energydesignresources

design brief

DESIGN DETAILS

Summary

Building owners are spending more money on complex building systems than ever before and yet many find they have building system problems. Providing design details on construction documents can reduce these problems and save money. Design details increase the likelihood that designs will be correctly implemented in the field, reducing change orders and saving first costs. Using design details to specify an optimized system can also save energy and other operating costs.

For example, it is not uncommon for the connection between a duct and a supply plenum to be shown as a square (representing the plenum) with a line connected to it (representing the duct). A literal interpretation of this connection may result in a fitting with significant pressure loss. However, a simple expansion of the duct at the connection point by a bellmouth fitting can cut this pressure loss by 50% or more. This can translate into hundreds of dollars in annual energy savings for numerous fittings in a large air handling system.

Attention to design details can improve performance and efficiency in almost all aspects of a design. Design details are particularly important for:

- Piping and duct arrangements that minimize the number of fittings and bends.
- Pipe and duct fittings that minimize frictional losses.
- Fan and pump discharge conditions that minimize losses.

Although the energy savings for each detail may be small, the combined effects in a commercial building are significant. In a typical building, providing design details can save an owner approximately 5 to 15% in energy costs.

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CONTENTS

Introduction

Designers do not always provide design details and many energy-efficient designs are not implemented correctly in the field.

The building industry has changed considerably since the 1960's; designers today are forced to provide far more technically sophisticated designs in less time, for a lower fee. As a result, designers do not always provide well-developed design details and many energy-efficient designs are not implemented correctly in the field.

If drawings do not clearly show design details, then tradesmen at the site fill in the gaps. Due to their tight margins, tradesmen may use the lowest-cost solution that meets the contract document requirements. In addition, tradesmen don't always have the expertise or experience to recognize the energy implications of their solutions. Even if they do, they cannot afford to provide a more expensive solution if the documents do not clearly call for it. As a result, tradesmen may settle for less-than-optimal solutions. Though the energy savings for each added detail may be fairly small, the combined effects are surprisingly large.

This design brief is the first of a three part series on how to ensure energy efficient designs are implemented correctly in the field. This brief discusses the importance of providing design details and gives many examples of energy-efficient design details.The second is a design review guide that discusses how to effectively review design development documents and construction documents. The third discusses the importance of ongoing construction monitoring and describes what to look for during field inspections at different phases of construction. The complete series illustrates how designers can ensure that their energy efficient designs are properly implemented—by ensuring that they are clearly detailed, specified, and constructed.

The Importance of Design Details

Taking the time to develop, design, and document mechanical and electrical system details during design may add engineering design costs but ultimately benefits all parties involved, improves system performance, and reduces costs. Some of the reasons are listed below:

- The installed system is more likely to meet the design intent because the contractors have more information to work with. A detailed design drawing is far more useful to a contractor than a rough schematic with specifications. Fewer problems during construction result in fewer construction questions, less engineering time during construction, and higher levels of client satisfaction.

- The installed system is more likely to be energy efficient. Ambiguity in the design drawings allows contractors to work out the details with the lowest first-cost option. Contractors may be unfamiliar with the engineering and energy implications behind designs. Unclear designs are likely to result in solutions that cause problems or use unnecessary energy.

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- The contractor's exposure to risk is reduced. Fewer decisions are left to the contractor's discretion and the contractor can feel more comfortable bidding the project knowing that everyone is including the same things in their price.

- The owner's exposure to change orders during the construction process is reduced. Change orders add expense to the project because construction is delayed, materials put in place must be returned or scrapped, labor is expended unnecessarily, additional costs are incurred with quick shipping of materials and equipment, and there is no competitive bid process for the changes.

- The engineering safety factors used in the equipment selection process can be minimized. Equipment can be matched more precisely to the requirements of the project because the engineer is providing a more precise solution to the design problem. In addition, energy efficient design details may reduce the size of an HVAC system. Such a reduction can have a ripple effect through the project that may reduce the entire building's required electrical capacity.

To illustrate the importance of design details we will describe several common design details in piping systems and air handling systems that improve system performance and reduce operating costs with little or no increase in first costs. Additionally, we will discuss isometric drawings versus diagrammatic drawings. At the end of the design brief we will apply these principles to a hypothetical building and illustrate the first cost and operating cost savings that result.

How Energy is Saved

In most pipe and duct systems, energy is saved by reducing pressure loss in the system. Reducing pressure loss in turn reduces pump and/or fan energy.

Saving energy in pipes or ducts involves similar, fairly simple concepts. In most cases, energy is saved by reducing pressure loss in the system. Reducing pressure loss in turn reduces pump and/or fan energy. When assessing the energy implications of various pipe and duct details or configurations, it is important to remember three points:

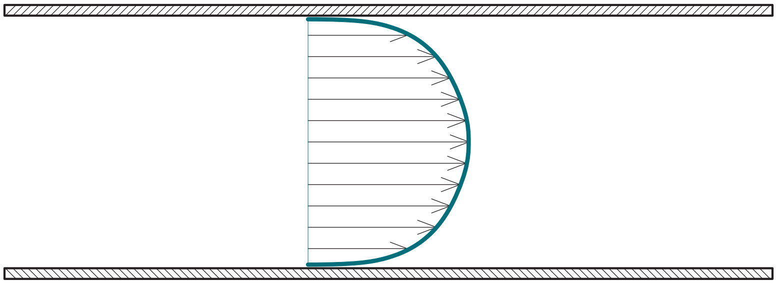
1. Pressure loss is proportional to the square of the flow.[1] Doubling the flow through a section of pipe or duct increases the pressure drop by a factor of four if all other variables are constant.

2. Pump or fan horsepower is proportional to the cube of the flow.[2] Doubling the flow will increase the pump or fan horsepower by a factor of eight if all other variables are constant. The amount of energy used by the system is dependent on the pump/fan horsepower, the efficiency of the pump/fan, the efficiency of the motor and drive, and the time the pump/fan is running.

3. Pressure losses in pipe and duct elements are based on research and testing that assumes a uniform velocity profile entering the element (see **Figure 1**). If this profile is distorted, the performance of the pipe or duct will not match its rated value, potentially increasing motor horsepower.

Figure 1: Velocity profile in a typical pipe

The pipe cross-section below illustrates a typical velocity profile. The exact shape will vary with fluid characteristics. The length of the arrows represents fluid velocity. Note the higher centerline vs. wall velocities.



Source: AMCA

Design Details in Piping Systems

Pipe Fittings

Below we describe several pipe fitting options that save energy with minimal, if any, first cost additions.

Long Radius vs Short Radius Elbows

Figure 2 compares the pressure drop of a long radius elbow with that of a standard or short radius elbow. As the figure shows, the losses through the fittings are nonlinear with flow, and the loss through the long radius elbow is about two-thirds the loss through a standard elbow.

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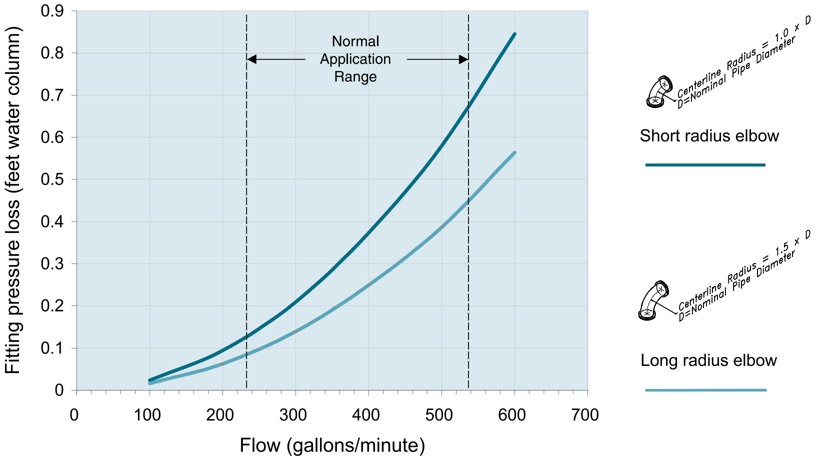
Figure 2: Pressure drop vs flow for 5 inch pipe elbows

The figure below illustrates the reduction in pressure drop that results when a long radius elbow is used instead of a standard or short radius elbow.



Source: PECI[3]

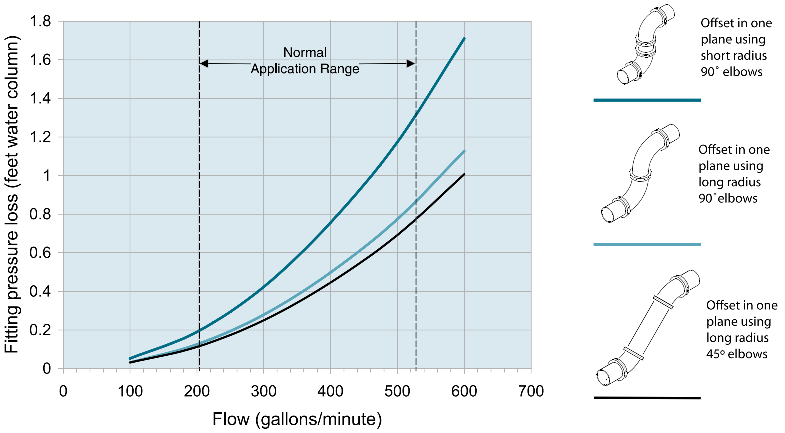
The fitting configuration used to make an offset can also make a significant difference in the resulting pressure drop.

Pipe Offsets in One Dimension

The fitting configuration used to make an offset can also make a significant difference in the resulting pressure drop. When changing the position of the pipe horizontally or vertically, it is often possible to make this change using two 45° elbows instead of two 90° elbows. As can be seen in **Figure 3**, the pressure drop for the 45°offset is significantly less than that for the 90° elbows.

Figure 3: Pressure drop vs flow for 5 inch pipe offsets in one plane

Using long radius 45º elbows instead of 90º elbows when making a piping offset results in a lower pressure drop.



Source: ASHRAE Handbook of Fundamentals

Pipe Offsets in Two Dimensions

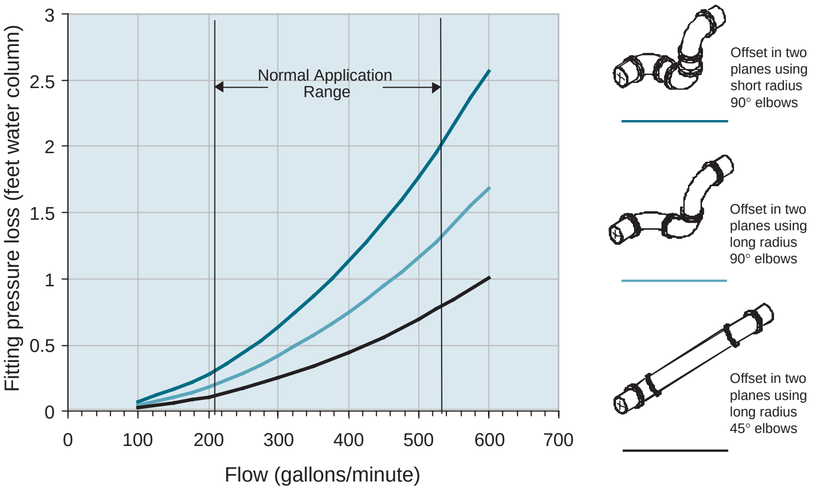
When the pipe offset must be made both horizontally and vertically, and available space allows the offset to be made with 45° fittings, the savings potential is even more dramatic. In addition, this design solution reduces first costs because only two fittings (and the necessary welds in larger pipe sizes) will be used. **Figure 4** illustrates this graphically.

Pipe Tee with Offset

A variation on the above theme occurs when a tee is installed in a pipe and then the pipe leaving the branch of the tee must be offset. By rolling the tee 45° in the direction of the required offset and then completing the offset with a 45° elbow, the pressure drop is reduced.

Figure 4: Pressure drop vs flow for 5 inch offsets in two planes

Using long radius 45º elbows instead of 90º elbows when making a piping offset in two planes results in even less pressure drop and greater energy savings. First costs are also lower due to the reduced number of fittings (and their associated welds on larger lines).



