

# FAN COIL ENGINEERING

e2

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## Fan Coil Introduction

### PROPERTIES OF COILS AND COIL DESIGN

Fan coil units can be used to introduce outdoor air into a space, circulate and filter air within a space, and provide heating and/or cooling within a space. The basic components of a fan coil unit are a heating/cooling coil, fan section, and a filter. Units may stand alone within a single space or be ducted to serve multiple spaces, and can be controlled by a manual switch, thermostat, or building management system.

Fan coil units are typically selected and sized to heat and cool a small zone with specific load requirements. A zone may consist of a single undivided space, a partitioned room, or multiple rooms with similar smaller loads that together add up to the total load the fan coil unit is designed to handle. Such fan coil systems can be controlled by a single, centrally located thermostat. If the system incorporates a ducted return air system, a return air sensor mounted in the common duct could also provide accurate comfort conditioning temperature control. Vertical fan coil units, either in stack configuration for a high rise or floor mounted stand-alone units in individual spaces are usually utilized only for single room applications and are often controlled by a thermostat mounted in the space or on the unit itself. Depending upon the control system of the building, the control of most fan coil units can be incorporated into the Building Control System or Building Energy Management System if dictated by the design.

Typically, the water in a hydronic piping system that serves the fan coil units and other HVAC equipment is supplied to the central plant or building by the local utility; from there, heat is transferred to or from the water by means of a boiler used to supply hot water or a chiller used to provide cold water. Chemical treatment of water is often involved, including addition of propylene or ethylene glycol to prevent freezing. It is important to note that these additives alter the heat transfer properties of the fluid; this difference should be accounted for when selecting and sizing the system. The water is then piped through hot water or chilled water primary and secondary supply lines. Supply water is piped to the bottom of the coil to ensure that any air bubbles forming in the supply water will be transmitted to the upper level where they can be discharged from the system through the optional air vent on the return pipe immediately outside the coil.

Two-pipe and four-pipe configurations are piping options used in fan coil unit systems. Just as it sounds, a two-pipe system is literally served by two pipes – a supply and return. Either chilled or hot water through the pipes can be supplied and returned, not both. This requires system changeover from heating to cooling or cooling to heating. Although they have the advantage of lower initial costs associated with piping and installation, two-pipe systems offer less flexibility with heating and cooling demand as it will not allow heating in one unit and cooling in another. This can sometimes be problematic, such as when seasonal or occupancy loads change. Four-pipe systems consist of chilled water supply and return and hot water supply and return. An actuated three-way valve with chilled and hot water supply entering can be controlled by a room thermostat or return air sensor and signal either the hot or chilled water supply side to open or close. In contrast to two-

FIGURE 1: COIL DESIGN

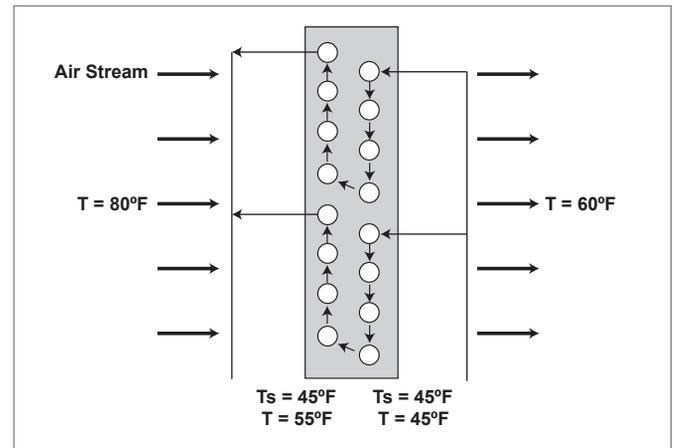


FIGURE 2: PARALLEL FLOW

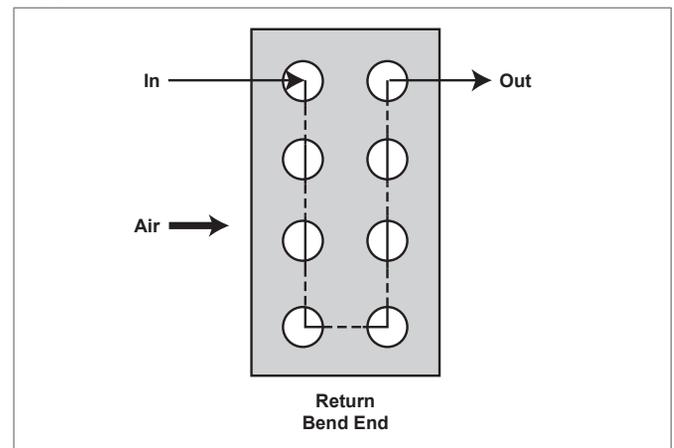
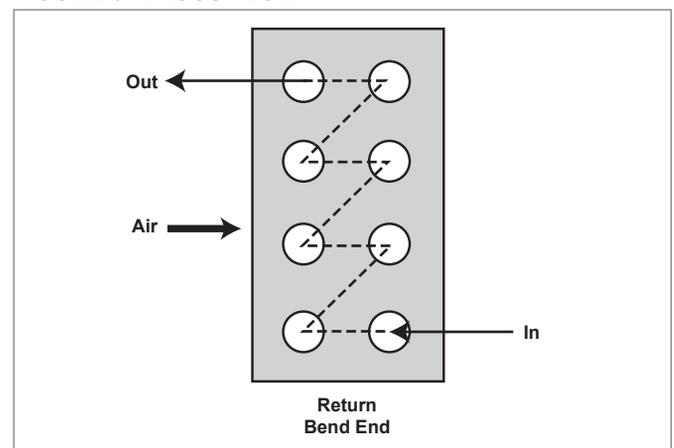


FIGURE 3: CROSS FLOW



pipe systems, four-pipe systems often have higher piping and installation costs but are capable of maintaining higher levels of occupant comfort in all seasons.

