PECI O&M Best Practices Series

Putting the "O" Back in O&M

Best Practices in Preventive Operations, Tracking and Scheduling

Prepared with funding from the U.S. EPA and U.S. DOE

September 1999

ACKNOWLEDGEMENTS

Appreciation is extended to the Climate Protection Division of the U.S. Environmental Protection Agency (EPA) for funding this project in cooperation with the U.S. Department of Energy (DOE). Roger Mosier of PECI is the primary author of this publication.

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PUTTING THE "O" BACK IN O&M

Best Practices in Preventive Operations, Tracking and Scheduling

Introduction

Many building owners have implemented projects and programs to improve the energy efficiency of their commercial facilities. Successful energy-efficiency strategies include purchasing the most efficient equipment available, right-sizing this equipment to match the building loads, and commissioning the equipment to ensure that it runs efficiently and as specified. Projects that include these components result in buildings with equipment that operates at or near the highest possible efficiency.

Redefine preventive maintenance to include operational activities.

The next challenge for owners and operators is to ensure that this efficient performance will continue over time. Redefining the preventive maintenance program to include operational activities that are critical to energy-efficient building operation promotes long-term energy-efficient performance. Owners can benefit from tracking the performance of major equipment and implementing a preventive maintenance plan to help prevent performance degradation. Equipment performance degrades over time for several reasons:

- Schedule changes that are intended to be temporary often become permanent. Tenants, facility managers, custodial staff, service contractors, controls contractors and others change energy management system and other equipment settings without recording or documenting the changes.
- Power outages may alter schedules for timeclocks and energy management systems.
- Renovations, additions and build-outs may not take operational issues into account.

Efforts to ensure efficient equipment operation may be partially wasted if the equipment runs during hours when it is not needed. No matter how efficiently equipment operates, owners should match equipment schedules with actual occupant requirements. Scheduling can have a profound effect on energy use, particularly if equipment runs continuously without need.

All of these efforts can significantly improve operation and maintenance practices. They positively affect not only energy costs and equipment lifetime, but indoor environmental quality (IEQ) as well. IEQ encompasses the total environment of the building and includes thermal and acoustical comfort, proper illumination, adequate outside air ventilation, and control of indoor air pollutants. Energy-efficient O&M provides benefits in all of these areas.

The research and development of this document was conducted by Portland Energy Conservation Inc. (PECI) and funded by the Climate Protection Division of the Environmental Protection Agency (EPA) in cooperation with the U.S. Department of Energy (DOE). This document provides an in-depth discussion of the three topics described above: preventive operation and maintenance, tracking, and scheduling.

BEST PRACTICES IN PREVENTIVE OPERATION AND MAINTENANCE

Typically, the primary goal of the preventive maintenance (PM) plan is to improve reliability and increase equipment life. In many buildings operation and maintenance staff implement rigorous, maintenance-focused PM programs. However, even when the staff meticulously maintains equipment, operation that relies on inadequate control strategies or improper scheduling can result in significant energy waste, higher energy bills, reduction in the useful life of equipment, and poor indoor environmental quality. PM tends to focus on component-by-component care, rather than taking the holistic view that operation is of equal importance to maintenance. Staff can enhance PM goals by incorporating procedures to promote efficient operation and thereby reduce energy bills.

Focus on how and when equipment operates as well as on maintenance and repair issues.

Traditional operation and maintenance in commercial buildings involves either an intentional O&M program with one or more types of maintenance plans or no O&M program at all. In the second case, owners repair and replace equipment when it breaks down. In either case, the owner, users, and maintainers of the building equipment too often focus on maintenance and repair issues, without paying sufficient attention to how and when equipment *operates*.

REDEFINING PREVENTIVE MAINTENANCE

Optimizing facility operation can provide significant energy savings and comfort benefits. However, staff should take steps to maintain that optimization. Preventive operation is a risk reduction strategy to help ensure that equipment runs efficiently, functions properly, and does not fail prematurely. A good program can even lengthen the life of equipment. A sound operation *and* maintenance program for a facility not only includes maintenance plans and activities but also emphasizes operating equipment in the most energy-efficient manner. Preventive O&M plans differ from typical preventive maintenance plans in that they call for periodically checking operational and control issues. These periodic checks also investigate issues that

Just as staff perform certain maintenance tasks to prepare equipment for heating or cooling season, they should also review and adjust operation strategies seasonally.

affect efficiency. Examples include when and how long equipment operates and what causes it to cycle ON or OFF.

Poor maintenance adversely affects operational performance; likewise, poor operation practices can increase the amount of maintenance required to keep equipment running. The best preventive maintenance programs will include activities that optimize operation. Although some traditional PM tasks such as checking calibrations and cleaning heat exchangers certainly affect operation, many additional opportunities exist to optimize equipment. For example, just as staff perform certain maintenance tasks to prepare equipment for heating or cooling season, they should also review and adjust operation strategies seasonally. A good control strategy for cooling season is not necessarily optimal for "swing" season or heating season.

Finally, staff should track equipment performance over time. The ***Best Practices in Tracking*** section below describes steps to measure and verify the performance of equipment over time.

SETTINGS AND SETPOINTS

One of the keys to optimizing building operation is finding the proper setpoints, settings, and parameters for the control strategies. Finding and setting operational parameters to the proper values may be simple if the original design documentation is available. The challenge for facility staff is maintaining those values over time. Staff can create a table or reference list of all the building's adjustable settings to help them monitor and maintain the proper settings. In addition, staff should answer the following questions when assessing how settings and setpoints may have changed over time:

1. Have occupancy patterns or space layouts changed? Are HVAC and lighting still zoned to efficiently serve the spaces?
2. Have temporary occupancy schedules been returned to original settings?
3. Have altered equipment schedules or lockouts been returned to original settings?
4. Is equipment short-cycling?
5. Are timeclocks checked monthly to ensure proper operation?

6. Are seasonally-changed setpoints regularly examined to ensure proper adjustment?
7. Have any changes in room furniture or equipment adversely affected thermostat function? (Check thermostat settings or other controls that occupants can access.)
8. Are new tenants educated in the proper use and function of thermostats and lighting controls?

A reference list of operational parameters can help facility managers augment an existing preventive maintenance program by introducing a focus on operation. Staff should periodically revisit various building settings to determine whether they have been changed to incorrect values or whether there is a need to change the desired value.