Source: ASHRAE Handbook of Fundamentals

Pipe Tees

Pipe tees are common in pipe circuits. The way that tees are applied and fabricated significantly impacts the associated pressure drops. The most common application for a tee is to connect two individual lines into one common line or vice versa. Such a connection can be made either by using a manufactured fitting or by fabricating the joint in the field from the pipe in the system.

When discussing tees, two terms are typically encountered: run and branch. The run of the tee is the flow path that goes straight through the fitting. The branch of the tee is the flow path that approaches the tee from the side (typically at 90° to the run). Flow in and out of the branch usually has much more resistance than flow through the run because the fluid must make a turn. Regardless of whether the tee is combining or splitting flow, the pressure drop tends to be lowest if the largest percentage of flow passes through the run and the smallest portion passes through the branch. The size of the tee should be based on the combined flow entering or leaving the tee rather than one of the branch flows.

Regardless of whether the tee is combining or splitting flow, the pressure drop tends to be lowest if the largest percentage of flow passes through the run and the smallest portion passes through the branch.

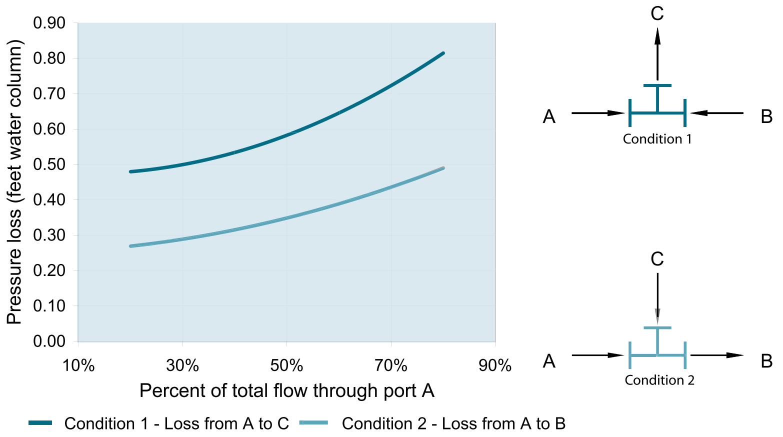
Tees that Combine Flow

When a tee is used to combine two separate flow lines, optimal performance results when one of the lines comes in through the branch, the second line comes in through one end of the run, and the combined flow exits through the other end of the run. This configuration is much more energy efficient than when the combined flow exits through the branch. The difference in pressure drop between the two configurations can be as high as a factor of two or three depending on the flow through the branch. **Figure 5** illustrates the pressure drop for a 5-inch tee in two different configurations.

When a tee is used to combine two separate flow lines, optimal performance results when one of the lines comes in through the branch, the second line comes in through one end of the run, and the combined flow exits through the other end of the run.

Figure 5: Pressure drop vs flow for a 5 inch tee that combines flow at 460 gallons per minute

When a tee is used to combine two flow streams into one, the best overall pressure drop configuration will result when one flow stream enters on the run and the other enters on the branch, and the combined flow exits on the other end of the run.



Source: ASHRAE Handbook of Fundamentals

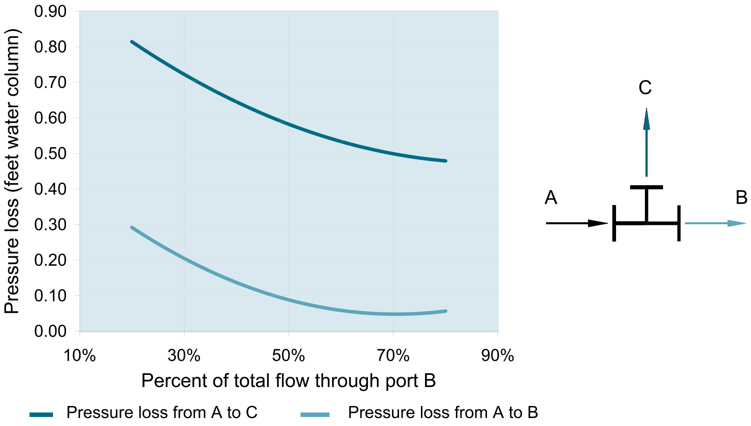
Tees that Split Flow

A similar result occurs when a tee is used to split the flow into two separate pipes but the pressure drop implications are even higher. A tee that brings in the flow in the branch port and splits it out through the two run ports can have more than 20 times the pressure drop of a tee that splits the flow between the branch and the run. The pressure drop associated with the tee depends on the percentage of flow split to the branch.

Regardless of how a tee is applied and oriented, designers must still consider the pressure drop through both branches because they can be quite different as illustrated in **Figure 6**. Note how the pressure drop actually decreases with an increase in flow through port B—the opposite of your intuition—whereas the pressure drop through port C increases with an increase in flow.

Figure 6: Pressure drop vs flow for the branches of a 5 inch tee that splits 460 gallons per minute

It is important to consider the pressure drop through both branches because they can be quite different. Note how pressure drop decreases as flow through port B increases, while pressure drop increases as flow through port C increases.



Source: ASHRAE Handbook of Fundamentals

Tees and Balancing

Deciding which load is connected to the branch and which load is connected to the run can have a significant impact on system balancing requirements. In most piping systems, the pressure required to move water through the various loads is seldom equal. Without balancing valves, water tends to flow to the load with short piping runs and low pressure drops while the loads with longer piping runs and higher pressure drops do not receive their design flow rates. The balancing devices in the low pressure drop legs must be "throttled" or partially closed while monitoring flow rate until the design flow rate is achieved. Essentially, this adds pressure drop to the low pressure drop leg so that the water tends to flow through the higher pressure drop leg.

Deciding which load is connected to the branch and which load is connected to the run can have a significant impact on system balancing requirements.

A designer can take advantage of the configuration losses associated with a tee by connecting the load with the lowest pressure drop to the branch of the tee with the highest pressure drop and vice-versa. This tends to add pressure drop where it would be needed anyway and minimizes the pressure drop in the run that already has the highest pressure drop.

There are occasions where it is desirable to use a tee so that the pressure drop through either branch is equal. Consider the cooling coil piping isometric in **Figure 11** on page 16. In this case, the tee has been applied so that it is equally difficult for the flow to go in either direction, thus making the split self balancing.

Manufactured Tees vs Saddle Joints

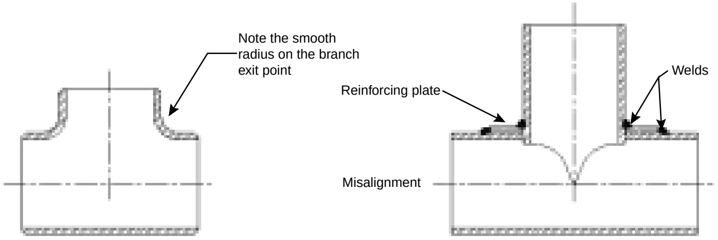
A manufactured tee fitting will have a much lower and more predictable pressure drop than a tee that is field fabricated by saddling one pipe into another.

The fabrication method of a tee can also have a significant influence on its pressure drop characteristics. A manufactured tee fitting will have a much lower and more predictable pressure drop than a tee that is field fabricated by saddling one pipe into another. The reasons for this become apparent if you study the cross-sections of these two joints shown in **Figure 7**.

Notice how the branch connection of the manufactured tee has a well-rounded transition between the branch pipe wall and the run pipe wall. This sharply contrasts with the relatively abrupt, rough edge of the saddle joint. The smooth radius of the manufactured tee offers much less resistance to branch flow and significantly reduces turbulence in the fitting, thereby reducing pressure drop through the fitting.

Figure 7: Manufactured tee and saddle joint cross sections

The smooth radius of the manufactured tee offers much less resistance to flow than the relatively abrupt and potentially misaligned edges of a saddle joint. As a result, the loss through the manufactured tee is lower and more predictable.



Source: Grinnell, Hydra-stop, PECI

In addition, the pressure drop in the manufactured fitting is much more predictable due to the manufacturing process. The pressure drop across a saddle joint depends on exactly how the joint is made, which depends on the skill of the pipe fitters and how difficult the joint is to access.

Experience has shown that the saddle connection can easily have 5-10 times the pressure drop of the manufactured fitting. As a secondary issue, the saddle joint is also more prone to failure due to stress in the welds at the joint and the potential for corrosion. In fact, many inspectors will reject such a joint for this reason unless the connection follows carefully prescribed and detailed fabrication instructions including reinforcements around the saddle.

Saddle joints can have 5-10 times the pressure drop of manufactured fittings and are more prone to failure due to stress in the welds.

Tee joints are typically used rather than saddle joints for pipe sizes less than 2 to 2-1/2 inches because material and labor costs are low enough that saddle joints are not an attractive option—except for making a tap into an existing line. Saddle joints can save first costs when larger pipe sizes are involved. But the added pressure drop could easily add hundreds of dollars in annual operating costs and their potential for failure is higher.

Pump Discharge Conditions

Pumps are often piped with combined function valves at their discharge. Combined function valves provide throttling capabilities, shut off capabilities, and back flow capabilities in one package. But the pressure drop through these devices can be quite high. In addition, many manufacturers use the portion of the valve seat that stops reverse flow in the check valve operating mode to provide the seal to shut off flow when the valve is used as a service valve. The check valve cycles every time the pump cycles (which can be several times a day) whereas the service valve will be used much less frequently (perhaps once a year when the pump must be drained for seal replacement or overhaul). Thus the operation of the check valve causes most of the wear and tear on the combination check valve/service valve seat.

Typically check valve seats require service every 5 to 7 years. However, if the valve seat on a combined function valve also provides the service valve function, the valve seat cannot be replaced without shutting down the system. This has several costly implications. At least a portion of the system will need to be drained. Since it is unlikely that there is a second service valve for each pump, the portion that must be drained will probably include the mains served by all the parallel pumps. This means that the redundant pumps cannot provide the redundant function and a system shutdown will be required to perform the work. Also, once the repair has been made, the system will need to be refilled and vented. Thus, what should be a simple, non-disruptive maintenance operation becomes a major operation and can result in a major system outage for critical systems if the system must operate 24 hours per day.

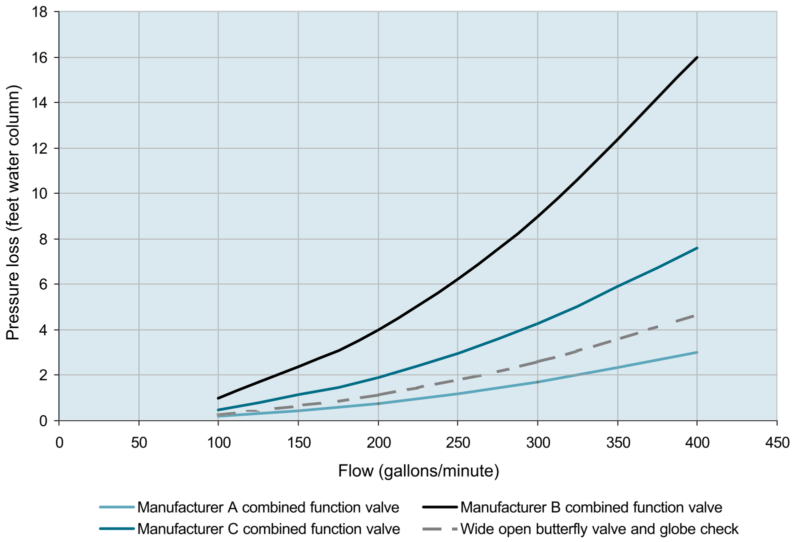
Often, a better solution is to use a butterfly valve with an infinite throttling handle and memory stop and a wafer or globe style check valve instead of a combined function valve.

Often, a better solution is to use a butterfly valve with an infinite throttling handle and memory stop and a wafer or globe style check valve instead of a combined function valve. The independent check valve provides the back-flow prevention function independently from the combination service valve/balance valve function provided by the butterfly valve. This allows the service valve to be closed to replace the seats in the check valve without having to shut down and drain a significant portion of (if not the entire) system. **Figure 8** compares the pressure drop through several combined function valves with that of a check valve/butterfly valve combination.

