energydesignresources

design brief

FIELD REVIEW

To assure a project's success, the design team needs to be involved in the construction process.

Summary

Developing well-detailed construction documents is an important first step in achieving energy and resource efficient projects. However, projects are not successfully completed until the building and its systems are constructed, commissioned, and fully operational according to the design intent. To assure a project's success, the design team needs to be involved in the construction process. This brief will identify some of the points in the construction process when field inspection, observation and interaction with the construction team can provide the most benefit.

Designers who complete periodic field review resolve problems early. As a result, the number of change orders is minimized and owners are more likely to receive a high performance, energy efficient building. Below are some examples that highlight the value of ongoing field review. In each case, the problems described would likely be caught during field inspections.

- Sensors that are located incorrectly may not give accurate readings. Incorrect readings may lead to unnecessary heating and cooling, resulting in increased energy costs over the life of the building.
- Adding or relocating a tap for a thermometer well once the system is operational can take a crew of tradesmen several hours to a day. Completing this work during construction would have only taken 20 minutes or less.
- Using a saddle joint instead of the manufactured tee shown on the drawings can add unnecessary pressure drop to a system. This can result in serious performance problems and energy consumption burdens.

contents

Introduction

In many ways, every building is a prototype. Few people expect the first prototype of a new car, airplane, or other complex machine to function flawlessly when first placed in operation in a development lab. Yet, there is a tendency to expect flawless performance from a new building almost as soon as it is placed on line, without the benefit of experimentation and testing. In reality, even well-designed, well-constructed buildings can encounter some problems during start-up and operation. Complex building systems and fast-paced construction schedules further contribute to building performance problems. Most buildings require modifications and adjustments during construction to assure the design intent is achieved. To facilitate this, the building construction process should include extensive and dynamic involvement of the design team.

Unfortunately, many buildings of all classes are built directly from construction documents with minimal design team involvement. Systems are installed in a three-dimensional, dynamic world as depicted in two-dimensional, static drawings. Conflicts are often resolved by builders who may not know how the system was intended to function. Designers often issue drawings for bid and never see the result until a brief final inspection at the end of the construction cycle. At this point, many of the installation details associated with the performance of the building cannot be inspected because they are covered by finishes, insulation and other elements. Operational problems are also difficult to detect because the final inspection is only a snapshot of the performance of systems that must respond to large variations in operating requirements from hour to hour, day to day and season to season.

Problems are identified early, when they can be resolved at little or no additional cost.

A design team that is involved in the construction process provides the following benefits.

- Designers can verify that their designs are being implemented as intended. Problems are identified early, when they can be resolved at little or no additional cost.

- Lines of communication are established between the design team and the construction team, so the construction team is more likely to seek input from the designers when they encounter field problems.
- Designers become more aware of the real world implications of their designs. This allows them to tailor future work to the realities of the construction process and improve the product they provide to clients.

The net result is that problems are resolved without compromising the design intent, the number of change orders is minimized and owners are more likely to receive a high performance, energy-efficient building. Beginning with field protocols and proceeding through final inspections, this brief recommends meaningful ways for designers to participate in the construction process and describes points in the construction process that would benefit most from field inspection.

Lines of communication are established between the design team and the construction team, so the construction team is more likely to seek input from the designers when they encounter field problems.

Field Protocols

Before going into the field, designers should be prepared for the conditions they will encounter. The following discusses some standard field protocols.

Dress and Equipment

Construction sites are dirty and somewhat dangerous places. A suit and tie is probably not the best choice for tromping around in the mud, climbing ladders and crawling inside systems and equipment. Loose clothing and ties can actually pose a danger around operating machinery. Hard hats, ear plugs and safety glasses are a good idea and will be mandatory on most sites. Sturdy shoes with steel toes may also be required.

It is wise to remove rings, chains, bracelets, watches and other jewelry. These items can easily be caught in machinery or on the corners of ducts or equipment. Metal jewelry can be particularly hazardous around live electrical equipment since it can brush up against a live conductor resulting in shocks, burns and damage to the equipment.

Tools of the trade include a flashlight, clipboard, tape measure, multipurpose tool, digital thermometer, and calculator. It can also be useful to have a pocket guide such as the ASHRAE HVAC Pocket Handbook and a psychrometric chart, duct and pipe fitting loss coefficient tables and page of useful formulas. Laminating these documents will make them more durable. This sounds like a lot to carry, but it will all fit into a clipboard such as the one shown in **Figure 1.**

Figure 1: Form holder clipboard

All of the tools needed for an inspection (flashlight, clipboard, tape measure, multipurpose tool, digital thermometer, calculator, and reference guides) will fit into a clipboard such as the one shown below.

Source: PECI

Dangers and Safety Precautions

Operating machinery and construction work can be dangerous. For this reason, designers should exercise caution at all times and should stick with someone who knows the site when they perform field inspections. Possible hazards include exposure to:

- Unguarded rotating machinery
- Live unenclosed electrical equipment
- Welding flashes and sparks
- Flying debris from grinding and cutting
- Noise

Operating systems and machinery can also have potential hazards that are not immediately obvious. Below are a few examples.

- The access door to the discharge plenum of a fan that is running at three inches water column pressure has a force of over one hundred pounds acting on it. Anyone entering the plenum (assuming they can even get the door open) could be injured and/or trapped inside if the door slams shut. If the door was not designed properly, designers entering the discharge plenum could also be knocked down since the door could swing open very quickly.
- High-voltage/high-current electrical equipment has a lot of energy flowing through it when it is live, especially at the moment when the circuit is closed. It is a good idea to stand and face away from the compartment door of the switch gear when the circuit is closed for the first time or after a repair. If

there is a short circuit and the switch malfunctions, the switch may explode and blow its door open. Even if the circuit protection works as it should, there are a lot of sparks, flames, and noise when a high-voltage fuse is blown. See **Figure 2.**

Issues in Existing Facilities

Many construction projects are modifications to existing facilities. Thus, the construction process and the start-up and final testing of the systems must proceed with minimal disruption to the ongoing operations at the facility. This is especially important in an industrial setting where a plant shutdown or unscheduled outage is expensive and/or dangerous and in a laboratory or health care environment where turning off the wrong circuit can disrupt research, contaminate an operating room or create a life-threatening situation. Less serious yet disruptive and expensive problems can crop up if the interactions between systems are not considered. For example, a design engineer was rigorously verifying the pressure relationships in recently remodeled operating rooms. It turned out that the smoke stick that he was using also tested the corridor smoke detectors, triggering a fire alarm that almost resulted in the evacuation of one wing of the hospital.

Good Working Relationships

Most tradesmen, especially foremen, are skilled craftsmen, with a lot of field experience. Designers will learn of problems sooner and be able to resolve problems more easily if foremen communicate openly with them. Designers who take the time to develop a solid working relationship usually find strong partners who will make sure the system is installed as intended.

Many times, tradesmen working on construction projects are members of a trade union. These organizations can have very specific rules regarding who can do what type of work. Failure to observe and conform to these rules while on site can lead to animosity with the workers and may even cause a labor problem.

Figure 2: Closing a high-voltage circuit

When energizing a circuit for the first time or after a repair, it is best to face away from the switch and not stand in front of the compartment.

