. In practice the dividing line between operations and maintenance may be hazy

[15] Federal Aviation Administration:
http://www.nasi.hq.faa.gov/nasiHTML/nas-architecture/comments/html/comments –
Gen. Comment 4. Attempting to meeting the primary economic objective of the NAS architecture. Discussion of maintenance issues in NAS modernization.

because good operating practices serve to minimize maintenance requirements. Continuous commissioning is an example; as long as the practice is observed, classifying its cost as Operations or Maintenance is immaterial

Maintenance costs serve to preserve a facility (i.e., extend its lifetime) and its performance, including energy efficiency. It is therefore an inherent feature of the maintenance function that O&M activities and costs are interactive with equipment capabilities, performance, and operating costs. The interaction is two-way. Newer and better equipment (compared to the converse) usually can be maintained with less effort and cost. Equally true, however, is that good and better O&M activities can decrease equipment costs, not only other current and future operating costs associated with the equipment but future capital investment costs as well.

For the same reason there is an inherent relationship between current costs and future costs, and an inherent relationship between current costs and future benefits. To sustain existing services and meet increasing demand while using existing obsolete technology and aging equipment it is necessary to increase staffing levels. Insufficient investment in good equipment may minimize the capital costs, but at the expense of higher operating and maintenance costs. Reductions in current O&M budgets imply reduced levels of current O&M care, which in the future will require even larger O&M expenditures to pay for reduced efficiency and to "catch up" on deferred maintenance. Perhaps of even greater significance, future O&M budgets will need to defray the costs associated with premature wear and other conditions that arise during the period of neglect.

Insufficient expenditures for maintenance can therefore lead to higher operating costs and to higher capital costs for premature replacements. The optimal operation is at the point where total life cycle costs are minimized. The evaluation of tradeoffs between long and short-term costs and benefits requires life cycle methods.

Consequential costs are the indirect result of some other condition – as we are informed when we listen to the old story of the war that was lost for the want of a nail, horseshoe, horse, and eventually the rider. In a facilities setting, deficient maintenance may result in failure of a piece of equipment, which in turn causes a system to fail. Consequential losses continue if this requires shut down of an assembly line which delays shipments that result in cancellation of an order or even a lawsuit for breach of contract and failure to perform.

Other consequential costs or benefits include productivity, such as the productivity associated with improved lighting or indoor air quality. The consequences of poor system performance or failure go well beyond fuel or other energy costs. In one example from the field, poor heating of a building resulted in poor people-performance, jeopardizing the organization's mission.[16] Both earlier[17] and more recent studies[18] confirm relationships between living environment and productivity, which can be impacted if there is a malfunction of energy systems.

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[16] "Site Assessment and Characterization", Pacific Northwest National Laboratory, http://www.pnl.gov/energy/energy/saac.htm, 10/13/97

[17] ASHRAE 1997 Fundamentals Handbook

[18] "Relationships Between the Indoor Environment and Productivity: A Literature Review", by Nisha Patet Sensharma et al, ASHRAE paper 4164 (RP-700) presented January 1998.

Potential savings from O&M measures therefore include consequential losses which are avoided, such as those arising from leakage, mildew, or avoidable wear. The benefits of better O&M potentially include reduced risk with respect to equipment failures, expensive repairs, building shutdowns, people safety/health, insurance premiums, and liability, liability claims, and litigation.

Only infrequently do managers attempt to quantify the value of consequential costs when decisions are being made about O&M, even though the consequential losses may far outweigh the operating costs. The decision maker is more likely to make a qualitative (and perhaps uninformed) judgement about the risk factors.

3.4 O&M Budgeting

The budgeting process attempts to anticipate future costs. It is a planning process that identifies goals, resources required to achieve those goals, and those resource costs. Budgeting is a process for allocating resources, both monetary and non-monetary. It is closely linked to resource management and control activities in which actual expenditures are compared with budgeted expenditures.