In the long term, the throttling function at the pump discharge is not required. Initially, the balancing contractor uses the discharge throttling valve to establish the design flow rate and balance the loads. However, once the final balance is completed, more efficient operation can be achieved by opening the throttling valve and trimming the pump impeller. However, many operators lack the skills, training, tools and/or funding to allow them to perform this last step.

Figure 8: Comparison of pressure drops through different pump discharge valve configurations

There can be considerable variation in the pressure drops through the valve or valves used on the discharge of a pump to provide the throttling, check, and service valve functions. Generally, this will not be consistent across the product line; i.e. manufacturer A may be best in a 4 inch size, but manufacturer C may be best at another line size. Designers should look at the specific requirements of each application before specifying a product or approach.



Source: Bell&Gossett, Muessco, Centerline, ASHRAE

A throttled valve at the discharge of a pump wastes energy by adding pressure drop to the system. This throttled valve affects the flow in the system or subsystem served by the pump, not just the flow through the branch. In most cases, the energy wasted by throttling the pump's discharge valve is less than the energy that would be wasted by pumping too much water. But reducing flow by trimming the impeller size typically saves even more energy.

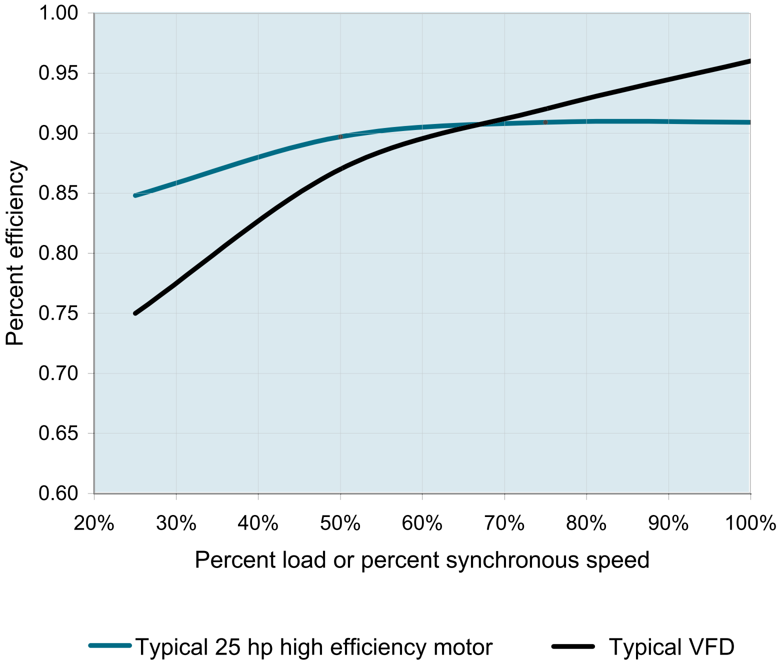
If pumps or fans are equipped with variable speed drives, it is tempting to balance the system by slowing the pump down with the drive rather than by trimming the impellers. While better than throttling, the result is not optimal in most cases since drive efficiency drops as a function of load and drive speed. **Figure 9,** page 14, illustrates this effect for a typical drive.

As a general rule, a variable speed drive is best applied as a control device, not a balancing device. A system's overall

A throttled valve at the discharge of a pump wastes energy by adding pressure drop to the system.

Figure 9: Variable speed drive and motor efficiency vs. load

Both motor efficiency as well as variable speed drive efficiency will vary with load. The combined effect of the reduction in motor and drive efficiency at low loads can actually result in a net increase in power requirements below certain speeds.



Source: Gould, ASHRAE

A system's overall efficiency is best optimized by adjusting the pump's impeller size so that the pump delivers the design flow when the drive is running at full speed. The variable speed drive can then be used to match the actual load conditions.

efficiency is best optimized by adjusting the pump's impeller size so that the pump delivers the design flow when the drive is running at full speed. The variable speed drive can then be used to match the actual load conditions. But there comes a point when the change in efficiency (with load) results in a net increase in energy. This usually happens at 20% to 30% of full load. Control algorithms aimed at preventing reductions in pump speed below this point produce the best system efficiency.

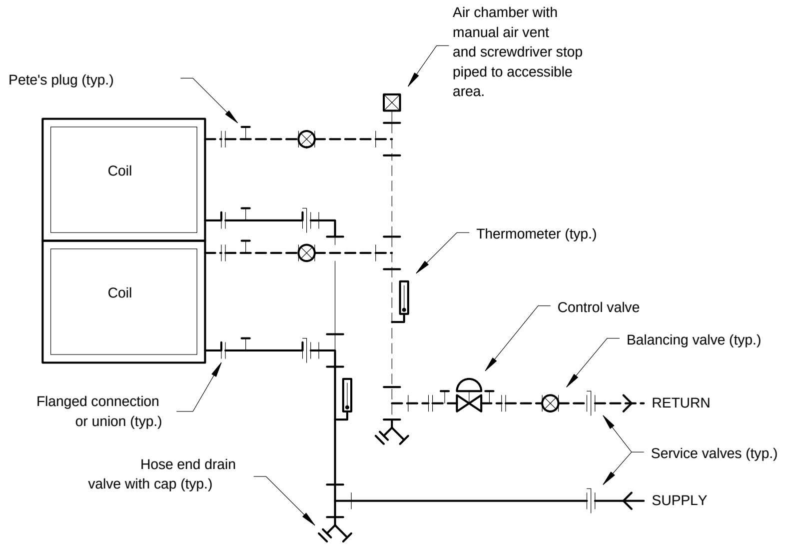
Similar concepts apply to fans except the performance change is achieved by changing the speed of the fan wheel by varying the ratio between the motor and fan pulley diameters (analogous to the pump impeller).

Coil Connection Details

Coil banks in air-handling units often consist of many smaller coils piped in parallel. **Figure 10** depicts a coil bank piping detail that is often seen on construction drawings.

Figure 10: Non-detailed coil piping schematic

This schematic illustration is often used on construction drawings.



Source: PECI

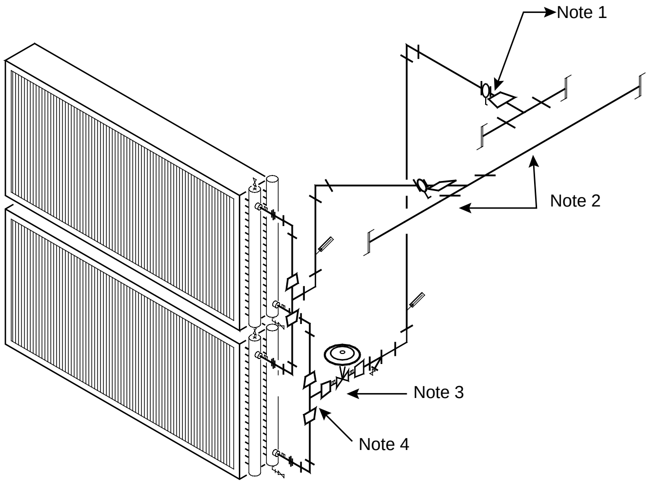
While nothing is wrong with this detail, several simplifications could be made that would reduce pumping energy and first costs. In some facilities, the operational advantages of the more complex arrangement outweigh the energy and first cost benefits of the simplified arrangement. In other cases, the simplifications could be adopted with little operational impact. The simplifications illustrated in **Figure 11** fall into the following general categories:

- *Eliminate the ability to isolate each coil in the bank from the piping system.* Eliminating the service valves for each coil in a bank reduces the resources required to construct a project, makes the piping connection more compact and lowers project first costs. There are also relatively minor energy savings since the pressure drop of the service valves is eliminated. A method must still be provided to isolate the entire coil bank from the system.

In some cases, the valves for isolating and balancing the individual coils in a bank can be eliminated if the coil bank is piped so that it self-balances and so that the bank can be isolated from the system.

Figure 11: Coil piping isometric with energy efficiency details

This isometric drawing provides physical as well as diagramatic information, which gives the designer more control over the actual installation, and the pressure drops associated with it. This figure also illustrates the energy efficiency details discussed in the text.



Source: PECI

Note 1: Butterfly valve with infinite throttling handle and memory stop provides service valve and balance valve functions.

Note 2: Service valves are located above and to one side of the coil pull space to allow the valves to be closed and downstream piping removed for coil access without draining the entire system.

Note 3:The control valve is equipped with pressure test ports immediately before and after it to allow the wide-open valve pressure drop to be used for flow measurement.

Note 4:A symmetrical piping arrangement on both the supply and return sides of the coil bank makes the coil bank self balancing, eliminating the need for individual coil balance cocks. Individual coil air vents and drain connections allow the coil pressure drop to be measured and compared to the manufacturers data as a cross check for balancing and for preventive maintenance purposes.

Eliminating these valves places some operational limits on the coil bank—particularly in regard to system failures and service needs. Individual coil valves allow one coil to be isolated to repair a minor leak or other service operation while keeping the remaining coils and system active. This could be the difference between performing service and repair functions during normal working hours without a facility outage and shutting down the system and performing the work on overtime.

Individual service valves may also prove useful in a catastrophic coil failure, although not as much as one might expect. Catastrophic failure can occur when coils freeze, are subjected to pressures beyond design capacity or experience undetected corrosion. They typically result in significant amounts of water spraying the interior and/or exterior of the air-handling unit, which starts to flood the area. When responding to such a problem, it is often difficult to determine the exact location of the failure. Time is of the essence to prevent water damage and maintain the operation of the central system. Often the quickest way to address the immediate problem is to simply close the common service valves to the coil bank and then determine where the failure is and what to do about it.

- *Provide a self-balancing piping configuration to eliminate the need for individual balance valves*. Regardless of whether individual service valves are provided for each coil, energy and first cost savings can be achieved by piping individual coils in the bank symmetrically so that they self balance. This allows individual balance valves to be eliminated or replaced by a service valve, which has less pressure drop and lower first cost. Balance valves have a much higher pressure drop than a service valve of the same size, even if they are in the wide open position. In most cases, this approach can be used without impacting the operation of the system. However, a method must still be provided to balance the coil bank with respect to the system.

Regardless of whether individual service valves are provided for each coil, energy and first cost savings can be achieved by piping individual coils in the bank symmetrically so that they self balance.

- *Select and configure components in the piping circuit to eliminate the need for a separate coil bank balancing device.* The need for an independent balancing device for the coil bank can be eliminated by installing gauge cocks across the coil control valve and a butterfly or ball valve with infinite throttling capability and memory stop in place of one of the service valves. This reduces both first cost and ongoing energy costs. Providing a handle with infinite throttling capability for the service valve allows the valve to be used to balance the flow. The memory stop allows the balance setting to be locked in place so that the valve can be closed to act as a service valve and then re-opened to the balanced position eliminating the need to re-balance. A control valve is a precision-machined component with a predictable pressure drop. Gauge cocks located on each side of the control valve allow the control valve's wide open pressure drop to be used as an indication of flow for balancing purposes. The gauge cocks need to be located immediately adjacent to the control valve so that only the valve pressure drop is measured. The vent and drain valves on the individual coils allow coil pressure drop readings to be obtained. This information can be compared to the coil design data and used as a cross-check when measuring flow and for maintenance purposes.

As with most design decisions, coil bank valve detailing decisions should not be made casually. The designer should review the considerations above with the owner and facility staff. This discussion may reveal that the first cost benefits of simplified piping circuit can be accommodated without compromising the operational capabilities of the system in less demanding applications.

As with most design decisions, coil bank valve detailing decisions should not be made casually. The designer should review the considerations with the owner and facility staff.

Isometric vs. Diagrammatic Details

Figures 10 and **11** illustrate another method to increase energy savings, minimize first costs, and improve project quality. **Figure 10** is a diagram or schematic. It illustrates the components that are required and the order they should be installed. However, it does not illustrate the physical arrangement of the components in three dimensions. **Figure 11** is an isometric, which conveys the same information, but also addresses the physical arrangement in three dimensions. With piping isometrics, designers provide more information and as a result, installations are more likely to be executed correctly in the field.

Design Details in Air Handling Systems

Differences Between Piping and Duct Systems

Saving energy in air handling systems is very similar to saving energy in piping systems; that is, reduce the pressure required to move the air/water and the fan/pump will use less energy. However, several differences should be kept in mind:

Saving energy in air handling systems is very similar to saving energy in piping systems; that is, reduce the pressure required to move the air/water and the fan/pump will use less energy.

