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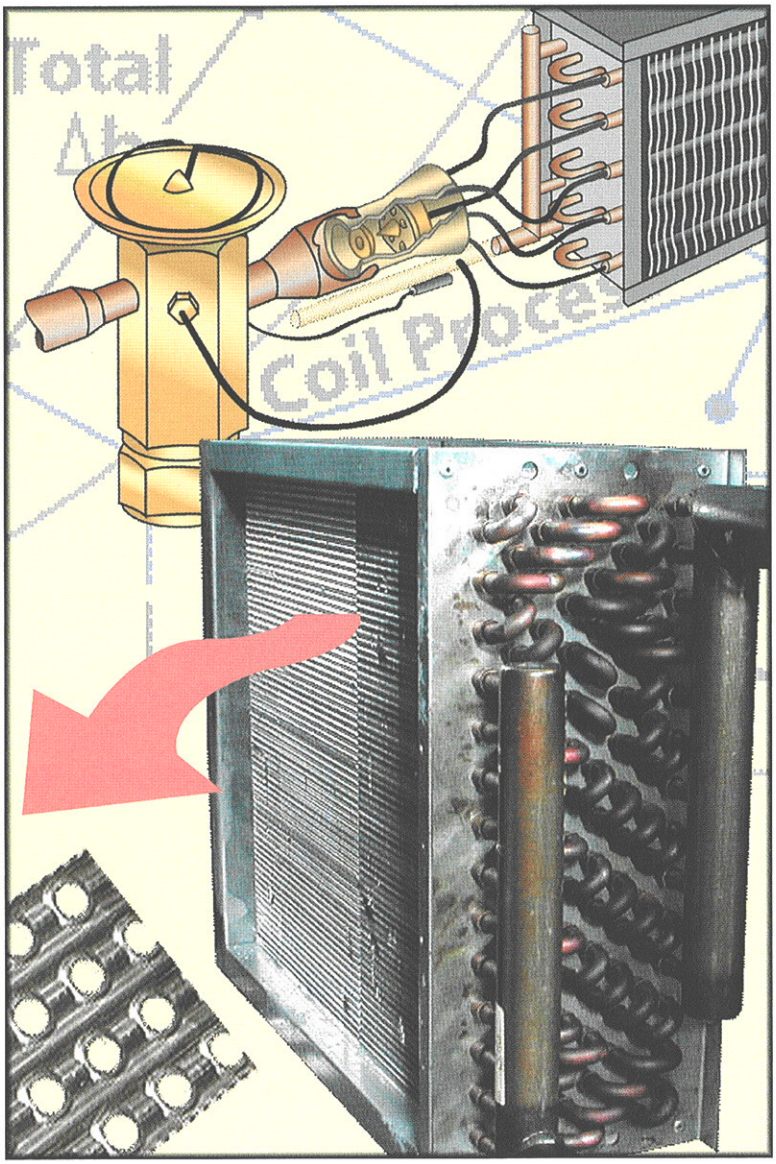


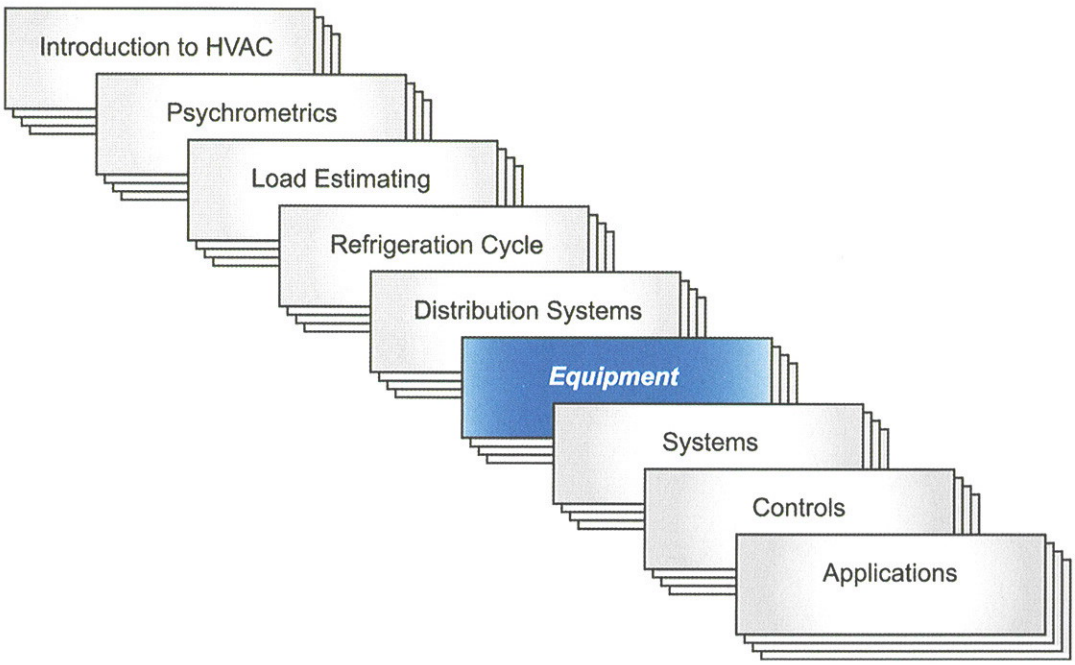
COMMERCIAL HVAC EQUIPMENT

Coils: Direct Expansion, Chilled Water, and Heating

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



There are many different coil applications used in HVAC design. They range from small residential sizes to large built-up coil banks in custom air-handling units. Regardless of their size, all coils serve the important function of changing the temperature of the air to satisfy comfort or process requirements. There are two main categories of coils, heating or cooling. Heating coils use electricity, hot water, or refrigerant hot gas as a heating medium. Cooling coils use direct expansion (cold refrigerant) or chilled water. In this TDP, a design engineer will learn about the components, features, and applications for direct expansion and chilled water cooling, and hot water, steam, and electric heating coils. With an understanding of these items, the design engineer can proceed with confidence to perform a proper coil selection and prepare a specification.

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Introduction

This TDP module reviews the terms, construction features, heat transfer characteristics, performance, and applications of the various types of heating and cooling coils. Heating coils use electricity, hot water, steam, hot gas reheat, or the reverse cycle of a heat pump unit to raise the temperature of the air flowing through the coil. Cooling coils use direct expansion (refrigerant) or chilled water to lower the temperature of the air flowing through the coil.

The term "coil" refers to a fluid-to-air heat exchanger. The fluid used in the coil may be water, steam, antifreeze solution, or refrigerant. The exception is electric heat coils, which do not use fluids. Coils are used for heating and cooling in air-handling units, packaged air conditioning units, and VAV terminals and can also be mounted in a duct or on a furnace. Figure 1 shows an example of a water coil.

The primary emphasis in this TDP will be placed on coils used in air-handling units operating in comfort air-conditioning applications because the design engineer for those products has the widest variety of coil types to choose from. In packaged equipment, the coil is already included as part of the unit design; however, some coil options may be available. The technical principles are the same for coils in packaged equipment and air-handling units.

"Cooling coil" is a generic term for coils that use chilled fluid or refrigerant as the cooling medium. The term "evaporator coil" has been used in the past for cooling coils that use refrigerant since refrigerant evaporates at a low temperature and pressure to extract heat from the airstream. "Direct expansion" or DX coil is the term that will be used in this TDP for coils that use refrigerant for cooling. If the heating or cooling coil application requires a fluid other than fresh water for purposes of freeze protection, that fluid will be referred to as antifreeze.

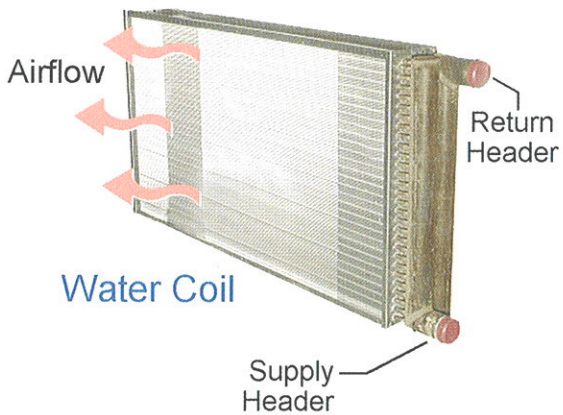


Figure 1

What is a coil?

Outdoor refrigerant condenser coils that are part of packaged equipment designs, such as condensing units and rooftop units, are not covered in this module because their design is normally determined by the manufacturer. For information on condenser coils in packaged equipment refer to TDP-634, Split Systems.

Before starting this module, the reader should have knowledge of the following topics: cooling load estimation, psychrometric theory, refrigeration principles, and air-handling equipment. The Carrier Technical Development Program for each of these topics is listed in the Prerequisite List on the inside back cover of this book.

Typical Coil Applications in HVAC Systems

In comfort cooling applications, there are five general application categories that use coils: residential systems, commercial packaged systems, duct mounted systems, air terminals, and air-handling units. We will discuss each and examine the coil designs that each of them use. Later in the TDP we will examine the construction and materials used in each coil type discussed below.

Residential Systems

Residential systems usually have less than five tons of cooling capacity. Residential cooling coils are usually a direct expansion (DX) design. Residential heating coils are available for heat pump units or electric heat. Hot water, steam, and chilled water coils are uncommon for residential applications so will not be discussed here

A residential split system is comprised of a separate indoor coil (fan required) or coil and fan combination unit, coupled to an outdoor cooling-only or heat pump condensing unit.

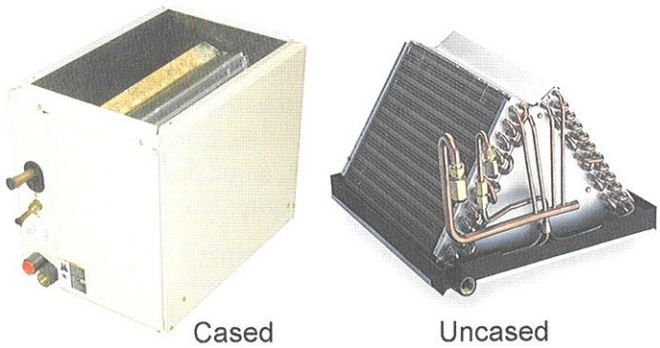


Figure 2

Residential Coils

The indoor DX cooling coil is often mounted on top of a residential furnace or fan unit. Residential cooling coils are similar to the larger commercial packaged unit cooling coils, but are available in smaller tonnage ranges. The coils are traditionally installed on the discharge side of the fan. Cooling coils are available in a number of configurations, "A," (shown here) "N," and slab. The coil can be a cased (factory enclosed) or uncased design. When an uncased coil is used, the field fabricated ductwork forms the casing around it when it is installed. See Figure 2 for an example of cased and uncased coils.

Commercial Packaged Units

Packaged commercial units are typically available in capacities from 7½ tons to over 100 tons. Packaged units are available in a limited number of pre-defined sizes. The advantage of the packaged air handler DX cooling coil is that the components, such as thermostatic expansion valves (TXVs) and nozzles, are normally factory selected and may be mounted at the factory. Nozzles and TXVs are discussed on pages 22 and 23 of the TDP.

Direct expansion cooling coils are used in small commercial applications. These coils depend on the airflow provided by a furnace or small commercial fan unit to circulate the air through the coil. Two types of coils can be used: an "A" coil design, which is used when two furnaces are twinned (used together as one), or a cased evaporator coil that is installed in the ductwork. See Figure 3 for an example. These coils are available in a variety of capacities. The most common capacities are 7½ and 10 tons.

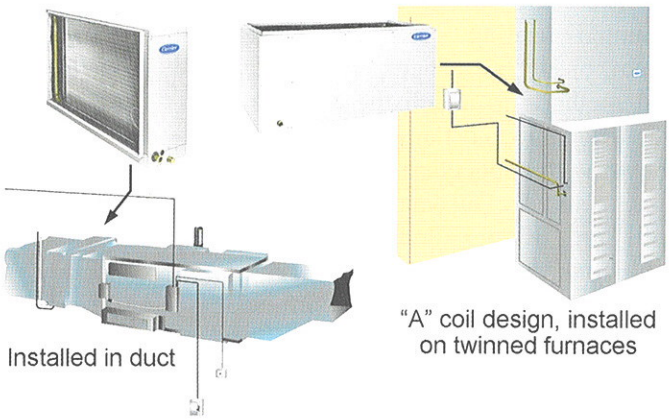


Figure 3

Small Commercial Packaged Unit Coils

Larger commercial packaged units include indoor vertical packaged products and outdoor rooftop units. These types of units will also utilize a direct expansion cooling coil. See Figure 4 for an example. However, chilled water coils are also available for use in many indoor packaged fan coils. Chilled-water cooling coils tend to be used in larger central station air-handling units which are discussed on page 26.

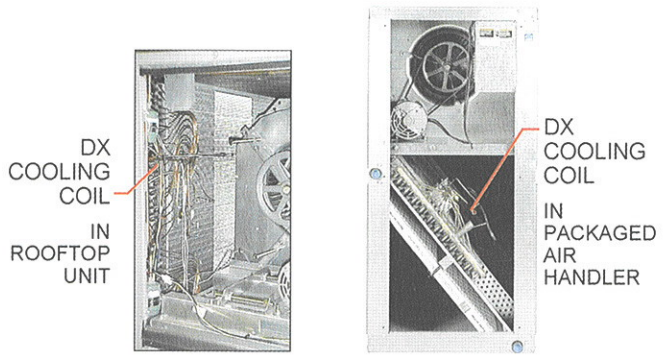


Figure 4

Large Commercial Packaged Unit Coils

Indoor commercial packaged air handlers often utilize hot water or electricity as the source for heating coils. Typically the air handler is available standard with a DX cooling coil, and a heating coil is a field-installed accessory.

Duct-Mounted Coils

Duct-mounted coils are usually heating type. Cooling coils are not typically used because a duct-mounted cooling coil would require an insulated condensate pan.

There are several types of duct-mounted heating coils: hot water, steam, or electric. There are also several methods to attach the ductwork. The drive slip and flanged casings are shown with connection details in Figures 5 and 6. Duct-mounted heating coils are often called reheat coils. Multizone systems that use a reheat coil in each zone supply duct are limited in their application by ASHRAE Standard 90.1 because of potential excessive energy usage.

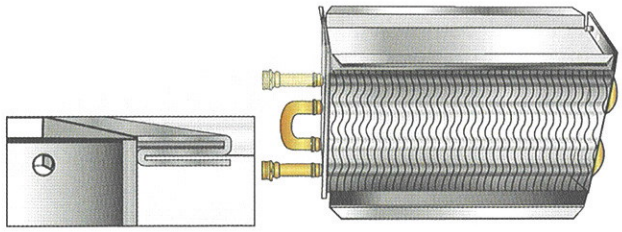


Figure 5

Duct-Mounted Coils with Drive Slip Casing

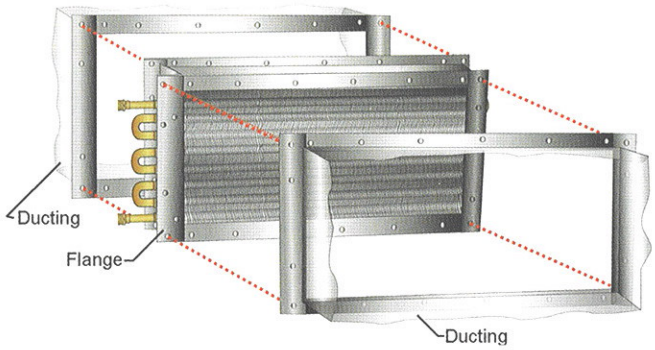


Figure 6

Duct-Mounted Coil with Flanged Casing

Air Terminals

Air terminals are used in variable air volume systems and dual-duct systems and often incorporate small hot water or electric heating coils. These coils are available factory mounted or ready to install as an integral part of the air terminal as an accessory. See Figure 7. The industry also classifies unit ventilators and fan coils as air terminals.

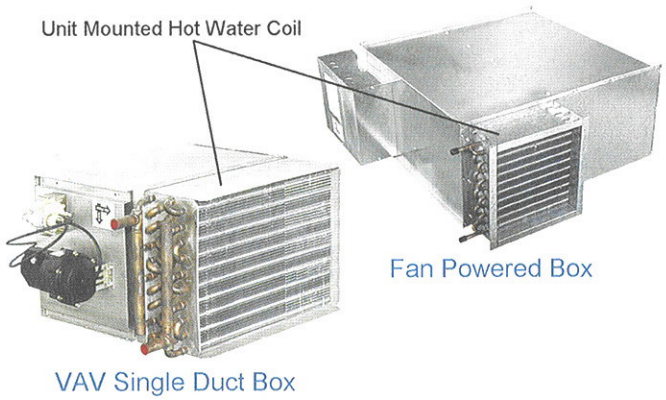


Figure 7

Air Terminal Mounted Heating Coils

Field Built-Up Coil Banks

Coils may also be stacked together to form a coil bank for larger custom applications. The built-up coil banks are stacked coils but can be comprised of more than 2 coils. The coils are arranged and supported by the contractor to fit a special configuration. Field built-up coil banks tend to be used for special large projects or industrial designs.

Air-Handling Units

The coils are important components in air-handling units. Central station air handlers, in particular, offer a wide selection of coil sizes, materials, row and fin options, and features to meet a broad range of applications. The cooling coil face velocity directly affects which cabinet size is chosen for the central station air handler. The cabinet size can be determined by the calculation shown in Figure 13. While packaged air-handling equipment typically offers only a draw-thru arrangement for the cooling coils, central station air-handling units also provide the option to locate the cooling coil in a blow-thru position downstream of the fan.

Coils in packaged products are most often DX and are matched to split system condensing units and heat pumps, although optional chilled water coils may be available. Manufacturers provide matched performance ratings with their condensing units and certify these ratings per ARI. As a result, packaged air handler coil capacity is classified by nominal cooling tonnage, rather than airflow.

Draw-Thru Versus Blow-Thru Coils

The position of the cooling coil within the air-handling unit affects the configuration. A draw-thru arrangement positions the cooling coil upstream of the air handler fan, motor, and drive such that the air is drawn through the coil by the fan. A blow-thru arrangement positions the cooling coil downstream of the fan such that the air is blown through the coil by the fan. Figure 8 shows a typical draw-thru air-handling unit arrangement, which is most common.

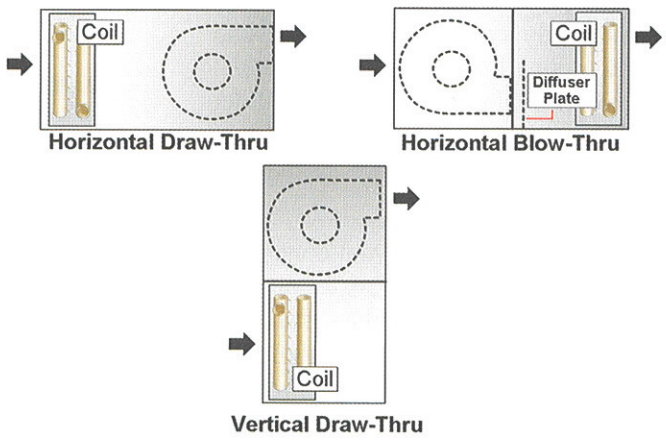


Figure 8

Draw-Thru and Blow-Thru Coils

Draw-Thru Arrangement

A draw-thru arrangement positions the cooling coil upstream of the air handler fan, motor, and drive such that the airflow is drawn through the coil by the fan.

Blow-thru arrangement requires a diffuser plate between the fan discharge and the cooling coil to achieve uniform air distribution. This can add to the length and cost of the air handler, therefore most designs are a draw-thru arrangement. Blow-thru is used on certain air-handling configurations which are discussed in TDP-611, Central Station Air-Handling Units.

Basic Coil Terminology and Construction

This section examines the terms that are used for both heating and cooling coils and also their different construction features.

Tubes

This section applies to steam, water, and refrigerant coils. Electric heating coils do not have tubes but are constructed from elements that heat the air. Electric heating coil construction is examined separately in the electric heat section on page 29.

The tube is a small-diameter conduit through which the heating or cooling medium passes as it rejects or absorbs heat. See Figure 9. Tubes are constructed from materials that have high thermal conductivity. Copper is the most common tube material due to its excellent heat transfer properties, reasonable cost, and durability. Steel is also used in coil tube designs, however it has a slightly lower heat transfer efficiency than copper and the labor costs for steel coils is much higher. Aluminum has also been used successfully on small residential and some small-capacity commercial equipment, like rooftop units. Other tube materials such as red brass and stainless steel are used for special applications as well.

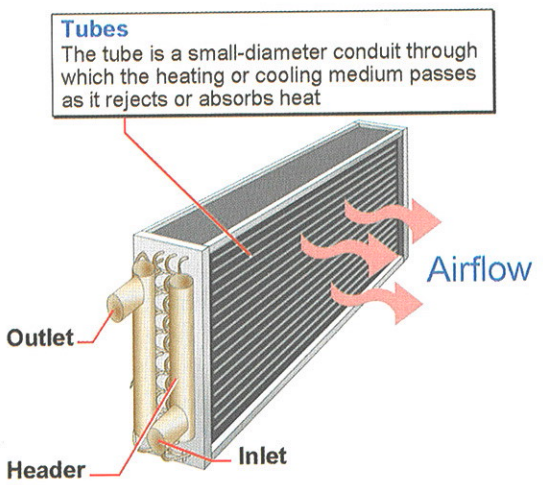


Figure 9

Tubes

The tube itself does not contribute very much to the heat transfer process (relative to the fins) other than distributing the heating or cooling medium. The fins, which are mounted on the tube, contribute most to the heat transfer because the fins constitute most of the coil surface area exposed to the airstream.

Although tubes with smooth inner walls are most common in coils, some manufacturers offer "enhanced" or rifled surface tubing or even internal devices intended to promote fluid turbulence in order to increase heat transfer. When these devices are used, the recommended maximum fluid velocity is usually decreased.

A prime surface tube has no finning or enhancements. Because of their limited heat transfer design, they are typically only used with steam coils.

Tube Diameters

Coils are made in several outside diameters (OD) such as 5/16, 3/8, ½, 5/8, ¾ and 1 inch. The three most widely used tube diameters in HVAC coils are ½-inch, 3/8-inch and 5/8-inch. The 3/8-inch OD is used in DX coils.

With larger tube diameters, lower waterside coil pressure drops may be achievable. It is possible to achieve similar waterside pressure drops with a smaller diameter tube by changing the circuiting of the coil. Circuiting will be discussed later in the TDP on page 16. Cross-sectional coil volume comparisons between ½-inch and 5/8-inch coils show that the 5/8-inch coil has around 25% more volume, which means that similarly circuited 5/8-inch coils will have a lower waterside pressure drop but less heat transfer. It is recommended that the smallest diameter tube with allowable pressure drop be used.

There are fewer larger OD tubes in a fixed face area coil than smaller OD tubes, therefore the 5/8-inch coil does not have a larger airside pressure drop.

Tube Wall Thickness

The coil's tube wall thickness is determined by the required working pressure of the coil. The coil's factory burst pressure testing also helps determine the wall thickness. The maximum allowable working pressure is determined by the manufacturer according to the ASME (American Society of Mechanical Engineers) rating requirements. The materials and construction chosen for other parts of the coil such as headers, also affect the tube wall thickness.

Tube Sheets and Support

On long tube lengths, the tubes may require additional support. Intermediate tube support sheets may be necessary to achieve proper support along the total length. The coil manufacturer typically determines the tube support sheet spacing and material required to support the tubes correctly.

Tube Face

Tube face is the number of tubes in the first row of the coil. The tube face is eight in the coil shown in Figure 10.

Rows

The tubes are arranged in rows within the coil. See Figure 10 for a depiction of coil rows. The more rows (if the number of fins per inch is constant), the greater the heat transfer capability of the coil. Typically, cooling coils will have more rows than heating coils. The primary reason a coiling coil requires more surface area than a heating coil is that coiling coils have a much smaller heat transfer coefficient. Coils must reduce their surface temperature below the dew point of the air passing over them in order to condense out the moisture, so greater surface area is required. More rows, however, result in increased airside pressure drop. Coil selection software will typically pick a coil with the minimum amount of rows necessary to do the duty requested.

Heating coils are often 1 or 2 rows deep. Cooling coils are often 3 rows deep or greater, especially in central station air handlers where even 10-row coils are available. The number of rows affects the amount of air that can pass through the coil untreated. For example, an 8-row coil will have a smaller amount of untreated or bypassed air than a 4-row coil.