Introduction

Fan Coil Introduction

FIGURE 4: HORIZONTAL 2-PIPE, STD RETURN

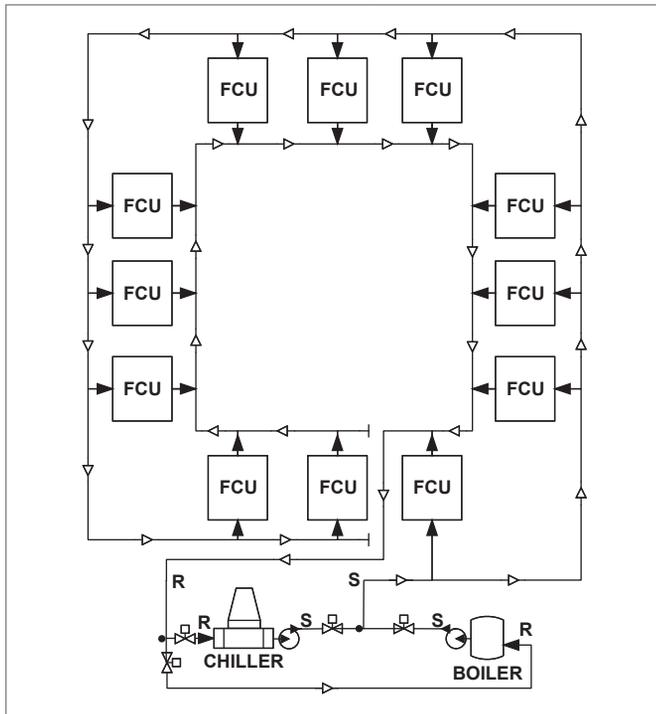


FIGURE 5: VERTICAL 2-PIPE, STD RETURN

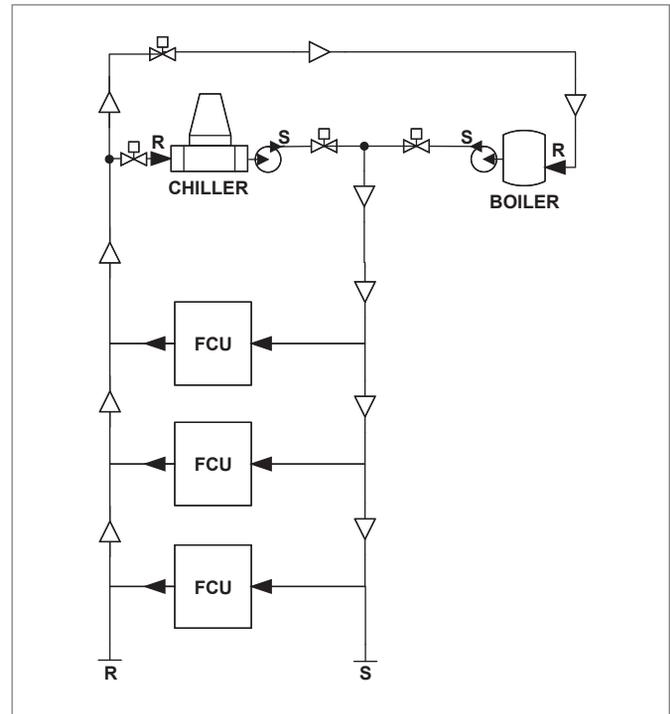


FIGURE 6: HORIZONTAL 2-PIPE, REVERSE RETURN

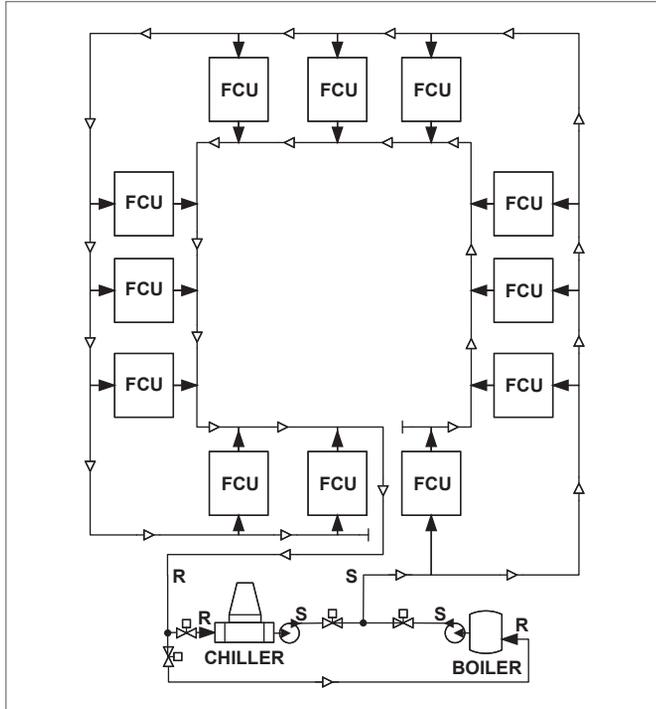
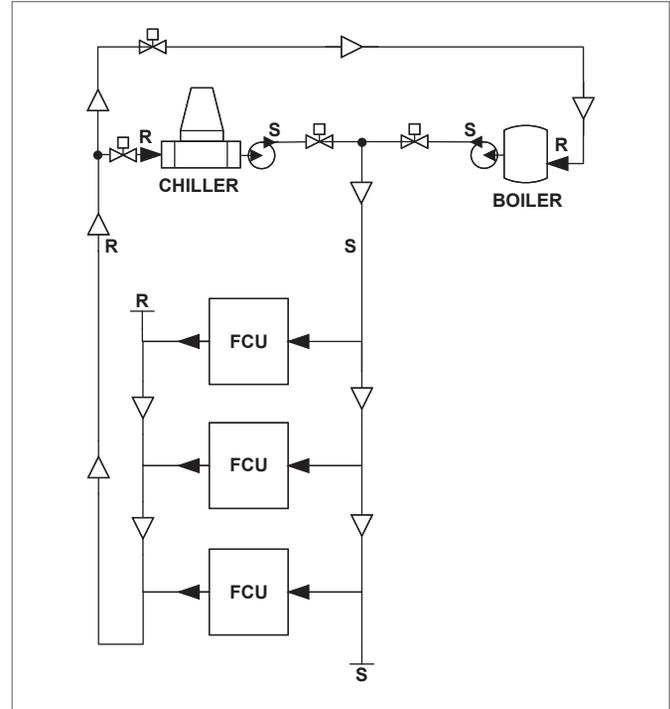