Organizations often establish separate budgets for operations and for capital improvements. Operating budgets are usually limited to a single operating year, while capital budgets normally entail multi-year projections. The plant operations manager is likely to be involved in budgeting for both types of budgets and his activities are affected by both. Changes in capital assets often impact the commitments for and costs of operations and maintenance.

Organizations vary in their approach and managerial commitment to budgeting. Budgeting strategies, which may be used, include:

- Status quo – budget to repeat last year's actual costs or budget
- Adjusted status quo – modify last year's actual costs for anticipated changes
- Straight line trend – project each year to show as much change as the previous year
- Staffing – budget costs in proportion to the size of the authorized staff
- Programmatic – base each cost on planned program elements
- Zero basis budgeting – budget each period on its own merits, ignoring prior budgets

Some organizations and managers follow budgeting practices with weaknesses such as:

- Failure to adjust for budgeting deficiencies of earlier periods
- Failure to conduct comparative analyses and benchmarking
- Failure to anticipate and assess atypical costs
- Budget distortion through end-of-period allocations
- Budget overstatements (padding)

Budgeting for O&M typically encompasses staffing and staff administration, materials management, facilities inventory, work control, financial control, and capital planning. Specific details will reflect the nature of the organization's operations.

Budgeting for O&M generally mirrors practices of the entire organization, and may indeed be dictated by corporate management. Some organizations, for example, discourage budget requests that exceed actual expenditures of the prior year; rather than rewarding managers for economies, this effectively encourages each manager to spend the entire budget each year.

The operations and maintenance group normally is responsible for providing support to other operating units of the larger organization – which in turn are likely to be carrying out the organization's primary goals. It follows that the O&M scope, and therefore the O&M budget, need to be established in parallel with the plans of other operating units. Even when a concerted effort is made to do this, the O&M manager may not receive all the information needed for O&M budgeting.

In most respects, however, budgeting for O&M activities is no different from budgeting in any other part of the organization, and the system for tracking overall costs and comparing them with the budget is likewise an overall corporate decision. However, detailed costs associated with individual work orders and/or specific equipment items are often managed independently by the operations organization. Here again, the advent of modern computer-based O&M management software with extensive cost tracking capabilities is allowing O&M managers to take advantage simple, competent, complete, and relatively inexpensive cost tracking capabilities. It is reasonable to expect that the new systems will provide better management information than in the past, and that the better information will eventually show up in improved operating results. If so, it will gradually become easier to anticipate O&M costs and validate cost savings.

4.0 Overview of O&M Measures

O&M improvements often require new ways to organize, operate, and manage the O&M process. Since acknowledging the need for improvements could imply that the organization, operations, and management were deficient, it is not surprising when managers and staff alike defend the *status quo* rather than risk criticism. They have already spent their budgets to do the best job they know, so it is natural to assume that there are no fundamental problems. Even the complaint log may support their position.

To help define the O&M opportunities and the related M&V issues Table 4-1 is a list of common O&M measures and with applicable categories of benefits.

Table 4.1
List of Common O&M Measures

Measure	Capital Cost Savings	Operating Costs - Energy	Operating Costs - Labor	Operating Costs – Other	Maintenance Costs	Consequential Costs
Commissioning and “continuous commissioning	X	X		X	X	X
Improved process tracking and scheduling		X		X	X	X
Improved setpoints		X		X	X	X
Improved maintenance, general	X	X		X	X	X
Improved preventative maintenance program	X	X			X	X
Repairs	X	X		X		X
Predictive maintenance	X	X	X	X	X	X
Proactive maintenance	X	X	X	X	X	X
Monitoring and data logging		X		X	X	X
Training	X	X	X	X	X	X
Documentation			X		X	X
Downsizing			X	X		X
Out-sourcing O&M			X			X

Monitoring is included in the table because it can be a mechanism for reducing O&M costs and improving performance. Monitoring provides an O&M management tool, even without an expert diagnostician. Typical system monitoring will record fuel consumption, efficiency, and

[19] Don Jarrell, Pacific Northwest National Laboratory, Richland, Washington; Jan 1998 telecom with Gale Corsen

other conventional performance parameters, often using an EMS. Information from those results can serve to identify warning symptoms for conditions that need attention, especially when operating conditions are found to fall outside the system design parameters. Staying within design conditions is therefore a measure of O&M effectiveness as well as an operating standard.[20] Downsizing of the O&M staff can be an effective strategy if the staff is too large, their time is being wasted, and/or if physical properties change that should lead to reduced labor; otherwise, the strategy is likely to be counter-productive.