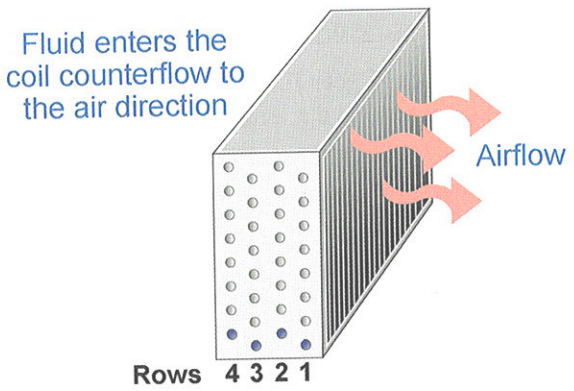


Figure 10

Coil Rows

Fins

The coil fin is a thin metal plate mechanically bonded to the tube to improve the heat transfer efficiency by increasing the surface area in contact with the air. The fins are stamped from sheets and contain holes where the coil tubes are attached. They generally have "enhanced" surfaces, which create turbulence in the airstream to reduce air bypassing the coil surfaces and improve heat transfer. See Figure 11.

The fins are stacked on the tubes and spaced at specific intervals. The spacing is generally expressed as the number of "fins per inch" which is the number of fins present in a one-inch length of the tube. Fin spacing can also be represented in fins per foot, which is used by some manufacturers. Fin spacing on coils ranges from 4 to 20 fins per inch. For typical comfort cooling applications, ranges from 8 to 14 fins per inch are common. This range provides a reasonable balance between heat transfer performance

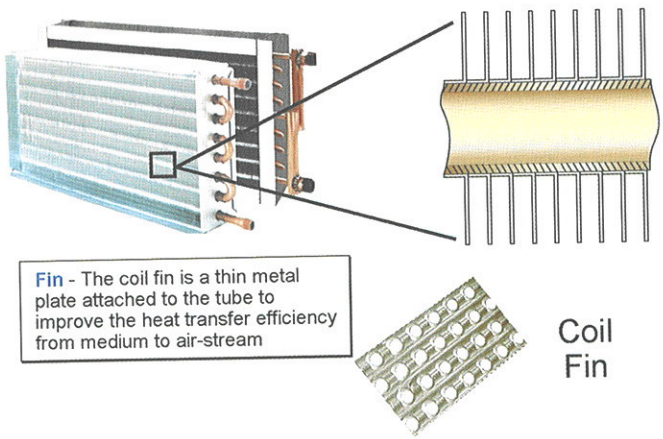


Figure 11

Rows and Fins
(Photo courtesy of Heatcraft USA)

and air friction, which relates to fan energy required to pass the air through the coil. The more rows and fins per inch, the higher the heat transfer capability, but the higher the airside pressure drop. The fin spacing should take into account possible lint and dirt accumulation which is a function of the level of filtration involved.

When fins are stamped, the holes are extruded. When the holes are extruded, they are shaped with flat edges so the tube does not rest on a sharp cut edge.

Fin Material

Aluminum and copper are the most popular materials for fins on cooling coils used for comfort applications. See Figure 12 for an example of bonding fins and tubes. The fins are bonded to the tubes by expanding the soft copper tube with a device called a mandrel. This creates a secure bond between the tube and fin with excellent heat transfer properties. Aluminum tubes with aluminum fins have been used successfully for residential cooling coils and for some small capacity comfort commercial equipment. Copper tubes with aluminum fins, however, dominate the commercial equipment market as the most popular material combination. Copper finning on copper tubes, while significantly more expensive, is a material combination which offers corrosion resistance on appropriate applications. Other tube and fin materials and coil coatings are available where standard coil offerings are not suited to the air content.

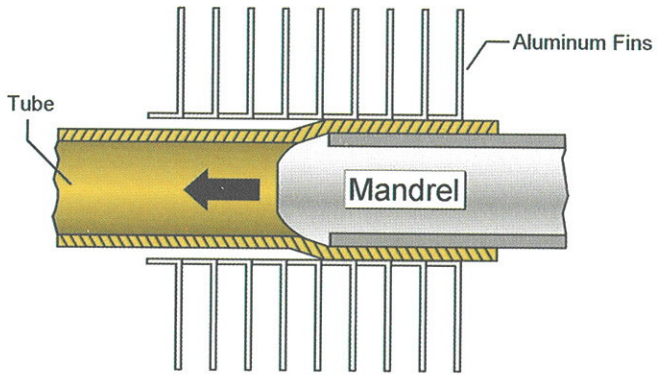


Figure 12

Fins and Tube Binding

Face Area

The actual effective area of the coil is defined as the width times the length of the finned area through which air passes. This is called the finned or face area. This area does not include the extra dimensions for the casing. It is generally expressed in square feet and is also used by many air handler manufacturers to define the model size of the air handler.

Face Velocity and Required Face Area

This is the air velocity in fpm across the finned or face area of a coil. It is determined by dividing the air volume in cfm by the coil face area in square feet. See Figure 13.

This is the air velocity in fpm across the finned or face area of a coil. It is determined by dividing the air volume in cfm by the coil face area in square feet. See Figure 13.

The relationship between airflow volume (cfm), velocity (V) and area (A) is:

$V = cfm / A$

From this, we can determine the required face area of the coil.

For example, if the airflow is 25,000 cfm and the maximum face velocity is 500 fpm then:

$A = 25{,}000 \text{ cfm} / 500 \text{ fpm}$

Minimum coil area (A) = 50 ft^2

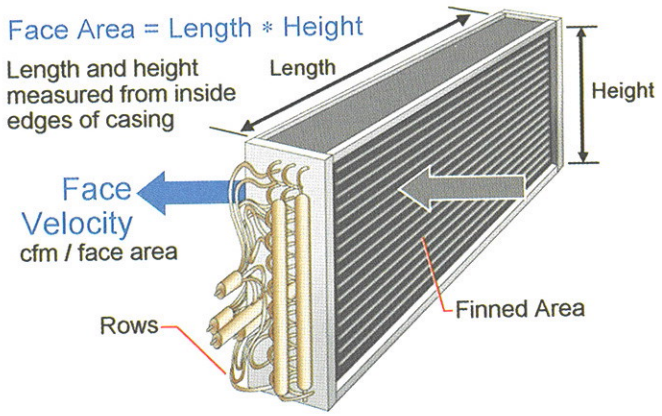


Figure 13

Face Area Calculation

A cooling coil with at least 50 square feet of face area will be required. The height of active surface times the length should be 50 square feet or greater.

Bypass

The number of rows of tubes and fins will change the coil performance. The amount of air, expressed as a portion of the total airflow, that passes through the coil untreated is called the bypass. The bypass for any coil depends upon the coil construction (the number of tubes, size [face area], number of fins, and the tube and fin spacing). The bypass is also affected by the velocity of the air passing through the coil. The bypass factor is the ratio of untreated (bypassed) air to the total air. Bypass factors are shown in Tables 1 - 3.

Table 1
Bypass Factors and Rows

ROWS	BYPASS FACTOR
2	0.31
3	0.18
4	0.10
5	0.06
6	0.03

Table 2
Bypass Factors and Fins

FINS PER INCH	BYPASS FACTOR
8	0.31
12	0.18
14	0.03

Table 3
Bypass Factors and Velocity

AIR VELOCITY	BYPASS FACTOR
300 fpm	0.11
400 fpm	0.14
500 fpm	0.18
600 fpm	0.20

Casing

The supporting metal structure or frame for tubes and header is called a casing. It is usually made of galvanized steel but can be stainless steel or other materials. The end panels that the tubes pass through are called tube sheets. In addition to structural support, they also contain the airflow as it moves across the coil. The assembly of tubes, fins, and coil casing is sometimes referred to as the coil core.

Header

The header is a large diameter pipe to which the tubes are connected. It serves as a distributor of the heating or cooling medium to the coil tubes. See Figure 14. Headers are typically of non-ferrous metal (copper) or steel.

Non-ferrous material

Non-ferrous headers are typically made of copper and contain no iron or steel.

When copper is used for the header and for the tubes, the connecting joint between the header and the tubes will also be copper. This is considered desirable from a corrosion standpoint since the use of dissimilar metals should be avoided.

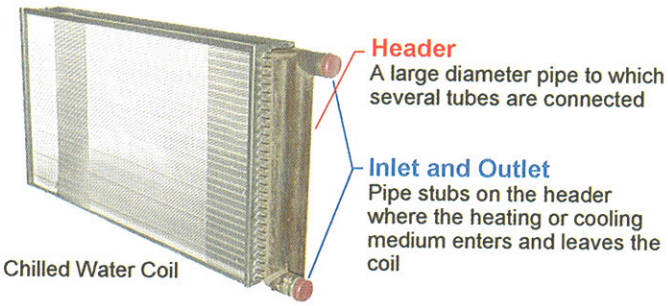


Figure 14

Header

Some manufacturers offer a removable plug for each return bend to access the tubes for cleaning. Another method for mechanical tube cleaning is to make the header a removable assembly. This is not a standard practice as most water in a closed loop is filtered and maintained free of sand and other foreign materials. See Figure 15.

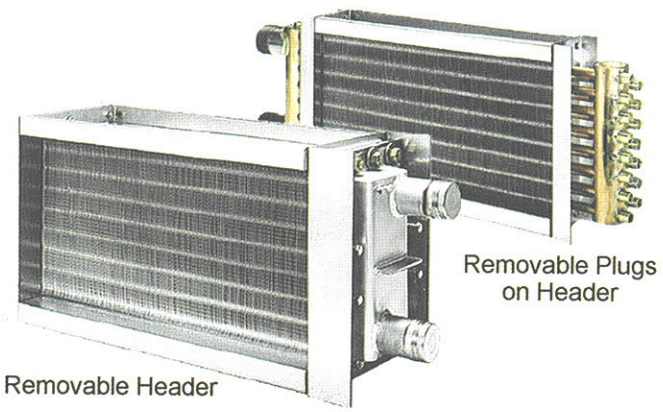


Figure 15

Coils with Removable Tubes
(Photos courtesy of Heatcraft USA)

Inlet and Outlet Connections

The inlets and outlets are on the header where the heating or cooling medium enters and leaves the coil. For water coils the inlets and outlets are sometimes referred to as the supply and return connections. The connections may be sweat/brazed/welded, flanged, pipe thread, or grooved type.

Piping the Coil

In water coils, the inlet (supply) is the pipe stub located on the downstream side (where the air leaves the coil). The outlet (return) is the stub on the entering air-side of the coil. Such an arrangement is known as counterflow, which maximizes heat transfer. See the Heat Transfer section of this TDP for more information.

Copper connections are either brazed (DX) or sweated (room or fan terminals). Brazing and sweating are often looked on as the same thing, but they are different. Brazing results in a stronger joint. Both involve sealing the joint with a high temperature and a joint material. New refrigerants require the use of brazing to avoid using acid flux with the POE (polyol ester) oil used in the newer refrigerants.

Pipe thread connections provide a seal within the threaded joint. A lubricant is used on the pipe threads when screwing the connections together. Male pipe thread (MPT) is the most commonly supplied coil connection. Pipe thread connections are used on water and steam coils generally up to 2½ inches of size.

Grooved connections use a clamp mechanism to attach the piping to the coil pipe stubs. Grooved connections might be used in a facility where no welding sparks are desired. Grooved connections are used mostly on water coils and never used on DX coils.

In steam coils, the inlet is always positioned higher than the outlet so that condensate will drain out of the lower connection.

Direct expansion coils also follow the counterflow arrangement. However, some DX coil designs will route the last pass of the refrigerant circuit back to the warm entering airside of the coil to accomplish superheating of the refrigerant suction gas.

Coil Hand

When you stand in front of a coil, the connections will either be on the right side or the left side. This is what is meant by "hand" connections – right or left. Face the entering air side of the coil to determine its hand connection. There are exceptions which vary by coil manufacturer. See Figures 16 and 17.

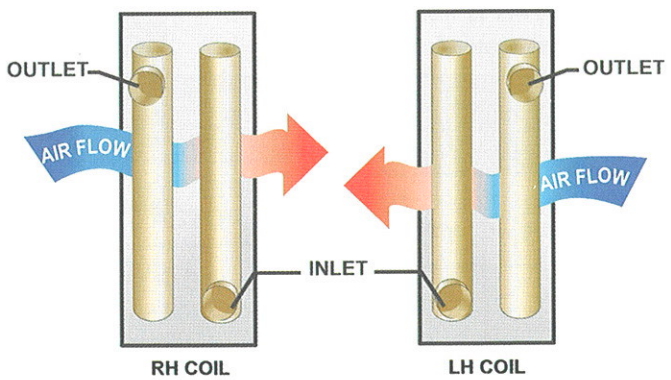


Figure 16

Chilled or Hot Water Coil Hand

Correct coil hand is determined by side of the connections which maintain maximum heat transfer within the coil. In water coils, the inlet will be closest to the air exiting the coils. In DX coils, the refrigerant distributor will be normally closest to the air exiting the coil and the suction connection is closest to the entering air.

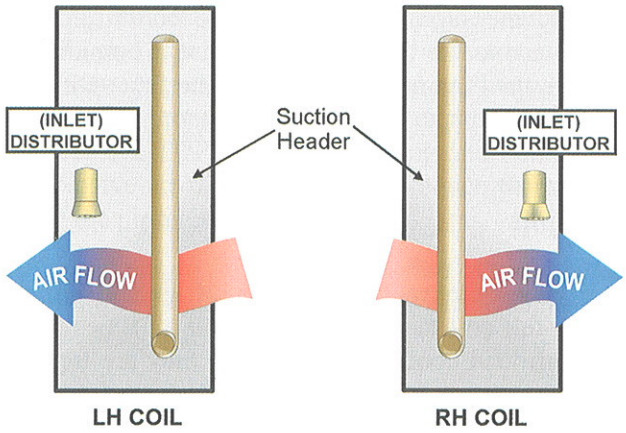


Figure 17

DX Coil Hand

Coil Splits

Face Split

The term face split applies to DX coils only. Face-split coils divide the face of the coil horizontally, on a plane parallel to the airflow (as shown by the dotted line in Figure 18). Each split can be piped to a separate condensing unit. Each split is controlled independently of the other by a liquid line solenoid valve placed in the liquid line upstream of the TXV. Because of their design, face split coils can create uneven leaving air temperatures when one split is deactivated.

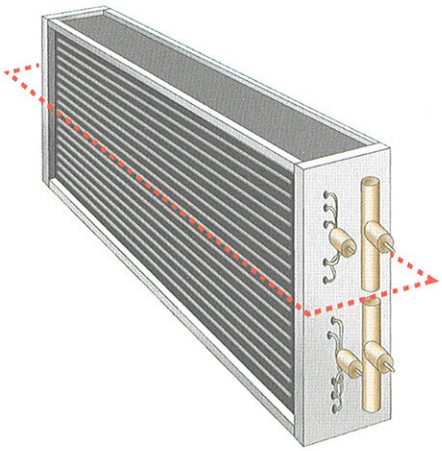


Figure 18

Face-Split Coil

During part load, a face-split coil deactivates the top face. This creates an inactive top coil, which basically becomes a large bypass for untreated air. This untreated air (slightly more than 50% of total airflow) mixes with the treated air from the bottom face and results in a mixture temperature that is often too high to maintain proper room relative humidity control.

NOTE: Water coils use either flow modulation or water temperature adjustment as a capacity control technique.

Face-split coils are often used on constant volume systems. They are not generally applied on variable air volume (VAV) systems or others requiring uniform coil leaving air temperature. When staging a face-split coil, the top split should never remain on with the bottom split off where latent load is involved. This causes the water condensed on the top split to run down the

fins onto the surface of the inactive bottom split. A portion of the condensate will then re-evaporate into the airstream and cause a humidity rise in the conditioned space. To avoid this problem, the bottom split should be the first split on with load increase and the last split off with load reduction.

Row Split

In row split arrangement, each refrigerant split covers the entire face of the coil. This ensures that the full coil face will be active at all times to provide uniform air temperatures leaving the coil at all load conditions. Although they are frequently called row split coils, intertwined coils differ from true row splits in that each split passes refrigerant through all rows of the coil. The circuits of each split weave in and out, or intertwine, throughout the coil to ensure equal load on each split at full-load operation when both are active. See Figure 19.

Intertwined circuited coils are historically preferred for variable air volume VAV systems and others that utilize discharge air control because the full face active feature delivers a slightly more consistent leaving air temperature off the coil. Examples include multizone and double-duct systems.

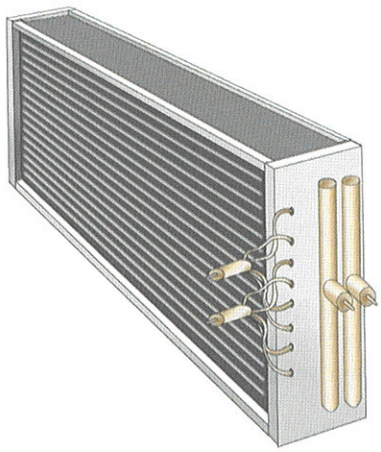


Figure 19

Row Split Coil

Vent and Drain Connections

Vent connections are located on the top of water coils and are used to allow purging of air from the coil, primarily when filling the system with water, but also allow periodic venting to maintain performance or if a vapor lock is suspected in the coil. Vent connections are frequently located on the inlet and outlet stubs or the top of the headers. See Figure 20.

Air bubbles tend to separate out of water or an antifreeze solution in areas where pressure drop is experienced. The flow of air bubbles back

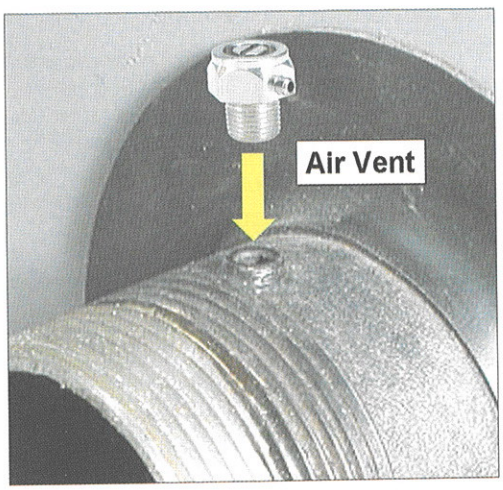


Figure 20

Vent Connection

out of the coil is enhanced by a proper water piping connection to the coil. Air is normally vented at the air separator and not at the coil in a chilled water or hot water system. Elimination of the air from the water system when it is drained is necessary to prevent excessive air build-up within the water system over time. From a systems standpoint, proper application of expansion tanks or compression tanks and air separators are required. See TDP-502, Water Piping and Pumps for a discussion on hydronic system accessories. Excessive air in the system can reduce thermal performance and lead to noise and even vibration of the piping.

Drain connections are used to drain coils for service, or for freeze protection of coils that are not in service during cold weather, such as a cooling coil during the winter. The drain connections are located at the lowest point in the coil to ensure complete drainage.

Return Bends and Hairpins

Return bends are 180° elbows soldered to the coil tubes to reverse the flow back through an adjacent tube in the coil. To minimize the number of return bends and associated solder joints, many manufacturers use "hairpins" which are simply tubes bent at an angle of 180°. A hairpin then results in two tubes within the coil.

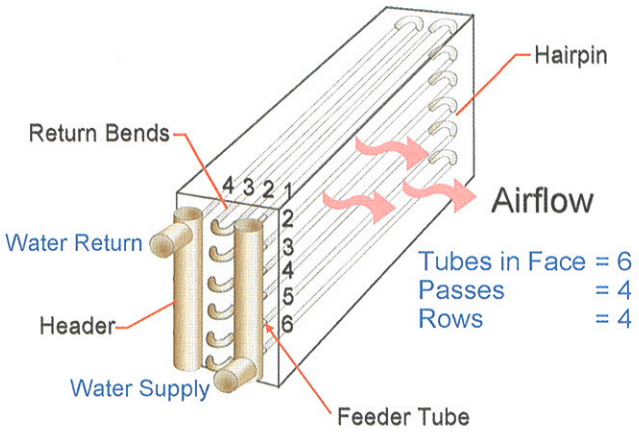


Figure 21

Return Bends and Hairpins

Coil Passes

The number of times the fluid traverses from one end of the coil to the other across the airstream in a given circuit is the number of passes. Shown in Figure 21 is an illustration of a 4-row coil core. The tubes may be connected in different ways to vary the flow pattern of individual circuits, which, in turn will change the pressure drop and heat characteristics of the coil to meet specific job requirements.

Refrigerant Distributor

Direct expansion (refrigerant) coils use a return header similar to a water coil. See Figure 22. It is generally called a suction header, since it is connected to the inlet of a compressor, rather than a water loop. On a DX coil, the supply header is replaced by a refrigerant distributor, nozzle and feeder tubes. Their functions are explained in more detail on pages 22 and 23.

Many distributors contain a nozzle, which has a small orifice designed to add turbulence to the refrigerant and improve mixing of the flash gas and liquid refrigerant to ensure that all circuits within the coil receive equal quality flow.

Quality, as it refers to refrigerant coming out of a distributor and nozzle assembly, means that it should normally be about 20% superheated refrigerant gas and 80% liquid prior to entering the coil.

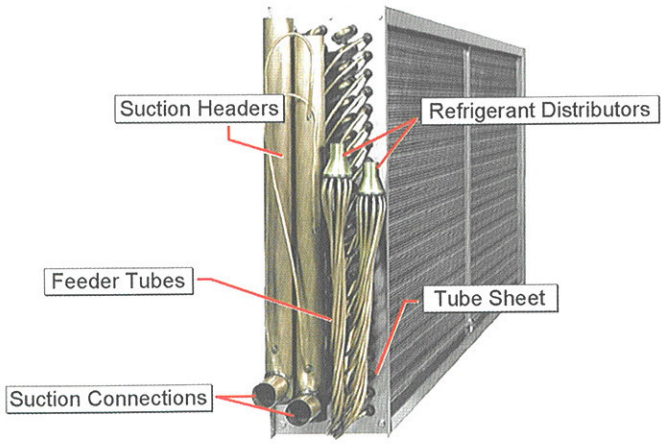


Figure 22

Refrigerant Distributor
(Photo courtesy of Heatcraft USA)

Coil Circuiting

Circuiting applies to both water coils and to DX coils. The path of travel that the cooling or heating medium takes as it enters, travels through the coil, and leaves the coil is a complete circuit. See Figure 23. The refrigerant is introduced into each coil tube typically through a small feeder tube on a DX coil. This is different from the short straight piece of piping from a water coil header that is used to introduce the water into the coil tube. Each coil type offers multiple circuiting arrangements to meet the capacity required within the pressure drop constraints that have been defined. For a water coil, the maximum waterside pressure drop is defined by the user and is job specific. A circuiting arrangement is then selected by the computer to stay within that pressure drop.

For a DX coil, the coil manufacturer has designed the coil to stay within a workable refrigerant pressure drop in the tubes. The user does not need to define the refrigerant pressure drop limitations as with a water coil. The DX selection program will use those circuiting arrangements that are able to deliver the required heat transfer.

The design of the headers and the arrangement of the hairpins and return bends divides the coil core into several independent passages called circuits. Each circuit connects to the supply and return headers (or distributor and suction header in the case of a DX coil). In any coil, these circuits can operate simultaneously to provide the coil's heat transfer capacity. By varying the coil return bend and hairpin turn arrangements, several circuiting types may be provided for the same coil core.

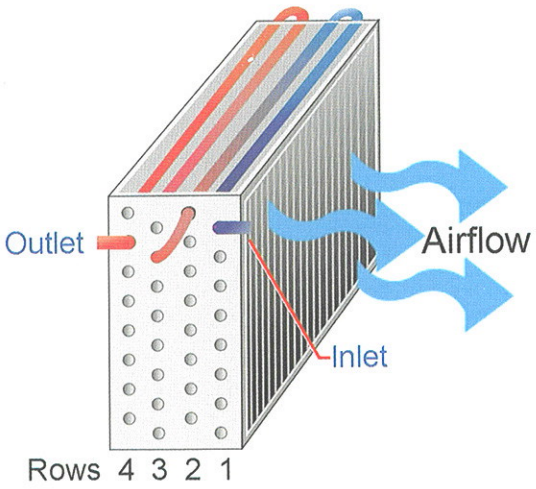


Figure 23

Coil Circuiting

This coil core illustrates the concepts related to various circuiting types in Figures 24 to 27. In each figure the coil will be viewed from the coil connection end. In each figure, solid lines interconnecting tubes represent return bends or hairpin turns on the near end while the light dotted lines represent those on the far end of the coil.