EXAMPLE PREVENTIVE OPERATION PLAN

This section contains a sample preventive operation plan for a typical air-handling unit that is part of a built-up system. The frequencies (weekly, monthly, etc.) presented for this unit are meant to be used as a guide. Staff should integrate this list into the normal preventive maintenance schedule. Frequencies often depend on the quality of the surrounding environment (dirty, clean, industrial, rural, urban) where the unit is located, the budget for performing preventive operation, and accessibility of the unit or the components within the unit. In order to make preventive operation cost effective, these activities should be performed only as frequently as actually needed.

TABLE 1
Sample Preventive Operation Plan

Task Description	Frequency
Fans (Discharge, Return, Exhaust, etc.)	
Measure and record whether fan RPMs are correct (according to design).	Semi-annually
Filters	
In addition to the maintenance issue of condition, check type and direction.	Monthly
All Dampers (Return, Exhaust, Outside Air, Mixing, etc.)	
Tighten and adjust damper blades and linkages.	Semi-annually
Check that damper blade seals are in good repair and verify that dampers close tightly (face & bypass and hot & cold deck semi-annually, others annually).	Semi-annually
Check that all actuators and linkages function properly.	Quarterly
Heating and Preheat Coils	
Check heating valve for proper function (stroke valve open and closed).	Monthly
During heating season, measure and record the difference in temperature between the entering heating water and leaving heating water at the heating coil.	Quarterly
During heating season, check heating coil valve for leaking. Measure and record the change in temperature across the heating water coil after the coil valve has been closed for several hours.	Annually
Cooling Coil	
Check cooling valve for proper function. (Stroke valve open and closed).	Monthly
During cooling season, measure and record the difference in temperature between the entering chilled water and leaving chilled water at the cooling coil.	Quarterly
During cooling season, check cooling coil valve for leaking. Measure and record the change in temperature across the chilled water coil after the coil valve has been closed for several hours.	Annually
Temperature Controls	
Check that all setpoints are correct per conservation requirements, design, or owners needs.	Quarterly
Check that sensors are secure.	Annually
Check and calibrate all temperature space sensors associated with unit.	Annually
Check and calibrate all air handler sensors (discharge air, mixed air, outside air, etc.).	Semi-annually

Task Description	Frequency
Temperature Controls (cont'd)	
Check that setback and setup temperature setpoints are correct.	Quarterly
Check that reset schedules such as supply air, chilled water and heating water are correct.	Quarterly
Check comfort levels in space, both dry bulb temperature and relative humidity, with manual instruments.	Quarterly
Check that all deadbands are correct (no simultaneous heating and cooling unless by design).	Quarterly
Basic Control Strategies	
Check that time-of-day (TOD) and holiday schedules are correct according to owners or occupant's requirements.	Weekly
Check that optimum-start and coast-down strategies are working correctly.	Quarterly
Check that morning warm-up, night-purge, and pre-cool strategies are working correctly.	Quarterly
Check that soft-start strategies are functioning properly to reduce peak.	Quarterly
Check that economizer is controlled to take advantage of free cooling using outside air.	Semi-annually
Check that all related pneumatic receiver controllers and transducers are operating properly.	Semi-annually
Check minimum outside air delivery.	Semi-annually
Calibrate pneumatic receiver controllers.	Annually
General	
Check for presence of space heaters, open windows, covered diffusers, and personal fans as an indicator of a possible equipment operational and thermal comfort problem.	Semi-annually
Check for presence of microbial growth on walls or ceiling tiles, wet carpets, and musty smells as an indicator of an operational problem that may cause inadequate indoor environmental quality.	Semi-annually
Verify that outside air intakes are not receiving contaminated air.	Semi-annually

At first glance, this list may appear to significantly increase the workload of O&M staff. However, performing these tasks on a regular, proactive basis should actually *save* staff time in the long run, because preventive operation helps to reduce occupant comfort complaints and equipment malfunction. Staff who spend more time on preventive operations generally spend less time "fighting fires" and troubleshooting operational problems.

BEST PRACTICES IN PERFORMANCE TRACKING

Unless building O&M staff have adequate and correct information to assess day-to-day equipment performance, opportunities for energy savings may be lost. In order to understand when major plant equipment is not operating as efficiently as it could be, facility personnel should regularly track actual equipment performance data against baseline performance data.

The baseline performance level (for example, kW/ton for a chiller) may be determined from a combination of manufacturer's data and data obtained from monitoring equipment performance. The goal is to obtain a performance benchmark for future reference. When equipment fails to meet this benchmark, owners may need to improve or increase maintenance procedures (such as cleaning, lubricating, etc.) or work to optimize operating parameters (such as setpoints, lockout strategies, capacity control strategies) or both.

Benchmark your building's energy use. Check out the Benchmarking Tool website at www.epa.gov/buildings.

In conjunction with performance tracking, energy consumption may be analyzed as an indication of whole building or end-use performance. Benchmarking the annual building energy consumption is an elementary step in assessing a building's potential for improvement. Measurements that are affected by climate should be weather-normalized.[1] Whole building energy use benchmarking and weather normalization tools are available at the U.S. EPA/DOE Benchmarking Tool web site: www.epa.gov/buildings. To use this tool, you will need to know the building size and age, the types of space usage in the building, energy billing information. After gathering this information, staff will only need to spend about 30 minutes using the tool to benchmark building energy use.

Performance tracking is a deeper form of measurement than energy accounting. Energy accounting is a whole-building best practice that involves tracking the combined energy use of all building systems. This topic is not covered in this document, which focuses on equipment-specific tracking.

[1] Weather normalization involves adjusting energy use data to account for year-to-year or month-to-month climate variations. This allows owners to compare energy use for the same building over time.

Steps for Tracking Performance

This section describes methods to assess the operation of four types of major plant equipment: chillers, boilers, unitary equipment, and coils. To gain the full benefits of tracking equipment efficiency and performance, start by forming a long-term plan. Taking one-time measurements is beneficial, but a strategy of consistent and ongoing monitoring offers much greater impact over time. Also, start at the building level by tracking whole-building performance, then progress to the equipment level.

Baseline data puts performance indicators in context.

O&M staff may find it useful to develop O&M procedures and forms for these tracking activities. Forms may include the task description, checking method and frequency for each piece of equipment, reporting formats, procedures for addressing non-conformance issues, and how to resolve performance deficiencies. In many cases, the procedures for gathering data on equipment performance fit nicely with other PM work and require very little extra staff time.