Source: PECI

Project Meetings

Construction involvement usually includes attending project meetings. These meetings can be very beneficial, especially on large or complex projects with fast-paced construction schedules. They open the lines of communication between the various parties, allowing issues to be discussed and resolved in an interactive atmosphere rather than in writing. Critical path issues and scheduling issues can be targeted, coordinated and discussed. By attending some of the construction meetings, the design team can proactively address dimensional conflicts and other issues that come up in the course of a project.

Construction meetings open the lines of communication between the various parties, allowing issues to be discussed and resolved in an interactive atmosphere rather than in writing.

Most construction projects include the following meetings.

Pre-bid Meeting

The pre-bid meeting occurs during the bidding phase of the project and provides an open forum for contractors to clarify issues they have on the project and questions arising from the contract documents. It allows the design team to emphasize critical points in the project design or schedule. If the project is a modification of an existing building or system, a walk through of the project with the design team can be an important part of the pre-bid meeting process. During the pre-bid meeting, it is not unusual for concerns to be brought up that focus attention on issues that appear to be weak points or flaws in the project. This feedback can be very informative to the design team. It is important that the design team address these concerns in a straight-forward manner and either demonstrate how the current contract documents deal with the issue or follow-up by addressing the issue in an addendum. It is also wise to document the minutes of the meeting in an addendum to the construction documents.

Project Kickoff Meeting

The project kick-off meeting typically occurs after the contract has been awarded but before significant work is done. The format is similar to the pre-bid meeting but only includes the successful contractor, foremen and suppliers. Topics include critical points in the project and schedule, critical project criteria, and general questions and answers. During the project kickoff meeting, contractors shift their focus from selling their services to delivering the requirements of the contract. Thus it is appropriate to spend a few minutes pointing out some of the more important requirements, such as duct fabrication, piping installation and control system details, along with an explanation of why they are important. For work in an existing facility, a walk-through with the foremen at this point can be valuable because it allows the designer to point out the critical aspects of the project and begin building a working relationship with the crew.

Construction and Commissioning Meetings

Most projects have regularly scheduled construction meetings to discuss and resolve problems, review schedules and deliveries, and emphasize critical issues and target dates. The frequency of these meetings will vary with the size, complexity and nature of the project. Typically, they occur at least once a month but on complex projects, during intense periods of work, they can occur several times a week. Commissioning meetings are focused construction meetings during which the start-up, testing, tuning and adjustment of the systems are discussed. The designer's role in both of these meetings can range from answering technical questions and providing guidance to running the meetings and acting as the construction manager—depending on the contract, the agreement with the owner and the requirements of the project.

The designer's role in meetings can range from answering technical questions and providing guidance to running the meetings and acting as the construction manager—depending on the contract, the agreement with the owner and the requirements of the project.

Project Inspections

The focus of this design brief is energy efficiency. As a result, the following discussion targets areas where project inspections in the construction process can improve a building's energy efficiency. However, other aspects of the mechanical and electrical design are just as important and should be included in field inspections.

When conducting field inspections, it is important to keep the big picture in mind. Designers are part of a team that is constructing a building and the lines between the various disciplines can become indistinct. Code-related issues are a good example. Designers are responsible for designing and specifying a system that meets the requirements of the applicable codes. But they have a vested interest in making sure the system is installed correctly and passes all necessary tests, even though installing and testing are the responsibility of the contractor.

Most successful projects have a design and management team that function as an integrated group with a free exchange of information and observations. A team member that has expertise in one area may have a valid observation about the work of another discipline. Designers with this big picture view of the project are rewarded with buildings constructed on schedule and on budget that perform at peak efficiency.

The primary purpose of rough-in inspections is to verify the portions of work that will soon become difficult to inspect and to set a baseline for subsequent work.

The timing of field inspections can be critical because later phases of construction often cover up earlier work making omissions or misinterpretations difficult to detect. In addition, discovering a problem early usually makes it less difficult and less costly to correct. Prepare field reports following all inspections to document what was observed and how problems should be resolved.

Let's take a look at each of these inspection types in more detail. Specific requirements vary from system to system and project to project, but the concepts are universal.

Rough-in Inspections

One of the first phases of construction involves laying out the primary equipment and termination points and installing the primary system runs to these locations. This preliminary step is usually called system rough-in. The primary purpose of rough-in inspections is to verify the portions of work that will soon become difficult to inspect and to set a baseline for subsequent work. Many of the items that need to be inspected will soon be covered by wall coverings, concrete floor slabs, or back-fill and site landscaping. These inspections typically occur very early in the construction process and are on the critical path for the project. The project engineer may need to be flexible in his or her availability.

Many times, the local code authority and the insurance underwriter also need to participate in rough-in inspections in order to grant an occupancy permit and assure insurance coverage. This is particularly true for plumbing, electrical, fire protection and other life safety systems.

Many times, the local code authority and the insurance underwriter also need to participate in rough-in inspections in order to grant an occupancy permit and assure insurance coverage.

Inspecting the mechanical and electrical work in the following categories is often useful in assuring the success of a project and avoiding problems with later phases of construction. Once rough-in inspections have been performed and approved, it is more difficult to resolve problems and assign responsibility. It is important to be thorough in performing and documenting rough-in inspections.

General Rough-in Inspections

Areas to look at during rough-in inspections include:

- Necessary components, fittings, accessories and connections should be installed correctly.
- Necessary tests should be performed. All pressure tests, leak tests, and quality tests should be performed while the lines can be accessed without excavation or removal of wall or ceiling coverings. Many of these tests are required by code and failure to properly perform and document these tests can result in problems gaining a certificate of occupancy. The designer may need to witness or spot check these tests depending on the project requirements.
- Utility and support system connections, such as make-up water connections, power connections and fuel connections, should be at reasonable locations.
- Drainage system inlets and termination points, such as floor drains and roof drains, should match the conditions that exist

at the site and the final slopes of the installed building elements. Last minute field changes are often made in the pitch of the roof, the grading of the site, or the slope of the mechanical room floor. These changes may require adjustments to the termination points of the drainage systems serving these areas.

- It is a good idea to make sure the mechanical, electrical and plumbing contractors have coordinated with the general contractor to assure structural openings are properly sized and correctly located. Openings in floor slabs, shear walls, and other structural elements should be sized to match the systems that will pass through them and located as required by major duct, pipe and conduit routes prior to ordering steel or pouring concrete.
- Housekeeping pads should be located correctly, sized properly and not block access to floor drains or plumbing clean-out points. For air handling equipment, the pads need to be high enough to allow a cooling coil condensate drain line trap to be installed. On high-pressure systems, this can require five or six inches. Pads for electrical equipment should comply with code-dictated clearances.

Improperly located control system elements can have a significant impact on system performance, efficiency and diagnostic capability.

Control System Rough-in Inspections

Control-system rough-ins typically occur later in the construction cycle after the primary elements of the mechanical systems are in place. Improperly located control system elements can have a significant impact on system performance, efficiency and diagnostic capability. In addition, adding control system elements after a system is operational can be a major problem. For example, adding or relocating a tap for a thermometer well once the system is operational can take a crew of tradesmen several hours to a day to set up and isolate, drain, and fill the section of piping that needs to be worked on. This work would have taken a tradesman 20 minutes or less to complete during fabrication.

