energy**design**resources

design brief

DESIGN REVIEW

Through design review, owners can maximize a building's energy efficiency and save both capital and operating costs.

Summary

Energy-efficient design can be improved by design review. A process of review both enhances design and fosters communication between designers, owners, and builders. As a result, design review helps ensure that an energy-efficient design is implemented correctly in the field.

Design review may entail:

- Internal checks of calculations, specifications, and drawings by the project engineer
- Peer review of the calculations, specifications, and drawings
- Construction phase review of coordination drawings and shop drawings

In one sample office, an internal check of cooling load calculations resulted in more efficient design. The project engineer revised loads based on actual observed occupancy and hours of operation rather than hypothetical extremes. The new load profile revealed energy savings to be gained by reducing the terminal equipment minimum flow setting to match actual ventilation and cooling requirements. In a 15,000 square foot office building, this internal check could eliminate over $1,000 per year in unnecessary fan and reheat energy, while increasing occupant comfort. Through design review, owners can maximize a building's energy efficiency and save both capital and operating costs.

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Introduction

Proper detailing of energy-efficient design is an important first step toward realizing energy-efficient buildings. Yet many excellent design ideas have been lost in translation as a project moves from concept to completion. Design review can help ensure clear communication throughout the design process. By providing checkpoints along the path to completion, design review increases the likelihood that the building will deliver the energy efficiency and performance the owner intended.

The most fundamental and on-going review is the internal check of evolving calculations, drawings, and specifications. A project engineer typically begins a project by documenting initial design decisions. This process includes documenting estimates of system loads, developing a system schematic, developing a sequence of operation and control system points list, developing preliminary equipment schedules, and estimating budgets. Because many projects run on tight schedules, project engineers often delegate further development of the design to others on the design team. This introduces the possibility for misunderstanding or misinterpreting the project engineer's original intent. By reviewing calculations, specifications, and drawings, project engineers can guarantee that their ideas are properly represented on the contract documents. Specifically, the project engineer may wish to:

- Review calculations of system loads.
- Verify that the evolving design details accurately reflect their ideas.
- Verify that the mechanical design is coordinated with the architectural, structural, and electrical design.
- Verify that the control system points list reflects the project requirements.

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- Verify that the control system operating sequences accurately reflect the requirements of systems and the loads they serve.
- Verify that the specification details reflect the equipment performance requirements.
- Verify that the project appears to be within budget.
- Spot check the equipment selections.

In addition to ongoing internal checks, many larger projects use peer review to bring a second set of eyes to the design process. Peer review assures both the design team and the owner that nothing obvious has been overlooked and provides a chance to catch problems while they are still on paper, and less expensive to remedy.

Finally, participating in both the coordination drawing process and shop drawing review serves as a final check to ensure the building will meet the design intent. Coordination drawings resolve potential conflicts between the structural, mechanical, and electrical systems. Shop drawing review ensures that all equipment selections are optimized to the needs of the project. By carefully reviewing shop drawings, the designer can verify that subtle differences between project specifications and substituted equipment do not compromise the design intent.

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This brief will explore these review processes—internal checks, peer review, and construction phase review—in greater detail and identify some of the energy and resource savings that can result.

Internal Checks of Calculations, Specifications and Drawings

Project calculations, specifications and drawings are constantly in flux during design. Architectural dimensions and wall locations may shift as the architect develops the design to meet the owner's needs within the framework of construction and code requirements. These changes travel downstream to the mechanical, electrical, and structural designs, which must shift to accommodate them. In addition, the mechanical and electrical designers are constantly revising their designs as they finalize their calculations. To ensure that the evolving design continues to reflect the original design intent, including implementation of the details and features required for energy efficiency, the project engineer should review project calculations and progress check sets of the contract drawings. To review a progress check set, the drawings, specifications and other pertinent documents are printed in their current state. The project engineer can then conduct a detailed sheet by sheet review of all documents, or spot check key areas with further review based on these results. This review may occur several times during the design process, and should always include a final check set of the contract documents.

A reduction in the size of an HVAC system in the early stages of design can have a ripple effect throughout the project, reducing the electrical capacity required for the system itself and the entire electrical service, if the change is significant enough.

Review Load Calculations

Early in the development of construction drawings, designers perform detailed load calculations. A review of the calculations by the project engineer can reveal opportunities to reduce energy and operating costs. In addition, the analysis may reveal the opportunity to reduce the first costs of the Heating, Ventilation and Air Conditioning (HVAC) and electrical systems. A reduction in the size of an HVAC system at this stage can have a ripple effect throughout the project, reducing the electrical capacity required for the system itself and the entire electrical service, if the change is significant enough. These savings can keep a project in budget and release money for other energy-conserving or architectural features that were previously unaffordable.

Traditionally, ventilation, cooling, and heating loads are calculated based on worst case scenarios. Cooling loads are calculated with all equipment operating at or near nameplate values, occupant loads are assumed to be at a maximum, and often, these conditions are assumed to exist 24 hours per day. Heating loads are calculated at the other extreme. Little credit is taken for internal gains, infiltration is assumed to be high, and extreme outdoor conditions are assumed to prevail 24 hours per day.

Ventilation loads are often driven by code and the designer's understanding of the maximum number of occupants that will be in any given space. Lacking occupancy information, designers may assume all chairs in an office or conference room are filled.

While it is certainly important for the designer to understand the extremes facing a system, a significant amount of energy can be saved over the life of a building if these peak loads are tempered with an understanding of the real daily load profile. Specifically:

- The real operating loads associated with equipment are seldom at their full nameplate values. For example, a personal computer with a nameplate rating of seven or eight amps may draw only two or three amps on average.

- Thermal time lags associated with how heat enters or leaves a space can significantly affect peak cooling loads. Building mass tends to delay and diminish the effects of outdoor peaks. In addition, internal heat gains are at least partially delayed. When lights or a piece of equipment are turned on or people enter a space, the latent heat they emit tends to place a nearly instantaneous load on the space. However, the impact of the sensible heat they emit will be delayed through some fairly complex thermodynamic and heat transfer interactions. These effects, when combined with the scheduled nature of most loads, can significantly shift and reduce peak cooling loads.

- Real occupant loads are seldom as high as design loads. For example, an office plan may show a chair at every desk, as well as one or two other chairs for visitors. In most cases, the visitors' chairs will be empty most of the time. In addition, the conference area may be empty or used at less than maximum capacity for many hours of the year. Observations of conference rooms reveal that they are used about half of the time during which the building is occupied. The actual occupant load is usually about one third of the maximum seating capacity and these occupants tend to come from nearby offices.[1]

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All of these effects can be accounted for either by using computer based hour-by-hour load calculations or by manual calculations such as the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Transfer Function Method, described in the ASHRAE Fundamentals Handbook.[2]

To understand the impact of these effects on load calculations, let's look at a typical interior office and a typical perimeter office located on the west side of the building.The characteristics of the loads that the offices see are summarized in **Table 1**. In addition to the indicated internal gains (people, lights and equipment), the office with the western exposure will also see external gains and losses through the walls and windows. Note the differences between the design loads and actual loads for both people count and the office equipment.

The load profile is significantly affected by considering the actual, observable operating environment.

Table 1: Cooling loads in sample offices

Observed occupancy and equipment current are significantly lower than design.

Item	Design	Actual
Number of people	2	1
Lighting level	1 W/SF	1 W/SF
Computer current	6 amps (nameplate)	0.5 amps (avg per reading)
Monitor current	2 amps (nameplate)	1.5 amps (avg per reading)

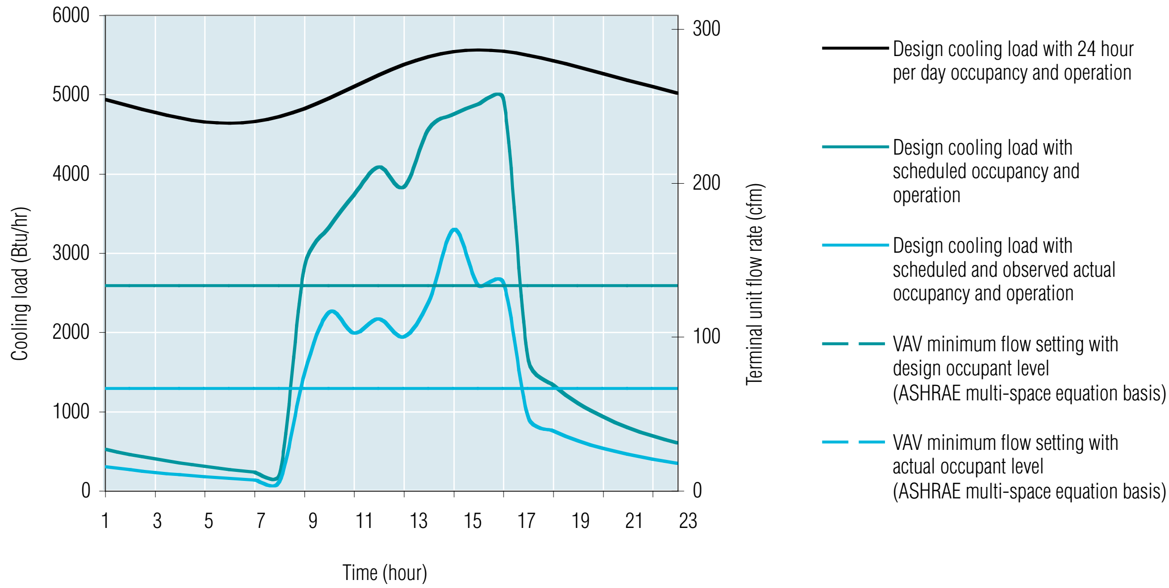
Source: PECI

We calculate the load for these spaces using three different approaches. The first assumes that equipment draws the nameplate current and all seats are occupied. We assume these conditions persist 24 hours per day. The second uses the same equipment and occupancy assumptions, but schedules occupancy and operation of lights and appliances to reflect the anticipated use of the space. Finally, we calculate the loads based on the measured power consumed by the office equipment and the actual occupant count typically seen in the space. San Diego summer design conditions (99° F) are used for all the calculations.[3]

