energydesignresources

design brief

IMPROVING MECHANICAL SYSTEM ENERGY EFFICIENCY THROUGH ARCHITECT AND ENGINEER COORDINATION

Summary

Technological advances and economic pressure frequently join forces to reduce the design and construction time for building projects. Narrowing the design window places intense pressure on the design team to produce construction documents as quickly as possible. As a result, other factors like life cycle cost, distribution efficiency, access, maintainability, and system integration may not receive a thorough evaluation to provide the best overall solution to the design problem.

Failing to take these factors into account during the early stages of design can have long-term negative impacts on the efficiency of a building and its systems. For example, a constricted mechanical space will probably remain constricted for the life of the building, compromising the efficiency and maintainability of the machinery and eroding the building's operating budget for years to come. Correcting such a problem subsequent to construction may be an economic and practical impossibility, while preventing it during early phases of design may have little first cost implication and yield substantial ongoing benefits.

This design brief explores techniques that use the "fuzzy" information available during schematic design as a foundation for establishing a project's design intent and making good long-term mechanical and electrical systems decisions. Properly applied, they allow the mechanical designer to:

- Suggest more efficient system alternatives with better life cycle cost profiles for consideration.
- Ensure that the architectural elements of the building are configured to promote distribution system efficiency.
- "Right size" building systems from the very start, improving energy efficiency, as well as first cost.
- Coordinate with other team members to capture the additional savings that "ripple out" of these decisions.

Tight design timelines can compromise the design team's ability to consider factors like life cycle cost, distribution efficiency, access, maintainability, and system integration.

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Who Should Read this Brief

This brief is targeted at HVAC designers. Those new to the field will find that it outlines an approach to the design development process that includes an efficiency focus from the start and provides a firm foundation to carry the design successfully into contract documents, construction and operation. Experienced designers may find ideas that they can use to enhance the process they already have in place. The brief may also be of interest to architects, engineers in other disciplines, owners, and facilities personnel because it will provide insights into the interrelationships between their particular area of interest and HVAC systems. Thus, it will help them understand how their participation in an integrated approach to design and operation will provide persistent benefits in terms of efficiency and performance.

Introduction to Integrated Design

The purpose of this design brief is to help HVAC designers optimize building systems and improve their integration with the overall building design, right from the very start. It may seem like the information available during schematics and design development lacks the details necessary to make firm HVAC design decisions. However, in many cases it is possible to come remarkably close to the final design requirements based on past experience and industry data, tempered by available information. The HVAC designer’s participation in schematics and early design development frequently results in more efficient systems that are better integrated with the overall project requirements, a definite benefit to all parties.

Modern buildings contain a vast array of highly specialized components from a variety of manufacturers, all assembled into one interactive structure that aims to meet the needs of its owner. Because these many components are physically connected, or at least in close proximity, they will each interact with one other and the surrounding environment. For example, the performance of a fan must be considered in the context of the duct system it serves, including the impact of the filters, heat transfer elements, economizer dampers, terminal unit regulators, and the integrity of the building envelope in the area it serves. The integrity of the building envelope will dictate the performance requirements necessary for some of the air handling unit components. The dimensions imposed on the duct system by the building structure will influence the performance parameters required from the fan to meet its design objective. By changing one piece of the puzzle, the designer impacts the entire system, triggering changes elsewhere. Thus, integrated design[1] and the system concept[2] are important parts of any successful design process.

Integrated design and the system concept both address the interactions of various building elements and systems in order to optimize overall design. When abiding by these design practices, HVAC engineers don't simply design or select an air-handling unit. They design an air handling system of which the air handling unit is an integral component, along with its ducts, terminal equipment, return and exhaust fans, control system and the building envelope and structure. Similarly, the architectural team doesn't design a skylight. They design a daylighting system of which the skylight is a key component along with the building envelope and structure, the building's orientation on the site, lighting fixtures, the lighting control system and perimeter- and ceiling-mounted HVAC equipment.

As an HVAC designer, it is important to remember that for most owners and architects, the HVAC equipment, while important, is not the primary focus of the project. The owner's business needs are the project's primary driver, and the architect works to create an aesthetically pleasing building that accomplishes the desired functions. Although everyone recognizes that HVAC systems are necessary, the space occupied by machinery reduces usable, income-generating floor area and may even impact the building floor plan and appearance. In the latter instance, the HVAC systems may be thought of as compromising the building's "architectural statement." As a result, the owner and architect may exert considerable pressure on the mechanical designer to minimize and/or understate the interface and support requirements of the HVAC machinery. While this interaction between the team members is desirable and necessary to optimize the overall design, concessions sometimes compromise the efficiency and long-term viability of the HVAC equipment by reducing its quality, serviceability and ease of access.

Both owner and architect have a vested interest in preventing these kinds of problems, but, in order to make good decisions, they need clear, factual information they can relate to beginning very early in the design process. The development process in this design brief provides the mechanical designer with powerful tools to advocate for the HVAC systems from very early in design and use decision-making techniques that are grounded in the realities of the project, not derived from purely speculative positions. Using these techniques allows the designer to proactively advocate for the needs of the HVAC system rather than reactively responding to locations that have been selected by the architect. Without input from the HVAC designer, the locations selected may be based on the building's programming needs rather than the realities of the HVAC system necessary to serve them.

Technical professionals like engineers and architects are trained to seek exact answers to their problems. While this is a highly desirable quality in the long run, there are points during the building design process, especially during the early design phases, when insisting on a precise answer is counter productive. Many of the techniques described in this design brief are estimating techniques intended to establish preliminary requirements that can then be developed into exact solutions. The details associated with parameters developed by these initial estimates will change as the design evolves, either through interactions with other team members or through insights gained during the review and development process. Thus, someone implementing these processes for the first time should understand that these techniques represent a new approach to thinking about the design process. First-timers should embrace the initial approximations and the changes that will follow, knowing that they will lead to an exact solution. The initial design efforts will probably be completed in days or weeks using simple hand sketches and calculations, in contrast to the months or even years required to perform the detailed calculations and modeling that generate the complex CAD drawings and specifications that will ultimately define the project for construction.

As the HVAC designer, it is important to remember that the other team members are also driven to seek exact answers. For example, the architect may be reluctant to furnish floor plans, elevations and other important building information that can impact the HVAC design until he or she feels that the plan is reasonably firm. Unfortunately, if the HVAC designer waits until this point to begin advocating for the spatial, structural, and envelope requirements necessary to support integrated and efficient HVAC systems, it may be too late. The architectural program may already be locked in place and significant changes, like moving shafts or enlarging equipment spaces, might require taking over areas that are already firmly committed to the owner's primary functions. The demands placed on the architect in this situation may simply not be achievable and may place the architect in a difficult position before the owner.

Thus, an HVAC designer must be aggressively proactive in obtaining the architectural and structural information required for the early design efforts. A simple one-line drawing of the architectural program, supplemented by estimates of the glazing for each exposure and the owner's requirements for the areas encompassed by the architectural program, will provide the necessary information for initiating the processes described in this design brief. And, just as the HVAC design team asks for information from other team members, they should be generous with their knowledge and plans and freely share their preliminary information (with the caveat that it is approximate). For example, providing preliminary motor sizes to the electrical designer early on will allow him or her to assess their requirements and proactively integrate them into the overall building planning process. Proceeding in this manner initiates a dialog about integrated design among team members from the start, paving the way for a successful project that makes efficient use of energy and resources over the life of the building.

Early Design Planning, Budgets and Efficiency

An owner who has elected to build has implicitly committed to spending capital on HVAC systems and their operation at a level commensurate with the project's performance and quality requirements. The techniques outlined in this brief will help the HVAC designer allocate and monitor this budget wisely for maximum performance and efficiency. Examples include coordinating the HVAC requirements with the architectural features to ensure efficient distribution and right sizing equipment from the start. Issues of this type can be a major factor in the overall efficiency of the project.

Enhancements that optimize the performance and efficiency of a process, such as energy recovery or set point reset strategies, represent a second factor in the building efficiency equation. These features may add cost to the project beyond what might be envisioned by a budget based on a conventional design. Yet, they can be justified economically based on the return on investment that they will yield over the operating life of the building. To implement them, the owner will need to have funding available up front which may not have been included in the original budget developed for the project. The techniques outlined in this brief will allow the HVAC designer to identify desirable features early on while budgets are still flexible and capable of being adjusted to accommodate them. In some cases, the techniques may allow the designer to provide some of the enhancements within the framework of the base budget through savings generated by right sizing equipment.

The bottom line is that managing the project budget and managing the project efficiency often go hand in hand. As such, the discussions in this brief include a focus on budgetary issues to help the reader understand how to utilize available funds in a way that maximizes benefits. The insights gained will also allow the reader to assist the owner in understanding that an efficient building makes good business sense and investments in efficiency can yield returns that rival more conventional investment opportunities.

"Get Things Right on Paper"

The fundamental goal of the process described in this brief is "to get things right on paper" at the very beginning of the project. In order to do this, it's generally necessary to follow a process that includes the components listed below.

1. Understand and estimate the loads
2. Consider psychrometrics
3. Understand the architectural and owner requirements
4. Develop a system configuration to handle the load
5. Make preliminary equipment selections
6. Identify energy efficiency opportunities
7. Evaluate the system's utility service requirements
8. Evaluate the system's physical space requirements
9. Assess constructability and sequencing
10. Develop a system operating narrative and point list
11. Identify areas where detailing will be important
12. Develop or reassess budgets

While this brief will explore each of these topics in the order listed, it is important to understand that for many projects, several of these steps could be occurring concurrently or in a different sequence. On some projects a step in the process may recur several times as the design evolves, with each occurrence developing the concept in greater detail.

Bringing an awareness of these topics to the project from the start will provide a firm basis for design development and integrated design, improve the overall building efficiency and maintainability, and optimize the building's life cycle cost. It also will establish a foundation for documenting design intent, which in turn, establishes a firm foundation for a successful commissioning process and the persistence of the efficiency envisioned by the design.

1. Understand and Estimate the Loads

Among the first questions that must be addressed with regard to HVAC design are:

> *What are the loads that this system will serve and what are their characteristics?*

These are critical questions. Failing to consider the magnitude of the load, its profile, and the potential interactions of the various zones can lead to application problems that plague the system for life, as occurred in a building described in the Side Bar 1. Despite a concerted effort at energy efficiency, a mismatch between the system, its equipment and the application resulted in a system that is more energy intensive than a conventional approach. In addition, the space is plagued with comfort problems. Solving these problems may require engineering and capital expenditures that are of the same order of magnitude as the original project.

Obviously, the story in Side Bar 1 is an example of a good idea gone wrong. Most projects result in a better match between the building, the system, and the load it serves, even if the decisions are less than ideal. But most projects, including this example, can benefit from participation and analysis by a knowledgeable HVAC designer during early design. While the information required to develop a model or perform a detailed load analysis is often unavailable during the early design stages, there is usually enough information to give an HVAC designer clues about what to expect. For instance, the Side Bar 1 building's envelope geometry, coupled with the low population density and high efficiency lighting and office equipment, would have been a strong indication to an experienced HVAC design professional that a system approach utilizing energy recovery from the building interior might not be viable. Supplementing

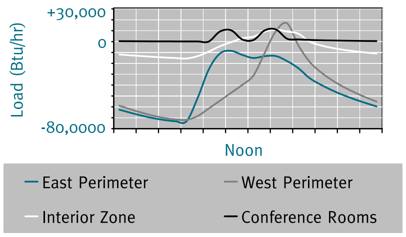
Side Bar 1: A system and load mismatch

The architectural design team for a high efficiency renovation project on the East Coast wanted to recover internal gains to heat the perimeter during winter. As a result, the project was committed to a water source heat pump system during the very early phases of design and prior to the involvement of an HVAC engineer.

It seemed like a good plan, but several factors were not in the approach's favor. The space was long and narrow, and thus had a relatively large perimeter area. The envelope included large, double hung windows and the building's historic significance prevented their replacement with a more efficient model. Finally, the office space was very lightly loaded due to efficient lighting, equipment design goals and low population density.

As a result, there was little if any heat to recover during most of the heating season, as seen in the graph below. Note how the interior zones and conference rooms show only a slight heat gain while the perimeter zones nearly always show a significant heat loss.

Loads at 37°F Outside Air Temperature



this type of information with complimentary data from readily available sources can often provide significant insights, very early in the project, about what the real nature of the load will be. This information can usually be obtained fairly quickly.

Integral to the dimensional components of the load is the acceptability of the load and the building envelope, relative to current standards like ASHRAE 90.1 or Title 24. If aspects of the building and its envelope do not meet code-dictated standards, designing a system to meet the loads imposed by the non-compliant structure will be a waste of everyone's time.

Below are some techniques that may be useful in this effort. Some of these approaches lend themselves to new or existing construction, while others are useful only for renovation, remodeling and remedial work on existing systems.

Use Past Experience and Common Practice

Many times, industry rules of thumb and insight gained in previous projects can be used to assess the requirements for a new project.[3] For example, past experience may reveal that typical office loads can be handled with 1/2 to 1-1/2 cfm per square foot @ 55° F–60° F supply temperature range. Someone familiar with the health care field may recognize that certain hospital processes can be handled by installing one ton of central plant capacity for every 165 to 275 square feet of conditioned area, depending on outdoor air requirements and equipment loads. While the answers provided by these techniques may not be exact, they can provide a surprisingly accurate first pass assessment, as can be seen from the story in Side Bar 2.

Use Standards Dictated by Code or Good Practice

Often times, facilities like hospitals or clean rooms have minimum air change rates that must be met to comply with code or process cleanliness requirements. For example, a semiconductor manufacturer may require an air change rate of 20 cfm per square foot to meet quality assurance requirements in one of their Class

Side Bar 2: How did he do that?

A project engineer for a large design/build mechanical contractor was taking some graduate students on a tour of one of his projects. As they drove to the site, he engaged the students in a discussion of their graduate thesis project, which involved designing the central chilled water plant for a hypothetical hospital building.

After asking about the building square footage, the nature of the hospital functions that would occur there and the location of the building, the project engineer casually observed that the students were probably looking at a 550 ton chiller plant. The students were astounded! The engineer's off-the-cuff estimate was within 25 tons of their design—which they arrived at after weeks of modeling.