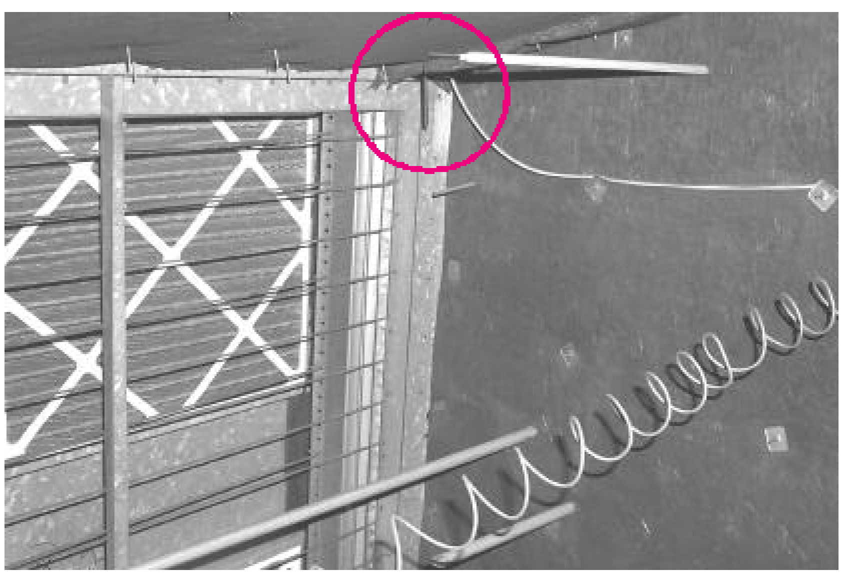
Areas to look at include:

- Sensors should be located to ensure accurate readings. A single point sensor located in a 6-foot high by 10-foot wide mixed air plenum will not provide reliable readings of the average mixed air temperature in the plenum. See **Figure 3.** At the time the picture was taken, the sensor indicated the mixed air temperature was at set point (55°F) when in fact the true average mixed air temperature was 48°F. Stratification caused the incorrect reading, which led to unnecessary preheating by a downstream control loop. If the mixed air sensor correctly reflected the average mixed air temperature, it would have reduced the outside air brought in by the economizer and achieved the required 55°F setting without using preheat, saving nearly a thousand dollars a year in energy cost.

- Sensors should be installed to facilitate service without a system shutdown. Temperature sensors should be installed in a thermometer well. Pressure and flow sensors should have isolation valves unless they are safety related.
- Sensors should be located so they are accessible for calibration while in operation. True calibration in the field is very difficult, but verifying that the information from a sensor is reasonable is important. For example, a second empty well should be installed next to temperature sensors to allow calibration to be checked.

Figure 3: Single point sensor located in a 6-foot high by 10-foot wide mixed air plenum

The sensor shown below did not provide accurate readings of the average mixed air temperature in the plenum. Stratification caused incorrect readings which led to unnecessary preheating by a downstream control loop.



Source: PECI

Figure 4: Modulating control valve

Modulating control valves are typically at least one size smaller than the line in which they are located if they have been properly sized.

Source: PECI

- Final control elements should be oriented properly in the system. Flow arrows on valves should match the flow direction. Damper blades should be oriented to rotate in the proper direction as the damper modulates. For example, mixing dampers should rotate so that the outdoor air and return air streams are directed into each other rather than away from each other.
- Modulating final control elements should appear properly sized for the system. Modulating control valves are typically at least one size smaller than the line in which they are located if they have been properly sized. Designers should expect to see a reducer before and after them. See **Figure 4.** Similarly, modulating control dampers are usually smaller than the ducts or plenums they serve. This reduction in size is often accomplished by installing a blank-off plate inside the duct that blocks the portion of the duct that is not occupied by the damper.
- Non-modulating (on/off) final control elements, such as smoke dampers or seasonal isolation valves, should be installed to minimize ongoing pressure drop. In contrast to modulating elements, these final control elements should be the full size of the pipe line or duct in order to minimize pressure drop and ongoing energy consumption. Dampers with aerodynamic low-pressure drop blades should be installed in these locations rather than higher-pressure drop flat plate blades. Most projects incorporate both designs for different applications and it is easy for dampers with similar dimensions but different blade styles to be installed in the wrong place.

In-progress Inspections

In-progress inspections involve observing the current state of construction to identify problems while they can still be corrected with minimal disruption to the construction process or operation of the facility. They are ideally scheduled with construction meetings.

Duct System Inspections

The designer should inspect the duct system to ensure that fittings are fabricated as shown in double line drawings, standard details, and specifications. Duct system inspections should ensure that:

- Fitting fabrications meet the requirements of the contract documents. Divided flow fittings should be provided where indicated and plenum and riser connections arranged to minimize pressure loss. Turning vane installations can be verified by looking down the open duct or by looking for the screw pattern that holds the vane mounting rail running diagonally across the corner of the elbows.
- Balancing devices are installed where required by the drawings and specifications. Usually this is at every major branch. Manual actuators for these dampers should be locking quadrants rather than manual regulators. They should be located as far from the terminal outlets as possible to minimize air flow noise.
- Appropriate duct construction standards are met. This may require bringing a vernier caliper or micrometer on site to check the duct sheet metal gauge against the standards for the required pressure class. This is not a straightforward evaluation since there are numerous sheet metal gauge and duct reinforcement combinations that can be used to achieve a given pressure class rating. Additional information on the specifics of duct construction can be found in American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) guides and Sheet Metal and Air Conditioning Contractors National Association (SMACNA) duct construction standards.[1]
- Terminal units and flow-measuring stations have duct connections that promote a uniform duct velocity profile. Typically several feet of straight duct at the inlet and outlet are required. Otherwise, inaccurate measurement and control result. See **Figure 5.**
- Duct connections to fans minimize system effect, which can degrade fan performance and damage the equipment. Inlet connections should provide an unrestricted path to the fan and ensure a uniform velocity profile. Outlet connections should include sufficient duct length for the uniform velocity profile to re-establish itself before the introduction of fittings.

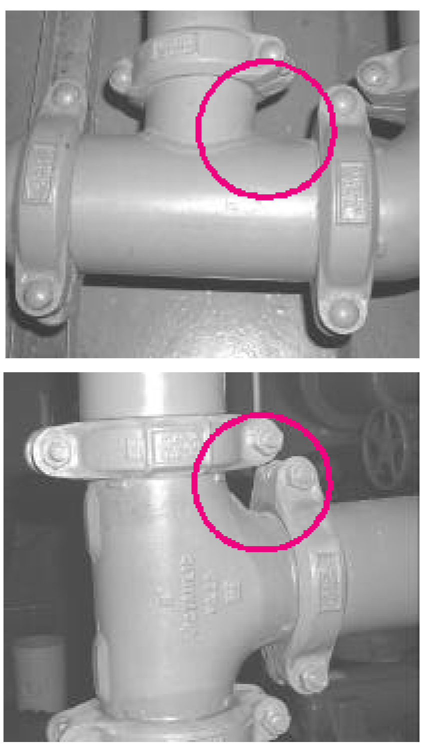
Figure 5: Inlet connection to a VAV box.

The duct offset immediately before the inlet connection to this VAV box will cause erroneous flow sensor indictions and may affect the perfomance capabilities of the box. This could lead to energy waste or indoor air quality problems.

Source: PECI

Figure 6: Saddle joint vs manufactured tee

The saddle joint shown on top will likely have a higher pressure drop than the manufactured tee shown below. Note the smooth transition to the branch connection on the manufactured tee. The saddle joint also has a higher likelihood of failure and may not be accepted by some code officials in critical applications.