Determining the Baseline

Performance indicators are not very meaningful without context. A baseline provides information on how well the equipment performed at some point in the past under specific operating conditions. Manufacturer's literature often includes this data. Product documentation should include performance data obtained by factory testing. You can request copies of this literature from the equipment manufacturer.

In cases where the equipment is old or where its configuration or capacity has been changed in some way, manufacturer's product data will most likely not be useful. In these situations, use the first performance data set you gather in the field as your baseline for future reference. When developing the baseline efficiency measurement, test the equipment and systems under replicable conditions and only after applying rigorous annual PM procedures to ensure that equipment is in the best condition possible. If necessary, hire a test engineer to assist in readying the equipment for baseline data collection.

Measuring Performance

The first step in actually obtaining performance data entails determining which equipment to measure, what data points to collect, and how they will be collected. Tracking methods may include manually logging data from permanently installed gages, using hand-held instruments and portable dataloggers, using permanently installed monitoring/metering equipment, using the energy management system (EMS), or a combination of these methods. Regardless of the method selected, calibrate the instrumentation first, particularly the EMS.

The "Efficiency Parameters" section below lists some specific data to collect for certain equipment and calculations. Decide which equipment to track based on the potential for energy savings weighed against the resources needed to obtain the required data. Focus on larger equipment first to discover and solve larger energy-use problems; then investigate smaller equipment.

Looking for a performance tracking guideline? The International Performance Measurement and Verification Protocol (IPMVP) lists options for measuring and ensuring savings through performance contracts. Visit www.ipmvp.org.

Implement a Tracking Schedule

A tracking schedule is a written plan for how frequently staff should measure equipment performance. When data can be obtained by EMS trending, O&M staff can easily track the parameters continuously. They can view standard efficiency and performance reports generated by the EMS to visually determine whether equipment needs attention. Staff can track more resource-intensive data less frequently. For instance, O&M staff can track chiller performance once a year by monitoring the chiller during its peak season.

EFFICIENCY PARAMETERS

Tracking equipment efficiency and performance often requires calculating or estimating (rather than just observing) proper efficiency parameters. Often efficiency calculations rely on a series of measurements. The values measured may vary due to changes in factors such as heating or cooling load, which makes the tracking process more complex. Thus the performance tracking results may take the form of a curve. However, it may be acceptable in some cases to track a surrogate for efficiency in place of efficiency itself. Surrogates, such as increases in energy consumption, demand, or hours of operation over time, may indicate operational problems.

Only critical parameters need to be tracked regularly. These key parameters indicate when a problem exists and indicate when operators need to gather more in-depth information or begin troubleshooting.

Chillers

Chiller efficiency is measured in chiller kW per ton of refrigeration. The lower the value, the higher the efficiency. The efficiency of the chiller will vary with the load on the chiller and on entering and leaving condenser and evaporator temperatures. Most chillers are less efficient at part load. The full picture of chiller efficiency will consist of a profile, or efficiency curve (see Figure 1 below), that describes the efficiency versus percent load, with the lowest kW/ton value called the "peak" efficiency. For example, in Figure 1, the chiller's peak efficiency of .58 kW/ton occurs at 70% load.

Today's chillers are much more efficient than their predecessors.

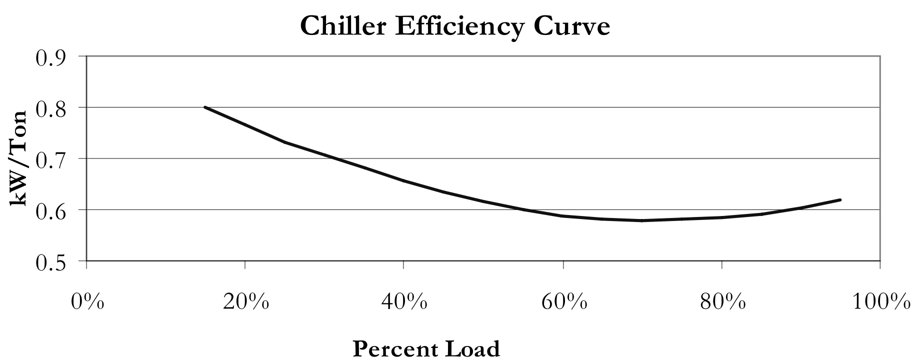

FIGURE 1
Centrifugal Chiller Efficiency Curve

Due to continuing improvements in chiller design and manufacture, today's chillers are much more efficient than their predecessors. The range of typical peak efficiencies is shown in Table 2 below:

TABLE 2
Range of Peak Chiller Efficiencies (100% load)

Peak Efficiency (kW/ton)	Type of Chiller
Below 0.5	State of the art
0.5 – 0.6	Very efficient; newer chillers from the mid-1990s
0.6 – 0.8	Typical existing chiller
0.8 – 1.0	Fairly inefficient; typical for older chillers (10 + years)
Over 1.0	Very inefficient

To measure peak efficiency, collect data over time, either by using dataloggers or EMS trending capabilities. Datalogger or EMS time-series data capture the various stages of chiller loading and generate enough points to develop an efficiency curve. To generate this data, trend the following points at 15-minute intervals for 2-4 weeks: primary chilled water flow rate, entering and leaving chilled water temperatures, and chiller kW. If chiller kW is not available, trend chiller current. Water flow values in recent and reliable test and balance (TAB) or startup reports may provide less accurate substitutes for trend data. Also, for reference, consider trending the condenser water flow and temperatures. Condenser water flow and temperature affect efficiency and will help to further define your curve for later comparison with the baseline or manufacturer's curves.[2] It is also valuable to trend outside air temperature for reference.

Put all of the data collected into a spreadsheet (See Figure 2 for an example) and add the calculated value of kW/ton in a new column.

The associated calculations are as follows:

$$Tons = 0.0417 \times GPM \times (CHWRT - CHWST)$$

$$kW = Volts \times Amps \times 1.732 \times PF / 1000$$

GPM = Gallons per Minute chilled water flow

CHWST = Chilled Water Supply Temperature

CHWRT = Chilled Water Return Temperature

PF = Power Factor, available on startup report or assume 0.85

Volts available on startup report

[2] Entering condenser water temperature can significantly affect chiller efficiency. Entering condenser water temperature is unlikely to be consistent for any given chiller loading condition. However, if a large number of temperature measurements are taken with the trend logs, facility staff should be able to detect a general drop in efficiency by looking at the graph.

