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# Optimizing New and Existing Building Energy Management Systems (EMS)

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## 1. OVERVIEW OF ENERGY MANAGEMENT

The first innovation of automatic building control was a bimetal-based thermostat with a hand-wound spring-powered motor which controlled space temperature by adjusting a draft damper on a coal-fired furnace or boiler. In 1890, the first pneumatic-powered control became available.

In today's design, construction, and facility operation automated energy control has become standard practice. Virtually all nonresidential buildings have automatic controllers with a computer as the central processor. These systems are called Energy Management Systems (EMS), Energy Management Control Systems (EMCS), or Building Automation Systems (BAS). Building owners, facility managers, and engineers must regularly address the issue of computerized energy management, assessing existing systems, specifying and commissioning new systems, evaluating service contract options, or optimizing EMS operations.

Controls technology has evolved at a rapid pace. With many existing EMS, there are numerous possibilities for system replacements or upgrades, more powerful computers, more zone-level control, more accurate sensors; more complex control programs, better service, and other enhancements. Continuously advancing technology, combined with the dynamic nature of today's buildings and rising energy prices, makes decisions more complicated for building owners, facility managers, and engineers.

Most of the advanced features available with EMS are under-utilized. For example, the trending and monitoring capabilities of EMS are powerful tools for improving heating, ventilation, air-conditioning (HVAC), lighting and for reducing energy use, however most facility managers and system operators simply do not have the time to setup or understand those resources. Those responsible for EMS upgrade or purchase are not always able to study their facility's exact energy management needs themselves. Owners and building managers usually rely on vendors or consultants to provide specifications, which may not provide the optimal system for the build. Also, the commissioning process, critical to the success of an EMS, is relatively unknown to most facility staff.

EMS manuals usually focus on the specific equipment installed, rather than the system's potential capabilities. The purpose of this course is to provide specific training and information on choosing, maintaining, and optimizing the right EMS for a building.

### 1.1 EVALUATING AN EXISTING ENERGY MANAGEMENT SYSTEM

Some building owners and facility managers have been involved with energy management systems for years and have established a pattern of performing periodic system upgrades every few years. Others may have had only one EMS for a decade and are anticipating a full replacement. Some have in-depth knowledge of the latest technologies and others do not. Whatever the circumstances, careful consideration should be given to the following questions:

- What are the energy management needs of the facility?
- What are the controls requirements to meet those needs?
- Does the existing EMS meet the controls requirements?
- What are the full capabilities of the current system? Are those capabilities being used appropriately?
- Is the current system technologically obsolete? If not, can the current system be upgraded, or is it an “orphan” system?
- Are problems with the system due to lack of maintenance or service?
- Have the software, firmware, and hardware revisions been kept current? If not, what is the extent of the upgrades required?
- Is the controlled equipment in need of replacement or upgrade?
- Are there an excessive number of trouble or comfort calls for which the EMS is the cause rather than the cure?

When answering these questions, the engineer should consider not only current facility needs for energy management, but predicted future needs as well. For upgrade or replacement projects, the decision making process should be systematic and rigorous. This is particularly important when justifying the economics of the choice.

## 1.1 THE EVALUATION PROCESS

When designing a new energy management system, upgrade, or replacement project it is necessary to examine and define the requirements for energy management and controls.

### 1.1.1 Evaluating Energy Management Requirements

An evaluation of energy management needs should begin with a technical assessment (number and type of points required to operate an EMS per the design requirements, potential control strategies and equipment, etc.) with the building management perspective being considered. Determine the exact requirements for functionality and operations.

An EMS operator’s needs and opportunities are not static. For example, changes in a utility rate structure may offer new energy savings through load-shedding strategies. In this case, the engineer must assess whether these strategies would be better accomplished on a new system that makes such implementation easier. Internal management needs may also change. Some organizations will require more detailed utility usage information for accounting purposes to pass along costs or to report energy usage to upper management.

### 1.1.2 Evaluating the Energy Management System

In addition to clearly defining a building’s EMS needs, the engineer must also evaluate the state of the current system. Determining whether an existing system can and should be upgraded is even more complex than the specification of a new system and requires an honest and complete analysis of the current system.

The EMS operator may be the most appropriate person to answer questions and provide insight. If sufficient expertise is not available in-house, consult with a knowledgeable consultant other than the vendor. With the help of the system operator, put together a list of negative and positive aspects of the current system. In addition to a thorough technical evaluation, consider other factors, such as ease of operation, required training level of the EMS operator, customer (occupant) comfort and controllability.

Determine whether the EMS vendor has an upgrade path for the existing EMS. If he does, compare the cost to system replacement and review the relative benefits of an upgrade versus a replacement. Some further points to consider when evaluating the EMS:

- Are any EMS problems due inadequately trained operating personnel? If this is the case, would replacement of the system solve the problem, or will the same problem exist after the system has been replaced?
- Are problems due to lack of maintenance of the EMS, including software, firmware, and hardware upgrades?
- Are there a number of points that are being operated in "hand" condition, overridden by the operators, non-operational, or completely bypassed? Why? If so, will upgrading the system really solve these problems?
- Has the existing system met your expectations from the time it was installed?
- Have any savings been documented due to the use of the existing system?
- Will the proposed changes allow greater energy, and/or cost savings than the existing EMS system?

If the system has been serviced by the vendor (either by contract or casual labor calls), has the service been up to expectations and have the costs seemed appropriate? If there is a service contract, is it fully understood? Inadequate service could account for poor performance.

Is the EMS system or several different systems consisting, in some cases, of only one field panel. If there are systems from more than one manufacturer or separate incompatible systems from one vendor, would both systems be upgraded?

Are there plans to expand the facility or perform major system improvements that will result in adding points and functions to the existing EMS? Is the existing EMS worth including in these plans? Does it have the capacity to handle these changes?

If a replacement is being considered, do the system components have any resale value? Some companies purchase the EMS components of older systems for sale to facilities still using those systems. Will the vendor of the existing EMS offer any kind of trade-in allowance for the old equipment?

After considering all the relevant factors, the engineer, with the help of a consultant or vendor, can begin to formulate options for EMS upgrade or replacement.

### 1.1.3 System Upgrades

An existing energy management system should be upgraded if:

- It can be upgraded to the current vendor product line.
- It does not perform the functions the owner thinks necessary.
- The shortcomings of the existing system will be corrected in the upgrade.

If older revisions of software or firmware are being used, "rev up" the software and/or firmware. If the EMS is running on an older PC without enough memory or hard-drive storage capacity, replace the PC with the model the vendor recommends for current operation. System software and archives should be backed up frequently. Store the backups at a location other than the EMS control room.

If mechanical system inadequacies or lack of maintenance is partially or fully responsible for perceived EMS shortcomings, those systems should be "tuned up" to improve efficiency and operation. Problems may have arisen because the use of the facility area has changed since the initial EMS installation and the EMS was not revised to accommodate those changes.

If neglect or lack of maintenance is a factor, a repair of the system, its components, or its controlled equipment will be required rather than an upgrade. If a service contract will not be purchased, then the system operator and technician will need to be trained to perform the preventive maintenance and repair functions that a service contract would provide. Most vendors have advanced training that includes preventive maintenance functions.

### 1.1.4 Converting a Pneumatic System

There are some special considerations when converting an existing pneumatic system to DDC. Because of the close control of a DDC system, any poorly functioning equipment will be revealed very quickly by failure to hold temperature, pressure, or humidity within the designated control parameters. Energy waste from leaking or sticking dampers and control valves will also be revealed. Allow additional funds in a budget to correct the problems that become apparent.

Converting an existing pneumatic system involves replacing all pneumatic sensors, controllers, and relays. Time clocks are replaced with DDC outputs; equipment ON/OFF control is wired into the DDC; and the DDC then enables and disables all equipment, including that under operating control of any remaining pneumatics. The only pneumatic devices remaining are damper and valve actuators. These could be operated from an electronic-pneumatic transducer or directly from a pneumatic output at the field cabinet. A more expensive option is to replace these actuators with electronic actuators, eliminating the transducers entirely.

### 1.1.5 System Replacement

In addition to cost, an important issue in system replacement may be the relationship with the vendor of the existing EMS. Vendor issues are often a primary factor in a decision to replace rather than upgrade. It may be the vendor support, not the system, which is inadequate. If availability of training ranges from none to very poor, replacement of the EMS and an accompanying change of vendor may be in order.

Also consider replacement if:

- The control system is primarily pneumatic.
- The EMS cannot be upgraded to current technology. Changing vendors should be considered in this case as the system is considered an "orphan" system.
- The EMS does not have functions required to implement the desired types of energy management strategies, or it will not interface with VAV boxes that will be upgraded from pneumatic control to DDC control.
- The system is overly complex and arduous to use, so that its features are under-utilized, or it is one

or more software/firmware revisions behind.
- There are significant comfort problems/occupant complaints that a new system would resolve. (Note: Be careful not to confuse poor mechanical system design with poor EMS function, e.g., if the use of the area has changed since the initial installation and the EMS was not revised accordingly.)
- The potential return on investment of the proposed replacement meets capital project criteria, or utility rebates or local/state/federal tax credits (or rebates) are available.
- Enhanced use of advanced energy management strategies is anticipated. Full use of these advanced capacities can bring a rapid return on investment.

When completing the final analysis, compare the cost per point to replace the system with the cost per point to upgrade the existing system. If the costs for replacement are close to what an upgrade would cost, replace the system. As a system ages, the service contract costs rise; a new system would defer service during the warranty period, and have lower service costs than the old system (for the same number of points). These first year's savings could be applied toward the new system.

## 2. SPECIFYING AND SELECTING A NEW ENERGY MANAGEMENT

The success of an EMS projects chiefly depends on:

- Complete specifications
- Quality hardware and software
- Competent players
- Commissioning

This section offers detailed guidelines for tackling the first three elements; the fourth element, commissioning, is discussed later in this course.

### 2.1 Procurement Methods

There are two recommended procurement methods for larger control systems. In the traditional approach, called spec and bid, an engineer designs the system and writes the specifications, which are then let out to bid. In the design-build approach, the owner develops general performance specifications which are let out to bid to qualified targeted firms. The proposals returned include additional specifications. The chosen firm finishes designs the system and installs it. During the final design process, refined specifications are usually developed and submitted for approval.

### 2.2 Specification Types

There are three general types of specifications that can be used to start the specification process: 1) Standard Guide Specification, 2) Proprietary Specification, and 3) Performance Specification.

2.2.1 Standard Guide Specifications: Standard Guide Specifications are available from many agencies and groups. Standard industry specifications provide a "generic" form of control specifications. Other companies and large owners such as state and local governments have developed their own sets of control guide specifications. Most vendor can provide a generic specification.

2.2.2 Proprietary Specifications: Proprietary Specifications are specifications from vendors that state the brand

and model number of the products being specified, sometimes adding the phrase "or equal approved by. . ." These specifications may limit competition and lead to higher costs. However, for critical applications, this may be required to get the system or vendor that is needed.

2.2.3 Performance Specifications: Performance Specifications describe the control device generically, listing its intended function and necessary characteristics. A concern with performance specifications is that bidders often supply the lowest price and/or quality product that meets the specification. On the other hand, detailed specifications may require more design budget and time than is available and may limit creativity on the part of the bidding vendors. Requiring detailed specifications for hardware also means that the controls engineer/spec writer must be well qualified in the field. Very detailed specifications must be accompanied by commensurate detail on the performance of those components if the design intent and the real needs of the owner are to be met.

Obtaining a balance between component specificity and performance language in control specifications can be difficult. One solution is to develop a specification that combines the best characteristics of the three types described above.

Such a specification would include:

- A detailed written design intent narrative for each system, including the purpose of the system.
- Measurable performance criteria ("shall maintain duct static pressure during normal operation [except during startup] of within +/- 0.2 inches from the setpoint").
- Detailed specifications as to what equipment is to be supplied, with detailed component descriptions and specifications in as many areas as the owner and specifier feel comfortable. (Note: When upgrading or renovating an existing system, very detailed specifications of manufacturers, model numbers, ranges, etc., are warranted in order to keep the new components compatible with existing equipment and O&M procedures.)
- A clause requiring the vendor to meet the design intent and performance specification, as well as the detailed specifications. Where there is a conflict, the vendor is required to meet the performance specification with an approved alternate component.

## 2.3 SPECIFICATION DEVELOPMENT AND REVIEW

It is recommended that at least two sets of specifications are obtained as reference guides before proceeding with writing a specification, one from an owner representing the owner's point of view, and one from a controls vendor providing good detail on component specifications. Read through each of them and make notes about the system's needs as well as a list of questions and issues needing clarification.

Candidates for providing guild specifications include controls vendors or consulting engineers. Make sure that the specifications are customized to the project in question, not just an edited version of the last project. Often, local control vendors will offer to write a control specification in order to develop a working relationship. Take advantage of their expertise, but make sure they do not inappropriately limit competition.

If the project is a negotiated proposal with a single vendor, the specifications may be less detailed than a job going out for bid. However, even if there is full confidence in the vendor screen and approve their programmer and site technician.

A commissioning consultant should be used and should be involved during development of specifications and design of the system. This will provide an unbiased expert technical review and ensure that the specifications contain adequate quality assurance procedures.

In all cases, the facility manager or owner should assist in a significant way: becoming involved early on with developing design intent and performance criteria; consulting the engineer or vendor if questions arise; and, if answers are unsatisfactory, calling another vendor for a second opinion. The specifications should be completely reviewed prior to the final draft. If the facility staff reviews the design and specifications before they are let out to bid, ideally as an integral part of the design team, there will be fewer change orders. Items such as additional monitored points, control strategies, and user interface features, if added later, will cost considerably more than if they had been included in the original specifications.

## 2.4 A SPECIFICATION CHECKLIST

This section provides items that should be covered in the control specification. This is not a technical or exhaustive discussion of control specifications, but a practical guide.

### 2.4.1 Hardware

Expandability: Specifying the wrong model or brand can limit future options. A less flexible model or brand may not allow:

- Upgrades to new software versions or programs, without the purchase of expensive hardware;
- Upgrading to the next "higher" model, without changing the entire front end and some panel hardware;
- Expanding the system to cover needed points for renovations or additions.

Specify any potential upgrades to the system, both the number of points and controllers in each cabinet and software enhancement compatibility.

2.4.1.1 Make sure the upgrade limitations and opportunities of the system are clearly understood. Specify any features that will be included in the system capabilities, but not set up. Vendors may offer a basic control system software package with a number of optional modules. Without these modules, the package may not function as hoped. For example, the ability to customize system graphic schematics or to view trend graphs onscreen may require software modules not included in the basic package, although the specifications say the system is "capable of" these functions (i.e., the system is capable if it has the right modules).

2.4.1.2 Interfaces with Other Equipment and Controls: A frequent source of problems is the interface of the EMS with equipment that has some standalone controls. Clearly specify the responsibility of all parties regarding the setup, control, and testing of equipment that has some integral controls but will be interfaced with the EMS. Delineate the respective responsibilities of the controls contractor and the equipment contractor for specific functions and sequences. It should be stated clearly:

- What is being controlled.
- What is being monitored.

- What is just being enabled.
- Who is providing the wiring and tubing between equipment and controllers.
- Who is providing the equipment and controllers, valves, dampers, actuators and sensors.
- Who is providing the programming.

2.4.1.3 Interoperability BACnet: Specifying that systems or components be BACnet-compatible is highly advocated. However, the words "BACnet-compatible" only mean the equipment controllers have the potential capacity to communicate with each other. It does not mean that the interface will be easy or automatic, significant and sometimes problematic adaptation may be required. LonWorks is another protocol that many manufacturers use. It works well for equipment that is compatible with its protocols. The future is likely to be dominated by BACnet controllers. Your main concern should be to specify compatibility with systems likely to be added to the facility in the near future.

For equipment that must communicate with other brands or equipment types, state the requirements precisely and specify that it be set up and operable. Specify that the gateway for communication between desired equipment will be provided and made functional. Specify the subcontractor who is responsible, if known.

2.4.1.4 CPU and Monitor: Software and graphics require increasing amounts of computer resources and speed, making it difficult to plan ahead accurately. For systems with color graphics, specify CPU speed, cache, memory, etc., to be at least equal to that of the current typical upper-end personal computer. (This may require some forethought in projects with a timeline of a year or more.) Similarly, specify a terminal that will not be obsolete before it's installed. Current public-sector purchasing is a good benchmark.

Also, if programming must be accomplished with the workstation off-line, consider specifying another workstation or laptop. Specify any accessories needed, such as modems, serial ports, etc. Some facility managers have found it more economical to purchase the CPU and monitor themselves, using the configuration specified by the vendor.

2.4.1.5 Distributed Panels: To increase flexibility for future change and expansion, require that panels where any changes or additions might be made use universal input/outputs (I/O). This allows for each input or output to be software-assigned as either digital or analog. Or require that the panel be modular, with the capability of receiving digital or analog modules anywhere in the panel. Specify that each controller panel have a permanent label affixed with its control drawing ID; also include descriptive, non-numerical names that succinctly identify the systems being controlled in the panel.

Make sure the software/hardware system has auto-build network features. This allows the configuring of a new point in one panel to be automatically recognized and usable by all other panels, greatly reducing the time it takes to make changes in the system.

Field panels should also operate in a "standalone" mode during a communications break with the central terminal. For larger facilities, a desirable feature is the ability to access the entire system by plugging a laptop PC into any field panel.

2.4.1.6 Network Criteria: Gain an understanding of the how the CPU and network configuration options and features will affect speed (the rate at which panels share information). This will determine how quickly information (temperatures, status, etc.) fill the graphic schematics, how fast point displays scroll on the screen, how long it takes to back up the system, etc.

2.4.1.7 Printers and Portables: If specification of printers and portable terminals (laptops or handheld keypad units for servicing) is delayed, it may not be done at all. Specify at the beginning that the printer for handling alarms as well as the graphics, or color, printer for trend graphs, etc., be provided and hooked up. Include any desired laptop or portable handheld diagnostic or controller setup terminals.

2.4.1.8 Sensors: Sufficient sensor accuracy is necessary to minimize unnecessary hardware costs and ensure proper system control. For example, general control of chilled water supply and monitoring the return may need a temperature sensor accuracy of +/- 0.3°F to 0.5°F. However, if the chilled water supply and return is being used for energy consumption calculations in a performance contract or for billing purposes in a purchased chilled water arrangement, sensor accuracy may need to be significantly better. In those cases, the sensors should also be calibrated to within 0.1°F of each other. For a sample of recommended sensor accuracy values, refer to the Calibration section of Appendix A: Sample Control Specification Language. Sensors should also have their range specified as well as any special operating conditions (outdoors, within a caustic exhaust fan, etc.).

2.4.1.9 Valves and Actuators: Specifying the right valve and actuator is important to ensure optimal system control without unnecessary modulation or hunting. Valves must be sized correctly; in some cases, a pair of valves in series may be necessary to provide the proper turndown ratio for tight control. Valves must also be able to provide tight close-off against worst-case system-head pressures. Question the vendor on these issues.

2.4.1.10 Dampers: Specify the tightness and leakage rate of dampers appropriate for the application, as well as blade and edge seals for most applications and special support shafts for large dampers, if necessary. Be specific.

2.4.1.11 Monitored Points: To assist in commissioning and for improved control and troubleshooting of the system, additional monitored points may be needed beyond the minimum necessary to control the building to the specified sequences. Confer with the commissioning consultant and determine what additional points should be added to the specifications.

2.4.1.12 Test Ports: Newer EMS designs tend to omit many test ports because data can be read from an EMS readout. However, such ports can be valuable for calibrating and checking EMS sensor accuracy. Make sure that sufficient test ports for handheld instrument readings are provided near all piping system sensors at the primary system level to aid in calibrating control points and in commissioning and operating the systems. Also, consider test ports for troubleshooting in strategic locations where sensors or gages are not planned. Confer with the commissioning consultant to determine these port locations.

2.4.1.13 Ensure that gages are provided in the following locations, even if a sensor is included as a point in the control system:

2.4.1.13.1 Pressure gages on both sides of all pumps greater than 1 hp;

2.4.1.13.2 Mercury thermometers in the return and supply of all primary thermal plant equipment (chillers, cooling towers, boilers, converters, etc.).

Gages are often provided by the mechanical contractor, but retrofits may require the controls vendor to supply them.

2.4.1.14 Offsite Communications: Specify who will have modem access to the site terminal and what the level of access will be. It is generally advisable to give the vendor access to the system to simplify service and troubleshooting. Clearly state any software setup that the contractor should perform at any other sites. Specify what alarms and warnings will occur offsite and specify auto-dial/auto-answer features and setup. Specify clearly any tie-in requirements to other facilities' EMS via modem, dedicated line, or the Internet.

2.5 Software and Control Capabilities

2.5.1 User Interface and Graphics: For larger systems (buildings over 50,000 square feet), make sure the EMS program runs in a Windows™ or Unix™ environment and that the system is menu-driven.

The controls vendor's idea of "schematic graphics" may be different from what is expected. Review options and levels of detail with the vendor before specifying. If desired, specify that the contractor complete all schematic setup displays, including where applicable: status of monitored and controlled ON/ OFF points; current analog input; current setpoint and DDC output; identification for each point; state of each control loop and equipment (auto, manual, normal, alarm); point alarm lockout status; symbolic graphic of equipment; and online directory of schematics.

Compare among systems, and specify as needed, the nested or layered linkages that will be set up for facility mapping and navigation. In some systems, users can click on an onscreen facility map to bring up a floor plan that displays zone temperature information and the serving HVAC system schematic. Some systems even allow current temperatures in zones to be represented by different colors for quick floor assessment. Specify how much mapping and linking will be done and the graphic representations to be provided.

2.5.2 User Access to Programming: Clearly specify the accessibility of the different types of programming to which staff will have access to upon installation (not as add-ons later). Determine if facility staff can access setpoints, reset schedules, deadbands, sensor and actuator calibration adjustments, controller setup screens, loop-tuning parameters, graphical programming screens and inputs, line programming portions of the system, override schedules, override values, etc.

If facility staff plans to do custom programming or editing, the actual programming code of a few vendors should be viewed and compared for "user-friendliness." Some EMS have features that allow the user to step through a program sequence electronically, simulating the sequence, to aid in testing and debugging the sequence before it is online. Consider this feature.

Compare the relative ease among systems of adding and modifying graphics to the schematics and inserting point display information. Specify accordingly.