Source: PECI

- All dynamic elements located inside a duct, such as smoke dampers, fire dampers, automated control dampers and flow measuring stations, have an adequately sized access panel. The panel should be located so that it can be reached without undue difficulty, should be large enough to allow a service technician to fully access the duct interior and should be immediately adjacent to the duct mounted component.
- The sealing technique used on the ducts appears to meet the requirements of the specifications. There should be visible evidence of appropriate caulks and sealants required by the specifications at most of the joints in the ductwork.
- Manufacturer's installation requirements are followed. Unfortunately these instructions are often lost and equipment is installed in a manner that leaves it prone to failure or in violation of its U.L. listing. Designers should look for these types of problems when on site, paying particular attention to the connection, support, and mounting requirements for fire, radiation, and smoke dampers and the reinforcement requirements for multi-section dampers.

Piping System Inspections

The designer should inspect the piping system to verify that fittings and fabrications are installed as shown in the drawings, isometrics, standard details, and specifications. Piping system inspections are similar to duct system inspections and should ensure that:

- Turns and offsets are made using long radius elbows, assuming they are specified. Long radius elbows can be identified by measuring the centerline radius of the fitting, which should be equal to one and a half times the nominal line size.
- Tees and branches to piping mains are made using fittings rather than saddle joints, unless indicated on the drawings or approved by the project engineer, and should be oriented to optimize the pressure drop through the fitting. The difference in pressure drop through a manufactured tee compared to a saddled joint can be significant. See **Figure 6.** If the contractor saddled pipes together on a project instead of using the tee

fittings shown on the drawings, serious performance problems and energy consumption burdens could result.

- Connections to existing piping systems are made using the technique shown in the drawings. Contractors are often tempted to make connections to an existing system using hot taps rather than by shutting down and draining the system. But hot taps can have performance, predictability, durability, and strength problems. If a shutdown of the central system is difficult, hot taps offer a viable alternative that can be developed and engineered into a project. Problems can arise when the designer specifies a manufactured tee and the contractor uses a hot tap.
- Flow meters have the required number of straight pipe lengths upstream and downstream of the flow element. Most flow meters require a uniform velocity profile at their entrance to function accurately.
- Control valves have the correct flow orientation. Most globe-style, two-way control valves are designed for flow in one direction only. If the flow direction is reversed, the valve will "chatter" or rapidly open and close when the valve plug is near the shut-off position. This chatter can generate a severe water hammer that can cause large lines to move several inches back and forth. In addition, all three-way valves are not the same. Some are designed to mix two fluid streams into one stream (mixing valve) and others are designed to divert one fluid stream into two separate streams (diverting valve.) If a mixing valve is used in a diverting application (or visa-versa), valve chatter will likely result.

Connections to existing piping sytems should be made using the technique shown in the drawings.

Control System Inspections

The designer should inspect the control system components to verify they are installed per the contract documents. Control system components are often overlooked during the construction process because they are hidden inside ducts or panels. However, proper installation of control system components can make the difference between a building that works and one that doesn't. Control system inspections ensure that:

- Actuators are located properly and are accessible with other equipment in place. Actuators and dampers with high temperature fluid systems (such as steam or exhaust gasses) should be located to promote cooling and protection from radiant heat. Some gear train type actuators must be orientated correctly to maintain proper lubrication. Actuator systems serving multi-section dampers should have identical mounting arrangements and linkage systems. Actuators located outdoors need to be rated for weather exposure. The pneumatic air serving the control system needs to be dried to meet worst-case conditions, especially if lines run outdoors, to prevent frozen condensation and system failure.

- Electronic components of the control system are protected from dust, dirt and extremes in temperature. Most current systems are designed so that the control enclosures can be installed and wired before the electronic modules are installed, thus limiting the electronics exposure to the hazards of a construction site. The enclosures should be thoroughly cleaned prior to installation of the electronic cards. The enclosures should then be kept closed. Direct digital controllers (DDC) can be ruined by water from a leak during a pressure test or by a misdirected hose stream during cleanup. NEMA 1 enclosures will protect the electronics in most cases but oil tight/dust tight NEMA 13 enclosures may be worth the modest additional cost in some applications.

Electronic components of the control system should be protected from dust, dirt, and extremes in temperature.

General Inspections

Below are some examples of additional questions to ask during inspections that relate to energy and operational issues.

- *Is the overall quality of the materials and workmanship as specified in the contract documents?* The materials and equipment should be protected until they are installed. Dirty pipe ducts and fittings will more than likely show up as a problem at start-up or down the road operationally.

  On one project, the owner and operators fought problems with plugged strainers and fouled heat transfer surfaces for months after their chilled water system had been modified. During construction, a load of top soil was dumped uphill from where the pipe was being stored prior to installation. During a heavy thunderstorm, some of the top soil washed downhill and into the open ends of the pipe. Since the heavy rains washed the exterior of the pipe clean and the installing fitters did not pay careful attention to the pipe, the lines were installed full of mud. The mud was then distributed through the entire system because the piping extensions were not flushed out prior to activating them.

- *Is the work proceeding in a logical and orderly manner?* Piping should be pressure tested before it is insulated. It is difficult to pressure test insulated pipe and costly to repair the damaged insulation that results. The chilled water system should be insulated before operational testing. Otherwise it is difficult to dry the condensation on the piping before installing the insulation and may require a system shutdown. Also, moisture protection is needed to protect other tradesmen's work if chilled water pipes are operational without insulation.

- *Is the right equipment installed and oriented correctly?* Nearly identical pieces of equipment can be easily confused. In addition, the factory may mislabel a component. Designers should verify shipping and nameplate data and make sure equipment connection location (right side vs left side) and component sequences make sense for installation and operation.

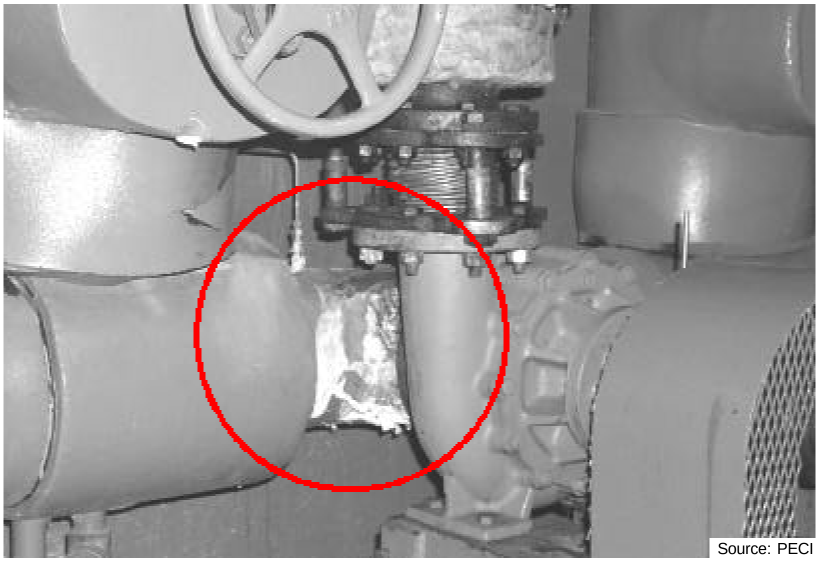
  Figure 7, page 18, illustrates how a piece of equipment that was improperly oriented very early in a project can cascade into a significant operating cost penalty for the life of a building. The initial problem was that the pump was installed facing the wrong way, which meant the suction diffuser would not fit between the pump inlet and the wall. A short radius elbow was installed between the suction diffuser and the pump inlet. The elbow defeated the benefits of the suction diffuser and distorted the pump's performance characteristics.