Next, determine percent load for each point by dividing the kW by the maximum chiller kW (taken from submittals or O&M documentation). In a spreadsheet, plot the kW/ton values on the "y" axis and the chiller percent load on the "x" axis. The most accurate measurement will require a kW meter or EMS point. Refer to Figure 2 for a sample spreadsheet format, with the columns "% Load" and "kW/Ton" to be plotted as an efficiency curve. EMS systems rarely have the ability to calculate kW/ton. However, when this capability is available, trending chiller efficiency as a standard value is a powerful diagnostic and tracking tool. Your graph will not be a single line, but a scatterplot of points that form a "cloud" shape.

Trend				Calculate				
Time	Amps	CHWRT	CHWST	kW	Tons	*% Load*	*kW/Ton*	
13:00	175	55	42	30	38	***15%***	***0.80***	GPM 300
13:15	178	55	42	70	105	***35%***	***0.67***	Volts 480
13:30	182	56	42	110	182	***55%***	***0.60***	PF 0.85
13:45	185	58	42	150	260	***75%***	***0.58***	Max kW 200
14:00	190	59	42	190	300	***95%***	***0.63***	

FIGURE 2
Sample Spreadsheet Format

Save calculations and charts as benchmarks to track performance over time. Repeat measurements every year during periods of similar weather. Using trend line or curve fit spreadsheet functions, draw an average line, indicating efficiency performance for that year. The higher the line, the lower the efficiency.

Save calculations and charts as benchmarks to track performance over time.

The trend lines in Figure 3 show a drop in efficiency over time: the average chiller kW/ton has increased, demonstrating performance degradation. Performance degradation could be caused by refrigerant leaks, changes in water flows, changes in cooling tower operation, fouled tubes or chiller capacity control.

Note that the method described above can have elements of uncertainty due to changing power factor or lack of knowledge of the kW draw at maximum load. Other more sophisticated methods are available involving advanced software and measurement methods. See Pacific Gas & Electric's CoolTools internet site at www.pge.com/customer_services/other/pec/cooltools for more information on this subject.

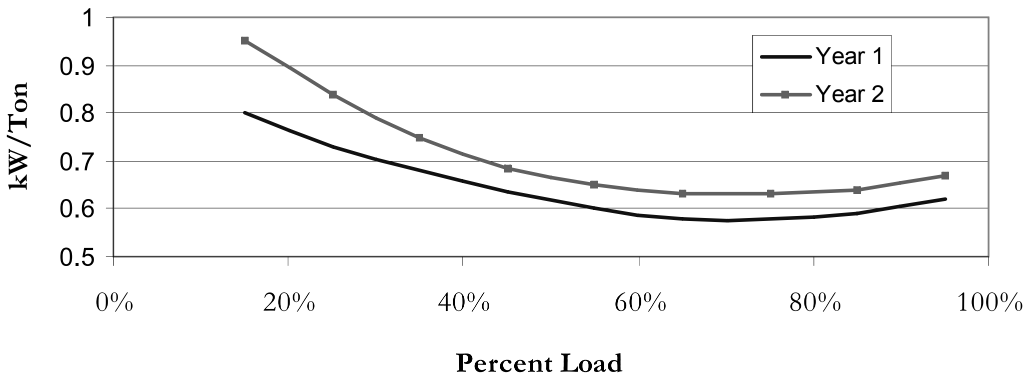

FIGURE 3

Chiller Efficiency Tracking Over Time

Boilers

O&M staff typically keep a daily log of the boiler's operating pressures and temperatures. Deviations in the entries may indicate potential problems. Unfortunately, this data provides little information regarding efficiency.

Boiler efficiency can be measured in a number of ways, some more practical in the field than others. For example, "overall" efficiency is defined as the gross energy output of the boiler divided by the energy input. It would certainly be useful to measure this parameter, but it is almost impossible to obtain this value for an installed boiler due to the difficulty in taking precise measurements. It is easier to measure other types of efficiency values, such as combustion efficiency and production efficiency.

Repeat measurements each year during similar weather conditions.

Combustion efficiency is the most commonly applied measurement of boiler performance. It is calculated as follows:

$$\text{Combustion Efficiency} = \frac{(\text{Energy Input} - \text{Stack Loss})}{\text{Energy Input}}$$

The energy input is the heat content of the fuel measured in Btu, and it is obtained by metering the fuel input to the boiler. The stack losses are also measured in Btu and are determined by measuring the temperature of the flue gases and the corresponding percentage of oxygen and carbon dioxide. O&M staff can use a combustion analyzer or a chemical test kit to obtain these values, and can take measurements at any load condition. Staff should track combustion efficiency once a month during the heating season. For a conventional boiler, the combustion efficiency may range from 70% to 85%, depending on the firing rate it was tested at and whether it has a power draft or atmospheric burner. However, for a condensing boiler, the value should be higher, perhaps up to 95%.

Production or "net" efficiency is the ratio of the net useful energy output of the boiler to its gross energy input. For steam systems, production efficiency is a meaningful measure of the entire cost of steam energy rather than simply the combustion component. Because production efficiency varies with the load on the boiler, its value will take the form of an efficiency profile. For the purposes of benchmarking and tracking performance over time, combustion efficiency is recommended because it is relatively simple to measure. Production efficiency can be estimated through a series of measurements involving steam temperature, steam pressure, feedwater temperature, fuel use, and fuel energy content.

It is also a good idea to periodically measure factors such as boiler water usage and blowdown frequency that may not directly contribute to efficiency, but give an indication of possible problems.

Interpreting Results. If staff perform efficiency tests or have them performed by contractors, the following guidelines and information will assist them in interpreting the results.

Combustion efficiency tests provide indications about three parameters that affect efficiency: fuel, air and temperature. Too much fuel or too low a combustion temperature result in incomplete combustion. Too much air results in low heating capacity and cool stack temperatures. Charts and graphs provide a means to combine the actual values for these factors giving the combustion efficiency of the boiler.

The typical combustion or efficiency test will measure or calculate the following parameters.

%Excess air	This is the amount of air used above what is needed for perfect combustion. Ideally, excess air is minimized below 20% during high fire. During medium or low fire excess air may exceed 50%, unless there is an automatic oxygen trim (modulator) and forced draft fan operating.
%O_2	This is the percent of oxygen in the flue gas. This is minimized below 5%; ideally about 1%-2%. Too low a level of O_2 will

result in increasing CO levels, which can pose a health risk. The $\%O_2$ level will normally increase at lower firing rates, unless there is an oxygen trim control.