The purpose of circuiting is to provide several different path lengths of water or refrigerant flow within the coil in order to achieve the heat transfer and Δt in the fluid as required by the specific application.

The term non-trapping circuit applies to water coils only. If the coil vent is open and the coil is isolated from the system, then the tubes will not trap water inside of them when flow has stopped. The water from each circuit drains into the header and can be removed by the drain in the header. This feature may be desirable to prevent freezing of standing water in the coil.

Full, half, quarter, and double circuiting normally only applies to water coils.

Tube Fluid Velocity

Part-load operation requires additional design and selection considerations for coils. Chilled water coils use either flow modulation or water temperature adjustment as a capacity control technique. Where water temperature adjustment is used, flow is usually relatively constant. Where water flow modulation is used, the water velocity within the tubes of the coil can vary through a rather broad range.

As an example, one manufacturer suggests a range of coil tube velocity from slightly greater than 1 foot per second up to about 12 feet per second. A coil selected for a design load flow of 8 feet per second tube velocity would allow smooth sensible capacity modulation down to about one eighth (12.5%) of the coil design flow rate. Flow modulation alone, or in conjunction with water temperature reset, is generally used to provide adequate range for part-load capacity control when using water coils.

Fluid Velocity Design Range

The typical design range for velocity is approximately 1 to 12 feet per second.

A selection of circuiting arrangements is available to increase or decrease pressure drop. Greater pumping energy is required to offset the higher coil pressure drop. At excessive velocities, noise and tube erosion can also result. Factors that increase turbulence such as internal tube enhancement increase the temperature difference across the tube wall. Internal enhancements or a device mounted the tube are used to reduce the heat transfer film coefficient. However these devices tend to increase the fluid-side pressure drop.

The waterside pressure drop for water and antifreeze mixtures in coils can range from less than a 1 ft wg head pressure to upwards of several dozen ft wg. If the pressure drop rises too far for economical pumping, it can often be reduced by decreasing the path length of the fluid through the coil.

Full Circuiting

For full circuiting, each circuit passes through each row once and then exits into the return header. Shown in Figure 24 is a circuit flow pattern referred to as "full" circuiting. Each tube in the last row is fed with heat exchange fluid from the supply header or refrigerant distributor. The fluid traverses the 4-row coil shown in this example a total of four times in each circuit (i.e., four passes) and exits into a return header at the same end of the coil as the supply connections. Each set of tubes interconnected in this manner represents a separate, enclosed circuit with a source of supply and a means of return.

In this example, there are eight circuits for this 8-tube face coil. The number of passes will vary with coil row depth. A full circuit coil is the most commonly used arrangement. A full circuit coil has a good balance between heat transfer and waterside refrigerant pressure drop.

Full Circuiting

In a full circuiting arrangement, the number of circuits equals the tube face count of the coil.

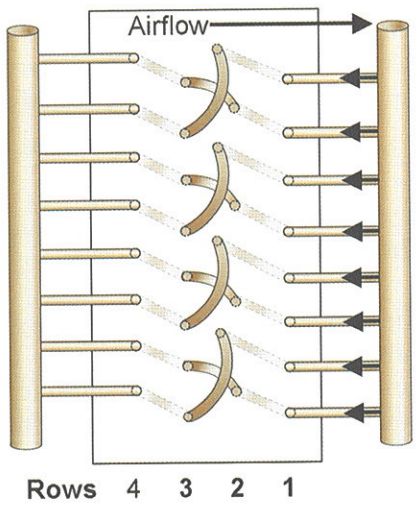


Figure 24

Full Circuiting

Half Circuiting

For half circuiting, each circuit passes through each row twice and then exits into the return header. Therefore there are half the number of circuits as full circuiting and each circuit travels twice as long. Shown in Figure 25 is an illustration of "half" circuiting. Every other tube of the last row, or half the tubes as the name implies, is fed with heat exchange fluid. The number of circuits will be half that of the full-circuited coil, or 4 in this case. For the same 4-row coil core, the fluid now makes 8 passes, which means that it travels twice as far through the coil before being returned as in the full-circuited coil. A half circuit coil would be selected over a full circuit coil when a lower flow rate is required.

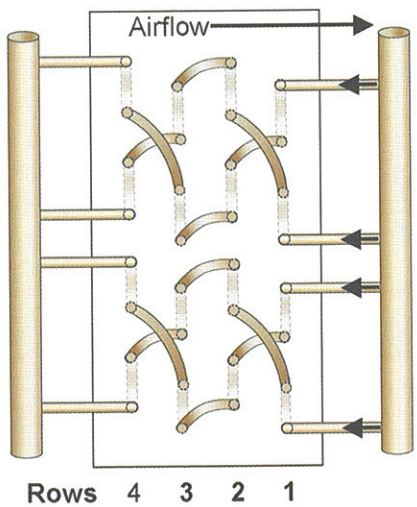


Figure 25

Half Circuiting

Quarter Circuiting

For quarter circuiting, each circuit passes through each row four times and then exits into the return header. Therefore there are one quarter the number of circuits as full circuiting and each circuit travels four times as long. This type of circuiting has the highest pressure drop and the lowest flow rate. Quarter circuiting is shown in Figure 26. In this case each fourth tube (one quarter of the tube face) of the last row is fed with heat exchange fluid. The number of circuits is ¼ of the tube face and for this coil, this results in 16 passes per circuit or twice that of half circuiting. Quarter circuiting accommodates the lowest possible flow rate through the coil. Quarter circuiting is also called high rise circuiting.

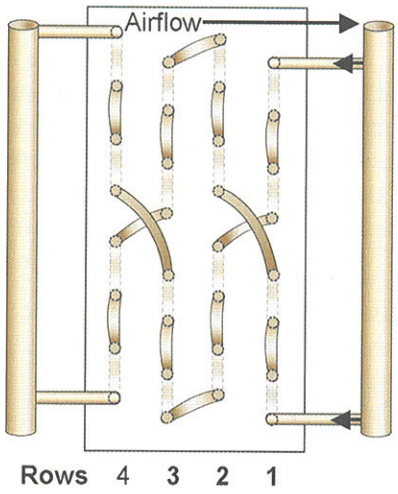


Figure 26

Quarter Circuiting

Double Circuiting

For double circuiting, each circuit passes through every other row and then exits into the return header. Therefore there are twice the number of circuits as full circuiting and each circuit travels half as long. This type of circuiting has the lowest pressure drop and the highest flow rate. Shown in Figure 27 is double circuiting. In this case, every tube in each of the last two rows (double the tube face) is fed with heat transfer fluid. This represents the circuiting arrangement with the greatest number of circuits (twice the tube face) and the fewest passes (two in this case). It handles the highest fluid flow rates through the coil.

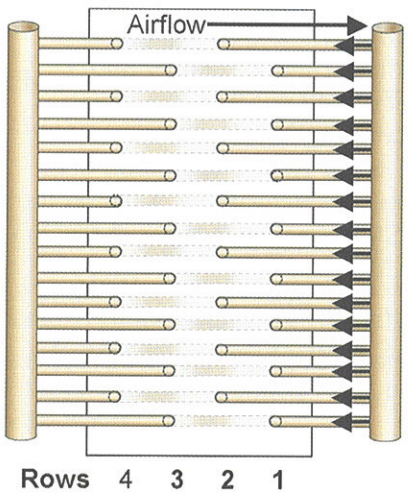


Figure 27

Double Circuiting

Coil Cost Factors

Coil circuiting permits a given coil core to accommodate a wide range of fluid flows and pressure drop requirements to meet the designer's needs. For a given heat removal capacity, the greater the distance traveled through the coil by the fluid in one circuit (i.e., the less the number of circuits), the lower the required flow rate of the heat transfer fluid will be. This is true because the fluid inside the tube has a longer time to exchange heat with the air on the outside of the tube. This means that each pound of fluid circulated through the tubes of the coil will absorb more heat than in a shorter circuit. Longer circuits also produce higher heat transfer fluid tube velocities, with the accompanying higher circuit pressure drop. See Figure 28. There is a practical limit to the length of the circuit. Manufacturers may not offer all circuit types for every length coil.

The rate of heat exchange is influenced by the thermal resistance to heat transfer created by a stagnant layer of water immediately inside the tube wall. Higher tube velocities make this boundary layer thinner, thereby enhancing heat exchange. However, since pressure drop varies as the square of the velocity (or flow), pumping energy can quickly exceed the small gains in heat transfer. Maximum velocities are limited by pressure drop, tube erosion, and noise constraints.

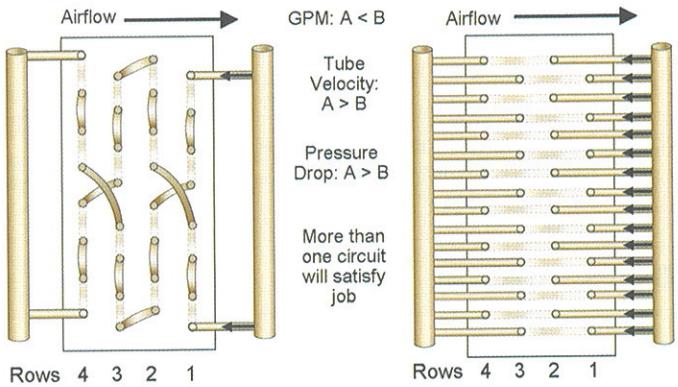


Figure 28

Comparing Circuits

Frequently more than one circuiting type will satisfy the job at hand. There will typically be a combination of coil size, row depth, fin spacing and circuiting which is optimal for the system. This may not be synonymous with the coil that has the lowest cost. However, when two or more coil arrangements satisfactorily meet the performance requirements, the least expensive coil should be selected. Shown below is the cost ranking for the various coil parameters from highest to lowest cost impact.

Cost Ranking Factors for Coils (from highest cost to lowest)

1. Face area (this is frequently related to the size of the air handler cabinet)
2. Rows
3. Fin spacing (fins per inch)
4. Circuiting

It is less expensive to increase the number of fins per inch than to increase the number of rows in the coil.

Types of Coils

Direct Expansion

A direct expansion coil transfers heat through the evaporation of the refrigerant. The refrigerant in the coil evaporates (boils) and absorbs heat from the air passing over the fins through the coil. This is in contrast to a chilled water coil where the cold water cools the warmer air passing through the coil.

Shown in Figure 29 is a schematic representation of a system with a direct expansion cooling coil and air- cooled condensing unit. This type of system requires 2 steps of heat transfer to move heat from indoors to outdoors.

The first step is an air-to-refrigerant heat transfer from the air entering the cooling coil through the coil tube wall into the refrigerant within each coil circuit. The next step is a refrigerant-to-air process as heat within the refrigerant is rejected, after compression, through the condenser tube wall to the outside air. Direct expansion refrigeration systems can make use of water-cooled condensing units in addition to the air cooled variety shown. In that case three steps of heat exchange are involved instead of two.

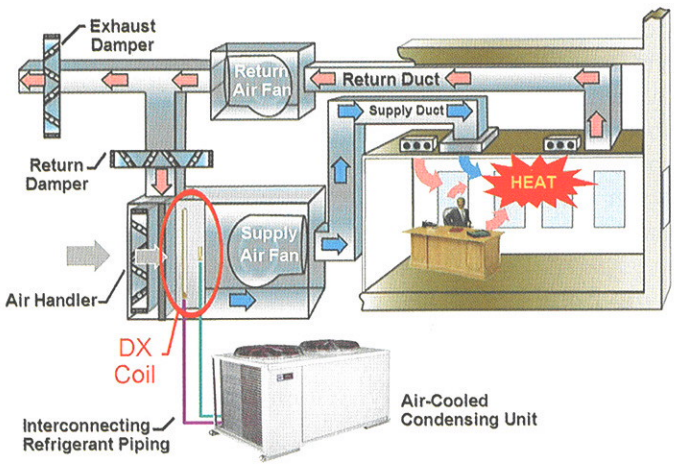


Figure 29

DX Coil System

Direct expansion systems are most frequently applied with one or two condensing units for each air-handling unit that contains a DX coil. This tends to limit the maximum refrigeration system capacity to about 150 tons. By contrast, a chilled water system typically feeds several chilled water cooling coils from a single chiller. This enables a designer to treat physically separated air-handling units and systems from a common refrigeration system without the complications which result from extensive refrigeration piping systems. As a result, the maximum capacity of central water chiller systems is almost unlimited. The benefits of chilled water systems tend to grow the larger the system becomes.

How DX Coils Work

A TXV is a device that is used to meter the flow of liquid refrigerant into the distributor. As the warm temperature liquid refrigerant passes through the TXV orifice, the resulting pressure drop causes a small percentage of the liquid to evaporate, producing flash gas. This flash gas, in turn, cools the refrigerant liquid/vapor mixture to a level below the air temperature entering the coil to allow heat transfer from the air to the refrigerant. See Figure 30. Typically the saturated refrigerant temperature inside the DX coil is between 40 and 45° F.

From the TXV, the low temperature mixture of gas and liquid refrigerant flows into a distributor that, with the help of the nozzle, evenly distributes it to all circuits within the evaporator. Within each circuit, the liquid evaporates as it passes through the coil, absorbing heat from the airstream. The TXV has a sensing bulb mounted on the suction line leaving the coil. It controls the valve position to maintain a constant superheat at the coil outlet to ensure that no liquid refrigerant returns to the compressor.

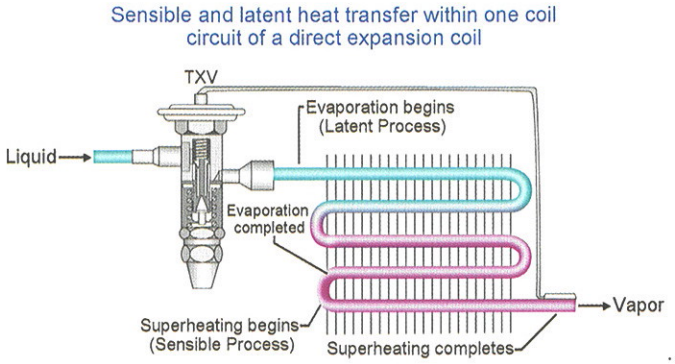


Figure 30

DX Coil Operation

In comfort cooling applications, the cooling system will run at peak design load only a small percentage of the time. The majority of time, the system will operate at part load. Low load with a direct expansion coil is more restrictive than that for chilled water coils. It is imperative that the designer fully understand how the DX coil, thermostatic expansion valve, and distributor function, and what their limitations are.

Low-Load Limiting Factors

Shown in Figure 31 is an evaporator with thermostatic expansion valve, distributor/nozzle, and feeder tube assembly. Within this group, three devices define the minimum load limit. They are:

- Thermostatic expansion valve (TXV) low-load limit
- Distributor nozzle low-load limit
- Evaporator circuit low-load limit

Thermostatic Expansion Valve (TXV)

A thermostatic expansion valve should not operate below the published percentage of the nominal capacity. Below a certain percentage of the nominal valve capacity, the valve's clearance between its needle and seat alternates between being too far open (over capacity with too little superheat) and too far closed (under capacity with too much superheat). This "hunting" action causes loss of system capacity control and poses the threat of liquid flood-back to the compressor. For these reasons, this unstable range of operation should be avoided. The stable operating range for a typical thermostatic expansion valve used on a comfort system is from slightly more than 100% to about 50% of nominal rated capacity. There are,

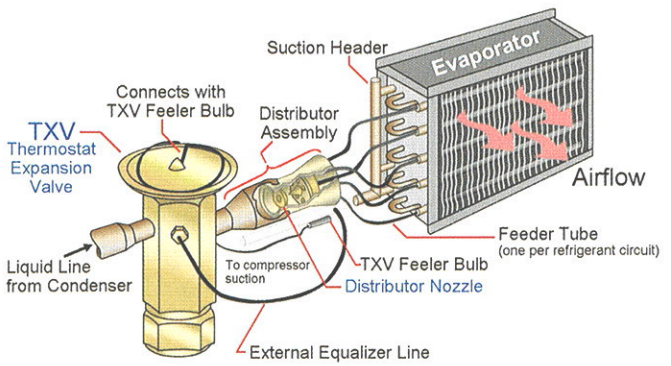


Figure 31

DX Coil with TXV

however, valves that can operate with stability below 40%. For example, one valve manufacturer publishes a minimum capacity of 35% for their standard comfort air-conditioning valves, and 25% for their "broad range" model. Specific manufacturer's data should be checked when selecting specific valves. For a complete discussion of TXVs, see TDP-403, Expansion Devices and Refrigerant Specialties.

Distributor Nozzle

Because of the wide application range possible with central station air handlers, the system designer, aided by manufacturer's selection software, usually selects the nozzles for these product types. The nozzle performs the function of equally distributing the mixture of gas and liquid refrigerant leaving the TXV to each of the feeder tubes. See Figure 32. The nozzle is rated for optimal performance with a flow capacity in tons equal to 25 psi pressure drop across its orifice. The nozzle should be selected to operate from 50% to 200% of rated capacity. Shown in Figure 33 is an excerpt from the nozzle capacity table published by Sporlan Valve Company. Below 50%, the nozzle does not add enough turbulence to the refrigerant stream to produce a homogenous mixture of gas and liquid on its leaving side. The liquid refrigerant tends to settle out and enter the bottom feeder tubes and circuits while the upper tubes get only gas. This results in inefficient evaporation, incorrect superheat sensing by the TXV feeler bulb and possible liquid refrigerant flood-back to the compressor. Operation below 50% of design capacity should therefore be avoided. Nozzles may be easily changed during installation. There are a number of nozzles which fit a given distributor body. Each nozzle contains both a letter and number code. The letter code refers to the outside diameter of the nozzle and is determined by the inlet connection size of the distributor. The number code on the nozzle refers to the orifice size and is determined by the operating capacity of the system.

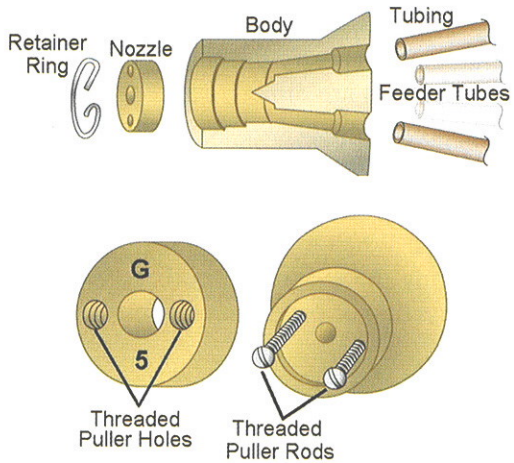


Figure 32

Distributor and Nozzle

- Nozzle creates pressure drop to provide turbulence and mixing of liquid-vapor mixture
- Acceptable nozzle load range 50 to 200% of nominal

Example:
Nozzle Size 5
- Nominal (optimum) cap = 6.1 tons
- Acceptable range: 3.1 to 12.2 tons

- Check full and minimum load

	R-22 Nozzle Capacity (tons)		
Nozzle Load – Percent of Nominal	50	100	200
Nozzle Pressure Drop (psi)			
Nozzle Orifice Size			
1.5	0.9	1.8	3.6
2	1.2	2.4	4.8
25	14.8	29.6	59.2
30	17.1	34.2	68.4

Source: Sporlan Valve Co.

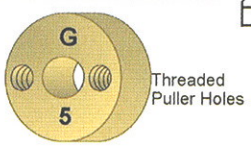


Figure 33

Distributor Nozzle Load Limit

Evaporator Coil Circuit

Oil has an affinity for refrigerant and oil and refrigerant mix in any proportion, so oil continually escapes from an operating compressor and is pumped out into the system. This oil flow is normal and acceptable if it returns to the compressor crankcase at roughly the same rate at which it leaves. The system, including refrigerant piping and coils, must be properly designed to ensure that the oil will return to the compressor.

Although the liquid refrigerant evaporates in the evaporator coil, the oil remains and clings to the evaporator tube walls because oil mixes well with liquid refrigerant and poorly with refrigerant vapor. Therefore, the velocity of the refrigerant flowing within the coil tubes must be maintained above a minimum level to keep the oil entrained (the oil is carried along with the refrigerant). The proper coil circuiting must be selected to ensure adequate design velocity. Manufacturers will specify the design velocity range for their coils. Since velocity and refrigerant flow (and capacity) are directly related, some manufacturers express velocity in terms of tons of cooling capacity per coil circuit, or simply "tons per circuit." This expression makes it easy to select and evaluate full and part-load performance.

With adequate design velocity at full design load, low gas velocity in the evaporator can occur at part load. When the load on the system drops, the compressor capacity must be reduced to prevent freezing the evaporator coil. Compressor capacity control is generally achieved through compressor cycling or compressor displacement reduction (cylinder unloading).

Carrier recommends an optimum design range of 0.8 to 2.0 tons per circuit for its ½-inch tube coils, with a minimum flow rate of 0.6 tons per circuit. For 5/8-inch tube DX coils, 0.9 tons per circuit is the recommended minimum. For 3/8-inch tube coils, 0.4 tons per circuit is the recommended minimum.

Each of the three limiting factors (TXV, distributor nozzle, and evaporator circuit) can become problems where compressor cycling or unloading reduces the flow rate within the system. It is important to select a coil, expansion valve, and nozzle that will satisfy both full and part-load requirements.

If the reduced flow at minimum system load is passed through only part of the coil, controllable and safe system operation can be sustained. Coil splits make partial deactivation of the evaporator possible by maintaining a minimum tons per circuit loading within the active split.

The following example illustrates how coil split deactivation, when coordinated with compressor capacity reduction, can keep the system in a safe, stable operating range.

Split Coil Control Example

A direct expansion coil with split arrangement is used on a job that requires 15 tons of capacity on design day. The direct expansion coil has two liquid and suction connections as shown on the coil in Figure 34.

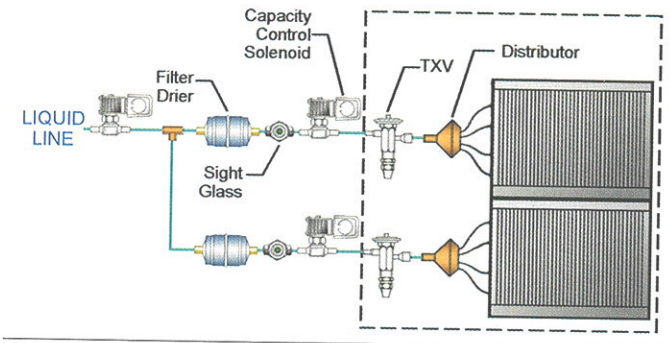


Figure 34

Split Coil Control Example

The compression/condensing equipment is a factory-assembled air-cooled condensing unit. The reciprocating compressor is equipped with cylinder unloaders, which allow it to unload to a minimum of 33% of design refrigerant flow through the system.

Table 4 shows the relationship between compressor unloading at each step of control and its affect on the TXV, nozzle, and coil circuit loading. The center columns represent the loading with the full coil active. As you can see, at 67% compressor capacity, the components are within their acceptable load range with the full coil active. If one split were deactivated at this point, the columns at the right show that the TXV load and coil circuit load would increase above their recommended ranges. Therefore, the full coil should remain active when the compressor is operating at 67% capacity.

Table 4
DX Coil Part Load System Analysis

% Full Load Capacity	Tons	Full Coil Active		½ Coil Active	
		Tons per Coil Circuit	TXV & Nozzle Loading & Design	Tons Per Coil Circuit	TXV & Nozzle Loading Design
100	15.0	1.875	100		
67	10.0	1.25	67	→2.50*	133*
33	5.0	6.25	33*	1.25	67

* Problem area

However, when the compressor unloads to 33% capacity, the coil circuit loading falls to 0.625 tons/circuit, which is near the minimum limit. Also, the TXV and nozzle fall to 33% load, below their minimum acceptable limits. Therefore, one split of the coil should be deactivated when the compressor is operating at 33% capacity. The right hand column shows that this brings the loading back into the acceptable operating range.

DX coil split deactivation, when coordinated with compressor capacity reduction, can keep the system in a safe, stable operating range.

Many direct expansion systems, especially larger systems over 30 to 40 tons, utilize multiple condensing units or "dual circuit" condensing units that have two independent refrigerant systems. Although they require two sets of refrigerant piping, valves, etc., the installed cost is frequently lower, due to the fact that smaller sizes are less expensive and easier to work with. Multiple condensing units generally provide more steps of capacity control, allowing the system to more closely match load changes. One other primary benefit that separate refrigerant systems provide is redundancy. They allow partial system operation in the event of a refrigerant leak or component failure in one of the systems.