Designers should verify shipping and nameplate data and make sure equipment connection location (right side vs left side) and component sequences make sense for installation and operation.

Support systems should be securely attached to the structure, should meet spec and code requirements, and should be strong enough to support the combined weight of all lines.

Figure 7: Improperly installed pump

The pump shown below was installed facing the wrong way, which meant a short radius elbow was needed to connect the suction diffuser to the pump inlet. However, the elbow defeated the benefits of the suction diffuser and distorted the pump's performance characteristics.


Source: PECI

- *Are the supports and bracing systems adequate and installed correctly?* Support systems should be securely attached to the structure, should meet spec and code requirements, and should be strong enough to support the combined weight of all lines. Don't forget that the load can double or triple when the piping system is filled with water. Attachment points for seismic bracing should be installed before lines are insulated.

- *Are the architectural and structural elements adequate for the mechanical/electrical design?* The architectural and structural elements of the building must allow the mechanical and electrical systems to fit and perform as intended. For example, a field change that increased the structural depth requirement could mean less space in the ceiling cavity for the mechanical and electrical systems. This could make the ceiling cavity more congested and could result in inefficient fittings and unanticipated high pressure losses.

  Paying attention to the building envelope is also important. The insulation should meet the design requirements, the joints should be sealed and the soffit and reveal details should block any air pathways to the building exterior. If not, systems could see heating, cooling, dehumidification, and pressurization loads that are far higher than designed. HVAC systems have been blamed for problems that were actually the result of improper envelope construction.

- *If HVAC systems are being operated temporarily, are provisions in place to satisfy local code authorities and protect completed work?* Many times the general contractor asks the mechanical electrical, and plumbing (MEP) trades to run their equipment to provide temporary heating, cooling or ventilating to allow work to continue on the project. The design team, owner, and commissioning provider should be involved in this decision if it was not addressed by the project specifications. Approval from local code authorities and insurance companies is also important.

  The design engineer should require that control and safety systems are complete enough to safely run the unit. Safeties need to be in place, motor overloads need to be set, and basic temperature and volume control sequences need to be in place. It may also be necessary to perform some of the commissioning tasks prior to temporary start-up. If cooling is provided, the lines serving the unit (and the accessories and specialties) need to be completed, tested, insulated and vapor sealed. If the temporary heating source is steam or high temperature hot water, the hot water piping system must be tested and insulated well enough to prevent tradesmen from accidentally being burned. Temporary filters need to be in place to prevent contamination of the duct system by construction dust. This dust may require filtration levels that are higher than would be required by normal operation. Additional temporary filters may also be required to protect return ducts at their termination points. Inadequate filtration during temporary operation could lead to problems with significant clean-up costs. The owner may be faced with the loss of use of the facility during the interim period.

The design engineer should require that control and safety systems are complete enough to safely run temporary heating, cooling and ventilating equipment.

The design engineer also needs to assess the loads the unit places on the central utility systems. These loads could exceed those seen in normal operation and overtax both the unit and utility systems. For example, the heating load for a system with a 30 percent minimum outdoor air rate is very different than what it would see if it were operated with 100 percent outdoor air in the middle of the winter to flush out the building. In addition, the heating coil piping configurations and control sequences used by the 30 percent outdoor air system (the normal operating mode) may be unsafe for use at 100 percent outdoor air without some modification.

Testing

Factory Tests

On many projects, the performance, efficiency, first cost and operating costs of building systems primarily depends on several pieces of key equipment such as a chiller, boiler or large, custom air-handling unit. Owners often pay a first cost premium for improved efficiency, performance, or construction quality for this equipment. Factory inspections provide a way to verify that the owner is in fact receiving the efficiency and performance specified.

By witnessing the certification and performance testing of major equipment, the design team can be assured that they will be getting what they specified.

Measuring or detecting subtle differences in equipment efficiency and performance is often difficult in the field because of the accuracy of the field measuring equipment. Factories have testing equipment with the necessary accuracy to meet industry standards and have a controlled environment, free from external influences and interactions. Correcting equipment problems is also easier at the factory. Equipment is more accessible and problems can be corrected using factory equipment and factory craftsmen.

By witnessing the certification and performance testing of major equipment, the design team can be assured that they will be getting what they specified. Field inspections and commissioning testing can then focus on assuring that the equipment is installed correctly and will provide the required performance when integrated with other systems on the project.

On-Site Tests

Designers may choose to witness on-site tests depending on the owner's needs and designer's concerns. Listed below are some testing issues to consider.

- Duct leakage testing should occur as each section in a given pressure class is completed. This should occur before connecting to a different pressure class or section that does not require testing.
- Pipe flushing and testing should be completed before operating the system or opening the valves that connect a new extension to an existing system. Note that for existing systems it may be necessary to provide special temporary flushing and circulating pumps to properly flush and pressure test the new piping.
- Testing of fire alarm, sprinkler and other life safety systems usually requires a coordinated effort between trades. For example, sprinkler zone flow switches are typically installed by the sprinkler contractor but must interface with and trigger fire alarms, which are typically installed by the electrical contractor. Designers should require that these interfaces be verified prior to performing acceptance testing for local code authorities.
- Commissioning tests are another area where extensive coordination between the disciplines is required. For mechanical systems, these tests include pre-start checks, individual equipment start-up tests and functional testing of systems. Electrical systems are often tested to meet International Electrical Testing Association (NETA) requirements. Designers should work closely with commissioning providers to assure the tests adequately verify that the design intent has been achieved.

Designers should work closely with commissioning providers to assure the tests adequately verify that the design intent has been achieved

Resolving Problems

Construction projects often involve a great number of people working at a rapid pace. As a result, there are many opportunities for problems to arise. Problems identified during field inspections are typically resolved by one of the following avenues:

- Unforeseen problems on an existing site and owner additions/changes that are clear changes in scope require additional financial support from the owner. These problems are typically handled by change orders that expand the contract scope to include the necessary requirements. Change orders are typically negotiated with the contractors working on the project rather than bid competitively. Thus, designers should include language in the original contract documents that addresses how the costs will be documented and negotiated and how markups will be capped.

- Design problems that arise when applying a new or less proven technology may require that the contract scope be expanded to achieve the design intent. In some cases, however, the best decision is to adjust the design intent and live with the system. Resolution of the issue may include an expansion of the designer's contract depending on how the problem is resolved and the relationship between the designer and the owner.

- Problems that result from designer errors or omissions may require that the designer cover change order costs needed to correct the problem. These items are typically handled as claims under the design professional's errors and omissions insurance policy.

- Problems caused by contractor oversights or misinterpretations are covered by the contractor. Including a drawing or specification reference to the contract requirement is often helpful in streamlining resolution. However, once a mistake has been made, forcing a contractor to tear it all out and "put it in as shown on the drawings" may not be in anyone's best interest due to the delays and bad feelings that can result. It is usually well worth the time and effort to work with the contractor to find common ground that minimizes correction costs yet still provides the owner with a satisfactory system. This approach fosters good long-term relationships and makes the contractor more amiable to making other corrections.