CO	This is the amount of carbon monoxide in the flue gas and is generally required to be less than 200 ppm.
$\%CO_2$	This is the percent of carbon dioxide in the flue gas. O_2 rather than CO_2 is now generally preferred as the combustion efficiency parameter.
Stack temperature	This is the temperature of the flue gas. Some efficiency tables and graphs use "net" stack temperature, which is the stack temperature minus the air temperature being supplied to the combustion chamber. Trying to achieve a lower temperature is generally better, unless there is a significantly high oxygen level. For non-condensing boilers, ideal stack temperatures at high fire are below 420°F, but not less than 320°F. Low stack temperatures indicate too much oxygen and incomplete combustion, high stack temperatures indicate excess air or dirty heat exchanger surfaces (need more water treatment or blowdown). Temperatures at low fire will be at least 100°F less than at high fire. Temperatures should be checked weekly or more during the heating season.
Efficiency	Combustion efficiency is defined earlier in this section.

Immediately after a tune-up, observe the flame color and shape to use as a benchmark until the next tune-up.

Efficiency testing should be done at multiple firing rates. Lower firing rates will have lower efficiencies than high fire, unless there is a modulator that adjusts the amount of intake air at differing firing rates. Immediately after a tune-up, observe the flame color and shape to use as a benchmark until the next tune-up.

Contact your boiler manufacturer if you need specific guidelines or assistance in measuring the efficiency of your boiler. Ask about other values to track in addition to efficiency or as surrogates. Staff may find it effective to track stack temperature. For example, if stack temperature exceeds 420°F, then the boiler may not be operating as efficiently as it could. Further investigation through flue gas analysis is warranted.

Cooling Coils, Heating Coils, and Heat Exchangers

This section discusses equipment where heat is transferred between two fluids, usually air and water. It focuses primarily on heating and cooling coils (water coils) rather than refrigerants, direct expansion, or steam coils.

Coils and heat exchangers are susceptible to fouling, scaling, improper air or water flow and other problems that decrease their efficiency and waste energy. A proxy for the more difficult calculations to determine cooling coil efficiency is to measure the temperature of the air coming off the coil at various times throughout the cooling season. *Staff should take these measurements under identical (as close as is possible) temperature and flow conditions.* The results of the temperature measurements can reveal coil problems. For instance, if the most recent discharge temperature measurement is higher than those taken previously (under identical conditions) this indicates scaling or fouling problems.

Take measurements under repeatable conditions. Either wait for the condition to reoccur, or force the system into the desired condition.

But how can staff obtain identical conditions? In the cooling coil example, chilled water temperature may vary if a reset schedule is in place, and chilled water flow will vary with pump speed and cooling coil valve position. Likewise, on the air-side, entering temperature will likely vary with fraction of outside air and also with building load; airflow may vary as well if the system is variable air volume.

Measuring the exiting air temperature at a repeatable condition can be done in one of two ways: wait for the conditions to reoccur, or force the system into the desired condition. In the cooling coil example, the best conditions for measurement in either case will be during peak load conditions. Peak conditions require maximum cooling, where chilled water pumps run at full speed, cooling coil valves will be wide open, and chilled water temperature will rest at the lowest value on the reset schedule. Likewise, outside air dampers should be at minimum, and airflow should be at maximum. Staff can then monitor the entering airflow until it reaches the desired temperature, and then take a measurement during the correct conditions. Note that most of these conditions (chilled water temperature and flow, and air dampers and fan speeds) can be "forced" by manual override of points in an energy management system. With the right controls, staff can usually obtain the performance measurement if outside air and solar conditions are similar. They can employ a similar process for heating coils.

Since the problems with heat exchangers occur due to dirt and other fouling, an appropriate preventive maintenance program with proper cleaning schedules may obviate this performance tracking exercise. However, as building operators are aware, some heat exchangers cannot be cleaned without significant labor, and it may be more cost-effective to perform cleaning only when the efficiency drops below a certain acceptable threshold. For example, plate-and-frame heat exchangers are often designed for ease of disassembly and cleaning, but the location of the heat exchanger may add many hours to the task. Likewise, heating and cooling coils in air handling units may be easily cleaned on the outside, but cleaning the inside of the coils is typically more difficult, and it is difficult to tell when they need cleaning. Thus, the practice of monitoring performance may help staff discern when cleaning is necessary.

Some heat exchangers cannot be cleaned without significant labor, and it may be more cost-effective to perform cleaning only when the efficiency drops below a certain threshold.

Unitary Equipment

Unitary equipment is often used in small commercial buildings. "Unitary" refers to packaged air conditioning units, heat pumps, or other small equipment. Their overall performance is measured in an energy efficiency ratio (EER) (similar to the residential parameter of seasonal energy efficiency ratio or SEER). The higher these values, the better the efficiency. For example, a unit rated at 36,000 Btu (or 3 tons) with an electrical demand of 3600 Watts has an EER of 10.

$$EER = \frac{\text{Rated cooling capacity in Btu}}{\text{Electrical demand in Watts}}$$

Unitary equipment often has short, straight duct sections before and after coils, making it difficult to obtain accurate temperature and air flow measurements. Thus, EER can be a difficult parameter to measure accurately. It is usually more cost-effective to qualitatively assess the efficiency and condition of the unit through some routine maintenance checks. The airflow across the coil during full cooling should meet the manufacturer's design specifications and not be restricted by improper operation, dirty filters, restricted return or other problems. The refrigerant charge should be sufficient according to the O&M documentation for the unit. Also, the coils should be kept clean and regularly inspected. If these conditions are met, staff can safely assume that the unit meets its design efficiency.

Steps to Take in Response to Sub-Optimal Performance

In most cases, standard troubleshooting or maintenance tasks can solve the problems discovered through equipment performance tracking. For example, if a heating coil shows signs of deteriorating efficiency, the facility staff should have a list of items to check, either from the product literature or from their own experience: dirty coils, bad valves, bad air flow, leaky tubes, etc.

A drop in performance sometimes indicates an operational (rather than a maintenance) problem.

Sometimes a drop in performance indicates an operational problem, such as a change in setpoint, rather than a maintenance issue. Determining the root of this problem may require some sleuthing. The daily routine of responding to comfort problems and emergencies may necessitate on-the-fly adjustments to setpoints and other parameters. Once made, these adjustments may be forgotten, and may begin to have an adverse affect on the equipment performance. For example, changes to chilled water temperatures or duct static pressure setpoints to meet cooling demands should be reversed to the original schedule once the crisis has passed.