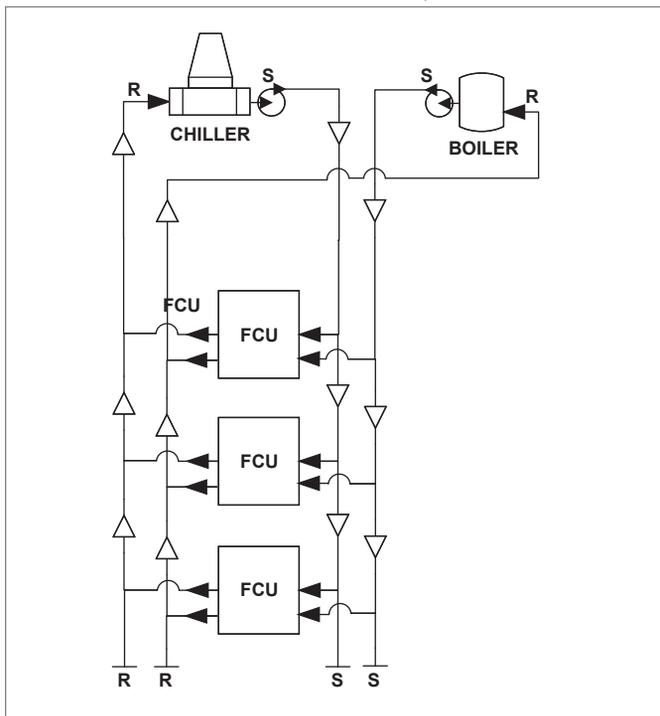
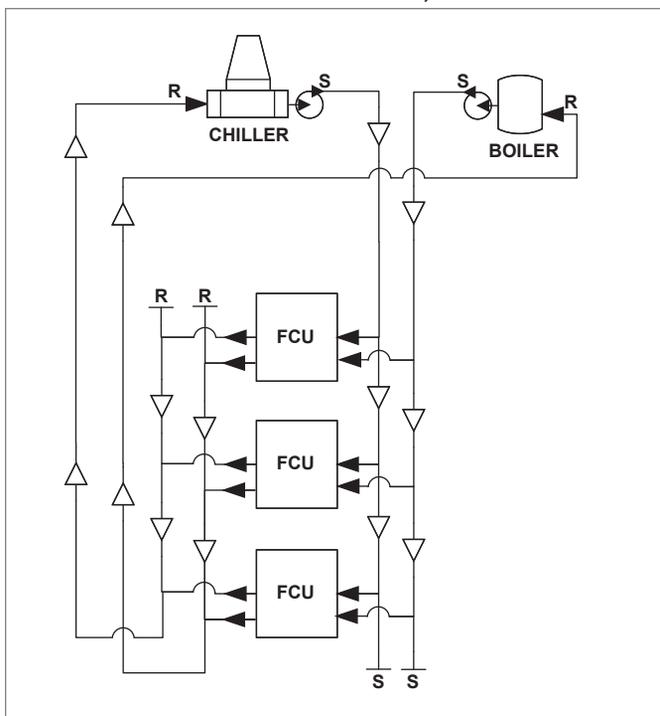
FIGURE 7: VERTICAL 2-PIPE, REVERSE RETURN



Two different configurations are available for return piping, standard return and reverse return. In the standard configuration, (Figures 4, 5, and 8), water flows from the first fan coil in the loop through the last, and returns from the last unit back through the first. In a reverse return system, (Figures 6, 7, and 9), both the supply and return flow run from the first unit in the system through the last and returns to the chiller through a separate riser.

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**Fan Coil Introduction**
**FIGURE 8: VERTICAL STACK 4-PIPE, STD RETURN**

**FIGURE 9: VERTICAL STACK 4-PIPE, REVERSE RETURN**

**VERTICAL STACK RISERS**

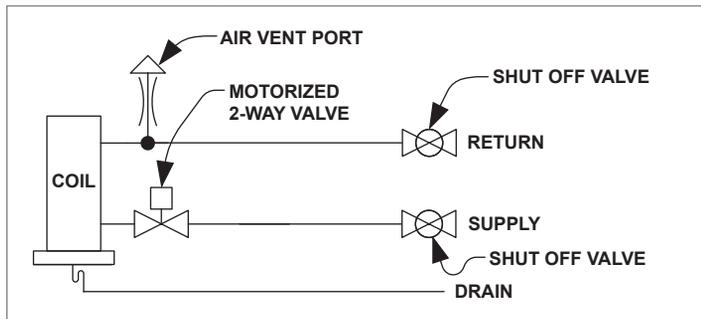
In high rise buildings such as apartments, condominiums, or hotels where the lay-out of each floor is very similar, utilizing vertical stack fan coil units in the design can decrease installation costs and simplify the scope of equipment to be supplied. Each floor can be “typical” of the ones above and below, and therefore use common supply, return, and condensate pipes. This common piping is known as a riser, and vertical stack fan coil units are pre-piped with riser piping. In riser systems, a two-pipe system would consist of three pipes, including the condensate return pipe, and a four-pipe system would consist of five pipes including the condensate return. If the piping provided is not long enough to connect from floor to floor, riser extensions can be installed to connect the unit to another unit on an adjacent floor. Riser extensions can also be used as the reducer, as the pipe diameter must decrease or increase to maintain head pressure and flow requirements. In order to accommodate for expansion and contraction of the fluid within the pipe due to temperature changes, vertical stack units are equipped with internal expansion loops.