The project engineer explained his technique, simply a combination of his past experience and some rules of thumb. This approach allowed him to estimate the order of magnitude of the project so he could see the big picture design issues and converse more intelligently about the project with the students.

His calculation was certainly not a firm design number. In contrast, the student's efforts resulted in a clear insight into the nature of the loads and the details necessary to develop a good design solution.

Side Bar 3: ASHRAE Load Profile Data

Load profile information can be extracted from Table 1 - General Design Criteria in the *1999 ASHRAE Applications Handbook, Chapter 3 - Commercial and Public Buildings.*[4]

In addition to providing load profile information, the table provides general recommendations for indoor design conditions, air movement and air change rates, noise criteria, and filtration for a variety of commercial and public occupancies.

1000 clean rooms. Or state hospital licensing requirements may dictate air change rates for various locations in the facility. For example, a common licensing requirement for operating rooms is 25 total air changes per hour and 5 outdoor air changes per hour.[4] In these situations, the size and capacity of the equipment and distribution systems will generally be set by the air change requirements and the system's entering and leaving conditions rather than the load in the area served, especially if requirements are for 100% outdoor air operation. In many cases, these systems have significant parasitic loads, like reheat, associated with them if the capacity provided by the stipulated air change rates exceeds the actual load requirements. These requirements are important to note early in the design process because they can have significant first cost and operating implications that need to be included in the project definition and budget.

Use Data From Industry Associations Like ASHRAE

The ASHRAE Application Handbook is a valuable resource in developing a basic understanding of the HVAC requirements for many applications. The handbook provides information on anticipated load profiles and their magnitude, as shown in Side Bar 3.

Understanding the load profile can help the designer anticipate capacity increments required in the central plant. In turn, this leads to an understanding of the quantity and size of the supporting equipment like pumps and cooling towers and the space required to accommodate them.

The ASHRAE Pocket Handbook is another useful reference because it includes a table of parameters like square foot per ton, occupants per square foot, lighting watts per square foot, and air change requirements for different exposures for a variety of building and occupancy types.

Perform a Block Load Calculation

The techniques discussed to this point require assessing the load for new project based on previous projects. Modern computer technology makes generating a block load specific to a new project easier than ever. The designer can take advantage of this technology in several ways.

- Develop a simple spreadsheet to perform a manual load calculation using the ASHRAE Transfer Function Method or a similar technique.
- Purchase a software load program, like the one used to generate the information for the graph shown in Side Bar 1.

While more time consuming than other techniques, using a software program to analyze general load characteristics provides a lot of insight for very little effort. For instance, the data for the Side Bar 1 graph was generated in only a few hours using a commercially available hour-by-hour load program. Once developed, this type of information allows the designer to play “what if?” games and can serve as the basis for a more detailed load calculation later.

Use Building Operating Data

Sometimes the trending capabilities of an existing building’s DDC control system can provide a real time load calculation or an assessment of the expansion capability of an existing system. Obviously this information needs to be tempered with good engineering judgment to assess the impacts of any new additions and identify parasitic energy burdens that may show up as false loads. But using this approach as a first step can provide the answers for very little effort, as shown in Side Bar 4. Similarly, maintenance logs and discussions with operators can provide valuable insights into the capabilities and quirks of an existing facility.

Integrated Design Examples

Throughout this design brief, a hypothetical project for the PG&E Pacific Energy Center (PEC) will be used to illustrate the concepts that are discussed. The text in these areas is highlighted so the reader can easily locate them.

Side Bar 4: A Practical Design Approach

A project engineer, facilities director, and operations supervisor were standing in the central plant of a Midwest hospital contemplating the renovation of the central heating water system. As they wondered just how low the system's supply temperature could get in the summer, it dawned on the project engineer that a one row reheat coil might be able to deliver neutral air when supplied with water in the 85°–95° F range.

Neutral air would be more than adequate in the summer when there was only a reheat load and no space heating load. If the hot water system could operate at that low of a supply temperature, then it seemed possible that the reheat requirements could be satisfied via heat recovery from the condenser water system.

The engineers began speculating about modeling all of the existing coils at the new condition. The operations supervisor, accustomed to operating in the real world, said “lets see when we get a cold complaint” and began lowering the hot water system temperature in 5°F increments.

The result? The system provided a comfortable environment during the non-heating season with 85°–90º F water. On that basis, heat recovery was incorporated into the design without further engineering analysis. The owner realized a significant savings in engineering costs during design and a major reduction in gas consumption when the system came on line.

The PEC project is a renovation of an existing system, replacing aging rooftop equipment and enclosing it in a penthouse. Additional insight into the PEC project, and the decision to provide a penthouse, can be found in Side Bar 9. Some of the other owner's requirements include:

- Configure the new installation to realize the full benefit of the economizer cycle and eliminate the recirculation problem that currently occurs.
- Maximize the reuse of piping, ductwork, electrical, and other distribution and utility systems to support the new air handler, boiler and chiller and manage first cost.
- Coordinate with seasonal conditions to minimize the disruption of services.

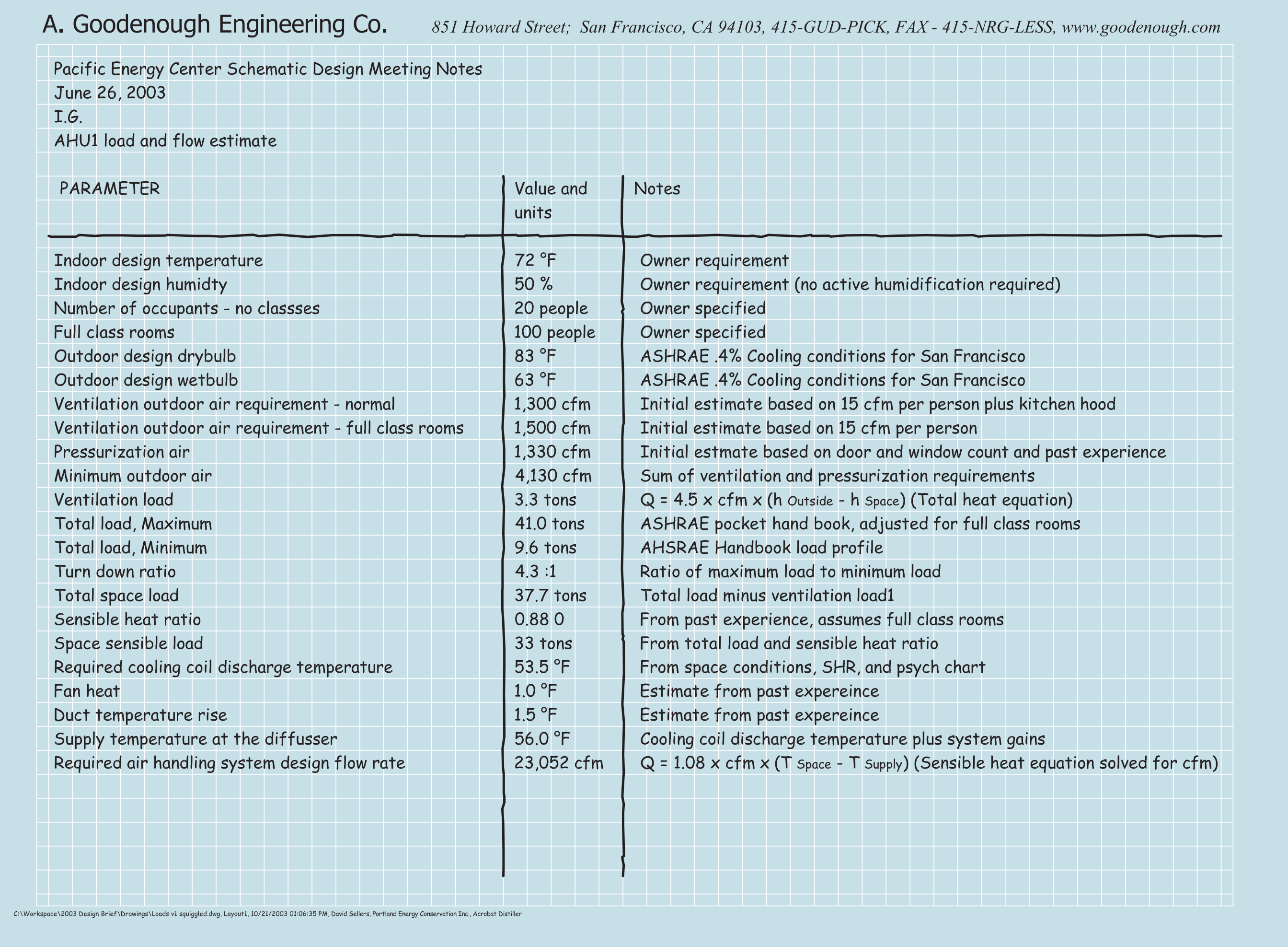
For a more in-depth experience with integrated design, visit the web site at http://www.ctg-net.com/EDR/IntegratedDesign/. The website provides an interactive learning experience utilizing[5] integrated design techniques to evaluate design strategies, goals, and energy efficiency measures to employ in a 15,000 square foot office building in San Jose California.

Estimating the Load for the PEC Air Handling Unit

Figure 1 illustrates how some of the techniques outlined in this section generate a load estimate and preliminary flow rate for the air handling unit in the PEC example. Notice that all the parameters are easily obtained from readily available sources. Equations can be found in the ASHRAE handbooks.

In this particular instance, the control system had not been programmed to track load-related parameters, so it was not possible to use building data to estimate the load. However, the control system programming could be modified to track key system parameters while the project was under design. The data would provide a crosscheck on the initial estimate and design calculations as well as a baseline for comparison when the new system comes on line. It could also reveal previously unrecognized performance issues that could easily be addressed as a part of the project.

Figure 1: Developing Load Information for the Air Handling Unit in the PEC Example



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Pacific Energy Center Schematic Design Meeting Notes
June 26, 2003
I.G.
AHU1 load and flow estimate

PARAMETER	Value and units	Notes
Indoor design temperature	72 °F	Owner requirement
Indoor design humidty	50 %	Owner requirement (no active humidification required)
Number of occupants - no classses	20 people	Owner specified
Full class rooms	100 people	Owner specified
Outdoor design drybulb	83 °F	ASHRAE .4% Cooling conditions for San Francisco
Outdoor design wetbulb	63 °F	ASHRAE .4% Cooling conditions for San Francisco
Ventilation outdoor air requirement - normal	1,300 cfm	Initial estimate based on 15 cfm per person plus kitchen hood
Ventilation outdoor air requirement - full class rooms	1,500 cfm	Initial estimate based on 15 cfm per person
Pressurization air	1,330 cfm	Initial estmate based on door and window count and past experience
Minimum outdoor air	4,130 cfm	Sum of ventilation and pressurization requirements
Ventilation load	3.3 tons	$Q = 4.5 \times cfm \times (h_{Outside} - h_{Space})$ (Total heat equation)
Total load, Maximum	41.0 tons	ASHRAE pocket hand book, adjusted for full class rooms
Total load, Minimum	9.6 tons	AHSRAE Handbook load profile
Turn down ratio	4.3 :1	Ratio of maximum load to minimum load
Total space load	37.7 tons	Total load minus ventilation load1
Sensible heat ratio	0.88 0	From past experience, assumes full class rooms
Space sensible load	33 tons	From total load and sensible heat ratio
Required cooling coil discharge temperature	53.5 °F	From space conditions, SHR, and psych chart
Fan heat	1.0 °F	Estimate from past expereince
Duct temperature rise	1.5 °F	Estimate from past expereince
Supply temperature at the diffusser	56.0 °F	Cooling coil discharge temperature plus system gains
Required air handling system design flow rate	23,052 cfm	$Q = 1.08 \times cfm \times (T_{Space} - T_{Supply})$ (Sensible heat equation solved for cfm)

C:\Workspace\2003 Design Brief\Drawings\Loads v1 squiggled.dwg, Layout1, 10/21/2003 01:06:35 PM, David Sellers, Portland Energy Conservation Inc., Acrobat Distiller

2. Consider Psychrometrics

Psychrometrics and load calculations go hand-in-hand, and therefore it is important to ask:

> *What are the psychrometrics associated with the local environment and the load and how will they impact the design?*

Taking a few minutes to plot some critical points associated with the project on a psych chart will often reveal considerations that might not otherwise be apparent. This can help focus the designer on the most appropriate HVAC process strategies and identify energy conservation features. Initially, psychrometric points to assess for cooling and dehumidification processes might include summer design conditions, space conditions, and the proposed cooling coil discharge conditions. Similar points should be assessed for heating/humidification processes.

Psychrometric Requirements for the PEC Project

Side Bar 5 illustrates some of the psychrometric points associated with the example and their related considerations.

3. Understand the Architectural and Owner Requirements

An important question to ask the owner early in the design process is:

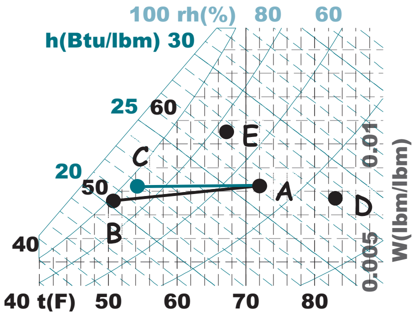
> *What are the programming requirements in terms of zoning, scheduling and use of the space?*

Zoning, scheduling and other owner/architect program requirements can have a significant impact on system design and first cost. For example:

- Zones can be expensive. In addition to the terminal control device itself, each zone requires a connection to the duct and piping utilities, along with the start-up, commissioning, and maintenance efforts associated with the terminal unit. An owner who wants an independent zone for every office space on a given exposure should be made aware of the cost implications compared to grouping several offices on one zone.
- Zone level scheduling may imply high turn down requirements.[6] If a VAV system needs to operate at design and at 10% of design due to schedules that shut down flow to many of its zones, it will require much more attention during design and operation and higher quality, more sophisticated controls and equipment, compared to a system that will only see a 50% reduction in capacity.
- Different ventilation requirements may make multiple systems desirable. The ventilation requirements in some areas may be different enough from others to justify a separate system in order to prevent over-ventilation and the associated unnecessary energy use.