It is usually well worth the time and effort to work with the contractor to find common ground that minimizes correction costs yet still provides the owner with a satisfactory system.

Final Inspections

If the design team has performed in-progress inspections, then much of the final inspection will simply involve verifying that items previously identified have been resolved. If ongoing field inspections have not been performed, the work will be more challenging since some potential problems will be covered by systems and other finishes.

If the design team has performed in-progress inspections, then much of the final inspection will simply involve verifying that items previously identified have been resolved.

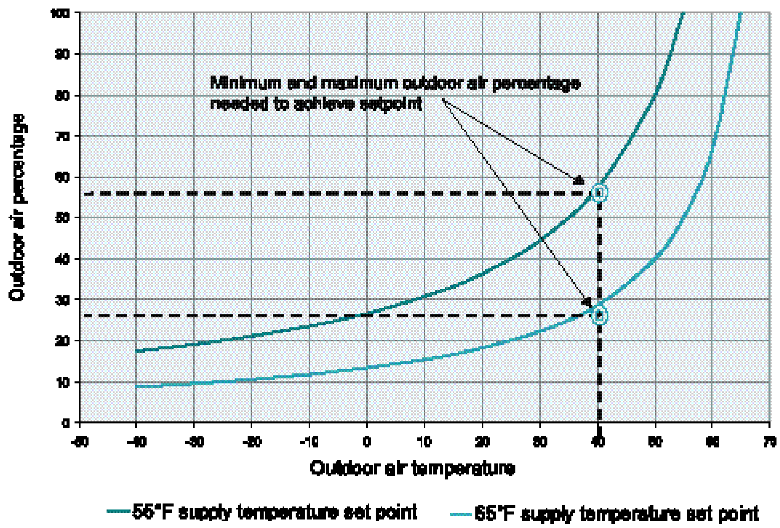
Regardless of whether field inspections have been done or not, designers need to be sure that operating systems are performing according to the design intent. A thorough commissioning process is the best way to do this. The following are a few fairly simple procedures that can also be used to determine how well systems are performing. They can be used as a final verification of a commissioning process or as a quick, big picture method of identifying operational problems.

- Observe system operation via the DDC System. System performance can be evaluated by looking at the information available at the operator's console.

  For example, when it is 40°F outside and the return air temperature is 75°F, the mixed air temperature must be between 40°F and 75°F in an air handling system with an economizer. In addition, assuming a supply temperature set point in the 55°-65°F range and a 20 percent minimum outdoor air setting, this system should be able to achieve set point by blending outdoor air and return air as can be seen in **Figure 8**, page 24. An active heating or cooling coil in the unit under these conditions may indicate a potential problem. Similarly, a temperature rise or drop across an inactive coil should be investigated. However, bear in mind that temperatures are often reported in tenths of a degree, but are measured with an accuracy of half a degree or more. Apparent temperature rises of a half a degree are usually related to sensor accuracy whereas deviations of several degrees usually indicate a problem.

Figure 8: Percentage of outside air required for different supply temperatures

At 40°F outside, this economizer equipped system should be using between 29% and 58% outdoor air to achieve a supply set point in the range of 55°F to 65°F. Since this is well above the 20% minimum outdoor air requirement, the system should not need to use any heating or cooling energy.

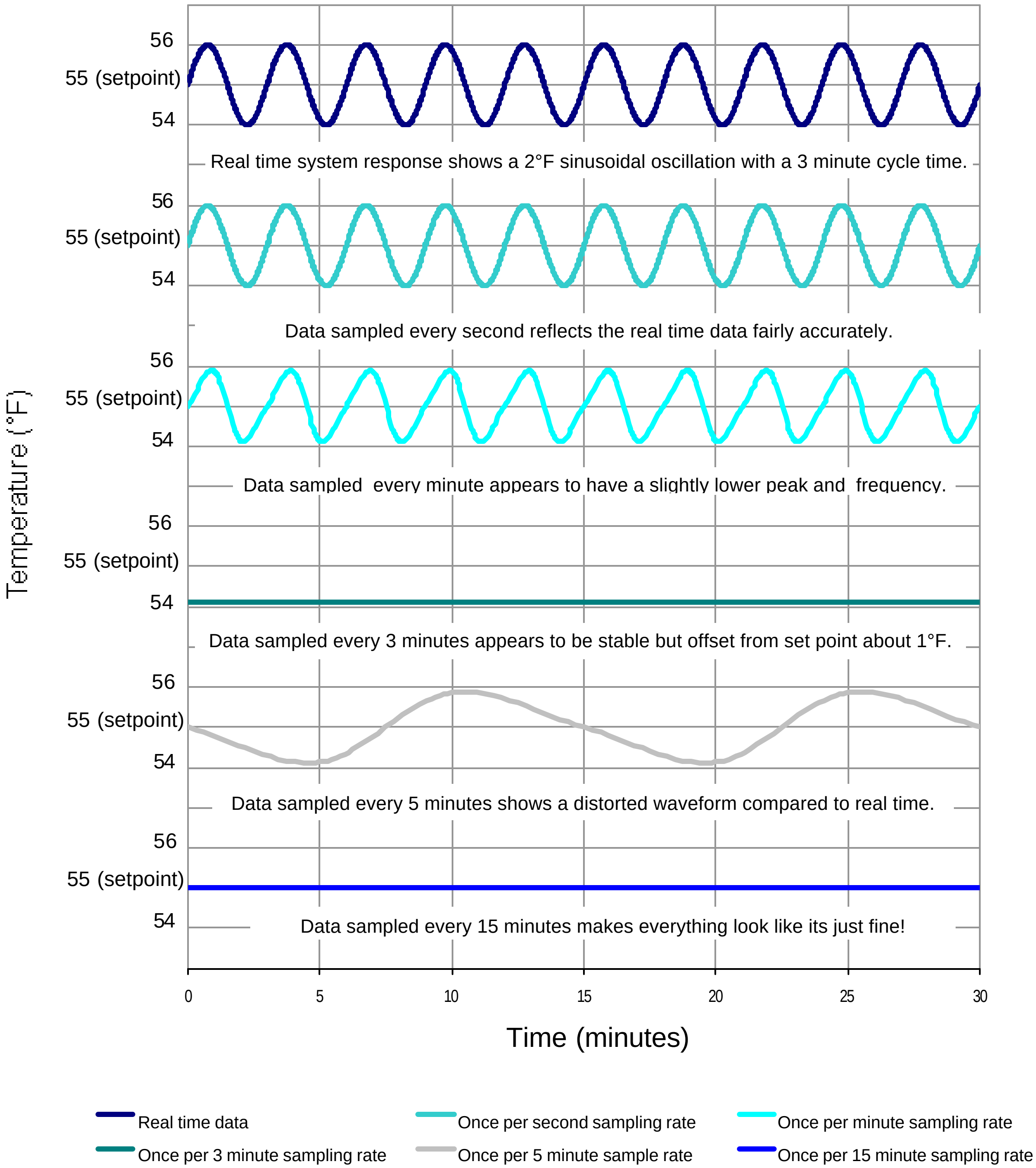


Source: PECI

- Trend critical central system input and output points and analyze the results. Modern DDC systems are capable of sampling points frequently and storing the data for further analysis. They can also export this data in formats that can be accepted by most spreadsheet programs. Analyzing the data over time reveals time-related problems such as control loop hunting and problems that occur when operators are not present. The frequency of the data samples used in the trend is important. **Figure 9**, page 25, illustrates how long sampling rates distort the data and can hide the fact that a control loop is hunting, especially if the sampling rate is a harmonic of the frequency of the control oscillation. Trend data should have the shortest sampling rate possible, ideally every one or two minutes or less. The controls contractor can usually avoid overloading the controller memory by archiving the data to the hard drive on a regular basis. **Figure 10**, page 26, is an example of a graph generated from trend data that identified a problem that had not been noticed because it was happening when the operators were typically off duty.