**HYDRONIC SPECIALTIES**

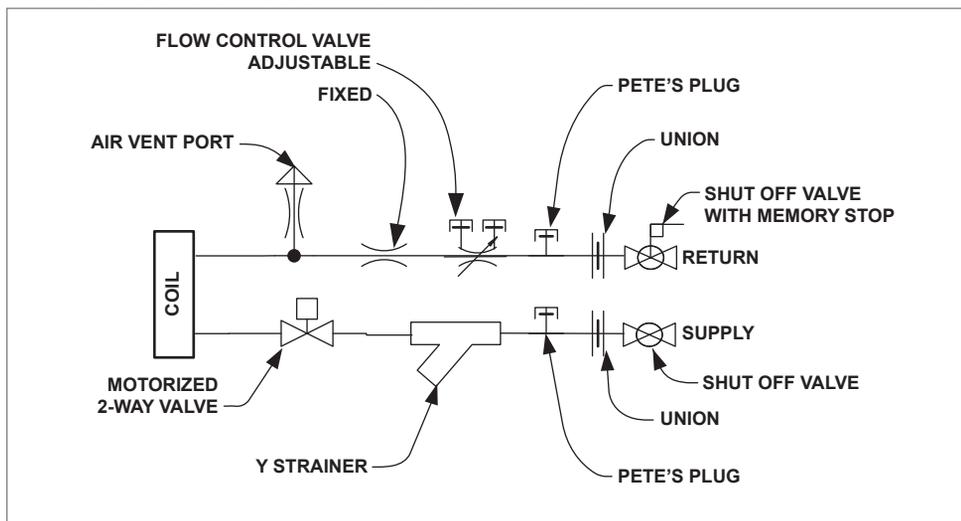
All hydronic systems require the use of various valves and fittings in order to provide flexibility, control flow, provide feedback and respond to feedback from the temperature control system, and accommodate changes in pressure and temperature. These items may be provided either by the installing contractor or may be installed at the factory. Unions can be provided for the connection of the water coil to the supply and return water lines; they allow the water coil to be removed from the unit without cutting into the water lines and soldering them together during installation and maintenance. Manual shut off valves, frequently ball valves, are located on both supply and return water lines to enable the coil to be isolated during installation and maintenance. Drain valves allow the coil to be drained during maintenance or removal. Pressure and temperature ports, also known as P&T or “Pete’s” plugs, can provide the installer or maintenance technician a tool for connecting a pressure gage for reading the water pressure at the coil. Circuit balancing valves, also known as CBVs or circuit setters, help to control the flow to the coil and often have an integrated pressure test port. Two-way and three-way valves that are “motorized” have actuators that are signaled by the thermostat to open and close and allow hot or cold water into the coils. “Y” strainers installed in the supply line upstream of the coil help remove sediment from the stream before it reaches the coil and causes blockages or damage. An Aquastat Switch can be installed in the water supply line and connected to the thermostat. Aquastats are most commonly used where there is a two-pipe system or supplemental electric heat. The Aquastat senses when the supply water is for heating or cooling. For a two-pipe system, if a zone thermostat is calling for heat and the supply water is cold, the thermostat will be locked out. For supplemental heat, the heat will be locked out when warm water is available in the supply lines.

**Fan Coil Introduction**

**FIGURE 10: 2-PIPE, 2-WAY VALVE, AND 2 SHUT OFF VALVES**



**FIGURE 11: 2-WAY VALVE COMPONENT OPTIONS**



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**Fan Coil Product Overview**

**HORIZONTAL STANDARD CAPACITY – HORIZON SERIES**

- Concealed unit for installation above ceiling with sidewall supply and plenum return.
- Concealed unit for installation above ceiling with sidewall supply, plenum return, and attenuated fan section.
- Recessed unit with sidewall supply and exposed return air section.
- Fully exposed unit with painted sheet metal enclosure.

**HORIZONTAL HIGH CAPACITY – HORIZON-X SERIES**

- Concealed unit for installation above ceiling with ducted supply and plenum or ducted return.
- Concealed unit with ducted supply and return with attenuated blower cabinet.
- Exposed unpainted sheet metal unit with ducted or in-space supply and/or return options.

**VERTICAL STANDARD CAPACITY – VEGA SERIES**

- Concealed unit for field provided custom cabinet installation.
- Exposed unit with painted sheet metal enclosure, flat top.
- Exposed unit with painted sheet metal enclosure, slanted top.
- Concealed unit for field provided custom low profile cabinet installation.
- Exposed unit with low profile painted sheet metal enclosure, flat top.

**VERTICAL HIGH CAPACITY - VEGA-X SERIES**

- Concealed vertical unit with ducted supply and plenum return.
- Concealed vertical unit with ducted supply and return.
- Concealed vertical unit with ducted supply and return with attenuated blower cabinet.
- Exposed vertical unit with ducted supply and painted sheet metal return enclosure.

**VERTICAL STACK – VESPER SERIES**

- Concealed Independent (pre-piped risers) unit for field provided custom cabinet installation.
- Exposed Independent (pre-piped risers) unit with painted enclosure.
- Exposed Independent primary unit with painted enclosure and pre-piped secondary connections.
- Exposed Dependent secondary unit with painted enclosure and pre-piped primary connections.
- Exposed Pre-paired primary/secondary unit with painted enclosures.

## Fan Coil Product Overview

### HORIZONTAL STANDARD CAPACITY – HORIZON SERIES

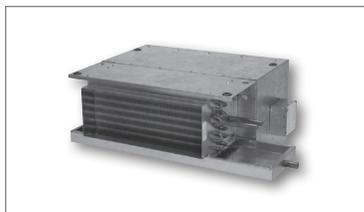
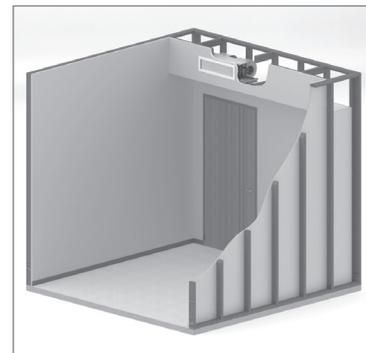
Horizontal fan coil units are most commonly utilized to provide comfort cooling and heating to a space and are typically mounted above or flush with the ceiling or in a soffit. Each fan coil unit may be controlled by a thermostat mounted in the space. Each unit consists of a fan section capable of supplying up to 1,200 CFM as well as chilled and/or hot water coils sized up to 5 combined rows. Various air filtration options are also available, as are a number of additional standard and optional features.



#### HFH

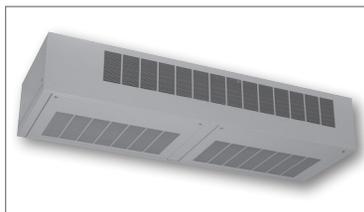
The Horizon HFH concealed horizontal fan coil unit is designed for above ceiling or soffit installation. Conditioned air is supplied horizontally through a sidewall supply air grille; return air is re-circulated through the unit via a plenum or ducted return system.