Side Bar 5: PEC Example—Psychrometrics

The psych chart below illustrates some of the important psychrometric points for the PEC project.



Note the following:

- For the PEC location, the cooling design condition (D) and the dehumidification design condition (E) are significantly different in terms of psychrometric parameters, but are very similar in terms of energy content, as reflected by the enthalpy. This may not be true for all locations and could impact the cooling load significantly, especially at high ventilation rates.
- The coil discharge requirement associated with a design load with full classrooms (point B) is several degrees lower than that associated with no occupancy in the classrooms (point C; point A is the class room design condition). This leads to an energy conservation strategy which is discussed under energy features for the PEC project.

Identifying these requirements and the features and costs associated with them early on will allow the design and budget to reflect them from the very start. If funding is tight, these early projections will allow the HVAC designer to assist the owner in making informed decisions about where to cut costs.

Program Requirement Impacts on the PEC Design

Since the PEC project retrofits a new AHU to an existing duct system, the zoning issues are already fixed. However, some program issues still need to be considered:

- The estimated turndown ratio[7] of 4.3:1 (see Figure 1) can have a significant adverse impact on the performance of the economizer, coils and diffusers if it is not accounted for in their selection.
- Given the large variation in occupancy that could occur due to training functions, it is not out of the question that the air handling unit could operate with a significant outdoor air percentage. Thus, the heating coil may need to provide a preheat function in addition to a warm-up function.

4. Develop a System Configuration To Handle the Load

Once the designer obtains a basic understanding of the magnitude and profile of the loads to be served, other questions arise:

> *What system approach should be used for the project and how will it be configured to best match the requirements and characteristics of the load?*

These questions are fundamental to early design and initiate many processes. But serious problems can occur when considered outside of the context of the load characteristics, as was seen in Side Bar 1.

The nature of the load (office space, surgical suite, retail space, etc.) and its psychrometric requirements will generally dictate the HVAC process to be employed. The magnitude of the load provides the information necessary to arrive at preliminary equipment selections. The load profile provides insight into the system turndown requirements, which can have a significant impact on configuration, control requirements and equipment selections.

Considering all of these factors together will help a designer arrive at the best overall system solution for a particular project. For example, the need to maintain very specific pressure relationships, temperature and humidity parameters, and air change rates in an operating room may drive the HVAC designers to select a constant volume reheat system supported by central chilled water and hot water systems for that area. The energy intensity of this approach will also cause the designers to consider energy recovery systems, lower duct velocities, and focus their attention on the details of the duct design to minimize fan energy. They will also need to coordinate closely with the architectural team to ensure that the building envelope is suitable for the high relative humidity levels. All of the disciplines will need to be involved to ensure that the operating room is air tight so that the HVAC system can maintain the desired pressure relationships.

While many of these details associated with these decisions and requirements will not be worked out until later in the design process, identifying them during early design will ensure that they are proactively pursued as an integrated part of the project. This allows the team to solve problems “on paper,” while the design is still relatively simple and inexpensive to change, compared to the complexity such changes involve during construction.

As HVAC designers become familiar with the project specific issues, they can begin to develop requirements for the systems. Bringing these requirements together with the load information will allow the system configurations to emerge.

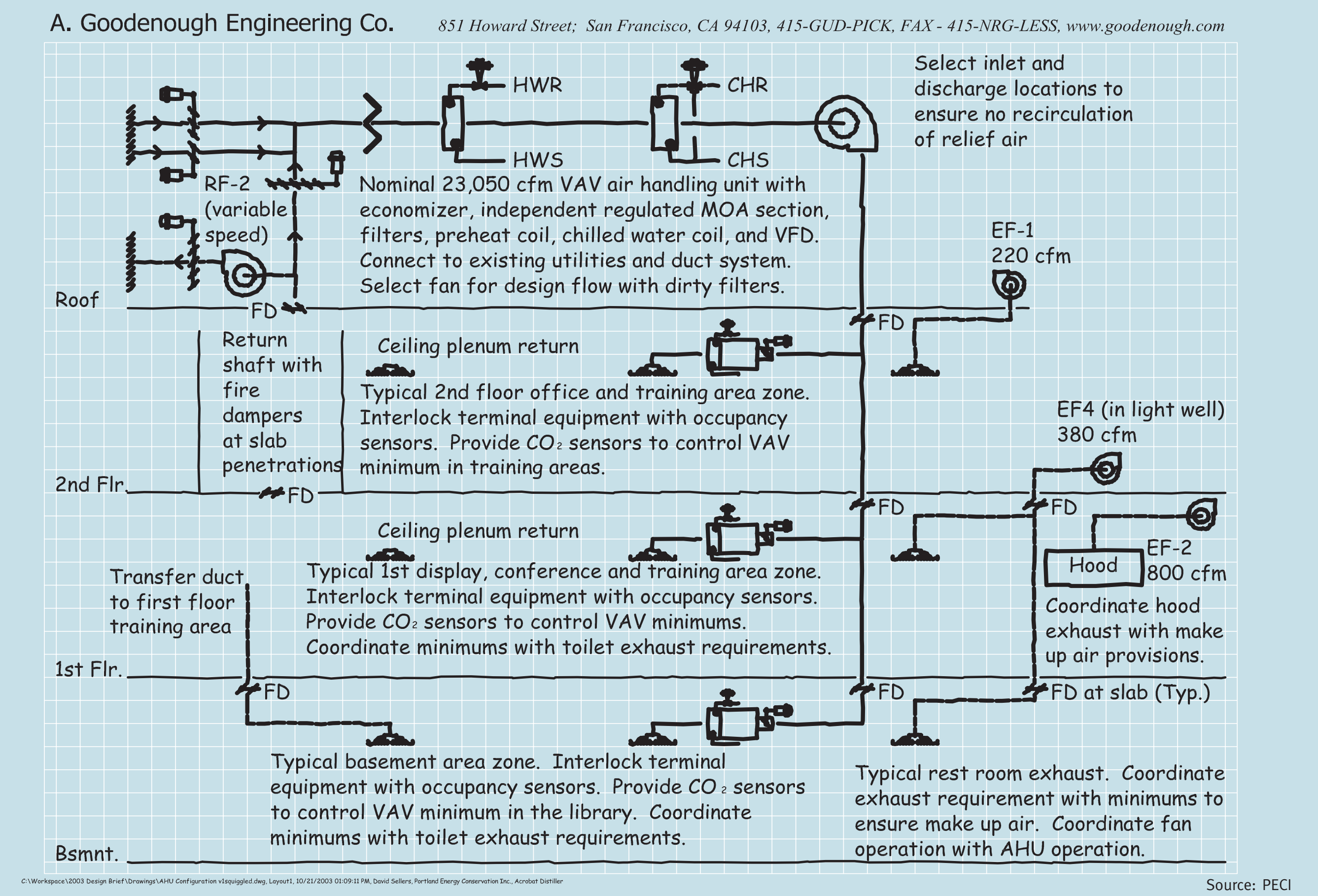
Developing the PEC System Configuration

Because the PEC project is a retrofit rather than new construction, the existing equipment dictates some of the system selection and configuration decisions. Specifically, the new air handling unit will serve existing VAV terminals, thus it needs to function as a VAV air handling unit. But, design requirements for the air-handling unit begin to emerge from the information developed to this point.

- The ASHRAE table referenced in Side Bar 3 indicates that filtration levels between 30% and 65% are considered appropriate for our application. Optimizing the filter selection can have a significant impact on operating costs.[8]
- The same ASHRAE[9] table used to establish the summer design condition tabulated in Figure 1 also indicates that the winter design condition is 37° F and that it is unlikely the temperature will ever drop below freezing. As a result, it is probably unnecessary to go to the expense associated with making the preheat coil freeze proof. In addition, the turndown issues associated with economizer operation will be less of a problem.
- Existing services like chilled water, hot water and the DDC system can begin to be evaluated in terms of their suitability for the new performance requirements.

Figure 2 illustrates the system configuration for the PEC air handling unit in the form of a system diagram sketch. Note how the diagram portrays the air handling requirements and the loads served in terms of a system, and not just the air handling unit. The interface requirements and "order of magnitude" sizing information that is beginning to emerge will help define the interfaces with the building architecture and electrical system. The sketch can be used to convey these concepts to the rest of the team for discussion and coordination purposes. It can also become the basis of the system diagram on the contract documents.

Figure 2: A Schematic Design System Diagram for the Air Handling Unit for the PEC Project



Select inlet and discharge locations to ensure no recirculation of relief air

Nominal 23,050 cfm VAV air handling unit with economizer, independent regulated MOA section, filters, preheat coil, chilled water coil, and VFD. Connect to existing utilities and duct system. Select fan for design flow with dirty filters.

Return shaft with fire dampers at slab penetrations

Typical 2nd floor office and training area zone. Interlock terminal equipment with occupancy sensors. Provide CO_2 sensors to control VAV minimum in training areas.

Transfer duct to first floor training area

Typical 1st display, conference and training area zone. Interlock terminal equipment with occupancy sensors. Provide CO_2 sensors to control VAV minimums. Coordinate minimums with toilet exhaust requirements.

Coordinate hood exhaust with make up air provisions.

Typical basement area zone. Interlock terminal equipment with occupancy sensors. Provide CO_2 sensors to control VAV minimum in the library. Coordinate minimums with toilet exhaust requirements.

Typical rest room exhaust. Coordinate exhaust requirement with minimums to ensure make up air. Coordinate fan operation with AHU operation.

C:\Workspace\2003 Design Brief\Drawings\AHU Configuration v1squiggled.dwg, Layout1, 10/21/2003 01:09:11 PM, David Sellers, Portland Energy Conservation Inc., Acrobat Distiller

Source: PECI

5. Make Preliminary Equipment Selections

Once a system configuration has been identified, the next logical question is:

> *What are the characteristics of the equipment that will be selected for the system defined by the system diagram?*

Making preliminary equipment selections paves the way for firming up many other factors associated with the building's design. The PEC project designer's estimating efforts thus far have provided a flow rate for the air handling system that, while approximated, has some basis in the realities of the project. But that is only half the fan capacity equation. To pick a fan, it is also necessary to know the static pressure requirement. It may seem like an impossible task at this stage of design development. After all, there may not even be drawings available, other than broad-line architectural drawings. The temptation is simply to guess, perhaps based on the requirements for a similar project. But, with a little thought and some experience, it is possible to develop an approximation based on what is known about the project, coupled with general design standards.

For most air handling systems, the pressure losses fall into three categories: 1) losses through the heat transfer and filtration equipment in the air handling unit proper; 2) losses through the distribution system; and 3) losses through the terminal system.

Air Handling Unit Pressure Losses

For many systems, a significant portion of the pressure loss occurs within the air handling unit itself because many of the major system components like coils and filters are housed there. The information developed for the project at this point already provides a fairly detailed picture of what the air handling unit will look like (see Figure 2). This information can be combined with common design standards like selecting louvers, coils and filters for face velocities of 500 fpm or less, catalog pressure drop data available from manufacturers, and past experience with similar systems and projects. As a result, the static requirements for the proposed air handling unit can be projected with a relatively high degree of accuracy, even though there are no specific equipment selections at this point in the design.

For example, a designer may know from past experience that in order to achieve good linearity and mixing, the pressure drop through the economizer dampers needs to be significant relative to the total system static pressure, perhaps as high as .25 in.w.c.[11] Catalog data or a designer's past experience may tell them that the pressure drop through a typical chilled water coil will be in the range of .75 in.w.c. to 1.25 in.w.c. depending on the depth of the coil and whether it is wet (condensing) or dry.

Side Bar 6: High Velocity Duct System Pros and Cons

Smaller ducts with higher velocities and friction rates have the potential to save first cost by minimizing the required square-footage of sheet metal for a given air flow. Smaller ducts also occupy less space and reduce ceiling cavity and mechanical shaft requirements. This increases usable, rentable floor area and accommodates architectural features like vaulted ceilings and daylighting.

However, higher velocities and friction rates generally result in higher static pressure requirements, which translates into higher operating, costs, all other things being equal. The higher static pressure requirements for a given flow can result in:

- A higher fan class with more static capability and a larger motor[12]
- A larger electrical service to accommodate the larger motor
- Heavier duct construction to accommodate higher pressures
- Increased duct system sound attenuation requirements
- Increased architectural sound attenuation requirements

All of these factors can add cost back into the project with the net result being a wash or even an increase in first cost, all other things being equal. When coupled with the increase in operating cost, the life cycle cost of the system may be much less attractive than a low velocity duct systems.

Distribution System Pressure Losses

During the early stages of design, the configuration of the supply and return distribution system can be more of an unknown than that of the air handling unit. But the pressure requirements associated with these elements is a direct function of two items that are defined at this time:

1. <u>The Physical Arrangement of the Building:</u> Even though the design team may not have decided on the exact location of the equipment room, mechanical shafts and supply and return diffusers, they probably have talked about the general size and arrangement of the building. Building geometry has a lot to do with the losses in the duct system. For instance, a long, thin four-story building with roof-mounted equipment requires a distribution system that spans the roof to the first floor and extends out to the floor perimeter in all directions.
2. <u>The Velocity and Friction Rate Design Targets Established by the Mechanical Designer:</u> This is one area where the mechanical designer has significant influence from very early in the design process. The velocities and friction rates established for the project's duct system have a direct impact on a number of important factors including energy consumption, noise, leakage, duct pressure class requirements, and first cost.

A designer can establish the general length of the duct run by first assuming an equipment location and then calculating the length of the run based on floor-to-floor heights and floor plan dimensions. Fittings can be accounted for by applying a multiplier to the duct length to convert it to equivalent feet of duct. Typical multipliers range from 1.5 for systems with short runs and/or a minimal number of anticipated offsets, to 2.0 for long duct runs with a lot of potential obstructions. A pressure drop can then be estimated based on the equivalent feet of duct evaluated at the targeted friction rate. Factors that influence velocity and friction rate decisions are outlined in Side Bars 6 and 7 respectively. Additional information is available in the EDR *Design Details* brief.