Figure 9: The impact of sampling time on observed data

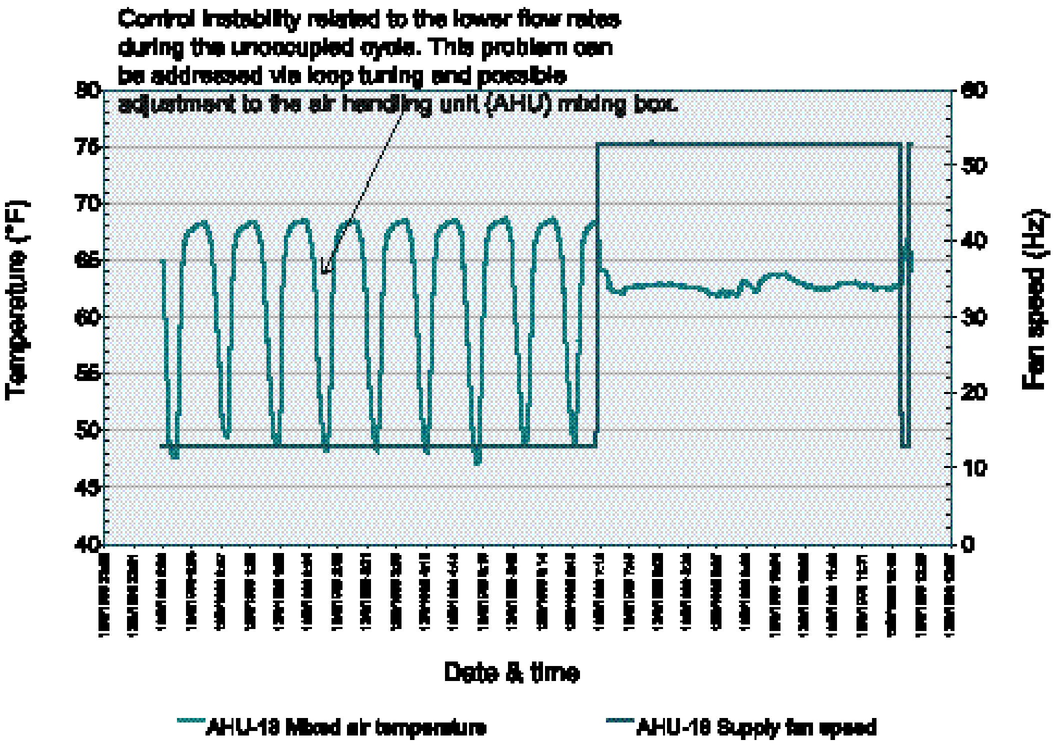
The rate at which data is sampled can result in an inaccurate picture of what is going on. Sampling rates that are a multiple of the frequency of the disturbance can mask instability. Other rates can distort the wave form.



Source: PECI

Figure 10: Sample trend data

Below is an example of a graph generated from trend data that identified a problem that had not been identified because it was happening when operators were off duty.

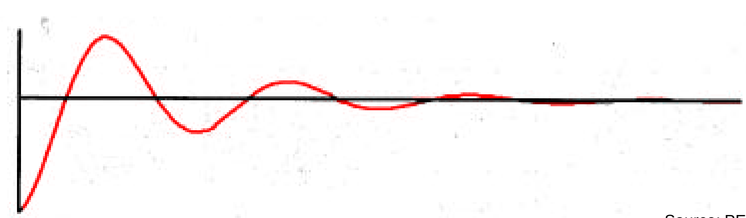


Source: PECI

- Have the contractors shut down the systems, wait 20 minutes, and then restart them. This is a simple but revealing test, especially on a near design day. Ideally, the system should start up without difficulty or safety trips and become stable in a relatively short period of time—15 to 20 minutes at the most. Control points may wander around during the start-up process as the various control loops interact and attempt to meet the load, but the deviations should not be extreme.[2] The peaks in the oscillations should drop in magnitude with each cycle as illustrated in **Figure 11.**

Figure 11: Quarter decay ratio

Control points may wander during start-up as control loops interact and attempt to meet the load. Peaks in oscillation should drop in magnitude with each cycle as shown below.



Source: PECI

If the systems are not well-tuned, interlocked and programmed, many undesirable operational issues will be identified by this test. The oscillations may not stabilize or may even increase over time until the actuators are simply bouncing against their limits or a safety system is tripped and the unit shuts down. Related systems can fail to respond to the shut down or start up of the primary system. The system or building can be damaged when this happens.

All of these problems are reasons why there may be resistance to performing this test. However, even if systems don't have time-of-day schedules, they still need to be able to handle power failures, equipment failures and unscheduled power outages safely and effectively. Otherwise they will be a liability to the owner. Though it is generally a good idea to perform this test, extreme resistance may indicate a problem that needs to be resolved before proceeding.

A substantial portion of a contractor's payment is generally released when items identified for correction by the final inspection or final-testing reports are resolved. This payment provides an incentive for quick turn-around on the resolution of problems. It is therefore wise to be as thorough as possible when performing final inspections to be sure all problems are identified.

Seasonal Inspections

Even though most tuning can be accomplished at start-up, the first year of operation will probably uncover conditions where further adjustment and tuning will be required. These typically show up during seasonal changes when the performance characteristics of the building and system components change. This can change the time constant in one or more control loops or forces the system into an operating mode that was never actually tested. The benefits to returning to the site for an hour or two during the first year include fewer performance problems, improved customer satisfaction and increased real world experience. Designers may want to

Even though most tuning can be accomplished at start-up, the first year of operation will probably uncover conditions where further adjustment and tuning will be required.

talk with the operators about how things are working, spend a little time looking at what's going on in the systems on that day and suggest solutions to problems that they may be encountering. Designers may even want to take some of the trend data back to the office to analyze for an hour or two. This will provide invaluable training in how systems work in the real world and may uncover additional areas for optimization.

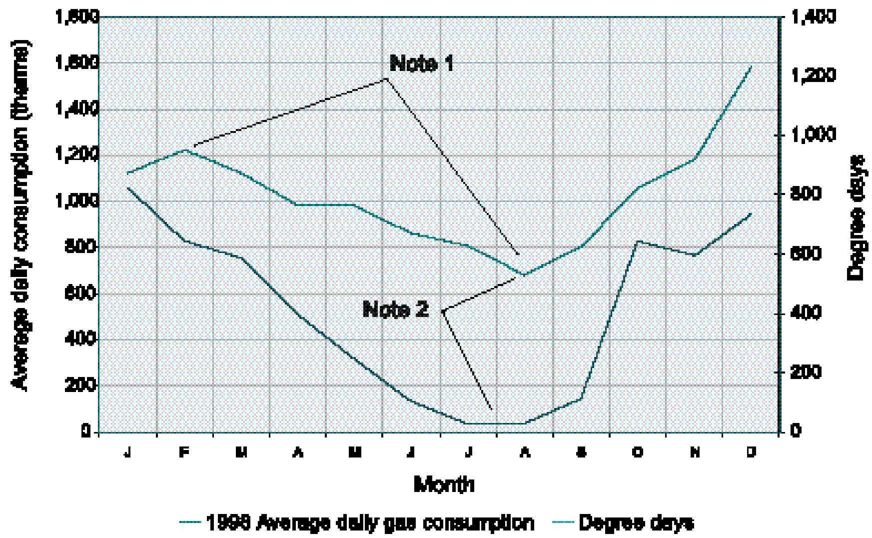
Energy Tracking

Though not part of a typical inspection, tracking building utility patterns is an easy way to flag deviations from intended performance.