2.5.3 Trending: Often the more powerful trending features are not included in a vendor's base package. Consider specifying comprehensive trending capabilities to aid in system operation, troubleshooting, and commissioning. Clearly specify the trending capabilities of the system.

2.5.4 Alarms and Warnings: Specify that the EMS should have multiple levels of alarm designations, each with options for annunciation and reporting, including offsite reporting, (monitoring sites, pagers, etc.). Specify which will be set up by the vendor and which by facility staff.

2.5.5 Reports: Specify that the system will be set up to generate automatically the following types of reports: general listing of all points; all points in alarm, overridden, disabled or locked-out status; DDC controller trend overflow warning; history of equipment ON/OFF commands and status and reason for the command; weekly schedules and holiday program; limits and deadbands.

2.5.6 Security: Specify the levels of security access to the system to be provided and set up.

2.5.7 Control Strategies: All too often, EMS power and flexibility are underutilized, particularly if the desired control strategies are not explicitly listed in the specifications. List every energy-conserving, demand-limiting, and comfort-related control strategy to be included in the system. Do not use or accept "the system shall be capable of" phrase: State that the strategy will be programmed, set up, tested, and fully functional.

2.6 Installation and Documentation

2.6.1 Vendor and Staff Qualifications: The success of a controls project depends more on the individuals hired to install the system than on the hardware and software chosen. In the project specifications, it is important to require approval of the qualifications of the company, the lead programmer, and the lead installing technician. Even if a designated company is to be used, the staff qualification requirements are important. Most companies have a range of skill on staff and, without a written request or specification, there is no guarantee that higher-level staff will be assigned to the project rather than someone marginal or even incompetent.

2.6.2 Sequences of Operation: One of the keys to a successful EMS installation is the clarity and completeness of the written operation sequences. Ideally, the full operation sequences for each piece of equipment should be in the original job specifications. If the specifications are not detailed and explicit enough, significant interpretation is required of the controls programmer, who may not have the expertise and certainly will not know the engineer's full intent for each control loop. To prevent this provide extra-detailed sequences and have the facility technical staff review them for clarity. Involving a commissioning consultant during design will also ensure that the sequences are sufficiently detailed.

2.6.3. Submittals: Submittals requiring approval of all control equipment prior to installation are valuable for early identification of areas needing to be changed. A detailed review of the control drawings at this stage can identify control points, sequences of operation, schematics, etc., that are incorrect, unclear or need to be changed.

2.6.4 Commissioning: Commissioning, a systematic quality assurance and quality control process, will reduce problems at turnover. Include detailed commissioning requirements in the specifications.

2.6.5 Completion Milestones: After substantial completion of a project (when the owner can take useful occupancy of the system) the contractor may lose interest in the full completion of his tasks. To avoid frustrating delays, add a milestone to the specifications: functional completion (the point when all remaining test, adjust and balance (TAB) and commissioning responsibilities of the contractor are complete, except for seasonal or deferred testing.) For example, functional completion could be specified as 60 days after substantial completion, with a monetary penalty for default.

2.6.6 O&M Manuals: The completeness and accessibility of the O&M documentation is critical to the ongoing use of an EMS. Often the documentation contains non-applicable information and is all in one binder without dividers or even a table of contents. In the specifications, provide detailed requirements for O&M manuals to include PDF copies on CD.

2.6.7 As-Built Drawings and Documentation: Controls contractors often develop as-builts early to obtain payment at substantial completion before the system is fully debugged and while sequences and parameters are still changing. As-builts should include complete point data for each point in the system, including "virtual" points, and a fully commented copy of each DDC panel operating program. It is best to require that the updated as-builts be submitted after all commissioning testing is complete.

2.6.8 Training: The key to a fully utilized EMS is the training of facility staff. Must often, this important aspect of a project is inadequate in duration, planning, or content. It is necessary to provide detailed requirements in the specification regarding operator training and levels of training for operators.

2.6.9 Warranty: Consider specifying a warranty of three years for all control equipment, analog sensors, and I/O modules, and a warranty of one year from acceptance for all other materials, installation, and workmanship. Be clear in the warranty about electrical components that are related to or part of the controls installation, which may not be included in the warranty.

2.6.10 Support: If maintenance contract or onsite assistance during the first few months or year will be part of the original job specifications, make sure all details are clear. Include the response time for emergency service calls and specify whether after-hours visits and regular phone support are provided. State that the supplier shall have an in-place support facility within 50 miles of the site with technical staff, spare parts inventory, and all necessary test and diagnostic equipment.

2.7 Special Considerations for Retrofits

- Make sure that the specifications state that the contractor has viewed the site to his satisfaction and has an understanding of current site and equipment conditions.
- Clearly state for each piece of existing (and any new) equipment how the equipment will be controlled, how the equipment interfaces with the new controls system, and who will make that interface. Clearly state any responsibilities of other vendors.
- For each piece of equipment, identify what troubleshooting, if any, will be completed by the contractor on existing equipment, hardware, or software that is found to be malfunctioning.
- Specify that when connecting to existing pneumatic valve and damper actuators, the following shall be verified: spring ranges; good condition of diaphragms; and good condition of all linkages, bushing, packing, stems, valve seats, etc.

2.8 SELECTING EMS PROPOSALS

Making a good final selection requires learning as much about the prospective EMS as if you already owned it. In some cases, price will be the foremost consideration, but many other technical, financial, and vendor considerations are important. A proposal-ranking scheme is recommended to help sort out all these complexities, so that bids can be evaluated not only on lowest price, but also on value, as determined by examining the costs and benefits of each proposal.

2.8.1 Functionality and Vendor Support Considerations

As a first step in evaluating bids, consider the following factors:

### 2.8.2 Vendor Qualifications

- Experience and background levels of personnel in charge of user training.
- Clarity and user-friendliness of the manufacturer's operator manuals and as-built documentation.
- Response time to repair problems, stocking practices for repair parts, and the skill required to make replacements.
- Type of service contracts available (see Chapter 4: Service Contracts for Energy Management Systems).
- Manufacturer and/or vendor experience in installing and servicing an EMS for the particular application.
- Qualifications of lead programmer and onsite installing technician (see Appendix A: Sample Control Specification Language).
- Availability of local technical and service support.
- Vendor reputation for timely project completion.
- Field training capability.
- Availability of expanded training in classroom (offsite) environment.
- Vendor willingness to enter into long-term pricing agreement.
- Vendor's past history of avoiding production of "orphan" systems (i.e., systems that cannot be upgraded without replacement of major portions of the system).
- Commissioning and installation quality control features.

### 2.8.3 Hardware

- Capability to expand in order to control additional systems, buildings, and modifications to the original EMS.
- Use of two-wire communications cable.
- Use of standard sensor hardware.
- User-friendly operating system and graphics.
- Use of DDC-type field panels.
- Use of field panels that interface with terminal or PC.
- Software that will be compatible with revisions or upgrades.
- Terminal controllers with proportional/integral/derivative (PID) control.
- Field DDC panels with PID control.
- Field DDC panels with automatic loop tuning.
- Terminal controllers with the capacity to have their points unbundled.
- Standard operating environment (MS-DOS, Windows, UNIX, etc., as appropriate).
- Method of sensor calibration that follows an industry standard (4-20 mA, 0-5 or 0-10 vDC, thermistor, etc.).

### 2.8.4 Functionality

- System ability to get back online automatically after power is restored.
- Number of password-controlled levels of access.
- Central computer's capability to integrate DDC, energy management, and lighting control, as

well as fire and security/access and facility management programs.
- Compatibility with existing EMS hardware.
- Ability to communicate with other competitive systems.
- Compatibility with existing local area computer networks and ability to utilize those networks for energy management.
- Use of standard personal computer front end.
- User access to information from the network at the field panel.
- User access to point data at the field panel level.
- User access to programming at the field panel level.
- English language readouts at the field panel level (not coded).
- Field panel information available by menu prompt.
- Field panels that can operate in "standalone" mode in the event of a communications loss.
- Ability to tie into other facilities via modem, dedicated line, or the Internet.
- Adequate trending features (see Appendix A: Sample Control Specification Language).
- Trend data exportable to spreadsheet or database software.
- Automatic system diagnostic features.
- Standard auto-dial/auto-answer modems.
- Alarm functions that can initiate auto-dial to remote computer.
- One programming language for entire system.
- Programming language that is simple and accessible.
- Dynamic graphics with real-time point values.
- Comprehensive online help with a search function.
- Simple method of graphics generation.
- CAD or scanned graphics import capability.
- Terminal controllers that interface at controller thermostat for PC or terminal.
- Adequate number of control strategies.

### 2.8.5 Cost Considerations

- Costs and time required to alter the EMS database and/or software.
- Costs of adding points after the EMS is installed. User-friendliness in adding and deleting points and changing the software. Ability to perform these changes without shutting down the system.
- Overall cost per hardware point (if this varies significantly from bid to bid, find out why).
- Total number of hardware points and software points.
- Total number of monitoring-only points not needed for sequence control.
- Software costs included in bid or as extras.

### 2.8.6 Other Selection Considerations

2.8.6.1 Number of Vendors: It is advisable to narrow the list of vendors to those that are appropriate prior to performing a formal evaluation. Some systems may be too small for your application, or the potential vendor may be too far from your facility.

2.8.6.2 Facility References: To help decide on a vendor, contact similar facilities where the vendors under consideration have completed projects that have been operational for at least a year. (Have the vendor provide a reference list with facility manager names and telephone numbers.) Discuss the system with the facility manager and system operators; find out whether they are satisfied with the system, service, installation, and competence of service personnel. A site visit and system demonstration would be most beneficial. Have the owner's primary system operator attend the system demonstration and discuss the system with the operator at the site. Try to make the site visit without the vendor's representative so that the demonstration will be performed by the building operators and they can speak freely about the system and any shortcomings it may have.

2.8.6.3 Vendor Support: A vendor in close proximity to the facility has the advantages of faster response time and lower service response costs. Make sure the local vendor has full service capabilities and isn't relying on technical assistance from a distant branch, regional, or main office. Determine the vendor's level of customer support by telephone. If a new system is to be installed, see if the vendor can access the EMS from his service office to assist with problems or troubleshooting, at least until the operator is fully trained on the system. Find out if the vendor has 24-hour emergency service and determine the standard response times, if the vendor is local and has an onsite training facility, training will be more convenient. (It is generally desirable to receive training away from your facility to allow you to concentrate without distractions.)

2.8.6.4 Vendor Staff Qualifications: Concern about the brand of the EMS can overshadow the importance of the contractor's role in the project. The vendor's delivery team will often have a greater impact on the project's outcome than the equipment itself. For this reason, facility managers should conduct thorough interviews, inspections of previous job sites, conversations with references, and visits to potential vendor's offices. Even if you are already committed to a vendor, it is a good idea to contact other vendors to obtain a second or third opinion about how best to upgrade your system and meet your energy management needs. This helps keep the vendors competitive. Refer to the Qualifications section of Appendix A for additional details.

2.8.6.5 Long-Term Financial Considerations: Real-world decisions about EMS projects are often driven by available funds, budget cycles, and expected returns on investment. The following guidelines take into account not only the obvious initial costs of the system, but also less obvious future financial impacts:

- If the system is not competitively bid and a "captive" vendor is chosen, the vendor should be willing to enter into a pricing agreement that would allow a guaranteed pricing structure. Maintenance costs, replacement part costs, software and hardware upgrade costs, and operator training costs need to be taken into consideration along with initial purchase price. A long-term pricing agreement may extend up to five years.
- It is in your best financial interest to have the least possible dependence on a vendor for maintenance, operations, programming, graphics, database construction, and even installation. This translates to a simple programming language/system, ease of graphics generation by the operator, and ease of operation of the main system.
- The system should have no proprietary sensors. The fewer proprietary components required, the more components can be purchased in a competitive market at lower costs.
- All systems require operator training. The more complex the programming language the higher the cost, not just training costs, but operations and maintenance costs as well.
- A system that does not require the vendor to make programming changes will most likely incur lower long-term costs than programs/databases that are "burned" into an EPROM (Electronic Programmable Read Only Memory) that is installed in the field cabinet. Hard-coded programs will mean more dependence on the vendor, resulting in higher service/maintenance costs.
- The capability to make operational changes (programming and database changes) to

mechanical systems at the operator level is highly desirable. This also leads to easier implementation of energy management strategies.

- To ensure that interfaces with upgrades in hardware and equipment in the future are reasonably possible, the vendor should be actively working on becoming completely BACnet compatible. Ask about vendor commitment to interoperabiity and BACnet. "Adapting" is the wrong answer they should be "adopting" the standard.

## 3. COMMISSIONING A NEW ENERGY MANAGEMENT SYSTEM

Today's buildings and their internal systems have become increasingly complex. The design and construction disciplines have become fragmented and specialized. Yet low-bid policies are still the norm. More than ever before, energy management systems need a comprehensive, systematic quality assurance process.

Ideally, the commissioning process starts in the design phase and continues through the construction phase and the warranty period. It provides documentation of design intent and verification of equipment performance. Commissioning also verifies that complete and accessible equipment documentation remains onsite and that facility staff is adequately trained to operate the EMS.

This section will look at the commissioning process as it relates to control systems, providing an overview of the process, tips for managing a commissioning authority, and additional commissioning resource material.

### 3.1 THE COMMISSIONING PROCESS

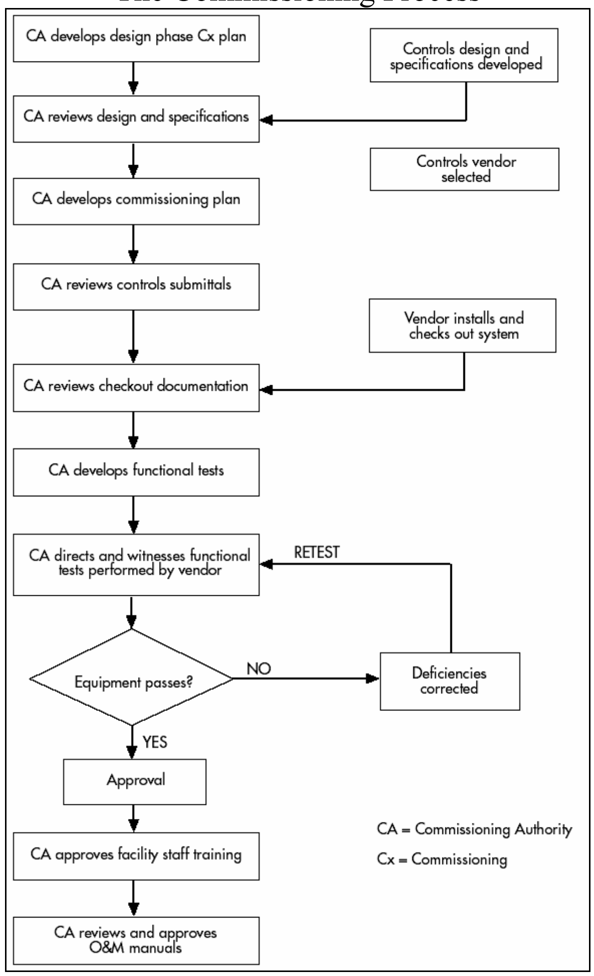
The commissioning process for control systems includes the following activities:

- A commissioning provider/consultant is engaged by the owner.
- The commissioning plan for the design phase is developed by the commissioning consultant.
- The controls are designed and project specifications are developed, including commissioning requirements for the construction phase. The commissioning provider conducts a focused review of the design.
- A controls vendor is selected.
- A commissioning plan for the construction phase is developed and finalized.
- The commissioning authority reviews and approves controls submittals.
- The vendor installs and checks out the system and documents the process, with review by the commissioning authority.
- The commissioning authority develops functional test procedures.
- The vendor executes the functional test procedures with direction and documentation by the commissioning authority.
- Deficiencies are corrected and retested.
- The O&M documentation is reviewed and approved by the commissioning authority.
- The commissioning authority approves the training plans and verifies that specified training is conducted.
- Deferred seasonal testing is conducted later.
- Near the end of the main warranty period (typically one year), the commissioning authority

returns to the site and reviews the current system performance, interviewing the facility staff and helping to address any outstanding issues still under warranty.

Figure 3-1 provides a graphic summary of the above steps.

FIGURE 3-1.
The Commissioning Process




3.2 Procurement Methods and Commissioning

Specifying and Selecting a New Energy Management System, described are two primary methods for procurement of larger control systems, spec and bid, and design-build. The commissioning tasks remain essentially the same in either method. The main differences are :

- Who the commissioning authority deals with and
- When the design documentation is developed. With the design-build method, the commissioning authority works with the vendor's team during design and construction. In the spec and bid method, the commissioning authority coordinates with the engineer at the beginning of the project (and possibly throughout construction if the engineers have construction observation responsibilities). Generally, the commissioning authority does not work with the vendor until the construction phase.

Two features of the design-build approach make commissioning especially necessary:

- The consultants, vendors, and contractors may be working contractually together and may tend to minimize or even hide each other's mistakes
- Documentation is generated later than in the spec and bid approach. Commissioning, which focuses on timely, complete documentation overseen by an independent authority paid by the owner, will offset these potential problems.

## 3.3 ELEMENTS OF A SUCCESSFUL COMMISSIONING PROJECT

There are five primary components of a successful commissioning project.

- Start early, before or at the beginning of the design phase.
- Have complete specifications, including commissioning specifications.
- Involve competent players.
- Develop a detailed commissioning plan.
- Follow the commissioning plan.

### 3.3.1 Commissioning During Design

It is considerably less expensive and disruptive to the construction schedule if design changes are identified early, during design, rather than later, during construction. For this reason, bringing a commissioning authority on board during the design phase is valuable. In addition, the sooner the design and construction team members buy into the commissioning process, the smoother and more effective the project will be. This applies to both design-build and spec and bid projects.

During the design phase, commissioning has the following objectives:

- Provide a commissioning-focused design and specification review.
- Ensure that the design and operational intent are clearly documented.
- Ensure that commissioning for the construction phase is adequately reflected in the bid documents.

### 3.3.2 Design Review

The commissioning authority should cover at least the following during the review of the design documents:

- Verify that the design documentation is clear and complete; that there are sufficient isolation valves, dampers, interlocks, pressure and temperature plugs, pressure gages, thermometers, flow meters, and monitoring points; and that there are adequate trending capabilities to efficiently commission the system.
- Review HVAC, lighting, fire control, security control system strategies and sequences of operation for completeness, clarity, adequacy and efficiency. Review the capabilities and features of the specified system against the owner's expressed wishes and needs.
- Review the control system relative to efficient O&M and building control. For example, make certain that offsite alarm, monitoring and remote-access features are clearly understood and

documented and that there is sufficient access around equipment for proper servicing.
- Verify that the specified O&M documentation requirements are adequate.
- Verify that the specified operator training requirements are adequate.
- Verify that bid documents adequately specify building commissioning, including the issues listed above. Vendors will rarely include commissioning in their bids, and it is difficult to get cooperation for commissioning when it is added on later.

### 3.3.3 Design and Operational Intent

The commissioning authority sees that the controls engineer clearly and completely documents the intent behind the controls features specified and that the operational and control sequences are fully documented as early in the design phase as possible. Without this oversight, control sequences may be documented only in vague, general terms. If performance specifications (specifying what the system will do, but not how the sequences will accomplish it) are not followed up with full sequence documentation, the vendor's site-based technician may develop important control sequences and parameters without adequate input from the original controls or system engineer. Such onsite programming is generally poorly documented and rarely reviewed and may lead to inefficient or defective sequences. To allow the commissioning authority to optimize sequences during design reviews, design intent and control sequences must be documented during design.

### 3.3.4 Commissioning Specifications

The commissioning authority may help the specification writer to specify the commissioning requirements for the control system using one of two methods. The commissioning authority may provide a boilerplate commissioning specification, which the controls engineer incorporates into the specification and the commissioning authority then reviews for approval; or, the commissioning authority may write the commissioning specification, which the controls engineer then approves and uses in the specification.

Commissioning requirements should be explicit. The specifications should describe what systems and components are to be commissioned; what testing will be required; what testing documentation will be required; and what acceptance criteria will be used. This is especially critical for interfaces with existing controllers or standalone controllers. Additional specification guidelines are found in Specifying and Selecting a New Energy Management System.

### 3.3.5 Competent Players

There are three players essential to the success of a commissioning project: the commissioning authority, the controls vendor, and the project manager. Below is a discussion of the recommended requirements for each of these individuals.

### 3.3.6 Commissioning Authority

Selecting the right commissioning authority is the single most important step to a successful commissioning process. The commissioning authority should have excellent qualifications in commissioning project field experience, control and HVAC systems troubleshooting, energy efficient strategies and communication skills. The following list provides specific language that may be used in soliciting a commissioning authority.

### 3.3.7 Project Experience

- Experience as the principal commissioning agent for at least three projects over 100,000 square feet. (Increase or reduce the size of required project experience, depending on your project.)
- Excellent verbal and writing communication skills. Highly organized and able to work with both management and trade contractors.

### 3.3.8 Technical Experience

- Extensive experience in the operation and troubleshooting of EMS, HVAC systems and lighting controls systems. Extensive field experience. A minimum of five years in this type of work.
- Knowledge of building operation and maintenance and O&M training.
- Knowledge of test and balance of both air and water systems.
- Experience in energy-efficient equipment design and control strategy optimization.
- Direct experience in monitoring and analyzing system operation using EMS trending and standalone data-logging equipment.
- Experience in writing commissioning specifications.

### 3.3.9 Education and Credentials

A bachelor's degree in engineering and professional engineer (P.E.) certification is strongly preferred; however, other technical training and past commissioning and field experience are more important than formal certifications.

### 3.3.10 Management Requirements

- The member of the commissioning firm designated as the commissioning authority must be fully qualified and must be assigned to the project for its duration.
- The commissioning authority will ideally be an independent contractor and not an employee or subcontractor of the controls vendor.

### 3.3.11 Controls Vendor

The previous section provided guidelines for obtaining the qualifications of controls companies and their key staff. Review these qualifications and call the references. Obtaining information about problems the vendor had in past projects may not cause you to change your mind about the vendor, but it will alert you to areas to watch closely and/or discuss with the vendor before the problem is repeated on your project.