If staff cannot identify the cause for the drop in efficiency, consult an engineer or have the vendor investigate the problem. The expense for such an action is often justified by the performance improvement and resulting savings.

BEST PRACTICES IN SCHEDULING

Although individual pieces of equipment may be well maintained and perform efficiently, unless owners periodically review controls and occupant needs, equipment may be operating more than is necessary. Because many parties, perhaps even tenants, often have access to lighting and HVAC controls, schedule changes to meet special needs or unusual conditions may not get returned to their original settings. Over time, these schedules become further and further removed from matching actual needs. Thus, improvements to equipment schedules provide some of the simplest and largest opportunities for energy savings in commercial buildings. However, owners should take care not to change equipment schedules in ways that will adversely affect occupant comfort, safety, reasonable convenience, and productivity.

GETTING STARTED

Improvements to equipment schedules provide some of the simplest and largest opportunities for energy savings in commercial buildings.

Many facility managers continue to accept suboptimal schedules because they are unaware of scheduling problems. Furthermore, it is easy to assume that equipment turns ON and OFF as expected. A quick walk through the building after hours can be quite revealing. For buildings where equipment should be OFF after hours, managers can detect stray equipment operation by simply entering the building during unoccupied hours and listening for unexpected noise. Building staff should perform an after-hours walk-through once every six months to observe the behavior of heating and cooling equipment, lighting, and office equipment such as copiers, printers, and computers. Alternatively, staff can use portable dataloggers at the electric panels to track whether equipment is ON when it should not be.

Most buildings utilize an EMS to automatically schedule equipment. These systems offer control features such as setup/setback, optimum start/stop, and lockouts. With all of the possible scheduling contingencies, managers may feel daunted by the process of evaluating schedules. However, the presence of an EMS usually makes the job easier by offering a summarized printout report of equipment schedules. Your EMS vendor should be able to generate these schedules. The printout should consist of a list of the equipment and when each piece is scheduled to come ON and turn OFF. In some cases, ON/OFF times will be calculated values based on optimum start and stop routines. For older systems or systems where an EMS is not present, such as unitary equipment and domestic water heaters, timeclocks offer a viable method of scheduling equipment.

Armed with a list of schedules, the facility manager can begin to determine whether current schedules meet current needs. For example, examine the HVAC schedules in relation to the lighting schedules. In general, lighting and HVAC schedules should overlap, and discrepancies, such as disparate startup times, should be accounted for. Likewise, components of the same system will usually follow the same schedule. For example, chilled water pumps generally should not run when the chiller plant is scheduled to be OFF.

Common Scheduling Issues

Suboptimal schedules often remain unnoticed and can be quite easily tolerated. Building tenants rarely complain that lighting and HVAC equipment remain ON after hours. In addition, managers and occupants may believe that equipment needs to be running, when in reality it does not. ("Someone must have set up this schedule for a good reason.") This section discusses some common scheduling problems, issues, and possible resolutions, and strategies.

Moving Away from 24-Hour Schedules

In general, lighting and HVAC schedules should overlap, and discrepancies, such as disparate startup times, should be accounted for.

In many facilities, equipment operates continuously for valid reasons. However, unless a facility is actually used 24-hours a day or has special requirements (such as round-the-clock humidity or temperature control), owners could probably save significantly on their energy bills and increase equipment life. To take an extreme example, assume that an entire system, such as an office building central chiller plant, runs around the clock. Often in this case, all the manager needs to do to save energy is change the equipment ON/OFF times. However, extenuating circumstances may make the facility manager reluctant to shut down the chiller. For example, some tenants may work late or on weekends and demand space conditioning at odd hours. When there is no such reason for the system to be ON, turn it OFF on a normal schedule. Shut down all systems when workers leave and start them up as necessary to bring the building to temperature when they arrive. Even if some tenants work late, heating and cooling systems rarely need to be run around the clock. Start by shutting down the HVAC system at a late hour such as midnight; this will accommodate occupants and demonstrate savings. Then, fine-tune the schedule to more precisely meet tenants' needs. Note that there is generally no need to provide outside air ventilation if the building is wholly unoccupied, except possibly during the first few months of occupancy in a new building to purge the outgassing of new materials.

Some spaces may require that temperature or humidity be controlled within specific limits. For spaces that require 24-hour environmental control, managers should consider modulating the HVAC systems based on outside conditions. The systems may be *enabled* around the clock, but will only come ON when outside air falls outside of certain parameters, when space conditioning will likely be required.

A setup/setback strategy *(sometimes called night high-and-low limits) changes the heating and cooling setpoints during unoccupied hours to allow the system to use less energy yet still keep the building within reasonable temperature limits. For example a heating setback of 60°F, so that as long as indoor temperatures remain above 60° and a cooling setup of 80° allows the space temperature to rise to as high as 80° or drop as low as 60° before the HVAC will cycle on.*

Often, the entire central plant operates continuously to serve a small 24-hour need such as computer center or telecommunications rooms. Today's computer systems generate considerably less heat than their predecessors and may not require as much cooling. Consider the following:

- Determine the real maximum temperatures that the spaces can tolerate. The previous setpoint may be much lower than is necessary. Install stand-alone HVAC equipment for this space, so that the central plant can be turned OFF.
- Sub-cool the space with the central plant for a few hours after occupants leave and then shut the central plant OFF. Let the space temperature float up to the maximum limit before turning central plant equipment back ON.
- Consider a heat exchanger (water-side economizer) in the chiller system to allow the cooling tower alone, without the chiller, to meet the isolated load during low general load periods.

In some climates, it may be impossible to turn OFF the entire system due to the large amount of time and energy required bringing the building back to temperature. If the HVAC system cannot be shut down due to very high or low climate temperatures, managers can implement a setup/setback strategy.

Some equipment, particularly pumps, may be operated during unoccupied periods to guard against possible coil freezing. This energy wasting practice can often be

Start by investigating the schedules of your largest energy-using equipment, including lighting. Then, move to smaller equipment.

replaced by improving plenum air-temperature sensing combined with control strategies to energize the pump at a low temperature threshold.

Scheduling Individual Equipment

Perhaps a pump, fan, or other piece of equipment sometimes runs continuously or longer than its associated system. Usually this is due to an EMS control program oversight or improper interlock. Perhaps the correct schedule was somehow overwritten or erased.