The results of these analyses for a typical interior office and a typical perimeter office are depicted in **Figures 1 and 2**. Note that the predicted load is significantly affected by considering

Figure 1: Interior office cooling loads

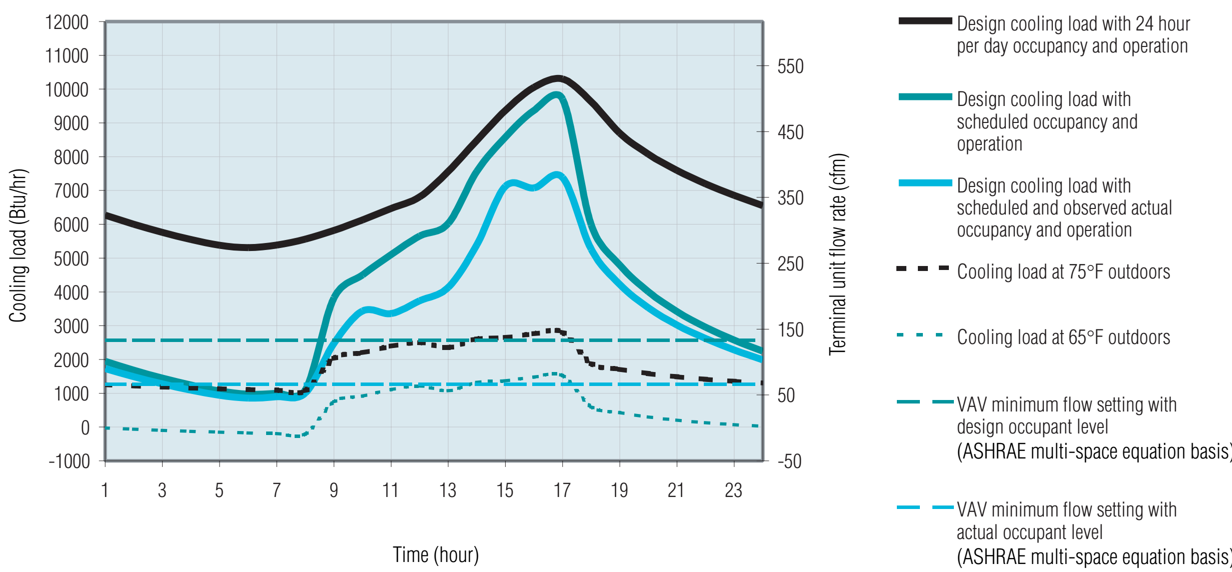
Actual observed loads can be much smaller than worst-case scenario loads. In this case, the ventilation rate based on actual occupancy is half the rate based on design occupancy. At the higher VAV minimum flow setting, the cooling capacity of the ventilation exceeds the actual cooling load, thus the air must be reheated to some extent. The lower VAV minimum flow setting eliminates this inefficiency much of the time.



Source: PECI

Figure 2: West exposure office cooling loads

Because this perimeter office experiences external heat gains, the actual cooling load is closer to the design cooling load. However, a minimum flow rate based on actual occupancy still saves reheat and fan energy. The lower flow setting allows the terminal to function in a variable flow mode rather than a reheat mode at temperatures above 65°F outside. The higher flow setting requires reheat until about 75°F.



Source: PECI

the actual, observable operating environment. The effects are much more significant for the interior space load since it is not influenced by any solar or transmission loads. If these "reality-based" loads can be expected to persist unchanged over the life of the building, it may be possible to reduce the size of the terminal equipment and the central system. Even if designers choose to retain flexibility and not reduce the terminal or central system sizes, the reduction in initial design settings will achieve significant operating savings by reducing the need for fan and reheat energy.

Reducing the minimum flow setting to reflect the more typical single occupant level would save both fan energy and reheat energy.

The savings potential is even greater when revised cooling loads are combined with ventilation rates reflecting actual occupant counts. Although each office has two chairs, typically only one is occupied. Most codes allow actual occupancy levels to determine ventilation requirements; thus, the minimum ventilation rate could be cut in half.

Ventilation rates required by code are plotted in **Figures 1 and 2**, page 7. Typical code for our sample office requires 20 cubic feet per minute (cfm) of outdoor air per occupant. If the office is served by a 30 percent minimum outdoor air system, the minimum flow setting for the terminal unit would be 67 cfm for one occupant, and double that for two. Note the relationship between the flow settings and the cooling capacity: 133 cfm of supply air provides over 2,500 Btu/hr of cooling.

Let's look more closely at the relationship between the ventilation rate and the flow requirements for the different cooling loads in each space. If the variable air volume (VAV) minimum flow setting for the interior office is at the higher level associated with two people, it provides more cooling than the actual load condition, except for a few hours in the afternoon. The air handler spends a significant portion of time moving air that it does not need to move to meet the cooling load. To make matters worse, most of the time, this air is reheated to some extent. Reducing the minimum flow setting to reflect the single occupant level would save both fan energy and reheat energy. At

9¢/kWh, this would save $10 to $12 per year for just this office alone. In a 15,000 square foot office building, this could easily add up to over $1,000 per year or a present value of over $31,000 over a 20 year building life at a 5 percent interest rate.

The implications for a perimeter office are less significant, yet there are savings to be gained. At outdoor temperatures above 65°F, the perimeter office requires cooling flow above the minimum ventilation setting based on one occupant (See **Figure 2**, page 7). But if the minimum ventilation setting were based on two occupants, the cooling capacity of the ventilation flow would exceed the cooling load until outdoor air temperatures were closer to 75°F and reheat would be required up to this point. In the San Diego area, there are approximately 800 hours per year between 65°F and 75°F during typical office occupancy hours.[4] If the terminal unit minimum ventilation setting were at the higher level, then the unit would spend most of these 800 hours wasting energy in a reheat mode when it could be in a variable flow cooling only mode.

Verify Design Details

The detailing of design drawings can significantly impact a building's energy consumption. (See Design Brief *Design Details* for a full discussion of this topic.) Targeted spot checks enable the project engineer to quickly assess whether the desired design details have been incorporated. Critical areas to target include:

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Mechanical Rooms: Mechanical rooms are typically some of the most complex spaces associated with a project. In addition, since the central equipment is located here, the ductwork and piping carries large volumes, typically at higher velocities than the branch lines. A bad fitting or bad detail here will have a much more significant impact on a system's energy consumption than a bad fitting or detail in a small pipe or duct at the end of a system.

Duct and Piping Chases: Space is at a premium in the shafts that allow pipes and ducts to travel vertically through a building.

Chases tend to run in the core of a building, which often contains many of the structural elements of a building's seismic load-bearing system. The structural shear walls and heavy beams in this area, combined with the architectural desirability of high ceilings, can lead to a very narrow duct path out of the chase, which can push duct velocities even higher than they were in the riser duct. This velocity increase triggers a pressure drop precisely where it is least desirable: at the transition fittings and dampers that are required to tap the riser and exit the chase. Careful detailing is required at these points to assure that the fittings minimize system pressure drops.