Chilled Water Coils

A chilled water coil removes heat from the system through the use of cold water flowing through the coil. When the air passes through the coil, heat is transferred from the warmer indoor air to the cold water.

Shown in Figure 35 is the position of the cooling coil (circled) within a typical air-conditioning system. It also shows the relationship of a chilled water cooling coil to the refrigeration system components. This figure illustrates a four-step heat transfer process required to move heat from indoor air to outdoor air. The first of these steps is an air-to-water heat exchange that occurs as the water in the coil absorbs heat from the air coming back from the conditioned space as well as from the outdoor air used for ventilation. The second step is from water to refrigerant, which occurs in the cooler portion of the central water chiller. Here heat flows from the water coming back from the cooling coil, across the tubes of the cooler into the refrigerant inside the tubes. The third step is a refrigerant-to-water heat transfer as refrigerant from the cooler, after compression, passes its heat through the wall of the tubes in the condenser into the condenser water. Finally, a water-to-air heat transfer occurs as water leaving the condenser rejects its heat to the outdoor air by action of the cooling tower.

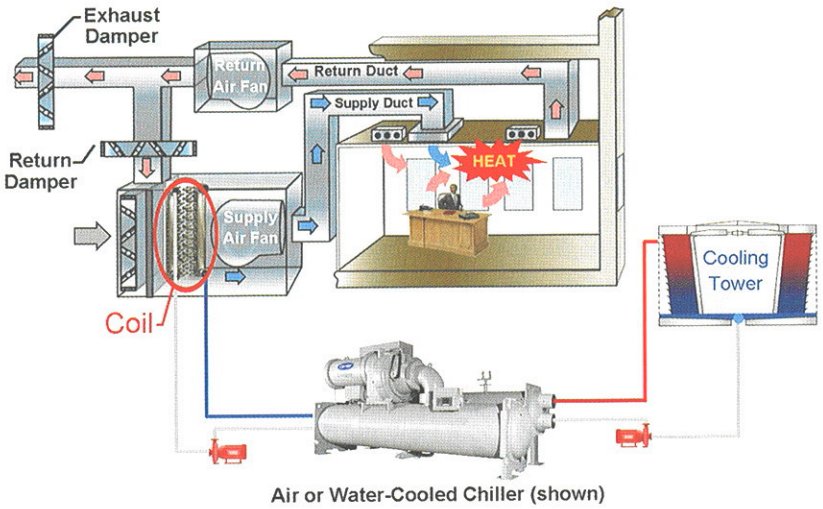


Figure 35

Chilled Water Coil System

Chilled water systems tend to be matched with larger capacity refrigeration machinery than direct expansion systems. Larger capacity central machinery tends to achieve better full load and part load efficiencies than does smaller equipment. This helps to offset the heat transfer disadvantage of chilled water systems as discussed above. In addition, water-cooled condensing systems tend to be used on larger tonnage systems. These, in turn, tend to be primarily chilled water systems. Lower compression ratios that result from water-cooled condensing again tend to enhance chilled water system efficiencies. Finally, the larger capacities delivered by chilled water systems make the use of centrifugal compressors feasible. The centrifugal compressor tends to be more efficient than an equivalent capacity reciprocating compressor, particularly at part load. This tends to facilitate energy efficiency in the chilled water system.

Chilled water coils are made up of a number of heat transfer circuits. These circuits are grouped together to make up the entire coil construction. The existence of splits or subdivisions within a coil offers no operating benefit for chilled water coils. Consequently, chilled water coils are not subdivided into splits. They can, however, be stacked as shown on page 48 of the application section of this TDP.

Shown in Figure 36 is a typical chilled water coil. Chilled water coils normally contain 6 to 8 rows. Chilled water coils often are asked to produce air in the 50 to 55° F range as part of a central system in a large air-handling unit, therefore 6 to 8 rows are usually needed. Other numbers of rows are less common and depend upon the application. Popular fin spacings are 8 or 14 fins per inch.

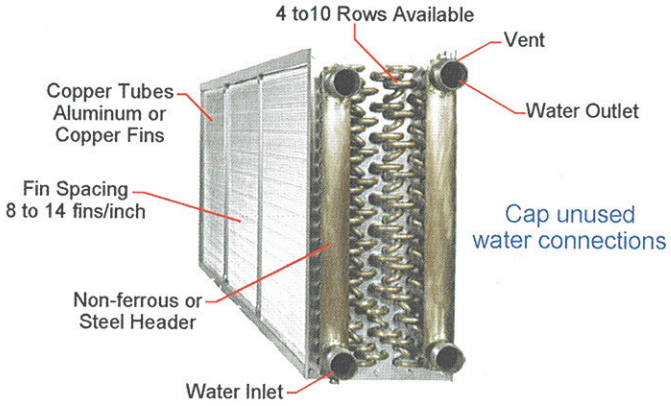


Figure 36

Chilled Water Coil
(Photo courtesy of Heatcraft USA)

Heating Coils

Heating coils are commonly used directly with air-conditioning systems and are designed to heat air under forced convection. Such coils are usually located within the air conditioning apparatus and/or ductwork. The media used in heating coils includes steam, hot water, and electricity. These coils are basically used for preheating, and for tempering or reheating. The size of the coils is determined by the required heating capacity, space, coil face velocity and air friction limitation. The coil air velocity is determined by the air quantity and the coil size. The number of rows and fin spacing is determined by the required temperature rise.

There are preheat and reheat types of coils. A preheat coil tempers the mixture of return and outdoor air in an air-handling unit. A reheat coil supplies added heating capacity during cold weather applications. A preheat coil can also be used to temper or heat the free cooling (economizer) air when the outside temperature is too low.

There are different types of heating media:

- Hot water – water temperature is typically 120 to 200° F.
- High temperature hot water – water temperature is typically above 212° F but still in a liquid state due to the pressure of the system. The maximum temperature is usually 250° F.
- Steam – Steam pressures range from 2 to 250 psig at the coil supply connection, with 5 psig being the most common.
- Electric – typical voltages are 208/230, 460 and 575 V.

Hot Water

Hot water heating coils are similar in construction, size and appearance to chilled water coils other than row depth. Although comfort heating systems seldom require hot water coils with more than two rows, greater depth of surface is available. Fins are usually spaced at either 8 or 14 fins per inch of tubing. See Figure 37.

In order to provide optimum combinations of capacity and water-side pressure drop, various circuiting arrangements are employed. Some manufacturers use turbulators to produce the turbulent flow necessary for efficient heat transfer at the expense of pressure drop.

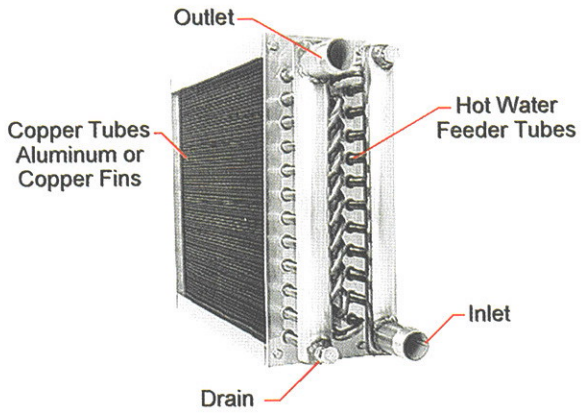


Figure 37

Hot Water Coil
(Photo courtesy of Heatcraft USA)

Hot water heating coils are used on low, medium and high temperature hot water systems. Normally the standard application calls for a hot water temperature of 150 to 200° F. In some larger systems however, particularly those which use a central plant, high temperature hot water may be supplied to the heating coil. Such high temperature hot water usually has a temperature of about 250° F or higher but is still in a liquid state due to the pressurized system in which it is circulated. The purpose of the higher temperature is to reduce the quantity of water required to perform the specified heating function, and thereby reduce the pumping energy. While hot water temperatures in this type of system may reach 300° F or more, the previously mentioned 250° F is used for normal applications. Applications involving temperatures in excess of 300° F are less common.

Selecting of hot water heating coils is based on producing the desired leaving air temperature (capacity) while attempting to maintain the desired Δt in the hot water flow. For instance many systems are based on a 20 to 40° F Δt for the heating circuit. The cooling flow is often based on a 10° F Δt, that is why the system heating gpm is usually less than the cooling gpm.

Steam

Steam heating coils consist of a series of tubes connected to common headers and mounted within a metal casing. To ensure efficient heat transfer, either plate type or spiral type fins are bonded to the tubes mechanically or with solder. Fins are mostly of aluminum with standard spacing of 8 or 14 fins per inch. One-row and two-row coils are available with many selectable tube faces, depending on size and use.

Since the proper performance of steam coils depends on the uniform distribution and condensation of steam in the tube, several methods have been devised to ensure this uniformity. Individual orifices may be built into the supply end of each tube or distributing plates may be installed within the steam header.

Shown in Figure 38 is a "Non-Freeze" type steam-distributing coil that provides uniform steam distribution and leaving air temperature as well as a minimum possibility of freeze-up. This design features a tube within a tube, with the inner tube perforated along its entire length. Steam is supplied to the inner tube and admitted through the orifices to the outer tube where condensation takes place. The condensate is then collected in the return header.

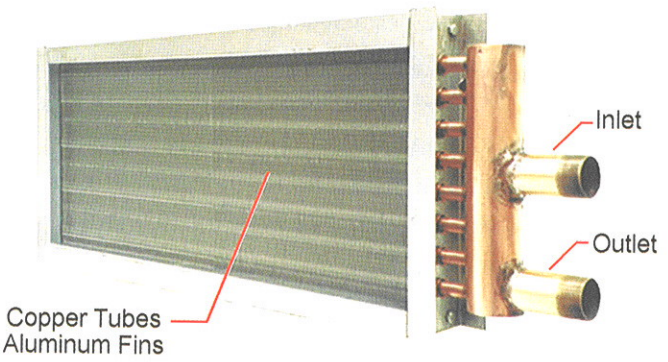


Figure 38

Steam Coil
(Photo courtesy of Heatcraft USA)

Are non-freeze steam coils really non-freeze?

The term "non-freeze" is somewhat misleading and implies that the coil cannot freeze up. This is true as long as the piping and the steam traps are sized and installed to assure rapid and complete condensate removal. It is recommended that full steam pressure be supplied to the coil without throttling when air temperatures entering the coil are below freezing. This will ensure that full design pressure is available to force the condensate out of the coil through the trap. When steam is throttled, it is possible for the pressure in the coil to reduce to a point that will result in condensate hang-up in the coil. In some instances, the pressure may even drop into the vacuum range. At reduced steam flow, the condensate can be cooled so rapidly that coil freeze-up is virtually unavoidable.

Steam coils are also available as a simple U-bend design. This design is not considered non-freeze and depends on complete drainage of the condensate as it uses a single tube as opposed to the tube-within-a-tube design of non-freeze designs.

Electric

Electric heating coils provide heat through the resistance of electricity through the wires. See Figure 39. There is no flow of heating medium as in a hot water or steam coil. Electric heating coils are commonly available in either the finned tubular type or the open type as illustrated. The finned tubular type heater is made of finned steel sheaths containing resistance wire surrounded by refractory material, while the open type consists of a series of electrical resistance coils framed in a metal casing and exposed directly to the airstream.

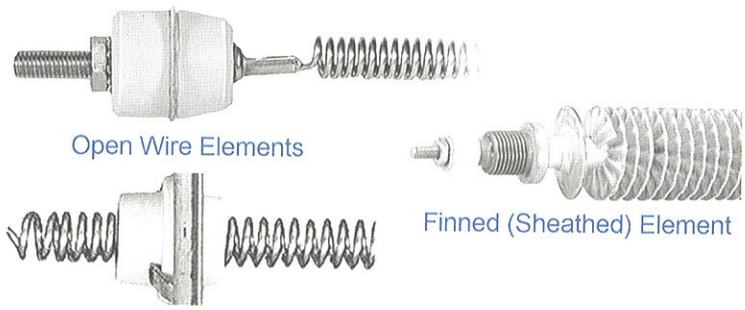


Figure 39

Electric Coil Elements
(Photo courtesy of Brasch Manufacturing Company, Inc.)

An important thing to remember when selecting and specifying an electric heater is that NEC limits the amp draw per stage to 48 amps. Based on the voltage of the heater, this defines the maximum wattage output per stage.

Example: 50 kW heater at 460 volts must be at least 3 stages.

Watts = VA (watts = voltage * amps)

Watts = 460 (48)

22,080 is the maximum number of watts per stage allowed, so this must be a 3-stage heater.

Electric Heaters

With electric heaters, all of the electrical engery used is converted to heat. Thus, heat capacities in Btuh are determined by multiplying the kW rating of the heater by 3,413 Btuh/kW.

Standard voltages include 208 and 230 volts in single or three phase but heaters are also available for operation on 460 and 575-volt service.

In addition to size and capacity, an electric heating coil selection should specify these electrical characteristics and the number of circuits required.

Electric heating coils are usually chosen to fit a branch duct of given dimensions without requiring entering and leaving duct transformations. Therefore, face velocity is not the usual determinant of coil size. However, for Underwriters' Laboratories' approval, a minimum face velocity must be maintained and uniform airflow provided. This minimum velocity is a function of entering air temperature and the total watts per square foot of duct area. Airside pressure drops are usually quite small, compared to steam and water coil pressure drops, seldom exceeding 0.10 in. wg for an open-type coil.

Each electric heater must have a means of disconnect (contactor), a primary and a secondary limit switch for protection, and an air flow proving device to shut down the heater on a loss of airflow.

Electric Duct Heaters

Electric duct heaters can be slip-in or flanged. A slip-in heater is placed into the duct through a hole that is cut in the ductwork. A flanged heater is supported by flanged sections of the duct that are attached to both sides of the heater.

Electric heaters are often installed in ductwork, but may also be installed in the air conditioner or air-handling unit. When the heaters are installed in the air conditioners, the combination that results must be tested by Underwriters' Laboratories (UL) to pass certain requirements. When heaters are provided separately, they must be installed at least 4 feet from the HVAC equipment.

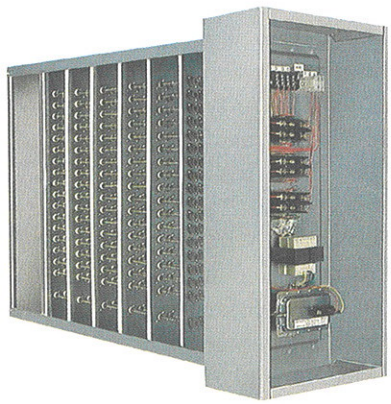


Figure 40

Electric Heating Coil
(Photo courtesy of Brasch Manufacturing Company, Inc.)

Electric Heat Components

An automatic reset thermal cutout is a thermally operated safety device that is required to deenergize the entire heater to prevent overheating.

Heat limiters or replaceable thermal cutoffs are secondary thermally operated safety devices used to protect the system against overheating in the event of failure of the primary safety device or the automatic reset thermal cutout and its circuit. Heat limiters are set to operate at higher temperatures than the automatic reset thermal cutout.

A manual reset thermal cutout is an alternate, secondary thermally operated safety device. It is set to operate at a higher temperature than the automatic reset thermal cutout. If any of the manual resets are tripped, then it is necessary to correct the unsafe condition and reenergize the heater by pressing the reset button.

A linear thermal cutout is a safety device that extends across the entire width of the heater and is used to provide additional protection for long heaters. The linear thermal cutout may be either automatic or manual reset. The safety device will open if the temperature exceeds the setting of the linear thermal cutout.

A contactor, also referred to as a relay, is an electrical device that magnetically pulls in to close an electric power circuit when the holding coil in the contactor is energized. Contactors are used when either the control thermostat or the safety cutouts or an airflow switch do not have sufficient electrical rating to carry the resistive load. There are operating contactors and safety contactors. Operating contactors are required to switch the electric load of each heater step and are operated by the control device, the automatic reset thermal cutout, or the airflow switch. Safety contactors are required with silicon control rectifier (SCR) control, pneumatic-electric (PE) switches, or for step controllers. When operating contactors are not required for each step and the total heater electrical load exceeds the resistive rating of the automatic reset thermal output and/or airflow switch, a safety contactor is required.

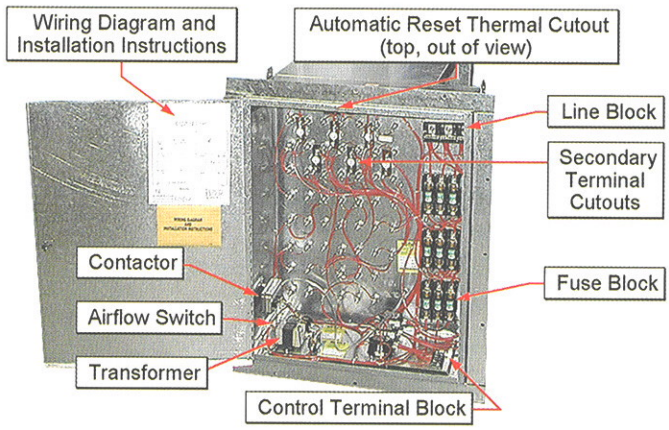


Figure 41

Electric Heat Coil Control Box
(Photo courtesy of Brasch Manufacturing Company, Inc.)

The room thermostat is a temperature control device that is mounted in the area it serves. Thermostats are available in either one step, two steps, three steps, or modulating type, and are also classified as line voltage (to 277 v) or low voltage (24 v). The voltage ratings of the thermostats must conform to the control voltage of the heater.

The duct thermostat is a control device with a remote bulb mounted in the duct or plenum of an air-handling unit to measure air temperature. The bulb should be mounted in a location that does not contact radiant heat directly from the heater. The duct thermostat is available in single, two-step, three-step, or modulating type for line or low voltage.

The transformer is a device that provides control voltage from the line voltage when two voltages differ. Transformers may be built into the terminal box of the heater or in a separately wired remote control panel.

An airflow switch is designed to prevent the heater from operating when there is no airflow in the duct. The most commonly recommended type is a pressure differential airflow switch. The airflow switch is connected in the control circuit in series with the control thermostat and automatic reset thermostat.

The fan interlock relay closes the control circuit to the heater when energized by the fan supply voltage. If it is impractical to interlock the fan and heater electrically by using the fan interlock relay, then an airflow switch is recommended.

The National Electrical Code requires overcurrent protective devices for any circuit which is over 48 amps. This protection is normally in the form of supplementary one-time fuses, but may also be in the form of resettable circuit breakers. The overcurrent protection devices may be built into the terminal box of the heater or in a remote control panel.

The safety disconnect switch may be interlocking or non-interlocking with the control box or panel door.

Heat Transfer and Coil Formulas

Airside Heat Transfer

The heat transfer in comfort air cooling can be determined by the use of formulas for each of the heat transfer steps: airside, coil, and waterside.

Airside heat exchange in a coil can be found with the following three formulas.

Formula 1:

$q_t = 4.5 * cfm * \Delta h$

Where:

q_t = Total heat exchanged as either capacity from an air cooling coil or load from a space. This is expressed in Btuh.

4.5 = Air total heat constant. This converts standard air (70° F and sea level) volumetric flow rate (cfm) to mass flow rate (pounds/hour).

cfm = Cubic feet per minute of standard air.

Δh = Air enthalpy difference between air entering and leaving the coil.

Formula 2:

$q_s = 1.10 * cfm * \Delta t$

Where:

q_s = Sensible heat exchanged as either capacity from an air cooling coil or load from a space. This is expressed in Btuh.

1.10 = Air sensible heat constant. This converts standard air volumetric flow rate (cfm) to mass flow rate (pounds per hour) and incorporates the specific heat of moist air per pound per degree F temperature change.

cfm = Cubic feet per minute of standard air.

Δt = Air dry bulb temperature difference.

Formula 3:

$q_l = 0.69 * cfm * \Delta gr$

Where:

q_l = Latent heat exchanged as either capacity from an air cooling and dehumidifying coil or load from a space, process or outdoor air.

0.69 = Air latent heat constant. This converts standard air volumetric flow rate (cfm) to mass flow rate (pounds per hour), converts grains of moisture per pound of dry air to pounds of moisture per pound of dry air and incorporates the latent heat of vaporization of one pound of water.

Δgr = Air specific humidity difference (grains per pound of dry air).

Overall Coil Heat Transfer

Coil heat exchange can be found through the following equation. This is the heat transfer taking place from the air to the coil.

$q_t = U * A * LMTD$

Each component in this formula will now be discussed.

The formula above is somewhat oversimplified because it ignores the fact that part of the coil is wet while the remainder is dry. When water covers the finned tube surface, heat exchange progresses more rapidly than on a dry coil. To accurately reflect the impact of condensate on cooling coil surfaces the wet and dry portions must be rated separately or the overall heat transfer coefficient for the coil (U) must be adjusted to reflect the net result of wet and dry portions combined. For more detail see ARI standard 410. The simplified equation above will suffice for establishing a working understanding of air cooling coils.

q_t = Coil heat transfer capacity in Btuh.

U = Overall conductance factor (also called coefficient of heat transfer) expressed in Btu/hr/ft^2 coil outside surface area per degree Fahrenheit difference. The overall conductance factor is the reciprocal of the sum of all the resistances to heat flow through the coil and surrounding surface films (i.e., $U = 1/R_T$). This total resistance can be thought of as resulting from a series of layers from outside the coil to inside the coil tube as follows.

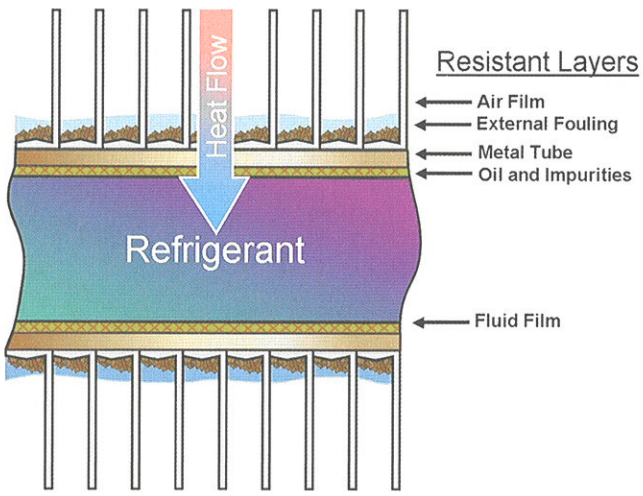


Figure 42

DX Coil Heat Transfer

$$T = R_A + R_D + R_M + R_F + R_{HTF}$$

Where:

R_T = Conductive resistance to all layers combined.

R_A = Resistance of air film adhering to fins and tubes.

R_D = Resistance of dirt on outside of tubes and fins (external fouling).

R_M = Resistance of metal of fins and tubes of coil.

R_F = Resistance of fouling layer inside tubes.

R_{HTF} = Resistance of heat transfer fluid film inside tube adhering to tube wall.

A = Total effective coil surface area. This includes all airside exposure of the finned coil over which the airstream flows expressed in square feet.

LMTD = The logarithmic mean temperature difference (°F) between the air temperature outside the coil and the heat transfer fluid temperature within the coil tubes.

Coil Selection

A design goal in coil selection is to achieve a reasonable match of airside and waterside capacity.

The general format of the coil heat transfer equation follows that of any conductive heat transfer process ($q = U * A * \Delta t$). While heat moves to the coil and away from the coil by means of conductive, convective and radiant modes of heat transfer, the heat moving from the air outside the coil into the media within it does so primarily through conductive heat transfer. For a system, which maintains a stable space condition, the coil absorbs airside load and provides equal airside capacity. Likewise, the refrigeration machinery absorbs waterside load and provides an equal amount of waterside capacity. These segments of the system need to work in harmony. Therefore, when dealing with air handlers that have a selectable coil, a design goal in coil selection is to achieve a reasonable match of airside and waterside capacity. Computer selection software determines the best balance of airside and waterside capacity in making a coil selection.

Factors Affecting Coil Heat Transfer Capacity

There are factors that have implications for coil selection, application and maintenance which will now be discussed.

As mentioned before, the overall conductance factor (U) is the reciprocal of the sum of the resistances to heat flow (R_T) from outside to inside the coil. Anything that effects a resistance component which is part of R_T in one direction effects the U and, therefore, the coil capacity in the opposite direction.