The duct velocity/friction rate decision is highly interactive, with other disciplines involved in the design of the building. By bringing an awareness of these interactions to the design team during the early stages of the design process, the mechanical design professional helps the team achieve the over-all project goals, while advocating for and ensuring the energy efficiency of the HVAC system.

Terminal System Pressure Losses

The terminal equipment associated with an air handling system varies from a simple diffuser for a constant volume single zone system to something as complex as a double duct pressure independent variable volume box for a high end commercial system.

All but the simplest terminal equipment can be represented as a "mini" air handling system with an equipment pressure requirement and a distribution pressure requirement. The terminal distribution duct system will be a low velocity duct system for a variety of reasons including sound, flexibility and the small ratio of cross sectional area to hydraulic radius for the ductwork generally encountered there.[13] The techniques used to evaluate these requirements are generally similar to those outlined earlier.

Like any flow control device, the terminal unit needs a pressure drop that is significant relative to the system serving it. In the past, this resulted in selections at 1 to 1.5 in.w.c. Recent research and experience indicates that VAV terminal units equipped with current technology controllers can be sized for a total pressure drop as low as 0.5 in.w.c. and still deliver satisfactory performance.[14]

PEC Static Pressure Projection

At the PEC, the terminal equipment is a VAV reheat unit. Figure 3 illustrates the static pressure requirement estimated for the example. Often such an estimate can be accomplished by hand during the course of a design charette with the other team members. The pressure gradient diagram for the system is illustrated in the Side Bar 8.

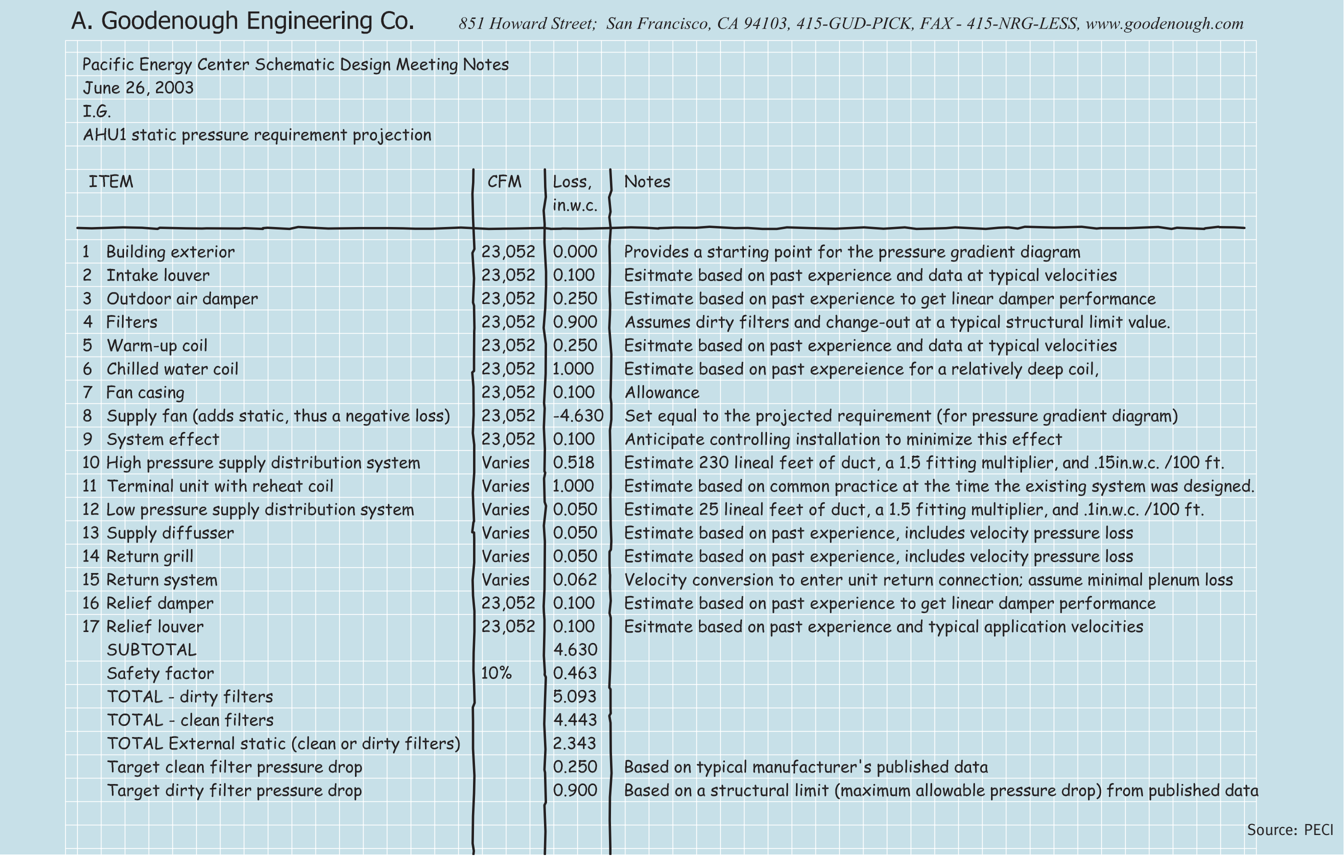
Side Bar 7: Low Velocity Duct System Pros and Cons

Larger ducts with low velocities and friction rates have the potential to save energy and operating cost by minimizing the fan static requirements for the system. It is important to remember that the duct system's pressure requirement vary with approximately the ***square*** of velocity; if you double the velocity it will take nearly four times as much static pressure to move the same volume of air through the system, all other things being equal. Thus lower velocities translate to a reduction in horsepower.[6]

Low velocity systems are also more tolerant of the inevitable adjustments that get made to accommodate existing conditions. Thus lower velocity systems can tolerate the less than optimal fitting configurations often used to solve problems in the field, without the energy penalty that a similar solution places on a high velocity system.

However, lower velocity generally requires larger ducts, mechanical rooms, mechanical shafts and ceiling cavities, which translates into higher first cost. Higher costs are frequently offset to some extent by lower costs in other areas (see side bar 6 for examples). For a project utilizing low velocity ductwork, savings in these other areas, combined with improved operating cost, can result in a significantly improved life cycle cost picture.

Figure 3: The Static Pressure Requirement Estimated During the Schematic Design Charette



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Pacific Energy Center Schematic Design Meeting Notes
June 26, 2003
I.G.
AHU1 static pressure requirement projection

ITEM	CFM	Loss, in.w.c.	Notes
1 Building exterior	23,052	0.000	Provides a starting point for the pressure gradient diagram
2 Intake louver	23,052	0.100	Esitmate based on past experience and data at typical velocities
3 Outdoor air damper	23,052	0.250	Estimate based on past experience to get linear damper performance
4 Filters	23,052	0.900	Assumes dirty filters and change-out at a typical structural limit value.
5 Warm-up coil	23,052	0.250	Esitmate based on past experience and data at typical velocities
6 Chilled water coil	23,052	1.000	Estimate based on past expereience for a relatively deep coil,
7 Fan casing	23,052	0.100	Allowance
8 Supply fan (adds static, thus a negative loss)	23,052	-4.630	Set equal to the projected requirement (for pressure gradient diagram)
9 System effect	23,052	0.100	Anticipate controlling installation to minimize this effect
10 High pressure supply distribution system	Varies	0.518	Estimate 230 lineal feet of duct, a 1.5 fitting multiplier, and .15in.w.c. /100 ft.
11 Terminal unit with reheat coil	Varies	1.000	Estimate based on common practice at the time the existing system was designed.
12 Low pressure supply distribution system	Varies	0.050	Estimate 25 lineal feet of duct, a 1.5 fitting multiplier, and .1in.w.c. /100 ft.
13 Supply diffusser	Varies	0.050	Estimate based on past experience, includes velocity pressure loss
14 Return grill	Varies	0.050	Estimate based on past experience, includes velocity pressure loss
15 Return system	Varies	0.062	Velocity conversion to enter unit return connection; assume minimal plenum loss
16 Relief damper	23,052	0.100	Estimate based on past experience to get linear damper performance
17 Relief louver	23,052	0.100	Esitmate based on past experience and typical application velocities
SUBTOTAL		4.630	
Safety factor	10%	0.463	
TOTAL - dirty filters		5.093	
TOTAL - clean filters		4.443	
TOTAL External static (clean or dirty filters)		2.343	
Target clean filter pressure drop		0.250	Based on typical manufacturer's published data
Target dirty filter pressure drop		0.900	Based on a structural limit (maximum allowable pressure drop) from published data

Source: PECI

Equipment Class and Quality

Once the fundamental system parameters have been identified, it is worthwhile to take a moment to assess their implications in terms of equipment class and quality. For example, an owner may state a preference for unitary, packaged equipment due to budget constraints and in-house maintenance capabilities. But preliminary analysis of the load and system requirements may reveal that the requirements are beyond the capabilities of the machinery preferred by the owner. By identifying an issue like this early in design, the design team can discuss it with the owner and find alternatives *before* the building design and budget are based on an unviable system concept.

PEC Equipment Class and Quality Issues

At the PEC, quality and equipment class constraints include:

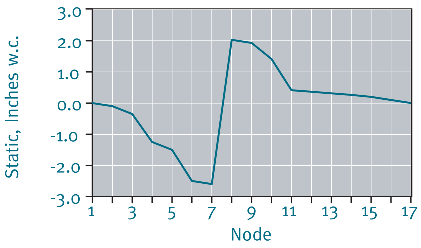
- *Existing Conditions:* The new equipment needs to interface with the existing chilled and heating water systems, the existing control system, and the existing duct system.
- *Owners Goals:* The owner values energy and resource efficiency, thus high efficiency equipment with a long life cycle is preferred over less efficient machinery. Equipment life expectancy is also an issue, as can be seen in Side Bar 9.
- *Installation Access:* Since the project replaces roof mounted equipment with new machinery, modular construction may be a necessity to allow the components to be rigged into place in a cost effective manner.

All of these issues impact the project budget and need to be considered as the budget matures. There are a variety of ways to address the project goals which allow for interaction with the other disciplines as well as the budget. For example, one way to meet the owners goals for equipment life expectancy is to build a mechanical penthouse, as proposed in the initial scope definition of the project. This allows the designer to select standard factory equipment, optimized to meet the project's needs, from a variety of modular product lines. But, there may be a first cost advantage to purchasing a custom air handling package that includes a service corridor as well as the boiler and chiller. While the latter option increases the equipment cost, it could significantly reduce installation costs and architectural requirements. Using the existing structural supports may also be a viable option. Identifying options like these early in the design process gives the team time to fully evaluate them from a cross-disciplinary perspective.

Side Bar 8: Pressure Gradient Diagrams

A pressure gradient diagram provides graphic visualization of a system's pressure losses and their magnitude relative to one other. It helps identify major losses and provides a focus for energy saving design efforts.

Static Pressure Requirement, Dirty Filters



Side Bar 9: Equipment Rooms and Sustainability

At the PEC the existing rooftop machinery has been degraded by exposure to the elements and is in need of major repair or replacement. In addition, it is difficult and dangerous to service during the rainy season, which has an adverse impact on the persistence of energy efficiency efforts. Specifically:

- Exposure to the elements has rapidly degraded the equipment compared to similar machinery serving the building but located indoors.
- The roof membrane and pipe insulation has been worn and damaged due to foot traffic and/or the need to crawl on it to gain access to machinery.
- The high voltage VFD must be serviced while exposed to the elements and standing on a concrete block.
- The numerous roof membrane penetrations associated with the supporting structural steel, ductwork, utility piping, and conduits represent potential leaks and a significant expense when the building is re-roofed.

Installing new machinery in a penthouse will maximize the benefit of the capital cost associated with its repair or replacement and improve maintainability, which directly relates to the persistence of efficiency.

6. Identify Energy Efficiency Opportunities

The knowledge and insight gained via the process described in this brief will often reveal answers to the following question fairly early in the design process:

> *Are there energy efficiency measures that should be considered for inclusion in the project?*

The success of these features depends in large part on the way they coordinate with other system and building elements, so that savings in one area are not offset by an increase in consumption in other areas. For example, adding air-to-air heat recovery to a system will also add pressure drop and fan energy. Identifying desirable options early on allows time for the designer to address this type of interaction. In addition, it allows for the inclusion of desirable features in the project scope and budget, either directly or as alternate price packages. When identified early on, the design team can often accommodate these features with minimal extra design effort. On the other hand, waiting to incorporate them until the end of the design cycle can require significant redesign effort, which may make the feature less attractive to the owner. Finally, identifying these features allows the commissioning tests necessary to optimize them to be identified and included in the project's commissioning specification as it is developed.

Energy Conserving Features for the PEC Project

The project information generated to this point makes the following worth considering:

- The variable dehumidification requirements illustrated in the psych chart in Side Bar 5 may make discharge temperature reset a desirable feature under some operating modes. This would minimize the reheat burden in addition to saving cooling energy.
- The high variation in occupant load also lends itself to demand controlled ventilation, both for the control of

minimum outdoor air at the central air handling unit as well as minimum flow control for the terminal equipment serving the zones with variable occupant loads.

- The static pressure estimate and pressure gradient diagram indicate that a significant portion of the system's energy burden is associated with moving air through the existing duct system, something the designer will have little control over—replacing the entire duct system is not justified from an economic or sustainability standpoint. However, it might be possible to minimize the energy impact of this existing condition by employing discharge static pressure reset for the air handling system to optimize the fan performance to the varying load. The static pressure reset should be carefully coordinated with any discharge temperature reset routines to ensure that the two strategies do not counter-act each other.
- The mild San Francisco climate results in a significant number of hours per year when the chiller operates in conjunction with the economizer process to maintain the required discharge temperature.[15] During this time, building heating loads will be at a minimum or non-existent. Thus, there is merit to considering a refrigerant to water heat exchanger in series with the air cooled condenser to allow the condenser heat to be recovered to the heating water system for reheat and minor space heating during moderate weather.[16]

On a cautionary note, it is important to be conservative when implementing newer, less proven strategies targeted at saving energy or improving another design aspect. It is frequently desirable to include some sort of "back door" that allows the system to revert to a more conventional, proven mode of operation if problems arise when the new feature is commissioned or if it fails during operation. In most cases, this kind of insurance is easily accommodated when the designer plans for it during the early design phases and provided it does not significantly increase the project cost.