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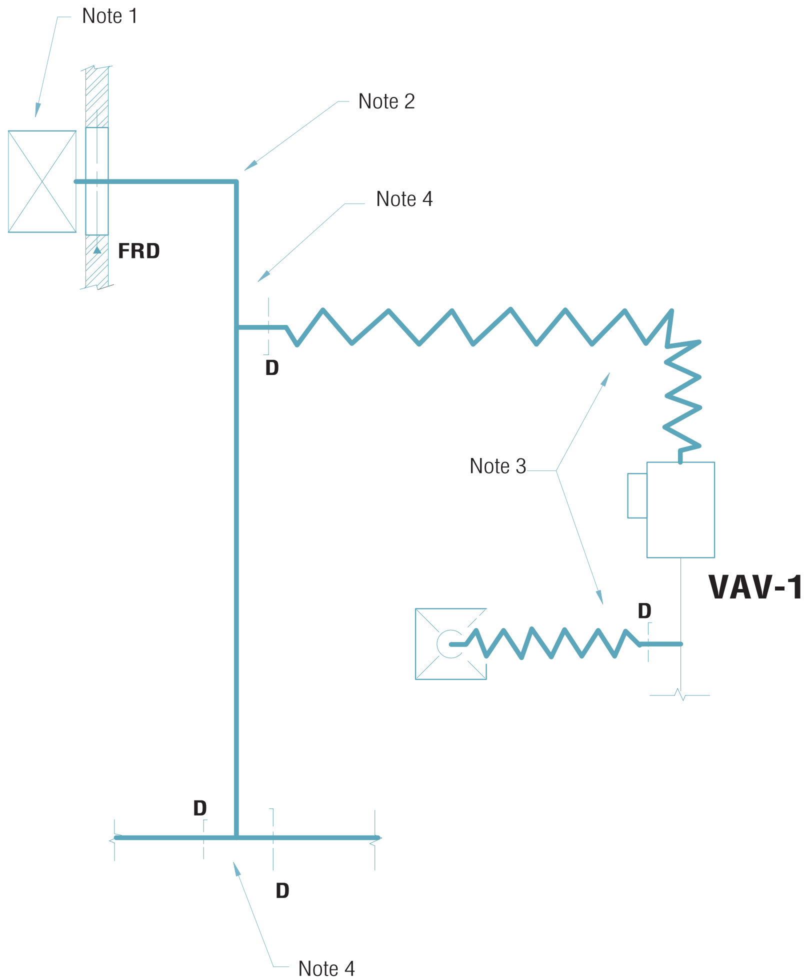
Typical Distribution Systems: The potential for dramatic adverse impacts on the central system is lower in the distribution ductwork and piping due to the lower flow rates and velocities. However, since the techniques used to divide the system flow at branch locations or make connections to terminal units will occur at every branch and terminal location, the potential exists to replicate a problem hundreds of times throughout the project.[5] The cumulative impact of such a replication can be as significant as the impact of a bad feature at the central equipment.

In each of these key areas, the project engineer should check that drawings are sufficiently detailed. Consider the duct arrangements shown in **Figures 3 and 4**, pages 11 and 12. For ease of interpretation, duct dimensions are not shown in the illustrations. Both figures depict the same section of ductwork. **Figure 3** uses a "single-line" technique, while **Figure 4** uses a "double-line" technique, which shows much more fabrication detail. Although the single-line drawing is quicker to develop, it leaves much of the duct fabrication detail up to the installer. Under pressure to meet a tight construction schedule, field staff may solve fabrication problems with fittings that have significantly higher pressure drops, resulting in systems with higher energy consumption. Even if the specifications call for more efficient fitting details such as turning vanes and low-pressure take-off fittings, if these details are not shown on the

Figure 3: Non-detail oriented duct layout drawing

This single line drawing leaves much of the duct fabrication detail to the discretion of the installer.



Source: PECI

1. The duct riser connection is not detailed. Lacking additional information, the installer will most likely use a straight tap due to ease of fabrication. This fitting can have significantly higher pressure drops than a divided flow fitting, adding operating cost to the system for its entire life.

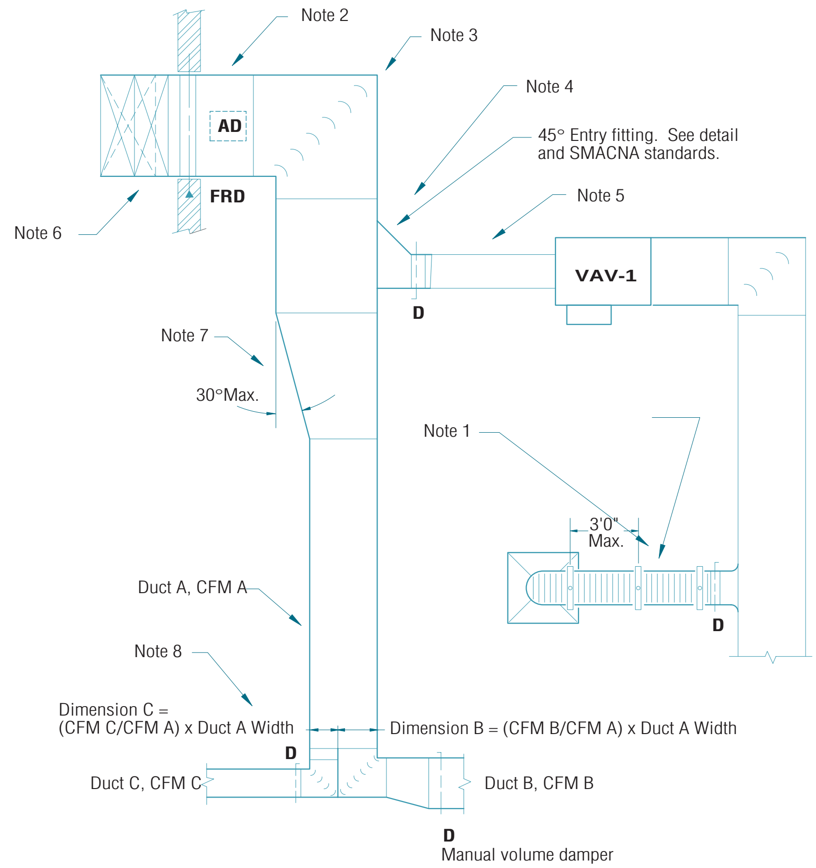
2. In a single-line drawing, turning vanes cannot be indicated visually. Even if the specifications require them, the installer may miss the requirement. The lack of turning vanes can be difficult to detect after installation, especially if the duct is externally insulated. If the fan has sufficient reserve capacity, the balancer may simply speed it up to overcome the problem, thus penalizing the system with an unnecessary energy burden for the rest of its life. If the fan doesn't have sufficient excess capacity, the system may not be able to achieve design performance.

3. Long flex duct runs are subject to high pressure drops due to the nature of the material and sag between the supports. In addition, the sharp bend ahead of the VAV terminal distorts the flow profile entering its flow-measuring element, resulting in calibration errors and inconsistent indications. This can waste energy since the actual delivered flow may be higher than the required set point. Indoor air quality problems can result if the delivered flow is below the required set point.

4. The flow division is left to the discretion of the installer. Straight taps or splits with expanding elbows will often be provided, due to ease of fabrication. These fittings can have very high pressure drops.

Figure 4: Detail oriented duct layout drawing

Double line drawings allow designers to clearly communicate design details.



Source: PECI

1. Flex duct length limits and support requirements control pressure drops due to duct sag and excessive length.
2. Fire damper access is shown.
3. Turning vanes are shown, assuring a lower pressure drop fitting than a mitered elbow without them.
4. A low pressure drop take-off fitting minimizes the loss through the branch connection.
5. The manufacturer's recommended straight duct length is shown entering the VAV terminal unit. This assures that the terminal unit flow-measuring element is accurate. Thus, the unit will control to the desired set point, minimizing fan energy and reheat (for units equipped with reheat coils) and helping to meet indoor air quality requirements.
6. A flow dividing type fitting is shown for the connection to the riser duct in the duct shaft, resulting in a much lower pressure drop through the branch connection than a straight tap.
7. Transition angles are specified, assuring low pressure losses through the transition.
8. A flow dividing type fitting is shown with non-expanding elbows, assuring low pressure drops through the flow division.

drawings, they may not be installed. On most projects, the drawings are more readily available than the specifications and tradesmen are much more likely to consult the drawings than attempt to read through hundreds of pages of specification in search of design detail. Thus, a well detailed, double-line duct drawing is more likely to result in the project engineer's desired energy performance.

Despite the obvious advantages of double-line drawings, the extra production time required may discourage project engineers. However, there are compromises that minimize production costs, while taking steps toward assuring a superior design. If the duct systems in the mechanical rooms, shafts, and main runs are drawn double-line, drawing the remainder of the system as single-line duct may not result in significant energy burdens or performance problems. Similarly, piping circuits do not always require double-line drawings. A single-line piping diagram showing scaled fitting lines and isometrics for critical equipment may adequately convey the project engineer's requirements because piping systems are generally fabricated from standard fittings (as opposed to duct systems, which are often made from custom fittings).

Standard details can provide the necessary detail for very little engineering effort beyond the initial investment to develop them. For example, the double-line drawing of a duct layout, shown in **Figure 4**, can be turned into a standard detail fairly easily. Once developed, a standard detail can be used on subsequent projects, (with appropriate modifications to match the project requirements) thus amortizing its development cost. Checking standard details is crucial because they will be replicated over and over, sometimes hundreds of times. Thus, a mistake or error in the detail will also be replicated hundreds of times. With each use, these details should be reviewed and edited to match the specific project requirements. The title and captions should clearly indicate where they do and do not apply.