FIGURE 12



#### HFHP

The Horizon HFHP is also a concealed horizontal fan coil unit that is designed for above ceiling or soffit installation, but the fan section on this model is located within an insulated plenum for sound attenuation. Conditioned air is supplied horizontally through a sidewall supply air grille, and return air is re-circulated through the unit via plenum or ducted return.



#### HFEC

The Horizon HFEC horizontal fan coil unit, most commonly used in high-bay open areas, is designed to be installed in the space below the ceiling and is fully exposed. Return air is drawn in through return air grilles located on the bottom of the unit, and air is supplied into the space horizontally through a supply air grille in the side of the unit.



#### HFI

The Horizon HFI horizontal fan coil unit is designed for above ceiling or soffit installation but has a painted exposed return air grille and access panel. Conditioned air is supplied horizontally through a sidewall supply air grille; air is returned to the unit through the return air opening on the exposed face of the unit.

*NOTES: Custom design options may be available.  
Contact your sales representative for design assistance.*

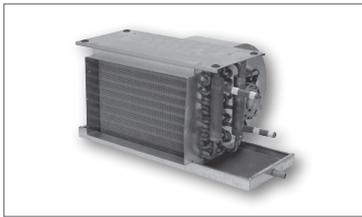
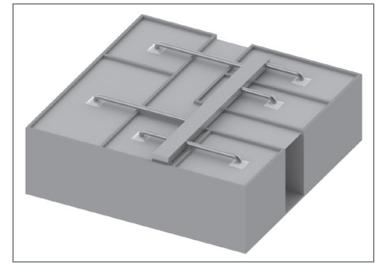
Product Overview

Fan Coil Product Overview

**HORIZONTAL HIGH CAPACITY – HORIZON-X SERIES**

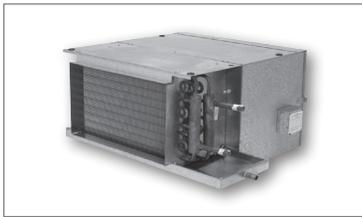
Horizontal fan coil units are most commonly utilized to provide comfort cooling and heating to a space and are typically mounted above or flush with the ceiling or in a soffit. Each fan coil unit may be controlled by a thermostat mounted in the space. Each high volume unit consists of a fan section capable of supplying up to 2,000 CFM as well as chilled and/or hot water coils sized up to 6 combined rows. Various air filtration options are also available, as are a number of additional standard and optional features. Due to sound levels and size constraints, high volume units are typically either mounted in plenum spaces in hallways or non-critical rooms with supply and return ducts running to and from the space that is to be conditioned. The use of a high volume unit may be to condition one large space or to condition air for a multi-room space if the rooms are similar in use and exposure.

FIGURE 13



**HGH**

The Horizon-X HGH concealed horizontal fan coil unit is designed for above ceiling or soffit installation. Conditioned air is distributed through one common duct to a large space or through a common duct serving branch lines throughout the space. Return air is supplied to the unit either via ducted return from the rooms, or room air return into the plenum where the fan coil unit is located.



**HGHP**

Like the Horizon-X HGH, The Horizon-X HGHP concealed horizontal fan coil unit is designed for above ceiling or soffit installation; however, the fan section on this model is located within an insulated plenum for sound attenuation. Conditioned air is distributed through one common duct to a large space or through a common duct serving branch lines throughout the space. Return air is supplied to the unit either via ducted return from the rooms, or room air return into the plenum where the fan coil unit is located.



**HGEC**

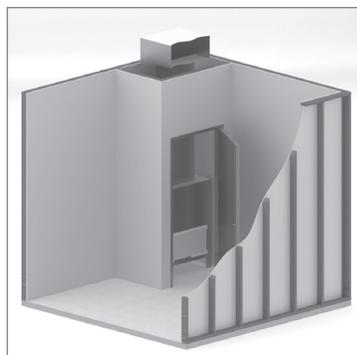
The Horizon-X HGEC is designed for larger spaces where noise is not a critical issue. This unit is provided in an unpainted galvanized cabinet to be mounted above the conditioned space and can be ducted to multiple spaces or discharged directly into the space.

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**VERTICAL HIGH CAPACITY - VEGA-X SERIES**

The Vega-X VGH concealed vertical floor mounted fan coil unit is designed to accommodate large spaces where easy access to the equipment for maintenance purposes is preferred. Typically, the unit is located in a closet within the conditioned space. Conditioned air is supplied through one common duct to a large space or through a common duct serving branch lines throughout the space. If the unit is contained within a closet, there must be a method by which to get the return air back into the space either via a ducted return system or through transfer air grilles in the door or walls of the enclosure.

FIGURE 14



VGH



Each high volume unit consists of a fan section capable of supplying up to 2,000 CFM as well as chilled and/or hot water coils sized up to 6 combined rows. Various air filtration options are available, as are a number of additional standard and optional features.

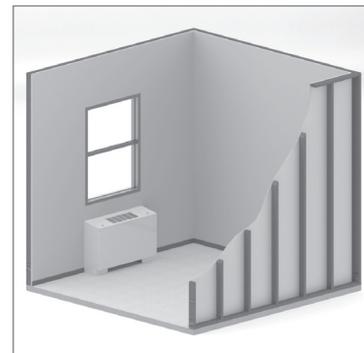
NOTES: Custom design options may be available.  
Contact your sales representative for design assistance.

## Fan Coil Product Overview

### VERTICAL STANDARD CAPACITY – VEGA SERIES

Vertical floor mounted fan coil units are frequently utilized to independently provide comfort cooling and heating within a room and/or to boost the efficiency of other heating and air conditioning system applications. Vertical fan coils, frequently referred to as cabinet unit heaters, are often located against walls beneath windows or along the perimeter of a room to accommodate maximum load requirements. Typically, each fan coil unit is controlled by a thermostat mounted either directly in the unit or within the space. Each unit consists of a fan section capable of supplying up to 1,200 CFM as well as chilled and/or hot water coils sized up to 5 combined rows. Various air filtration options are also available, as are a number of additional standard and optional features.