A “Back Door” for the PEC

The heat recovery heat exchanger proposed as an energy conservation feature has the potential to provide heat some of the time, but not all of the time. Thus, a boiler sized for the building’s heating load is necessary whether or not the strategy is implemented. In and of itself, the boiler provides a back door if a problem arises with the heat recovery strategy or the heat exchanger fails. The “back door” is made even wider by including valving that allows the heat exchanger to be bypassed for service on both the water and refrigerant sides.

7. Evaluate the System’s Utility Service Requirements

Having identified the flow and static pressure requirements for our proposed fan system, the designer might ask:

> *What are my systems utility requirements so I can coordinate them with the other design team members?*

Without input from the HVAC designer, the electrical engineer can only guess at the HVAC power requirements, which can contribute significantly to the sizing of the distribution system. To prevent problems later on, the electrical engineer may overstate the motor size, “just to be safe.” This can ripple out beyond motor size and result in a larger drive and electrical service, unnecessarily burdening the budget.

Identifying Electrical Loads

Fan power is a direct function of flow and static pressure, two of the parameters for which evaluation techniques have already been discussed. By assuming a fan and motor efficiency, you can use the fan power equation to estimate motor size.[17] Because the information used to evaluate the equation is based on project-related facts, the result helps ensure that the HVAC equipment and the utility systems serving it are right sized from the start. This has many benefits including optimizing first cost and matching the actual operation point for machinery to the peak efficiency or "sweet spot" on its performance curve. Of course, since the information is preliminary, some caution should be exercised when applying it, as discussed in Side Bar 10.

Projecting the Motor Size for the PEC Air Handling Unit

Figure 4 illustrates the calculation the project designer performed during the schematic design charette for the hypothetical PEC project. Interface and coordination issues related to the motor are also noted.

Firming Up Other Aspects of the ME Design

Many of the techniques we've already discussed can be used to firm up other aspects of the mechanical and electrical design. For instance:

- Variations on the load, flow, and static pressure requirement projection techniques can be used to make preliminary pump selections.[18]
- Once flow rates are identified, preliminary duct and pipe sizes can be developed based on the project's design friction rates, velocity limits and standard practice.
- Once design conditions, loads, and flow rates are known, nomographs, catalog tables, or selection software can be used to make preliminary equipment selections for fans, coils and other components.
- Preliminary equipment selections can be used to assess the cost/benefit of various options. For instance, the efficiency penalties associated with a plug fan compared to a housed fan can be contrasted to the first cost savings and packaging advantages that may be provided by the plug fan design.

Early assessments of this type are important because they will help adjust dimensions and budgets to accommodate realistic projections of the requirements while they still remain flexible. Failing to take advantage of opportunities at this point may

Side Bar 10: Sizing Close vs. Safety Factors

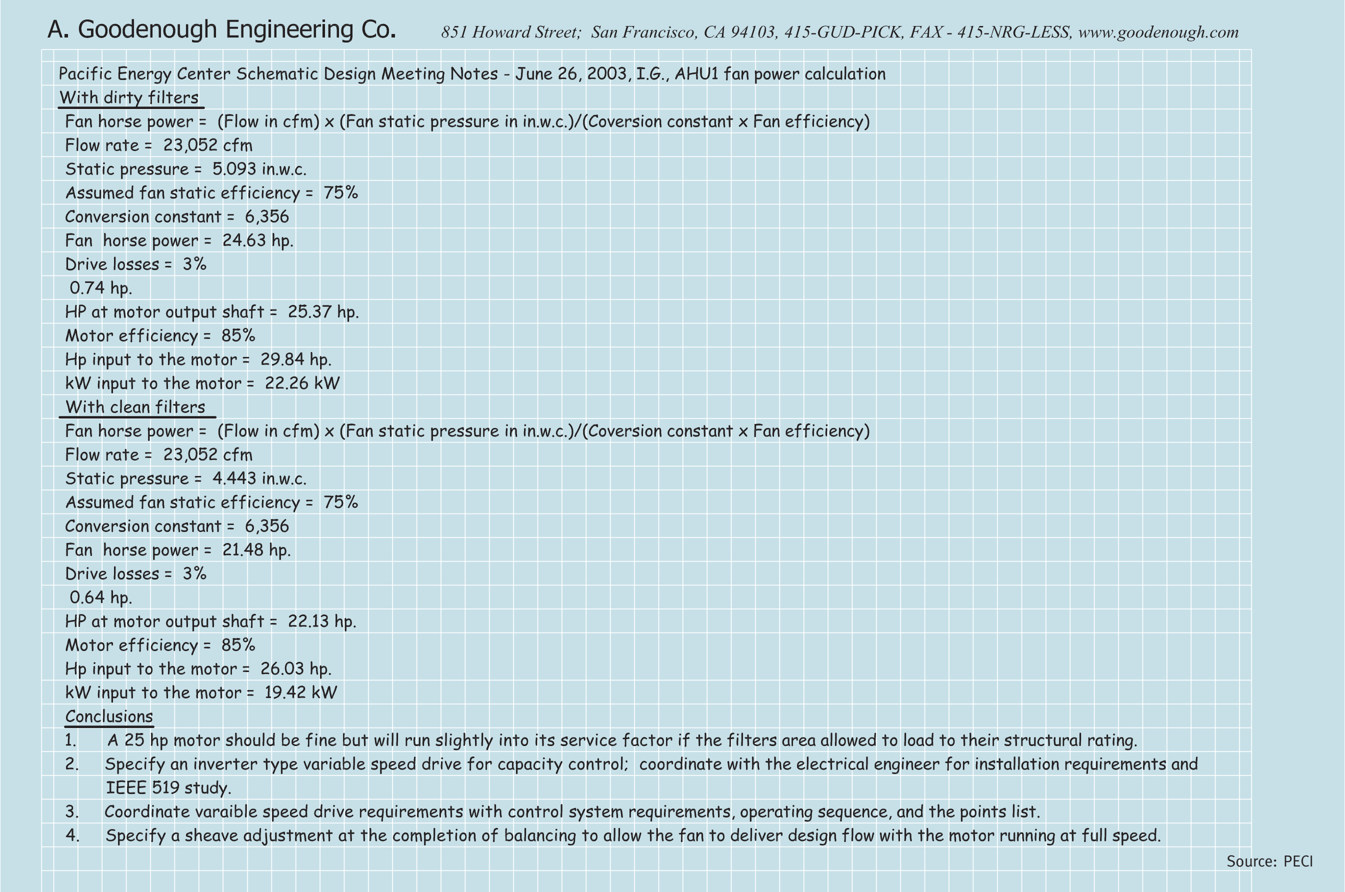
Sometimes, the results of a motor brake horsepower projection will clearly identify the motor size relative to the standard sizes available. But, not all calculations yield such clear-cut answers. It is not at all unusual for the result to end up on the boarder line between two motor sizes. When this happens, choosing a motor is a little trickier.

Factors to consider include:

- The degree of confidence; well-developed numbers based in fact merit tighter tolerances than off-the-cuff guesses.
- Upsizing electrical designs at the last minute can be difficult, but downsizing electrical designs at the last minute may not be possible, so the sizing calculations should be reviewed in a timely manner to ensure adequate capacity and optimum first cost.
- Installing some additional capacity in the central system may make better use of capital and resources if it allows the central unit to serve a variety of loads in the long term without major modification or demolition.

Regardless of the final decision on motor size, the installed system can be and should be tuned during the commissioning process for efficient operation at the current condition.

Figure 4: The Fan Power Requirement Estimated During the Schematic Design Charette



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Pacific Energy Center Schematic Design Meeting Notes - June 26, 2003, I.G., AHU1 fan power calculation

With dirty filters

Fan horse power = (Flow in cfm) x (Fan static pressure in in.w.c.)/(Coversion constant x Fan efficiency)
Flow rate = 23,052 cfm
Static pressure = 5.093 in.w.c.
Assumed fan static efficiency = 75%
Conversion constant = 6,356
Fan horse power = 24.63 hp.
Drive losses = 3%
0.74 hp.
HP at motor output shaft = 25.37 hp.
Motor efficiency = 85%
Hp input to the motor = 29.84 hp.
kW input to the motor = 22.26 kW

With clean filters

Fan horse power = (Flow in cfm) x (Fan static pressure in in.w.c.)/(Coversion constant x Fan efficiency)
Flow rate = 23,052 cfm
Static pressure = 4.443 in.w.c.
Assumed fan static efficiency = 75%
Conversion constant = 6,356
Fan horse power = 21.48 hp.
Drive losses = 3%
0.64 hp.
HP at motor output shaft = 22.13 hp.
Motor efficiency = 85%
Hp input to the motor = 26.03 hp.
kW input to the motor = 19.42 kW

Conclusions

1. A 25 hp motor should be fine but will run slightly into its service factor if the filters area allowed to load to their structural rating.
2. Specify an inverter type variable speed drive for capacity control; coordinate with the electrical engineer for installation requirements and IEEE 519 study.
3. Coordinate varaible speed drive requirements with control system requirements, operating sequence, and the points list.
4. Specify a sheave adjustment at the completion of balancing to allow the fan to deliver design flow with the motor running at full speed.

Source: PECI

mean they are gone forever. For instance, if a designer simply assumes that a plug fan will be used for the air handling unit and allows the equipment room dimensions and distribution shafts to be sized based on this assumption, it may not be possible, at a later time, to enlarge the room or reconfigure the shafts to pick up the extra efficiency points that a properly applied housed fan wheel design would have provided.

Considering Energy Sources

Early design information can also provide insight into the most desirable energy source for the HVAC functions. While this may be more important for new construction than retrofit, it does have its place in that arena on occasion. For instance, a renovation project with a system that currently uses electric reheat coils may do better with an upgrade to hot water reheat with heat recovery from a condenser system, rather than simply installing additional electric reheat coils. In new construction, a life cycle assessment of electric reheat (if they are allowed by the energy code) may reveal significant advantages over hot water or steam, especially if factors, such as concurrent demand with the cooling electrical load and electrical distribution costs, are considered.

8. Evaluate the System's Physical Space Requirements

Related to the previous topic is the following question:

> *What are my system's physical space requirements so they can be coordinated with the architectural design program?*

Without input from the mechanical designer, the architect can only guess about the space requirements for machinery. Because the architectural team has their own design issues to deal with, they may inadvertently slight the needs of the mechanical system in an effort to address their own requirements. The process outlined in this design brief helps the HVAC design team provide vital information to other project team members built on assessments that tie into project specifics. This allows the HVAC requirements to be integrated in a proactive manner.

Because equipment size generally relates to capacity, it is often possible to estimate size once capacity is known. For example, dimensions for an air handling unit can be estimated based on approximate flow rate, design face velocity based on good practice, fan clearance requirements, and commonly available filter sizes. Typically, several size options can be identified, providing the designer with some flexibility in interfacing with the available space requirements and also providing some perspective on the cost/benefit relationship associated with a larger machine and a potentially lower pressure drop/energy requirement.

Side Bar 11: Weighing in On Structural Loads

Structural engineers often need equipment weights early in the project. There are a variety of techniques to accurately identify the loads associated with HVAC machinery, even before the equipment and vendors are selected.

In most cases, the equipment is constructed of sheet metal and metal shapes of various gauges, which are typically set by standard specification language. The estimated unit dimensions can be converted to pounds of sheet metal based on areas and pound per square foot values obtained from a standard engineering handbook.

Similar techniques can be used to assess the weight of coils and other elements. The weight of water in a coil can be derived from the tube information used to estimating the coil weight. Setting up a standard spreadsheet to perform the calculations can make things even easier.

If you have made preliminary equipment selections, you can contact vendors and have them provide estimates of the anticipated weights. But, the technique outlined above has the advantage of providing you with the information when you need it based on fundamentals and can often yield a more timely answer vs. playing phone tag.

Regardless of the source of the preliminary estimates, the final numbers should be reviewed with the structural engineer after the design is finalized so there are no surprises.

When using this technique, there are several points to remember:

- Overestimating is better than underestimating at this point in the process. It's easier to give up space that has been allocated than to obtain space allocated for some other function.
- Identifying several comfortable options and then presenting them to the team is usually more desirable than only having one approach to the problem. Providing two or three alternatives demonstrates flexibility and tacitly acknowledges that the other members of the team have interests of their own.

Once physical sizes are identified, a sketch showing the arrangement of the system, its interconnections to the distribution system, and its service requirements can be developed. Structural loads can also be identified and estimated, as shown in Side Bar 11. Generating these types of sketches can be surprisingly easy,[20] and they can serve as a useful checklists and memory joggers for the mechanical design team as the project moves forward. For the other project team members, they provide a wealth of useful information for further discussion and to aid their development processes. Also, they can be especially useful in advocating for sufficient equipment maintenance access provisions.

There are two components associated with access for equipment maintenance. One is the physical space requirement that allows equipment to be serviced, removed and replaced. Examples include space to pull coils and remove tubes from tube bundles, space to remove fan shafts and fan wheels, and space to stage and replace filters. For electrical equipment like starters and drives, there are usually code-dictated clearances to grounded objects that must be complied with, in addition to logistic considerations.

A second, subtler requirement involves perception. Equipment located in an area designated as a storage room on the drawings is likely to have access blocked by the building tenants when they actually use the space for storage. The design team can ensure that the machinery receives the maintenance required to maintain peak performance in addition to making things safer by designating rooms containing machinery as mechanical rooms and providing them with an different key from the storage spaces. It is also important to remember that units that must be serviced by a ladder will receive less maintenance than they would if they were located at floor level or provided with an access platform. This is especially true for equipment that must be accessed through a ceiling while on a ladder. The bottom line is that equipment that is easily accessible will be better maintained.

Access for equipment replacement is also an important consideration. In new construction, it is important to remember that a machine room that is easily accessible before walls, roofs and finishes go up may become “building locked” without some forethought during design. The access route to the room should provide: sufficient clearance at doors, hallways and other passages leading to the equipment location to accommodate the largest replaceable component; be structurally suitable for equipment as it is moved in; be kept clear in future expansions; provide for efficient supply of utilities to the machinery; provide for efficient distribution of the process streams; and accommodate access for service. Taking these considerations into account will promote upgrades to more efficient technologies as they become available, facilitate good maintenance practices, and minimize material and labor waste associated with temporary access.