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The following true story illustrates this point. A manufacturing company needed to build a new plant on a very short schedule. The owner requested redundancy for critical systems so that maintenance could be performed without shutting down the entire system. The designer decided to use a standard detail from a previous similar project for the steam coils on the critical systems. The standard detail showed redundant steam traps with isolation valves on both sides, manual bypass valves around the control valves and traps, and service valves on each side of the control valves to allow servicing while the system was operated via the manual bypass. Unfortunately, the detail was labeled *Typical Steam Coil Piping* with a note indicating that it applied to ***all*** steam coils on the project. Thus, a detail intended to apply only to a handful of primary, 100,000 cfm air-handling systems on the site was applied to every single steam coil. The $400 unit heaters had $4,000 of pipe valves and fittings associated with them, although most served no useful function and will waste thousands of dollars of energy due to bypass valve leakage and on line losses (not to mention first costs).

Verify Coordination Between Design Specialties

The process of design review includes a spot check to verify that the mechanical design is coordinated with the electrical, structural, and architectural design.

The process of design review includes a spot check to verify that the mechanical design is coordinated with the electrical, structural, and architectural design. Many of the following coordination checks will ensure energy efficiency in addition to verifying systems integration:

- Is the structural support adequate in the areas where mechanical equipment will be located?
- Do the architectural and structural details provide the necessary sound isolation and moisture protection in mechanical areas?
- Are intake and exhaust penetrations through walls adequately sized to prevent high pressure drops and moisture penetration?
- Are chase sizes large enough to allow adequately sized ductwork?
- Are the structural clearances around chases and other areas with large duct and piping mains sufficient to allow the systems to be installed without high pressure drops?
- Is there sufficient space above the ceiling and below the structure to allow the necessary mechanical system to be routed in conjunction with the electrical, plumbing and specialty systems without an excessive number of offsets and/or restricted duct sizes?

- Have general rules been established for routing ducts, pipes, conduits and specialty systems through the ceiling cavity? If so, do they meet the requirements of the mechanical systems?

- Is there a suitable access route to allow worn-out equipment to be removed and new equipment to be installed? Does this route contain adequate structural strength to support the equipment that might be moved through it?

- Are the electrical service requirements coordinated with the requirements of the mechanical systems in terms of voltage, capacity, reliability, and source? An air-handling system that has its fans powered by the emergency system, its Direct Digital Control (DDC) controllers powered by an Uninterruptible Power Supply, and an interlock circuit on normal power may experience a few problems when there is a momentary power surge on the utility line.

- If the project will use variable speed drives, who will specify them? If the drives require isolation transformers or line reactors, who is responsible for sizing and specifying them?

- Have the motor horsepower requirements changed since design development?

- Has the type of starter that will be used for large machinery been coordinated with the electrical designer? Often, changing the type of starter or the voltage that is used to serve a large motor can improve electrical system performance and reduce first costs.

These coordination issues have ripple effects with significant implications for energy and resource conservation. For example, if a coordination problem between a mechanical system and a structural element is not resolved at design, the field solution may require additional fittings. These fittings will introduce pressure drops that will persist for the life of the system or possibly the life of the building. As another example, consider an equipment room with a poor access route. The lack of suitable access may delay

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the replacement of an existing, outdated piece of equipment with a more efficient machine simply because the cost to bring the new equipment into the building is too high.

Review Control System Sequences and Point Lists

Design review should include a check of the evolving control sequences and point lists to be sure they clearly reflect the performance levels and energy efficiency envisioned during design development. Even if the final control system design is delegated to the controls contractor, the HVAC design team must clearly specify the system's requirements in the contract documents. These include accuracy requirements, psychrometric requirements, process requirements, sequence requirements, and data handling and monitoring requirements.

To fully develop the control system requirements, engineers must consider HVAC operation under all possible modes and potential conditions, including extremes beyond design.

Most systems spend considerable time serving loads at conditions other than design. To fully develop the control system requirements, engineers must consider HVAC operation under all possible modes and potential conditions, including extremes beyond design. Outdoor design values represent statistical averages, which are frequently exceeded for brief intervals. When reviewing the system's requirements, a project engineer might ask the following questions:

- Where actuators are to be sequenced, will the sequencing be accomplished in the controller software or in the actuator hardware?
- Are stand-alone safeties provided to function independently of software, control switches, and other influences, to guarantee a shut down and lock out of the system if there is a serious problem?
- Can efficiency or performance benefits be realized by automatically adjusting control loop set points based on some measured or calculated parameter? If so, what are the parameters and when should they be in effect?

- Are there critical settings for certain parameters such as flow, temperature and pressure that must be maintained regardless of the other requirements? Does the sequence clearly define them and indicate how to accomplish this?
- Does the arrangement of the system components (coils, filters and fans) have significance from a psychrometric or process standpoint? (For example, is the heating coil in the preheat or reheat position?) If so, does the sequence address the psychrometric requirements of the component's location in the most efficient manner possible?
- Are there transient conditions requiring an independent control loop that only activates when the transient condition occurs?
- Are there times when portions of a control sequence should be disabled or over-ridden based on process requirements or environmental conditions?
- What positions should the various actuators return to when the unit is shut down? Are these positions the same positions that the actuators should fail to upon loss of power?
- Are there any sensing points not required directly to control the system but required for operations and monitoring?
- Should set points be adjustable without reprogramming the system?
- What type of control algorithm should be used?
- Are alarms appropriate? If so, what points should they apply to, and what should the set points be?
- Should certain alarms be disabled under certain conditions?
- Should "smart alarms" be provided using the programming capabilities of the system and information from multiple sensors?

- Should any functions be independent of the DDC system?
- Is the complexity of the control sequence commensurate with the ability of the people who will have to operate the system?

Let's look at a non-detailed discharge temperature control sequence and consider how answering these questions might improve it.

> **Air Handling Unit (AHU) 1**
> **Discharge Air Temperature Control**
>
> **The control system shall modulate the economizer dampers, hot water valve and chilled water valve in sequence as required to maintain the discharge air temperature. The discharge air temperature shall be reset from 55°F to 65°F as a function of the outdoor air temperature.**

This sequence is typical of what is found on contract documents, and at first glance, seems reasonable. But, there are many unanswered questions.

Will one output serve all actuators with the sequencing achieved by the actuators' hardware, or will sequencing be accomplished via software with independent outputs provided for each actuator? Providing one output will entail a lower first cost, but much less flexibility for solving future problems. The additional cost associated with providing independent outputs for each function (outdoor air damper, return damper, relief damper, hot water valve, and chilled water valve) will pay for itself many times over during the life of the building. For example, operating pressures often shift the actuator spring ranges, causing the strokes of the various control elements to overlap and waste energy. This problem is much easier to address if changes can be made in software rather than by adjusting positioning relays or start points on actuators (or even replacing actuators if they are not adjustable). The software solution is also much more persistent than a mechanical adjustment which will shift over time due to wear or human intervention.

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Is a freezestat necessary? Most air-handling systems are connected to an outdoor air source and include coils that transfer heat from water or steam to the system's air stream. Thus, the potential exists to freeze coils not specifically designed to preheat subfreezing air. Protection is typically provided by a freezestat which will shut down and lock out the unit if it detects air near freezing. Freezestats are installed downstream of any preheat coil but ahead of other coils in the system. (Preheat coils should not be confused with warm-up or reheat coils, neither of which are designed to handle freezing air.) Even if the unit does not have water coils, a freezestat may still be desirable to prevent an undetected malfunction from circulating freezing air into the building. When this happens, the plumbing and sprinkler systems in the area can be destroyed and severe water damage may occur.

Even if the unit does not have water coils, a freezestat may still be desirable.

What outdoor air temperature range affects the reset of the discharge temperature and what happens outside of this range? The designer probably knows the relationship between outdoor temperature and the discharge temperature required to meet the system's loads. However, if the relationship is not specified, it will either be found by experimentation in the field or it will never be found. As a result, the system may waste energy or fail to perform under certain operating conditions.

Is the reset schedule in effect year round or only when dehumidification is not an issue? Under humid conditions, a discharge temperature of 65°F can cause humidity control problems, even though it may meet the sensible cooling needs of the load. If this is the case, then the reset must be modified or disabled when dehumidification is an issue.

How is the minimum outdoor air setting for the system maintained? Indoor air quality requirements dictate a mandatory minimum outdoor air percentage for most air handlers. Some codes require that this be positively controlled. The sample control sequence does not address this issue and how it will be coordinated with the sequencing of the valves and dampers.