R_A is used to represent resistance to conductive heat transfer caused by the air film clinging to the exterior of the coil tubes and fins. This represents a substantial portion of the total resistance to heat flow through the coil. In fact, the U value of the coil is determined primarily by the resistances to heat flow of the fluid surface films inside and outside the coil. Factors which reduce the thickness of the outside film of air reduce its R and increase U, thereby increasing capacity. Increases in both air velocity and turbulence enhance the rate of coil heat transfer by reducing this film. For a given cfm of air, coil face area reductions increase coil face velocity and velocity over the coil fins and tubes. Factors which increase air turbulence over the coil fins and tubes are air velocity over the coil tubes, surface roughness of tubes and fins (an increase in roughness initially increases turbulence), tube spacing (the closer, the more turbulent) and fin shape. As air velocity and turbulence over the coil surface increases, the tendency for condensate to be carried off the coil surface into the airstream also increases.

R_D is used to represent the resistance to conductive heat flow caused by the dirt or external fouling on the coil. Any build-up of foreign matter on the coil surface detracts from heat transfer efficiency. Factors which increase the external fouling layer build-up over a fixed time period are: reduced air velocity, increased particle content in the airstream, wetting of the external coil surface, and alternating wetting and drying of the coil surface. During the design of the system, proper coil face area selection will ensure that air velocities over the coil do not drop below minimum values, which helps to prevent airside fouling. Proper selection of air filtration devices can also helps to avoid airside fouling in addition to improving space air quality. Coil surface wetness is a function of dehumidification capacity (and load) which the coil encounters. This is not a controllable variable for the designer if space air quality control is a top priority. Periodic cooling coil cleaning is a service procedure that may be required to restore a coil to its original heat exchange capacity when airside fouling becomes severe. Coils do not achieve full capacity at start-up because of the oils present on the coil from construction. In a period of time, the oils will be removed from operation and the coil will achieve full capacity.

R_M represents the resistance to heat flow caused by the metal of which the coil tubes and fins are constructed. Metals inherently possess a low resistance to conductive heat flow (R). Metal provides the lowest resistance to heat flow of any of the layers listed in the coil heat transfer equation. The metals used in tube and fin areas of the coil are selected based on a compromise between heat transfer efficiency (Low R), external and internal corrosion resistance, structural strength, compatibility to manufacturing techniques and cost. The system designer for packaged air handlers rarely has a selection of coil materials. Even for air handlers where the coil is selectable, the material selection for coil tubes and fins is quite limited. Coils sold separately offer more material flexibility.

R_F is the fouling created by impurities that build up on the inside of the coil tubes. Like airside fouling it detracts from coil efficiency. Factors affecting internal fouling on a DX coil are the amount of oil in the evaporator and refrigerant velocity through the coil tubes. Excessive oil in the evaporator tends to cling to the wall of the tube and create a fouling effect. Low tube velocity also tends to allow oil to build up on the tube wall as well as particles of impurity, which circulate with the refrigerant. Additionally, refrigerant gas bubbles, which are formed when the refrigerant boils within the coil tubes, tend to stick to the tube wall at low velocities. Since conductive heat flow is greater through a liquid than a gas, a coil tube with gas coating the inside of the tube performs poorly compared to one with liquid coating the inside of the tube. The gas bubbles clinging to the inside tube wall at low refrigerant velocity act as a fouling factor. Increased tube velocity tends to create a scrubbing action and moves the gas bubbles along with the fluid stream. This also reduces the thickness of the oil layer and releases the particles of impurity from the tube wall. Proper coil circuit selection and coil control at partial capacity ensures adequate tube velocities to keep the waterside fouling factors to a minimum.

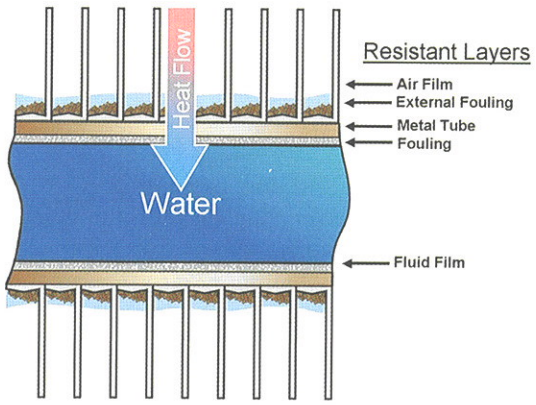


Figure 43

Chilled Water Coil Heat Transfer

R_{HTF} is the resistance to conductive heat transfer caused by the film of heat transfer fluid adhering to the inside of the coil tube. This waterside film resistance, like the airside film resistance, represents a significant portion of the total resistance to heat flow into the coil.

As with airside film resistance, increases in fluid velocity and turbulence within the tube tend to reduce the film thickness, thereby reducing its resistance to heat flow.

The next component in the coil heat transfer formula ($q_t = U * A * LMTD$) is coil surface area (ft^2), A. Anything that increases the total coil tube and finned heat exchange area increases its heat transfer capability. Things which accomplish this increase are increased face area, increased tube rows, addition of finning, closer fin spacing and closer tube spacing. Of these variables the ones which are most frequently controllable by the system designer are face area, coil rows and fins per inch. The equipment style and the manufacturer's versatility in product offering determine the selectability of these items.

Log Mean Temperature Difference and Counterflow

The final component in the coil heat exchange formula is the logarithmic mean temperature difference, LMTD between the air outside the coil and the heat transfer fluid within the coil tubes. A mean temperature difference is required because both air temperature and coil heat transfer fluid temperature are changing as they flow through the coil. This means the temperature difference at any point within the coil is different from that at another point.

Shown in Table 5 is a typical chart illustrating the air temperature changes as they progress through a chilled water coil. The entering air row of the coil absorbs the greatest amount of heat. Each additional row absorbs less than the one immediately upstream. The temperature change of both the water and air that is associated with each row of the coil can readily be seen. The airside figures summarize as shown in Table 5.

Table 5
Air Δt per Row

Row	Air Δt	% Total
1	9.0	41
2	6.0	27
3	4.3	20
4	2.7	12
TOTAL	22.0	100

Since the heat absorbed from the air enters the water within the coil, the waterside (water) load associated with each row will match the airside figures.

Log mean temperature difference is enhanced in chilled water coils by arranging the air and water for counterflow through the coil. This was the case for the water coil illustrated. Figure 44 shows a chilled water coil circuited for counterflow and parallel flow. While less efficient, the parallel flow arrangement, when used on chilled water coils, still provides a substantial percent of possible capacity.

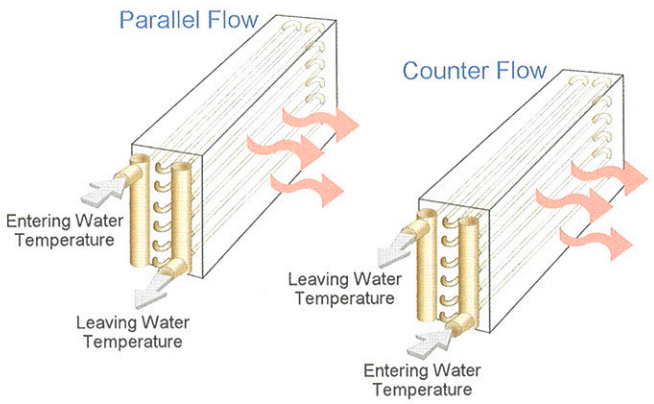


Figure 44

Parallel and Counter Flow

Direct expansion coils achieve optimum heat exchange efficiency (maximum LMTD) when refrigerant is piped for flow parallel to the airstream. This occurs when the refrigerant is fed into the entering air row of coil tubes. Most of the evaporator's capacity comes from the conversion of liquid refrigerant to vapor within the coil tubes (a latent heat absorption process for the refrigerant). The temperature at which this boiling process takes place (saturation temperature) is pressure dependent.

Since refrigerant flow through each coil circuit involves pressure drop, the saturation temperature drops within a coil tube the farther the refrigerant progresses in each circuit. This pressure and temperature drop helps to maintain a high temperature difference between air and the heat transfer fluid. The greater is the circuit waterside pressure drop, the greater will be this decrease in saturation temperature, and the better the heat transfer efficiency will appear for the parallel flow arrangement. Beyond a practical upper limit, however, extra pressure drop will detract from compressor and system capacity more rapidly than capacity will be added to the evaporator. Proper circuiting selection, when offered as a selectable product feature, will maintain coil refrigerant pressure drop within reasonable limits.

Heat removal capacity provided by a direct expansion coil results primarily from liquid refrigerant boiling within the coil tubes. A sensible heat addition to the refrigerant takes place in most evaporators as well. Once boiled into a saturated vapor, additional (sensible) heat is added to the refrigerant near the end of its journey through the refrigerant circuit. Superheat is planned into the coil's performance as a protective measure for all compressors. The TXV control device maintains it at a reasonable level.

Parallel flow of refrigerant and air through the coil optimizes the latent heat exchange process involved in boiling the refrigerant within the DX coil tubes. Unfortunately, the sensible heat exchange process involved in superheating the refrigerant vapor is inefficient when arranged in this manner. One way of resolving this problem is to feed the second row of tubes with refrigerant, continue to the leaving air row and then return to the entering air row to achieve the desired superheat. Where coils are row split this arrangement is more difficult to execute. Superheat quantity and quality suffer badly on the leaving air split of a conventional row split coil.

Some DX coil designs pipe refrigerant so that it is in a counterflow configuration to the airflow. While this is not optimal for heat transfer efficiency, it has advantages in simplicity of coil piping, quality of superheat and adaptability to a variety of coil splits. Where coil circuiting is a selectable parameter, selecting circuiting which gives low design coil pressure loss can minimize the efficiency loss of this type design.

The arrangement of flow of the heat transfer fluid within the coil relative to airflow through the coil is important. This impacts the log mean temperature difference in the coil heat exchange formula. Other factors influencing the LMTD are the general temperature levels of air and heat transfer fluid entering the cooling coil. Higher air entering and lower water or refrigerant entering temperatures increase log mean temperature difference, thereby increasing coil capacity. On the other hand, any drop in chilled water temperature or refrigerant temperature has a capacity reducing effect on the water chiller or compression equipment, respectively. These opposing capacity effects must be balanced by arriving at an operating point that gives optimal system performance. Most engineers accept 42 to 44° F entering water temperature to a chilled water coil and about 40 to 45° F saturation temperature leaving a DX cooling coil as design targets which represent a reasonable compromise between evaporator and system capacity, efficiency, and cost.

Waterside Heat Transfer

Waterside (or sometimes called tube-side) heat transfer, like airside heat transfer, is equal to the coil heat transfer. It can be quantified by the appropriate mass flow heat transfer formula for the fluid gaining heat within the coil tubes. For example, heat absorption by the chilled water within a chilled water coil at comfort air conditioning levels can be quantified:

$$q = 500 * gpm * RISE$$

Where:

- q = Total heat gain to the water within the coil (Btuh)
- 500 = A constant which converts volumetric water flow rate (gpm) to mass flow rate (pounds per hour)
- 500† = 60 min/hr * 8.33 lb/gal.
- gpm = Volumetric water flow rate through coil (gallons per minute)
- RISE = Water temperature increase from the time the water enters the coil until it leaves (F)

† Specific heat of the fluid is not shown in the equation but is essential in any mass flow heat exchange calculation. For water, specific heat is 1 Btu/lb °F.

An example using the waterside heat transfer equation for a chilled water coil follows:

Airside and Waterside Balance

The airside heat transfer and the waterside heat transfer of a coil should balance.

We can set the airside total heat equation equal to the waterside total heat equation and within reasonable tolerances we should get the same total heat transfer. Let's use a cooling coil as an example.

Airside:

cfm: 4,000

Enthaply (h) difference entering to leaving air: 7.0 Btu/lb

Waterside:

gpm: 18

Rise: 14° F

Airside heat transfer	=	waterside heat transfer
4.5 * cfm * Δh	=	500 * gpm * RISE
4.5 * 4,000 * 7	=	500 * 18 * 14
126,000 Btuh	=	126,000 Btuh

Application Topics

Chilled Water Coils for Heating Service

When hot water is used as the heating medium, the approach of using an existing chilled water cooling coil for heating has the advantage of reducing first cost. However, when using a coil in this way, the resulting heating capacity will greatly exceed the job requirements. If the capacity of the cooling coil is controlled by the throttling of chilled water, the control valve will be substantially oversized for the heating application. Because of this oversizing, problems can result in trying to maintain even leaving air temperatures and conditions in a space. Under these circumstances, it is preferable not to throttle the heating water but rather control the room temperature by other means such as face and bypass control or water temperature reset with changes in outdoor temperature. Because of freezing problems, this application normally should only be used where the mixed air temperatures entering the coil are always above 35° F. In locations where freezing conditions occur and this heating method is used, some necessary precautions must be taken to protect the coil from freezing.

Electric Heater Application Information

Each duct heater must be provided with an approved integral, automatic-reset temperature-limiting control or controllers to deenergize the circuit or circuits.

Resistance-type heating elements in electric space heating equipment must be protected (not greater than 60 amps). Equipment rated more than 4 amps and using resistance-type elements must have the heating elements subdivided, and each subdivided load should not exceed 48 amps).

Provide uniform and adequate airflow over the face of the heater in accordance with the manufacturer's instructions.

Heat pumps and air conditioners having duct heaters closer than 4 feet to the heat pump or air conditioner must have both the duct heater and heat pump or air conditioner approved for that type of installation and must be marked on the unit.

Ensure that the fan circuit is energized when any heater circuit is energized.

There must be a disconnect within sight of the heater for the heater, motor controller(s), and supplementary overcurrent protection device(s) of all fixed electric space heating equipment.

A return elbow or grille must be placed under any heater to prevent the heater or parts from falling into the conditioned space.

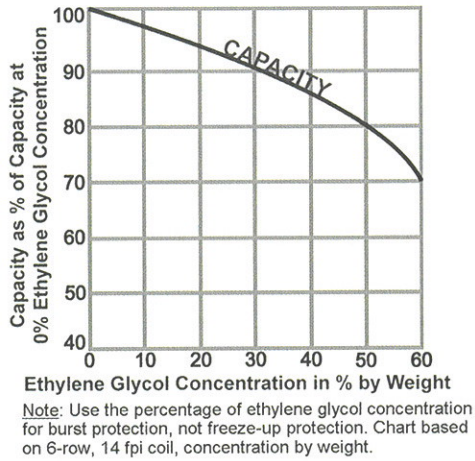
Antifreeze Effects

Antifreeze solutions, such as ethylene glycol and propylene glycol are commonly used. While they provide freeze protection, they have the following adverse impacts on the system:

- reduce coil heat transfer capacity
- increase coil pressure drop which increases water pumping energy
- reduce chiller capacity, resulting in higher equipment first cost

Generally, the use of antifreezes cause higher flow rates and much lower fluid Δt in the hydronic coils as compared to a fresh water selection. Shown in Figure 45 are effects of antifreeze solutions on a cooling coil.

In addition to the performance penalties, ethylene glycol's toxicity also raises environmental and safety concerns related to handling, exposure, system leaks, etc. These issues should be evaluated when choosing antifreeze. Propylene glycol fluids are recommended for use where incidental contact with potable water is possible, or where use of a propylene glycol-based fluid is required by state or local regulations.



Note: Use the percentage of ethylene glycol concentration for burst protection, not freeze-up protection. Chart based on 6-row, 14 fpi coil, concentration by weight.

Figure 45

Antifreeze Effects on Cooling Coil

Coil Corrosion Protection

Corrosion protection, while typically applicable to the packaged unit condenser coil, applies to the evaporator coil also. Applications such as paper mills, photo labs, beauty salons, or other facilities that have airborne contaminants that are recirculated to the evaporator coil require special evaporator coil treatment. On coastal applications, because outdoor air is brought in and mixed with the return air, the evaporator coil should have the same treatment as the outdoor coil. See Figure 46.

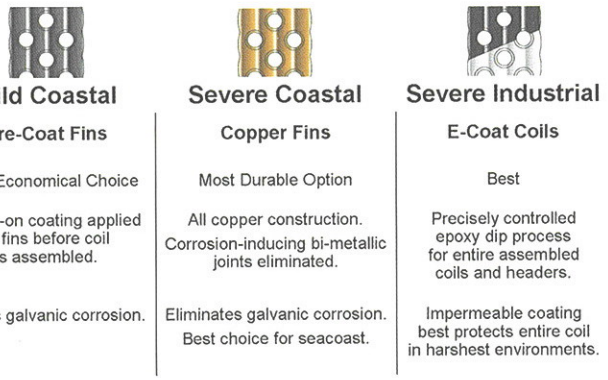


Figure 46

Corrosion Resistant Coil Options

Standard Coil Construction

The standard coil construction for packaged units is copper tubes with aluminum fins. This generally provides the highest performance for non-corrosive environments (e.g., non-polluted environments). Standard coil construction meets the requirements for the majority of applications and locations.

When dissimilar metals used in coils (such as the copper and aluminum) are mechanically connected in the presence of an electrolyte, a reaction occurs. This reaction is known as galvanic corrosion. There must be a bi-metallic couple (bond or contact) between two dissimilar metals in

the presence of an electrolyte solution. Galvanic corrosion will not occur if those ingredients (bi-metallic couple, two dissimilar metals, and an electrolyte solution) are not present. An electrolyte in the presence of the copper-tube and aluminum-fin bond is sufficient to initiate a corrosion reaction.

Electrolytes are electrically conductive solutions. Common electrolytes include sources of chloride contaminants such as seawater, road salts, pool cleaners, and household cleaning agents. These electrolytes are typically sodium or calcium chloride compounds. Other electrolyte sources include sulfur and nitrogen compounds generated by combustion of coal and fuel oils. Since it is common to experience salt-water contamination many miles from the coast, protection from ocean-borne electrolytes in inland areas may be necessary.

Elimination of the bi-metallic couple can eliminate galvanic corrosion. This can be accomplished with an all-copper coil or through isolation of the two metals with a protective coating. Three methods are commonly available to achieve coil protection.

Pre-Coated Aluminum-Fin Coils

Pre-coated aluminum-fin coils have a durable epoxy coating factory-applied to the fin. This option offers protection in mildly corrosive coastal environments, but is not recommended in severe industrial or severe coastal environments. Aluminum fin stock is coated with a baked-on epoxy coating prior to the fin stamping process. This process is known as "pre-coating." The dissimilar metals of the coil are insulated from one another by a thin layer of inert epoxy pre-coating material. As a result, the electrical connection between the copper and aluminum is broken, thus preventing galvanic action.

Copper-Fin Coils

Copper-fin coils eliminate the bi-metallic bond found on standard coil construction. A copper fin is mechanically bonded to the standard copper tube. All-copper tube sheets are also provided to enhance the natural resistance of all copper construction. A protective Mylar strip installed between the coil assembly and sheet metal coil support pan further protects the coil from galvanic corrosion. Durability in a coastal unpolluted marine environment can be substantially improved over the standard or pre-coated coil construction, since the bi-metallic construction is not present.

Coastal Environments

Copper-fin coils provide increased corrosion resistance in coastal environments where pollution sources are not present.

Copper is generally resistant to unpolluted coastal environments, since a natural protective film is formed to coat the copper surfaces. Furthermore, a mono-metal bond exists between the tube and the fin. Uncoated copper coils are not suitable for polluted coastal applications or industrial applications, since some pollutants attack copper.

Electro-Coated Coils

Electro-coated (E-coat) coils provide superior protection against many corrosive atmospheres with the exception of formic acid and nitric acid environments. Electro-coated coils have a durable and flexible epoxy coating uniformly applied over all coil surfaces after the coil is fabricated. A consistent coating is achieved through a precisely controlled electro-coating process that bonds a thin impermeable epoxy coating on the specially prepared coil surfaces. This can be applied to aluminum-fin coils or copper-fin coils. See Figure 47.

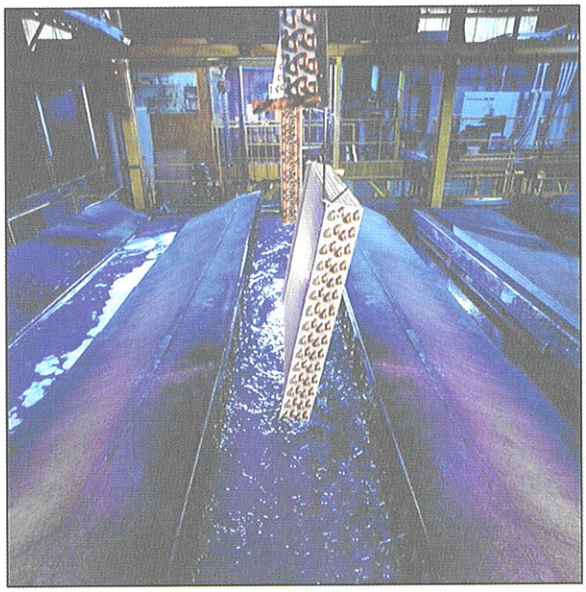


Figure 47

Electro-Coating Process

An electro-coating system applies a DC charge to the coil immersed in a bath of oppositely charged epoxy molecules. The molecules are drawn to the metal, forming an even, continuous film over the entire surface. An oven bake cures the coating uniformly to ensure consistent adhesion on all coil surfaces. Finally, a UV protective topcoat is applied to shield the finish from ultraviolet degradation.

Electro-coating is superior to conventional phenolic coatings, which are applied manually by dipping and baking. Electro-coating is a more durable, evenly coated, non-brittle, non-flaking coil protection product than phenolic coatings.

Coil Maintenance and IAQ

Coils that are kept clean both internally and externally can deliver maximum heat transfer efficiency. In addition, clean coils ensure the best possible indoor air quality. The building airflow passes constantly over the coils so coil maintenance is important to maintaining good overall IAQ.

Internal

Generally coils in closed pressurized chilled water and hot water systems stay clean by maintaining the chemical balance of the system. The potential for biological growth and corrosion is minimized. If the fluid in circulation is an antifreeze mixture, the fluid should be analyzed periodically to confirm the concentration percentage has been maintained and the corrosion inhibitor is still working. See Figure 48.

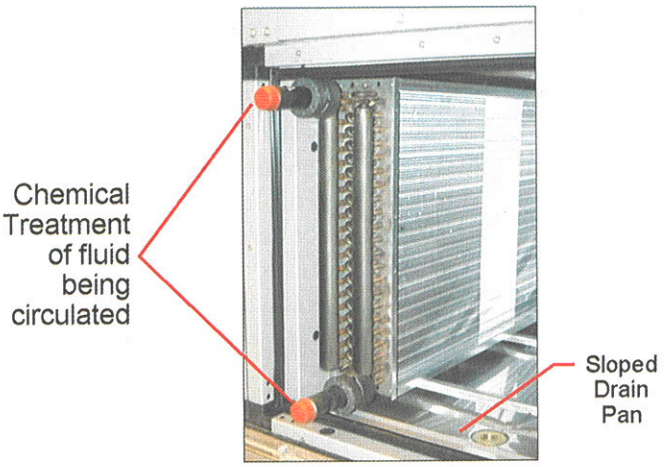


Figure 48

Coil Maintenance

The waterside fouling for chilled water coils is caused by corrosion, particle deposit and air bubbles, which cling to the tube wall. Corrosion can be controlled by proper chemical treatment of the water circulated within the chilled water loop. Since most chilled water systems used for comfort applications are not open to the atmosphere (i.e., closed loop systems), initial treatment of the water at the time of system filling is adequate. Open systems, on the other hand, require periodic treatment of the water. Chemicals are usually added which effect acidity/alkalinity and corrosion. In addition, antifreeze chemicals are added where the coil and/or piping will be exposed to freezing conditions. For a detailed discussion on water treatment, see TDP-641, Condensers and Cooling Towers.

For DX coils, the moisture content of the refrigerant should be checked and the condition of the compressor oil analyzed on a regular basis. Oil can break down if the compressor malfunctions. The acids can harm copper tubing.

External

To keep coils and drain pans clean, they can be washed with low pressure water and a coil cleaner or mild detergent if required. Care must be taken not to damage the fins on coils with too high a water force. In certain applications, like restaurants, where dirt and grease accumulation may be heavy, removal of the coil for cleaning its exterior surfaces may be necessary. Also, condensate drain lines must be kept open and flushed with water as required.