5.0 M&V Issues For O&M Projects

The energy and non-energy savings from O&M measures are difficult to quantify because:

- O&M measures are usually not limited to new pieces of equipment whose impacts can be isolated and measured
- Baseline O&M procedures and costs are difficult to quantify, particularly if the current O&M practices are resulting in sub-standard comfort, equipment lives, indoor air quality, etc.
- Valuation of O&M savings may require trade-offs between short-term and long-term benefits and thus may require a long period of evaluation to determine true net benefits
- Valuation of O&M costs and savings may involve intangibles such as risk and quality of service.

As a step towards addressing these complexities and preparing approaches and options for O&M M&V it is important to further define the issues which underlie the complexities. Thus, the following is a discussion of some of the issues associated with quantifying the savings from O&M measures. The issues are compiled into the following categories:

- Valuation of savings
- Determining and adjusting baselines
- Persistence of savings and time period for analysis
- O&M Measure's Indirect Effects
- Can O&M savings justify M&V/metering activities

[20] Don Jarrell, Pacific Northwest National Laboratory, Richland, Washington; Jan 1998 telecom with Gale Corsen

5.1 Valuation of Non-Energy Savings

Projecting, and then documenting true, benefits is particularly difficult to do with O&M measures. Indeed, O&M cost savings have a way of being diverted and ultimately disappearing altogether. The following are discussions of a few topics.

Energy Costs. Many energy cost issues for O&M projects are similar to those for energy efficiency measures; such as calculating energy costs versus just kWh, kW or therm savings. However, other issues such as the trade-off between energy and other non-energy benefits – such as comfort - can effect the valuation of the overall O&M project.

Labor Costs. When a project involves reductions in facility staffing as a means of reducing costs there are several M&V issues (beyond labor relations and equity issues). These M&V issues include: defining the baseline cost, tasks and performance of the existing labor force, defining how labor costs will be reduced by the project - and not just transferred to another "accounting category", and providing sufficient oversight to ensure that the tasks and performance of the labor force's replacement are equal to or above the specified requirements.

If, for example, O&M changes are projected to provide labor savings, those savings will be realized only if the staff is reduced. If a facilities department is already understaffed, any labor savings are likely to be redirected to other pressing needs. It might be argued that the labor should be redirected, perhaps with benefits that need to be evaluated on their own merits.

Operating versus capital costs savings. O&M measures can affect both labor cost and capital cost accounting categories; sometimes in opposite directions. Therefore, the M&V process must take into account all cost accounting categories which are affected by the O&M measures to ensure that all debits and credits are properly accounted for and used in the calculation of performance.

Another related issue is calculating a potential difference in residual value at the end of the performance period – a concept related to salvage value. For example, a facility owner would probably rather have performing systems at the end of the contract period instead of systems that are at the end of their useful life.

5.2 Determining and Adjusting Baselines

Setting baseline M&V procedures. Determining the baseline from which savings are calculated for O&M measures often requires evaluating what the existing standards of performance are for O&M activities. These existing standards are often not well documented and the baseline definition can thus involve identifying the incremental value of "more robust" O&M measures versus "well done, conventional" measures – both of which need to be defined for the calculation of savings. In addition, while the standard for acceptable practice may be defined for the facility, actual practice may be sub-standard. Thus, should the savings be based on the O&M standard or the actual O&M practices?

Adjusting baselines. Baseline adjustments are one of the more difficult aspects of energy project M&V. Some of the unique issues associated with O&M measures are:

- Adjusting labor costs, equipment repair costs, and equipment replacement schedules based on changes in the facility's operation, e.g. changes to longer life lamps paid for by the facility.