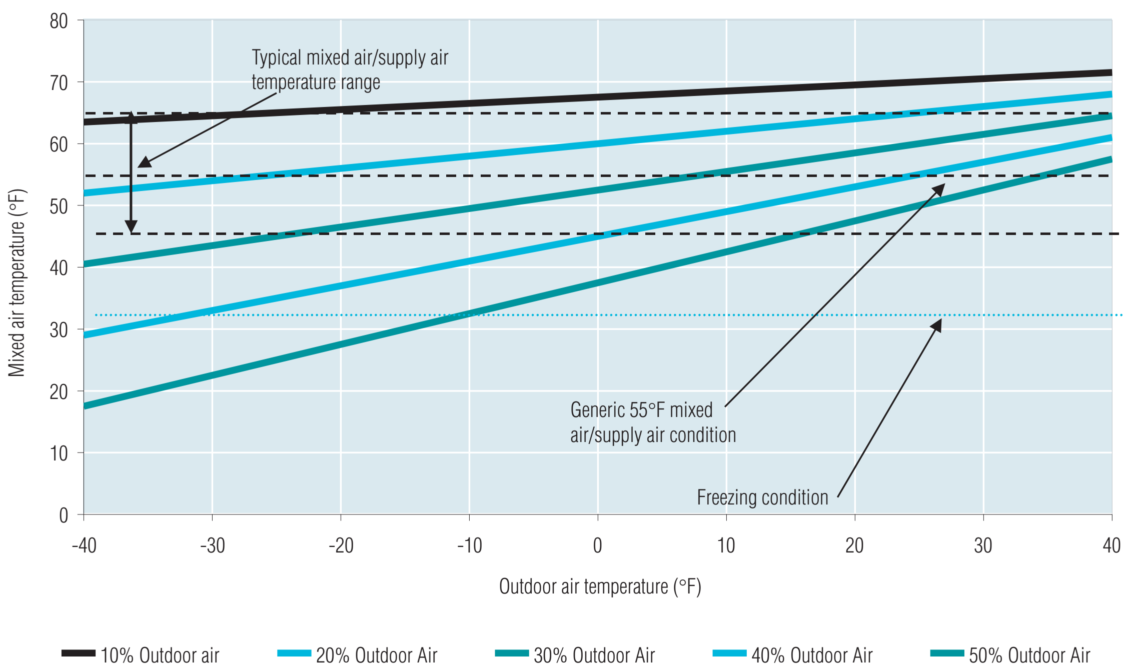
Is the heating coil in the reheat position or the preheat position? If the heating coil is ahead of the chilled water coil, then it will function to preheat the air entering the chilled water coil to protect the coil from freezing during extreme winter weather. Usually, freezing is only an issue for systems with high percentages of outdoor air, as illustrated by **Figure 5**.

If the heating coil is downstream of the chilled water coil, it will not be able to protect the chilled water coil from freezing, but it will be able to reheat the air. The reheat function should only be necessary when the chilled water coil is cooling the air more than the cooling load requires, in order to dehumidify the air. An optimized controls sequence will clarify the heating coil's function and provide interlocks that simply close the hot water valve when it is not needed, thereby assuring that simultaneous heating and cooling will not occur unless required for a reheat process.

Is a mixed air low-limit function necessary? Controlling all of the various elements of an air-handling system based on AHU

Figure 5: Mixed air temperature vs. outdoor air temperature at various outdoor air percentages

Mixed air temperature rarely falls below freezing, except in systems with a high percentage of outdoor air and extreme outdoor conditions. Since most air-handling units serving occupied offices have minimum outdoor air settings of 30% or less, the mixed air will rarely be anywhere near freezing.



Source: PECI

discharge temperature eliminates many simultaneous heating and cooling problems. However, there is one problem associated with this approach which occurs at start-up during cold weather. Consider an air-handling system that is equipped with an economizer and operates on a schedule, when it is started with outdoor air temperatures that are below freezing. Overnight, while the system is shut down, the air in the vicinity of the discharge sensor tends to stabilize in the 65°F to 75°F range for most mechanical rooms. When the system restarts, the discharge temperature sensor sees that the discharge temperature is significantly above set point (usually in the 55°F to 60°F range) and begins to drive the economizer dampers toward the 100 percent outdoor air position. Since there is some distance and much warm equipment between the mixed air plenum and the discharge sensor, it will take some time for the discharge temperature to drop to match the mixed air temperature in the plenum. The unit will stay at the 100 percent outdoor air position until the temperature at the discharge sensor drops toward the discharge temperature set point. However, since the freezing outdoor air is delivered directly to the mixed air plenum, the mixed air temperature will quickly drop below the set point of the freezestat. The unit must then be manually restarted. In most cases, it will take numerous restarts before the discharge temperature will drop toward the mixed air temperature and close the economizer dampers in time to prevent a freezestat trip. Frustrated operators may solve the problem in one of several ways: they may defeat the scheduling program, prevent the economizer operation, manually crack the hot water valve open so that there is always enough heating to protect the freezestat, or jump the freezestat. The first three solutions will waste energy. The last solution can lead to freezing the water coils, and in extreme cases, the entire building plumbing system. A mixed air low-limit function would eliminate these problems.

In most cases, it will take numerous restarts before the discharge temperature will drop toward the mixed air temperature and close the economizer dampers in time to prevent a freezestat trip.

Is there a point in the cooling mode when the economizer should be disabled so that the system is cooling a mix of *recirculated air and minimum outdoor air instead of 100 percent outdoor air? If so, how is this decision made?* In most climates there are many periods of time in the summer when it takes more energy to cool and dehumidify 100 percent outdoor air than to cool and dehumidify a mix of return air and minimum outdoor air. If this changeover is not included in the control sequence, the unit will use more energy than is necessary and may not be able to maintain the required space conditions during hot, humid weather. This switch may be triggered when the outdoor air temperature is above the return temperature or the outdoor air enthalpy is above the return enthalpy. It is also possible to assume a fixed return condition (temperature or enthalpy) thereby saving the cost of those sensors. The HVAC engineering team is in a much better position to evaluate these options than the controls contractor.

It is crucial to ensure that when the unit is shut down, the various dampers and valves take positions appropriate for the safety and efficiency of the system.

What positions should the various actuators return to when the unit is shut down? It is crucial to ensure that when the unit is shut down, the various dampers and valves take positions appropriate for the safety and efficiency of the system. If the outdoor air dampers are not forced closed, the area served by the unit may fill with unconditioned air, potentially freezing components or building plumbing systems during extreme winter weather, or causing condensation problems in extreme summer weather. Heating coil valves are often designed to fail fully open when the unit is off line, to help protect the coils from freezing. However, moving water through an inactive coil can waste pumping energy and make the unit difficult to start, especially if there is not a mixed air low-limit control loop. Adequate protection usually can be achieved by placing the heating coil valve under the control of a nearby upstream or downstream sensor at shutdown with a set point in the low to mid 40°F range. This will minimize hot water use. If the chilled water coil is served by a variable flow chilled water plant, it is important to positively close the chilled water valve when the unit is off line. Otherwise, the valve will gradually be driven open since the AHU discharge controller will be attempting to achieve set point, but there will be no air flow to bring the cold air to the sensor's location. This chilled water flowing through the open valve will see no temperature rise since there is no air flow (the unit is off) and therefore no cooling load. This places a thermal "short circuit" into the plant and can cause very significant operating problems.

Are there any points that would enhance monitoring, even though they are not needed for direct control? The desired sequence *could* be achieved with a sensor in the discharge of the air-handling unit to control everything in sequence supplemented by a sensor in the mixed air plenum to provide a low limit function at start-up. However, having a sensor in the discharge of the heating coil would allow an alarm to be generated if the system were simultaneously heating and cooling or if the unit were heating but not on minimum outdoor air. These energy-wasting problems might otherwise go unnoticed, since they could easily be masked by the other elements in the system.

Are alarms appropriate? Monitoring and controls points can easily be programmed to generate an alarm if their value is outside an appropriate range. Typically, the HVAC design team will know the expected operating range at various points in the system, as well as what values or combinations of values indicate a problem.

Are the set points adjustable without reprogramming the system? In most cases, the building operator should have access to the set points and tuning parameters without having to open the program code. This requires the set points to be entered as variables that will be set to appropriate values by operator commands. If adjustable set points are not specified, the controls contractor may assume that they are not desired and simply "hard code" the set points and loop tuning settings into the program, making them difficult and even dangerous to adjust.

Set points and tuning parameters should be entered as variables that will be set to appropriate values by operator commands.

What type of control algorithm should be used? Most current technology control systems are capable of a variety of analog control strategies including Proportional (P), Proportional plus Integral (PI), and Proportional plus Integral plus Derivative (PID). All of the strategies have their place. PID algorithms are very precise and can save significant amounts of energy, but they are also much more difficult to tune, understand and maintain. In our example, PID is appropriate for the overall discharge temperature control loop, but would add unnecessary complexity to the mixed air low-limit loop since the loop only functions on occasion. The HVAC design team is probably in the best position to decide where to apply the various control strategies, although they may need to consult with the controls contractor to understand the pros and cons of the various options.

Are there any functions which should be independent of the DDC system? It is often desirable to have some functions remain independent of the DDC system. For instance, it may be tempting to use the DDC mixed air temperature sensor for a software-based freezestat. But, if the air-handling unit starter is in the manual mode (no longer under DDC control), or the DDC controller has an output board failure, the DDC system will not be able to shut it down, even if it detects a freezing condition. In addition, the sensor that is providing the freezestat function is in some ways trying to monitor itself for a failure. A better solution is to provide an independent, hardwired freezestat that will shut down and lock out the unit regardless of the operating mode or state of the DDC hardware. Generally, all safety devices (including smoke detectors, fire alarm relays, and static pressure cut-out switches) ought to be independent of the DDC system. Similarly, interlocks that return valves and dampers to normal positions when the fan is shut down should also be independent. Triggering these circuits independently of the DDC system makes temporary manual operation of the unit less complex if a controller fails. Plus, the inadvertent shut down of the unit will still place the unit in a safe state with the outdoor air damper closed.