### 3.3.12 Project Manager

The project manager should take an interest in following the commissioning process and, most importantly, must openly support the commissioning authority. The commissioning authority must have your full support, especially if the vendor's staff resists full compliance with the commissioning authority's plan. The project manager should facilitate regular commissioning meetings and should process the commissioning authority's requests for information and reports on possible deficiencies. With proper support, the commissioning process can be successful for all parties involved.

### 3.3.13 The Commissioning Plan

A successful commissioning project needs a solid commissioning plan. Typically, the commissioning authority writes the commissioning plan, which should assign responsibilities and deal with priorities and procedures. A good commissioning plan incorporates the following elements:

- Objectives and scope
- Players and responsibilities
- Communication, reporting and management protocols
- Documentation requirements of the equipment installation
- Documentation requirements of the commissioning process
- Scope of manual testing and monitoring (specific)
- Recommended training format and verification
- Schedule
- Further details of required testing, documenting and reporting where the specifications are weak (if applicable)

### 3.3.14 Putting the Plan into Action

There are a number of tasks in a commissioning plan: installation and initial checkout; operational checkout; functional testing; O&M documentation; and training. Below is a discussion of some of the most relevant issues for each topic.

### 3.3.15 Installation and Initial Checkout

Before functional testing by the commissioning authority begins, require that an initial checkout (sometimes called a point-to-point and operational check) be completed and documented by the controls vendor. This can be done as part of the installation. (Refer to Appendix A for additional calibration and setup procedure details.) Require that the documentation forms and procedures for the initial checkout be pre-approved by the commissioning authority. These forms should contain a list of every control point in the system, along with a space to check as each point undergoes, and passes or fails, the following four tests:

#### 3.3.15.1 Hardware Check:

- Verify wiring to each point and sensor location.
- Verify software point address in the control system.
- Verify that points are set up in the local device controllers.
- Verify that all points in the controller or sensor are communicating properly with the control system.

#### 3.3.15.2 Software Load and Check:

- This applies to controllers such as those found in terminal units; the controller is powered up and the approved software program (with setpoints, deadbands, etc.) is uploaded to the controller and proper communication again verified.

3.3.15.3 Calibrations:

- Verify that all sensors are located away from causes of erratic operation.
- For all sensors, check the sensor reading in the EMS against a recently calibrated test instrument. Calibrate as needed. (Enter an offset in the EMS, or use another suitable method.)
- For valve and damper actuators and states of other devices, verify at both extremes of the actuator range that the reading in the EMS matches a visual observation of the device. Refer to Appendix A: Sample Control Specification Language, for complete procedure and requirements for calibration of sensors, points and actuators and to the Calibration of Equipment section of Chapter 5: Strategies for Optimization.

3.3.15.4 Response Check:

- This mainly applies to controllers such as those found in terminal units, but may be applicable to other equipment. Change setpoints such that each controlled actuator (damper or valve) moves to the full open position. Verify that the CFM or flow, etc., at full open is per specification and visually verify that the readout in the EMS is consistent with the actual conditions of the actuator. Observe proper staging. Repeat the procedure to observe the actuator naturally going to the fully closed position. Repeat for each actuator in the controller.

### 3.3.16 Operational Checkout

The controls vendor should be required to run each piece of equipment through the entire sequence of operation to verify that the system functions as intended. For small controllers like terminal units, the initial checkout procedures described above will suffice as the operational checkout, except for interaction tests with other equipment or tests for conditions such as power failure and fire alarm.

The operational checkout by the vendor ensures that the system is ready for functional testing and verification by the commissioning authority. Without this assurance, functional testing often becomes a debugging process for the controls contractor with a significant amount of the system requiring retesting and reprogramming. Vendors should do their own debugging before the commissioning authority functionally tests the system.

### 3.3.17 Functional Testing

Functional testing verifies that the EMS and controlled equipment actually work as intended. The commissioning authority develops detailed test procedures and documentation forms. Typically, each piece of equipment is run through the entire sequence of operations, and all alarms are checked. The system is also tested by checking equipment interactions and interlocks. This is done in start-up, shutdown, unoccupied, and occupied modes, as well as power failure, manual modes, full- and part-load conditions.

During testing, the controls vendor typically operates the equipment under the direction of the commissioning authority. Tests may be manual, where physical conditions, setpoints, or point values are changed and the system's response is observed (at the control system terminal, visually, or by handheld instruments) and documented. Other tests may require the vendor to trend a number of points in the system (if the points have been calibrated). The commissioning authority may then analyze the data in tabular or graphical form, verifying proper sequencing and operation. Portable dataloggers are also a useful and convenient way to monitor equipment and verify proper operation.

Areas that fail in the testing are investigated and corrected by the vendor and retested by the commissioning authority. Additional information on functional testing will be covered later in this course.

### 3.3.18 O&M Documentation

Facility staff need complete, clear, and accessible documentation about the controls system to use it efficiently. The commissioning authority should make sure that documentation follows the requirements in the specifications. Of special importance is as-built documentation, which is often provided before functional testing is complete. Since functional testing always results in some changes, corrections, or enhancements to the control sequences, the commissioning authority must verify that the final as-builts reflect these changes.

### 3.3.19 Training

The specifications should require the vendor to provide a training agenda for review by the owner and commissioning authority. The plan should indicate who will do the training; the qualifications of the instructor; the topics covered, with the time expected on each topic; the technical rigor of each subject; and any videotaping desired. The commissioning authority ensures that the training actually takes place as planned. (Refer to the Training section of Appendix A for additional details.)

### 3.3.20 Managing the Commissioning Authority and Process

The following are a list of essentials that will assist the facility manager, project manager or owner's representative in managing the commissioning authority and the process.

### 3.3.21 Support and Scope

3.3.21.1 Hire a well-qualified commissioning authority:

- Have a comprehensive and clear scope of work for the commissioning authority.
- Read the commissioning specifications and the commissioning plan front to back.
- Let all players know you support your commissioning authority.

3.3.21.2 Reporting:

- Have clear reporting and paper paths and request-for-information protocols.
- Insist on frequent progress reports and updates from the commissioning authority.

3.3.21.3 Schedules and Meetings:

- Follow through in a timely manner on your tasks (scheduling meetings, testing, issue and document reviews, conflict resolution, etc.).
- Make sure that commissioning gets included in the master schedule.
- Schedule or facilitate regular commissioning meetings.

3.3.21.4 Deficiencies:

- Have the commissioning authority keep a continuous current deficiency or issues log, with a record of the resolution.
- Develop a clear policy on dealing with identified deficiencies.
- See that all deficiencies are corrected in a timely manner.
- Near the end of the project, have the commissioning authority and the project manager go through the control specifications line-by-line to ensure all requirements are being met.

## 4. SERVICE CONTRACTORS FOR ENERGY MANAGEMENT SYSTEMS

Often service contract options are the last thing considered when purchasing an EMS, yet without proper maintenance and operation, these expensive and sophisticated systems frequently end up underused, overridden, and blamed for any number of O&M problems. For an EMS to remain cost-effective, long-term maintenance should be considered early in the project-planning phase.

The purpose of this section is to help the building owner and manager understand what types of contracts are available, who provides them, and how to make the best choice among them.

### 4.1 EMS Service Contract Providers

The major providers of EMS service contracts are:

4.1.1 EMS Manufacturers: A manufacturer may be the sole distributor and installer of the system it produces, or it may qualify other firms to distribute and install its systems. Most manufacturers of EMS offer a variety of service agreements or contracts for their systems.

4.1.2 Mechanical Contractors: Mechanical contractors install, repair, and perform O&M on all types of mechanical equipment, including EMS. They may also distribute a particular manufacturer's EMS and provide maintenance agreements or service contracts for that system. Their service technicians are factory-trained by the manufacturer of the EMS they distribute.

4.1.3 National Maintenance Service Firms: National maintenance service firms mainly serve large retail chains and owners of multiple buildings. These firms qualify mechanical contracting businesses throughout the country as their subcontractors; the subcontractors are then considered part of their service team. This type of national firm may also be a full-service mechanical contractor with its own technicians and distribution rights to a particular manufacturer's EMS. Their service technicians are trained by the manufacturer of the EMS.

### 4.2 Various Types of Service Contracts

In the EMS industry, there is no standard or set of definitions for the various kinds of service contracts or agreements. Each manufacturer or distributor puts together a unique package of service offerings. The package often consists of three or four types of contracts at different levels of comprehensiveness and with different features. Below, we briefly discuss five traditional types of contracts:

- Full-maintenance agreements
- Software monitoring agreements
- Full-service agreements (combination of the above two)

- Preventive maintenance agreements
- Open or flexible agreements

Within these five types, there can be many variations, depending on an owner's needs and the contractor's willingness to modify or customize service agreements. Many EMS vendors also provide service contracts that not only include the EMS but also all other building equipment and systems. For the purpose of this document we will only discuss service contracts for EMS.

### 4.3 Full-Maintenance Agreement

The full-maintenance agreement may be thought of as an extended warranty. This type of contract is generally purchased following the installation of a new system. For a set annual fee, the contract covers all labor and materials for EMS hardware failures and generally includes an emergency response arrangement. Both the duration of the agreement and the emergency response feature are usually negotiable. Typically, these contracts are purchased to cover a one- to five-year period. One of the main advantages of this type of contract is ease of budgeting. The owner knows exactly what maintenance will cost no matter how sparse or extensive the repairs are for the contract period.

However, this type of contract is usually expensive because of the risk to the provider. Contracts are often more expensive for older systems because they are more likely to fail. The contract price should be closely scrutinized. The cost should reflect the age and condition of the system. The owner should compare the total cost of the service contract to the cost of a new system. Over the contract period, the cost of the contract may be close to or the same as the cost for a new system. When evaluating a contract of this type, consider the fact that the newer distributed (DDC) systems are much less prone to failures than the older mainframe type systems. Failures of any size in a distributed system typically do not become catastrophic as long as the system is well grounded and surge-protected. In addition, if there are well-trained onsite staff to do most of the repairs for the system, this type of contract may be inappropriate.

### 4.4 Software (Remote) Monitoring Agreement

The software-monitoring type of contract may be purchased anytime during the life of the system. With this type of contract, the service provider remotely monitors the EMS for problems. When a problem occurs, the decision on how to remedy it depends on the contract arrangements. The contractor may have the authority to make certain limited decisions about how to solve particular problems. For example, the contractor may have the authority to raise or lower setpoints within a certain range to alleviate comfort problems. However, some owners may require contractor notification whenever any problem arises. Usually, major or permanent changes to the system regarding scheduling, setpoints, or programming are done at the request of the owner. Emergency response arrangements vary according to the level of involvement of the service provider in actually repairing the system.

The software monitoring contract is most appropriate for facilities where knowledgeable staff is not always available and/or where the need for consistent and reliable operation is critical.

### 4.5 Full-Service Agreement

The full-service agreement combines the two contracts discussed above and addresses both hardware and software issues. The full-service agreement is often purchased by owners who have complex multiple facilities and prefer to outsource most work that is not a core business component. This is the most expensive service contract. An emergency response arrangement is typically part of the agreement.

4.6 Preventive Maintenance (PM) Agreement

The PM agreement is generally purchased for a fixed fee and includes a preset number of scheduled visits each year. The purpose of this type of contract is to periodically inspect the system for problems and perform the agreed-upon PM activities that keep the system in good working order and the programming current for the season. The contract may or may not include any arrangements regarding emergency calls. The main advantage of this type of contract is that it is generally less expensive than either the full-service or full-maintenance contracts. It also provides a focus on high-quality preventive maintenance. However, budgeting and cost control for emergencies, repairs, and replacements are more difficult, because these activities are generally done on a time-and-materials basis. The owner carries most of the risk.

4.7 Open or Flexible Agreement

Another option is the purchase of a block or pool of hours for labor at a set annual fee. Under this arrangement, the owner may use these hours for a range of needs from programming to installing hardware or upgrades. If, at the end of the year, the hours are not exhausted, some service providers allow the owner to roll them over to the next year. This type of arrangement may be purchased alone or in combination with several of the other agreements discussed above.

4.8 Mix, Match, and More.

The following discussion highlights some cost-effective ways of obtaining appropriate, high-quality service agreements.
Owners with well-trained and available onsite staff should consider purchasing any combination of the following service arrangements:

- Flexible agreement
- Preventive maintenance agreement
- Long-term purchasing agreement

The long-term purchasing agreement allows the owner to keep an inventory of EMS parts onsite for an agreed-upon time, usually three to five years. The amount of inventory is based on the likelihood of EMS failures and the urgency of the possible repair. Parts that seldom fail or are not critical to the owner or tenant's business are generally left out of the inventory. For example, the failure of a control panel board for a packaged rooftop unit serving a major tenant would be considered urgent; the failure of a space temperature sensor for an infrequently used conference room would not.

Although an owner may keep an inventory of parts worth several thousands of dollars, under this agreement a part is not paid for until it is used. The failed part is removed and sent back to the manufacturer. The agreement is usually negotiated so that the owner pays published list price for the parts less a certain percent (20% to 60%). At the end of the agreement period, the contract may be renewed or the unused inventory may be returned to the supplier at no further charge. The fees paid to the supplier for this type of agreement are minimal and are generally related to the interest rates and property taxes on the inventory. The long-term purchasing agreement may be effectively coupled with a preventive maintenance (PM) agreement from the same supplier that offers annual software, firmware, and hardware upgrades plus any agreed upon PM activities and emergency response arrangements. Another cost-effective arrangement is the purchase of a pool of labor hours from the vendor based on an assessment of programming needs for the year. This arrangement works well for owners of somewhat smaller buildings that have building operators with expertise in EMS operation. Combining this with a PM contract that includes system upgrades often provides the owner with the most quality at the least cost.

Some EMS suppliers offer a technical support agreement. With this option the owner can purchase a range of technical support activities from one day of hands-on training for their building operators to a weekly onsite visit by a technician (coach). When the agreement requires a technical coach for the building operators, the duration of the arrangement may last anywhere from a few weeks to years. This agreement can also be coupled with several of the other types of contracts, depending on the owner's needs.

## 4.9 Selecting a Service Agreement

Selecting an optimal, cost-effective service agreement for the EMS can be confusing. The following list of considerations are meant to help the owner and manager develop objectives for their contract and evaluate the fit of various contracts to their needs:

- Owner's overall economic objective
- Importance of system performance to the bottom line
- Training and availability of in-house staff
- Size and complexity of the EMS
- Sophistication of the required control strategies
- Budget constraints
- Objectives for purchasing a service agreement

## 4.10 Owner's Overall Economic Objectives

The first thing to consider is the owner's economic commitment to a property. If the owner is a short-time investor and intends to sell within two years, a basic PM agreement with repairs and emergency service billed on a time-and-materials basis may be the most appropriate arrangement. If the owner has a long-term investment in the property, more careful evaluation of all the factors is worthwhile.

## 4.11 Importance of System Performance to the Bottom Line

EMS performance may contribute to economic success. Take, for example, a building housing a single tenant, where the owner is responsible for all the building operation and maintenance. Not only is the productivity of the tenant's employees critical to the tenant's business, but the owner's ability to keep the tenant may depend on how well the control system maintains comfort. Retail profits may also be affected by how well the EMS operates. For example, if the EMS humidity controls are not well monitored and maintained, products sensitive to excessive moisture can be lost. In sensitive laboratory environments, the control system is critical to bottom-line success: Experiments can be jeopardized when temperature, humidity, and pressure are not consistent.

## 4.12 Training and Availability of In-House Staff

For a facility without expert in-house building staff, a rigorous type of service contract is recommended. Even if there are expert building operators on staff, EMS upkeep may be too time-consuming for them, and a service contract may still be necessary. The more control expertise and available time the building staff has, the less critical the need for a rigorous service contract. In some cases, purchasing a block of programming hours along with a minimal PM contract that includes system upgrades may be sufficient.

### 4.13 Size, Complexity, and Sophistication of the EMS

The size of an EMS alone does not usually dictate the need for a service contract. The complexity of the system and the sophistication of the control strategies have a greater impact on service requirements. A large facility with several buildings and a significant number of rooftop packaged units (RTUs) with integral controls may need the EMS only to enable and disable the RTUs according to a simple time-of-day schedule. An expensive monitoring or full-service contract is not appropriate for this situation. In contrast, a relatively small facility with a full DDC system controlling the heating and cooling plant, along with a VAV air distribution system and space static pressure, would require a rigorous level of service.

### 4.14 Budget Constraints

Few owners or managers have an unlimited budget for operating and maintaining an EMS. Budget constraints are often the deciding factor in choosing a service agreement. However, installing an expensive and complicated system without the budget to maintain it generally means that any savings initially gained from the system will quickly disappear. Owners and managers need to avoid being "penny wise and pound foolish" when it comes to selecting service agreements. An appropriate service arrangement will often pay for itself.

## 5. OPTIMIZATION OF AN ENERGY MANAGEMENT SYSTEM

Once an EMS is in place and fully operational, the facility manager must supervise its operation for total optimization. In this section, the term "optimization" will be used to refer to activities that move beyond common EMS routines and into customization for maximum occupant comfort and minimum energy consumption. Because buildings are dynamic, with frequent changes in floor plans, space use, weather conditions, plug loads and occupant densities, EMS optimization is an ongoing process.

Historically, energy management systems have been installed to control equipment with greater accuracy and automation than is possible with manual or pneumatic controls. Today, forward-looking building owners may install state-of-the-art EMS with several agendas in mind:

- To increase occupant comfort and improve building operation.
- To "take control" of the building (assuming the old system was not adequate).
- To allow interoperability with other facilities, perhaps by taking advantage of a campus-wide LAN.
- To reduce energy use and improve the bottom line.

This section will examine steps that can be used to optimize EMS operation, particularly strategies to reduce energy consumption and improve occupant comfort. It will also help owners and managers to understand and master the full capabilities of an EMS, even if some of the control strategies discussed are not applicable at present, they may provide ideas for future upgrades.

## 5.1 BASIC EMS CAPABILITIES

Before trying to optimize a system, it is important to understand basic EMS capabilities. Features may vary widely from model to model, but some basic capabilities are almost universal. Discussed below are several standard EMS capabilities:

- Scheduling
- Setpoints
- Alarms
- Safeties
- Basic monitoring and trending

With each of these features, there are opportunities to move beyond minimal utilization without significant effort or complexity.

## 5.2 Scheduling

Older energy management systems have many of their capabilities frequently disabled or eliminated due to functionality. In the past, these systems have not done a good job of scheduling. Today's systems allow for greater flexibility in scheduling, defining ON/OFF times, and set-points as well. With multiple scheduling scenarios available in most EMS, even elementary time clock and scheduling features offer significant savings. The first step in smart scheduling is to shut down unnecessary equipment when it is not needed. Given the complexity of a building and the amount of equipment with potentially different schedules, this task requires some effort. Taking control of schedules is the quickest and simplest way to see an immediate reduction in energy bills.

Schedules need to be checked periodically to assess whether they still apply. Zone HVAC schedules should be consistent with lighting and occupancy schedules. Lighting sweep schedules, which turn off lights at scheduled times, should be set so that they work for tenants and cleaning staff to minimize both lighting on-time and nuisance overrides. In addition, the following EMS capabilities should be investigated and used to reduce unnecessary equipment use.

5.2.1 Daily Scheduling: Many EMS software packages provide for up to 5 or 7 user configurable start and stop schedules for each piece of machinery for each day of the week. Customize these schedules to fit the needs of the facility and to reduce the time equipment is running unnecessarily.

5.2.2 Calendar Scheduling: In addition to typical holiday schedules, calendar scheduling allows for greater flexibility in EMS operation. Schedules can be programmed to service unusual events such as production schedules or seasonal changes in occupancy or occupancy hours. The EMS operator can enter schedules for any number of control points for any date during the year. Depending on the EMS software, calendar schedules may be erased once the dates have passed and schedules were successfully implemented.

The scheduled dates may repeat in subsequent years (as is the case with holiday schedules). Calendar schedules allow the building manager to automatically provide space conditioning only when and where it is needed. Automatic conversion to and from daylight savings time should be a convenient feature in a system.

5.2.3 Exception Scheduling: If there is an exception to the regular schedule (e.g., a half day or longer hours than normal), this feature allows programming of the exception for that day only rather than changing the regular schedule. Once the exception period is passed, the program returns to the original schedule.

5.3 Setpoints

Setpoints range from those inside equipment logic, which are rarely changed, to space temperature setpoints, which need constant adjustment. Some setpoints are defined by the operator and associated with a schedule; others may be adjusted by internal calculations of the program (e.g., reset temperatures or pressures).

5.3.1 Space Temperature Setpoints: The building manager's job, among other things, is to maintain occupant comfort while identifying ways to reduce energy consumption. Controlling the space temperature may be the single most time consuming and problematic task a building operator deals with. Often, the possibilities for reducing energy use by altering space temperature setpoints are not investigated for fear of adversely affecting comfort. This may be the case at times, but large multi-zone buildings with DDC can present opportunities to move beyond a traditional building-wide setpoint.

The following information should be reviewed when considering space temperature setpoint changes:

- Time of day
- Number and fluctuation of occupants in zone
- Humidity conditions
- Size of zone
- Location of zone
- Zone exposure (perimeter or core, south or north, etc.)
- Impact on reheat or simultaneous heating and cooling
- Impact on pumping, fan, or plant efficiency
- Equipment in zone (e.g., computers or laboratory equipment).

Consideration of all these factors could lead to a well-justified decision to allow the afternoon summer temperature in a north-facing zone to drift up by 2 degrees. Additionally, an entire floor of tenants with sedentary jobs could have a warmer setpoint than a floor of more active workers. Remember that comfort is a function not only of space temperature but also of radiant temperature (direct sunlight), airflow, and humidity.

It is important to carefully analyze the net impact on adjusting space setpoints. For example, increasing the zone setpoint during the swing season to save cooling energy may result in increasing reheat energy in zones that require reheat.

5.3.2 Dual Setpoint Control (Deadband): The most common strategy for optimizing space temperature setpoints is to have separate heating and cooling setpoints or one setpoint with a wide deadband (greater than $4^{\circ}$F). This lowers the potential for simultaneous or overlapping heating and cooling, thereby reducing wasted energy and comfort complaints.

5.3.3 Other Setpoints: The building operator should be familiar with a number of other basic setpoints. It is critical to have an understanding of the purpose behind each setpoint and the impact on energy and other systems when the setpoints are altered. An up-to-date consolidated list of all primary setpoints as part of the system documentation is a must.