- In piping systems, most connections and changes in direction are made using manufactured fittings with very consistent dimensions and very repeatable pressure drops. Fittings in duct systems are typically custom fabricated. As a result, duct system drawings are far more subject to interpretation (or misinterpretation) in the field with potentially damaging results from the standpoint of pressure drop and performance.
- Duct systems handle air, a compressible fluid whereas piping systems handle water, an incompressible fluid. Because of this, issues that are insignificant in piping systems may cause problems in air handling systems. Closely coupled fittings are one example.[4]
- Air handling equipment tends to be modular or custom fabricated. This gives an informed designer more flexibility in controlling an air handling system's performance and pressure drop.
- Air handling equipment lends itself to scheduled operation. If a space is unoccupied, it is usually possible to turn off some of the air handling equipment even though the pumps, chillers and boilers in the central plant may need to operate round the clock to serve the remaining air handling equipment. An air handling system that serves a typical office

may only need to run 2,600 hours per year while the chilled water pumps may need to run 3,000 or 4,000 hours per year depending on the climate and the nature of the other loads.

Duct Sizing

Over the years, many different approaches have been developed for sizing ductwork. They range from the relatively simple equal friction method to the much more complex static regain method. With the equal friction method, the duct is sized to maintain a constant friction rate for its entire length. With the complex static regain method, the velocity in the duct is reduced as you move out through the system, making up for or regaining some of the static pressure losses in the system. Modern computer programs make it easier than ever to implement the more complex approaches on a personal computer.

Regardless of the approach used, the pressure loss in a duct system depends on the cross-sectional area of the duct; the smaller the cross-sectional area, the higher the velocity and pressure drop. In fact, with all other things being equal, the required fan power for any given section can be cut in half by increasing the duct's cross sectional area by a factor of about 1.3.[5] In other words, a 12 inch by 12 inch duct (1 square foot) would be replaced by a 13.5 inch by 13.5 inch duct (1.3 square feet). Since duct sizes are custom fabricated, this is much easier to achieve than with piping where diameters come in standard sizes.

A good rule of thumb is to design for duct velocities below 2,000 feet per minute and frictional rates below 0.15 - 0.20 inches water column/100 feet where possible.

From an energy conservation standpoint, it is tempting to increase the cross-sectional area of the duct to lower the pressure losses. However, duct sizes are typically constrained by the available space and larger ducts require more sheet metal. At some point, the lower pressure drops do not justify the added cost of the sheet metal. A good rule of thumb is to design for duct velocities below 2,000 feet per minute and frictional rates below 0.15 - 0.20 inches water column/100 feet where possible and use the static regain approach at locations where the duct velocities must be higher.[6] Low velocity duct design results in a system that is more amenable to field modifications during construction and future modifications.

Duct Fittings

Duct fittings can be one of the most significant sources of pressure loss in a duct system. Fitting losses can be even more significant than equipment elements such as coils, filters, and dampers. Fitting manufacturers and organizations such as ASHRAE offer data to help designers evaluate the pressure losses associated with different fitting combinations. This data also allows designers to more accurately project the final system static pressure requirements which in turn allows designers to reduce the safety factors needed in selecting the fan. Using fittings with low pressure drops is particularly important when higher velocities are needed. Increasing the velocity through a given fitting from 2,000 feet per minute to 2,800 feet per minute nearly doubles the pressure drop through the fitting.[7]

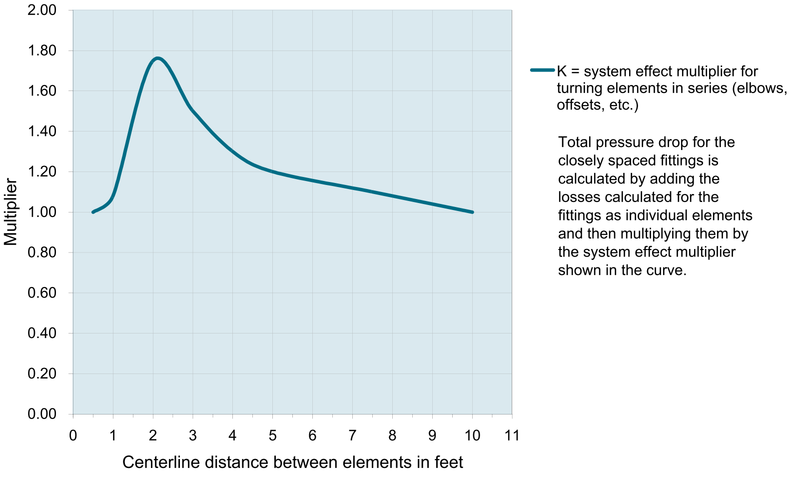
Duct fittings can be one of the most important sources of pressure loss in a duct system.

Complex Fitting Arrangements

Figure 12 illustrates the impact of placing two duct fittings close to each other. As shown in the figure, the pressure loss

Figure 12: Pressure loss vs flow for closely spaced duct elements in a 12 inch round duct

Placing two duct fittings close to each other increases the total pressure drop as shown in the graph below.



Total pressure drop for the closely spaced fittings is calculated by adding the losses calculated for the fittings as individual elements and then multiplying them by the system effect multiplier shown in the curve.

Source: AMCA, ASHRAE

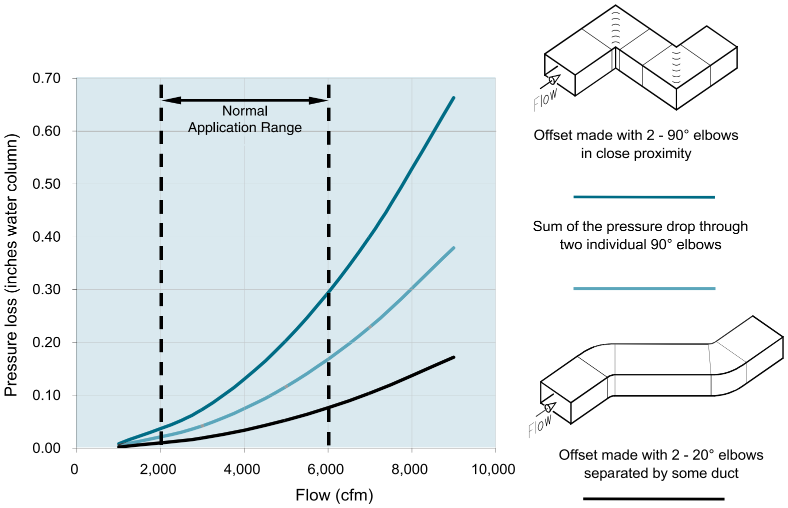
through the closely spaced duct fittings can be significantly higher than predicted by the fitting loss coefficients. The first fitting distorts the velocity profile and the space between the fittings is not sufficient for the distorted velocity profile to redistribute itself. The second fitting or element sees a non-uniform velocity profile rather than the uniform bullet-shaped profile that is used to determine the fitting loss coefficient. As a result, the performance based on the uniform profile is not achieved.[9]

When air must flow through a duct run with a complex series of fittings and space constraints prevent adding distance between the fittings, consider reducing the velocity of the air.

Figure 13 compares the pressure drop through two different combinations of fittings used to offset a duct. When applied to the main duct of a 10,000 cfm air handling system, the low pressure drop option can save between $120 and $400 in annual operating costs in a typical office building and hospital respectively. When air must flow through a duct run with a complex series of fittings and space constraints, prevent adding distance between the fittings and consider reducing the velocity of the air.

Figure 13: Pressure drop vs flow for two closely spaced elbows in a 12" x 24" duct

Increasing the space between two elbows will reduce the total pressure drop through offset.



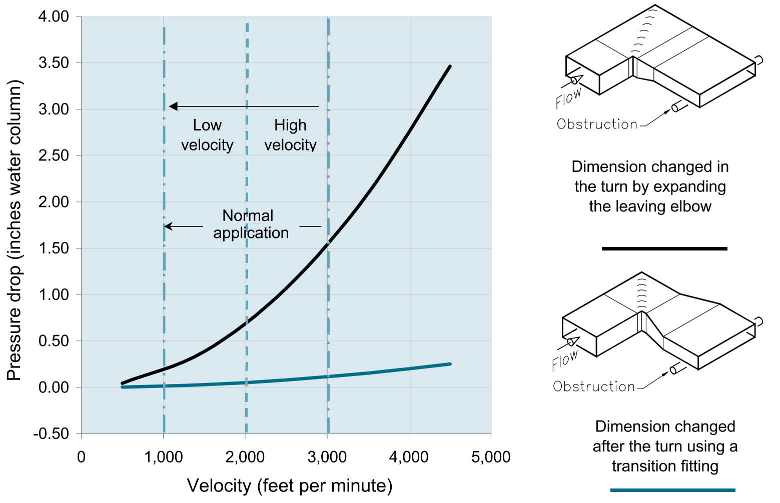
Source: ASHRAE

Duct Elbows

Designers often use an elbow in a rectangular duct system to change the dimension of the duct. This creates a large pressure drop problem as shown in **Figure 14**. The high losses are related

Figure 14: Pressure drop vs flow for a duct turn with a dimension change

Pressure drops can be reduced if duct dimension changes are made after an elbow with a separate fitting rather than changing dimensions in the elbow.



Source: ASHRAE

to the increase in cross-sectional area that occurs through the elbow. A significant improvement in pressure drop can be achieved by using an elbow with the same entering and leaving cross section and a transition piece after the elbow to make the duct size change.

Connections to Vertical Risers

Typically, riser ducts in multistory buildings are relatively large, carrying large volumes of air at high velocities. The pressure loss through a poorly designed fitting is much greater in ducts with higher velocities, so improving fitting efficiency in these ducts can significantly reduce overall system pressure loss.

The pressure loss through a poorly designed fitting is much greater in ducts with higher velocities, so improving fitting efficiency in these ducts can significantly reduce overall system pressure loss.

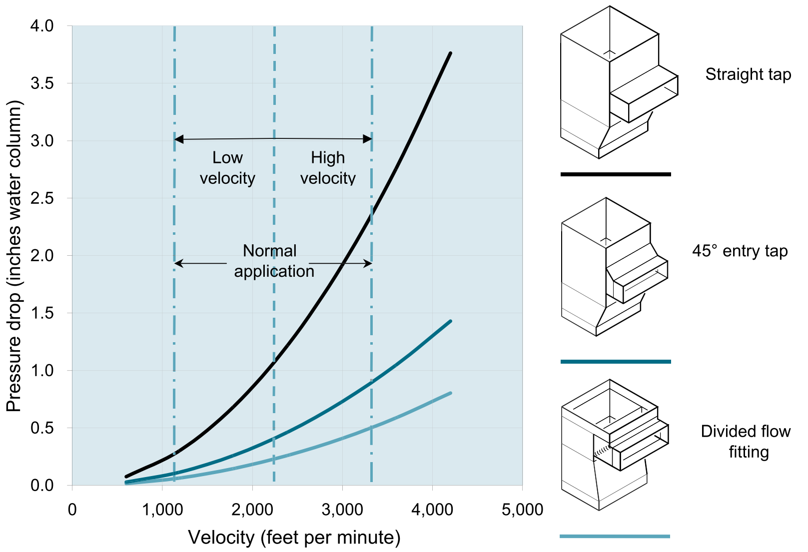
Improving the efficiency of fittings in duct shafts is not always easy. In most cases, space is at a premium. This often leads to a very narrow duct path out of the chase, which tends to push duct velocities higher. For this reason, it is important that someone with mechanical expertise is involved early in design to ensure that the chase is not undersized. In addition, a fire damper will usually be required in the duct where it penetrates the chase wall to prevent the spread of fire between floors. This damper adds additional pressure drop and takes up some of the limited available space. All of these problems tend to push designers and tradesmen to make duct connections to risers with simple, straight taps. The size of the tap is often dictated by structural and ceiling clearances.

The 45° branch connection expands the branch duct size prior to its connection to the riser. This reduces the entry velocity to the branch and reduces the dynamic losses.