FIGURE 15



#### VFH

The Vega VFH concealed vertical floor mounted fan coil unit is designed for installation in field provided custom cabinets that are built to match the architectural features of the room. Conditioned air is supplied vertically into the space through a supply grille mounted atop the unit.



#### VFFC

The Vega VFFC exposed vertical floor mounted fan coil unit with a flat top is factory supplied in a painted sheet metal enclosure. Conditioned air is supplied vertically into the space through a supply grille mounted on a flat surface atop the unit.



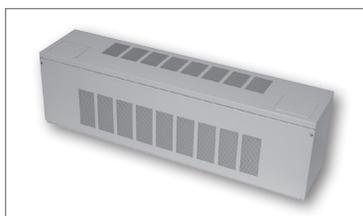
#### VFSC

The Vega VFSC exposed vertical floor mounted fan coil unit with a sloped top is factory supplied in a painted sheet metal enclosure. Conditioned air is supplied vertically into the space through a supply grille mounted on a sloped surface atop the unit; the sloping of the surface helps to discourage placing items over the supply openings on the top of the unit where they have the potential to interfere with the performance of the unit.



#### VFLH

The Vega VFLH is a low profile version of the standard VFH concealed vertical floor mounted fan coil unit. It is designed for installation in field-provided custom cabinets that are built to match the architectural features of the room, with specific consideration for height constraints, such as windows located lower on a wall. Due to the decrease in size, 600 CFM is the maximum volume of airflow this unit is capable of supplying.



#### VFCL

The Vega VFCL is a low profile version of the standard VFFC exposed vertical floor mounted fan coil unit with a flat top. It is factory supplied in a painted sheet metal enclosure with specific consideration for height constraints, such as windows that are located lower on the wall. Due to the decrease in size, the maximum volume of airflow the low profile unit is capable of supplying is 600 CFM.

*NOTES: Custom design options may be available.  
Contact your sales representative for design assistance.*

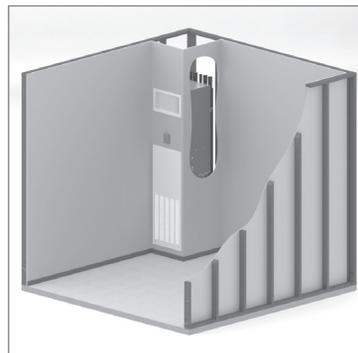
**Fan Coil Product Overview**

**VERTICAL STACK – VESPER SERIES**

Vertical stack units are ideal for high-rise applications such as hotels, condominiums, or apartments, where units will be placed in a “stack” pattern, one directly over another level by level. These units are equipped with factory or field installed supply, return, and drain piping risers that connect to the units above and/or below them decreasing field installation time and cost, as well as reducing construction site waste. The units are installed behind the wall or in a closet in the conditioned zone and are typically controlled by a thermostat located in the space.

Each unit consists of a blower capable of supplying up to 1,200 CFM and chilled and/or hot water coils sized up to 5 combined rows. Various air filtration options are also available, as are a number of additional standard and optional features. Some standard features include fiberglass casing insulation, riser slot knockouts, drain pans with drain connections, manual air vents on coils, and electrical enclosures with access doors for field wiring.

**FIGURE 16**



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**VPH**

The Vesper VPH is a vertical stack fan coil stand-alone type unit designed for installation in field provided custom cabinets, walls, or closets. The supply and return grilles are visible from the space.

**VPHP**

VPHP is a vertical stack recessed primary is identical to the VPH standalone unit with the exception that it is designed to connect to a secondary unit (VPHS) in the field. The VPHP comes with the risers and piping connections.



**VPHS**

The Vesper VPHS Vertical Stack Recessed Secondary is manufactured such that it is ready to connect to a VPHP primary unit in the field. The VPHS unit does not come with any risers or piping connections.



**VPIP/VPIS**

The Vesper VPIP/VPIS twin pack models are pre-piped to one another at the factory. The VPIP/VPIS system is controlled by a single thermostat. This system may be provided in a back to back or side by side configuration.

*NOTES: Custom design options may be available.  
Contact your sales representative for design assistance.*

## Heat Transfer Principles

Thermal energy, also known as heat, moves from higher temperature regions to lower temperature regions. This is known as “Heat Transfer”, and occurs by means of conduction, convection, radiation, or a combination of any of the three. When considering heat transfer theory, it is important to understand that although the methods may differ, there are other factors that apply to all three, such as:

- Heat lost or gained may be expressed in British Thermal Units per hour - BTU/h. This is the amount of energy required to raise one pound of water one degree Fahrenheit in one hour. Coefficients used to estimate the value of the heat transfer include:

**K-Factor** - The Thermal Conductivity Factor is the measure of a material’s ability to transfer heat. Materials which transfer heat readily have high k-factors; that is, they are highly conductive. The K-factor is a measure of heat transfer in BTU/h that will pass through 1 sq. ft. of material, 1” thick with a 1°F temperature difference between the two surfaces.

**C-Factor** - The Thermal Conductance Factor is the measure of heat transfer in BTU/h which will pass through 1 sq. ft. of material with a 1°F temperature difference between the two surfaces. The C-factor for a material 1” thick would be equal to the K-factor of the same material; the C-factor of the same material at three inches thick would be 1/3 of the K-factor.

**R-Value** - The Thermal Resistance Value is the measure of the ability of a material to slow heat flow. The higher the R-Value, the better the insulating properties of a material and the less conductive the material is. This is measured as the reciprocal of conductance. To determine R-Value, divide the thickness of an insulator by its K-factor ( $R = \text{Thickness}/K$ ) or calculate the reciprocal of C ( $R = 1/C$ )

**U-Coefficient** - “U” is the overall coefficient of conductivity, determined by adding the C-Factors of various materials and any applicable calculated C-Factors of air spaces. Higher U-Factors indicate higher conductivity, and thus lower resistance and poorer insulation values.  $U = C_1 + C_2 + C_3 + \dots + C_n$ .

- The greater the difference in temperature (expressed as  $\Delta T$ ), the greater the amount of heat transferred.
- Time and surface area are directly proportional to the amount of heat that is transferred.
- Thermal resistance of the materials involved in heat transfer has an impact on the rate of heat transfer.