## 5.4 ALARMS

Registering and recording alarms is a critical part of any EMS. In addition to basic alarm functionality, an EMS provides options in specifying how alarms are monitored, reported, routed, and ultimately dealt with. For any monitored or controlled point, systems' basic alarm functions can be set up to register and display the following:

- Equipment failures
- Sensor failures
- High parameter value (temperature, pressure, etc.)
- Low parameter value (temperature, pressure, etc.)
- Invalid temperatures (sensor is being tampered with)
- Manual override of machinery at remote locations
- Communications problems

5.4.1 Alarm Features: Alarms are fundamental and critically important, so most systems will need little or no extra configuration to provide basic alarm functionality. However, building managers benefit from alarm-handling features that assist in formulating a quick and accurate response. Alarm messaging provides extra information on the source of the alarm, such as the state of the equipment when the alarm was generated. Additional messages can sometimes be attached to alarms as well. Alarm routing is a feature that gives flexibility in delivering messages to a prescribed series of outputs (e.g. computer screens, printers, or remote monitoring sites via modem). In addition, some systems have a paging feature that works with alphanumeric pagers where the actual alarm text with current point value is displayed on the pager.

Responses for some noncritical alarms can be dealt with via automatically pre-programmed alarm handling routines.

Often there is a distinction between an "alarm" and a "warning." A point may generate a warning if it is slightly out of range but an alarm if it is significantly out of range. Once the operator understands the alarm programming of the EMS, there is often latitude to use some creativity in defining points and alarms. For example, the difference between a temperature and its setpoint may be a more relevant point to alarm than the temperature itself. Alarms are a potentially powerful tool to be used in managing a building, but if not well defined and used for a intended propose they can become an annoyance or even worse.

5.4.2 Nuisance Alarms: If alarms are poorly defined and too easily set off, the operator will acknowledge alarms without review just to get rid of them. This could cause real problems if a significant alarm comes in. A log should be created of all alarms to be reviewed periodically to improve the alarm rules and limits. For those facility managers who have little time to do anything but respond to alarm after alarm, this approach is worthwhile. Furthermore, if enhanced alarm handling features are available but underused, it may be that full utilization will result in faster problem-solving response time and better documentation for future reference.

## 5.5 SAFETIES

Safeties are sequences programmed into an EMS that are automatically initiated to protect equipment, property, or life. The condition that initiates the safety sequence may also generate an alarm (high duct static fan shut down, freeze condition fan shut down, etc.). Using safeties can protect equipment and the building itself from damage and may also reduce or eliminate the need for alarm reporting to remote sites to engage an after hours emergency service call. For example, a high-water condition in the cooling tower may indicate a clogged intake screen or faulty make-up valve. This condition is serious enough to require immediate attention for a tower without a separate float control. After hours, an alarm would be required to sound offsite for immediate service. A safety sequence would simply close the make-up water valve and/or shut down the chillers until the normal facility operators could deal with the issue the following morning.

Safeties that protect life and equipment (freeze-stats, high pressure limits, and smoke detectors) should not rely on software and programming functions to work, they should be hardwired.

## 5.6 BASIC MONITORING AND TRENDING

In addition to controlling equipment, EMS has the basic capability to monitor or record various parameters of equipment operation. In EMS terminology, monitoring is referred to as trending. Trending can be executed on most points that control equipment, for other monitored-only points that may have been installed, and for some software or virtual points (calculated values such as resets).

Monitoring and trending through EMS offer significant advantages over other data measurement methods. With the sensors already in place to monitor equipment, the cost of monitoring through EMS is often less than that of purchasing or renting other devices or taking spot measurements with handheld instruments. The communications structure of EMS facilitates monitoring many data points simultaneously. Since trend data are an actual record of performance, EMS trends are often used to verify equipment operation, energy conservation project results, and energy savings performance contracts.

5.6.1 Trending Points: Ideally, the EMS should be capable of providing the following types of information:

- Temperature
- Pressure
- Damper and valve position commands, including variable frequency drive control signals
- Virtual points (internal calculations such as enthalpy or changing setpoints and targets)
- (ON/OFF) status or stage
- Flow rate (water or air)
- Alarm state
- Current
- Power demand (kW)
- Energy consumption
  (kWh, therms, gallons, etc.)
- Revolutions per minute (RPM)

- Virtual points

Some types of data points are not commonly used because of the cost of their sensors or transducers. These include air and water flow rates, power demand and energy consumption. If a necessary point is not available, it is usually a simple matter to add it, especially when there are open input channels in the panel.

5.6.2 Basic Trending: There are two basic trend types, a data stream and a change of value (COV). In a data stream, the EMS at each time interval gathers the current value of a data point and stores it with the exact time the parameter was polled. A COV trend records the time and parameter value only when the parameter changes by a preset amount.

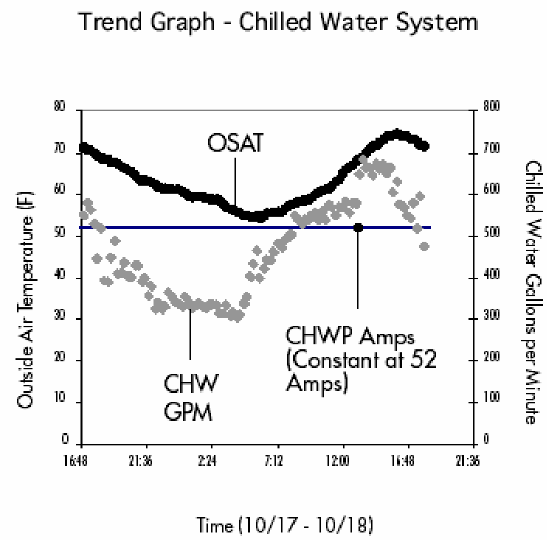
Instructions can be given to the EMS to track more than one data point at the same time. The data is stored in the control field cabinets or the central computer. When the cabinet memory is full, it may download the trend data to the central computer's hard drive or begin erasing the oldest data. It is important to understand how to set up this memory and data management in your system.

The data can be retrieved and viewed in a tabulated numerical form on the computer screen or on a hard-copy printout or, preferably, by a graph of the data. Many energy management systems have features that allow trend data to be viewed graphically. Some even provide a real-time view of the graph as events are actually happening, although these tools are typically inflexible. For more rigorous graphical analysis, the data may be exported to a commercial spreadsheet program. EMS software will typically have some default trend plots (sometimes called history logs) already set up in the system. Other custom trends can be set up and initiated at will.

FIGURE 5-1.
Example of Trend Graph

Trend Data

| Date | Time | CHW GPM | OSAT | CHW Pump Amps |
|---|---|---|---|---|
| 17-Oct | 5:00 PM | 549.69 | 71.19 | 52 |
| 17-Oct | 5:15 PM | 578.56 | 70.56 | 52 |
| 17-Oct | 5:30 PM | 562.19 | 70.38 | 52 |
| 17-Oct | 5:45 PM | 529.75 | 69.94 | 52 |
| 17-Oct | 6:00 PM | 445.38 | 69.25 | 52 |
| 17-Oct | 6:15 PM | 517.25 | 68.5 | 52 |
| 17-Oct | 6:30 PM | 393.44 | 68.5 | 52 |
| 17-Oct | 6:45 PM | 388.31 | 68.19 | 52 |
| 17-Oct | 7:00 PM | 448.13 | 67.69 | 52 |
| 17-Oct | 7:15 PM | 486 | 67.69 | 52 |
| 17-Oct | 7:30 PM | 407.06 | 67.38 | 52 |
| 17-Oct | 7:45 PM | 411.75 | 66.75 | 52 |
| 17-Oct | 8:00 PM | 432.88 | 66.25 | 52 |
| 17-Oct | 8:15 PM | 402.38 | 65.63 | 52 |
| 17-Oct | 8:30 PM | 401.25 | 65.19 | 52 |
| 17-Oct | 8:45 PM | 426.25 | 64.69 | 52 |
| 17-Oct | 9:00 PM | 426.63 | 63.56 | 52 |




Trend can be useful for dealing with comfort problems (trend the terminal air flow and coil valve position), documenting conditions (trend the space temperature over time) or troubleshooting equipment malfunction (trend change of value for the static pressure sensor to detect hunting). Figure 5-1 provides an actual example. It shows that as the outside air temperature goes down, the chilled water flow also goes down, as expected, since the cooling load is tied to outside air temperature. However, the speed of the chilled water pump (current is used as a surrogate for speed) remains constant even though it is controlled with a variable speed drive, indicating a malfunction somewhere in the system.

## 5.7 PREREQUISITES FOR OPTIMIZING EMS OPERATIONS

For EMS optimization, it is critical to know the current status of your system, what it was intended to do and how well it is doing it. Whether a new system is being installed, new features being added to an existing system, or working to improve the current system, take time to examine the following items before attempting significant enhancements:

- EMS Documentation. Make sure it is adequate.
- Sequences of Operation. Gather, examine and understand them.
- Current Control Strategies. Examine and understand them.
- Calibration of Equipment. Calibrate all sensors and actuators.
- Functional Testing. Make sure equipment is operating as intended.

These above topics will be discussed in the following sections.

## 5.8 EMS Documentation

When embarking on optimizing a EMS, it is necessary to assess the state of documentation and bring it to a satisfactory level in order to adequately understand and troubleshoot the system. Documentation consists of user manuals, product literature, software help files, control drawings, written sequences of operation, points lists, program code, and other materials that describe the particulars to your installation. These support items are essential to assuring the long-term integrity of the system.

Unfortunately, even for new installations, system documentation is not always provided in an easily usable form. Sometimes documentation is simply missing; other times the operator is hindered by too much poorly organized documentation.

There are two basic types of EMS documentation: system and application.

System Documentation consists of those materials (usually reference manuals) included by the manufacturer to explain and document a particular system. System documentation may contain large amounts of information, but that information may not be easy to find and use.

Organized product documentation will make system information considerably more accessible and less likely to research.

There may also be a need to augment system documentation. After receiving all available manuals from the vendor, check to see if there is a need to compile with additional materials. Often, there is a need to add supplementary instructions and documentation on features that are often used. More in-depth technical information is usually available from the controls vendor. Make sure documentation from past alterations or upgrades have received and are available.

Information specific to the EMS installation can be found in the application documentation. This includes materials such as up-to-date control drawings and schematics; checkout documentation, written sequences of operation, a points list, and ongoing logs of system and controlled equipment changes. Because programming and EMS points are likely to evolve over time, it is important to have a process for keeping application documentation up to date. The information can be difficult to assemble, but it is required in order to get the most from a EMS.

Points lists and time-of-day schedules can easily be printed out. If the orginal vendor cannot supply missing information, there may be a need to develop schematics or control drawings.

Obtaining clear, correct, and complete control sequences with setpoints, lockouts, and parameter schedules for each piece of equipment is normally the biggest documentation challenge. Copying (or printing) critical information from equipment setup screens is a start. The actual program code, particularly the programmer's comment statements, can also yield sequence information. Make sure access to an electronic or hard copy of the code is available. One doesn't have to know how to program to follow the logic of most control program code once given a few syntax pointers. Obtain help from the vendor if necessary. An additional benefit of constructing application documentation is that a comparison of the sequence of operations with the actual programming may uncover errors in the programming.

Original specified sequences or control vendor sequences should be gathered and carefully reviewed and annotated to reflect what is really happening in your building. As a last resort, you may need to experimentally observe equipment operation under varied conditions (simulated or real) to develop some sequences.

## 5.9 Sequences of Operation

Sequences of operation are the actual commands and actions that an EMS carries out such as performing calculations, opening valves, moving actuators, etc. Accurate and complete control sequences are absolutely critical for system optimization. Often, the optimizing improvement consists of fine-tuning or changing the current sequence to a better one. Also, if complete sequences are not known, particularly regarding interlocks to other equipment, changes that improve one area may have negative impacts in other areas. For example, one might think that resetting the duct static pressure setpoint as low as possible, subject to zone demand without any limitations, is a good strategy. However, an understanding that the terminal box may have erratic control below 20% design flow would suggest a lower bound on the static pressure reset to avoid adverse effects.

Sequences are clearly documented during design and updated at the end of installation. However, sequences, especially basic ones, are sometimes omitted from drawings or binders. Moreover, changes to sequences are sometimes made “on the fly” during installation or during callbacks, with no written record to show design intent or sequence changes.

Even when sequences are included in the documentation, they are frequently incomplete, unclear, or partially incorrect. Often, sequences documentation from the original specs varies considerably from sequences documentation from the controls vendor with no indication as to which version is correct. (Obtaining or developing sequence documentation was covered in the Application Documentation section above.)

This section covers both the control strategies themselves (demand limiting, optimum start/stop, etc.) and some of the primary sequences of operation and key parameters required to implement the strategies. Often the control system software will come equipped with strategy menus or have potential software upgrades for common strategies. Generation of sequences from scratch occurs mainly for specialized or advanced control strategies.

More than any other information, the actual sequences of operation give the most insight into the operation of the building systems. Without them, it is difficult to determine whether particular strategies are effectively designed or properly carried out.

## 5.10 Current Control Strategies

Control strategies are made up of a combination of control sequences. Once the current sequences are understood future strategies can be planned. The following questions should be asked:

- What strategies have been attempted in the past? If strategies were attempted and subsequently abandoned, why?
- What strategies are currently up and running?
- What strategies run smoothly as designed?
- What strategies require significant maintenance and ongoing fine-tuning?
- What is the intent behind current strategies?
- Are current strategies periodically assessed for effectiveness?
- Are current strategies delivering quantifiable energy savings, improved comfort, or improved control?

A clear understanding of the owner’s or tenants’ energy management goals and budgeting policies is important before beginning a system tune-up or optimization. If a primary goal in EMS operation has been comfort management or process control, with little concern for energy use, an new entirely different challenge from the main goal is to maximize energy efficiency. It is best to interview those who have been involved with the EMS to find out how to approach an optimization project.

### 5.11 Calibration of Equipment

Calibration is the process of adjusting sensors and actuators so they read and move correctly relative to their limits and the initiating stimulus. Thermostats, transducers, valve and damper actuators, and other devices all require calibration. Pneumatic actuators are particularly prone to drift. Moreover, it is very common for DDC controls to be installed without sufficient calibration. These devices should be calibrated before optimization of your system is begun.

The actual calibration process may not be in the general user's manual. Ask the vendor to provide the technical application manual, or appropriate pages, for calibrating sensors and actuators.

Generally, sensor calibration can be accomplished by facility staff. However, the vendor may be required to assist in calibrating some or all of the actuators. Start with the systems that are having comfort or operational problems. Calibration is more critical to sensors used for control than to those used for monitoring or diagnostics. For example, an air handler discharge flow station that may be used for monitoring but has no control responsibilities is less critical than the discharge air temperature sensor. Likewise, a discharge duct static pressure sensor used only as a high-limit safety need not be as precisely calibrated as the sensor downstream controlling the fan speed.

The following is a list of sensors and actuators that will most need calibration:

- Outside air temperature
- Mixed air temperature
- Return air temperature
- Discharge or supply air temperature
- Coil face discharge air temperature
- Chilled water supply temperature
- Condenser entering water temperature
- Heating water supply temperature
- Wet bulb temperature or RH sensors
- Space temperature sensors
- Economizer and related dampers
- Cooling and heating coil valves
- Static pressure transmitters
- Air and water flow rates (where economically feasible)
- Mixing valves
- Terminal unit dampers and flows

If necessary, set up a maintenance plan to ensure that the system remains calibrated.

### 5.12 Functional Testing

Ideally, optimization strategies should only be carried out on systems that are fully functional relative to the current written sequences of operation and control. Functional testing is the procedure of verifying that the equipment is operating according to the written control sequences. Functionally testing equipment could, in itself, be considered part of optimizing the system.

Functional testing should follow calibration of sensors and actuators because it frequently relies on EMS readouts for verifying system operation and sensor and actuator values. Functional testing is accomplished by making a change in a setpoint or physical condition, watching the system respond accordingly, and comparing the results to the written sequences. For example, it may be wished to functionally test a supply chilled water reset strategy that resets the supply water setpoint between 42°F and 48°F when the outside air temperature ranges from 90°F to 60°F. Part of the test could be to overwrite the outside air sensor to be 90°F and then observe the supply water temperature setpoint and the water temperature itself change to 42°F on the EMS screen.

The easiest way to functionally test equipment is to start with the sequences of operation. Go through each paragraph one line at a time. Think about how the system can be tested to cause the system to move through the sequence described, perhaps by overwriting a sensor value in the EMS or changing a setpoint. For example, to put a VAV box into full cooling and observe the airflow increase, one can either overwrite the space temperature to be much warmer than the setpoint or lower the setpoint. Changing the schedules may also be required to observe startup and unoccupied operation of equipment.

Be sure to document the test procedures and the results, and don't forget to return the system back to normal after changing any setpoints or schedules.

If the actual sequences do not match the written sequences, make sure to look at the latest version of the sequences. Frequently, the sequences listed in the control drawings have subtle differences from those in the earlier project specifications of the design engineer. Next, review the actual program code, asking for help from controls vendor if necessary.

Another way to functionally test equipment is to use the trending capabilities of the EMS or portable dataloggers.

Many energy management systems have real-time monitoring features that allow observation of the monitored parameters of a valve graphically onscreen.

Often, written sequences do not list all conditions or modes. It may be necessary to develop sequences from what is known or surmise about the operation during certain conditions such as alarms or equipment failures. Full functional testing will observe the equipment operating through a range of conditions from startup, shutdown, low load, high load, alarm conditions, etc.

Functionally testing all control sequences may require more time and resources than are available. Prioritize the efforts and develop a plan to test the systems over time. Start with those systems that are the most troublesome, the most critical, or that use the most energy. Lastly, be sure to update your written sequences with clarifications and corrections identified during testing.

## 5.13 BEYOND BASIC OPTIMIZATION OF ENERGY CONTROL

In this section ways to improve upon an existing control strategies will be discussed. This optimization information may also be helpful when specifying a new EMS or an upgrade to an existing EMS. The strategies discussed here are currently used in many facilities today.

Many of the DDC controllers and advanced EMS available today can be expanded to control every piece of equipment in the building, including all pumps, fans, valves, dampers, compressors, lighting controls, and more. An important consideration in setup is that how much control is wanted, needed, or affordable. Each controlled or monitored point must be installed, configured, and tested. The cost of upgrading or replacing an EMS is directly proportional to the number of points installed.

A common practice when installing or upgrading EMS is to reduce the number of controlled points to meet budget requirements. When capital budget is tight, owners often plan to add points in the future when more capital is available. However, once funds are available, the need for control at various levels should be examined.

For example, a small 1/15 hp domestic hot water circulating pump only needs to run when the building is occupied. A separate control point to allow the pump to be scheduled will save little, if any, energy over just wiring it in series to come on when the main air handler comes on. Scheduling control of the pump would be unnecessary control. On the other hand, tying small chilled-water coil circulating pumps directly to the chiller because they only need to run when the chiller is on (thus eliminating a control point), would result in inadequate control. During a freeze shutdown condition, the coils may be damaged unless the control system can control the pumps to run during the freeze condition.

## 5.14 Energy and Demand Control

Energy costs money. To enhance the investment made in EMS, use it to reduce energy consumption and demand charges in buildingS. This can be accomplished through a wide variety of strategies, some simple, some complex. Energy reduction strategies usually involve changing setpoints and/or using special software routines. Some strategies are standard options on many EMS; others must be custom-programmed.

Reducing energy consumption also reduces pollution. For every unit of energy use avoided, a unit of pollution is not generated. The environmental benefits are most pronounced for electricity generated at coal-burning plants. Up to two-thirds of the energy sent from the electric plant is typically lost in transmission. Therefore, the reduced electricity use onsite can significantly reduce consumption of generating resources. Pollution prevention through energy savings is environmentally responsible planning.

Table 5-1 lists selected control strategies that can save energy or reduce demand. Many of the strategies require only setpoint changes to current programming, others may require some control programming. Each strategy consists of setpoints, parameters and sequences that will ultimately determine how successful the strategy is for saving energy or improving building control. Often, energy saving strategies are nominally incorporated, but because of faulty sequence logic or ineffective parameters, the strategy does not meet its potential. For example, resetting the entering condenser water temperature setpoint from the cooling tower to be equal to the outside air dry bulb temperature is not nearly as effective as setting it equal to the outdoor wet bulb plus five degrees. Question the design engineer, energy consultant, or reference materials about the most effective settings for each strategy used. Following the table are additional details describing each strategy.

TABLE 5-1.
Selected Energy-Conserving Control Strategies

| | | |
|---|---|---|
| **Scheduling**<br>• Holiday scheduling<br>• Zonal scheduling<br>• Override control and tenant billing<br>• Night setup/setback<br>• Optimum start<br>• Optimum stop<br>• Morning warm-up/cool-down<br>**Ventilation Control**<br>• Carbon dioxide<br>• Occupancy sensors<br>• Supply air volume/OSA damper compensation routines<br>• Exhaust fans<br>**Air-Side Economizers**<br>• Typical air-side<br>• Night ventilation purge | **Resets**<br>• Supply air/discharge air temperature<br>• Hot deck and cold deck temperature<br>• Mixed air temperature<br>• Heating water temperature<br>• Entering condenser water temperature<br>• Chilled water supply temperature<br>• VAV fan duct pressure and flow<br>• Chilled water pressure<br>**Lockouts**<br>• Boiler system<br>• Chiller system<br>• Direct expansion compressor cooling<br>• Resistence heat<br>**Energy Monitoring**<br>• Whole building or end-use<br>• kWh or demand | **Miscellaneous**<br>• Simultaneous heating/cooling control<br>• Zone-based HVAC control<br>• Dual duct deck control<br>• Chiller staging<br>• Boiler control<br>• Building space pressure<br>• Variable speed drive control<br>• Heat recovery<br>**Lighting**<br>• Lighting sweep<br>• Occupancy sensors<br>• Daylight dimming<br>• Zonal lighting control<br>**Demand Control**<br>• Demand limiting or load shedding<br>• Sequential startup of equipment<br>• Duty cycling |

## 5.15 Scheduling

5.15.1 Holiday Scheduling: EMS software will typically provide for holiday schedules. These schedules could be as simple as a full-day shutdown at setback levels (such as a typical weekend day) or could be a partial shutdown of the facility for various hours of the day. Holiday schedules can be programmed a year or more in advance, often for 26 or more special holiday schedules. Each holiday can be designated as a single date or a range of dates for extended shutdowns. This feature reduces unnecessary energy use on unoccupied dates.