- Period of time for assuming existing baseline conditions e.g., how long should the current, perhaps poor, maintenance procedures be assumed to have continued in the absence of the O&M measure.

5.3 Persistence of savings and time period for analysis

A simple O&M measure such as cleaning filters may achieve substantial energy savings, but only so long as people continue the practice. Concerns about persistence apply to a wide variety of maintenance and operational items. Experience tells us that, after certain procedural improvements are made, a tendency to slip back into earlier practices can occur in which clogged filters are continued in use, controls are no longer optimized, drive belts are slipping, and repairs are not made. It is easy to conclude that many O&M measures have short lives.

Another important characteristic of O&M measures is the inherent coupling of short-term and long-term effects. O&M budget cuts "today" do not result in long term savings if they lead to still higher O&M costs "tomorrow". Few tools exist to place a meaningful value on the impacts of "deferred maintenance".

Long-term versus short-term savings. Reducing O&M costs in the short term is relatively easy. It is the ability to reduce O&M costs, and related equipment costs, in the long term while maintaining necessary performance levels (e.g. comfort and safety) that are difficult. Thus, M&V of O&M measures will tend to be a lengthy process to ensure that long-term savings are not sacrificed to achieve short-term benefits. This involves evaluating the persistence of savings and life-cycle savings.

Time period for analysis of performance. Several issues arise out of the time period for analysis. A standard response would be that savings should be determined for the full term of the performance contract. However, if the contract term is relatively short then certain O&M measure impacts might not be considered – whether these are beneficial (e.g., extended equipment life) or not (e.g., shortened equipment life). For longer term contracts a related question is how long is "fair" for attributing savings to a measure? For example, some measures might correct deficiencies, such as broken economizer systems, that would have been repaired at some point even without a performance based contract.

5.4 O&M Measure's Indirect Effects

A related aspect of O&M savings is the concept of consequential losses and savings. Additional attention to preventative maintenance may add to the operating staff budget, but if the effect is to avoid emergency repairs and/or cause interruptions of service then the consequential costs could far outweigh any benefits.

Performance standards. As part of an O&M project it is important to set facility standards for short term and long term satisfactory operations, e.g. comfort, lighting levels, temperature ranges, and air quality. For the M&V of an O&M measure it is important to:

- Define criteria, methods and metrics for evaluating if the facility's performance standards have been met; and

- Define how baseline conditions will be adjusted (or whatever technique is used) if operating standards are currently below standard and will be brought up to standard by the implementation of the O&M measures, e.g. outside air levels are brought up from below standard to levels required by standards. Note, that in some cases the existing performance will be above standard, such as 100% outside air when it is not required, and the O&M measures may reduce the performance, but not below the set standard.

Valuation of indirect benefits. Operating and maintenance practices can have an important bearing on an organization's less tangible costs, such as work stoppages, occupant satisfaction, consequential liability and insurance costs, and other risk factors. Measures for O&M savings have the same potential. These costs are often difficult to identify and even more difficult to value, requiring probability estimates for unlikely but critical events. For example, what if an O&M measure simultaneously changes several factors such as energy, IAQ, and comfort - how is this accounted for, verified and measured? What if multiple changes result in degradation of some factor as well as improvements in others - how is this accounted for?

5.5 Can O&M Savings Justify M&V/Metering Activities

Measurement and verification activities have an overlap with several activities that can be considered O&M activities. These include metering, commissioning and re-commissioning. Logic and the arguments of some practitioners indicate that just the M&V activity of tracking O&M activities and their results would result in improvements. Tracking costs and comparing them to "norms" indicates where more effort is needed, e.g. high equipment failure rates, or where attention in general is required, e.g. excessive chiller run times even when outside air temperatures indicate an economizer cycle should be operating.

The M&V difficulty is how can one measure the effects of the measurement. By definition a measurement system should not effect the item(s) being measured. Specifically, in this situation there are two issues:

- It is hard to determine whether the M&V activity, perhaps an elaborate one, was required to identify a problem or whether a much simpler activity, such as an audit was all that was required. For example, an elaborate metering (M&V) procedure can identify that an economizer damper linkage is broken or that a hot deck is operating at too high of a temperature. However, an experienced HVAC technician can also observe these problems using a regular interval, preventative maintenance inspection checklist.