Figure 15 compares the pressure drop through a simple straight tap to those associated with a 45° branch connection and a divided flow fitting at different velocities. As can be seen by the illustrations on the graph, the 45° branch connection expands the branch duct size prior to its connection to the riser. This reduces the entry velocity to the branch and reduces the dynamic losses. The more complex divided flow fitting is arranged to slice some of the air flow from the riser and guide it into the branch duct with an elbow. The elbow is designed so that the ratio of its cross-sectional area relative to the total riser cross-sectional area is approximately the same as the ratio of the required branch flow to the total branch flow. A transition after the elbow adjusts the elbow outlet dimensions to the branch duct dimensions. **Table 1**

Figure 15: Pressure drop vs velocity for a riser tap that takes 20% of the main flow out of the branch

Connecting to a duct riser using a 45° tap or a divided flow fitting results in a much lower pressure drop than a straight tap.



Source: ASHRAE

Table 1: Potential energy cost savings for riser connections in a 10,000 cfm air handling system

Fitting Configuration	Static pressure savings at design flow compared to base case (inches water column)	Annual energy cost savings at 2,600 operating hours/year (typical office building)	Annual energy cost savings at 8,760 operating hours/year (typical hospital building)
Straight tap	0.00	Base case	Base case
45° exit fitting	1.19	$481	$1,619
Divided flow fitting	1.51	$610	$2,055

Source: ASHRAE, PECI

compares the annual savings potential of the three different configurations illustrated in the graph for a 10,000 cfm system.

Connections to Terminal Devices

Efficient fittings at connections to terminal devices (such as VAV units) from the duct mains are also important. The techniques that can be used are similar to the branch connections described above. A straight tap is often satisfactory in low velocity connections to terminal devices. But at higher velocities and/or larger flow rates, a bellmouth connection or a divided flow fitting has merit. The bellmouth connection has little if any additional first cost since many manufacturers make duct tap fittings that include a bellmouth as a part of their standard product line.

At higher velocities and/or larger flow rates, a bellmouth connection or a divided flow fitting has merit.

The dampers associated with branch connections and the connections to terminal equipment such as VAV boxes, diffusers, and reheat coils should be provided with locking quadrants rather than regulators. Lower cost manual regulators typically rely on friction between the blade support assembly and the actuating lever to hold the damper position. This arrangement may suffice for small dampers with low-velocity air flows and low static pressures (12 inches or less in diameter at 500 fpm or less) where vibration is not a factor. For a little more money, a specialized manual regulator often referred to as a quadrant can be provided. Quadrants have a locking mechanism (usually a wing nut) located near the end of the adjustment lever that is much more resistant to the effects of vibration and the aerodynamic loads imposed on the manual adjustment mechanism by the flow in the duct. The small additional cost will pay for itself many times over in high velocity systems. System energy consumption and performance will improve since the balanced settings will be retained. Problem calls related to dampers blown closed will also be minimized.

Long flex duct runs can have extremely high pressure drops compared to sheet metal ducts due to the internal roughness of the duct and the tendency of the duct to sag between supports.

Long flex duct runs can have extremely high pressure drops compared to sheet metal ducts due to the internal roughness of the duct and the tendency of the duct to sag between supports. System performance will be improved and energy consumption minimized if designers take the following steps when specifying and depicting flex ducts:

- Restrict the maximum allowable length of flex duct to 5 to 7 feet.
- Specify the minimum bend radius allowed for a flex duct.
- Specify close spacing of the flex duct hangers. Three feet between hangers will minimize sag and maintain relatively low pressure losses.
- If a long flex duct run must be used, consider over-sizing the duct to compensate for the higher pressure loss rate.

Most terminal units require a fixed length of straight duct at their inlet to provide proper flow regulation. Flex ducts should be avoided at this location for reasons stated above. Without a length of straight duct, the flow measuring element in the terminal unit may become de-calibrated due to the flow's non-uniform velocity profile. This will result in obvious performance problems and can have significant energy implications. The calibration error could force the terminal unit minimum flow settings higher than the set point, wasting fan and reheat energy. Calibration errors resulting in lower minimum flow settings could lead to indoor air quality problems.

Air Handling Unit Cross-Sectional Area

One of the easiest ways to reduce pressure drop in an air handling system is to maximize the use of available cross-sectional area. This can be accomplished by selecting coils and filters that take advantage of all the cross-sectional area in the fan casing.

The cross-sectional area of the casing is typically determined by the inlet requirements of the fan, the mounting requirements of the coils, and the available physical space. Filter banks are sometimes installed in custom or modular air handling units with a blank-off panel to make up the difference between the filter bank area and the air handling unit casing area. If the entire cross-sectional area of the air handling unit is filled with filters, the following advantages will be realized without significantly affecting first costs:

- Larger cross-sectional areas result in lower velocities and lower pressure drops. In one example (a 10,000 cfm unit), adding filters to fill the entire cross-sectional area reduced the system's pressure loss by 0.29 inches water column with no added first cost. The change resulted in annual energy savings between $55 and $200 depending on the unit's operating schedule.
- The filters tend to last longer since the net air flow through each module is reduced and each module will take longer to accumulate its maximum dust load. This reduces maintenance costs, resource requirements, and waste stream for the life of the system. The specifics will vary from system to system and depend on system configuration, system operating hours, and the local ambient environment.

By selecting the largest possible casing size for the fan, designers provide a larger cross-sectional area through the fan which results in lower velocities, lower pressure drops, and quieter operation with less vibration.

Similar logic can be applied when selecting the casing size for modular air handling components. Most product lines allow a range of fan sizes to be applied in any given modular casing size. By selecting the largest possible casing size for the fan, designers provide a larger cross-sectional area through the fan which results in lower velocities, lower pressure drops, and quieter operation with less vibration. Designers can then take advantage of this area by selecting the largest coils and other components that are available for the module size. In one manufacturer's line, using the largest available coil for the casing size resulted in savings of 0.67 inches water column at 10,000 cfm or $130 to $425 annually depending on the hours of operation.[10]

Larger component sizes also provide more flexibility for future modifications to the system. A system that is currently sized to the limits of its performance will probably have to be replaced if the programming or loading in the area changes significantly. Often, the programming of a space changes once every 5 to 10 years, whereas, properly maintained air handling equipment located indoors can easily last 20 years before it needs replacement.

Extended Surface Area Filters

Filter selections are another area where operating costs, maintenance costs, and waste management requirements can be reduced.

Filter selections are another area where operating costs, maintenance costs, and waste management requirements can be reduced. Often the filter selection made by the original project designer will follow the system over its entire operating life. Air handling systems are typically equipped with final filters that are selected to provide the quality of air required for the occupied spaces in the buildings. Since these filters are relatively expensive, roughing filters or prefilters are commonly provided ahead of the final filters. Prefilters can be replaced for a lower cost than final filters and remove many of the larger particles, thus extending the life of the final filters. Prefilters do nothing to make the air that is supplied to the building any cleaner. Despite their advantages, prefilters add pressure drop to the system and while inexpensive, add costs and must be installed and disposed.

Recent advances in filter technology have resulted in extended surface area filters with high dust-holding capacity, longer life, and lower pressure drops. The units are designed to fit conventional filter framing systems and can be applied to existing systems without retrofit work. These high-performance filters typically cost more than standard filters but they usually have lower life-cycle costs because of their lower pressure drop and longer life. They are also a "greener" choice; they use fewer consumables and generate a smaller waste stream since they can last over twice as long as conventional filters.

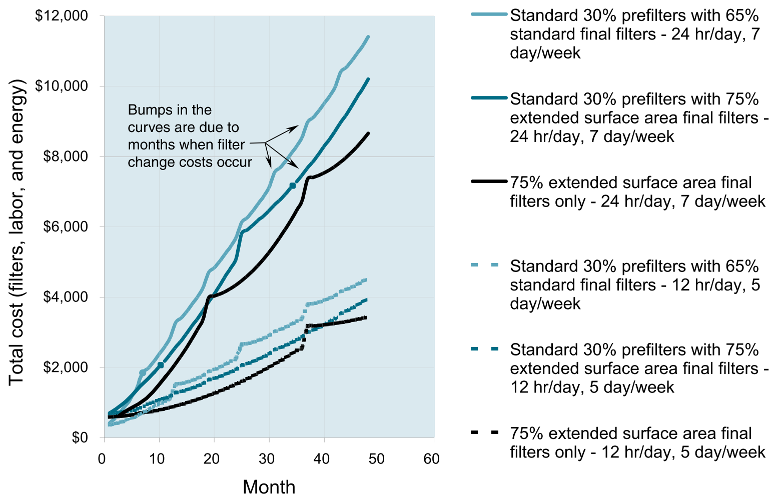
Owners and engineers are now experimenting with the total elimination of the prefilters (remember, prefilters don't make the air any cleaner, they just slow down the rate that the final filters load up). If the prefilters are eliminated, the system pressure requirement drops, reducing energy use. On the negative side, the final filters load up more quickly since they must capture and retain all particles in the air stream.

Owners and engineers are now experimenting with the total elimination of the prefilters.

Figure 16 compares the total filter costs for a 10,000 cfm air handling system using different combinations of prefilters and final filters. The steeper curves result if the unit is operated 24 hours per day, such as in many health care applications. The shallower curves represent a typical office schedule. Costs include energy, filter, maintenance, and disposal costs and are

Figure 16: Cost comparison of filter options

Eliminating prefilters and/or using extended surface area filters can reduce total filter costs. Costs shown include the filter, labor, disposal, and energy used to overcome filter pressure drop.



Source: Viledon, PECI

based on a modeling program. Note that significant savings can be achieved in all cases and accumulated savings will increase over the life of the building.

Fan Inlet/Discharge Conditions

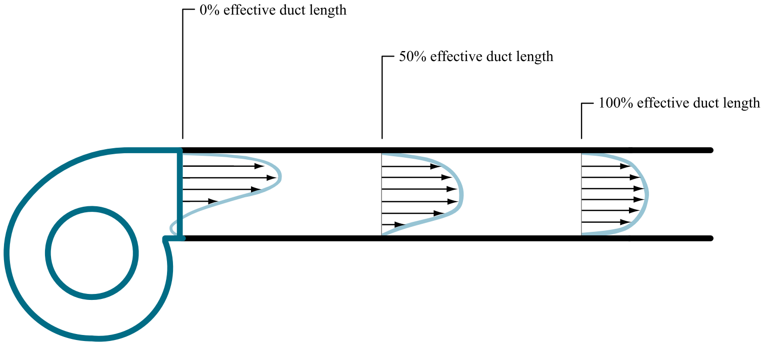
Providing good details at the inlet and outlet of an air handling system's fan can save a significant amount of energy and operating costs. Poorly designed or applied fittings on the inlet or discharge of a fan will prevent a fan from achieving the performance predicted by its fan curve and can even lead to fan failure.

Poorly designed or applied fittings on the inlet or discharge of a fan will prevent a fan from achieving the performance predicted by its fan curve and can even lead to fan failure.

As illustrated in **Figure 17**, the air flow at the discharge of a fan is very turbulent and has a non-uniform velocity profile. As the air flows down the duct, it interacts with the wall of the duct. The air closest to the wall has more friction and tends to be slowed down relative to the air in the center of the duct. The turbulence associated with the process causes energy to be exchanged between the faster and slower moving air molecules. The net result is that the velocity profile shifts to a more uniform bullet-shaped distribution as the air flows down the duct. The length of duct needed for a uniform velocity profile to reform is referred to as the 100% effective duct length. It is

Figure 17: Fan discharge velocity profile

The air flow at the discharge of a fan is very turbulent and has a non-uniform velocity profile. If fittings are installed before the point where a uniform velocity profile is established (termed 100% effective duct length), both fan and fitting performance will suffer.