5.15.2 Zonal Scheduling: Zonal scheduling refers to controlling HVAC system at the zone level with schedules, so that unoccupied areas can be shut down. Ideally, this means that when a space is unoccupied, the dampers of the terminal units go past minimum to shut. The zone terminals do not open (except to maintain a low or high limit) until the zone is occupied (controlled by occupancy sensors or tied to light switches, etc.). This saves energy during generally occupied periods and greatly saves during after-hours overrides.

5.15.3 Override Control and Tenant Billing: When tenants need to work in the building outside of normal schedules, manual override is often used to obtain heating, ventilating, or air-conditioning. This feature allows the operator to take control of any piece of equipment as needed. Override of automatic control may also be needed at times of testing, equipment malfunction, or as part of a problem-solving effort.

An increasingly popular override feature enables the occupant to dial into the system and request heating, cooling, lighting, or other equipment operation. Override could be accomplished for the whole building (gross override) or for part of the building (zone- or block-level override). This feature is desirable when occupant use is widely variable and difficult to program as a schedule into the EMS; furthermore, the property managers can, for an agreed-upon cost per square foot, bill tenants for the off-schedule operational hours they request. The override request can be telephoned in, executed and timed automatically by the EMS, which also computes billing information.

5.15.4 Night Setup/Setback: Most energy management systems have setback and setup capabilities included and programmed as standard features. This commonly used strategy changes setpoints during unoccupied hours. The space temperature setpoints are reduced in the winter and increased in the summer, reducing energy use. This strategy may save more energy than turning systems completely off during unoccupied periods, if morning warm-up or cool-down use inefficient energy sources (e.g., resistance heat). However, except in extreme climates, most setup/setback routines are used more as a safety. In these cases, the energy savings strategy is to turn the equipment off all night, except in the most extreme weather, when the setup/setback will be initiated. For HVAC systems that use heat pumps, this strategy should be used with caution, especially in winter, the cost of the make-up electric resistance heat often outweighs the energy savings from the setback. Auxiliary electric resistance heat should be locked out during the warm-up cycle, regardless of system type.

5.15.5 Optimum Start: EMS can provide customized routines for starting up the building in the morning. Starting the equipment only as early as required to bring the building to setpoint at the occupied time yields energy savings. These routines take into account outside temperature and inside space temperatures when initiating the morning warm-up or cool-down cycles. This strategy is most appropriate for facilities that have unoccupied periods when the zones are allowed to go beyond normal temperature comfort limits.

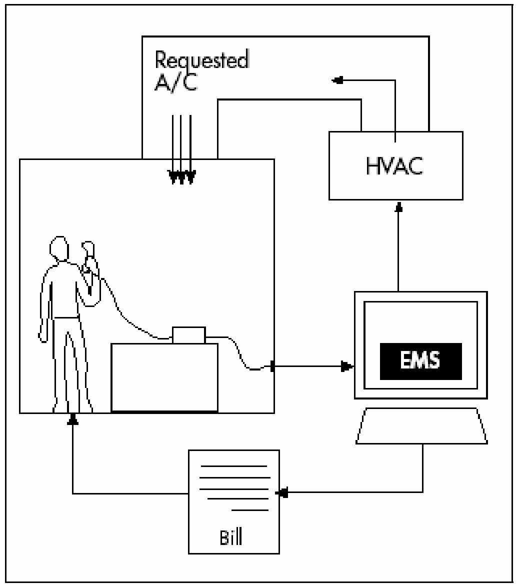
The goal for an optimum start procedure in heating mode is to provide as much heating as possible to warm up the building for the least amount of energy possible, while avoiding demand spikes and setpoint overshoot. Normal equipment heating operation, when used in building startup, will frequently produce longer lead-time and wasted energy. Some best practices can be incorporated by using your EMS:

- Close outside air dampers. Also, turn off exhaust or relief fans.
- Open return air dampers. This will facilitate rapid warm-up.
- Open terminal dampers 100% and drive full heat from the central boiler or heating plant to air handlers.
- For electrically heated buildings, keep careful tabs on electric energy use and demand.
- Watch for excessive cooling directly after warm-up sequences.
- Carefully evaluate shutting down or having large setbacks or setups with heat pump systems.

5.15.6 Optimum Stop: The optimum stop strategy determines the earliest possible time to turn off equipment before unoccupied periods and still maintain occupant comfort. This is known as “coasting.” Some equipment may be turned off in the afternoon while the building is still occupied. However, it is important to carefully evaluate shutting down equipment (fans, etc.) that provides ventilation for occupants.

5.15.7 Morning Warm-Up/Cool-Down: On days of extreme temperature, the greatest daily demand for heating or cooling may occur in the morning as the building is prepared for occupancy. Nighttime conditions due to equipment scheduling and setbacks for unoccupied hours will necessitate a significant and rapid change in temperature. Usually, these cycles are basic time-clock functions with some interlocks. The optimization of the warm-up sequence is covered in the “Optimum Start” topic above.

FIGURE 5-2.
Override Control

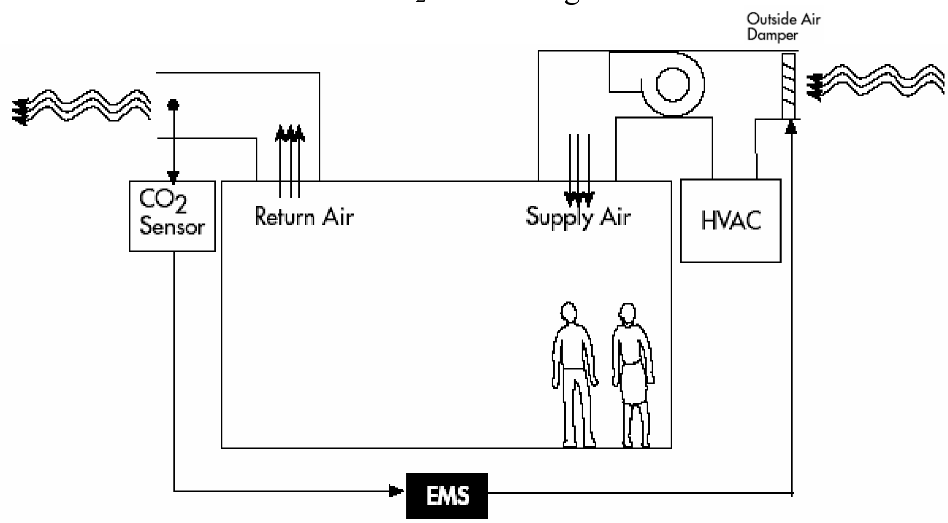



5.16 Ventilation Control

Nonresidential buildings require a minimum amount of outside air for ventilation. Depending on the function of the building, this requirement is approximately 15 to 40 cubic feet per minute (CFM) per occupant. In some buildings, such as hospitals and laboratories, there is a need for 100% outside air supply. Earlier methods, which set the outside air dampers' minimum position as a fixed value, will not maintain a constant supply of fresh air in VAV systems, as the terminal units turn down during heating or periods of low cooling load. Consequently, strategies that allow variable control of minimum outside air damper position are used. Available strategies are provided below, as well as information on controlling exhaust fans.

5.16.1 Carbon Dioxide Monitoring: In this strategy, the $CO_2$ level is generally used as an indicator of the number of occupants, as $CO_2$ is not itself a dangerous contaminant. Calculations are used to relate the $CO_2$ level to the fresh outside air, in CFM per person, being provided to the space. $CO_2$ monitors are typically placed in the return air stream. When the $CO_2$ level rises to a predetermined threshold, outside air dampers open further to
increase the outside air volume.

FIGURE 5-3.
$CO_2$ Monitoring




5.16.2 Supply Air Volume/Outside Air Damper Compensation Routines: According to a schedule set up by the air balancer, this strategy increases the outside air damper minimum setting as the supply fan flow decreases (via inlet vanes or variable speed drive) in order to keep the minimum outside air volume constant.

5.16.3 Flow Sensing Methods: There are a number of outside air flow sensing methods that can dynamically measure and regulate the minimum outside air flow using the EMS. One method is to use a pitot tube flow station, if adequate lengths of straight duct is provided (unfortunately rare) and outdoor air velocity doesn't go below 800 feet per minute. Another method is to maintain a minimum pressure differential across a flow plate in the outside air intake.

5.16.4 Occupancy Sensors: This strategy detects occupants in a space. When the space is unoccupied, the lights are turned off and the VAV box minimum airflow is set to zero. This is especially effective in intermittently occupied spaces such as conference rooms, cafeterias, break rooms, etc. Savings come from cooling, heating and ventilation reduction. Ideally, the strategy should be disabled during periods of outside air economizing.

5.16.5 Injection Fans: An EMS can provide control of a dedicated outside air fan that delivers a constant volume of outside air into the mixed air stream.

5.16.6 Exhaust Fans: Dedicated system exhausts (rest room, mechanical room, garages, meeting rooms, etc.) can be programmed to start and stop as required. In parking garages, carbon monoxide sensors can be used to cycle exhaust fans when the levels approach predetermined limits.

5.17 Air-Side Economizing

Economizing, in this context, means the use of cooler outside air to cool a building.

5.17.1 Typical Air-Side: Air-side economizing, also known as free cooling, is the practice of bringing outside air directly into the building to augment or supplant mechanical cooling. In this strategy, the EMS compares the outside air conditions with either the inside conditions or a preset condition or setpoint. When outside air will benefit cooling, the outside air dampers open to maximum or to meet a mixed or supply air temperature minimum setpoint. The simplest method is dry-bulb economizing and examines dry-bulb temperatures only. In concept, a more efficient method is to compare enthalpy (total heat content of the air, including moisture). However, the enthalpy sensors may require more maintenance and calibration.

5.17.2 NightVentilation Purge: For climates with a large nighttime temperature drops (dry climates), purging or flushing the building with cool outside air in the early morning hours, with supply fans in economizer mode, can reduce the cooling load in the building later in the morning and save energy. When implementing this strategy, investigate whether the cooling energy savings outweigh the increased fan energy and fan heat penalty (for dry climates this usually means not purging until the outside air temperature is at least 6°F below inside air).

5.18 Resets

Reset routines are among the most common and most effective energy-saving practices for EMS. The logic and calculation power of DDC allows for more than just the simple proportional reset strategies of the past to be incorporated. Polling numerous point values and using them to make calculations for optimized reset routines can easily be accomplished with DDC.

The intent of a reset strategy is to identify changes in demand (cooling, heating, pressure, flow rate) and reset delivery of air or water to meet that demand. This is accomplished by monitoring the control point in question (e.g., discharge air temperature) and several other parameters that impact that point (e.g., return air temperature, outside air temperature). When these parameters indicate that load is decreasing or increasing, the control point can be reset to better fit the current demand.

5.18.1 Supply Air/Discharge Air Temperature: For fan systems that use terminal reheat, resetting the supply air temperature setpoint up as the cooling load decreases reduces required reheat. Higher discharge air temperatures can also increase efficiency of direct expansion compressors. Supply or discharge air can be reset based on indirect load indicators, such as outside air, but the preferred method is to base reset on direct indicators of load, such as return air/supply air temperature difference or cooling coil valve position. There are many ways to set up the routine. One method is to raise the discharge temperature setpoint incrementally until one zone is 1°F above its deadband. Note the interaction issues in the Reset Interactions section below.

5.18.2 Hot Deck and Cold Deck Temperature: Many HVAC systems utilize a dual duct or multi-zone arrangement with parallel hot and cold decks. These systems meet cooling loads by providing simultaneous heating and cooling. Warm air from the hot deck and cool air from the cold deck must be mixed to deliver the proper temperature of supply air. Without reset or optimization, these systems are very inefficient, particularly when the deck temperatures are fixed. To minimize energy waste, reset the temperatures, decreasing the differential between the decks. With this strategy, the EMS selects the zones with the greatest demand for heating and cooling. The deck temperatures are then set to provide the warmest cold deck and coolest hot deck possible while still satisfying the extreme zones.

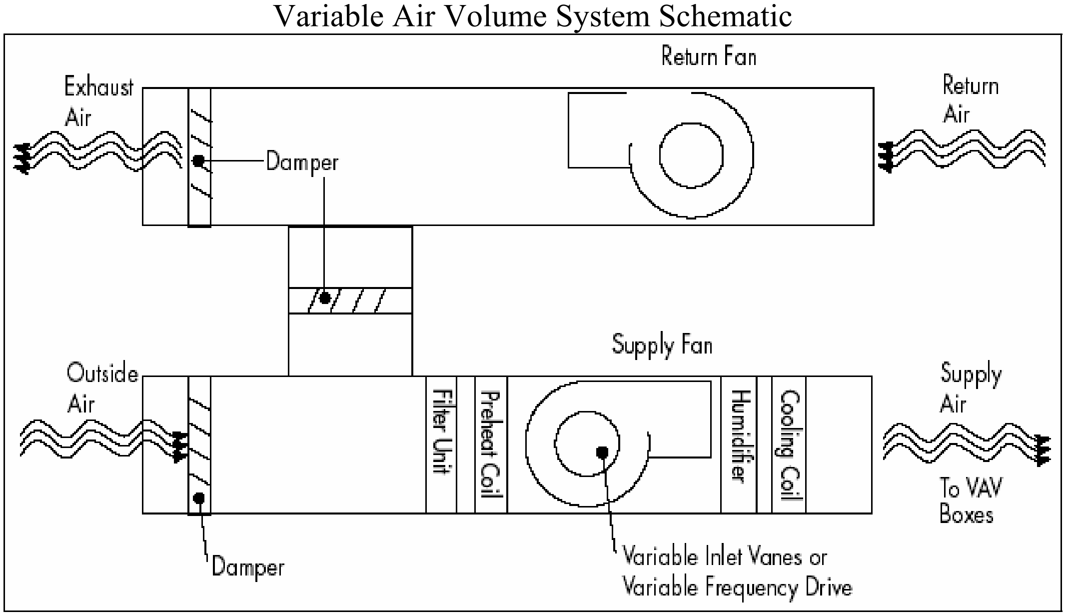
5.18.3 Mixed Air Temperature: Systems with a mixed air temperature setpoint can control the setpoint with a DDC system. By raising the mixed air temperature above the typical 55°F maximum when cooling loads in the building are low, the periods of free cooling (economizing) are maximized.

5.18.4 Heating Water Temperature: For hot water heating systems, the hot water supply temperature can be reduced as the heating requirements for the building are reduced. The most common form of hot water reset is to recalculate the hot water supply temperature setpoint as a function of outside air, an indirect load indicator. A preferable method is to reset the hot water using the supply and return water differential temperature (dT) to determine the actual building load. This is accomplished most effectively with 3-way valves. As the dT drops, the hot water supply temperature is reduced until the dT increases to a predetermined differential, or until a minimum hot water supply temperature (based on outside air temperature) is reached. Another load-based method is to reset the heating water temperature setpoint down incrementally until one heating valve is 100% open. Note the interaction issues in the Reset Interactions section below.

5.18.5 VAV Fan Duct Pressure and Flow: Resetting VAV airflow or static pressure down during periods of low cooling load reduces unnecessary fan energy. Traditional VAV fan control strategies use a fixed duct static pressure setpoint control that is independent of actual airflow requirements at the terminal units. With DDC data coming back from the terminal units in the form of damper position or airflow, the supply fan can be incrementally slowed down using a variable speed drive (or closed inlet vanes) to maintain one terminal box at 100% of design flow. This makes the fan run as slowly as possible while still keeping all boxes satisfied. Implementation methods vary: some reset the duct static pressure setpoint downward to meet the criteria; others bypass this intermediate calculation and go directly to the fan speed or inlet vane controller and simply reduce flow, without any duct static pressure setpoint.

In addition to load-related reset, other opportunities are available when addressing outside air requirements. In most VAV systems, each VAV box is assigned a minimum airflow setpoint, designed to ensure adequate outside airflow for maintenance of indoor air quality and usually kept constant over time. However, the box may deliver excess fresh air at the minimum airflow setpoint, depending on the outside air fraction in the supply air. Energy saving optimization would recalculate the box minimum airflow setpoint periodically throughout operation. This reset strategy and the calculation of percent outside air may involve direct measurement of outside airflow. Note the interaction issues in the Reset Interactions section below.

FIGURE 5-4.
Variable Air Volume System Schematic



5.18.6 Entering Condenser Water Temperature: Resetting the chiller entering condenser water to a lower value will save energy by increasing chiller efficiency. When outside air wet bulb temperatures are high enough that lower condenser water temperatures cannot be achieved, increasing cooling tower fan stages would be of no benefit. Therefore, make the attainable condenser water temperature the setpoint for controlling fans. This is typically equal to the outside air web bulb plus 5 to 10 degrees (the cooling tower approach temperature). This is subject to a minimum of usually 60 to 70 degrees entering condenser water temperature or a minimum pressure or temperature differential in the chiller, depending on chiller limitations.

5.18.7 Chilled Water Supply Temperature: For chilled water systems, the chilled water loop temperature can be raised as the cooling requirements for the building are reduced, increasing chiller efficiency. As with hot water reset, the typical variable for reset calculation is outside air. However, direct load-related parameters, such as supply and return water temperature difference or chilled water valve position, are preferable. A typical method of load reset is to raise the chilled water temperature setpoint until one chilled water valve is 100% open, subject to any special space humidity requirements that would require the chilled water temperature to remain at its minimum.

Chilled water reset is most effective when the chiller horsepower is more than three or four times the horsepower of the chilled water pumps. Under these conditions, the decrease in power drawn by the chiller will more than compensate for any additional chilled water pumping requirements due to higher chilled water temperatures. Note the interaction issues in the Reset Interactions section below.

5.18.7 Chilled Water Secondary Loop Pressure: Instead of controlling the secondary chilled water loop to a fixed differential pressure setpoint under all conditions, this strategy resets the pressure down as the load decreases (the chilled water valves close) to always have one cooling coil valve 100% open. This keeps the pumps operating at the very lowest pressure and speed possible. Note the interaction issues in the Reset Interactions section below.

5.18.8 Heating Water Secondary Loop Pressure: This strategy is the analogous to the one for chilled water systems.

5.18.9 Reset Interactions: There can be significant interactions among some of the reset strategies. For example, for a given load condition, when the chilled water supply temperature is reset up, the chiller efficiency is improved. But where warmer water is sent to the cooling coils, the cooling coil valves open further and call for more water, thus increasing the pumping speed and energy. In this case, saving chiller energy is done at the expense of increasing pump energy. A hand calculation has been made which shows that normally the pump energy per ton of cooling is greater than the chiller energy. Therefore, the ideal strategy would be to continue to reset the pump speed down as load decreases until the pumps reach their minimum safe flow (10-30%), then hold them constant and start to raise the chilled water setpoint, if the load is still decreasing.

A similar problem exists with VAV duct static pressure reset and supply air reset. When employing both strategies, reduce duct static pressure to its minimum, and then begin resetting the supply air temperature up, if there is little terminal reheat. If there is significant reheat, reset supply air temperature up first. These methods can easily be programmed using DDC.

5.19 Lockouts

Lockouts are used to ensure that equipment does not come on at a point when it is rarely, if ever, needed. This protects against nuances in the control system programming that may cause the equipment to turn on unnecessarily. When locking out a major piece of equipment, remember to also lock out any other associated equipment that doesn't need to be on.

5.19.1 Boiler System: The boiler and associated pumps can be locked out above a set outside air temperature, by calendar date, or when building heating requirements are below a minimum (see Heating Water Temperature above).

5.19.2 Chiller System: The chiller and associated pumps can be locked out below a set outside air temperature, by calendar date, or when building cooling requirements are below a minimum.

5.19.3 DX Compressor Cooling: Lock out direct expansion (DX) cooling when outside air conditions will allow economizer operation to meet the cooling loads. This should be subject to any relative humidity control that may require dehumidification with the DX even during economy cycles.

5.19.4 Resistance Heat: Resistance heating is a major source of energy waste in systems. Lock out all resistance heating above a set outside air temperature and in any warm-up modes, regardless of temperature, when possible. If locking out reheat above a set temperature causes overcooling of a space, consider raising the supply air temperature, reducing airflow, or rearranging diffusers.

5.20 Miscellaneous Strategies

5.20.1 Simultaneous Heating/Cooling Control: An EMS can be used to control and minimize simultaneous heating and cooling for a number of equipment types, including dual duct mixing, VAV boxes, and terminal reheat systems (as discussed in the Resistance Heat section above). This is accomplished by maintaining wide space temperature deadbands between heating and cooling, raising cold deck setpoints and lowering hot deck setpoints, and locking out heating and cooling when appropriate.

5.20.2 Chiller Staging: Most optimization strategies for central cooling plant equipment have two elements, staging equipment for maximum efficiency, and resetting output parameters for maximum energy savings. For facilities that use multiple chillers, the ideal strategy will determine the total cooling load on the chiller system, compare the part load efficiencies and capacities of all available chillers, and determine the most efficient mix of chillers to have online. This strategy is complicated by the need to keep run-times over the year close to equal and the danger of cycling the chillers so much that efficiency and equipment life are compromised. Some EMS have standard chiller optimization programs that require minimal programming.

5.20.3 Boiler Control: For facilities that use multiple boilers, some logic must be applied to determine sequencing. If the boilers are small, of roughly equal size and efficiency, and have little energy overhead associated with starting and stopping operation, the logic is simple: Add and subtract boilers as necessary to meet the load. To maximize efficiency in more complex plants, schedule the boilers to give preference to the most efficient boiler and minimize partial loading. In addition, it is sometimes desirable to control the boiler firing mode to increase efficiency.

5.20.4 Building Space Pressure: For VAV air handlers, it is advantageous to monitor and control space pressure. Lab environments often use this sequence to control flow of contaminants, fumes, or lab air.

The space pressurization level is maintained by monitoring the pressure and adjusting supply and return flows (via dampers, inlet vanes or variable speed drives) in order to achieve the desired pressure.

Space pressurization can have effects on both energy use and indoor air quality (IAQ). Unless there are special requirements, the recommendation is to maintain a slightly positive pressure inside the building relative to the outside. This ensures that no unfiltered or untreated air infiltrates the building and that exterior doors are not hard to open due to a negative pressure. This is especially critical for moisture control in humid climates.