- No metering or analysis activity itself will result in changes or savings. It is the follow-up activity as a result of the metering and analysis that results in benefits. Therefore, M&V or metering itself will not result in savings. Only, as a tool that is part of an O&M activity will metering result in savings.

6.0 M&V Options

This paper is intended to provide a starting point for development of M&V options and methods for O&M measures. It is not intended to provide those options and methods. Thus, this Section provides a framework of what the M&V options could look like based on the four generic M&V options defined in the International Performance Measurement and Verification Protocol (IPMVP).

Table 6.1 summarizes the IPMVP's four M&V "options". Option A is most appropriate for projects where the primary goal of the M&V activity is to verify the project's energy-saving potential, versus determination of actual long term savings. The other options (B, C and D) are all based on long-term data collection for determining savings over the term of a contract. All of these options involve verification of baseline and post-retrofit conditions as well as proper operation of the measures.

Table 6.1

IPMVP M&V Options

M&V option	How savings are calculated
Option A: Focuses on physical assessment of equipment changes to ensure the installation is to specification. Key performance factors (e.g. lighting wattage or chiller efficiency) are determined with spot or short-term measurements and operational factors (e.g. lighting operating hours or cooling ton-hours) are stipulated based on analysis of historical data or spot/short-term measurements. Performance factors and proper operation are measured or checked annually.	Engineering calculations using spot or short term measurements, computer simulations, and/or historical data
Option B: Savings are determined, after project installation, by short-term or continuous measurements taken throughout the term of the contract at the device or system level. Both performance and operational factors are monitored.	Engineering calculations using long term metering data
Option C: After project completion, savings are determined at the "whole-building" or facility level using current period and historical utility meter or sub-meter data.	Analysis of utility meter data using techniques from simple billing comparison to multivariate regression analysis
Option D: Savings are determined through simulation of facility components and/or the whole facility.	Calibrated energy simulation/modeling; calibrated with utility billing data and/or end-use metering.

Before defining a framework for O&M options, a few general points need to be made:

- Savings from O&M measures will typically fall into one or more of the following three categories: energy, labor, and equipment. A possible fourth category is in-directs, which almost by definition, are difficult to measure.
- Determining labor and equipment savings involves using the same concepts used for determining energy savings: performance period labor and equipment costs are subtracted from (adjusted) baseline values.

- The baseline costs and performance period costs should be tracked with standard accounting practices. A key is to make sure that all costs are accounted for, including all those which rise or fall, due to the O&M measures.

- In general, the baseline labor and equipment costs can be determined by either:

  - Use of a "control group" set of facilities, which are similar to the one(s) with the O&M measures, to determine what O&M costs would have been in the absence of the measures; or

  - Use of historical cost data, adjusted as needed to changing needs and uses of the facility, e.g. more operating hours or higher occupancy loads effect on HVAC system operating costs.

- There may be a practical minimum threshold, or level of effort, that must be conducted for measuring and verifying the savings from any O&M projects. However, this issues is the same for energy efficiency projects, the level of M&V rigor is going to vary according to (a) the value of the project and its expected benefits and (b) the risk in achieving the benefits.

6.1 Option A For O&M Measures

Option A is for projects where confirming the potential to generate savings is the primary objective of the M&V activities – versus the other options where actual savings are estimated based on actual operating conditions. Therefore, Option A involves determining savings by validating certain key performance criteria (such as the operation of a new O&M software program or repairs to outside air dampers) and stipulating other parameters (such as assumed reductions in labor hours). Payments could be subject to change based on periodic assessments of O&M activities.

With Option A the potential to generate savings needs to be verified, but actual savings are estimated (stipulated) based on the results of the "potential to generate savings" engineering calculations (with possibly short-term data collection). Post-implementation costs (labor, energy, maintenance costs, etc.) are not measured throughout the term of the contract - costs are predicted using analysis of information that does not involve long-term measurements.