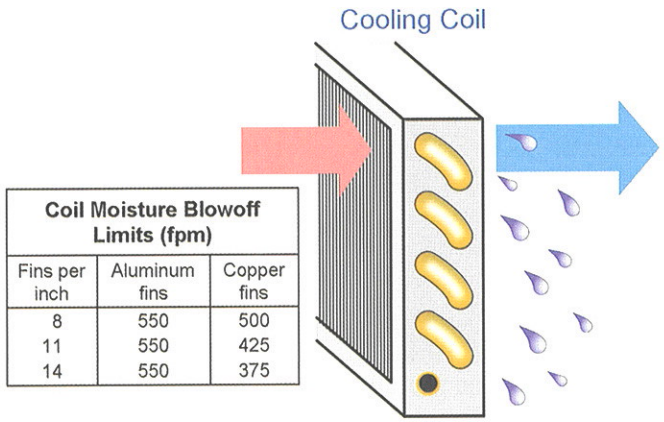
Providing proper filtration upstream of the coils is the single most important task that affects external coil maintenance and building IAQ.

Moisture Carryover

Cooling coils remove moisture by condensing out water from the airstream. This condensed water runs down the coil face, leaving water on the surface of the coil and falls into the drain pan. The design of the coil itself with respect to fin spacing, fin design, fin material, tube spacing, coil height, coil cleanliness, and moisture level of the entering air conditions, determines the maximum face velocity after which carryover (blow off) will occur. These may vary slightly from manufacturer to manufacturer.

Moisture carryover from cooling coils refers to the entrainment into the airstream of this water as a result of too high a coil face velocity. Carryover is undesirable because the water will enter areas of the air handler where it can cause damage or leak into the building. The introduction of moisture (condensate) back into the airstream can also lead to loss of relative humidity control. See Figure 49.

If the coil fins are not clean, the water may carryover even though the face velocity is within the maximum stated by the manufacturer. This can result from oils deposited on the coil fins during manufacturing or during operation on the jobsite. Coil cleaners are available to remove the film.



Coil Moisture Blowoff Limits (fpm)		
Fins per inch	Aluminum fins	Copper fins
8	550	500
11	550	425
14	550	375

Figure 49

Moisture Carryover

Carryover is not detrimental as long as it is caught in the coil drain pan. If it is not preventable, an eliminator section can be mounted downstream. Eliminator sections catch entrained water. However, this is not usually necessary because conventional means of preventing carryover like properly sized drainpans and adhering to maximum coil face velocities works best.

Velocity increase also brings with it increased airflow resistance which the fan must offset with increased horsepower. These negative byproducts must be balanced against heat transfer efficiency in arriving at a reasonable coil face velocity and fin/tube design.

Drain Pans and Condensate Trapping

Cooling coil sections must always contain a drain pan to collect the condensate water extracted from the air passing over the coil. ASHRAE Standard 62 requires a drain pan that will not allow standing water. To meet this requirement, drain pans will generally be sloped to a recessed bottom drain outlet. Drain pans will generally be constructed of galvanized or stainless steel or fire-resisant UV-rated plastic, and when part a of new air-handling unit design, may be coated with antimicrobial material to inhibit the growth of mold and bacteria.

Drain pans must be insulated to prevent the condensation of moisture on the outside of the unit casing. The insulation within the drain pan should be closed-cell foam and water resistant. Fiberglass is not acceptable for this purpose as it will absorb water, lose its insulating properties, and provide a source for mold and bacterial growth.

Condensate drain outlets must be properly trapped to isolate the air-handling system from the building drain system. Without traps on draw-thru units, air may be drawn into the air handler, introducing potentially objectionable smells and gases into the building. It can also impede water flow into the drain and cause water to backup into the drain pan. On blow-thru units, conditioned air can be lost, reducing the efficiency of the system.

Condensate Drains

Local codes and regulations must be checked for proper condensate piping practice regarding connection to open drains or sewers.

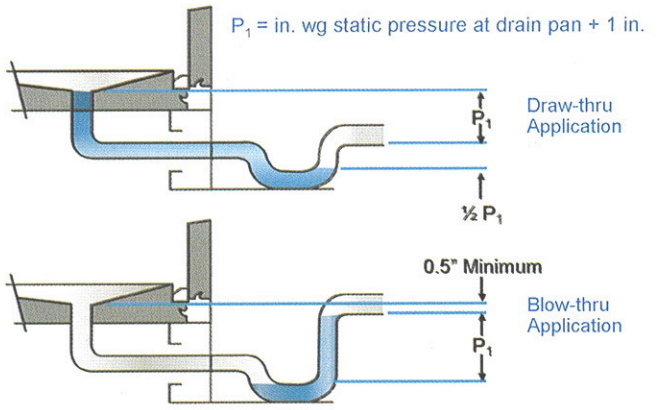


Figure 50

Condensate Trap Construction

The trap depth is dependent on static pressure, either positive or negative, at the drain location. When calculating trap depth on draw-thru or blow-thru applications, remember that it is not the total static pressure, but the upstream or downstream static resistance that should be used. For instance, when calculating the trap depth for a cooling coil condensate pan on the draw-thru side, trap against the coil pressure drop in that coil section and any other pressure drops upstream of it. See Figure 50.

For an example of a calculation for trap depth see TDP-611, Central Station Air-Handling Units.

For all units, provide condensate freeze protection as required. On units with internal spring isolators, be sure the unit is mounted to allow sufficient clearance for the required drain trap depth.

Coil Frosting

Coil frosting is the formation of frost or ice on the tubes and fins as a result of a coil surface temperature lower than 32° F. Condensed moisture can re-freeze on the fins and tubes resulting in partial blockage of airflow.

Frosting is most likely to occur if the saturated suction temperature of a DX coil has become too low. Improper fan operation, extremely dirty filters, or some other increase in system resistance may lead to an airflow reduction that can cause DX coil frosting.

Heat pump units use a defrost cycle to remove frost and ice from the coil.

Heat Pump Coils

Heat pump systems employ special indoor and outdoor coils that are designed to function as either an evaporator or condenser. Typically, the coils used are larger than a comparably sized cooling-only unit. In addition, the metering devices are different in order to accomplish both heating and cooling. When a heat pump unit is in cooling, it functions in the same manner as a cooling-only unit; the outdoor coil is the condenser and the indoor coil is the evaporator. However, when the unit is in heating, a 4-way valve is used to reverse the cycle, the outdoor coil is now the evaporator and the indoor coil is the condenser. In this way, heat is removed from the outdoor air and transferred to the indoor air. See Figure 51.

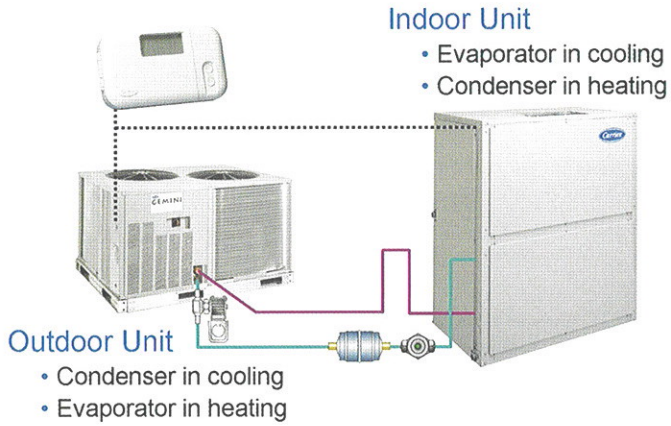


Figure 51

Heat Pump Coils

Heat pump system components are designed and tested as matched pairs and must only be applied according to the manufacturer's recommendations.

Coil Energy Recovery Loop

The coils used in a runaround loop are usually standard water coils. The water coils normally have a minimum of 4 rows up to 8 rows deep. Often the coil selected will be a 6 or 8 row coil to maximize heat transfer area. Sometimes the exhaust airstream contains corrosives, so a protective coating should be considered.

A coil energy recovery loop (or runaround loop) is actually a heat recovery system and distinct from individual pieces of equipment like energy wheels or fixed-plate heat exchangers. See Figure 52. Coil energy recovery loops are very flexible and well suited to industrial applications or comfort applications with remote supply and exhaust ductwork. They use standard finned-tube coils to transfer heat to and from an intermediate working fluid such as water or glycol-water solution. A pump circulates the fluid between the two coils

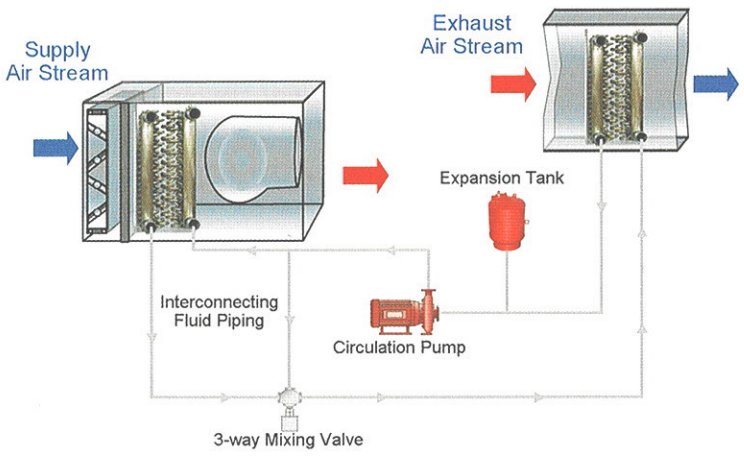


Figure 52

Coil Energy Recovery Loops

in a closed loop. The loop must be equipped with a flow control valve to modulate the heat transfer rate. Also, an expansion tank is necessary for thermal expansion and pressurization of the working fluid. The heat transfer rate must be controlled to prevent overheating or overcooling the supply airstream. If the outdoor airstream is very cold, an uncontrolled system may frost or freeze condensate on the coil in the exhaust stream.

Energy Recovery Loop

Maintenance requirements with an energy recovery loop are complicated because there are more component parts than with passive energy transfer equipment. The system also requires electrical power, motor controls, and temperature controls.

By regulating the fluid flow through each coil and blending warm fluid with the cold fluid entering the exhaust coil, the total heat transfer rate is limited to the maximum possible without freezing. Overheating is prevented in the same manner. Runaround loops are well suited for applications that must keep the two airstreams separate. They are useful for sensible heat recovery only and can be designed to transfer heat in either direction. They are also uniquely capable of simultaneous heat transfer between multiple locations using the same circulating system.

Spray Coils

A process that was popular in industrial applications in the past was a spray coil. Water is sprayed with nozzles onto a coil as shown in Figure 53. The coil is connected to a chiller. The spray water evaporates on the coil and provides a cooling effect.

Overall, the spray coil is not widely used anymore because the industrial user base such as the textile industry has shrunk and also because of the high humidity it produces. With the accompanying odor and building damage concern caused by mildew and mold growth, spray coil applications are less common. The spray coil is an inexpensive option to full mechanical cooling. Copper/copper coils are normally used for corrosive reasons.

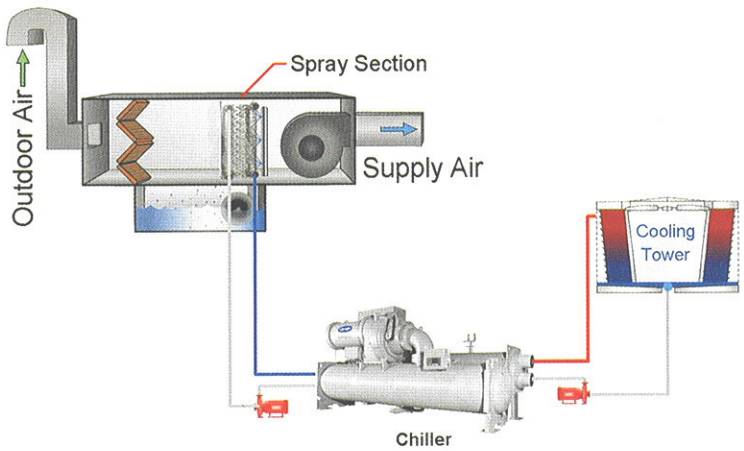


Figure 53

Spray Coils

Stacked Coils

Where air handler capacities – and consequently coil capacities – are large, individual coils may have to be stacked (combined) to meet the requirements. This approach basically involves stacking the separate coils one on top of another or in a staggered arrangement as shown in Figure 54, to produce the needed coil face area within the air-handling unit cabinet. The individual coils retain their coil casing as well as inlet and outlet connections. The coils are also frequently split internally in either face or row split fashion.

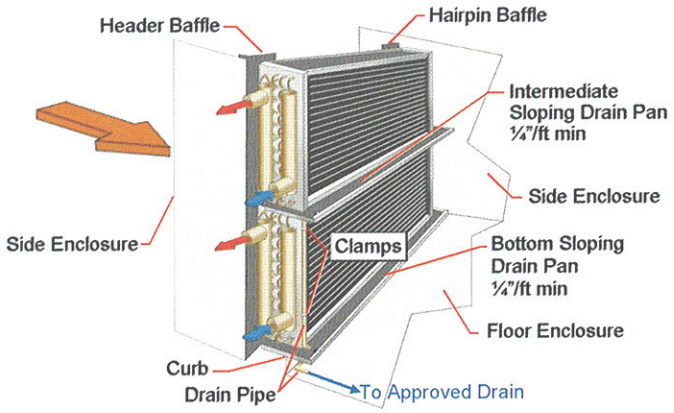


Figure 54

Stacked Coils

Care must be exercised in piping stacked or staggered coil banks. This is because it is desirable to maximize active coil face at partial load. For an example let's assume we have a staggered or stacked DX coil system (same concept applies to chilled water). If the coils are DX, and multiple condensing units are used, the best way to pipe them is to pipe each condensing unit to both coil sections. By doing so, the maximum amount of coil face remains active resulting in maximum moisture removal even if only one condensing unit is in operation.

Heating coils may also be stacked; however, in air-handling units this is less common than with cooling coils. The heating coil face velocity limitations are much higher so not as much surface is required for the same airflow as a cooling coil. Also, most heating applications can be handled by a one or two row coil, so if even more capacity is required, additional rows can be added versus larger face areas.

The staggered arrangement achieves the same result as stacking the coils but within a potential smaller air-handling unit cabinet. Care is taken by the manufacturer to achieve uniform airflow over both coil sections in either a stacked or a staggered arrangement.

Water Coil Control

Flow control valves should be carefully selected to match the operating characteristics of the system flow rate, coil pressure drop, close-off pressure, and type of action required. Most control valves have electrically operated actuators to stroke the valve open or closed. Other control valves have a full modulating proportional control. Spring-operated actuators are commonly found on heating coil valves. The spring return actuator will move the valve fully open in the event a power failure occurs. This is referred to as normally open.

Proportional control valves are most commonly used in HVAC applications. They modulate in response to a pneumatic or electronic control signal. They are used mostly to control fluid flow through heating and cooling coils. The valves are termed proportional because their output flow is not exactly linear in relation to the input signal. Despite their nonlinear response, these valves are an inexpensive way to control discharge air temperature off heating coils.

2-Way Valve Control

Two-way valves are commonly used in conjunction with face-and-bypass dampers to open when the outside air temperature drops below a predetermined set point – usually 55° F. The two-way, two-position control valve will open, allowing flow through the coil and the face-and-bypass dampers will modulate to maintain the discharge air temperature set point.

Two-way valves that are modulating type are used in variable flow cooling coil applications. This application requires the use of a VFD on the system pumps since the system flow varies due to the individual coils throttling the flow at part loads. See Figure 55.

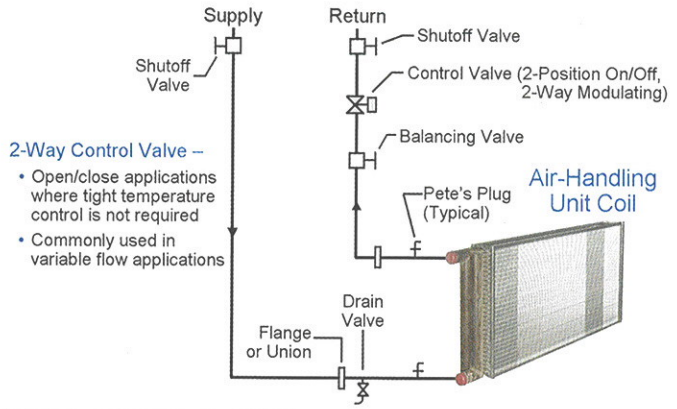


Figure 55

2-Way Valve Control

3-Way Mixing Valve Control

Three-way valves are typically used to provide a constant flow rate through the piped system while varying the flow through the hot water or chilled water coils. A system is shown in Figure 56. Three-way valves can be used in either a mixing or diverting type application. Three-way mixing valves offer good accuracy resulting in tight temperature control. Three-way valves are not used in variable flow systems since the system water flow remains constant due to the individual bypass line around each coil.

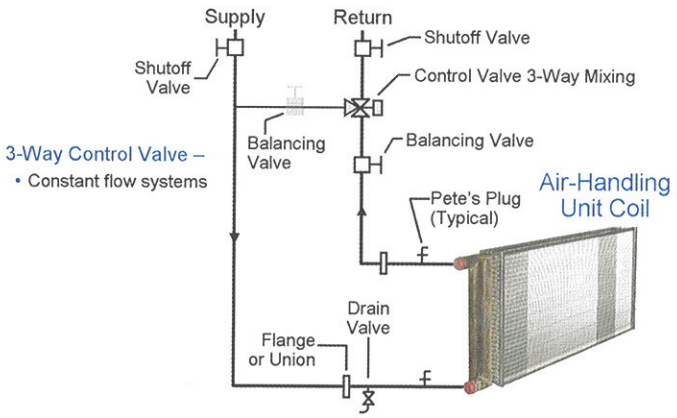


Figure 56

3-Way Mixing Valve

Face and Bypass Damper Control

Another control method that may be used with water (or steam) coils is face and bypass. With face and bypass control two sets of interlocked dampers are installed, generally in one section. The face dampers are located directly in front of the cooling coil and the bypass damper is located above the coil, controlling airflow through a bypass duct around the coil. See Figure 57.

This arrangement can be used with heating or cooling coils. They control heating capacity by diverting air around the coil, rather than throttling the hot water or steam to the coil. This minimizes the possibility of coil freeze-up in cold climates.

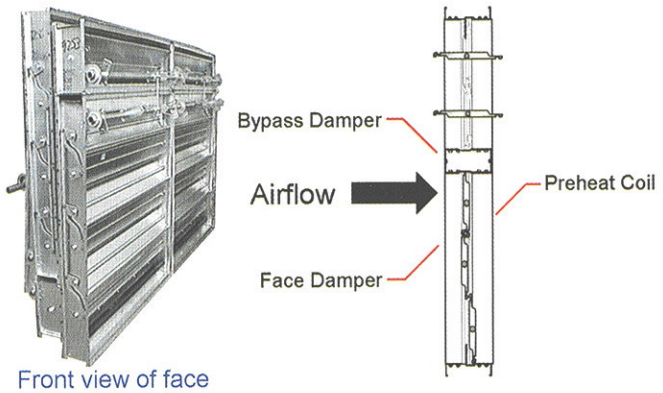


Figure 57

Face and Bypass Dampers

In cooling applications, face and bypass dampers are generally used only with chilled water coils, not direct expansion (DX) refrigerant coils. In chilled water applications they are effective in high latent load applications. In conjunction with a chilled water valve, they can reduce the leaving air temperatures off the cooling coil providing more dehumidification. This dehumidified air is then mixed with bypassed air to bring it up to an acceptable dry bulb temperature for distribution to the space.

On applications employing face and bypass sections, the fan selection and air distribution system must be designed for an air quantity about 10% above design dehumidified air volume. This additional air quantity compensates for leakage through a fully closed bypass damper and for air quantity variations when the dampers are in intermediate positions.

Traditionally, face and bypass has been discouraged in DX systems because if the controls allow the face dampers to close or significantly reduce airflow across the coil, the coil could freeze up and cause liquid refrigerant to flood back and cause compressor damage.

Often the coil used in a face and bypass arrangement will have no control valve. Temperature control is accomplished by bypassing air around the coil by fully closing the face damper. However, the radiant effect of the coil coupled with a backwash of the air after leaving the bypass can result in a residual heating effect. The amount of heat is a function of the design of the face damper and its ability to provide tight closure.

Steam Valve Control

See Figure 58 for a steam heating control diagram. When full design pressure is available, it should force the condensate out of the coil through the trap. When steam is throttled, it is possible for the pressure in the coil to be reduced to a point that will result in condensate hang-up in the coil. In some instances, the pressure may even drop into the vacuum range. At reduced steam flow, the condensate can be cooled so rapidly that coil freeze-up is virtually unavoidable. Standard or steam distributing construction is available for high and low-pressure applications. Standard steam type is the basic 5/8-inch or 1-inch tube steam coil, known as the single-tube design. The steam supply and condensate return headers and connections are normally at the opposite ends of the coil. Uniform steam distribution to each of the coil core tubes is accomplished by proper header assembly design. The steam supply connection should be located in the center of the header, with a perforated plate-type baffle located directly behind this connection. Properly sized orifices are located in each of the core tube entrances into the header. Steam distributing 5/8-inch and 1-inch tubes are the "freeze resistant" coils, known as the dual-tube design.

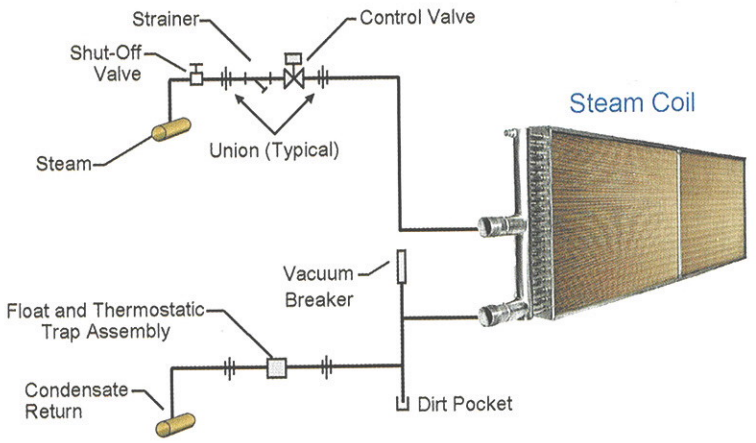


Figure 58

Steam Valve Control
(Photo courtesy of Heatcraft USA)

Steam Coil Drainage

Any steam coil can freeze when exposed to freezing temperatures without the proper drainage of the condensate.

This coil design utilizes a smaller inner tube, with precisely spaced, directional, orifice-type perforations. This is to help direct condensate flow to the return header.

U-bend (standard) steam coils can be used in applications where freeze protection is not a concern. This type of steam coil can be used when entering air temperatures are a minimum of 38° F. Standard coils should be controlled with only 2-way, on/off control valves so that condensate is not allowed to move so slowly (if throttled) that it could be susceptible to freezing.

Steam coils require a device to control the discharge of condensate from the coil but in the same time prevent any live steam from getting out. This device is called a trap and there are several types available. Traps are valves that sense the difference between steam and condensate and react automatically. There are two main types, those that are thermodynamically controlled, and those that are mechanically controlled. A widely used thermodynamically controlled trap uses a disc that closes to steam vapor, but opens to condensate which moves at a lower velocity than the vapor. Other thermodynamic types use pressure, liquid expansion, or a bi-metal element to function.

The mechanical trap may utilize a ball float or float and lever to prevent steam from passing through the coil unless it has condensed.

Electric Heater Control

In order to achieve incremental control of the heater output, heaters with multiple electrical circuits (stages) may be used. Although normal applications seldom require more then three stages, larger heaters may have six or more stages. The following devices may be used to control the electric heaters.

Step or program controllers generally operate heaters with more than three steps. They are normally operated by a modulating room or duct thermostat which energizes a varying number of steps depending on the deviation from the control set point. Depending on the type of step controller, various inputs are used, such as 0-135 ohm potentiometer, 0-16 vdc, 0-15 psi pneumatic, etc.

A silicon control rectifer (SCR) is a solid-state device that controls by modulating the flow of alternating current to heating components wired to the SCR. Depending on the capacity of the heater, several SCRs may be required. For close control, the SCRs offer the best system. However, in larger capacity heaters, the initial investment in SCRs can be expensive. In such a case, a step control-SCR vernier system should be considered.

A step control-SCR vernier system combines the advantages of the relatively low cost of the step controller with the modulation obtainable with SCR control. The system may use electric, electronic, or pneumatic step controllers and may be operated by various control signals. The first step on and the last step off would be the SCR step.

Most of the components used for electric heaters can also be built into a remote control panel. Remote control panels are used when code requirements do not allow certain features to be built into the terminal box of a heater, or the terminal box is in an inaccessible location when it is desired to have all control components in a readily accessible situation.