5.20.5 Air-Side Heat Recovery: For systems with a large fraction of outside air or systems with large auxiliary exhaust fans, heat can be extracted from the exhaust air stream via a coil heat exchanger and a water or glycol loop and transferred to the incoming cold outside air via heating coils. Heat wheel heat exchangers in the exhaust air stream are also used.

## 5.21 Lighting

As the market for lighting products has moved toward energy-efficiency, more and more building owners are implementing lighting retrofits and upgrades, often using EMS controls.

5.21.1 Lighting Sweep: The main energy saving strategy with lighting ON/OFF control is the same as that for other equipment: provide lighting only when and where it is needed. The simplest way to ensure that lights are turned off at night and remain off is to have the EMS periodically “sweep” them off. For example, the EMS 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.

5.21.2 Occupancy Sensors: For advanced control, lighting systems are tied to occupancy sensors and to the EMS to provide information on occupancy status. Both lighting and HVAC are set back or turned off when the space is unoccupied.

5.21.3 Daylight Dimming: In perimeter zones of the building with sufficient windows, the lighting can be dimmed to maintain a minimum light level in the space. This is best accomplished through continuously dimmable electronic ballasts (rather than lowering light output in discreet steps).

5.21.4 Zonal Lighting Control: Reducing the size of lighting zones can save energy by allowing only the occupied zones to be lit, rather than an entire floor. Savings can be significant in cases where there are smaller groups of tenants who start or end work at different times or frequently come in after normal occupied hours.

## 5.22 Demand Control

The goal of demand strategies is to reduce whole-building demand (the parameter upon which demand charge is based), not to reduce individual equipment demand. For example, it is acceptable for one piece of equipment to peak heavily in the middle of the night when other equipment is off and whole-building demand is low. Similarly, at times of peak demand, reducing any demand will contribute to lower demand charges.

It is wise to review the operation of the EMS demand limiter, especially as building loads and operations change. Also, review conditions when demand limiting is invoked. If it is during building startup, an improved startup sequence may be a better option. Exercise caution when implementing demand strategies. Most of the time, the reason the electric demand is high is that maximum cooling is needed; it may be that you cannot reduce demand without sacrificing comfort.

5.22.1 Demand Limiting or Load Shedding: This strategy can be based on a single electric meter, multiple meters, or on equipment current (e.g., chiller). Implementation of demand limiting or shedding varies. Typical methods are: When the demand (based on kW or current amps) on a building meter or piece of equipment approaches a predetermined setpoint (which may be different for each month), the system will not allow the piece of equipment to load up any further (e.g., chiller), or it may globally increase the space temperature setpoint, or some other setpoint, to stop the increase in equipment loading and thus the demand. Some methods increase the space temperature setpoint in one or more zones and if that is not sufficient, add other zones.

Another method is to select equipment to shut off, rather than just limit its loading. Parameters to be set for load shedding control points include: rated kW, minimum shed time, maximum shed time, minimum time between shed, shed type, and shed priority.

There are sophisticated EMS controllers that automatically integrate a demand-limiting and load-shedding strategy with utility real-time pricing rate structures. The control parameter, rather than the static kW demand limit, is the optimization of the real-time energy cost based on the hourly energy price.

5.22.2 Sequential Startup of Equipment: To eliminate demand spikes, program time delays between startup of major electrical load-generating equipment so that the startup peak loads stay below the peak demand later in the day.

5.23 Energy Monitoring

Energy consumption is an important parameter to track. It is the bottom line for most control strategies and has ramifications to maintenance needs as well. Whole-building annual kWh per square foot is a useful metric for comparison with other similar buildings. However, energy consumption is rarely monitored by EMS, other than possibly chiller kW, or total building or system kW for buildings with significant demand limiting. For monitored systems, the following may be tracked:

- kWh consumption and demand
- Time the peak occurred
- Selected demand limit
- Natural gas consumption
- Steam consumption and flow
- Time that any load was shed

For energy performance projects, kWh may be monitored for other equipment as well, including minimum, maximum, and average outside air temperatures (OSAT) and outside environmental information. In addition, it is useful to plot energy consumption versus different driving factors, such as OSAT, occupancy, or production.

Direct monitoring of energy consumption is difficult because of the initial setup required; the use of proxies may be more feasible and answer the same energy use questions. For example, monitor run-time for pumps rather than energy consumption, or variable frequency drive control signal rather than energy consumption.

Energy monitoring even a few major end-uses can greatly improve traditional monthly energy accounting. The uncertainty involved in using energy accounting software packages will be reduced if additional end-use data are available. The EMS can add critical information on major end-uses to the picture and allow for usable and reliable energy accounting recommendations.

5.23.1 Performance Contracts: EMS energy and performance monitoring capabilities can be utilized in energy performance contracts. The EMS can determine and document baseline conditions (hours of operation and occupancy, equipment efficiencies, etc.) and verify post-installation performance by aiding in commissioning and operations tracking. The EMS can also be instrumented to calculate and track weather conditions (degree days, etc.) and correlate that with whole building or end-use (equipment) energy consumption tracked in the EMS.

## 6. USING EMS FOR OPERATIONAL DIAGNOSTICS

Diagnostics are EMS features that assess how equipment and systems are working and identify problems or opportunities for improvement. Diagnostics can help you investigate control loops and verify their operation, learn more about your building, and ensure that efficient equipment operation continues as expected. This section will describe two primary methods of using EMS for diagnostics: Trending and Manual Testing.

### 6.1 Applications.

Before you can confidently use your EMS system for diagnostics, all sensors and actuators must be calibrated so that you can depend on the values and conditions reported by the trends.

### 6.2 Trending

This section contains an in-depth description of trending features and their use. The current system may already have a number of trending features; but software or even a hardware upgrade may be required to obtain all the features you need. Because details and instructions on trending capabilities and methods are not always found in O&M manuals, it may be necessary to contact the current vendor to determine the system’s features and how to use them. Read the manual, call the vendor for help, set up a few trends, and then analyze the data in a couple of different ways to become familiar with this feature.

Trend logging capabilities vary considerably among EMS systems. The extent of these capabilities in your system will, to a great degree, determine whether trending can reasonably be used for diagnostics.

### 6.3 Planning and Setting Up Trends

The first step in setting up a trend is to develop a trending plan: the points to be trended; the value type to be trended; the sampling rate; the trend group each point will be analyzed with; and the visual method of analysis to be used. To decide which parameters to trend, study the control drawings and the written sequence of operations. There are hundreds of trends that could be appropriate for your facility. Table 6-1 provides a small set of possible trends.

6.3.1 Trend Types: There are two trend types, value stream and change of value (COV). A value stream trend takes a reading of the point value (temperature, pressure, etc.) at each sampling interval. A COV trend records only at a pre-specified change in value or status. COV trends use less cabinet memory and are easier to follow on columnar printouts. However, the COV preset change amount must be carefully defined or resolution may be lost.

For ON/OFF status of equipment, consider using a COV trend. To graph ON/OFF values for illustration purposes, use a data stream trend. Also, generally use data stream trends for parameters that have changing values, like temperatures, pressures, voltages, controllers, etc. When trending a number of parameters by COV (10 or more), do not mix the COV parameters with the data stream parameters in setting up the trend or merge them at downloading. That would result in large data-stream gaps and difficult graphing and analysis. Generate the two types of parameters as different files and combine them later in the spreadsheet graph, if desired.

Trending the status of points and analyzing status requires some thought. An ON status simply indicates that the software has calculated that the device should be ON, without giving the reason why, e.g., overriding, a stuck relay, short cycle protection, etc. Depending on the goal of the trending, these other factors may need to be taken into account. Likewise trending a valve position command does not guarantee that the valve is actually at the commanded position. Calibration before trending may be required.

Some systems automatically generate reports called Scheduled and Process Start and Stop. The information for these reports is always being generated in the background. All it takes is a call for the report by system (e.g., AHU3), to obtain the date, time, event (command ON or OFF), status of the unit (normal, override) and the reason for the change in status (schedule, a process, manual command, etc.). Other such useful reports may be available in your EMS.

Many EMS will continually trend a point for the last 24 hours, if this option is simply selected in a "point history" menu. At any time, the point history can be called up and viewed graphically onscreen. This tool can be very valuable.

TABLE 6-1.
Sample Trends

| Issue or Equipment | Points To Trend | Sampling Interval | Analysis Summary |
|---|---|---|---|
| Identify unnecessary equipment operation (chillers, air handlers, pumps, exhaust fans, lights, etc.) | Change of value (COV), another indicator or an ON condition. Time-series also works well. | COV or time-series 15 min. | Make sure HVAC is not unnecessarily ON outside of occupancy periods. Verify that lighting ON times match HVAC. |
| Chiller start | Turn ON parameter (cooling coil valve position, outside air temperature (OSAT), etc.) | 15 min. | Make sure chiller is not ON unless the parameter requirement is met. |
| Chiller loading | Chiller current, OSAT | 15 min. | Make sure the chiller current draw goes up with OSAT. |
| Chilled water reset | Chilled water supply temperature, reset parameter (OSAT, valve position, etc.) | 15 min. | Graph chilled water supply temperature (CHWST) against OSAT or valve position and compare to reset schedule, or analyze columnar data. |
| Chiller efficiency | Primary chilled water and condenser flow (or values in TAB or start-up report), entering and leaving chilled water and chiller kW (or current, if no kW). For reference, also trend entering and leaving condenser water temperatures. | 15 min. for 2 weeks | Calculate the kW/ton of cooling for all points and add this column to the data. Plot the kW/ton (Y-axis) against the chiller % load. Save this graph as a benchmark. During similar weather the next season, repeat the trend and graph and see if the kW/ton generally remains the same or is degrading (possibly indicating fouling). Compare, by interpolation, to manufacturer's kW/ton data. Tons = 0.0417 x gpm x (CHWRT – CHWST). kW = Volts x Amps x 1.732 x power factor/1000. Get PF from start-up report |
| Cooling tower operation (fans, mixing valve and entering condenser reset) | Fan stage, valve position, tower sump, entering and leaving condenser water temperature, reset parameter (OSA WB, DB), fan stage parameter. | 5 min. | Compare the fan staging with the schedule, compare the entering condenser temperature with its schedule, and compare valve operation to expected (closed when entering condenser water is greater than setpoint). |
| Simultaneous heating and cooling | Heating element enable or valve position, supply temperature, cooling coil valve position | 2 min. | Make sure that when the cooling coil valve is open, the heating coil is closed. |
| Supply air reset | Supply air temperature, reset parameter (OSAT, zone demand) | 2 min. | Graph SAT against OSAT or zone demand and compare to reset schedule, or analyze columnar data similarly. |
| VAV duct static pressure control | Duct static pressure (and reset parameters if it is reset) | 2 min. | Observe, for fixed static pressure systems, that the pressure remains the same during the monitoring period and for reset, that the static pressure follows the reset schedule. |
| Short cycling | COV for ON/OFF issues | 2 min. | View columnar data for analysis. |
| Hunting | Actuator position or command or COV | 2 min. or COV | Plot against time and observe hunting. |
| Terminal unit | Zone temperature, heating coil valve position, air cfm or damper position, cfm setpoint (for applicable controllers). OSAT and the duct static pressure may also need to be trended. | 2 min. | Plot with two Y-axes for resolution (valve position on right axis). Observe that the zone temperature remains within 1°F of the deadband range, that the cfm is not over- or undershooting its setpoint or hunting, that the heating valve is not hunting and that the cfm is at minimum before the heating valve opens, etc. |
| Compressor staging | Compressor stage, OSAT, RAT, SAT | 2 min. | Observe that the stages are not short cycling, that the minimum ON/OFF times are not violated, and that the staging is reasonable relative to the causal conditions. |

6.3.2 Sampling Rates: The proper sampling rate depends on the purpose of the trend, the type of equipment being monitored, and the memory limitations of the EMS system. The number of points an EMS can sample instantaneously may be limited, so that trending a large number of points simultaneously (e.g., 100) can lead to discontinuous data and problematic analysis.

If the purpose of the trend is to investigate possible hunting of actuators or short cycling of equipment, the sampling rate should be ideally about 2 minutes. Some hunting can be detected using wider intervals up to 30 minutes, but the intensity of the hunting or cycling may be masked. Figure 6-1 illustrates this by comparing discharge air temperature and setpoint from a rooftop air conditioner during the same time frame sampled at three different rates (2, 16 and 32 minutes). Between every two peaks of each over-shoot cycle on the 32-minute sample, there are really two more cycles, as shown in the two-minute sample. The 32-minute sample would indicate a hunting rate of one-half cycle every 30 minutes, while the actual half cycle is once every 9 minutes (as shown in the 2-minute graph).

Hunting and short cycling can also be detected by using a COV trend of the equipment status, setpoint or parameter value. In such cases, it is important to set the incremental change at which the EMS will log a new value to be small enough not to lose resolution and mask some of the cycling.

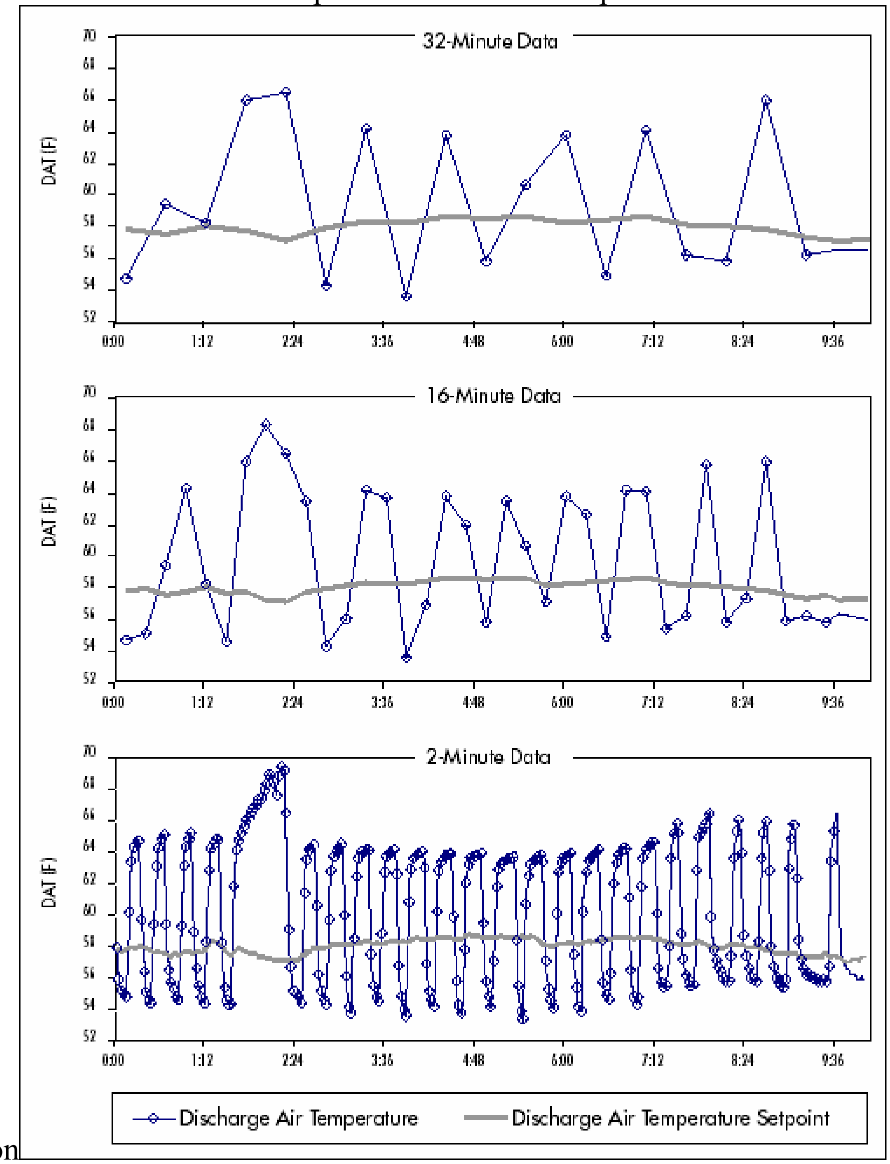
For trending parameters with a slow rate of significant change, such as space or outside air temperatures, a 15- to 30-minute sampling rate is generally adequate. Often, however, they must be sampled at a faster rate to be consistent with other points requiring a smaller time step. For best results with ongoing trends, trend data at fairly slow sampling rates, then temporarily increase the frequency when problems or mysterious behavior are detected.

6.3.3 Grouping Parameters: For trending projects of more than 6 to 8 points, assign each point to a group consisting of points that you want to analyze together. All points within a group should ideally have the same sampling rate. Be sure to enter appropriate point descriptors for each trended point during setup so they will be identifiable during analysis. It is often helpful to group together parameters that have the same units or expected range of values to facilitate graphing on the same axes.
Group together into one trend all parameters that you want to view together onscreen (unless your EMS can pull points from different trends for simultaneous viewing).

6.3.4 Large Trends: The "largeness" of a trend (how many points will be monitored, sampling frequency, and duration of the trend) is relative to the EMS. For a new system in a 200,000 square foot building, trending over 75 points at 6-minute intervals for one week may be considered large. Old systems may not be able to handle even a quarter of that amount. Most trend projects are not large, but for those times when a large-scale trending project is needed, the following provides some pointers.

Many EMS trends are generated and data initially stored in the control cabinet from which their points are controlled. The number of points that can be trended overall is limited by total available storage memory of all control cabinets together. For large data sets, when cabinet memory is at its limit, you may have to assign points in one trend a larger time step (interval) than points in another trend from the same cabinet to reduce the total number of stored values. For large trends, use COV data, which require less memory, whenever possible. Another solution is to add memory to the control cabinet.

FIGURE 6-1.
Effect of Sample Rate on Trend Graph




Resolution

Large trend projects may also strain the computer resources of the EMS, resulting in skipped polling, missing data points and skipped downloads. This is especially true for EMS that initiate and execute trends from the central computer CPU rather than from the distributed control cabinet CPUs. One solution is to divide the large trend projects into two phases, e.g., run a few trend groups one week and then a few other groups the following week.

6.3.5 Downloading: It is critical to fully understand how your EMS stores and handles trend data. You must know whether the data will automatically download to the hard drive when cabinet memory storage is full; whether you must specify when it should download; or whether it requires manual downloading. If your system does not download automatically, find out your vendor's rule of thumb for calculating the storage needed for large trends. To set the frequency of preassigned or manual downloads, find out how much storage is available in each cabinet and how to determine when cabinet memory is at its limit. Learn how to set up a first-in/firstout trend, where a set number of samples is stored in the cabinet before the old data is dumped or erased.

6.3.6 Starting Times: Some EMS can schedule start-and-stop times of trends, while others begin trending as soon as the trend is defined. For data to be viewed in columnar format or using the EMS software graphics, it is not critical that trends start at precisely the same time. For data to be graphed in commercial spreadsheets, identical start times and time steps are more important. (However, with a little effort, different start times and time steps can be accommodated in newer spreadsheets.)

6.3.7 Averaging: Snapshots of a point value (e.g., hourly snapshots of kW) are not always useful. Some sort of averaging over a time interval, or possibly a record of minimum or maximum values, is needed.

6.3.8 Totalization and Counting: Many EMS can total the number of hours a piece of equipment has been operating. This is valuable for preventive maintenance planning. An EMS can also total the number of times the equipment has turned ON and OFF during a given period. Dividing the number of times the equipment turned on by the number of hours the equipment was running (by schedule or by the totalization function), yields the cycling rate per hour. Short cycling and other malfunctions can be easily detected this way.

6.3.9 Auto-Diagnostics: Not strictly a trending function, but similar, are the auto-diagnostic functions of some equipment controllers. These can be valuable for predicting problems and for determining causes of malfunctions. For example, a particular VAV controller automatically calculates the ratio of damper actuator run-time to total controller run-time. Ratios over 5% indicate possible problems. The controller also calculates the moving average flow error of the terminal unit. If this is greater than 10% of the maximum box CFM rating, there may be a flow sensor or control loop malfunction. The moving average space temperature deviation is also tracked, which will immediately indicate a problem. This is all done continuously and automatically, without any setup of trends. These diagnostic features are being expanded to other types of equipment. Ask your vendor about them.

6.4 Types of Data Display

There are five ways that data can be viewed by the operator (depending on the system):

- Columnar display on the EMS computer screen
- Columnar hard copy printout
- Real-time graphical display on the EMS computer screen
- Graphical display in spreadsheets (historical data)
- Real-time graphical display in spreadsheets

6.4.1 Columnar Display on EMS Computer Screen: This view consists of columns of data, with time in the left column and columns of different trended points in adjacent columns. This is useful where analysis will be quick and further use of the data unlikely. This is a good way to view standing history logs when troubleshooting new problems without having to set up and analyze a special trend log or graph. This format provides accurate values, but is not nearly as easy as graphs for following trends and detecting subtle changes and correlations among parameters.

6.4.2 Columnar Hard Copy Printout: This is a printout of the columnar data viewed onscreen. It has the advantage of permanence and can be referred to again as needed.

6.4.3 Real-Time Graphical Display on the EMS Computer Screen: Some EMS can show current trend data (including multiple points) onscreen as a graph. The screen scrolls off, but can still be seen using the MS Windows screen control arrows. The scales or ranges for each point can be assigned, but this screen viewing method is often crude, lacks visible Y-axis scales, and has low resolution. Still, this method may be useful for analyzing current issues where the problems can be identified without high resolution. It is a good idea to save or print the graph of any interesting data, as it may be difficult to reproduce the situation that caused the interesting graph.

6.4.4 Graphical Display in Spreadsheets (historical data): The most versatile way to view and analyze trend data is to import the data into a commercial spreadsheet program and use its graphing capabilities. This is time-consuming, and other methods of viewing the data should generally be used first. However, spreadsheets may be the best option for troubleshooting a complex problem or fine-tuning control loops; they provide good resolution and printed graphs for analysis or for presentations to others. The spreadsheet graphing process may be cumbersome at first, but the process can become quite easy with practice. New commercial software for viewing monitored data is also becoming available and will further simplify the graphing process.