Generally, all safety devices (including smoke detectors, fire alarm relays, and static pressure cut-out switches) ought to be independent of the DDC system.

Very few of these questions directly concern control technology; they are primarily HVAC design and psychrometric issues. In fact, the answers to all of these questions probably seem obvious to the project engineer and designers responsible for the HVAC engineering on a project. Thus, they may not feel the need to address them directly in the operating sequence. However, if they are not addressed directly, they are not likely to be included in the project and problems may result. For this reason, it is a good idea for the project engineer to spot check and review the project operating sequences and points lists as part of the internal review process to be sure that they reflect all of the details required for successful and efficient operation of the system.

Verify Specifications

Most project specifications are developed from a generic specification master that is refined through the design process to reflect the project requirements. Spot checks of the project specifications will help assure that the design team is implementing the project engineer's ideas as intended. Items to check might include the following:

Most project specifications are developed from a generic specification master that is refined through the design process to reflect the project requirements.

Have generic design criteria been modified to reflect the current project? Some of the criteria included in a master specification are truly universal. For example, specifications for piping materials reference industry standards.[6] These can be left as is, or, if the materials will not be used on a project, removed to eliminate confusion. On the other hand, a generic reference to a leaving dry-bulb temperature of 55°F and a leaving wet-bulb temperature of 54.5°F for a cooling coil will need revision to reflect the psychrometric requirements of the project.

Do the specifications reference and use criteria from the applicable codes and standards for the jurisdiction where the building is to be constructed? There are many different national building codes, all of which are updated on a regular two or three year cycle. Different cities use different codes and many do not immediately adopt a new version of a code, so requirements vary with location. The project documents should reflect all of the applicable codes required by the authority who issues occupancy and construction permits. In addition, within a jurisdiction, the requirements of one code can conflict with the requirements of another code, both of which need to be referenced by the contract documents. During the review process, it is important to verify that these conflicts have been resolved in a manner that is satisfactory to all parties.

Are product-specific references current? It is not uncommon for a manufacturer to develop a new version of a product between initial design development and bidding. The new version may have different features and a different model number from the version in the original master specification. If these new features will affect the performance of the design, it is important to review the project specifications to verify that they reflect these changes.

Verify Revised Budgets

During a progress check set review, it is a good idea to re-evaluate the project budget based on the current documents.

As a project develops and more details are finalized, the project engineer can solidify cost projections. During a progress check set review, it is a good idea to re-evaluate the project budget based on the current documents. Equipment sales engineers are usually happy to provide estimating quotes to the engineering team because it enables them to become familiar with the project. Estimates for more generic components such as pipe, valves, and fittings can be based on readily available estimating guides or past experience. A construction manager will often perform the cost projections as a part of their basic service. If there are indications of an over-budget problem, it will be much easier to correct it during the design phase than to deal with bids that come in over budget.

Spot Check Equipment Selections

As a design develops, the final performance criteria for equipment become more precise. Ideally, final selections will be based on a fairly detailed evaluation of the systems' requirements, with a level of rigor appropriate to the significance of the system. However, a project engineer can quickly estimate the final criteria using past experience tempered by the current design documents. By spot checking selected pieces of equipment at various points in the design process, the project engineer can verify that the current equipment selection parameters shown on the plans and specs match the design requirements. If they do not, then the project engineer may want to determine the reason for the difference as well as spot check additional equipment.

By discovering oversized equipment early in design, the project engineer can reduce both the project's first costs as well as its on-going operating costs. Specifically, smaller equipment means that the electrical service and other support system requirements will be smaller. At a minimum, this will impact starters, variable speed drives, and the conduit and wiring runs from the distribution gear to the equipment. These changes may result in smaller distribution gear and transformers that can save both first cost as well as operating cost. Downsizing equipment also has ripple effects throughout the mechanical systems. For example, if the static pressure requirement for a large air-handling system is reduced, then the fan heat (the energy that the fan places in the air stream when it does work on it by moving it through the system) will be reduced. This will reduce the cooling load. If the cooling plant is a chilled water system, the smaller cooling load may allow downsizing of the chiller, the chilled water pumps, the condenser water pumps and the cooling towers. A more precise match between equipment and the load it serves usually results in improved efficiency, since the equipment can be chosen to be most efficient at a point closer to its actual operating point.

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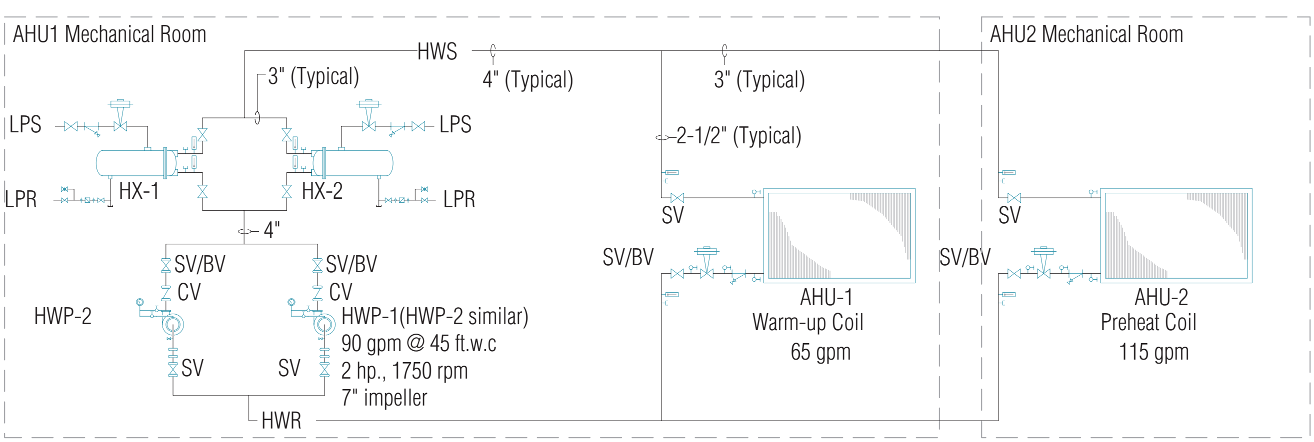
If these equipment changes are made early in the course of a design, it is much easier to take advantage of the ripple effects. If, on the other hand, the change is discovered at the last minute, then even if the equipment is downsized, the ripple effects may not be fully realized since there may not be time or engineering funds to go back and re-size the systems. Similarly, if the equipment is upsized, the ripple effects in mechanical and electrical systems must be addressed and it is much easier to do so earlier in the design process.

Below, we illustrate one technique to spot check a pump selection. A similar approach could be used for air-handling equipment. Consider the heating system shown in **Figure 6**. We will estimate the pressure loss in the system to determine if the pump selection is reasonable. As implied by the two-way valves, the system is a variable flow system. Since 100 percent redundancy is not required, the designer has designed the system with parallel pumps so that together, the pumps handle the design condition. This will reduce the first cost of the system and may allow selection of a pump with optimal efficiency at the part load condition where the system spends most of its operating hours. Due to the nature of pumps running in parallel, if one pump were to fail, the remaining pump would still provide 60 to 70 percent of the required flow. (See the design brief, *Design Details* for additional information regarding parallel pump selections.) Each pump will be selected to provide 50 percent of the design flow requirement of 180 gallons per minute at the full design pumping

Due to the nature of pumps running in parallel, if one pump were to fail, the remaining pump would still provide 60 to 70 percent of the required flow.

Figure 6: Heating System

This heating system design uses parallel pumps. Each pump is selected to provide 50% of the design flow at the full design pumping head. At normal operating conditions, only one pump will be running. Because the pumps are selected to handle only half of the design flow each, they can be optimized for efficiency at a point closer to where they will actually spend most of their operating time.



Source: PECI

head requirement. Specifically, the current pump selection is 90 gallons per minute at 45 feet water column, an estimated head based on the designer's past experience in a similar building.

The design is still in the early stages, but the loads are fairly firm, having gone through the review process described earlier in this brief. The flow rates, pressure drops, and temperature differentials for the heat exchangers and air-handling unit coils are also fairly firm numbers, since they are directly related to the loads. The locations for the various equipment rooms have been determined and are depicted on the architectural drawings. The heat exchangers and pumps are located in the same mechanical room as AHU1. AHU2 is located in a separate mechanical equipment room, closer to the portion of the building that it serves. A general concept of the pipe route between the mechanical rooms has been developed, but the piping runs have not been detailed. Since the AHU2 mechanical room is a significant distance from AHU1, the pressure drop to and from that location will be a significant part of the total pressure loss.

Table 2, page 30, shows the components of our sample heating system and their associated pressure drops.