First, examine the associated system (ventilation, heating, cooling, etc.). Determine whether the observed operation and schedule are incorrect. For example, it may seem that an outside air intake fan is scheduled incorrectly, but it may in fact be operating properly as part of a night purge strategy. If the equipment schedule should be modified, find out whether this schedule requires interlocks to other equipment. For example, most secondary chilled water pumps should be interlocked to turn ON with the chiller, but need not run when the chiller is OFF. Consult your chiller vendor or other sources as necessary to make sure the equipment is scheduled or interlocked properly.

Fine-Tuning Schedules

After you have checked to make sure that equipment is OFF when it should be, you may find further opportunities for fine-tuning. A general start-stop schedule of 6 AM to 5 PM may seem adequate, but may leave some additional savings on the table. On certain days, it may be possible to adjust this schedule so as to allow equipment to remain OFF longer.

The most common method of optimizing ON/OFF times is the optimum start/stop control strategy. This routine calculates the best times for HVAC to start up and shut down based on information about the outside conditions and the load in the building. See *Energy Management Systems: A Practical Guide* in the O&M Best Practices Series for more information on optimum start/stop. If an EMS is not available to handle optimum start/stop, some facility managers perform a form of optimum stop manually by allowing the building to "coast," (that is, maintain desired temperature without running equipment). In this case, the facility manager judges that some component of the HVAC, such as the chiller, could be shut down early, usually in mid to late afternoon. Coasting is appropriate only if the building will not drift more than a few degrees.

Otherwise this strategy may sacrifice comfort. Ventilation systems should remain ON as long as the space is significantly occupied. If your building does not have optimum start capabilities, trend space temperatures under a variety of outside air temperatures to determine how long it takes to bring the space to setpoint in the morning. This knowledge allows staff to start the HVAC system as late as possible.

A simple way to ensure that lights are turned off at night and remain off is to periodically "sweep" them off. For example, the lighting controls could be programmed to turn off all lights on various floors every hour on the hour from 9 pm to 5 am. Ideally, the switches that allow lights to be turned back on should only control small zones.

Lighting Schedules

Scheduling lighting to accommodate the tenant and janitorial traffic patterns can sometimes be tricky. Many organizations give up altogether and simply leave lights ON all the time. But scheduling lighting to increase OFF time is one of the easiest ways to reduce energy costs. Consider turning all lights OFF at some specified time, perhaps at 8 PM, and allow any occupants still in the building to turn lights back ON as needed. Or consider the common lighting "sweep," approach where lights are swept OFF several times during unoccupied hours to ensure that unused lights are not left on too long.

A key to keeping sweep strategies enabled is to make sure effective override features are made available to tenants that need them. Staff should check sweep systems quarterly to ensure that tenants, janitorial or security staff have not disabled them.

Schedule lighting strategies around the janitorial activities in the building. Many building owners incorporate occupancy sensors in restrooms, offices, and conference rooms as a means of circumventing a fixed lighting schedule for those areas. Owners may also find it useful to post a lighting policy or directive in tenant spaces asking tenants to turn lights OFF as appropriate.

Zoning Strategies

HVAC and lighting zones can make it easier to optimize schedules. Implement individually-tailored schedules by zone as appropriate. If equipment must run after hours to accommodate unusual activity, provide HVAC only during that time and only in the zones required. Some facilities have been successful with a system where tenants request (often via telephone) building services such as lighting or air conditioning during times that do not conform to normal schedules. Billing systems can be put in place to ensure that tenants are charged appropriately for the extra energy use. Advanced automated systems are also available

Compact fluorescent lights should be turned OFF only when they will remain so for at least 30 minutes. The recommended minimum OFF-time is much less for standard fluorescent and incandescent lights.

to implement this strategy.

Isolating certain lighting circuits can provide more flexibility in scheduling lighting. Facility managers have more options if the EMS controls smaller areas of lighting as opposed to an entire floor. This modular approach is commonly used in conjunction with occupancy sensors.

Equipment Life Issues

Moving from continuous equipment operation to a more efficient schedule will sometimes introduce additional ON and OFF cycles. There is a common perception that turning various kinds of equipment ON and OFF more often will decrease the equipment life. This concern is more valid for some equipment, such as fluorescent lighting, than others, such as pumps and fans. In general, mechanical equipment will only suffer from ON/OFF cycles if it is short-cycling, which can decrease equipment life. A rule-of-thumb definition for motor short cycling is:

1. When the motor turns ON, use a stopwatch to time how long it takes to get to full speed. This amount of ramp time = R.
2. Count the number of times the motor turns ON in an hour, N.
3. Multiply these two numbers, R x N.

The resulting value is a measure of the total time out of an hour that the motor uses to go from OFF to full speed. If this value is greater than 30 seconds, then the equipment is short-cycling. For example, if the ramp time is 3 seconds per cycle, short-cycling would occur if the equipment is turning ON and OFF 10 or more times per hour (3 x 10 = 30) Adjusting schedules to minimize unnecessary equipment run-time will rarely cause short-cycling. Even so, it is best to check with the equipment manufacturer if you think that there may be a problem.

For lighting, each time a lamp is turned ON/OFF, its life decreases. However, the benefits of scheduling outweigh the costs. That is, the energy savings gained from turning lights OFF will outweigh the slight expense of purchasing new bulbs and the labor to replace them. It is usually recommended that compact fluorescent lights should be turned OFF only when they will remain so for at least 30 minutes. The recommended minimum OFF-time is much less for standard tube fluorescent and incandescent lights.

Periodic Review of Schedules

A seasonal review and analysis of equipment schedules is a good way to uncover energy savings. As part of O&M planning, develop procedures to periodically review and monitor the EMS time-of-day schedules, optimum start/stop strategies, temperature setup/setback, and other strategies and parameters that stage or turn equipment ON or OFF. Also, review and monitor any other ON/OFF controls such as programmable and mechanical time clock settings, integral equipment controls, lighting photocells, sweeps, and occupancy sensors for proper operation. Small, inexpensive "stick-on" data loggers are available that can indicate when equipment is running more often than is needed.