Though not part of a typical inspection, tracking building utility patterns is an easy way to flag deviations from intended performance. One way to do this is to normalize the utility bill data to coincide with the calendar month and divide it by the number of days in the month to produce an average daily energy consumption. This allows the data to be compared to monthly weather information and keeps the data intervals uniform and consistent from year to year. If the building is not modified significantly, energy consumption rates should be consistent from year to year with differences attributable to seasonal weather variations. A sudden increase in consumption could indicate a problem or unintended operational change that needs to be investigated and corrected. The shape of the curves and the relative magnitude of the high and low points can also reveal a lot about a building's efficiency. **Figures 12 and 13**, page 29, are examples that identify inefficiencies not previously noticed by the owner and operators.

Figure 12: Average daily gas consumption

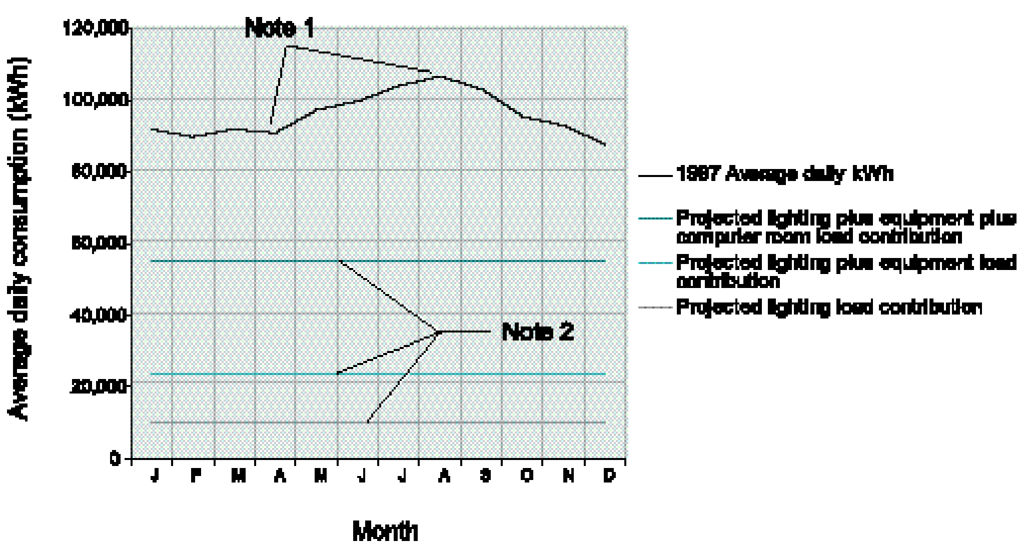
In a typical office building, the peak in the gas curve should occur in the winter (assuming gas is used to heat). The shape of the curve should be similar to the degree-day curve that is superimposed on the graph. In the summer, there should be very little gas consumption since there is no heating load. A high valley or base load on the gas consumption curve could indicate a problem. This office building has no labs or process loads, but its summer gas consumption was over 50% of its gas consumption on the coldest winter day (Note1). The degree day curve goes to nearly zero in the summer indicating no heating load, but the consumption curve remains quite high (Note2).



Source: PECI

Figure 13: Average daily electrical consumption

The electric seasonal peak should occur in the summer when mechanical cooling is used. High base load consumption probably indicates equipment is operating harder than it needs to or is running at a time when it could be scheduled off. In this building, the high valley in the electrical consumption curve relative to the summer peak may indicate high, non-season related consumption (Note 1). Simple hand calculations can often be used to identify some of the components of the base load. In this case, there are 35,000 to 50,000 kWh per average day that cannot be accounted for by lighting, office equipment, and computer room loads. In addition, these loads are a significant portion of the base load and may merit some investigation (Note 2).



Source: PECI

For More Information

National Environmental Balancing Bureau

NEBB publishes guidelines, standards and model specifications for environmental systems balancing. Of particular interest with regard to field review is the *Testing and Balancing Manual for Technicians* which discusses both the theory and practice of balancing.

8575 Grovemont Circle
Gaithersburg, Maryland 20877
Phone: (301) 977-3698
Fax: (301) 977-9589
www.nebb.org

Portland Energy Conservation Inc.

PECI has been a leader in developing commissioning methods that can be used during the construction process to assure that the project achieves design intent. The techniques can also be applied to existing systems in a retrocommissioning format. Their web site includes guide specifications and test procedures, which can be downloaded. The site also contains links to other commissioning related sites and resources.

921 SW Washington Street
Portland, Oregon, 97205
Phone: (503) 248-4636
Fax: (503) 295-0820
www.peci.org

PG&E Pacific Energy Center

The Energy Center contains numerous resources including a tool lending library and laboratories. The tool lending library is a particularly useful resource for field testing. It offers a wide variety of test equipment for facility commissioning and diagnostic testing of buildings and building systems. The Center also has a reference library that contains numerous reference books, technical bulletins, case studies, and publications about energy efficiency in building design and construction. Many of the references cited in this document and the other briefs in this series can be found there. In addition to the libraries, the Center sponsors an ongoing series of seminars related to energy conservation issues. Many of these seminars use the hands-on laboratory facilities at the center.

851 Howard Street
San Francisco, CA 94103
Phone: (415) 973-7268
www.pge.com/pec

Energy Design Resources

This brief is part of a design brief series that provides useful information regarding energy efficient design and operation. Of particular interest relative to this brief are Design Details, which discusses detailing techniques which provide more efficient HVAC systems and Design Review, which provides information on techniques to ensure that energy efficient details are properly depicted and interpreted.

www.energydesignresources.com

Notes

1. Sheet Metal and Air Conditioning Contractors National Association (SMACNA), *HVAC Duct Construction Standards* (1995), SMACNA, 4201 Lafayette Center Drive, Chantilly, Virginia 2015101209, tel 703-803-2980, fax 703-803-3732, web site www.smacna.org and American Society or Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), *1988 Handbook of Equipment*, Chapter 1 (1988), ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, tel 404-636-8400, fax 404-321-5478 web site www.ashrae.org.

2. David W. St. Clair, *Controller Tuning and Control Loop Performance* (1993), Straight-Line Control Company, 3 Bridle Brook Lane, Newark, DE 19711-2003, web site www.members.aol.com/ pidcontrol.

Energy Design Resources provides information and design tools to architects, engineers, lighting designers, and building owners and developers. Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison under the auspices of the California Public Utilities Commission. To learn more about Energy Design Resources, please visit our Web site at www.energydesignresources.com.

This design brief was prepared for Energy Design Resources by Portland Energy Conservation, Inc. (PECI), Portland, Oregon.