Source: AMCA

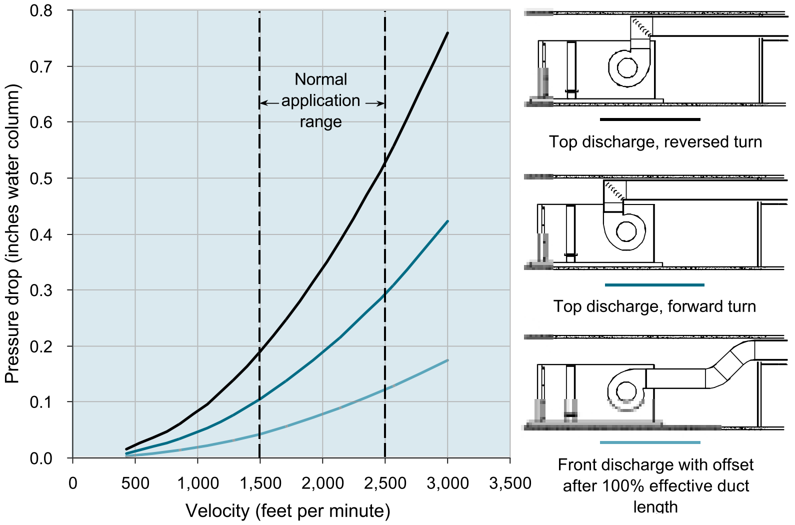
a function of the duct size and shape as well as the velocity and fluid characteristics. If fittings are installed in the duct prior to the 100% effective duct length point, they will impact the performance of the fan and fitting.[11]

Poor inlet conditions can have similar impacts. A non-uniform velocity profile entering the fan wheel causes the fan wheel to load non-uniformly, making its performance unpredictable and potentially damaging the wheel or shaft. The net effect of poor inlet or discharge conditions is the same as adding static pressure to the system. Through research and testing, tables and curves have been developed to help designers predict the additional losses associated with different configurations. Both ASHRAE and AMCA publish these system effect curves.[12]

Figure 18 illustrates the effect of two different improvements to a poor fan discharge configuration. In the base case, the fan discharges vertically through the top of the air handling unit. The

Figure 18: Impact of three different air handling unit discharge configurations

Fan performance can be significantly affected by the orientation and configuration of the discharge duct relative to the fan.



Source: AMCA, PECI

The most energy efficient solution is to use a fan that discharges in the same direction as the air must go anyway.

Table 2: Potential energy cost savings for improved discharge conditions in a 10,000 cfm air handling system

Air handling unit discharge configuration	Static pressure savings at design flow compared to the base case (inches water column)	Annual energy cost savings at 2,600 operating hours/year (typical office building)	Annual energy cost savings at 8,760 operating hours/year (typical hospital building)
Top, reversed turn	0.00	Base Case	Base Case
Top, forward turn	0.17	$69	$234
Front with offset	0.30	$120	$406

Source: AMCA, PECI

discharged air is turned immediately with an elbow to reach the point where the duct must exit the mechanical room. Since the elbow must be installed close to the fan discharge (at about 12% effective duct length) to allow the turn to be made below the ceiling level of the mechanical room, the velocity profile is non-uniform and the highest velocity air must make the sharpest turn, which creates a lot of turbulence and a large amount of noise. A significant improvement can be made by using a fan that is oriented so that the high velocity air turns on the side of the elbow that has the largest radius as shown in **Figure 18**. The most energy efficient solution is to use a fan that discharges in the same direction as the air must go anyway. A slight offset up is required to shift the duct so that it is above the ceiling level outside the mechanical room but this offset will have a minimal pressure drop because it can be located outside the 100% effective duct length. **Table 2** tabulates the savings that could be achieved by the improved arrangements for a 10,000 cfm system.

Putting It All Together

To illustrate the impact of attention to design details, let's apply them to a hypothetical building. The building is a 60,000 square foot office and student services building on a college campus that is about to undergo a renovation.

To illustrate the impact of attention to design details, let's apply them to a hypothetical building. The building is an office and student services building on a college campus that is about to undergo a renovation.

The building was originally built with an independent, packaged, air-cooled chilled water system for cooling and an independent, packaged hot-water boiler system for heating. Cooling is provided via air handling systems. Heating is provided via a perimeter system. Heating coils in the air handling systems provide warm-up capacity and back-up the perimeter system in an emergency. The heating coil in a make-up air unit preheats outdoor air most of the winter.

The original chillers and boilers are reaching the end of their service life. Recent expansions in the central plant provide the opportunity to serve the building more efficiently by cutting through the foundation of the basement mechanical room and connecting to the central heating and chilled water piping that run in a tunnel immediately adjacent to the mechanical room. The work will be completed during the winter when the central chilled water system is off-line and cooling is provided using an economizer cycle. This will allow all of the existing piping in the basement mechanical room to be removed prior to starting the new project which will make running the new piping circuit considerably easier.

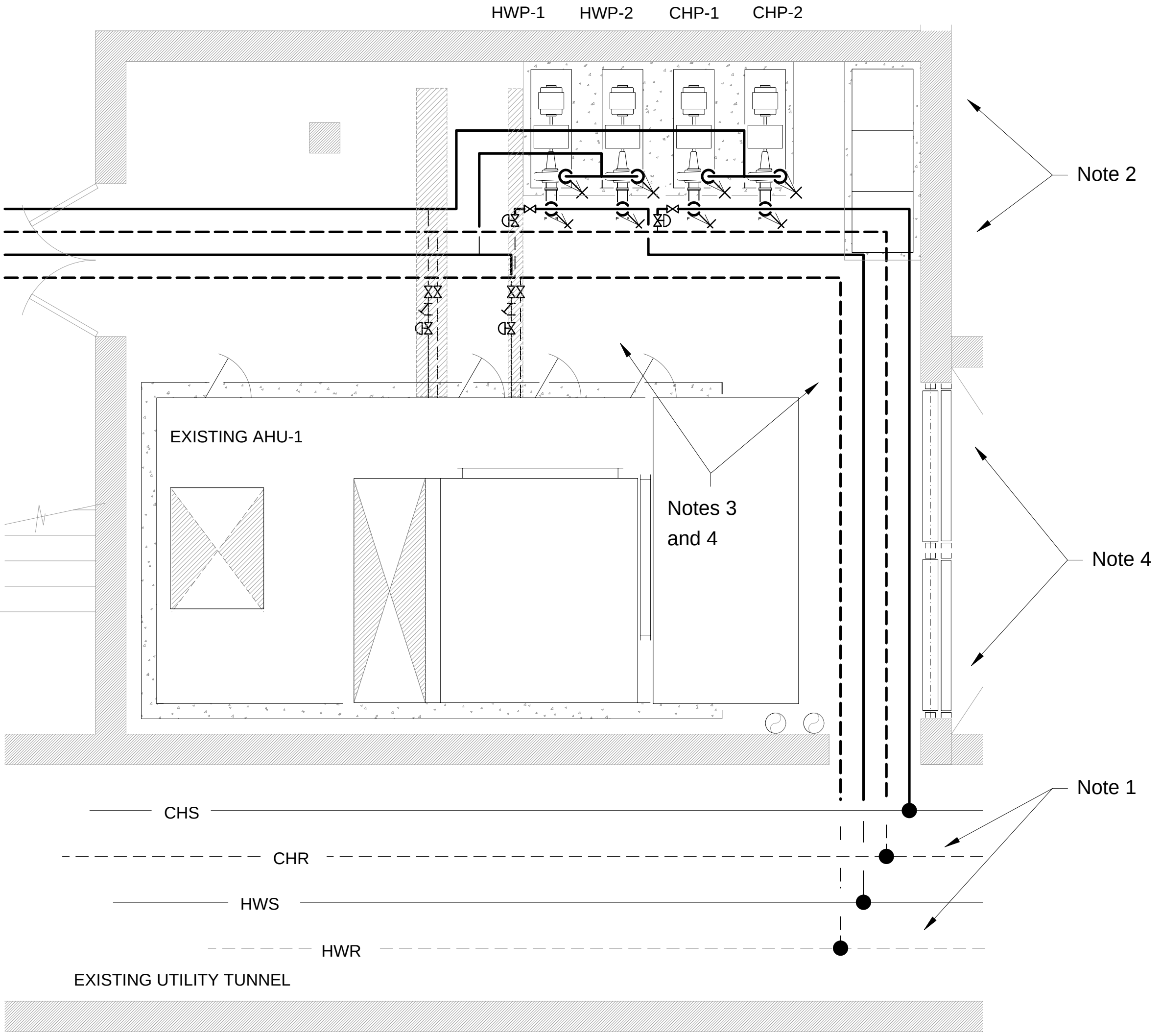
Figures 19 and 20 illustrate the basement mechanical room and the associated pump connection details as they might be shown on typical construction drawings for the proposed renovation. Both the chilled water circuit and the heating water circuit are depicted on the plan. Our discussions will focus on the chilled water circuit but similar considerations apply to the heating system.

The coil and pump connection details do not consider the physical arrangement of the piping. The piping at the pumps and coils simply will not fit as shown when actual fitting and specialty dimensions are taken into account.

While the information presented on the typical mechanical drawing is schematically and technically correct, there are several areas where problems or inefficiencies could arise because design details have been left out:

- Real world pipe fittings will not fit in the arrangement as shown.
- The connections to the existing piping in the tunnel will be more complex than is implied by the drawing. See Note 1.
- The current arrangement, if installed as shown, will cause electrical code violations at the existing motor control center of the northeast corner of the mechanical room. See Note 2.

Figure 19: Non-detailed mechanical room drawing



Source: PECI

This drawing illustrates the piping layout as it is often portrayed on construction documents where the details of the fitting arrangements and configurations are not shown. (Drawing notes, line sizes, and other information typically included on a real construction drawing have been eliminated in this illustration for clarity.) While it is schematically correct, additional detailing can avoid ongoing energy costs and higher first costs. Specific issues are noted below.

Note 1: The connections to the mains in the tunnel are much more complex than shown. The method of connection is not specified, nor are the fittings and elevation changes required to reach the lines indicated.

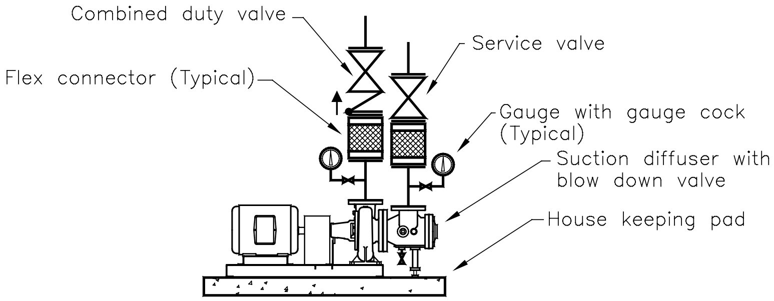
Note 2: The three squares in this area represent electrical equipment. Both the routing of the piping and the location of the pumps would create code violations due to clearance issues and the routing of the lines with water in them over the equipment.

Note 3: The piping configurations shown fail to consider the dimensions of the fittings and specialty items. The piping simply will not fit as shown using real fittings. Many more offsets and adjustments will be required than are indicated on the drawing.

Note 4: The schematic layout does not directly address the access needed to remove coils from the air handling unit. In addition, the access route for removing the unit or major components from the building via the louvers and area-well could be blocked by the new lines running in front of them unless additional clarification is provided to show the piping elevated in this area.

Figure 20: Pump installation elevation

Shown below is a typical pump installation elevation often found on construction drawings as a standard detail.