### CONDUCTION

Thermal conduction is the mechanism of heat transfer that occurs due to molecular movement within a material, without any movement of the material itself. Conduction is the only method by which energy may be transferred through a solid. The rate of conduction heat transfer is expressed with the following equation:

$$q = k \left( \frac{(t_{s1} - t_{s2})A_c}{L} \right)$$

Where:

- q = Rate of heat transfer.
- K = Thermal conductivity of the conductive surface.
- L = Thickness of the conductive surface.
- A<sub>c</sub> = Area of the conductive surface.

t<sub>s1</sub> = Temperature on side (1) of the surface.

t<sub>s2</sub> = Temperature on side (2) of the surface.

### CONVECTION

Thermal convection is the transfer of heat that occurs via a similar mechanism to conduction, but with the transfer of energy being between the surface and a fluid in motion. The two types of convection are forced convection whereby the motion of the fluid is caused by an external force such as a fan, pump, wind, etc., and free/natural convection whereby the motion of the fluid is caused by buoyant forces such as when colder air falls and warmer air rises. The rate of convection heat transfer is expressed with the following equation:

$$q = h_c A_s (t_s - t_\infty)$$

Where:

q = Rate of convective heat transfer.

h<sub>c</sub> = Heat transfer coefficient in BTU/(h\*ft<sup>2</sup>\*°F)

A<sub>s</sub> = Area of the surface.

t<sub>s</sub> = Temperature of the surface.

T<sub>∞</sub> = Temperature of the fluid.

### RADIATION

Thermal radiation occurs when matter emits thermal radiation at its surface, in the form of photons of varying frequency. Radiation differs from conduction and convection, as both of the aforementioned methods of heat transfer require a material substrate whereas radiation requires no medium for photon transport and, in fact, can be impeded or prevented if the two surfaces cannot “see” each other. The net energy exchange rate is dependent upon the relative size, orientation, shape, temperature, emissivity, and absorptivity of the two surfaces.

Each method of heat transfer has an influence on an individual’s perception of heating and cooling comfort.

### FAN COIL SYSTEM

Fan coil units facilitate the transfer of heat to or from an occupied space by use of a closed loop water system including a heating and/or cooling coil. A coil consists of a tube (usually copper, which is very conductive) that passes through a series of fins (usually aluminum). The purpose of the copper tube is to carry hot or chilled water that has been conditioned by a boiler, chiller, heat pump, or other device. The fins, in contact with the copper tube, increase the surface area on which heat transfer may occur, therefore increasing the total capacity of the coil. Coils come in various types consisting of rows of tubing that are circuited through the coil in various configurations (i.e. – two row, two circuit). Fan coil units utilize a fan to actively move air across a hot water or chilled water coil to be supplied into the space. Mixed air is returned through a grille or plenum back into the fan coil unit, most often through a filter section, re-circulated through the coils and re-distributed into the space through a supply air outlet such as a sidewall supply grille.

During the cooling season, warm room, outside, or mixed air is moved across a coil that has chilled water circulating through the tube. The warm air passing across the tube loses heat through the process of convection. This drops the temperature of the air and increases the temperature of the tube, or more specifically, the fluid therein. The water that has gained the heat

## Room Load Calculations

### Heat Transfer Principles

from the air passes through the chilled water return piping back to the chiller for heat removal and re-circulation. Meanwhile, the air that has transferred its heat to the water and been cooled passes through the supply air duct and/or outlets and into the space.

In the heating season when the temperature in the space is lower than desired, the room thermostat or return air sensor will signal the hot water valve to the heating coil to open and hot water to start flowing through the coil. This hot water from the boiler circulates through the hot water coil in the fan coil unit as cold air from the space or outside air passes across the coil. The air gains heat from the water circulating within the coil. The water that has lost the heat to the air passes back through the hot water return piping back to the boiler to be re-heated and re-circulated.

### Room Load Calculations

Most fan coil systems are used for either small areas or systems, or as a supplementary source of conditioned air in larger systems. Heating and cooling load calculations are dependent upon the type of system being used, room “tightness” and infiltration, the local design conditions such as extreme hot or cold temperatures or humidity loads and building construction including window quantity and quality, exposures, and building materials.

It is important to consider climate when selecting a fan coil unit. For example, in a high humidity climate, if a unit is selected for a high heating load that may occur during the winter, the thermostat will signal the oversized unit to short cycle. This may result in uncomfortable levels of humidity in the space. If there are very few humid days in the summer, selecting for the higher heat load would be justified. If there are very few extreme low temperatures during the winter but several high humidity days in the cooling season, selecting a unit around the lower cooling airflow requirements would be appropriate.

Additional information and a detailed discussion of calculating the cooling and heating loads in a space can be found in the Air Conditioning Contractors Association (ACCA) Manual N for Commercial Load Calculation, and through ASHRAE TC-4.0 Technical Committee for Load Calculations.

The following are some equations commonly used for heating and cooling load calculations in a space.

#### Total Heat Transmission for a Structure with Multiple Skin Materials

$$U = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

Where:  
U = Material conductivity.  
R = Thermal resistance.

#### Heat Transfer Through a Window or Wall

$$Q = U * A (t_1 - t_2)$$

Where:  
Q = Heat load in Btu/H.  
U = Material conductivity.  
A = Area in feet.  
t<sub>1</sub> & t<sub>2</sub> = Temperatures in °F.

#### Exterior Surfaces, Cooling

$$Q = U * A * \Delta T$$

Where:  
Q = Heat load in Btu/H.  
U = Material conductivity.  
A = Area in feet.  
ΔT = Temperature difference across the component under consideration.

#### Heating and Non-Exterior Cooling

$$Q = U * A * \Delta T$$

Where:  
Q = Heat load in Btu/H.  
U = Material conductivity.  
A = Area in feet.  
ΔT = Temperature difference in °F between indoors and outdoors across the component under consideration, taking into account the combined effect of radiation, time lag, storage and temperature.

#### Sensible Heating and Cooling Load

$$Q = 1.08 * \text{cfm} * \Delta t$$

Where:  
Q = Heat load in Btu/H.  
1.08 = Constant for density at sea level.  
cfm = Volume of airflow calculated by area in square feet x velocity in feet per minute.  
Δt = Temperature difference between the supply air and the room control temperature.