Coil Freeze Protection Considerations

The exposure of hot water, chilled water and steam preheat or reheat coils to subfreezing temperatures, either by accident or intent, creates the possibility of freeze-up within the coil tubes and may cause costly damage. The prevention of freeze-up requires consideration of the problem in the apparatus design and layout, in the selection of the equipment, and in the choice of the control methods.

Greater amounts of outdoor air are required by the current ASHRAE 62 standard than in previous years to maintain good IAQ. Elevated outdoor amounts are required to properly dilute indoor contamination levels and provide occupant comfort. However, with increased outdoor amounts comes the potential to freeze the coil in winter. Therefore, knowledge of the methods to prevent coil freeze-up is important.

Freezestat

A device that is often used is a freeze thermostat (or freezestat). This is used for coils that are not intended to heat entering air below 32° F. A freezestat is a coil sensor that is positioned across the face that shuts down the fan and closes the outdoor damper if the coil temperature reaches 35° F.

Air Blender

One method for freeze-up prevention is to ensure uniform entering air temperatures across the face of the coil. When the mixing of outdoor and return air takes place upstream of a heating coil, mixing should be promoted by introducing the denser and colder outdoor air at the top of the plenum. Provide as much airway length as possible. Use of an air blender is also recommended. Air handler manufacturers can provide a high quality air blender downstream of the mixing box as shown in Figure 59. The air blender helps mix the outdoor and return air by creating a churning action in the airstream. The airside pressure drop is not large, typically less than 0.25 in. wg. Blenders require little or no maintenance, however, they can increase unit length.

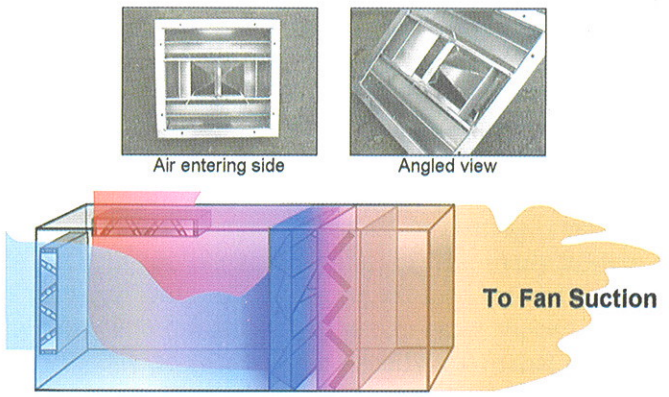


Figure 59

Air Blenders

Antifreeze Solution

A method of freeze prevention is to use an antifreeze mixture in the system. Glycol/water antifreeze solutions are capable of providing two levels of protection for the water system: burst protection and freeze protection. Burst protection allows for the fluid in the chilled-water loop to become slushy, but never to fully freeze solid to the point of rupturing or collapsing tubing. Freeze protection requires a greater glycol concentration so that the chilled fluid will not freeze. Adding glycol lowers the temperature at which the fluid freezes.

Antifreeze is expensive but is always protecting the system. Manufacturers often prefer this method of freeze protection also because it is very effective. However, the heat transfer of the coil is negatively affected depending on the percentage of antifreeze and type used.

Preheat with Energy Recovery

Another option is to provide preheating of the incoming ventilation air through a recovery device. This saves energy and introduces mixed air to the system at a higher temperature. There are many forms of air-to-air energy recovery available to transfer heat from the exhaust air stream to the incoming ventilation airstream. Coil runaround loops directly involve the use of separate coils in the exhaust and supply airstreams. For a complete discussion on systems that recover energy, see TDP-645, Energy Recovery.

Pumped Coils

Some designers like to use a pumped coil for freeze protection. Moving water will not freeze as quickly as standing water. The pump is activated to run continuously when the temperature of the outside air is at or below freezing. Figure 60 shows a pumped coil system schematic.

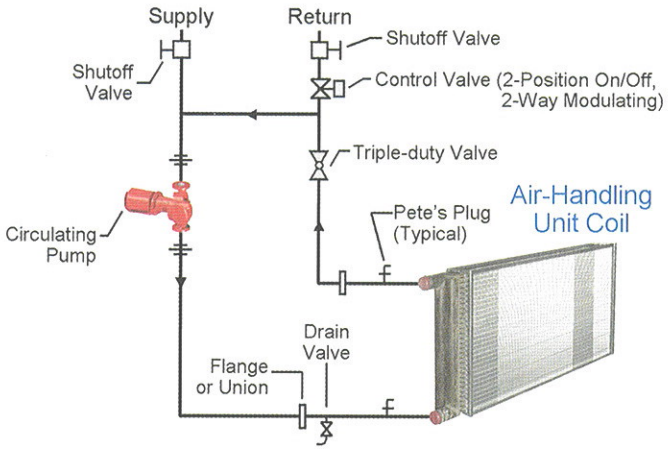


Figure 60

Pumped Coil

Steam Coil Considerations

Single-tube steam and hot water coils may be used for the tempering of subfreezing air, but the heating medium should not be modulated at entering air temperatures below 35° F. The steam should be supplied from the entering airside of the coil. Use of an inner distributing type coil is recommended.

A basic requirement for adequate freeze-up protection of steam coils is the positive and complete drainage of condensate from the tubes. Any type of steam coil may be damaged if condensate is allowed to accumulate and freeze due to poor design of the system or coil. For this reason an ideal position for a steam preheat coil is with the tubes vertical and with the condensate header at the bottom. For either horizontal or vertical airflow, steam preheat coils installed with tubes horizontal should be pitched downward toward the condensate header to facilitate drainage. Many steam distributing tube coils feature tubes internally pitched for either horizontal or vertical airflow. The use of a properly sized vacuum breaker can prevent hang up of condensate in the tubes.

For either steam or hot water, it is wise not to use a throttling valve to control the coil if the entering air temperature to the coil can be less than 32° F. The reduced flow and resulting low velocity in the tubes can increase the chances of freeze-up.

Cooling Coil Design Parameters

Load Estimation and Coil Selection

There are three important reasons for accurately estimating building cooling and heating loads and selecting coils and/or equipment to match those loads as closely as possible. They are:

- Equipment selection can be optimized.
- Part-load stability can be assured.
- Operating cost can be minimized.

From an equipment standpoint, unfortunately, it is common practice in heating, ventilating and air conditioning to overestimate loads for both cooling and heating. In fact, many designers routinely add a safety factor to the figures resulting from industry-accepted load estimating techniques. When equipment is selected for the job it is often difficult to get an exact capacity match with design load. As a result, the equipment capacity decided upon is usually above that indicated by the load estimate. The overestimate that can occur during load estimation is compounded during equipment selection. This practice adds extra cost and oversizes the job twice. Extra safety factors can result in part load capacity control problems and potential loss of humidity control resulting in IAQ problems.

For air handlers, moderately overestimating additional capacity can result in increased coil capacity while the air handler and compression equipment size remain unchanged. If the overestimate is more severe, a larger air handler size may be required. This could cause an approximate 10% air handler equipment cost increase, thereby possibly affecting the compression/condensing equipment size also.

Total installed cost increases if there is an unnecessary size increase in the air handler, compression or condensing equipment. The cost for electrical service, air ducting, air distribution terminals, refrigeration piping, rigging and installation labor are responsible for the higher cost.

Capacity Steps

The more closely the capacity step can match the coil load (i.e., the smaller the capacity step), the more smoothly and efficiently the system can operate at partial load. This situation is aided by avoiding equipment oversizing, and by selecting compression systems with more steps of capacity control.

The recent increases in the amount of ventilation air recommended in ASHRAE Standard 62-2004 have increased the importance of selecting and controlling cooling coils and air-conditioning equipment for optimum performance at part load. As with all air-conditioning equipment, the air-cooling coil has a limited, stable operating capacity range. Oversizing of equipment wastes some of this stable operating range.

Coil Psychrometrics

Illustrated on a psychrometric chart on Figure 61 is the airside performance of a 6-row, direct expansion cooling coil. The airside performance curve would look similar for a chilled water coil. The saturated evaporator temperature is the refrigerant temperature matching the pressure at the leaving end of the evaporator. The entering coil condition is t_{ma} for a draw-thru air-handling unit application. The numbered points (2 through 6) represent the air conditions leaving each row of the coil. The rows near the entering air face of the coil provide the greatest sensible and total capacity. The change for each row of finned tubes in dry bulb temperature and enthalpy, respectively, demonstrates this fact. Cooling coils first drive the air being treated toward the saturation curve and then cause the air leaving additional rows to move farther down along this curve. The last few rows the air passes over are providing primarily latent capacity. For this reason, latent capacity produced by coils with many rows is a higher percentage of total capacity than that produced by coils with fewer rows.

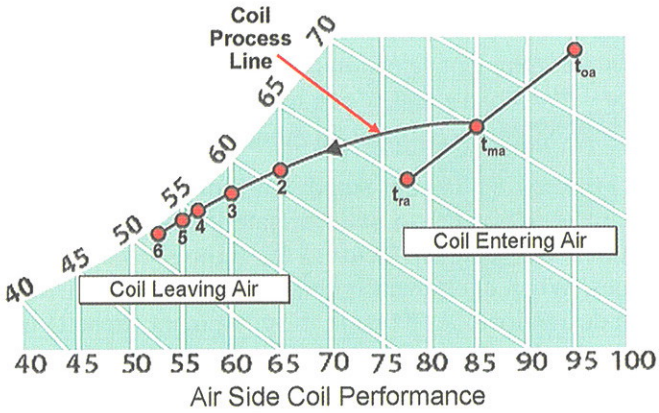


Figure 61

Psychrometric Chart – Coil Process Line

For a detailed explanation of coil psychrometrics, see TDP-201, Psychrometrics, Level 1: Introduction and TDP-204, Psychrometrics, Level 4: Theory.

Cooling Coil Requirements

The lines plotted on the psychrometric chart in Figure 62 represent the various processes that the air undergoes as it travels through the system. The two processes of particular interest here are the room process and coil process.

The room process line is important because it represents the effect the space sensible and latent loads have on the space temperature and humidity. The cooling coil must provide capacity great enough to offset all sensible and latent loads that occur in the building. If the coil sensible capacity is less than the sensible load generated, the space dry bulb temperature will rise above the design level. If latent capacity is inadequate, space relative humidity will climb above the design level.

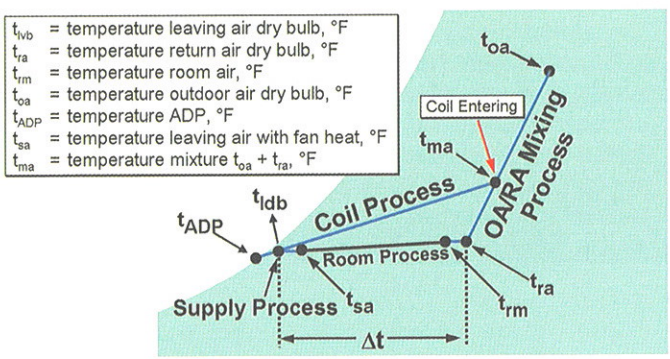


Figure 62

Psychrometric Chart – Room Process Line

The ratio of sensible and latent loads that occur in the space establishes the slope of the room process line. Since total load is the sum of the sensible and latent loads, the ratio may also be expressed in terms of sensible to total load. This is called the room sensible heat factor (RSHF). Stated in terms of an equation, RSHF = room sensible load/ room total load. Therefore, the slope of the room process line follows the RSHF line. The higher the RSHF, the lower the slope. High latent loads (low RSHF) will have steep RSHF and room process lines.

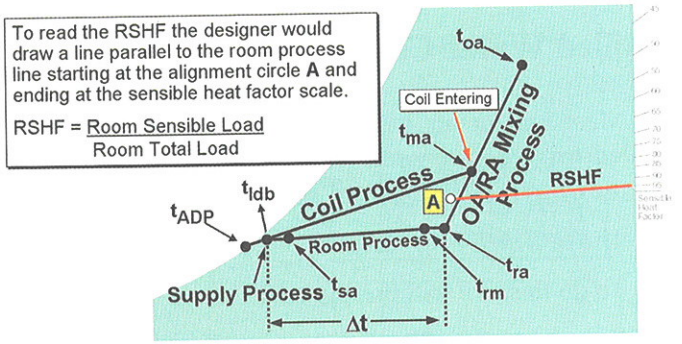


Figure 63

Cooling Coil Requirements

Sensible Heat Transfer

The RSHF concept is important because it is used to establish the temperature at which the coil must operate to properly handle the load in the correct proportions.

If the room process line is drawn from the room design point through the saturation curve on the psychrometric chart, the point at which the room process line intersects the saturation curve is called the apparatus dew point (ADP). This defines the average surface temperature at which the cooling coil must operate to handle the loads. The higher the latent load, the steeper the room process line and the lower the resulting ADP.

Coil Selection Examples

The coil apparatus dew point (average surface temperature) has a significant impact on the selection of the cooling coil. The ADP establishes the leaving water temperature that the chiller must supply, or the saturated suction temperature at which a condensing unit must operate. It also helps in selecting the coil airflow rate and air handler size. After the air handler size is selected, the cooling coil and heating coil rows, fins and circuiting can be determined based on the requirements of the job.

Coil Selection

The wide range of coils offered in central station air handlers allow the designer to closely match the sensible and latent capacity and other input parameters to the appropriate loads.

When one parameter is satisfied, other parameters will often miss the requirement. Common practice in these situations is to select a system and dehumidified air quantity that will match total sensible heat load with equivalent sensible capacity. Total capacity will be allowed to exceed or run slightly below. In this situation, any excess total capacity that occurs at peak load (design) conditions will result in room relative humidity below the original designer's target. This is considered desirable with respect to comfort applications.

Most commercial load estimating programs today will also do the psychrometric calculations needed for coil and system component selection. Shown is a load estimate summary with the coil selection data highlighted.

Chilled Water Coil Selection

Most coil or air handler manufacturers offer software to select their coils. Let's select a chilled water coil to satisfy the load requirements shown. For purposes of this exercise, we will use the Carrier AHUBuilder® software.

The first step is to select an air handler/coil size.

To do this, we will use the formula:

Face Area = Airflow (cfm)/design face velocity

Coil Face Area = 8758/500 = 17.5 ft^2 → Select a size 17 air handler.

Enter the selection parameters from the load estimate for entering air and water. The program will also allow the user to select the balancing criteria for both the airside (total capacity, sensible capacity), and the waterside (gpm or fluid temperature rise). See Figure 64.

The coil performance data for all coils will be displayed for analysis. Our goal is to select the most economical coil that best meets the job requirements.

To make evaluation easier, AHUBuilder has a "4-item browse mode" which sorts the data by user selected parameters. This allows the designer to quickly and easily compare the most pertinent data.

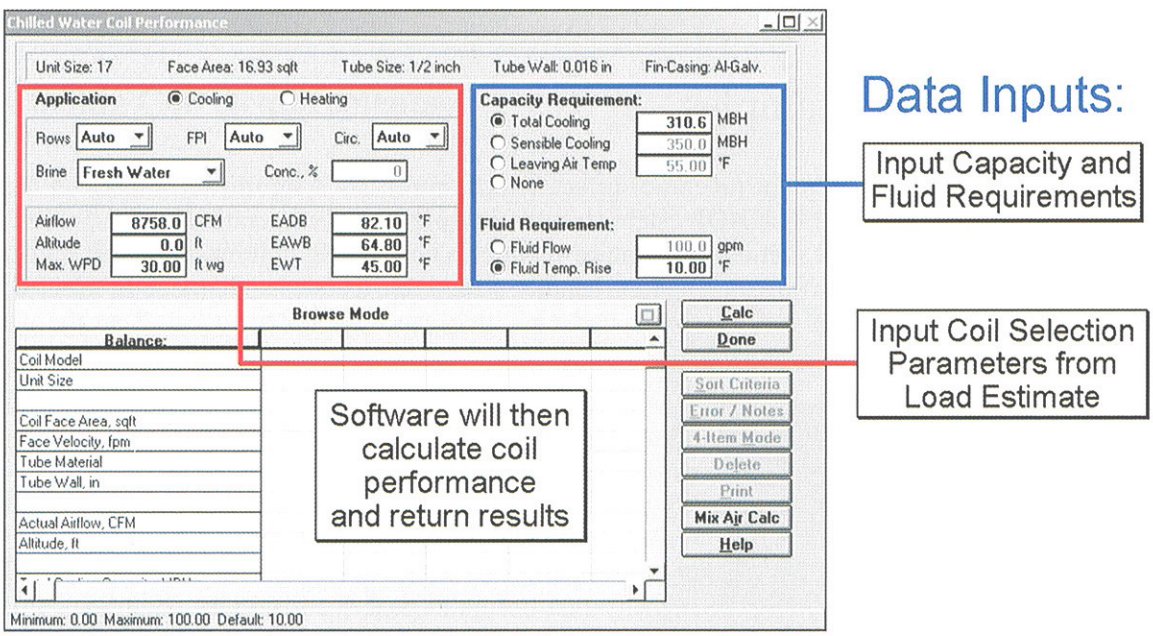


Figure 64

AHU Builder Selection Software – Chilled Water Coil

For this application, two coils closely meet the load requirements as shown in Figure 65. They are an 8-row, 11-fin per inch, double-circuited coil and a 6-row, 14-fin per inch, full-circuit coil. We will choose the 6-row coil as it has a lower first cost and the air friction is less than that of the 8-row coil. This will save fan energy and result in a more energy efficient system. The chosen coil has a higher pressure drop but better latent capacity.

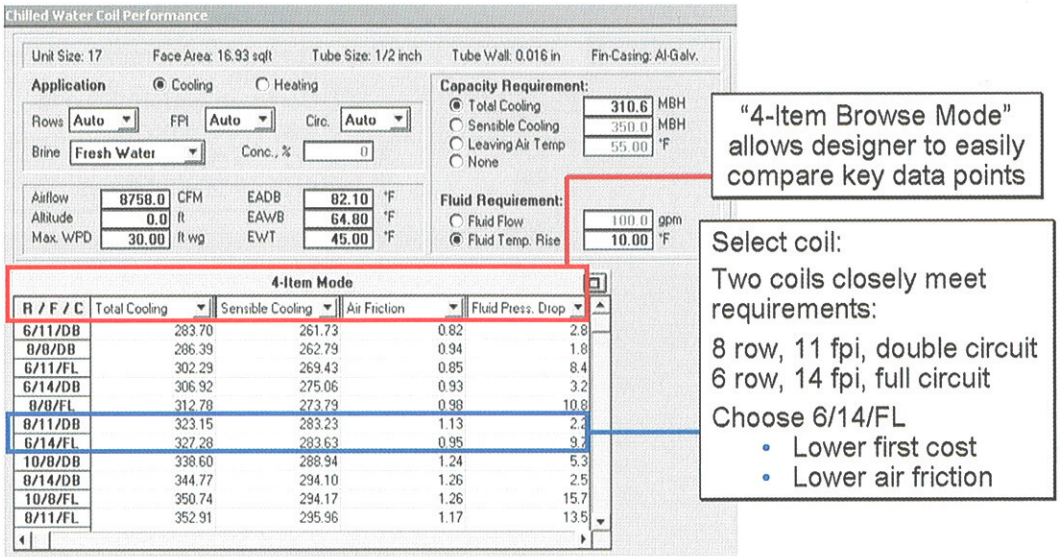


Figure 65

Chilled Water Coil Selection

Direct Expansion Coil Selection

Now let's select a direct expansion (DX) coil for this same job. The inputs will be similar to the chilled water coil, with a few differences. For DX coils, face or row split must be selected. The program will also balance the coil with a condensing unit. We will choose a nominal 30-ton condensing unit. See Figure 66.

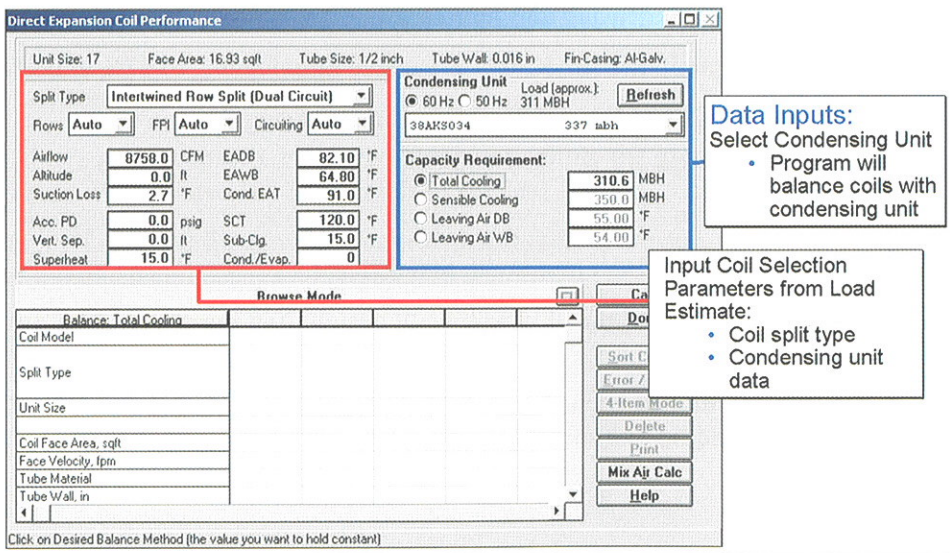
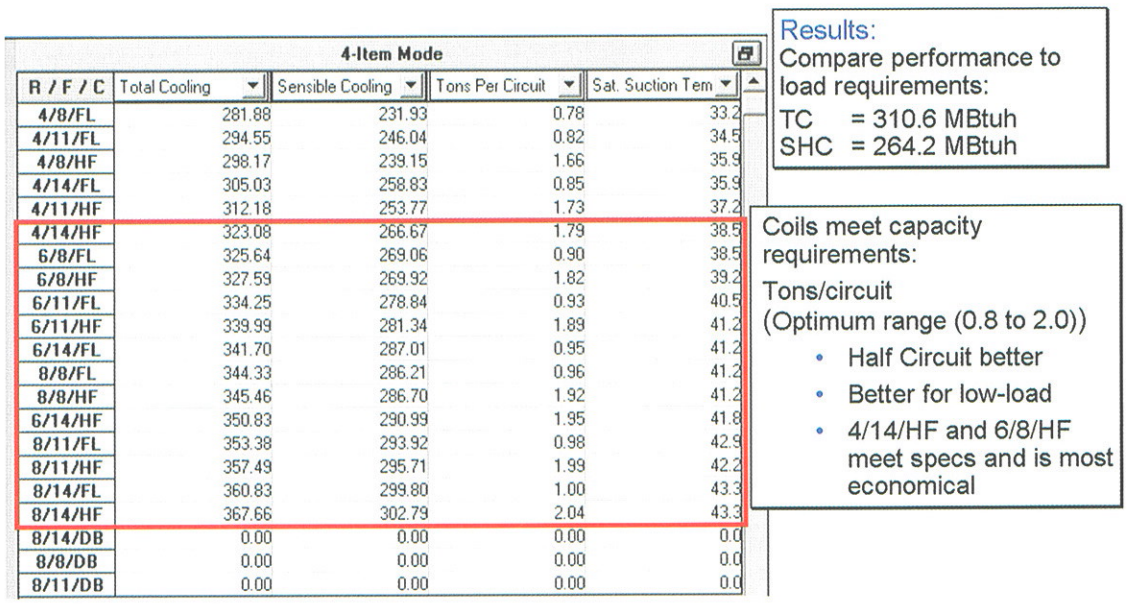


Figure 66

DX Coil Selection

Shown in Figure 67 are the results sorted for capacity, tons/circuit and saturated suction temperature. Looking at the data, many coils meet the capacity requirements. However, the half-circuited coils have higher circuit loading still within the optimum range of 0.8 to 2.0 tons per circuit. They make a better choice as they may eliminate the need for evaporator staging. Looking at the data, the two best matched coils are the 4-row, 14-fin per inch half-circuit coil and the 6-row, 8-fin per inch, half circuit. The 4-row coil is the most economical as we saw earlier.