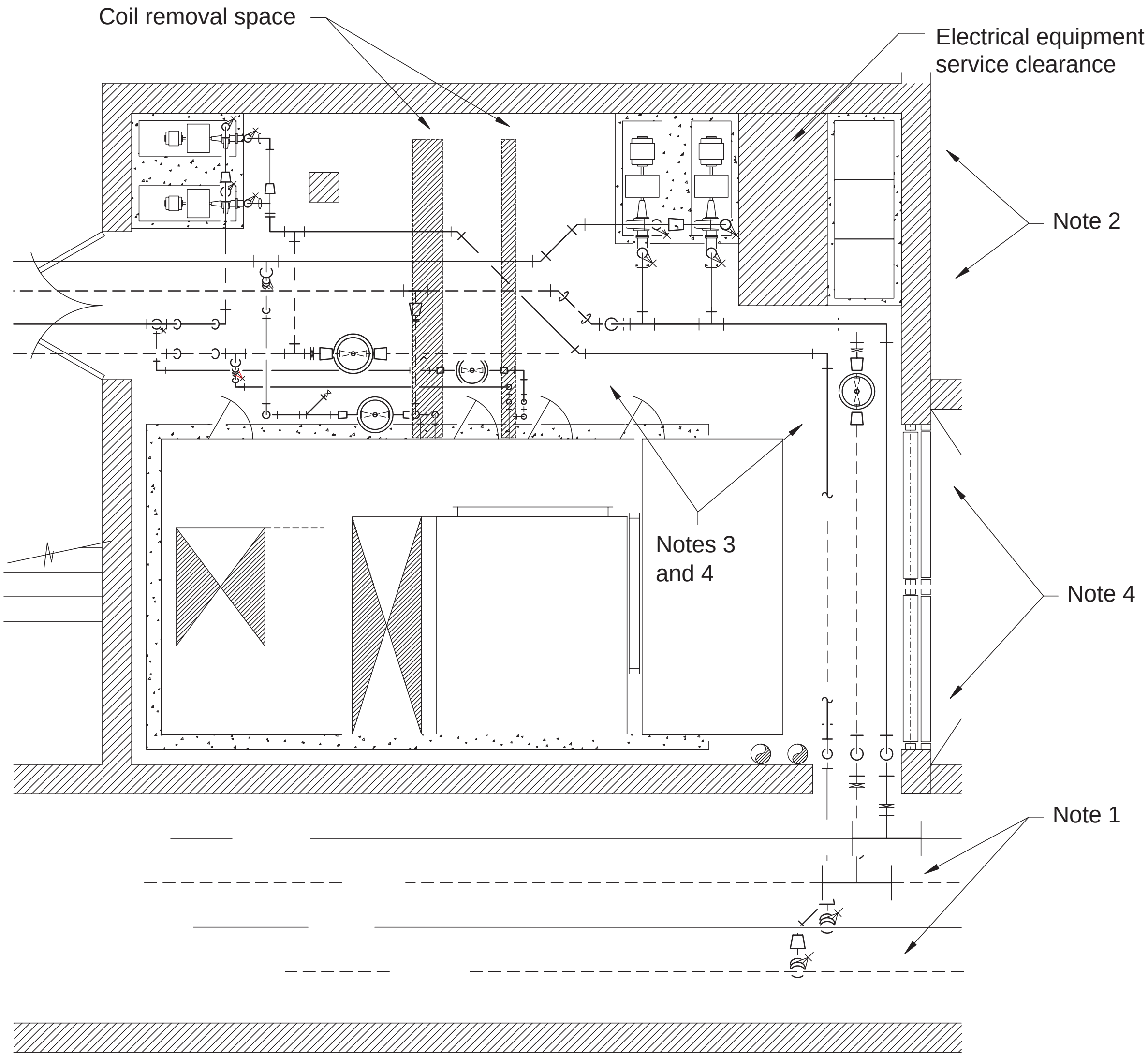
Source: PECI

- The coil and pump connection details do not consider the physical arrangement of the piping and access issues. The piping as shown at the pumps and coils simply will not fit when actual fitting and specialty dimensions are taken into account. See Notes 3 & 4.
- The pump and coil connections could be piped with lower pressure drops and fewer components by using different specialties and fittings.

All of the above items have first cost implications and many of them have energy and operating cost implications. Most projects attempt to address these issues with specification language that indicates that the contractor is responsible for making all offsets, changes in direction and modifications necessary to make the project fit the space that contains it and still provide a working system. Taking a more detailed approach to the problem at design may add engineering cost to the design process but will ultimately benefit all parties involved in the project and reduce overall first costs and operating costs. First cost savings are realized through fewer components and lower horsepower requirements. Energy savings are primarily realized by minimizing the pressure drops associated with the piping circuit and by accurately predicting the pump head requirement at the time of design. This allows the pump and motor selections to be made for optimum efficiency and performance with modest safety factors and lower first costs.

Energy savings can be realized by minimizing the pressure drops associated with the piping circuit and by accurately predicting the pump head requirement at the time of design.

Figure 21: Detailed mechanical room drawing



Source: PECI

This drawing illustrates the same mechanical room and piping circuit as Figure 19 but in this case the configuration, arrangement and physical dimensions of the fittings have been taken into account and developed. The notes below reflect areas that have been addressed.

Note 1: For the existing mains to fit through the available opening, some of the lines have been stacked on top of each other. This is further illustrated in Figure 22. Note that the specific technique of connection to the existing mains has been addressed.

Note 2: The electrical equipment has been identified and piping and equipment located as required to comply with the National Electric Code. Notice that the hot water pumps had to be completely relocated to avoid interference problems with both the electrical equipment and the air handler unit coil pull space.

Note 3: The fitting dimensions and arrangements have been taken into account and shown on the drawing using fitting marks. Note how this required that the piping be spread out.

Note 4: The arrangement of the piping as shown above and in the supporting details provides for removal of the air handling unit coils. Also, piping is shown elevated at the east end of the unit to maintain the access path to the removable louvers and area well for major air handling unit component replacement.

Figure 21 shows what the mechanical room piping arrangement might look like when some of the issues are addressed. It is not the only solution; there are probably as many solutions as there are pipe fitter foremen and engineers. But it is one workable solution that takes the physical constraints of the room and the size of the piping components into account.

Below we discuss the weaknesses with the design drawing shown in **Figure 19** to show how a more detailed drawing could address them. When shown, operating cost savings assume an electric rate of 9¢/kWh.

Specify Piping Fittings

Figure 19 does not show the pipe fittings that should be used. If the fittings are not shown, then the contractor may use the fittings that have the lowest first costs—which are typically not the more energy efficient fittings. This first cost difference is very small relative to the total project costs and it would probably not be apparent during the bidding process. Using piping fittings that have low pressure drops can save a significant amount of energy in the form of pumping horsepower. In the chilled water system in the mechanical room shown, using long radius elbows instead of short radius elbows can save $47 annually, using 45° offsets where possible can save $25 annually, and correctly orienting the run and the branch of the tees can save $83 annually.

Detail Connection to Existing Piping

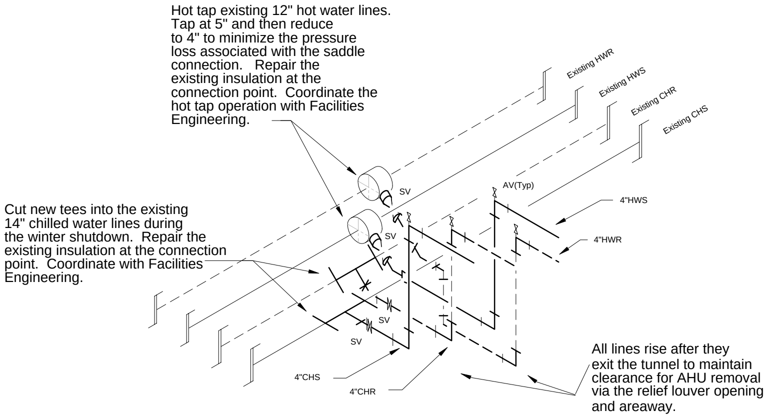
The connection requirements in the tunnel are much more complex than indicated in **Figure 19,** as can be seen from the connection detail shown in **Figure 22**. The four insulated pipe lines will not all fit through the available tunnel opening side-by-side. It is necessary to route at least one line under another line. This requires fittings that are not shown in **Figure 19**. If the piping details are not shown, the contractor will likely choose the least costly (not the most energy-efficient) fitting solution. Without knowing the fitting solution, the engineer has no choice but to include a sizable safety margin in his pump selection to be

Without knowing the fitting solution, the engineer has no choice but to include a sizable safety margin in his pump selection to be sure that the system will work no matter how it is installed.

sure that the system will work no matter how it is installed. In most cases, the safety margins are more than adequate and the systems work. But most systems have so much safety margin that the pumps are either moving more water than is necessary or the excessive pumping head is dissipated at the throttling valve at the discharge of the pump. In either case, energy is being wasted. Another element to consider is the most efficient way to connect to the existing utility lines. Using tees instead of hot taps could save approximately $120-$240 depending on how well the saddle joint was fabricated.[13]

Figure 22: Tunnel connection isometric

This figure illustrates the complexity of the piping connections required where the new line connects to the existing lines in the tunnel. In actual construction documents, clarity would be improved by showing a separate detail for each line, or by showing the detail four times, with one connection highlighted in each illustration.



Source: PECI

Fix Electric Code Violation

The schematic layout in **Figure 19** fails to account for the National Electric Code requirement to maintain clearance between the motor control center and grounded objects such as the pumps and piping. Typically, 36 to 42 inches are required depending on the voltage and other factors. In addition, the schematic representation runs piping over the motor control center which would be considered a code violation in most jurisdictions. This is certainly not good practice since a leak would rain water directly onto high voltage electrical gear. The piping would also restrict access to the electrical gear for future conduit connections. If the pumps are relocated toward the west end of the room to address the clearance requirements, they would prevent coil removal of the air handler and thus need to be totally relocated. When these considerations are taken into account, additional fittings are required. Without detailing the requirements, the fittings used (and associated pressure drops) will be out of the engineer's control. Worse yet, if the problem is not detected until after the pumps are set and the piping connected, there will be significant delays and change order costs incurred in moving the pumps to satisfy the code requirements. This will add even more fittings and could expose the engineer and contractor to litigation by an angry owner.

If the problem is not detected until after the pumps are set and the piping connected, there will be significant delays and change order costs incurred in moving the pumps to satisfy the code requirements.

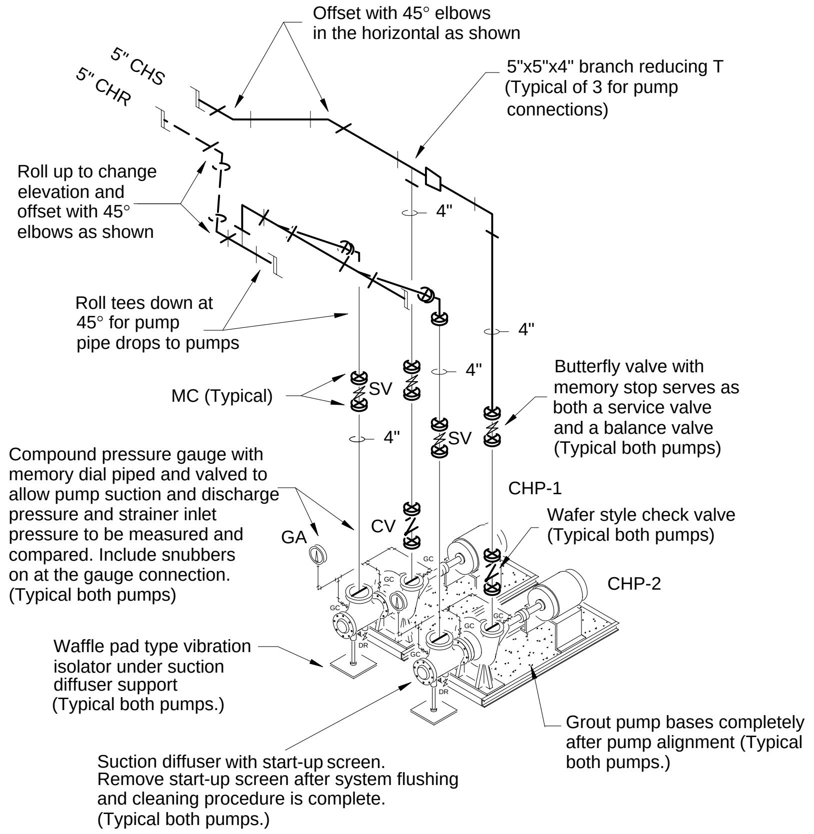
Specify Pump Connection Details

The piping details shown in **Figure 20** address the requirements for connecting the pumps but say nothing about the physical arrangement of the piping. In addition, the specialty fittings shown, though quite common, can be improved from both an energy and functionality standpoint. The piping isometric shown in **Figure 23** addresses these issues:

- By providing an isometric, both the piping specialties and the specific piping arrangement can be clarified and specified.
- A butterfly valve with memory stop and a wafer-style check valve are shown instead of a combined function valve. This reduces the pressure drop at the pump discharge. In our sample system, the butterfly valve may save approximately 4 feet water column in pumping head, $450 in first costs and $94 per year in operating costs.
- Mechanical couplings are shown for some of the connections leading to and from the pumps. While rubber or bellows-type flex connectors provide the ultimate in vibration elimination when properly selected and applied, mechanical couplings usually provide enough flexibility for vibration isolation. The flex connectors shown in **Figure 20** could be eliminated in

Figure 23: Chilled water pump piping isometric

The piping isometric shown below provides the details missing in Figure 20. In addition, other energy and cost conserving features are shown. While more complex to develop initially, once developed, such a detail can be easily adapted to the requirements of specific projects using standard CAD drafting techniques.