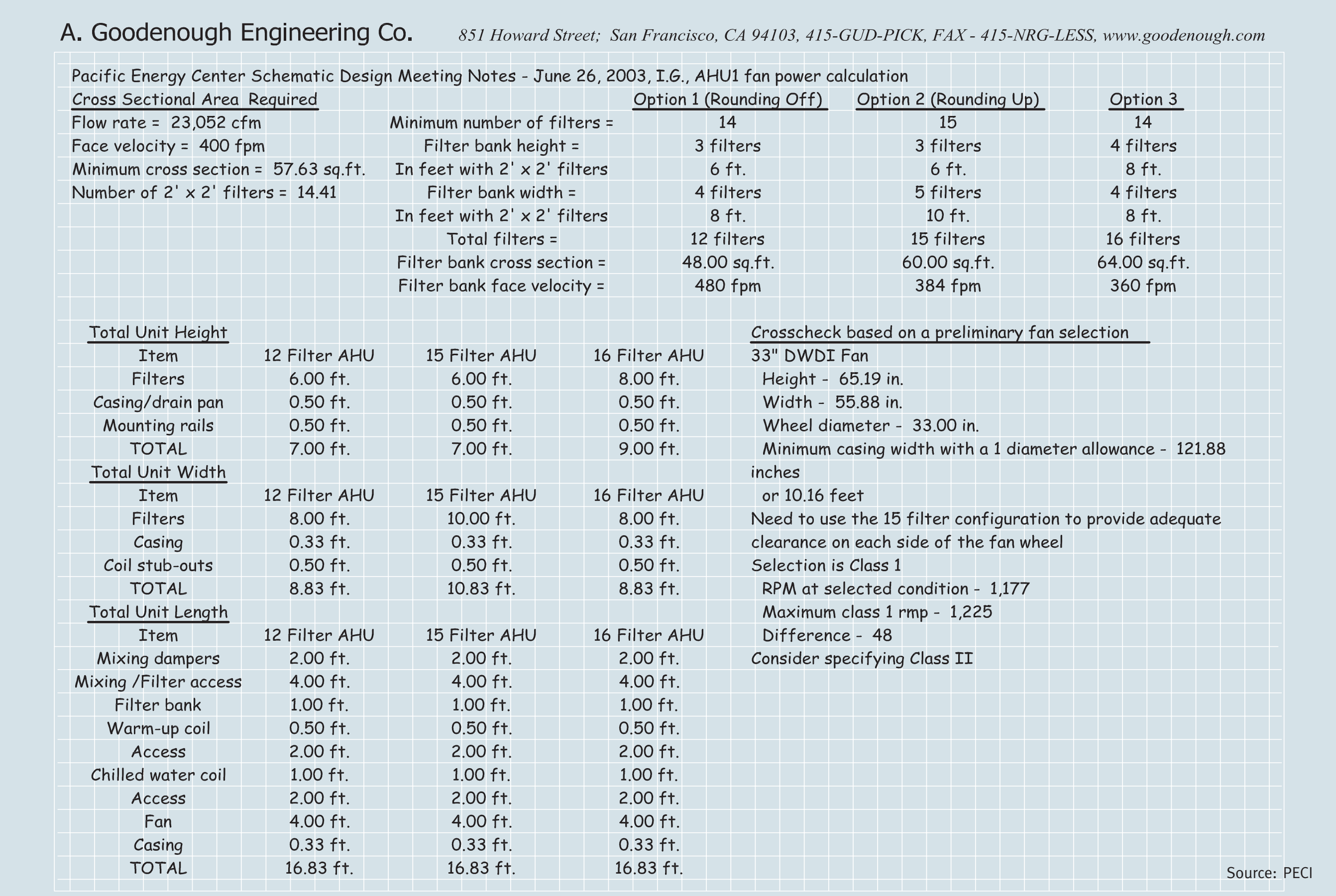
Techniques described in the beginning of this section may be used to size mechanical shafts and ceiling cavities. Be sure to allow for hangers, flanges, insulation, ceiling and shaft mounted equipment, branches crossing mains, structure (especially the heavy elements found around openings), removal of ceiling mounted equipment (ceiling tiles, lights, diffusers, etc.), pipe and duct entry and egress and the dimensional implications of the fire and smoke dampers, as well as shaft access for the facilities staff. Many shafts contain seismic braces and piping-expansion compensation equipment that on occasion requires inspection, maintenance and adjustment. Additionally, during remodeling and future expansion efforts workers need to access the shafts to accommodate tenant needs.

It is also important to remember that vertical clearances need to be considered in addition to the horizontal dimensions typically portrayed on plan views. For example, most air handling units have some sort of structure underneath them like mounting rails that adds depth beyond what is implied by coil and filter face areas. In addition, the unit must be high enough above the floor to accommodate condensate drainage.[22]

Estimating the PEC Air Handling Unit Size and Equipment Room Requirements

Figure 5 illustrates the simple calculations the PEC designer performed to get an understanding of the size of the air handling unit. Figure 6 illustrates the sketch generated as the next step in the process.

Figure 5: The Designer's Estimate of the Normal Air Handling Unit Dimensions for the PEC Project



A. Goodenough Engineering Co. *851 Howard Street; San Francisco, CA 94103, 415-GUD-PICK, FAX - 415-NRG-LESS, www.goodenough.com*

Pacific Energy Center Schematic Design Meeting Notes - June 26, 2003, I.G., AHU1 fan power calculation

Cross Sectional Area Required		Option 1 (Rounding Off)	Option 2 (Rounding Up)	Option 3
Flow rate = 23,052 cfm	Minimum number of filters =	14	15	14
Face velocity = 400 fpm	Filter bank height =	3 filters	3 filters	4 filters
Minimum cross section = 57.63 sq.ft.	In feet with 2' x 2' filters	6 ft.	6 ft.	8 ft.
Number of 2' x 2' filters = 14.41	Filter bank width =	4 filters	5 filters	4 filters
	In feet with 2' x 2' filters	8 ft.	10 ft.	8 ft.
	Total filters =	12 filters	15 filters	16 filters
	Filter bank cross section =	48.00 sq.ft.	60.00 sq.ft.	64.00 sq.ft.
	Filter bank face velocity =	480 fpm	384 fpm	360 fpm

Total Unit Height

Item	12 Filter AHU	15 Filter AHU	16 Filter AHU
Filters	6.00 ft.	6.00 ft.	8.00 ft.
Casing/drain pan	0.50 ft.	0.50 ft.	0.50 ft.
Mounting rails	0.50 ft.	0.50 ft.	0.50 ft.
TOTAL	7.00 ft.	7.00 ft.	9.00 ft.

Total Unit Width

Item	12 Filter AHU	15 Filter AHU	16 Filter AHU
Filters	8.00 ft.	10.00 ft.	8.00 ft.
Casing	0.33 ft.	0.33 ft.	0.33 ft.
Coil stub-outs	0.50 ft.	0.50 ft.	0.50 ft.
TOTAL	8.83 ft.	10.83 ft.	8.83 ft.

Total Unit Length

Item	12 Filter AHU	15 Filter AHU	16 Filter AHU
Mixing dampers	2.00 ft.	2.00 ft.	2.00 ft.
Mixing /Filter access	4.00 ft.	4.00 ft.	4.00 ft.
Filter bank	1.00 ft.	1.00 ft.	1.00 ft.
Warm-up coil	0.50 ft.	0.50 ft.	0.50 ft.
Access	2.00 ft.	2.00 ft.	2.00 ft.
Chilled water coil	1.00 ft.	1.00 ft.	1.00 ft.
Access	2.00 ft.	2.00 ft.	2.00 ft.
Fan	4.00 ft.	4.00 ft.	4.00 ft.
Casing	0.33 ft.	0.33 ft.	0.33 ft.
TOTAL	16.83 ft.	16.83 ft.	16.83 ft.

Crosscheck based on a preliminary fan selection

33" DWDI Fan
  Height - 65.19 in.
  Width - 55.88 in.
  Wheel diameter - 33.00 in.
  Minimum casing width with a 1 diameter allowance - 121.88 inches
  or 10.16 feet
Need to use the 15 filter configuration to provide adequate clearance on each side of the fan wheel
Selection is Class 1
  RPM at selected condition - 1,177
  Maximum class 1 rmp - 1,225
  Difference - 48
Consider specifying Class II

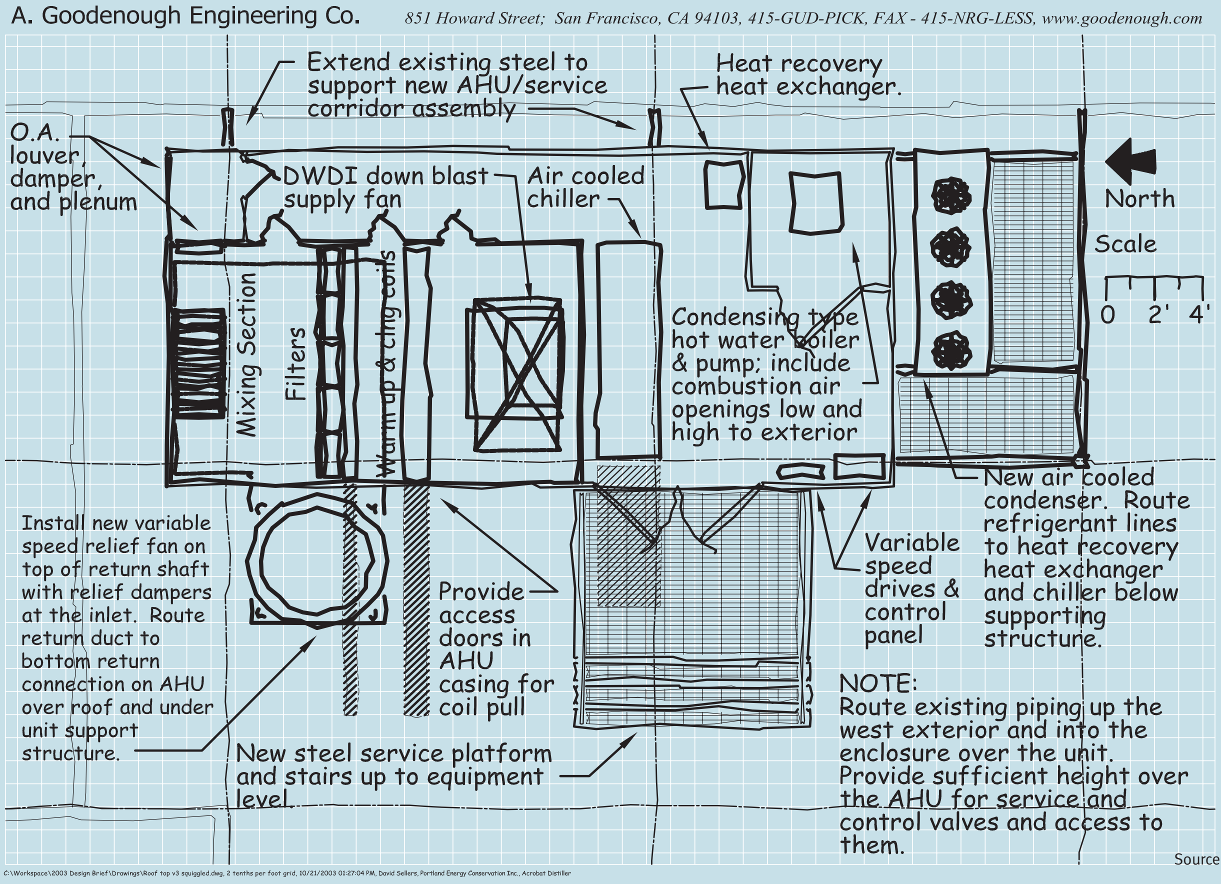
Source: PECI

In Figure 6, the following parameters have been acknowledged and documented.

- The drawing highlights space required for coil and tube removal in addition to ensuring that the piping can be disconnected without requiring a system drain down.
- The configuration provides several feet downstream of the economizer dampers to ensure mixing.
- The fan is configured to provide good inlet and outlet conditions, minimizing the impact of system effect. In this particular application, a plenum fan would provide no reduced unit length advantages, so a housed fan has been shown to maximize efficiency.[19]

Figure 6: The Designer's Equipment Room Sketch

The figure below is one of several sketches that might be developed in the course of a design development meeting. The sketch shows the general arrangement of the air handling unit and its components and surrounding service corridor and is drawn approximately to scale using the graph paper grid. The team might also sketch out an elevation and section of the equipment and its enclosure to allow clearances above the roof and over the air handling unit to be illustrated.



Install new variable speed relief fan on top of return shaft with relief dampers at the inlet. Route return duct to bottom return connection on AHU over roof and under unit support structure.

New air cooled condenser. Route refrigerant lines to heat recovery heat exchanger and chiller below supporting structure.

NOTE:
Route existing piping up the west exterior and into the enclosure over the unit. Provide sufficient height over the AHU for service and control valves and access to them.

C:\Workspace\2003 Design Brief\Drawings\Roof top v3 squiggled.dwg, 2 tenths per foot grid, 10/21/2003 01:27:04 PM, David Sellers, Portland Energy Conservation Inc., Acrobat Distiller

Source: PECI

The PEC project requires the use of a crane or helicopter to deliver new machinery to the roof, both of which represent a considerable expense that must be incorporated into the budget from the start.

9. Assess Constructability and Sequencing

A key question on any project is:

> *Can this be built in a real world, real time process?*

Renovation projects, like the PEC example included in this brief, are especially sensitive to the sequence of construction. Services for building occupants need to be maintained and the building needs to provide a safe and productive workplace during the construction process. Issues like these need to be considered during the design process because they impact the viability of possible design solutions, as well as the budget. Side Bar 12 provides a list of common considerations. Typically, planning and capital can address problems identified in the assessment. But occasionally, this process reveals a fatal flaw that would have crippled the project had it not been detected during the design phase.