6.4.5 Real-Time Graphical Display in Spreadsheets: Some EMS can set up trend logs and transfer the data live to a spreadsheet program using dynamic data exchange (DDE) software. This allows the user to view, real-time, any trend data desired. It has the advantages of real-time EMS computer screen display plus the versatility of a spreadsheet. Once the trend and DDE are set up, the user can at any time during or after the trend open the spreadsheet and view the historical and current state of the trended variables both graphically and in columnar form. Spreadsheets provide clear graphs with full resolution and have scaling and labeling features allowing for accurate analysis. For sophisticated users, dynamic optimization routines can be set up using the computational power of the spreadsheet on the trended data to actually send new setpoints back to the EMS.

## 6.4 Analyzing Data

Analysis of data begins with deciding how to display the data. For initial analysis, view the real-time onscreen graph. If more resolution is needed or if you are fine-tuning a control loop, use spreadsheet graphs. If the output is limited to columnar viewing, the method of analysis is limited to printing out the data and paging through it to diagnose the system.

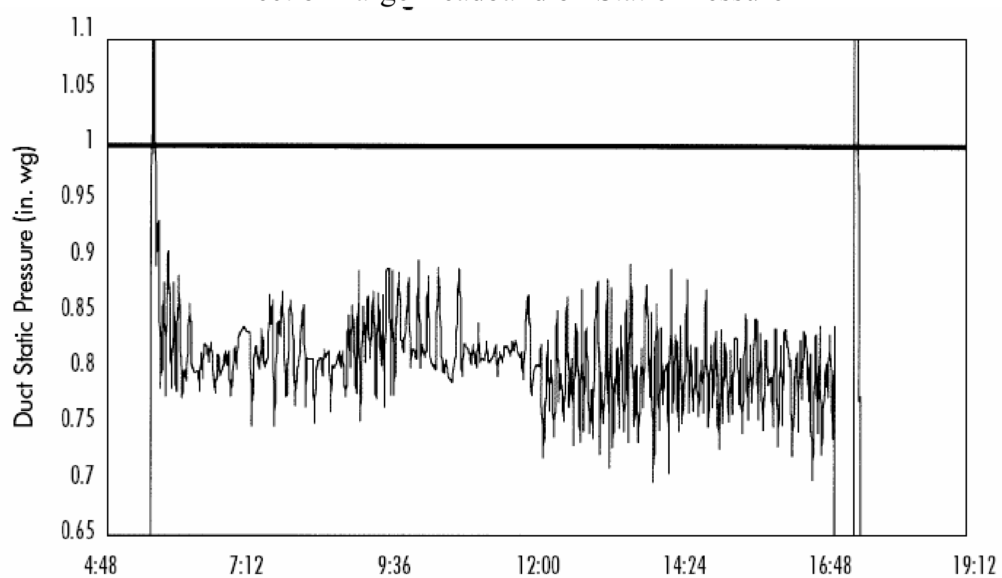
It may be difficult to predict at the outset what will be needed; this will become clearer as you go along. Consider constructing scatter plots (plotting one variable against another). Add points to trends as you uncover more clues to operation.

Also, think about the stream of values for each point: what should be happening to the point values at different times of the day, in comparison to the outside air temperature (for example) or to other points being trended?

Review the sequence of operations for the system being analyzed and recreate what is happening in the trends compared to what the written sequences say. For instance, when examining a heating water reset sequence, observe both variables in the strategy, e.g., outside air temperature (OSAT) and heating water supply temperature (HWST). You can also trend the setpoint itself. You should observe that when the OSAT rises, the HWST drops. For more accuracy, calculate from the actual reset schedule what the HWST should be for different OSATs and check the HWST in the trend. Better yet, graph HWST against OSAT with OSAT, rather than time, as the X-axis. For sample graphs, see Figures B-2 and B-3 in Appendix B. As the second graph shows, the reset strategy is not functioning properly (it is always 10°F to 15°F above the setpoint); this could not be easily detected from the first time-series graph.

Most control loops have bias or deadbands as well as time delays to prevent cycling or to save energy. Misunderstanding these parameters can lead to erroneous conclusions. Figure 6-2 represents actual data from a packaged rooftop air conditioner with duct static pressure controlled by its packaged controller and pressure transducer. The EMS monitored the duct pressure via the same air line using its own pressure transducer. At first look, it was thought that the reason duct static pressure setpoint was never met was that the packaged unit's transducer and the EMS transducer were simply not giving the same value (not calibrated together). On closer inspection, it was found that the packaged unit controller had a +/-0.25 in. water gage deadband. The problem was not calibration, but too wide a deadband.

FIGURE 6-2.
Effect of Large Deadband on Static Pressure




6.4.1 Documenting the Analysis: Write up your observations and conclusions. This will aid in future review of the problem and avoid unnecessary repetition of the analysis.

6.4.2 Reporting Data: Once a problem has been identified, consider graphing the most illustrative areas in a spreadsheet graph, if that has not already been done. Such graphic documentation is convincing and impressive, and may be helpful to management.

## 6.5 Manual Testing

Using EMS capabilities can improve the speed, reliability, and efficiency of manual testing. Manual testing with EMS uses onscreen control system readouts to verify performance of equipment. The EMS is used to change a setpoint or parameter and cause a reaction in the system of interest. System response can be immediately observed on the EMS screen. For example, to see if the heating valve position is working properly on a VAV box, the zone temperature setpoint could be raised 10°F and the response of the heating valve immediately observed. As with trending, calibration of all affected sensors and actuators is required before manual testing can rely on the EMS readouts.

Manual testing differs from monitoring or trending in that trending generally looks at the performance of systems over time, after the event. In trending, the operator must piece together the cause of a given response in the system whereas in manual testing, the operator deliberately initiates the action and immediately observes the response. Also, trending alone typically cannot record the extremes of system operation; it is limited to recording events under normal external conditions. With manual testing, the system can be easily taken to design conditions or tested under any other simulated condition. For example, to test an economizer damper, the outside air temperature, OSAT (or enthalpy if appropriate), could be overwritten during the cooling mode to be 50°F, simulating a condition good for economizing using the EMS. The damper response could then be observed in the EMS (or visually if damper position is not monitored). Manual testing also allows checking of components that may not be observable in the EMS, e.g., damper position, boiler stage, etc.

Simulating desired conditions may be accomplished by changing setpoints, overwriting analog input values, jumpering contacts, closing power disconnects, changing schedules, and false-loading equipment. Be sure to return all conditions to normal after testing is complete.

When manual testing, check the system response just above and below the deadband of the breakpoint. For instance, in the above economizer example, if the changeover setpoint was 65°F with a 2°F deadband (+/- 1°F), then overwriting the OSAT to be 50°F may verify that the economizer works, but not that it works properly. To do that, the OSAT should be overwritten to 63°F to see if the damper opens, and then overwritten to 67°F to see if it closes. Alternately, change the changeover setpoint rather than overwriting the OSAT.

Becoming familiar with the loop-tuning capabilities of your system can be valuable. The EMS manual or training can help you learn how and when to tune control loops to improve performance. Many controllers have self-tuning or auto-tuning capabilities, but they may not be enabled. Related to loop tuning are features that automatically calibrate their sensor to a known condition once each day (e.g., flow sensor calibrates to zero flow during OFF conditions). This, too, must be enabled to function. Enhanced loop tuning, particularly of zone-level controllers, will improve tenant comfort.

### 6.6 Manual Testing/Trending Combination

Manual testing and trending can be combined when necessary. A trend or point history log is started and conditions are altered or simulated as in a manual test; the response, however, is not viewed immediately but recorded in the trend data and studied later. This method is useful for investigating the response to a parameter or condition over time. For example, if you wanted to know if the chiller demand limiter was functioning properly, but the load on the chiller was not currently high enough, you could lower the EMS demand limit setpoint for a few days and trend the chiller demand limiting parameter (current or kW) during that period.

### 6.7 What To Test Manually

The rationale of the previous section on trending also applies to manual testing. The following are some additional areas to consider testing:

- Items in the Table of Sample Trends (Table 6-1) in the previous section
- Air-side economizer functions: Are outside air dampers fully closed during warm-up? Do economizer dampers open, and return air dampers close, to maintain discharge air setpoint

right at the economizer changeover point (enthalpy or dry bulb)? Is the enthalpy or dry bulb sensor calibrated? Does the changeover point setting allow the economizer to operate at the highest possible OSAT? Does the economizer start first, to maintain setpoint with a differential, before compressor cooling starts?

- Variable speed drives: Do the drives ramp up and down with the water or air pressure and demand, as expected? Does the drive allow the motor to drop to a very low speed when demand and load are at minimum?
- Boiler staging
- Building static pressure control
- Lighting sweep control
- Exterior lighting photocell control
- Equipment interfaces with the EMS (rooftop units, boilers, fire, life, safety, etc.)

## 6.8 Test Documentation

Small diagnostic tests can be designed and executed without prior written planning, but documenting the test itself is important. Notes should be kept on the conditions of the test, what was done to initiate a response and what the response was, or you may have to repeat the test to verify your recollections.

Longer tests or checkouts warrant a written test plan. For checking the full sequences of operation for a given system, complete written procedures are highly recommended. The process of designing and writing out test procedures may help clarify the problem even before testing is begun; and the writer's increased familiarity with the workings of the system may identify other possible problem areas.

## 6.10 Using EMS to capture non-energy benefits, some innovative examples.

By definition, an energy management system manages energy, this is its primary objective. However, as more powerful systems are developed and installed, EMS capabilities are expanding to include nontraditional functions. In this chapter, we will discuss potential applications beyond the traditional scope of EMS operations.

Remember that an EMS is, at heart, a computer program. It can process virtually any information as long as it has the proper sensors and transducers. Its actions are not limited to the traditional tasks of building systems. Non-energy tasks tap the vast potential of energy management systems.

## 6.11 Maintenance Control

Building managers can use the totaling and counting functions of their EMS trending capabilities to construct duty logs. A duty log offers valuable information about equipment: how much it is used, how much it is cycling, how well it is following assigned schedules, and more. With such a log, maintenance personnel can more readily determine if maintenance is due or if equipment needs preventive repair or replacement.

DDC systems can track and display information such as last time ON/OFF, daily equipment run-times, monitored data from analog inputs, energy use, and hardware performance. DDC systems can also accumulate and display monthly scheduled and unscheduled run-times for each piece of equipment controlled or monitored. Duty logs could show change-of-state for major loads for review on a daily basis if desired.

For equipment driven by motors, run-time is the basis for scheduling preventive maintenance. For filters and heat exchangers, pressure drop is the basis for scheduling maintenance. System operators can assist maintenance personnel by preprogramming instructions that associate maintenance schedules with equipment and report skill levels and tools needed for maintenance tasks. Furthermore, automatic sequencing can be used to equalize run-times. For example, with a lead-and-lag pumping arrangement, the lead pump can automatically be switched once per month (or other interval) to equalize run-time.

Some EMS have complete add-on computerized maintenance management systems (CMMS) or can interface with a standalone CMMS. This feature greatly enhances the automation of and connection between facility operations and equipment maintenance. Some examples of maintenance control are listed below:

6.11.1 Filter Control: Primary and secondary air handling unit filters can be monitored with differential pressure switches, so that when the filter reaches a certain pressure across the media it triggers a maintenance alarm at the DDC operator's console(s). This alarm can be linked to a message that gives the maintenance person information on the size and quantity of filters required. This strategy can save staff time as well as reducing energy waste from running fans against higher than necessary static pressures.

6.11.2 Water Treatment: Water chemical feed for cooling tower basins and for boiler systems may be administered manually or by a local specialty feeder. An EMS can be programmed to perform this function automatically, adjusting the feed rate based on other information to which it has access, such as blow-down or bleed-off rates.

6.11.3 Run-Time Tracking: EMS totalization features can accumulate the total hours of on-time for any piece of monitored equipment. Alarms can be programmed to notify facility staff when equipment has run for a given number of hours and requires service. Fan motor belts, bearing lubrication, pump seals/packing glands, etc., can be scheduled for maintenance by either total run-time or calendar dates. The DDC system can trigger maintenance alarms and be linked to messages. Run-time can also be used to alternate redundant pumps, chillers, boilers, and other equipment.

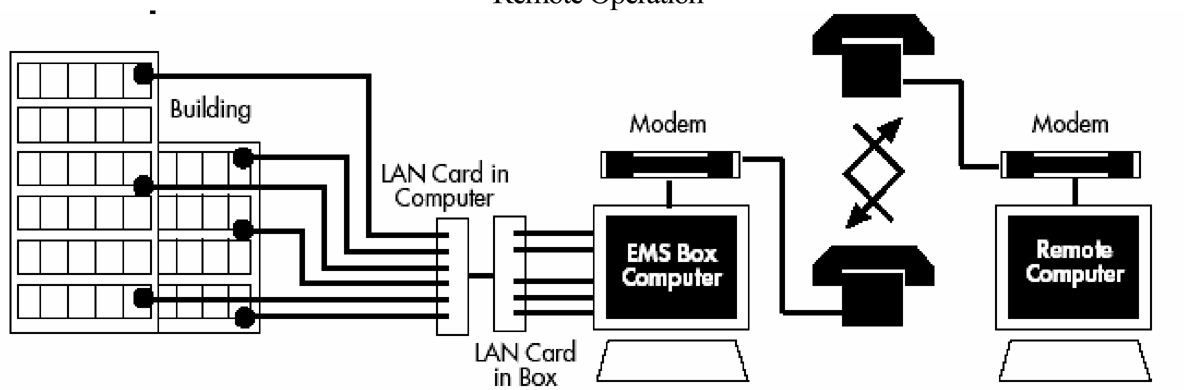
6.11.4 Sewer Fee Control: Cooling towers lose water through evaporation and require make-up water as well as some periodic blow-down or bleed-off of water to keep mineral buildup under control. If utility sewer rates are high and cooling tower flow rates are large enough, it may be cost-effective to install water meters on the make-up and blow-down lines. These meters will calculate the actual amount of water going down the drain to the sewer, allowing for possible reduction of the sewer bill, as the evaporated water will not be billed.

## 7. Remote EMS Operation

Remote EMS operation usually means remote monitoring or remote control. Some facility managers are responsible for multiple facilities, for example, a college campus or a network of company retail shops over a large geographical area. To best manage these situations, facility managers with advanced communications capabilities can take advantage of local-area networks or high-speed modems to connect their local computer terminal to a remote building EMS. Depending on the capabilities of the EMS, remote operators may be able to perform some control actions such as shutting down and starting up equipment.

With increasing technological advances in communications equipment, remote monitoring is becoming more widely practiced. Through a telephone or Internet connection, the offsite computer acts as an EMS terminal and can access alarms, trend files, and other data. Monitoring a building from a remote location is a good way to view building performance for comparison with other buildings or to simultaneously manage upgrade projects in various locations.

FIGURE 7-1.
Remote Operation




It may be difficult or impractical to access a remote EMS repeatedly during the day. It is best to have trend data saved automatically for download by the remote user, who can dial in, select the desired trend, and retrieve data for the past 24 hours (or some other time period). Data storage can often be an issue; to avoid cluttering their systems, many system operators download data to a tape drive or some other backup storage area.

## 7.1 Security Applications

Security is of premium importance to most building owners. Some sectors, such as the federal government, are required to maintain certain levels of security. Other organizations, both public and private, perform sensitive work requiring security clearances and access control. For these reasons, most commercial buildings operate under a form of secured or restricted access. There is often an opportunity for integration of security systems with EMS and other building systems such as HVAC and lighting. Through EMS, today's advanced security equipment allows facility managers to further refine security practices to meet their needs more exactly.

## 7.2 Card Key Access

Magnetic card key systems are a standard form of access control. Their minimum function is that of a lock and key. However, in many buildings, the access cards contain unique digital identification information, allowing for activity in the building to be remotely monitored and recorded. For organizations that wish to conduct in-house security analysis and monitoring, particularly during unoccupied hours, card key systems are ideal. For organizations that have less need for security monitoring, the access system vendor will typically store entry data offsite to be retrieved if needed. Although many card key systems can feed data directly to the building EMS, not all have that capability. Work with your security vendor to make sure your EMS can communicate with your security system.

When access is restricted between zones or floors, card key information is valuable for analyzing building occupancy trends. When the EMS is integrated with the security system, card key readers can act as a form of occupancy sensor to augment zone control. This is most successfully and accurately accomplished with an employee "key-in" and "key-out" system. For example, a worker enters her office space by sliding her access card through the reader, either at the main building entrance or at the entrance on her floor. When this occurs, the reader obtains the employee's identification and feeds her data to the EMS. The EMS can then look up the location of her office space in a database and subsequently activate lighting or zone-level HVAC at that employee's work space as appropriate. Furthermore, lighting and HVAC can be provided only to nighttime or weekend workers' zones based on a signal from the card key reader. In this way, access control will produce not only non-energy benefits such as enhanced security monitoring, but energy savings as well.

## 7.3 Industrial Applications

Industrial buildings have HVAC and lighting needs that are very specific to the nature of the onsite industrial or manufacturing activities. Nevertheless, it may be profitable to take a close look at your onsite processes to see whether they can be improved by integration with your EMS.
The following are some examples of possible industrial applications:

- Optimizing conveyor belt speed for mass production lines.
- Coordinating and integrating different manufacturing lines.
- Matching shipping with current production levels.
- Interfacing with computerized manufacturing equipment.
- Providing extra cooling upon demand to high-temperature manufacturing areas.
- Monitoring production at various points along a manufacturing line.
- Calculating and storing quality-control parameters.
- Providing precise environmental control for "clean rooms."
- Monitoring raw material inventory levels.
- Handling alarms for industrial applications.

A process or activity may be currently managed or supervised by a central computer system, which might be enhanced by integration with the EMS. An EMS is in a unique position to assist industrial applications because of its coverage of the entire building and its central processing power. Work with your controls vendor to develop adaptations.

## 7.4 Retail Applications

Retail stores are in an excellent position to derive non-energy benefits from energy management systems. A critical parameter for stores is that of customer traffic, and the EMS is an excellent vehicle for traffic data collection. With the proper motion sensors, the EMS can measure how many customers are shopping, when they are shopping, and their rates of entry and exit. For larger stores, it is possible to determine the areas of highest traffic within the store. A major ancillary benefit of this information is the ability to measure the effectiveness of promotions and marketing efforts. In this case, a direct correlation between the promotion and increases in consumer traffic (perhaps in a particular aisle or area), would provide marketing assessment data.

Additional benefits are possible for multi-store facilities such as malls or shopping centers. Information about customer traffic has traditionally been gathered by counting cars in the parking lots and garages, usually with pneumatic road tubes. Using EMS, you can refine car counting for reliability, or move toward people-counting instead. When you have the ability to determine customer traffic at various levels and locations, you will be able to implement the following tasks:

- Find high- and low-traffic areas.
- Evaluate special events.
- Compare number of shoppers to number of buyers.
- Evaluate business hours.
- Analyze seasonal trends.
- Determine expected shopping activity by day of week.
- Quantify effects of weather on shopping.
- Improve traffic to low-activity areas.

7.5 Miscellaneous Applications

Non-energy related tasks are not limited to security, industrial, and retail applications. Your own creative initiative may come up with successful applications for your facility. The following are just of few of the potential tasks that are presently implemented at facilities across the country.

7.5.1 Greenhouses and Farming: Use EMS to precisely control humidity levels in greenhouses, to schedule plant watering, or to operate irrigation systems.

7.5.2 Noise Control: Some facilities need to monitor and record noise levels. When possible, use the EMS to ratchet down noise-generating equipment or to activate noise cancellation systems if decibel levels go above prescribed safety levels. In addition, decibel-level logs may help resolve worker complaints about noise levels.

7.5.3 Environmental Compliance: Many organizations must carefully monitor pollutants or emissions. EMS can handle this job and provide documentation. At hazardous waste cleanup sites, EMS can monitor soil for toxic contaminant levels and generate alarms as required.

Indoor Air-Quality Monitoring: Many building owners with IAQ concerns use EMS to monitor and troubleshoot carbon ioxide, toxic substances, and humidity levels.

Animal Farms. EMS has been creatively applied to farming tasks. For example, at a hog farm, the EMS could schedule and automate feeding times while opening and closing gates to herd animals to the desired locations.
The cost-effectiveness of any application will depend on its benefits. Increases in productivity and efficiency can be factored into cost analyses; other benefits, such as improved customer relations, full environmental compliance, or enhanced security, may be hard to quantify in dollar amounts but are clearly desirable and worthwhile.

8. USING SPREADSHEETS FOR GRAPHING AND ANALYZING TREND DATA

Converting to Spreadsheet Format EMS data must usually be converted to another file format before use in a spreadsheet. In some systems, conversion to spreadsheet format is done after the data have been gathered; others allow the operator to choose the appropriate format beforehand. Storing data in a text file (.txt) with commas or tab separators between columns works well, but requires a conversion when importing to a spreadsheet. The preferred format is .csv, which requires no conversion by the spreadsheet. Make sure the layout of the stored data has date and time down the left column and as many columns of parameter values to the right as possible. See Figure 5-1, in Chapter 5: Strategies for Optimization, for an example. Don't allow data in large trends to start a set of new parameters at the end of the columns of the preceding data set. Read the EMS manual and call the vendor for help, as necessary. Before starting an important trend, experiment on a small trend to be sure the conversion process works.

## 8.1 Opening Data Files

When opening a data file, if it is not a spreadsheet or a .csv file, you will have to parse or delimit (divide) the data into columns. Newer spreadsheet software will automatically provide a systematic process to do this. Simply observe the data on the screen and mark where you want each column division. Scroll down into the columnar data past the text information at the top of the sheet. Put one column marker between each data point column. If the data spans more than two days, it is often useful to keep the day and the time together in one column. The spreadsheet can read them together. For trends of two days or less, separate the day from the hour/minute columns (later, graph only the hour and minute column). After parsing but before graphing, save the file as a spreadsheet file type, not as a .txt file.

## 8.2 Setting Up Graphs

Use the following pointers when setting up graphs: Combine data files if necessary. Often the points to be graphed together are found in different downloaded files. Open both files and combine the desired columns of data into one file before graphing. If data from one file has different time intervals, copy in the time column with the data.

8.2.1 Remove extraneous text: Some EMS data files will come with a few rows of text every 66 lines or so (for a page break). Delete non-data rows before graphing. (Macros can be used to do this.)
Convert text data entries to values. Status or COV trends, with "on or off" or "open or closed" as the column values, require some editing before they can be graphed. Perform a search and replace with "on" replaced by a "1" or some other value in scale with other variables being graphed and "off" replaced by "0" or other suitable value. Text such as "alarm," "missing data," or "-99" (missing) may need conversion as well.