Offset with 45° elbows in the horizontal as shown

5"x5"x4" branch reducing T (Typical of 3 for pump connections)

Roll up to change elevation and offset with 45° elbows as shown

Roll tees down at 45° for pump pipe drops to pumps

Butterfly valve with memory stop serves as both a service valve and a balance valve (Typical both pumps)

Compound pressure gauge with memory dial piped and valved to allow pump suction and discharge pressure and strainer inlet pressure to be measured and compared. Include snubbers on at the gauge connection. (Typical both pumps)

Wafer style check valve (Typical both pumps)

Waffle pad type vibration isolator under suction diffuser support (Typical both pumps.)

Grout pump bases completely after pump alignment (Typical both pumps.)

Suction diffuser with start-up screen. Remove start-up screen after system flushing and cleaning procedure is complete. (Typical both pumps.)

Source: PECI

some applications. A designer may want to consider this approach since it provides a slight improvement in pressure drop and eliminates the cost of the flex connectors (approximately $710 per pump for the 4-inch piping used in our hypothetical system).

- Another problem associated with the schematic layout is that the fittings and specialties simply will not fit as shown. Since the details were not addressed during the engineering process, the solution to this problem is left to the installing tradesmen. Pipe fitters may not be familiar with the pressure drops associated with various pipe fittings and may choose to put complex fitting arrangements together. As a result, the field solution may be less than optimal from an energy stand point.

Specify Coil Connection Details

The coil connection detail depicted in **Figure 19** also offers some opportunities for improvements. If the coil is piped as shown in **Figure 11**, then two service valves and two balancing valves can be eliminated (and a butterfly valve used instead of a service valve and balancing valve) as described in Coil Connection Details, page 15. This may save 4.7 feet water column of pumping head, $43 a year in operating costs and $400 in first costs in our hypothetical building.

Select Pumps to Minimize Costs

One final consideration that has the potential to reduce both first costs and operating costs is the selection of the pumps. Where two pumps are required for redundancy, it is quite common to select two pumps sized for the full capacity required. If 100% reserve capacity is needed then there is little choice but to do this. However, if the pump combination is selected to provide the required capacity (each pump selected for 50% of the required flow at the full head requirement), then one pump will still be able to deliver 60-70% of the design capacity with the other pump off. Many times, when the number of peak hours per year are considered, this provides an acceptable solution. Using two pumps selected for 50% of the required flow reduces first costs by reducing pump costs, piping costs, and often electrical service requirements. System efficiency is also improved because one pump can be operated at typical load conditions and optimized for this load. In our example, this could avoid $500 in first costs and $81 a year in operating costs.

Using two pumps selected for 50% of the required flow reduces first costs by reducing pump costs, piping costs and often electrical service requirements.

Table 3: Potential energy cost savings due to improvements in piping system details

Item	Avoided pressure drop (ft.w.c)	Annual operating cost savings	First cost savings (cost increases are shown as negative savings in parenthesis)
Using long radius elbows (Note1)	2.28	$47	($438)
Using 45° offsets where possible	1.13	$25	$575
Optimizing tee orientation	3.53	$83	$0
Using tees instead of hot taps for tunnel connection (Note 2)	5.00	$120	($560)
Replacing combined function valve at the pump with a butterfly valve and check valve	4.00	$94	$450
Use flex couplings for vibration isolation instead of flex hose	0.00	$0	$1,420
Simplify coil piping	4.68	$43	$400
Improve pump selection (Note 3)	N/A	$81	$500
Totals	20.62	$493	$2,347
Pumping horse power eliminated	3.69		
Future value of avoided first costs over a 20-year system life at a 5% investment rate			$6,228
Future value of the avoided energy costs over a 20-year system life at a 5% investment rate		$16,245	

Note 1 - The first cost savings may not show up at the time the job is bid; i.e., the contractor will probably estimate the same cost for long or short radius elbows. The field installer may realize the savings for the contractor by purchasing the slightly less costly (5-10% less in material only) short radius fittings.

Note 2 - The savings costs represent eliminating the actual purchase of the fabricated tee fitting and assume the contractor owns a hot tap machine.

Note 3 - The first cost savings are related to the smaller motor and pump size associated with the better selection. The smaller motor size has a ripple effect back through the entire electrical system in terms of a smaller starter, smaller conduit and wire size, etc.

Savings

Savings in the Piping System

Significant savings result when we combine all these effects for our hypothetical mechanical room. **Table 3** shows the savings that can result when the details we discussed are implemented in the chilled water system in the mechanical room. Additional savings can be achieved by applying these concepts to the remaining chilled water piping throughout the building and the other piping systems, such as the heating water system.

Savings in the Air Handling System

Table 4 shows the savings that can be realized if the duct details discussed previously are applied to the 10,000 cfm kitchen make-up air handling system in our hypothetical student and staff building. The savings for the entire building can be much higher

Table 4: Potential energy costs savings due to improvements in air handling system details

Item	Avoided pressure drop (inches w.c.)	Annual operating cost savings in typical office application	Annual operating cost savings in typical hospital application	First cost savings (cost increases are shown as negative savings in parenthesis)
Maximize the use of available air handling unit cross sectional area	0.29	$55	$186	$0
Use the largest available coil face area for the air handling unit casing size	0.67	$128	$430	($974)
Use extended surface area filters and eliminate prefilters	0.04	$277	$688	$0
Improve fan discharge conditions	0.30	$120	$406	$0
Improve offset geometry	0.30	$120	$404	$0
Improve elbow geometry	0.63	$256	$863	$0
Improve terminal unit connection	0.30	$120	$405	$0
Improve fan selection (Note 1)	N/A	$123	$415	$600
Total	2.53	$1,200	$3,796	($347)
Fan horse power eliminated	4.97			
Future value of avoided energy costs over a 20-year system life at a 5% investment rate		$39,671	$125,522	

Note 1 - The first cost savings are related to the smaller motor and fan size associated with the better selection. The smaller motor size has a ripple effect back through the entire electrical system (smaller starter, conduit, wire size, etc.)

when all the air handling systems are considered. Also shown are the savings that can result if the duct details are applied in a hospital application where the air handling systems are running 24 hours a day.

Total Savings

The savings calculations presented in **Tables 3** and **4** apply to specific systems in our hypothetical building. But what would the savings be for an entire building? This is a difficult question to answer without knowing the building's mechanical and electrical systems and operating schedules. However, it is possible to draw some general conclusions.

Using well developed details with an efficiency focus during design can save $0.08 to $0.29 per square foot per year in annual operating costs and $0.14 to $0.28 per square foot in first costs. For our 60,000 square foot hypothetical building, savings could amount to $5,000 to $17,000 per year in operating costs and $8,000 to $17,000 in first costs.[14]

Note that the operating savings are achieved with a reduction in construction first costs and will be achieved every year of the system's life. While there might initially be some engineering costs, energy efficient design details will soon become a part of the normal design process and will result in little additional engineering work. From the design team's standpoint, the ability to produce a detailed, energy efficient design provides the opportunity for a better fee structure. For the owner, the reduction in first costs provides additional funding for the superior design team and for additional features or systems in the building.

FOR MORE INFORMATION

Air Movement and Control Association International, Inc.
30 West University Drive
Arlington Heights, Illinois 60004-1893
tel 847-394-0150
www.amca.org

AMCA publishes a series of manuals related to air system design and operation, which can be ordered from their web site. Of particular interest relative to design issues are *Publication 200 - Air Systems, Publication 201 - Fans and Systems, Publication 501-93 - Application Manual for Air Louvers,* and *Publication 503-93 - Fire, Ceiling, and Smoke Dampers Application Manual*.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)

1791 Tullie Circle, N.E
Atlanta, GA 30329
tel 404-636-8400
www.ashrae.org

ASHRAE publishes numerous standards, guides and technical papers related to HVAC issues. A visit to their web site will uncover several references for almost any design issue encountered. Most of these documents can be ordered on-line.

PG&E Pacific Energy Center

PG&E Pacific Energy Center
851 Howard Street
San Francisco, CA 94103
tel 415-973-7268
www.pge.com/pec

The PG&E Pacific Energy Center contains numerous resources including a tool lending library, technical bulletins, case studies and a wide variety of publications about energy efficiency in building design and construction. Many of the references cited in this document can be found in their on-site library. The center also sponsors an ongoing series of seminars related to energy conservation issues.

Energy Design Resources

www.energydesignresources.com
This brief is part of a design brief series that provides information regarding energy efficient design and operation. Of particular interest relative to this brief are *Design Review*, which discusses techniques to ensure the designer's energy efficient details are properly depicted and interpreted and *Field Review*, which outlines techniques that can be used during the construction process to be sure that energy efficient details are fully implemented in the field.

Notes

1 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), *1988 Handbook of Equipment*, Chapters 3 and 30 (1998), ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, tel 404-636-8400, fax 404-321-5478, web www.ashrae.org.

2 ASHRAE, *1988 Handbook of Equipment*, ASHRAE [1].

3 Pipe element loss coefficients for all figures were taken from the following sources:

ASHRAE, *1993 Handbook of Fundamentals*, Chapter 33 (1993), ASHRAE [1].

Crane Company, *Crane Engineering Data Catalog* (1976) and *Flow of Fluids Through Valves, Fittings, and Pipe, Technical Paper Number 410* (1957).

4 Research suggests that the interaction between closely coupled pipe fittings can actually result in lower pressure drops than would be derived from multiplying the single element pressure loss by the number of fittings. However, designers should not necessarily discount the pressure drops calculated for complex pipe fitting arrangements since the effect is quite variable depending on fitting spacing, configuration, flow rate and other factors. For more information, see William Rahmeyer, *Pressure Loss Coefficients for Close Coupled Pipe Ells - Final Report on the ASHRAE Research Project 1035-RP,* ASHRAE [1].

5 National Environmental Balancing Bureau, *Testing and Balancing Manual for Technicians*, Chapter 4 (1992), NEBB, 8575 Grovemont Circle, Gaithersburg, MD 20877, web www.nebb.org.

6 ASHRAE, *1993 Handbook of Fundamentals* Chapter 32 (1993), ASHRAE [1].

7 ASHRAE, *1993 Handbook of Fundamentals,* [1].

8 Duct element loss coefficients for all figures were taken from the following sources:

ASHRAE, *1993 Handbook of Fundamentals,* Chapter 32 (1993) and *Duct Fitting Loss Coefficient Tables* (1997), ASHRAE [1].

United McGill Corporation, *Engineering Design Manual for Air Handling Systems* (1978).

9 Air Movement and Control Association (AMCA), *Publication 200 - Air Systems* (1987), pp. 9-10, AMCA., 30 West University Dr., Arlington Heights, IL, 60004, tel 847-394-0150.

10 This discussion focused on simply putting the largest available coil into a given casing size. It is also possible that additional analysis would reveal that using the next larger casing size would also provide a viable pay back. The trade-off typically involves added cost for a larger unit and more equipment room space vs. lower operating costs due to the lower velocities and pressure drops. Often, face velocities of 300 to 400 fpm (vs. the more standard 500 fpm) can be easily justified based on the energy savings. For a more detailed discussion of this topic, see training manual for the ASHRAE Professional Development Seminar titled *Air System Design and Retrofit for Energy Cost Effectiveness.*

11 AMCA, *Publication 200 - Air Systems*, (1987), pp. 5-6 [7].

12 AMCA, *Publication 201 - Fans and Systems*, (1987), pp. 22-38 [7].

13 Hot tapping allows a connection to be made to an existing water or steam system while the existing system is on line and operating at pressure. Generally, the hot tap must be at least one size smaller than the existing line. A hot tap requires that a saddle connection be made to the existing line. However, it is possible to mitigate the pressure drop impact of this connection by making it one line size larger than is actually required and then reducing the pipe size after the service valve.

14 Cost projections for first cost savings are based on information from the R.S. Means mechanical and electrical cost estimating guides published by the R.S. Means Company Inc. The projections include typical overhead and profit margins seen in the commercial construction industry and assume union labor is used for the work.

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