Side Bar 12: Drawing It Doesn't Build It

The real world imposes limitations that make even the best idea impractical. By identifying such limitations before fully developing an idea, the design team can redirect engineering effort towards more appropriate solutions—and save a lot of design time and expense. Failing to recognize impossible ideas until they assert themselves in the field can lead to disaster. It is a good idea to do a reality check on some important issues:

- Critical services that must be maintained during construction.
- The impact of local environmental and climate conditions on various phases of the project.
- The impact of the construction process on the users of an existing facility.
- The impact of the construction process on near-by neighbors and adjacent property.
- Availability of materials and equipment relative to the location as well as the current project time line and completion date.
- Availability of specialized skilled labor relative to the location as well as the project timeline and completion date.
- Trade interferences; 8 painters can't paint a phone booth 8 times as fast as one.

Construction Sequencing for the PEC Example

Figure 7 illustrates the preliminary construction sequence developed by the team working on the PEC project. Many projects face similar issues.

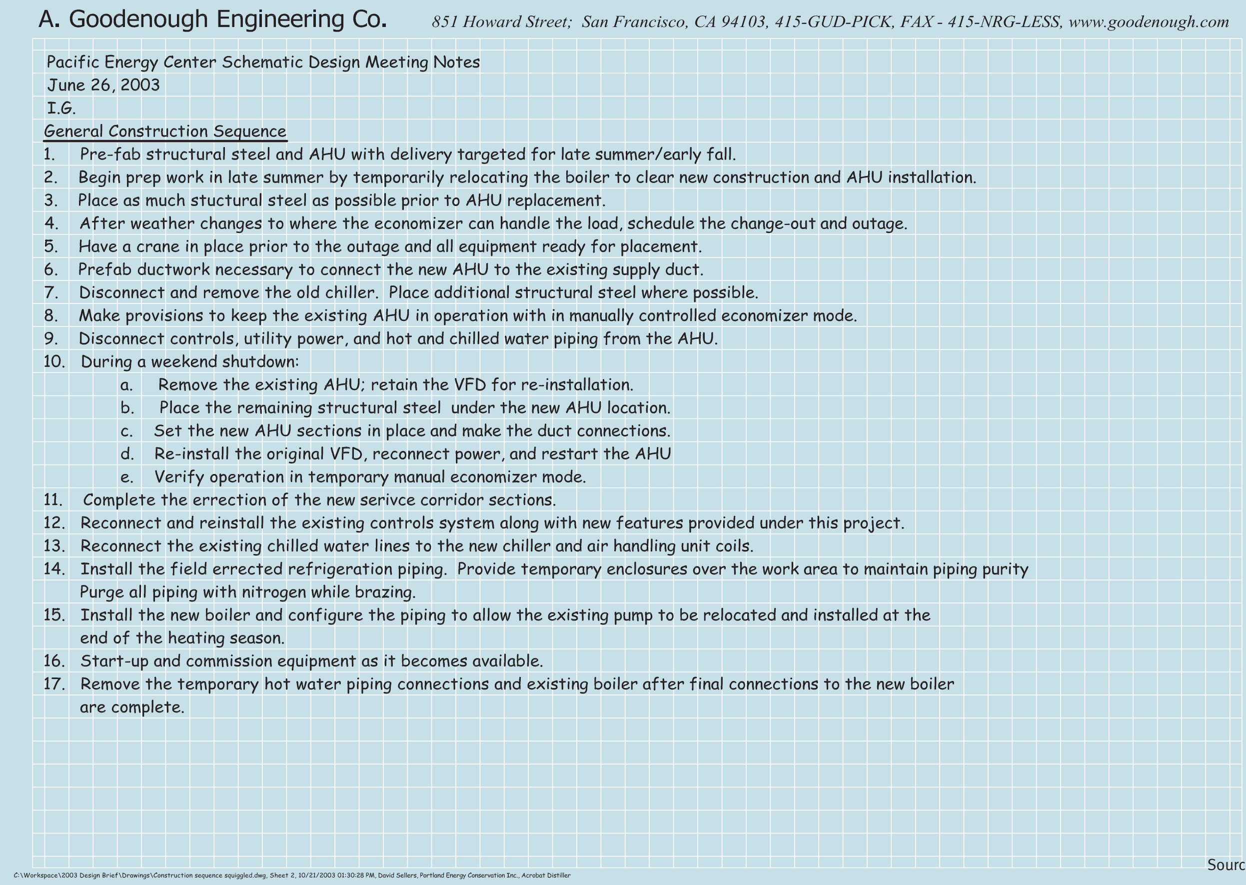
10. Developing a System Operating Narrative and Points List

Asking and answering the following questions may be one of the most critical steps in the HVAC design process:

> *How is this system intended to function and what details need to be addressed to ensure its successful operation?*

Designers frequently develop the project's control system information as the final step in their design effort. Often they provide only a general statement of operating requirements,

Figure 7: The Proposed Penthouse Construction Sequence Developed by the Team During the Charette



A. Goodenough Engineering Co. *851 Howard Street; San Francisco, CA 94103, 415-GUD-PICK, FAX - 415-NRG-LESS, www.goodenough.com*

Pacific Energy Center Schematic Design Meeting Notes
June 26, 2003
I.G.

General Construction Sequence

1. Pre-fab structural steel and AHU with delivery targeted for late summer/early fall.
2. Begin prep work in late summer by temporarily relocating the boiler to clear new construction and AHU installation.
3. Place as much stuctural steel as possible prior to AHU replacement.
4. After weather changes to where the economizer can handle the load, schedule the change-out and outage.
5. Have a crane in place prior to the outage and all equipment ready for placement.
6. Prefab ductwork necessary to connect the new AHU to the existing supply duct.
7. Disconnect and remove the old chiller. Place additional structural steel where possible.
8. Make provisions to keep the existing AHU in operation with in manually controlled economizer mode.
9. Disconnect controls, utility power, and hot and chilled water piping from the AHU.
10. During a weekend shutdown:
    a. Remove the existing AHU; retain the VFD for re-installation.
    b. Place the remaining structural steel under the new AHU location.
    c. Set the new AHU sections in place and make the duct connections.
    d. Re-install the original VFD, reconnect power, and restart the AHU
    e. Verify operation in temporary manual economizer mode.
11. Complete the errection of the new serivce corridor sections.
12. Reconnect and reinstall the existing controls system along with new features provided under this project.
13. Reconnect the existing chilled water lines to the new chiller and air handling unit coils.
14. Install the field errected refrigeration piping. Provide temporary enclosures over the work area to maintain piping purity Purge all piping with nitrogen while brazing.
15. Install the new boiler and configure the piping to allow the existing pump to be relocated and installed at the end of the heating season.
16. Start-up and commission equipment as it becomes available.
17. Remove the temporary hot water piping connections and existing boiler after final connections to the new boiler are complete.

C:\Workspace\2003 Design Brief\Drawings\Construction sequence squiggled.dwg, Sheet 2, 10/21/2003 01:30:28 PM, David Sellers, Portland Energy Conservation Inc., Acrobat Distiller

Source: PECI

which may or may not include a list of the required points. This practice can lead to problems when the system comes on line and issues ripple out beyond the construction phase to plague the building for life.

Generalized statements regarding the required operating sequence, while conveying intent, leave a lot open to interpretation. The pressures of a competitive bidding environment, coupled with misinterpretations of the statement of intent in the field, lead to operational problems that are difficult or impossible to resolve. The EDR *Design Review* brief takes a detailed look at a common generalized control sequence, identifies the details that need to be addressed and makes recommendations regarding how to handle these issues. Taking some time during the early stages of design to develop a detailed system narrative goes a long way towards preventing start-up and operational problems as well as documenting the design intent for the system. It also improves the design process by identifying problems when they can be addressed with design solutions rather than field solutions. Finally, the narrative provides an sound basis for commissioning the system, the related training process and systems manual.

Supplementing a detailed operating narrative with a points list clarifies the design intent of the project, helping to ensure that it is met and persists. In addition to providing valuable bidding and operating information, the point list helps to assess the control system cost very early in the process. When the project goes to bid it helps level the playing field, thereby ensuring consistent bids that reflect the project requirements. *The Control System Design Guide* referenced in the Integrated Design section of this design brief simplifies this task by providing the user with a set of spreadsheets with point recommendations for common system configurations. These lists can be used to initiate developing the control costs on a $/point basis during early design. As the design progresses, further edits can reflect the requirements of the particular system and project, as well as individual design standards.

Generating a Preliminary Point List for the PEC AHU

Figure 8 was extracted from the point list developed for the PEC project using the tool in the *Control System Design Guide*. The complete list as generated by the tool includes point names, sensor requirements, accuracy requirements, and alarm and trending requirements in addition to the information illustrated in the figure.

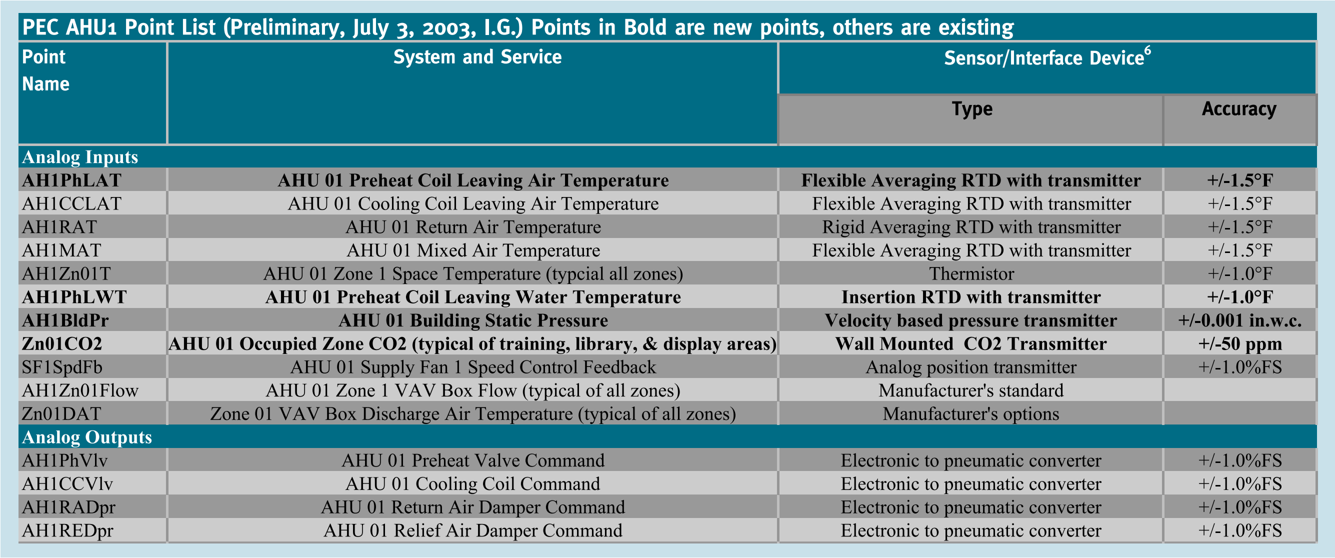
11. Identify Areas Where Detailing Will Be Important

Even though the design is fairly fluid during the early phases, when asked, most HVAC professionals would have several answers to the following question:

> *Where do I need to pay attention to details to ensure that the intent of the proposed design is achieved?*

Figure 8: Sample Point List

This figure illustrates part of the point list from the PEC project which was generated in a matter of minutes using the spreadsheet tool in the Control System Design Guide. The tool includes master point lists for 10 common system types as well as recommendations about which points are considered mandatory, which are considered optional, and the benefits associated with providing the optional points. Recommendations for analog inputs and outputs, digital inputs and outputs, hardwired safeties and virtual points are included.



PEC AHU1 Point List (Preliminary, July 3, 2003, I.G.) Points in Bold are new points, others are existing

Point Name	System and Service	Sensor/Interface Device[6]	
		Type	Accuracy
Analog Inputs			
AH1PhLAT	**AHU 01 Preheat Coil Leaving Air Temperature**	**Flexible Averaging RTD with transmitter**	**+/-1.5°F**
AH1CCLAT	AHU 01 Cooling Coil Leaving Air Temperature	Flexible Averaging RTD with transmitter	+/-1.5°F
AH1RAT	AHU 01 Return Air Temperature	Rigid Averaging RTD with transmitter	+/-1.5°F
AH1MAT	AHU 01 Mixed Air Temperature	Flexible Averaging RTD with transmitter	+/-1.5°F
AH1Zn01T	AHU 01 Zone 1 Space Temperature (typcial all zones)	Thermistor	+/-1.0°F
AH1PhLWT	**AHU 01 Preheat Coil Leaving Water Temperature**	**Insertion RTD with transmitter**	**+/-1.0°F**
AH1BldPr	**AHU 01 Building Static Pressure**	**Velocity based pressure transmitter**	**+/-0.001 in.w.c.**
Zn01CO2	**AHU 01 Occupied Zone CO2 (typical of training, library, & display areas)**	**Wall Mounted CO2 Transmitter**	**+/-50 ppm**
SF1SpdFb	AHU 01 Supply Fan 1 Speed Control Feedback	Analog position transmitter	+/-1.0%FS
AH1Zn01Flow	AHU 01 Zone 1 VAV Box Flow (typical of all zones)	Manufacturer's standard	
Zn01DAT	Zone 01 VAV Box Discharge Air Temperature (typical of all zones)	Manufacturer's options	
Analog Outputs			
AH1PhVlv	AHU 01 Preheat Valve Command	Electronic to pneumatic converter	+/-1.0%FS
AH1CCVlv	AHU 01 Cooling Coil Command	Electronic to pneumatic converter	+/-1.0%FS
AH1RADpr	AHU 01 Return Air Damper Command	Electronic to pneumatic converter	+/-1.0%FS
AH1REDpr	AHU 01 Relief Air Damper Command	Electronic to pneumatic converter	+/-1.0%FS

All of the schematic design/design development techniques discussed above help answer this question. For example, if efficiency measures have been targeted, they require some attention as the design progresses to ensure their intent is satisfied. Or, if the projected static estimate makes the proposed motor selection tight, extra attention to the details of the ducts and fittings may be in order. The precise areas of focus and level of effort required vary from project to project and are generally a function of the project's size and complexity. For most projects, the following areas are worthy of assessment:

- *Areas where air or water flow rates are high*. High water and airflow rates usually indicate high transportation energy costs. High flow rates have high velocities, compounding the energy burden they represent. Taking time to detail the project to ensure efficient equipment and distribution for these systems will go a long way towards producing a resource efficient building.