ESTIMATING SAVINGS DUE TO SCHEDULING IMPROVEMENTS

Estimating savings is a matter of determining how much energy the equipment in question consumes. For lighting, this is a simple calculation, but for most equipment, energy consumption varies with load. The load fraction can be approximated by measuring the running motor current and then dividing that by its rated current. kWh can be estimated as:

The payback for scheduling improvements is often less than one year.

kWh = (rated HP) x *(load fraction)* x *(0.746)* x *(number of hours).*

Dataloggers provide a simple way to measure the appropriate energy-use data. Owners considering changing an air handler shut-down schedule should log the energy consumption during the hours in question to determine how much the schedule change will reduce energy use. Computer simulation programs can also provide this information, but they are expensive and are more appropriate for larger energy projects. Engineering calculations are another viable option. However, they rely on estimated rather than actual savings data. For more information on logging equipment, see *Portable Dataloggers—Diagnostic Monitoring Tools for Energy Efficient Building Operation,* another publication in the O&M Best Practices Series.

Once the energy consumption has been calculated or estimated, multiply this value by the number of additional hours that the relevant equipment will be OFF each year. Calculate an annual dollar savings amount using a utility rate schedule. The payback for schedule improvements is usually very short, often less than one year.

Conclusion

Owners and operators who focus on both operation and maintenance issues benefit from improved building performance, comfort and reduced energy bills. The simple strategies proposed in this document—implementing a preventive operation program, tracking equipment performance, and optimizing schedules—are essentially risk-reduction strategies. Taking these steps helps ensure that equipment runs efficiently, performs optimally, and lasts for its maximum lifetime.

GLOSSARY

Baseline. The "before" data that is used in a "before and after" comparison. Baseline data may refer to energy consumption values, efficiency parameters, or other indications of building (or system) performance.

Chiller Efficiency. The efficiency of a chiller is usually measured in kW/ton, or the kW of energy input required to produce a certain tonnage of cooling. Chiller efficiency takes the form of an **efficiency curve**.

Combustion Efficiency. A common measure of boiler efficiency, defined as (energy input - stack loss) ÷ energy input. This parameter is most often calculated through a flue gas analysis.

Control Strategy. An approach to controlling equipment. Usually this term refers to automated routines implemented through an energy management system that are designed to control equipment while providing maximum energy efficiency.

Datalogger. A stand-alone electronic data gathering device that utilizes sensors to collect equipment information over time. Data collected could include temperature, pressure, current, humidity, or other operational information.

Efficiency Curve. For some equipment, the efficiency varies with the load on the equipment. In those cases the efficiency is plotted against load. This efficiency curve illustrates the performance of the equipment over its range of operational conditions.

Energy Accounting. The process of tracking and analyzing energy use for the purpose of detecting problems, trends, or savings opportunities. Typically, energy accounting is performed for an entire building. In the analysis process, adjustments may be made for variations in weather, space use, or other variables from year to year.

Energy Efficiency Ratio (EER). An efficiency parameter primarily used in reference to the performance of packaged air conditioning units. EER is defined as the rated cooling capacity in Btu divided by the electrical demand in Watts.

Energy Management System. The automatic system used for controlling equipment in a building. Most likely, this will be a computer-based system, including either pneumatic or digital components, or both.

Indoor Environmental Quality (IEQ). The total environment of a building including thermal comfort, proper illumination, adequate outside air ventilation, and control of indoor air pollutants.

Lighting Sweep Control. A **control strategy** that is intended to decrease lighting energy use during unoccupied hours. Lights are "swept" off at various nighttime intervals by the **energy management system** or other lighting timeclock.

Night Purge Strategy. For sufficiently dry climates with a large nighttime temperature drop, this **control strategy** will purge or flush the building with cool outside air in the early morning using supply fans in economizer mode. This will potentially reduce the cooling load in the building later in the morning and save energy.

Optimum Start/Stop Strategy. A **control strategy** designed to minimize the run-time of HVAC equipment. By analyzing both indoor and outdoor conditions, an energy management system will calculate the latest start times and earliest stop times for equipment, thereby maintaining comfort while decreasing overall energy consumption.

Overall Boiler Efficiency. A boiler efficiency measure defined as the gross energy output of the boiler divided by the energy input. This value is very difficult to measure.

Performance Tracking. The ongoing procedure of obtaining data that gives an indication of a system's performance. This data could include information on energy efficiency, energy consumption, or run-time. As part of the process, performance data is often compared to the system's **baseline**.

Production Efficiency. A boiler efficiency parameter defined as the ratio of the net useful energy output of the boiler to its gross energy input. This value is a meaningful measure of the entire cost of steam energy rather than simply the combustion component.

Setup/Setback Strategy. A **control strategy** in which the space temperature setpoints are changed during unoccupied hours to be reduced (set back) during the winter and increased (set up) during the summer. This feature is desirable in situations when turning equipment completely off at night would require excessive energy to bring the building back to comfort levels.

Short-cycling. Equipment that goes through a complete on/off cycle too often is said to be short-cycling. Continued short-cycling operation will potentially damage equipment and cause ineffective control.

Time-of-Day Schedules. The master schedules for the building that dictate when to turn equipment on in the morning and off at night.

Trend Log. A log of data that is collected through an energy management system. This data may consist of time-series or change-of-value (COV) data that can be collected for digital points such as temperature, pressure, or status.

List of Acronyms

Btu	British Thermal Units
DOE	U.S. Department of Energy
EER	Energy Efficiency Ratio
EMS	Energy Management System
EPA	U.S. Environmental Protection Agency
HVAC	Heating, Ventilating, and Air Conditioning
IEQ	Indoor Environmental Quality
IPMVP	International Performance Measurement and Verification Protocol
kW	Kilowatt
kWh	Kilowatt Hour
O&M	Operation & Maintenance
PM	Preventive Maintenance
RPM	Revolutions per Minute
SEER	Seasonal Energy Efficiency Ratio
TAB	Test and Balance
TOD	Time of Day

ENERGY EFFICIENT O&M RESOURCES

Grimm and Rosaler, *Handbook of HVAC Design*, McGraw Hill, 1990.

Monger, S., *HVAC Systems: Operation, Maintenance, and Optimization*, Prentice Hall, 1992.

Pacific Gas & Electric, *CoolTools Chiller Analysis Kit*, 1997.

Piper, J., *Handbook of Facility Management*, Prentice Hall, 1996.

Portland Energy Conservation, Inc. (PECI), *Energy Management Systems: a Practical Guide*, 1997.

U.S. Department of Energy et al., *International Performance Measurement & Verification Protocol*, 1999.

U.S. Environmental Protection Agency, *Energy Star® Buildings Manual*, 1998.

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