Data for stipulations may come from historical data, information from other similar projects and/or spot or short-term metering before and after start of the new O&M measures or activities during the first year of operation. A possible basis for deciding what should be stipulated is to stipulate items which are beyond the performance contractor's control and to measure and quantify items which are within their control.

Stipulation is the easiest and least expensive method of determining savings. It is can also be the least accurate (compared to using long-term measured data) and is typically the method with the greatest uncertainty of determining actual savings. Option A includes procedures for verifying that:

- Baseline conditions have been properly defined.
- The O&M measures, procedures, and/or systems -
  - that were to be initiated have been initiated.
  - meet contract specifications in terms of factors such as quality of service.
  - are operating and performing in accordance with contract specifications and is meeting all functional tests.
  - during the term of the contract, continue to meet contract specifications in terms of factors such as quality, operation and functional performance.

An example of Option A would be for an economizer repair program. The M&V activities would consist of checking the existing condition of the economizers and verifying their repair. A computer simulation may be used to predict energy use with the economizers in their existing (broken) condition (the baseline) and with properly operating economizers (post-installation energy use). Then savings would be stipulated as the difference between the baseline and post-installation predictions. Then each year of the performance contract the economizers' proper operation would be checked and the savings (payments) would not be re-calculated unless the economizer is not working to specification. The estimated savings would not be adjusted with changes in the weather or operation of the building as a whole.

6.2 Option B

Option B is for projects where long-term measurement of performance is desired. Under Option B, individual O&M measures or systems are continuously monitored to determine performance, and this measured performance is compared with baseline values to determine savings. Option B M&V techniques provide long-term operating (persistence) data on the O&M measures, procedures, and/or systems. In some case, these data can be used to improve or optimize the operation of the equipment on a real-time basis, thereby improving the benefit of the retrofit. Option B also relies on the direct measurement of affected end uses.

Option B is for projects where: (i) the potential to generate savings needs to be verified and (ii) actual energy use, labor costs, equipment costs, etc. during the contract term need to be measured for comparison with the baseline model for calculating savings. Option B involves procedures for verifying the same items as Option A plus determining energy savings during the contract term through the use of end-use metering. Option B:

- Confirms that the procedures, systems and O&M measures were installed and that they have the potential to generate predicted savings.

- Determines energy and other cost savings using measured data taken throughout the contract term based on individual component, system or cost category assessments.

Option B methods involve the use of post-installation measurement of one or more variables. The use of periodic or long-term measurement accounts for operating variations and will more closely approximate actual energy savings than the use of stipulations as defined for Option A. For example, energy use, labor costs, and equipment costs might be tracked after measure implementation for actual comparison with baseline values.

An example of Option B would be for an economizer repair program. The M&V activities would consist of checking the existing condition of the economizers and verifying their repair. Chiller, and related auxiliary energy consumption, would be metered before and after repair of the economizers. The pre-existing energy data and independent variable data would be used to establish a baseline model. Savings would be calculated each year as the difference between the baseline energy model and measured, post-implementation data.. The savings would thus be adjusted with changes in the weather or operation of the building as a whole.

An issue with Option B (and C) is that there may be changes which effect post-installation energy, labor or equipment costs which are not associated with the O&M measures – and beyond the contractor's control. For example, there may be an increase in square footage of conditioned space or an increase in facility operating hours. Therefore, and this can be very complex, data would need to be collected in order to derive correlations between each of the cost categories and key factors such as occupancy, hours of operation, weather, industrial production rates, etc. The baseline would be adjusted to account for these changes depending on which party assumes the risk for changes to each variable.

6.3 Option C

Option C involves determining savings by comparing total facility energy and/or O&M costs before and after implementation of the measures. This is a "bottom-line" approach where documented costs (e.g. from utility bills or a company's accounting/tracking system) are used to identify savings. Option C methods are useful when measuring interactions between systems is desired, when determining the impact of projects that cannot be measured directly, and when a direct connection between the M&V effort and "bottom-line" is desired.