- *Areas that are congested with other building elements*. This subject relates closely to high flow rates, discussed above. A good example of this occurs when branch ducts tap into a large riser and exit a fire rated shaft. Velocities in the riser and branch ducts tend to be high, meaning that the velocity pressures and velocity pressure related losses in fitting have the potential to be high. Subtle differences in how the branch taps the riser make a huge difference in the pressure loss that occurs there. Compounding this issue is the need to provide a fire or smoke damper in the branch duct where it penetrates the rated separation, a location that is often only inches from the point where the branch taps the riser. In addition, risers usually run in shafts that penetrate the building structure at each floor, often in the core of the building where structural loads are high. Thus, the penetrations are framed by structural members that tend to be deeper than those encountered at locations farther from the shaft, further constricting the available space.

- *Items requiring special attention to assure that design intent is achieved.* Items that are not typical or standard construction always merit additional detail in order to ensure that the requirements are conveyed to the field. Competitive bidding pressures make this especially important. For instance, a contractor who knows of special requirements may not include them in the bid if they are not shown on the drawings, in order to be sure their bid is competitive with one from a contractor who may not recognize or account for the undocumented issues and costs. Of course, necessary costs avoided during the bid process inevitably show up later as a change order or corrective repair after start-up. Or, they may never be addressed, in which case the system fails to meet its design intent, leading to performance problems, IAQ problems, and excess energy consumption.

The EDR *Design Details, Design Review, and Field Review* briefs take a closer look at detailing and it’s benefits, from design through construction.

Detailing the PEC project

At the PEC, there are several places where detailing is important:

- At the discharge connection of the air handling unit to minimize system effect and ensuring the system hits its design static pressure target.
- In the congested area below the penthouse where the large return duct must be routed from the existing roof penetration to the inlet of the new air handling unit.
- The requirements associated with the field-erected refrigeration piping, especially where the piping interfaces with the heat recovery heat exchanger.

12. Develop or Reassess Budgets

For the owner, the bottom line for a project is often:

> *What will the HVAC system cost and can I afford it?*

All the processes described in this brief can be used to develop and reassess the project budget as the design progresses. This is significant because budgets are frequently set during the concept phase, well in advance of design work. A cost estimate based on a list of items rather than a concept will nearly always prove more accurate, even when the list is loosely defined and subject to change. If there are budget problems based on the early design information, things will probably worsen unless corrective action is taken. If no additional funding appears and costs must be cut, it is much simpler to make cost control adjustments early on, which also allows designers to more effectively use their time.

If the project team includes one, a construction manager is the ideal candidate to develop the project budget from schematic and design development information. Usually, the construction manager undertakes this task willingly because it helps ensure that the project stays within budget. In fact, they may have already committed to a Guaranteed Maximum Price (GMP) even though detailed design work has yet to be done. When the project team does not include a construction manager, each team member should assess their particular area of expertise by drawing on past experience, preliminary quotes from vendors, industry standard estimating guides, and rules of thumb like $/square foot, $/cfm, $/control point and labor cost as a percentage of material cost.

It is important to consider the following details, regardless of who puts the estimate together.

- *Don't forget about vertical distances*: It's easy to lose sight of the fact that the building will be constructed in three dimensions when you are staring at two-dimensional plans. The costs will be related to the three dimensional realities.
- *Mobilization*: Like it or not, it will take the field staff some time to get up to speed on the project when they first arrive on site. In most cases, factors applied to labor costs account for this. If project phases require contractors to leave and return several times, it may be desirable to add extra contingency fees to cover the cost of getting re-acquainted with the project after being off-site.
- *Rigging*: This can become quite expensive for a site with restricted access. In addition to the direct costs of renting a crane or helicopter, there are many hidden costs, including: a "show-up" fee imposed by the rigging company regardless of whether or not they actually lift anything, local government fees for shutting down a street for the crane set-up, and lost productivity if the area below the rigging location is temporarily evacuated during the lift. Sequencing can also affect costs. It may be necessary to set up and take down the crane several times if all necessary lifting cannot occur simultaneously.
- *Miscellaneous Materials*: Usually, these are accounted for in factors applied to the project's material costs. Occasionally, covering a cost that would not be reflected elsewhere necessitates adding extra money to the budget.

- *General Construction Cost*: Most projects have some general construction costs, even if they are focused on pure mechanical or electrical renovations. For instance, it may be necessary to take down and then reinstall a ceiling to run new duct, pipe or conduit.

- *Contingencies*: It is important to include allowances in the estimate for contingencies in the design and construction process. These can generally be reduced as the project moves forward and the design firms up, but should never be totally eliminated due to the variable nature of a real world construction process and the realities of hidden, existing conditions.

- *LEED Requirements*: Buildings designed to incorporate aspects of the USGBC Leadership in Energy and Environmental Design (LEED) rating system are increasingly common. Features associated with this program, while both desirable and cost effective, frequently add first cost to the project. Considering them when composing the project budget may prevent added redesign costs. To quote one experienced design professional "As a designer, I am always challenged with the question 'How much does it cost to go green?' The answer is, 'It depends; maybe nothing. But it will be more if you have to redesign to incorporate it'."[21]

- *Commissioning*: Commissioning costs may not be reflected in general estimates prepared from schematic and design development information. Several useful papers and articles discussing commissioning costs can be found at http://www.peci.org.

- *Overhead and Profit*: Even though it may be one of the less palatable budget items, it is important to include an allowance for the contractor's overhead and profit.

- *Escalation*: For large projects a year or more may elapse between the finalization of the budget and the first capital outlay. Including a factor to accommodate inflation will help ensure that the concepts envisioned and budgeted for during early design are fully funded at the time of construction.

Side Bar 13: Schematic Design and Computers

With laptop computers and personal organizers becoming more and more common, many design professionals find themselves taking notes, doing calculations, and even making sketches electronically rather than by hand. In addition to improving the quality of the work, these electronic tools allow the SD and DD information to be directly incorporated in subsequent phases of the project. Helpful ways to improve this process include:

- Keep spreadsheets that document major parameters from past projects for estimating purposes on new projects. Example metrics you may want to track include installed capacity, square-footage, engineering hours, construction costs, etc.
- Develop spreadsheets for complex calculations to further streamline the development process. Examples include load estimates, static pressure projections, equipment sizing projections, etc.
- Use the preliminary information generated in an electronic format as the basis of the next phase of design rather than starting from scratch.
- Develop an electronic technical library to make useful design information accessible in the field or during meetings.

Budget Considerations for the PEC Example

The following issues will need to be considered as the budget for the PEC project is developed.

- Since replacement of the air handling unit is weather-dependent but requires extensive preparation, the construction team may have to mobilize on the site more than once.
- Placing equipment on the roof will incur significant rigging costs and may require a partial street shut down and/or overtime labor.
- Protecting the roof during construction requires additional costs not covered by normal budget items.
- Existing ceilings and walls need to be opened up and then returned to a finished state to allow connections to existing systems to be made.
- As a renovation project, hidden conditions may require funding once they are uncovered.
- Some of the interactive efficiency measures targeted require focused functional testing as a part of the commissioning process to ensure their design intent is realized.

Conclusion

The techniques in this brief will help the reader make energy efficiency a major focus of their project from the start. The strategies covered here will also help organize the design effort and provide a firm basis for documenting design intent. These steps will help move the design intent forward, into the construction documents and actual installation and start-up of the building and its systems, especially if the team takes full advantage of available computer technology, as discussed in Side Bar 13. If properly implemented, this process will yield benefits that start with the design team and last through the life of the building.

Notes

1 A detailed discussion of these philosophies is not the focus of this brief. However, understanding them is integral to a successful application of the concepts presented here. To explore these topics in greater detail, consult the following publicly available resources. The *Integrated Energy Design* brief from Energy Design Resources (EDR) is an obvious choice. In addition, several of the other EDR design briefs discuss different aspects of integrated design, including Building Integrated Photovoltaics, Daylighting, Design for Your Climate, Design Details, Design Review, Field Review, Glazing, Lighting Controls, Options and Opportunities, Radiant Cooling, Smart Buildings, and Underfloor Air Distribution and Access Floors. No cost downloads of all of these documents are available at http://www.energydesignresources.com/.

2 Chapter 2 of the *Functional Testing Guide for Air Handling Systems: From the Fundamentals to the Field* includes a section dedicated to the system concept. The topic is also a reoccurring theme through-out the Guide as well as the companion *Control System Design Guide*. Both can be downloaded as a package, free of charge from the Lawrence Berkeley Lab web site at http://buildings.lbl.gov/hpcbs/FTG.

3 *HVAC Equations, Data, and Rules of Thumb* by Arthur A. Bell Jr. (McGraw Hill, 2000) is a wealth of useful preliminary design information.

4 Hospital licensing requirements vary from State to State, but Table 3 in the *2003 ASHRAE Applications Handbook* is generally representative of most guidelines and is a good reference for initial estimates. (A similar table can be found in earlier editions of the Applications Handbook).

5 This site has just been developed and will eventually be seamlessly linked to the Energy Design Resources web site. If you have trouble with this link, go to the EDR web site and make the connection from there.

6 Zone level based scheduling applies schedules at terminal units on VAV fan systems to fully close their dampers when the zones they serve are unoccupied. This reduces the flow demand on the central system allowing it to back down and serve the remaining zones with out moving air to the unoccupied areas. Night set-back and set-up routines temporarily re-establish flow as necessary to maintain the unoccupied areas within limits. If all the zones served by the system are unoccupied, then the system shuts down. Usually the system turn down capability places a limit on how many zones can be shut down with out compromising the system's ability for stable operation under all conditions.

7 Turndown is an expression that relates the maximum capacity that a system must operate at to the minimum capacity it must operate at. Usually it is expressed as a percentage or a ratio. In the PEC example, the peak load is approximately 4.5 times the minimum load, as indicated in Figure 1, thus the turndown ration is 4.3:1.

8 Optimizing filter selections for best life cycle cost can be a real juggling act. Issues to be considered are discussed in the following resources:

The Energy Design Resources *Design Details* brief, available for no-cost download at the EDR site.

Filtration: An Investment in IAQ, by H.E. Barney Burroughs, Heating, Piping and Air Conditioning(HPAC), August 1997

The Art and Science of Air Filtration in Health Care, by H.E. Barney Burroughs, HPAC, October 1998

(Both HPAC articles can be downloaded for a nominal fee at http://www.hpac.com/)

9 This is table 1B of the ASHRAE Handbook of Fundamentals. In addition to providing design data, the table provides extreme maximum and minimum data and guidance regarding its applications.

10 For a more detailed discussion of some of the design and operational issues associated with economizer and preheat coil operation in sub-freezing weather consult *Chapter 5 - Economizer and Mixing and Chapter 7 - Preheat of the Functional Testing Guide* referenced in the Integrated Design section of this document.

11 For a more detailed discussion of damper sizing, point selection and other control system issues see the *Control Design Guide* referenced in the Integrated Design section. *Chapter 2* includes a discussion of damper sizing as well as a spreadsheet that will help the user generate a damper schedule. *Chapter 4* includes sample points lists in the form of a spreadsheet available to the user.

ASHRAE Guideline 16-2003. Selecting Outdoor, Return, and Relief Dampers for Air-Side Economizer Systems also discusses damper sizing in detail.

12 Additional information on the relationship between velocity, static pressure and fan horsepower can be found in the *2000 ASHRAE Systems and Equipment Handbook, Chapter 18 - Fans*, the *2001 ASHRAE Handbook of Fundamentals - Chapter 34 - Duct Design*, and the EDR *Design Details* brief.

13 Small ducts have a much larger perimeter per unit of cross sectional area enclosed as compared to larger ducts. Since the interaction of the air flow with the perimeter is the cause of most of the fictional losses in a straight duct section and since this loss is a function of velocity, a small duct at a given friction rate will have a much lower velocity than a large duct at the same friction rate. This has several interesting implications, which are illustrated in a downloadable PowerPoint™ presentation titled *The*

Relationship Between Duct Aspect Ratio and Sustainability at www.peci.org/papers/aspectratio.pdf. Additional discussion on this topic can be found in *Chapter 13* - and the *Supplemental Information to Chapter 13*, both contained in the *Functional Testing Guide* referenced in the Integrated Design section of this document.

14 *The Advanced VAV System Design Guideline*, scheduled for release in the summer of 2003 will contain a detailed discussion of terminal unit selection and sizing issues in addition to information regarding other VAV design topics. Watch the New Buildings Institute web site at www.newbuildings.org for additional information.

15 This is termed an integrated economizer. Additional discussion on this topic can be found in the EDR *Economizers* design brief.

16 For more information on this topic read *Making Energy Intensive HVAC Processes More Sustainable via Low Temperature Heat Recovery* available for no-cost download at www.peci.org/papers/lowtemp.pdf.

17 For those unfamiliar with the fan power equation, *Appendix C - Calculations of the Functional Testing Guide* referenced in the Integrated Design section of this document discusses the use of the fan power equation in detail including a discussion of how to evaluate each of the variables.

18 The EDR *Design Review* brief includes an example of using this technique to spot-check a pump selection on pages 26-32.

19 See pages 30-32 of the EDR *Design Details* brief for a discussion of fan inlet and outlet conditions and system effect as well as additional references on the topic.

20 There is even a program called Squiggle™ that takes files from common drawing programs and “de-accurifies” them by applying parameters like “wiggle,” “tilt,” “sputter,” “thicken,” “slide,” and “bend” to modify the line presentation resulting in machine plots that look like free-hand sketches. For more information go to www.signaturecad.com.

21 Glen Friedman, P.E., personal correspondence, July 28, 2003.

22 See Chapter 8 of the *Functional Testing Guide* referenced in the Integrated Design section of this document for a detailed discussion of condensate drain traps and their operating principles including illustrations.

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