8.2.2 Arrange columns as needed: Often you may not want to select all the columns of data in a spreadsheet for a single graph. Typically, having more than four data points on a graph makes interpretation difficult. To select columns that are not adjacent to each other, try pressing control or other function keys to allow selecting non-adjacent columns. Otherwise you will have to move the columns of data manually to be adjacent to each other.

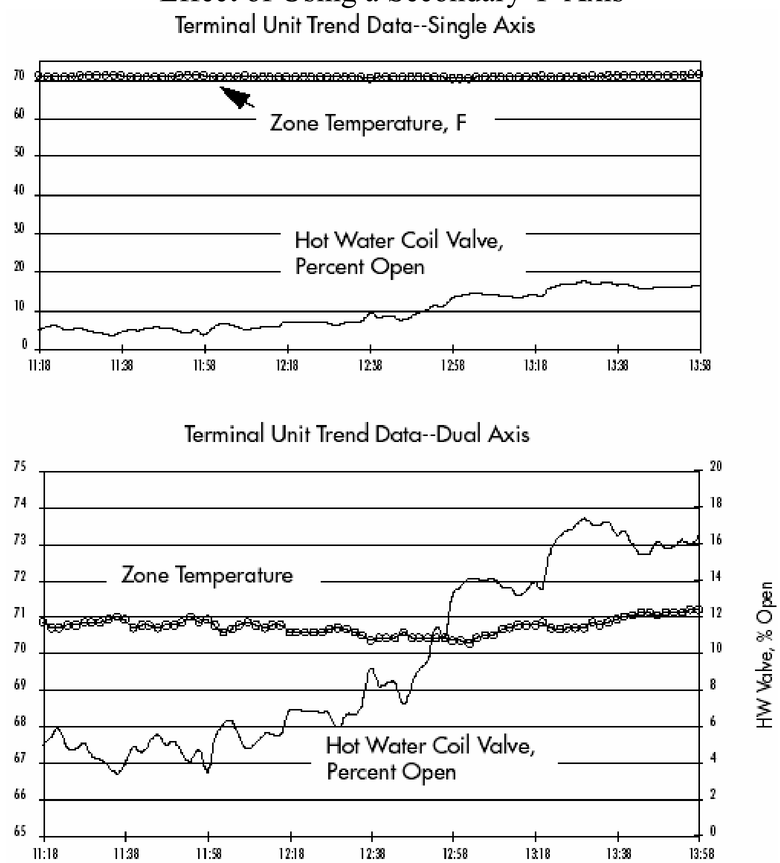
8.2.3 Graphing: The easiest way to graph in newer spreadsheets is to use the graphing wizard step-by-step procedure. Refer to your spreadsheet manual for details. Most graphing wizards choose the left-most column as the X-axis data. If the date and the time are in different columns, select only the day column for graphing.
Once a graph is developed, additional points (columns) can be added or deleted.

8.2.4 Types of Graphs: For time-series graphs (where time is the X-axis), it is best to designate the graph as an "XY plot" or a "line graph." For plotting one parameter against another, use "scatter plot" graphs without lines.

8.2.5 Scaling: Setting up the proper Y-axis scale is critical for obtaining good resolution. The spreadsheet may default to zero as the minimum and some value above the maximum data point for the maximum. This often makes interpretation of the data difficult. In newer spreadsheets, you can change the scale by clicking on the Y-axis and going to the appropriate menu. Normally, you want the maximum and minimum values to be set so the plot approaches the top and bottom of the graph at some point.

The X-axis may also need to be scaled or truncated to provide a "zoomed in" view of the data, if more resolution will help the analysis. Start the graph when something of interest is happening and end it when the area of interest is past by clicking on the X-axis and scaling as necessary.

FIGURE 8-1.
Effect of Using a Secondary Y-Axis




8.2.6 Multiple Y-Axes: When graphing two or more variables with a wide range of values, scaling the left Y-axis may not provide sufficient resolution. In such cases, assign he variables with similar maximum and minimum values to the right or second Y-axis. This greatly enhances the resolution of the data while still providing the comparison of all data to the common X-axis (time). Figure B-1 illustrates this. In the top graph, the spreadsheet default, there is little resolution to analyze the real relationship between the space temperature and the heating coil valve. In the lower graph, the coil valve data was assigned to the right Y-axis and scaled; the interpretation is clear. The dual-axis formatting illuminates a problem indicated by the data: Most of the time, the heating valve does not open more than 10%, although the zone temperature is continually below the setpoint deadband of 71°F.

8.2.7 Formatting: If the graphs are to be printed for presentation or review by others, they must be clearly legible. Increasing fontsizes and adding notes to the graph is easily done. Make sure to note on the graph: the file name; the date of the trend; the equipment and data points being shown; the units of each data point; and the sampling interval. Experiment with having a data series as a line, symbols only, or both, to improve clarity. In some spreadsheets, output may vary depending on whether you select the spreadsheet area behind the graph and print, or select the graph (or chart) itself and print. The key to formatting is to experiment until you are familiar with your options.

8.2.8 Graphing One Parameter Against Another: In spreadsheets, one parameter can be graphed against another. This is very useful for many types of diagnostics. For this type of graph, use only a scatter plot. One column of data (rather than time) gives the X-axis values and another column gives the Y-axis data. You can add lines later, if the X data were previously sorted in ascending or descending order and there are no missing X data.

Figures B-2 and B-3 illustrate the concept. Figure B-2 is a typical time-series graph with the heating water supply temperature (HWST) and the outside air temperature (OSAT) plotted against time. This particular EMS was supposed to have a HWST setpoint reset schedule of OSAT 20°F, HWST 180°F; OSAT 70°F, HWST 120°F. It can be seen from Figure B-2 that the HWST does drop as the OSAT increases, but it is difficult to ascertain accurately whether it follows the specified schedule. OSAT could be assigned to the right Y-axis for more resolution. A very convincing approach is to simply plot the HWST against the OSAT, as in Figure B-3. Scale the graph so the end points of the graph are the same as the end points of the schedule and draw in the schedule line. It can be clearly seen that the reset schedule is not working as intended, as all points are 12 to 15°F higher than the design schedule.

8.2.9 Trends with Different Time-Steps: In some spreadsheets, separate time-series trends with different time intervals (e.g., 2-minute and 15-minute) can be plotted on the same graph. To do this, bring the data with its associated time stamps into a common spreadsheet. Graph one pair of data. Do not use a scatter plot. Then go to the chart or graph data-source options and add the new X-axis values (time) and its associated Y-axis values. The data for both Y-series will be plotted on a common X-axis.

FIGURE 8-2.
Investigation of Reset Schedule via Time-Series Plot

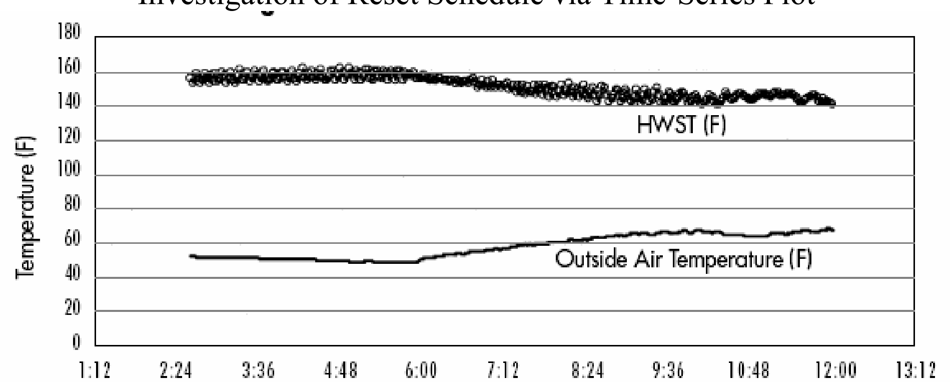
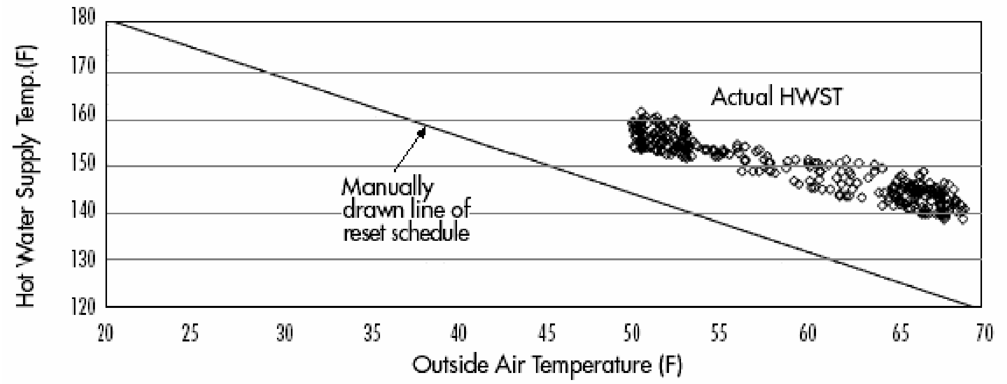


FIGURE 8-3.
Investigation of Reset Schedule via Plotting One Parameter Against Another



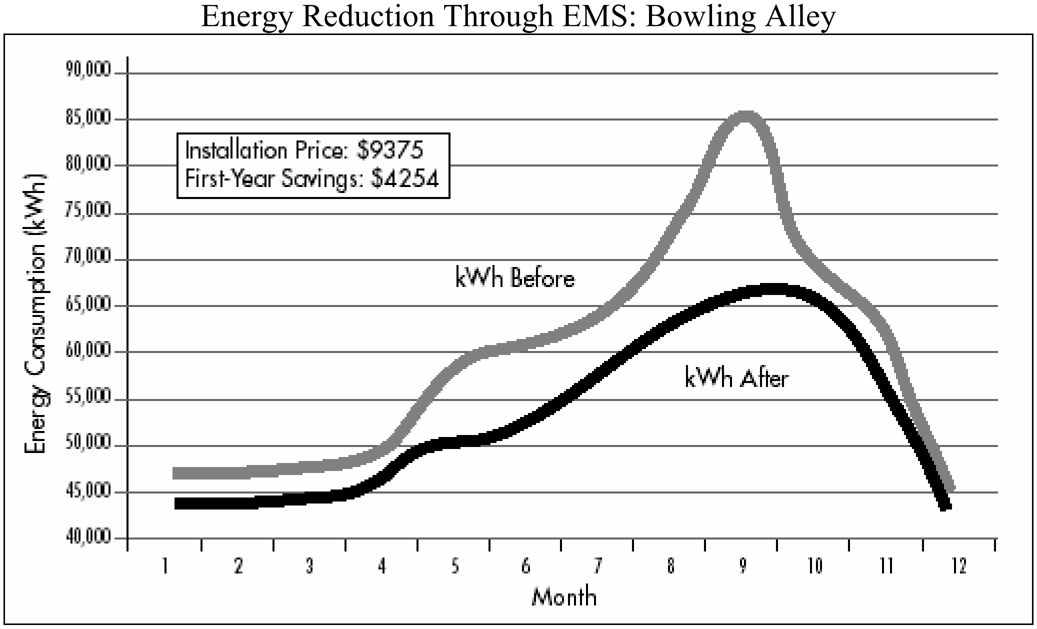

Optimization Example #1

Savings from Basic EMS

Energy management systems are often installed or upgraded as capital projects designed to save energy cost-effectively. In some cases, the savings will come from the more basic functions of the EMS, as demonstrated by the following example.

A bowling alley owner purchased a small EMS for the advanced temperature control technology, but did not expect significant additional savings. The building uses 11 rooftop heat pumps and packaged air-conditioning units for a total of 75 tons of cooling. The EMS was installed to control the heating and cooling equipment as well as the lighting and signs. Through basic scheduling and temperature control, along with optimum start routines, the bowling alley achieved significant energy savings as demonstrated in Figure 5-5.

FIGURE OPT-1
Energy Reduction Through EMS: Bowling Alley



## Optimization Example #2

### Underwriter's Laboratory Project

Savings from More Advanced EMS Features

This example demonstrates how the more advanced features of EMS can be used to the fullest to obtain energy savings, comfort, and reliability. The Underwriter's Laboratory (UL) facility is located in Camas, Washington. It consists of a two-story building with approximately 112,800 square feet of conditioned space. Facility use includes a mix of office space, testing laboratories, and storage space. Fuel use consists of electricity for most end-uses with natural gas for heating.

The energy management system for the UL facility is responsible for implementing and managing a variety of energy conservation strategies:

In this building, tight DDC allowed the space temperature heating setpoints to be lowered by one degree and the space temperature cooling setpoints to be raised by one degree, resulting in significant energy savings.

The DDC system's ability to collect information from every zone allowed the primary supply air temperature to be reset based on a signal from the zone with the greatest cooling load. This saves energy by reducing reheat and improving plant efficiency.

Fans are started to adjust morning warm-up or cool-down periods to be the shortest possible and still maintain space temperature setpoints by the beginning of the occupied period.

Centralized scheduling of equipment achieves energy savings from less occupant adjustment of space temperature setpoints and more consistent and sensitive ON/OFF scheduling of equipment. For example, fan operating hours have been reduced by about 5 hours per week.

For this strategy, chilled water temperatures are reset to the highest temperature that can still meet cooling loads. Energy savings are accomplished by increasing chiller operating efficiency, decreasing reheat energy, and reducing heat gain through piping. Also, heating water temperature will reset to the lowest temperature that can still meet heating loads. Energy savings are accomplished by reducing heat loss through the boiler and piping.

This control strategy keeps the outside air dampers closed when the HVAC systems are operating to bring the building "up to temperature." Energy savings are achieved by not conditioning outside air during the morning period before occupants arrive.

During unoccupied periods, the EMS sends timed pulses to low-voltage relays in the lighting circuits, turning off the lights on any particular circuit. Occupant override stations are installed for individual lighting circuits.

***Annual Energy Savings***
*• 273,750 kWh*
*• 21,4000 therms*

***Annual Cost Savings***
*• $17,211*
*(15¢ per square foot)*

## Optimization Example #3

### Various Optimization and Energy Saving Techniques Through Modeling

Savings for this measure can be estimated by performing a DOE-2 building energy model and simulating HVAC system energy use with and without the controls below.

### Building Descriptions

In order to verify the persistence of energy saving measures, the HVAC system at each building has been monitored. Each building has central hot water heating, chilled water cooling, evaporative condensing plant, and central air handling units. Both buildings are also equipped with a central EMS.

### Building 1

Building 1 is a 400,000 square foot, 20-story office building. The HVAC system is composed of one 3600 MBH gas-fired hot water boiler, one chiller at 550 tons, one chiller at 525 tons, and one cooling tower rated at 785 tons. A flat plat heat exchanger is provided for chilled water economizer when outside air conditions are cool. The air handling system consists of one hot deck fan and one cold deck fan per floor. Each fan is provided with the associated heating/cooling coil.

### Building 2

Building 2 is a 600,000 square foot, 30-story office building. The HVAC system is composed of two 2400 MBH gas-fired hot water boilers, two chillers at 550 tons, and one cooling tower rated at 1220 tons. Four variable air volume air handling units serve multiple floors.

Cold deck reset: The air handlers currently are set to supply air at 55 F from all air handlers all the time (except AHU-8, which was set to 60F). While this may be necessary on the hottest summer days, during other periods you would save money by allowing the supply air temperature to drift up as high as 65F. The simplest way to program this is to set the supply air temperature based on the outside air temperature. More advanced EMSs can optimize the setting by considering additional factors and even tailor it for each air handler. The change will slightly increase fan energy use because more air must be supplied to provide the same amount of cooling but the fan increase will more than be compensated for by reduced chiller and boiler energy use due to substantially reduced supply air cooling and reheating.

Hot water reset: HVAC systems have hot water reset capability but it seldom used. By reducing the hot water temperature from 180F to as low as 140F at times when full heating capacity is not needed, can reduce pipe distribution losses and increase boiler heat exchanger efficiency. As with cold deck reset, the simplest way to program this is to set the target hot water temperature based on the outside air temperature. More advanced EMSs can optimize the setting by considering additional factors.

Chilled water reset. By increasing the chilled water target temperature from 44F on the hottest days to as high as 54F on cold days, you can reduce pipe distribution heat gain and increase evaporator heat exchanger efficiency. This measure works in conjunction with cold deck reset.

Substantial elevation in chilled water temperature is only possible if the supply air temperature is allowed to rise at the same time.

Increase economizer use. The maximum temperature for economizer free cooling before lockout was set at 55F for all air handlers at the time of the audit (in January, except AHU-12, which was set at 35F maximum). By increasing the maximum temperature setting to 65F and increasing the cold deck target temperature at the same time, you can enjoy free cooling and turn your compressors off for a large portion of the year in Santa Clara's mild climate.

These programming type recommendations can save thousands per year if they are implemented together, but the HVAC system continues to run 24/7.

Turn off HVAC at night and on weekends. We recommend turning the main HVAC system off—all central chillers and supply fans but not exhaust fans or server room HVAC—at night. Most offices we have surveyed in Santa Clara turn the HVAC off some time between 8 pm and 12 pm, and on weekends, and then turn it on again at 5 am on weekday mornings to precondition the space before early arrivals. Even with the late evening hours your engineers sometimes work we suspect that you could do the same.
This directly saves substantial supply fan energy and saves some cooling and avoids reheating as well.

There are certain computer areas that may require 24/7 cooling that the central HVAC system currently provides. For example the server room has its own system, but that system has as backup part of the main system. Also, there are at least three electrical closets that might need spot cooling. We have included $50,000 in the budget for this recommendation to install four split systems to act as backups or run at all times if necessary to meet these critical needs. This measure alone saves an estimated $140,000 per year if shut off is midnight to 5 am weekdays and all weekends.

We have included this shut off as part of the "Upgrade EMS" recommendation because the existing system is not currently used for any dynamic or automated setting changes and we expect that software upgrades and training will be necessary to make use of such features.

General EMS comments. Because some of the shut-off savings occurs at the same time that the reset control savings would occur, the combined savings for the EMS measures is less than the sum of the individual measures.

Regarding cost, we have budgeted for spot split systems and also understand that Trane has provided a quote of $15,000 to update the system. Given the actuator and programming problems Trane is likely to find during the update, we have included an additional budget cost of $195,000 for a major overhaul of a ~150 point system.

This measure may be eligible for General Power rebates, but they have not been included because all of the described changes are more likely to be considered "reversible" programming changes.

**ENERGY AND COST SAVINGS (from DOE2 Model Summary in Program Notes)**

| | Annual Savings | | | |
|---|---|---|---|---|
| | kWh | therms | kW | $ |
| Reset controls measures | | | | |
| Cold deck/ventilation reset | 1,015,087 | 98,503 | 135 | 156,819 |
| Chilled water reset | (4) | (16) | 0 | (13) |
| Hot water reset | 53,301 | 1 | 5 | 4,046 |
| Economizer reset | (31,097) | (12,562) | (8) | (12,507) |
| Subtotal (less than the sum of the individual measures due to interactive effects) | 1,058,774 | 98,423 | 189 | $162,860 |
| Hours of use controls measures | | | | |
| Turn off HVAC at night and on weekends | 483,788 | 135,533 | (2) | $140,822 |
| **Simple total** | 1,542,562 | 233,956 | 188 | $303,682 |
| **TOTAL, less interactive effects** | **1,184,456** | **187,015** | **196** | **$241,875** |

**IMPLEMENTATION COST**

| | |
|---|---|
| Trane quote to assess condition of existing energy management control system | $15,000 |
| Includes basic recommissioning and version updating. | |
| Does not include repair of any broken sensors or actuators discovered. | |
| Does not include material upgrades to existing system capabilities. | |

$1,250 /point typical cost for a new energy management system.
Approximate number of points in your system for budget purposes

| | | | |
|---|---|---|---|
| 6 | /AHU | x | 15 AHUs |
| 12 | /chilled water plant or boiler | x | 4 chiller-boilers |
| 3 | /pump | x | 6 pumps |
| 156 | points total | | |

| | |
|---|---|
| Total HVAC energy management control system upgrade cost | $195,000 |
| (4) additional 5-ton split systems for spot server room capacity/redundancy | $54,000 |
| **Total cost** | **$264,000** |

**PAYBACK**

Simple payback time 1.1 years

# HVAC System Simulation Results (DOE-2)

| No. | Scenario | Modeled | | | |
|---|---|---|---|---|---|
| | | kWh | therms | kW | $ |
| 1 | Base case | 6,969,839 | 248,680 | 1,428 | $767,912 |

Savings When Each Measure is Modeled Separately without Interactive Effects

| No. | Scenario | Annual Savings | | | |
|---|---|---|---|---|---|
| | | kWh | therms | kW | $ |
| 1 | 0+Cold Deck Reset up to 65F | 1,015,087 | 98,503 | 135 | $156,819 |
| 2 | 0+HW Reset 180F down to 150F | (4) | (16) | 0 | ($13) |
| 3 | 0+CHW Reset 44F up to 54F | 53,301 | 1 | 5 | $4,046 |
| 4 | 0+Economizer 55F up to 65F | (31,097) | (12,562) | (8) | ($12,507) |
| 5 | 0+Cool & Heat off unocc (fans still on) | 483,788 | 135,533 | (2) | $140,822 |
| 6 | 0+Fan Power & Ctrl EEM | 161,217 | (2,985) | 13 | $9,739 |
| 7 | 0+Chiller Plant EEM | 389,654 | (2) | 226 | $40,110 |
| **Total without interactive effects** | | **2,071,946** | **218,472** | **369** | **$339,016** |

Savings When First Four Measures are Modeled Together with Interactive Effects

| | Scenario | Annual Savings | | | |
|---|---|---|---|---|---|
| | | kWh | therms | kW | $ |
| **Total with interactive effects** | | **1,058,774** | **98,423** | **189** | **$162,860** |

Savings When All Measures are Modeled Together with Interactive Effects

| | Scenario | Annual Savings | | | |
|---|---|---|---|---|---|
| | | kWh | therms | kW | $ |
| **Total with interactive effects** | | **1,575,302** | **182,145** | **386** | **$276,240** |

Savings, Only One Chiller Converted to Water Cooled Instead of Both

| | Scenario | Annual Savings | | | |
|---|---|---|---|---|---|
| | | kWh | therms | kW | $ |
| | 0+Half Chiller Plant EEM | 244,939 | (20) | 117 | **$23,790** |