Option C involves procedures for verifying the same items as Option A plus determining savings during the contract term through the use of whole facility cost data. Option C:

- Confirms that the procedures, systems and O&M measures were installed and that they have the potential to generate predicted savings.

- Determines an energy and other cost savings value using measured data taken throughout the contract term based on total facility costs.

An Option C example would be similar to the one for Option B. However, with Option C the total costs before and after the out-sourcing would be compared in total versus each individual cost categories.

6.4 Option D.

Option D involves using a calibrated model of a facility to determine savings. For O&M measures a model would need to be developed which showed the effects of different O&M measures, procedures, systems, etc. This Option is not considered to be very practical for O&M measures, and if used, would result in results and procedures similar to those associated with Option A.

7.0 Issues to Address in a Project-Specific Measurement and Verification Plan

At this time, measurement and verification plans for O&M measures will need to be custom developed by the contractor and the customer since there are no guideline M&V methods (as there are for water and energy measures). It is highly recommended that not only the definition of the measures and their projected savings be established early in the planning process, but also the M&V approach. Prior to the customer's approval of a project's scope and design, the contractor should submit a final M&V plan that addresses the following elements:

- Describe the facility and the project; include information on how the project saves energy and/or provides non-energy benefits and what key variables effect the realization of savings. An accounting type spreadsheet should be prepared which shows estimated baseline costs and projected performance period costs for categories such as: labor, materials, equipment replacement, energy, and demand. Each of these values will need to be verified (baseline) or determined during the pre- and post-installation M&V processes.

- Indicate how the customer's budget will directly be reduced, or services enhanced, by the implementation of the measure(s).

- Define the baseline O&M performance standard. If this standard is better and more expensive than the existing standard then document how the baseline O&M budget will be established and calculated.

- Define the minimum performance standards (indoor air, temperature ranges, lighting levels, safety requirements, etc.) that are currently in place and those required once the measure is in place. Determine if, and if so, how benefits (or losses) associated with improvements (or reductions) in performance standards will be allocated between parties. Indicate how compliance with performance standards will be verified during the term of the agreement and what will happen if they are not met.

- Indicate who will conduct the M&V activities and prepare the analyses and documentation.

- Define the details of how calculations will be made and the assumptions that will be made about significant variables or unknowns. For instance: labor cost inflation rates, labor hours per specific task, and equipment life times with and without the new O&M measure. Describe any stipulations that will be made and the source of data for the stipulations.

Describe any maintenance/management software that may be used. Show how calculations of O&M savings will be used to determine payments to the contractor, if appropriate.

- Specify what metering and data logging equipment will be used, who will provide the equipment, its accuracy and calibration procedures, and how data from the metering will be validated and reported, including formats.

- Specify what additional management oversight logs will be maintained, the nature and frequency of entries, and interpretation that is to be assigned to the results. Examples include logging of equipment failures and frequencies, equipment down time, and complaints.

- Describe any sampling that will be used, why it is required, sample sizes, documentation on how sample sizes were selected, and information on how random sample points will be selected, if appropriate.

- Define the level of accuracy which should be achieved—if not for the entire analysis, at least for key components.

- Indicate how quality assurance will be maintained and repeatability confirmed. For instance: "The data being collected will be checked every month and provided to the customer".

- Indicate which reports will be prepared, their containts, and when they will be provided.

8.0 Recommendations for Future Research

The issues identified in this paper and the framework for O&M M&V options provide a starting point for further development of M&V protocols for operations and maintenance measures. To continue the effort the following applied research efforts are suggested:

- Development of analysis and documentation tools for quantifying O&M benefits for each of the O&M cost categories (energy, labor, and equipment), pre-mature equipment failure, and indirect benefits such as improved indoor air quality and comfort. This would include developing statistically valid procedures for generalizing such benefits.

- Development and publication of case studies in which the costs and benefits of O&M measures are documented using different M&V options.

- Development and testing of techniques and tools for estimating (prior to implementation) the value of improved O&M