Pressure loss in the piping mains is estimated by multiplying the equivalent pipe length by the pipe friction rate. Although the exact fitting arrangements are unknown, the flow rates and corresponding piping friction rates are known. And, since the equipment room locations are selected, and the equipment has been positioned within the rooms, the linear piping distance between the various components can be estimated by measuring off the drawings. For example, by looking at the drawings, the project engineer can determine that it will take about 20 linear feet of pipe to get from the heat exchangers to AHU1. The fitting count in this run will be high because of the need to weave around in the mechanical room. But even with a high fitting count, the designer estimates that the effect of the fittings will be no greater than the effect of doubling the actual measured length of the run, based on past experience and information available from sources such as the

Even with a high fitting count, the designer estimates that the effect of the fittings will be no greater than the effect of doubling the actual measured length of the run.

Table 2: Pump head estimate

The pressure loss in our sample heating system can be estimated from the following components. A safety factor of 10% is included.

Item	Estimated pressure loss (ft.w.c.)	Comment	Flow rate (gpm)	Line size (inch)
Heat exchangers	4.50	Based on manufacturer's selection program		
Piping mains from heat exchanger to AHU1	0.84	20 linear feet doubled for equivalent feet due to complex fittings at 2.1 ft./100 ft.	180	4
Piping mains from AHU1 to AHU2	5.44	125 linear feet times 1.5 for equivalent feet due to less complex fittings at 2.9 ft./100 ft.	115	3
Supply side coil piping	1.20	15 linear feet doubled for equivalent feet due to complex fittings at 4 ft./100 ft.		
Coil	7.15	Based on manufacturer's selection program		
Control valve	7.15	Select Cv for pressure drop equal to the coil		
Return side coil piping	1.20	Same as supply side		
Piping mains from AHU2 to AHU1	5.44	Same as supply side		
Piping mains from AHU1 to pumps	0.84	20 linear feet doubled for equivalent feet due to complex fittings at 2.1 ft./100 ft.	180	4
Piping mains from pumps pumps to heat exchangers	0.42	10 linear feet doubled for equivalent feet due to complex fittings at 2.1 ft./100 ft.	180	4
SUBTOTAL	34.18			
Safety factor	3.42	10% of estimated pressure loss		
TOTAL	37.59			

Source: PECI

Notes

Heat exchangers and coil: The estimated pressure loss for the heat exchangers and coil is taken directly from the equipment schedules. These numbers are relatively firm, since they are based on equipment selections for the final load calculations.

Piping: Since the loads are known, the flow rates are also known, thus the pipe sizes can be determined by consulting a pipe sizing chart to match flow with acceptable friction losses. This information is used to estimate pressure loss through the piping run.

Control Valve: In most cases, the control valve needs as much pressure drop as the load it serves to provide linear control. So, it is reasonable to assume that the coil pressure drop and control valve pressure drop will be nearly identical.

Safety Factor: A 10% safety factor is included to cover unknowns and contingencies. This may be reduced as the design progresses and more detail becomes available.

ASHRAE handbook. Thus, the project engineer estimates the pressure loss for this particular section as follows:

> Equivalent length = 20 linear feet of pipe plus another 20 linear feet of pipe to account for the fittings.
>
> Pipe friction rate = 2.1 ft.w.c. of pressure loss for every 100 equivalent feet of pipe, a value taken directly from pipe sizing tables for the design flow rate of 180 gpm in a 4 inch line.
>
> Pressure loss = Equivalent length x pipe friction rate
> = (20 ft.+20 ft.) x 2.1 ft.w.c. /100 ft. = .84 ft.w.c.

A similar procedure can be used for the remaining piping runs with the fitting multiplier (the factor to convert linear length to equivalent length to account for fittings) varied depending on the complexity of the piping run.

This entire effort would probably take an experienced project engineer no more than 10 minutes to accomplish. The result indicates that the required pump head will come down from the design team's current estimate of 45 feet water column. At a minimum, this may change the pump impeller size and pump selection. These steps alone will save first costs. In addition, they will save operating costs because the extra head (the difference between the 38 feet water column and the 45 feet water column) would have been wasted as a pressure drop at the throttled discharge valve, or the owner would have needed to trim the impeller to avoid this penalty.

The reduction from 45 feet water column to 38 feet water column (or 16 percent) represents an overall reduction in pumping horsepower of about 0.45 horsepower, so the motor selections and electrical equipment requirements will probably not be affected. However, this is a small, 180 gallon per minute system. A reduction of similar magnitude (16 percent) on a larger system could easily result in a motor size change and the associated ripple effect savings in first costs. For example, in a 1,500 gallon per minute system, this change could drop the

In a 1,500 gallon per minute system, a 16 percent reduction in pump head could drop the brake horsepower requirements from around 21 to 14 horsepower.

brake horsepower requirements from around 21 to 14 horsepower. Since the motors used by HVAC equipment only come in standard sizes, this change has the potential to reduce the motor size from 25 to 15 horsepower.

Final Check Set

All of the preceding design issues should be reviewed in the final check set. This is typically the last chance to verify that drawings and specifications clearly reflect the project engineer's ideas. The project should be well coordinated, both between systems and within each system. Control sequences and point lists should thoroughly document the requirements for both the normal and extreme operating conditions that the systems will encounter over the life of the building. Specification items should be coordinated with the plans and should reflect current standards, codes, makes and models. Cost projections based on the final check set should be within budget. Scheduled and specified equipment performance criteria should reflect the final project requirements. If the proper calculations have been performed, the load estimates and consequent equipment specifications should be accurate, alleviating the need for large safety factors. In addition, final calculations that reflect the losses associated with the actual configuration shown on the drawings should be documented and on file.

If the proper calculations have been performed, the load estimates and consequent equipment specifications should be accurate, alleviating the need for large safety factors.

Peer Review

On most projects, the contract documents go through some sort of peer review. In an external peer review, the reviewing parties may include the owner's engineering and operations staff, code officials, or independent consultants. It is increasingly common for commissioning providers to perform peer review, bringing the benefit of their real-world operating and start-up experience to the design team. External peer review often occurs toward the end of the design process, although it can occur earlier or several times during the process for more complex projects.

In any external review, there are diplomatic points to remember:

A cooperative approach is easier for all parties to live with and learn from. The review aims to ensure the overall quality of the project, not to provide a platform from which the reviewing parties can promote their engineering skill at the expense of the design team.

The number of possible workable solutions to any given design problem is directly proportional to the number of engineers in the world raised to the power of the number of operators. While there are probably many "best possible designs," each will have its advantages and disadvantages. The review process will be more fruitful if it aims to improve on what is already there rather than totally change the course of the project.

The number of possible workable solutions to any given design problem is directly proportional to the number of engineers in the world raised to the power of the number of operators.

Value Engineering is not necessarily a process under which the design of a well-thought-out mechanical system is modified to remove all valves, dampers, access points, service features, efficiency measures, redundancy and performance features thus rendering it very inexpensive to build but impossible to operate and astronomically expensive to own. Unfortunately, value engineering has developed a reputation as just such a process. However, a fresh perspective can identify features that will actually improve the efficiency of a project while reducing first cost. (See *Design Details* for examples.) Naturally, if a project is over budget and the value engineering process is invoked to get it back on track, then some hard decisions will need to be made.

Construction Phase Reviews

Once a project has gone out to bid, there are still several drawing reviews during the construction process. Typically, these reviews serve as a final check, verifying that what the contractor proposes to furnish and install meets the requirements of the project as defined in the project's plans, specifications and other construction documents.

Coordination Drawings

Typical coordination drawings are large scale drawings on which all the elements of the building are superimposed to identify potential conflicts.

On large projects or projects with complex mechanical systems, it is becoming more common to develop a set of coordination drawings prior to actual construction. These drawings focus on complex structural, architectural, mechanical and/or electrical areas of the project such as mechanical rooms or core structures of a high rise building. Typical coordination drawings are large scale drawings on which all the elements of the building, (architectural, structural, piping, ductwork, equipment, electrical, fire protection, and plumbing), are superimposed to identify potential conflicts. Each element is drawn on a separate layer allowing selective cross-checking of individual elements, without the complexity of trying to interpret everything at once.

The process of developing coordination drawings usually starts immediately after the award of the contract and is usually managed by the construction manager. It typically consists of a series of meetings, where the project managers for the various construction contractors resolve the details of a specific area. This process has the potential to establish cooperative relationships that can persist throughout the project, to everyone's benefit. By participating in developing coordination drawings, the project engineer can learn much about practical field implementation issues and temper inevitable compromises to maintain the integrity and efficiency of the original design.

Even when a project has been well-coordinated, developed, and detailed during the design process, there are still countless details that should be resolved in coordination drawings. Details to resolve include:

- Differences in equipment selection. If the contractor has substituted an "identical" piece of equipment, it will undoubtedly have some differences in size, connection requirements, and other features.

- Ambiguities in two-dimensional drawings. Since drawings are two-dimensional depictions of a three dimensional world, there is usually one piece of dimensional information missing on the drawings, most often elevation.