4-Item Mode

R / F / C	Total Cooling	Sensible Cooling	Tons Per Circuit	Sat. Suction Tem
4/8/FL	281.88	231.93	0.78	33.2
4/11/FL	294.55	246.04	0.82	34.5
4/8/HF	298.17	239.15	1.66	35.9
4/14/FL	305.03	258.83	0.85	35.9
4/11/HF	312.18	253.77	1.73	37.2
4/14/HF	323.08	266.67	1.79	38.5
6/8/FL	325.64	269.06	0.90	38.5
6/8/HF	327.59	269.92	1.82	39.2
6/11/FL	334.25	278.84	0.93	40.5
6/11/HF	339.99	281.34	1.89	41.2
6/14/FL	341.70	287.01	0.95	41.2
8/8/FL	344.33	286.21	0.96	41.2
8/8/HF	345.46	286.70	1.92	41.2
6/14/HF	350.83	290.99	1.95	41.8
8/11/FL	353.38	293.92	0.98	42.9
8/11/HF	357.49	295.71	1.99	42.2
8/14/FL	360.83	299.80	1.00	43.3
8/14/HF	367.66	302.79	2.04	43.3
8/14/DB	0.00	0.00	0.00	0.0
8/8/DB	0.00	0.00	0.00	0.0
8/11/DB	0.00	0.00	0.00	0.0

Figure 67

DX Coil Selection Results

Now, check the selected coil at part-load operation with selected condensing unit to determine if any coil split deactivation is required with the selected condensing unit. Our example will be a 4-row, 14-fin, half-circuit coil that contains 2 TXVs. To check this, it is necessary to get the unloading capability from the condensing unit literature.

The selected condensing unit, the 38AKS034 is capable of unloading to 67% of design.

Tons/Ckt at part load = Full Load Tons/Ckt * Minimum Unloading

= 1.79 * 0.67

= 1.19

This results in acceptable tons per circuit with two active TXVs.

Result must be above the minimum allowed by coil design. (0.6 ton/ckt for the Carrier coil in this example.)

If resulting tons per circuit had been below the minimum, one split of the coil would have to be deactivated by closing a liquid line solenoid valve to one TXV when compressor is unloaded.

Heating Coil Selection

Hot Water Coil

Selecting a hot water coil involves entering minimum required data after which the selection software will arrive at an optimized coil selection. See Figure 68.

First, the entering air temperature and the entering water temperature are required.

> ***Oversized Heating Coils***
>
> *Often, after the air-handling unit size is fixed, the resulting heating coil face area tends to be a bit oversized. That is because the cooling coil selection face velocity of approximately 500 fpm is low relative to acceptable heating coil face velocities that can be greater than 900 fpm.*

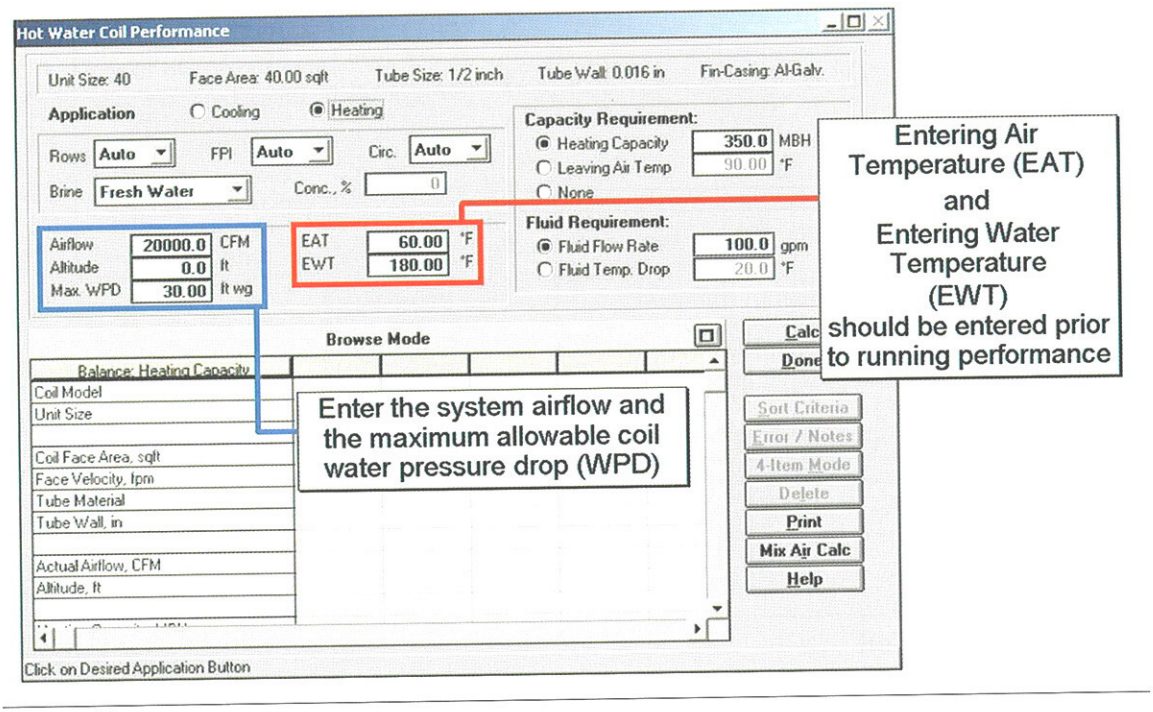


Figure 68

Hot Water Coil Selection

Next, the required capacity is entered along with either the gpm or the desired fluid temperature difference. We will use 100 gpm in this example.

Several coil row and fin combinations are displayed. As we see, our flow rate of 100 gpm results in far too much coil capacity.

If we reduce the flow to only 10 gpm through the coil, we can make the required capacity. The software allows the user to list coil performance details in a specific order of importance. In this case, the priority chosen was:

1. heating capacity
2. leaving air temperature
3. air friction
4. flow rate

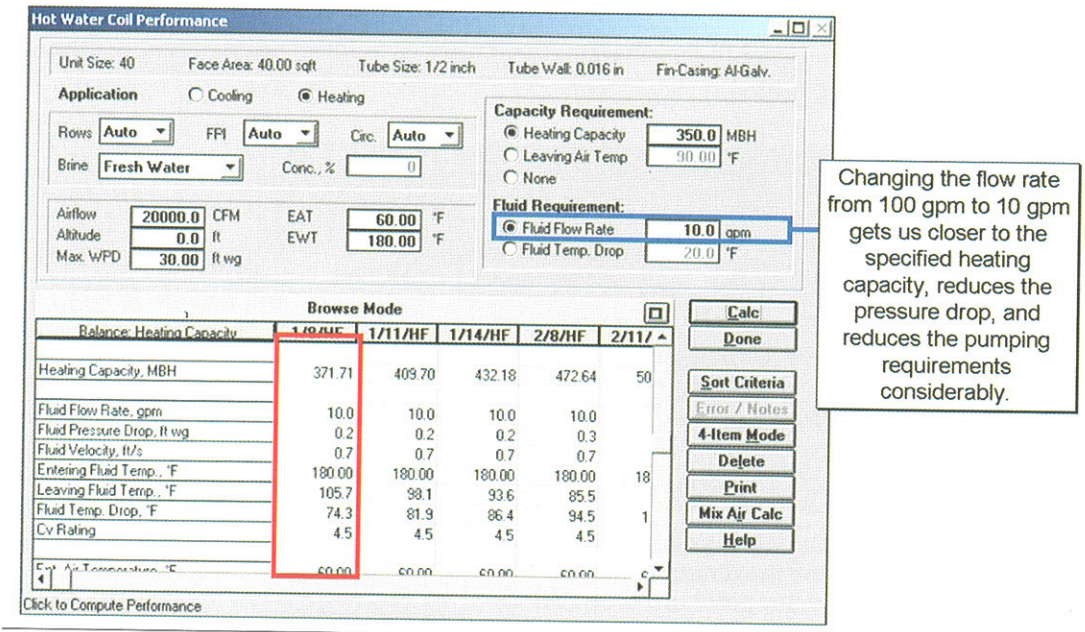


Figure 69

Hot Water Coil Selections

Electric Heating Coil

To make a selection for an electric heating coil, the user must first input the voltage for the heater and then select between an open wire or a sheathed element heater. See Figure 70.

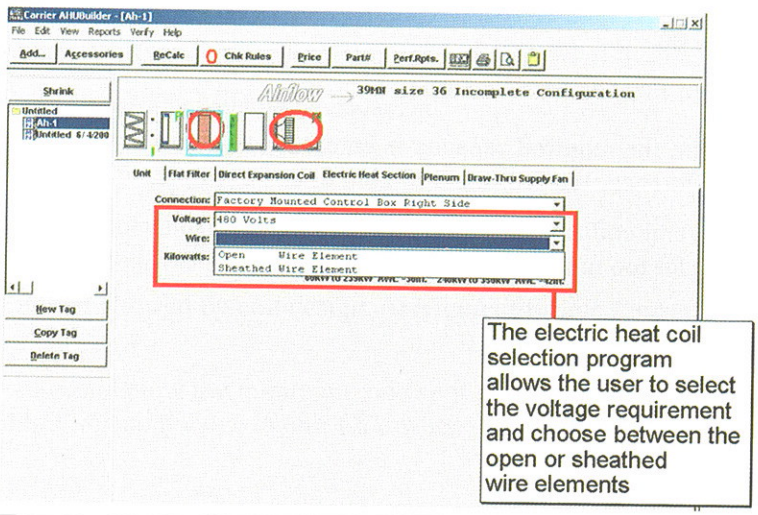


Figure 70

Electric Heat Coil Selection

Next, the desired kW is input. Once again, the air handler size has been previously fixed based on the cooling coil face velocity so the airflow has already been established. Standard heater sizes are displayed for that size of unit.

Steam Heating Coil

For a steam coil selection, the following parameters are input first:

- airflow
- altitude
- entering air temperature
- available steam pressure

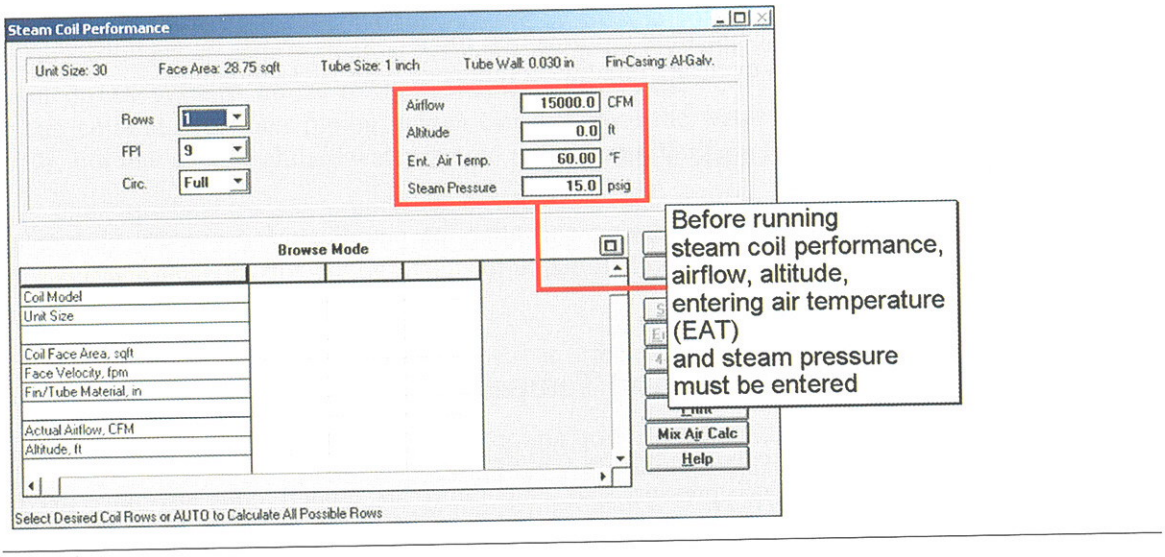


Figure 71

Steam Coil Selection

Coils are calculated and the heating capacity, leaving air temperature, air friction and, in the case of a steam coil, the condensate load in lb/hr is output.

Preheat Coils with Face-and-Bypass

Face-and-bypass dampers are typically used with preheat coils. The preheat coil is sized according to heating capacity requirements and coil face velocity limits.

Face-and-bypass dampers are commonly used in colder climates where there is a greater threat of coil freeze-ups. Full hot water or steam flow can be maintained through the coil while air is re-directed around the coil through the bypass dampers for temperature control.

ARI Certification and Coil Testing

ARI (Air Conditioning and Refrigeration Institute) is an independent non-profit organization. One of the main goals of ARI is to ensure that heating and cooling equipment delivers the performance ratings represented in catalog literature and computerized selection software. ARI has developed Standard 410, which establishes rating criteria and procedures for measuring and certifying product performance. Cooling and heating coil parameters like capacity, air friction, and water head loss are tested (within tolerances) to what the manufacturer says they will be. In this way, products are rated on a uniform basis, so that buyers and users can properly make selections for specific applications.

To qualify for ARI certification, coils are subjected to laboratory performance testing by the manufacturer. Once ratings under simulated (or actual) operating conditions have been obtained, they are submitted to ARI for verification. Chilled water, hot water, and direct expansion coils are included. Once certified, the ARI seal may then be affixed to the coil casing. ARI annually selects a significant portion of each manufacturer's production models to be tested by an independent laboratory under contract to ARI to ensure ongoing compliance with ARI guidelines.

Coil Testing, Proof and Leak Test

Coils are quality tested for defects during and after the manufacturing process. A typical proof test procedure for a manufactured coil would be to submerge the coil in water and pressurize it to 300 psig and check for leaks.

Working and Design Pressure and Temperature

The proof leak tests must exceed the typical coil design pressure or the maximum allowable working (operating) pressure. Since pressure and temperature are related, coils also have maximum allowable temperature limitations. Working pressure and temperature are the actual pressure and temperature the coil will be subjected to in everyday use. The Design pressure and temperature are the maximum allowable working pressure and temperature for the construction.

Standard ARI 410 requires testing by a manufacturer on a representative coil within a family of identically designed coils. That data is used to generate capacity data for other coils within the same family type.



Figure 72

Coil Testing

Summary

Coils serve the important function in an HVAC system of transferring heating or cooling from the water or refrigerant to the conditioned airstream. Each type and application of an HVAC system can utilize different coils. Coils are used in residential equipment, indoor packaged products, rooftop units, ductwork, air terminals (VAV boxes), and central station air-handling units. Air-handling units have the most variation in coil applications, so this TDP is focused on that category.

To properly apply heating and cooling coils, a knowledge of their construction and important features is necessary. Each coil component (including rows, fins, headers, inlet, outlet, circuiting, and face area) affects the final performance of the coil. With an understanding of coil components, a proper coil selection is possible.

The main types of coil that are used in the HVAC industry are direct expansion (DX) and chilled water for cooling. Hot water, steam, or electric coils can be used for heating duty. DX coils are matched with individual condensing units. The condensing units can be air or water-cooled. DX systems utilize refrigerant lines between the coil and the condensing unit. Chilled water coils utilize water piping, which can distribute the water over greater distances than DX coils. For that reason, chilled water is used in the larger buildings utilizing multiple coils.

The basic heat transfer properties of coils are airside transfer, waterside transfer, and an overall formula. The airside heat transfer should equal the waterside heat transfer. There are many factors that affect heat transfer, such as air film resistance, external fouling, tube and fin resistance, and fluid film resistance.

There are common application topics that affect coil selection and design. Important topics are moisture carryover, effects of antifreeze, corrosion protection, and condensate trapping.

The coil must be selected after the cooling and heating loads for the area being served have been established. The ratio of sensible and latent loads in the space establish the slope of the room process line and coil process line on the psychrometric chart. The leaving coil conditions reflect the correct ratio of sensible to total heat based on the load requirements. This is called sensible heat factor.

Selection of heating and cooling coils is done by computer software. The user must comprehend the coil properties and performance characteristics presented in this TDP module since most selections yield several alternatives, one of which may be the best overall.

A review of common coil piping methods and agency certification and testing methods for heating and cooling coils establishes a solid foundation on coils in the HVAC industry.

Work Session

1. Name five typical HVAC application types where coils are used.

_____

_____

_____

_____

_____

2. What is the difference between a draw-thru and blow-thru air handler configuration?

_____

_____

_____

3. What is the most popular fin and tube material combination applied to comfort commercial air cooling coils?

_____

4. Name the typical tube diameters used in HVAC coils.

_____

5. Using the coil picture shown, identify the following things:

a) Vent _____

b) Face area _____

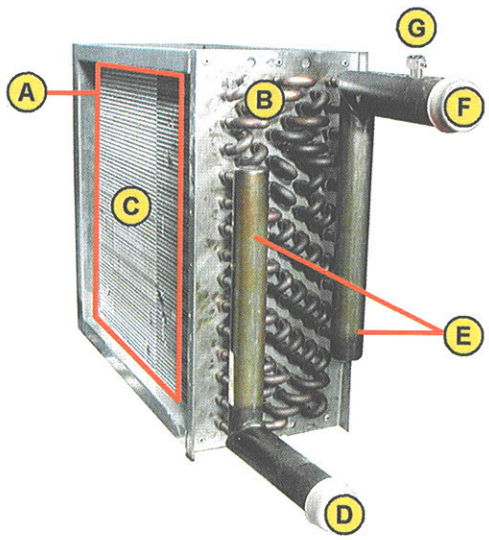
c) Outlet _____

d) Coil tubes _____

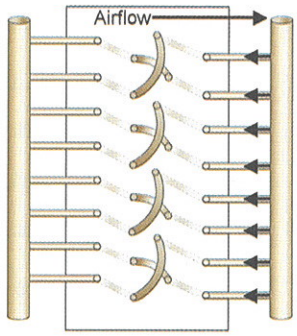
e) Coil fins _____

f) Supply and return headers _____

g) Inlet _____



6. For the coil shown here,



   a) What circuiting does it have? _____
   b) How many rows does it have? _____
   c) Is it a water or DX coil? _____
   d) What is its tube face? _____

7. Should the water inlet be located on the side of the coil that air enters or the side of the coil that air leaves and why?

_____

_____

_____

8. Describe what is meant by non-ferrous headers.

_____

_____

9. A designer has selected an air handler with a 4-row coil which is available in either half or full circuiting. The tube face of the coil is 8.

   a) Which circuiting has the longest circuits? _____
   b) How many passes does the refrigerant make in each circuit of the full-circuited coil? In the half-circuited coil? _____
   c) Which circuiting will have the higher tube-side pressure drop? _____
   d) Why? _____

_____

_____

10. Why are coil splits offered on DX coils but not chilled water coils?

_____

_____

_____

11. From most expensive to least, list the cost ranking factors for coils.

    Highest
    
    Lowest

    _____
    _____
    _____
    _____

12. What are the three things that limit the minimum load of a DX system at part load?

    _____
    _____
    _____

13. The general equation for heat transfer across the finned tube surface of a heat exchanger like a chilled water or DX air cooling coil is $q_t = U * A * LMTD$. What component is directly influenced by dirt build-up on the outside of the cooling coil?

    _____
    _____

14. In the equation shown above, why is a simple Δt not adequate?

    _____
    _____

15. What is a typical design saturated refrigerant temperature for the evaporator of a DX system?

    _____

16. What is a typical design water temperature entering a chilled water coil?

    _____

17. Accurate load estimation and equipment sizing is beneficial in three major areas. What are they?

    _____
    _____
    _____

18. The actual cooling coil airside performance curve is not straight. In a 4-row coil, the row nearest the entering air surface of the coil provides _____% of the cooling capacity.

19. Which is an accurate statement for bypass factor? _____

    a) A decimal expression of the coil's airside heat transfer inefficiency

    b) A decimal expression of the coil's airside heat transfer efficiency

    c) A decimal expression of the air that gets through coil untreated

    d) A decimal expression of the air which leaks through the mixing box dampers when closed

20. Name six methods used for heating coil freeze protection.

_____

_____

_____

_____

_____

_____

Notes:

Appendix

Work Session Answers

1. Five typical coil applications are:
   - Residential systems
   - Commercial packaged units
   - Duct-mounted coils
   - Air terminals, such as VAV boxes
   - Central station air-handling units

2. Draw-thru configuration positions the coil upstream of the fan and motor. Blow-thru configuration is downstream of the fan and motor. Blow-thru needs a diffuser plate to help distribute the air coming off the fan discharge evenly over the coil.

3. Copper tubes/aluminum plate fins

4. 5/16, 3/8, 1/2, 5/8, 3/4, and 1 inch

5. a) Vent G
   b) Face Area A
   c) Outlet F
   d) Coil tubes B
   e) Coil fins C
   f) Supply and return headers E
   g) Inlet D

6. a) full
   b) 4
   c) water
   d) 8

7. The water inlet should be located on the coil on the side that air leaves the coil in order to accomplish counterflow to maximize LMTD (heat transfer)

8. Non-ferrous headers contain no iron or steel and are typically made of copper.

9. a) half
   b) 4, 8
   c) half circuited coil
   d) Because every other tube in the face is fed with water so the individual circuits have a longer path of flow within the coil, hence more pressure drop.

10. Water coils use either flow modulation or water temperature adjustment as a capacity control technique. For that reason, splitting the coil is not a necessary method to achieve capacity control.

11. a) face area
    b) rows
    c) fins per inch
    d) circuiting

12. The three things that limit the minimum load of a DX system at part load are:
    - The TXV low load limit
    - The nozzle's low load limit capability
    - The circuits in the coil ability to entrain oil (expressed in terms of tons/ckt)

13. The overall conductance value or the "U" value.

14. Because both air temperature and heat transfer fluid temperature are changing as they flow through the coil. This means the temperature difference at any point is different from that at another point.

15. Typically 40 to 45° F

16. 42 to 44° F

17. The three major areas where load estimation and equipment sizing is beneficial are:
    - Equipment load can be optimized
    - Part load stability can be assured
    - Operating cost can be minimized

18. 41%

19. c)

20. Six methods used for heating coil protection are:
    - use of an antifreeze mixture in the circuiting
    - drainage of the coil in winter
    - use a pumped coil (constant circulation)
    - use of a face and bypass damper with constant flow of fluid through the coil
    - use of an air blender to ensure outdoor air and return air mixing
    - use of a smaller coil dedicated to the outdoor air intake

Range of Standard Rating Conditions

	Cooling Coils			Heating Coils		
Item	Volatile Refrigerant	Cold Water	Cold Ethylene Glycol Solution	Steam	Hot Water	Hot Ethylene Glycol Solution
Standard air face velocity, std. ft/min	200 to 800	200 to 800	200 to 800	200 to 1500	200 to 1500	200 to 1500
Entering air dry-bulb temperature, °F	65 to 100	65 to 100	65 to 100	-20 to 100	0.0 to 100	-20 to 100
Entering air wet-bulb temperature, °F	65 to 80	60 to 85	60 to 85	–	–	–
Tube-Side fluid velocity, std. ft/s	–	[1]1.0 to 8.0	[2]1.0 to 6.0	–	[1]0.5 to 8.0	[2]0.5 to 6.0
Entering fluid temperature, °F	–	35 to 65	0.0 to 90	–	120 to 250	0.0 to 200

[1] Application of coils at low velocity can lead to excessive fouling.
[2] Application of coils at low velocity can lead to possible air entrapment

Notes:

Prerequisites:

To obtain the highest benefit from this module, it is suggested that participants have prerequisite knowledge from the TDPs listed below, or equivalent.

TDP No.	Book Cat. No.	Instructor CD Cat. No.	Title
TDP-102	796-026	797-026	ABCs of Comfort
TDP-103	796-027	797-027	Concepts of Air Conditioning
TDP-201	796-030	797-030	Psychrometrics, Level 1: Introduction
TDP-301	796-034	797-034	Load Estimating, Level 1: Overview
TDP-400	796-037	797-037	Principles of Mechanical Refrigeration, Level 1: Fundamentals
TDP-611	796-049	797-049	Central Station Air Handlers

Learning Objectives:

After reading this module, participants will be able to:

- Identify where coils are used in HVAC applications.
- Define the component parts of coils.
- Describe the various types of heating and cooling coils and their applications.
- Identify the heat transfer properties of coils.
- Describe methods for piping and control of water and direct expansion coils.
- Identify key coil selection criteria and factors affecting performance.
- Select chilled water, DX, and heating coils.

Supplemental Material:

None

Instructor Information

Each TDP topic is supported with a number of different items to meet the specific needs of the user. Instructor materials consist of a CD-ROM disk that includes a PowerPoint™ presentation with convenient links to all required support materials required for the topic. This always includes: slides, presenter notes, text file including work sessions and work session solutions, quiz and quiz answers. Depending upon the topic, the instructor CD may also include sound, video, spreadsheets, forms, or other material required to present a complete class. Self-study or student material consists of a text including work sessions and work session answers, and may also include forms, worksheets, calculators, etc.



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