- Schematics and scale. Even on well-detailed drawings, many components and systems are still shown schematically. In addition, the drawings are small scale, so not all details can be shown. What is shown may not be exactly to scale. For example, the typical line weight used on a one-eighth inch scale drawing would scale to two inches, even if it represented a half-inch pipe. The larger scale used for the coordination drawings allows all parties to resolve problems related to scaling factors in advance of performing the work.

- Addenda and alternates. Often, during the bidding process, the contract documents are augmented by addendum. In addition, alternates may be used to identify the cost of various options. The coordination drawings reflect only the selected options and changes, reducing the chances for confusion in the construction process.

The coordination drawings reflect only the selected alternatives, thereby reducing the chances for confusion and errors in the field.

Shop Drawings Review

Shop drawings provided by the contractor depict the exact specifications, dimensions, and configuration of the equipment to be supplied for a project. They include equipment dimensions, materials of construction, performance specifications, wiring diagrams, installation information, rigging information, interface requirements, and operating sequences. Usually, the designer calls out the equipment that will require shop drawings in the specifications. The designer typically reviews the drawings, marks them up, stamps them with approval or rejection, and returns them to the contractor. This review process is important because it is the last opportunity to verify that the proposed equipment will fit the available space, be fully functional in the completed system and provide the performance described in the contract documents.

Small differences can translate into significant differences in operating costs, especially when these costs are viewed over the life of the building, system or piece of equipment.

Often, the differences between the contract document performance criteria and the shop drawing performance criteria for similar pieces of equipment seem insignificant. However, small differences can translate into significant differences in operating costs, especially when these costs are viewed over the life of the building, system or piece of equipment. Consider the following example of two 500 ton chillers proposed for a hospital application.

A contractor proposes (via the shop drawing process) to substitute a machine that is nearly identical to the machine in the contract drawings. Both chillers have identical efficiencies, evaporator flow rates and condenser flow rates. However, the contractor's proposed chiller has an evaporator pressure loss that is 0.9 feet water column more than the base machine and a condenser pressure loss that is 1.3 feet water column more than the base machine. The contractor's proposed machine costs $2,550 less than the base machine. But, the project has already been bid, and contracts are rarely changed to reflect minor differences between the bid price and the purchase price of components.

At first glance, the project engineer might be tempted to approve the substitution. The only difference appears to be a slight increase in pumping head associated with the higher evaporator and condenser pressure drops, both of which are well within the safety margin for the pumps selected. But let's look at how this translates into operating cost. Regardless of the load on the chiller, the evaporator and condenser pumps will need to operate at their rated flows and the added pumping head will require added pumping energy when the machine is running.

As can be seen from **Table 3** the contractor's machine will cost the owner over $12,000 in operating costs and investment revenue over the life of the chiller. Reviewing shop drawings allows the project engineer to identify many such hidden costs and make fully informed decisions about equipment selection.

Table 3: Added operating cost of the proposed chiller for the hospital

Pumping horsepower =(Flow in gpm) x (Pumping head in ft. w.c.)/(3,960 x pump efficiency x motor efficiency) where 3,960 is a units conversion constant.

Added evaporator pumping energy		
Flow rate	1,000	gpm
Increase in pumping head	0.9	ft.w.c.
Assumed pump efficiency	79%	
Assumed motor efficiency	85%	
Increase in pumping horsepower	0.36	hp.
Increase in kW	0.27	kW
Added condenser pumping energy		
Flow rate	1,500	gpm
Increase in pumping head	1.3	ft.w.c.
Assumed pump efficiency	81%	
Assumed motor efficiency	85%	
Increase in pumping horsepower	0.73	hp.
Increase in kW	0.54	kW
Summary		
Total pumping kW increase for proposed machine	0.81	kW
Assumed number of hours of operation per year	5,235	Hours
Electric energy cost	0.09	$/kWh
Added annual pumping kWh for the proposed machine	4,241	kWh
Added annual operating dollars for the proposed machine	$382	
Present value based on 20 year life and 5% per year investment of the added cost	$4,757	
Future value based on 20 year life and 5% per year investment of the added cost	$12,622	

Source: PECI

Control system shop drawings deserve special attention because control systems can be complex and must be high quality to ensure successful and efficient mechanical system operation. The following discussion focuses on reviewing drawings associated with DDC systems since most current projects will have this type of equipment. However, the ideas can easily be applied to the electronic, electric and pneumatic systems that are sometimes used for smaller projects or for new construction that modifies existing systems based on the older technologies. In reviewing control system shop drawings, a designer should:

- Pay special attention to details and sequences that apply to multiple pieces of equipment. A problem with the "Typical

VAV Unit Wiring Detail" quickly becomes hundreds of problems in the field if not identified prior to installation.

- Verify that the sensors meet the accuracy requirements of the specifications and the needs of the project. In addition, determine how the accuracy will be verified. Factory certification using National Bureau of Standards traceable calibration standards provides a good alternative to field calibration, which is extremely difficult to do with any degree of accuracy or precision.
- Check the amount of memory provided in the controllers. More memory means more flexibility for trending and program changes over the life of the system, both of which have energy-efficiency implications.
- Verify that the point names describe the system adequately. Most controllers come with default names for the various points and the controls contractor may be tempted to use them. However, if the alarm printer prints a message that says "Hi Limit Alarm – Point Name = Space Temperature," the operator will only know that one of the several hundred terminal units on the project is running a little warm. (Contrast this with the message that says "Hi Limit Alarm – Point Name = Rm. 201 Temperature.")
- Verify that the alarm settings for the various points are shown and that they match the system requirements.
- Check the interfaces to the other equipment. The drawings should include a copy of the equipment wiring diagram showing the specific connections required.

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Changes to control system programs are generally very easy to make if they are made before the information is entered into the controller. However, once the data has been entered, any change will have ripple effects that may discourage a contractor from implementing them. For example, changing a point name usually means finding every occurrence of that point name in every program on the system and making the change there also. If the system is operational and the programs are running, this may require some sort of shutdown while the revised program is uploaded and started. In addition, each change introduces the potential for some sort of typo which could cause other problems. Changing a sequence before it is installed may require re-thinking the logic a bit. Changing it after it is installed requires re-thinking the logic, rewriting the program, loading it into the controller (which may require a shut down) and then re-verifying and de-bugging the program. It would be a shame if an energy conserving idea was not implemented simply because it was not identified until after the equipment and software was installed and running.

Since many of the control system details will ultimately be important to the operators of the system, it is wise to include the operators in this review process. A DDC system goes a long way toward assuring efficient operation of a building, but only if the operators understand the system and actually use it. It is often useful to finalize the approval of the control drawings in a meeting attended by all concerned parties, including the owner/operators, the designer, the controls contractor and the commissioning provider.

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For More Information

Sheet Metal and Air Conditioning Contractors National Association (SMACNA)

SMACNA publishes numerous guides and standards regarding duct fabrication and design. Some of the more useful for design work include HVAC Duct Construction Standards; Fire, Smoke, and Radiation Damper Installation Guide for HVAC Systems; and HVAC Air Duct Leakage Test Manual. They also publish a number of useful technical papers. All documents can be ordered from the web site.

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Energy Design Resources

This brief is part of a design brief series that provides useful information regarding energy efficient design and operation. Two closely related briefs are Design Details, which discusses detailing techniques to provide more efficient HVAC systems and Field Observation, which provides information on techniques that can be used during the actual construction process to be sure your energy efficient details are fully implemented in the field.

Website: www.energydesignresources.com

Notes

1 Dave Sellers and Jerry Williams, "A Comparison of the Ventilation Rates Established by Three Common Building Codes in Relationship to Actual Occupancy Levels and the Impact of these Rates on Building Energy Consumption," *Proceedings, American Council For and Energy-Efficient Economy 2000 Summer Study on Energy Efficiency in Buildings* (2000). Available at the ACEEE web site, www.aceee.org.

2 American Society of Heating, Refrigerating, and Air-Conditioning Engineers, *1993 ASHRAE Handbook: Fundamentals*, Chapter 26 (1993), p. 17. ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, tel 404-636-8400, fax 404-321-5478, web site www.ashrae.org.

3 American Society of Heating, Refrigerating, and Air-Conditioning Engineers, *1993 ASHRAE Handbook: Fundamentals*, Ch. 24, p. 5. [2].

4 Departments of the Air Force, the Army, and the Navy, *Engineering Weather Data*, (1978), p. 3-61.

5 Flex duct is often used extensively in the terminal distribution system, often to the detriment of the system's performance and efficiency. Typically, flex duct is installed at these locations to eliminate vibration and provide access to the terminal units. But much better maintenance access can be provided by specifying the optional access panel in the bottom of the terminal unit casing offered by most manufacturers. Another option is to specify an access door in the unit's discharge plenum. For VAV terminals, vibration is seldom an issue. If the unit is a fan powered terminal, then potential vibration problems can be addressed using flex connectors similar to those typically provided on the air handling unit discharge.

6 There are numerous sources of industry standards. Most of the standards are referenced in: Reno C. King, *Piping Handbook,* 5th edition, (New York: McGraw-Hill) and Theodore Baumeister, editor, *Standard Handbook for Mechanical Engineers,* 7th edition, (New York: McGraw-Hill).

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