#### Latent Cooling Load

$$Q = 0.68 * \text{cfm} * GR$$

Where:  
Q = Load in Btu/H.  
0.68 = Latent load constant.  
cfm = Volume of airflow calculated by area in square feet x velocity in feet per minute.  
GR = Difference between absolute humidity between indoor humidity/area and outdoor humidity/area.

## Psychrometrics

The term “Psychrometrics” relates to the understanding and use of an instrument (psychrometer) to determine atmospheric humidity by the reading of two thermometers; one of these readings would come from a thermometer with a bulb or “wick” that is kept moist, the other a standard or “dry” bulb reading. Data regarding psychrometrics can be found on a psychrometric chart, which includes the following properties for moist air:

- Dry Bulb Temperature
- Wet Bulb Temperature
- Relative Humidity, or “RH”
- Dew Point Temperature
- Humidity Ratio
- Total Heat (Enthalpy)
- Specific Volume

### DRY BULB TEMPERATURE

Dry bulb temperature is the temperature of a substance as read by a common thermometer. This is an indication of the sensible heat – the type of heat that causes a change in temperature as heat is added or removed but causes no change in state. Latent heat, on the other hand, causes a change of state but involves no change in temperature. The changes in state associated with latent temperature are:

- Freezing - Removing heat, changing state from liquid to solid.
- Melting - Adding heat; changing state from solid to liquid.
- Vaporization - Adding heat; changing state from liquid to vapor.
- Condensation - Removing heat; changing state from vapor to liquid.

Note that a substance requires the same amount of heat for each change of state; if one BTU is required to freeze one pound of water, one BTU is also required to melt one pound of ice. The same principle applies for boiling and condensing. This rule is consistent for all substances. On a psychrometrics chart, dry bulb is shown by vertical lines originating from the “x” axis on the bottom of the chart. More detail on sensible and latent heat is contained at the end of this guide.

### WET BULB TEMPERATURE

Wet bulb temperature is the temperature of a substance as read by a thermometer that has a wet wick over its sensing bulb, and is used to measure the water content of moist air. The drier the air, the more water will evaporate from the wick, which lowers the reading on the thermometer. For example, according to the National Climate Data Center’s data on annual average wet-bulb temperatures, between 1996-2010 the average wet-bulb temperature in a very humid climate such as Honolulu Hawaii was 69.5. In contrast, the average wet-bulb temperature in a more arid climate such as Las Vegas, Nevada, was 50.8. If the relative humidity of the air is 100%, the air is saturated and the dry bulb and wet bulb temperatures will be equal. Slanted similarly to enthalpy lines (yet not exactly parallel), wet bulb lines on a psychrometric chart originate from where the dry bulb lines intersect the saturation line, and slope down and to the right.

### RELATIVE HUMIDITY

Relative Humidity is the ratio of water vapor pressure in a given sample of air to the water vapor pressure that saturated air at the same temperature can hold. Achieving 30-35% RH for heating conditions and 45-60% for cooling conditions yields optimal space comfort conditions.

$$RH = \frac{\text{Amount of Moisture Air IS Holding}}{\text{Amount of Moisture that Air CAN Hold}}$$

The 100% RH line is the saturation line. Relative humidity lines at less than saturated conditions fall below and to the right of the saturation line.

### DEW POINT (DPT) TEMPERATURE

Dew Point (DPT) temperature is the temperature to which air must be cooled before condensation is possible. As heat is removed from air, the relative humidity of the air increases until it reaches 100 percent, or saturation. The temperature at which this occurs is the dew point. At saturation, the dew point, dry bulb, and wet bulb temperatures are equivalent. If warmer air (air that still contains moisture) is passed over a surface that is below the air’s dew point temperature, the moisture in the air will condense on the surface. Understanding the interaction between dew point and surface temperature is important in determining and preventing problems that may be associated with condensation occurring in an HVAC system. Dew point temperatures are shown on the saturation line.

Next, determine the DPT of the atmospheric air in contact with the surface. If the surface temperature is equal or lower than the DPT, the surface will form condensation.

### HUMIDITY RATIO

Humidity ratio (W), also known as “specific humidity”, is the actual weight of water vapor per pound of dry air and is expressed in pounds or grains. 7,000 grains is equal to one pound of water.

$$\text{Humidity Ratio} = \frac{\text{Pounds of Moisture}}{\text{Pounds of Dry Air}}$$

Humidity ratio lines on a psychrometric chart originate at the vertical axis on the right side and run horizontally across.

### ENTHALPY

Enthalpy refers to the total heat of a substance, expressed in British Thermal Units (BTU) per pound. If air is moist, enthalpy indicates the total heat in the air and water vapor mixture and is shown in BTU per pound of dry air. Dry air at 0°F has a total enthalpy of 0 BTU/lb. Enthalpy values are found on a psychrometric chart on a scale above and left of the saturation line. Lines with constant enthalpy slope down and to the right and appear to be, although they are not precisely, parallel to the wet bulb lines.

### SPECIFIC VOLUME

Specific Volume (SpV) is the reciprocal of density. Density is expressed in a unit of mass per unit of volume. Specific density is expressed as cubic feet of air-water vapor mixture per pound of dry air.

$$D = M/V \text{ and } SpV \text{ or Specific Volume} = V/M$$

Where: D = Density, M = Mass, V = Volume

Lines of specific volume slope up and to the left of their origin, the horizontal axis. See table 1 for specific volume correction factors at altitude.

**Psychrometrics**

Understanding how air density, for which the constant is 1.08 at sea level (SEE TABLE 2), relates to mass and volume is helpful in understanding many of the above properties that are calculated according to air masses, densities, and volumes. It is also helpful in understanding the impact of altitude on the properties of air. Standard psychrometric charts are calculated at sea level, but are often provided with the adjustments for a specific altitude in locations that frequently encounter designs at higher altitude conditions. In the heat load calculation formula, the air density ratio at altitude should be multiplied by the air density constant 1.08.

$$\frac{BTU}{h} = 1.08 (ADR) * CFM * \Delta T$$

The specific volume of standard air at a certain altitude can be calculated by multiplying with the volume correction factors in this table (below).

**TABLE 1: VOLUME CORRECTIONS AT ALTITUDE**

Altitude in Feet	Volume Correction Factor
0	1.00
1600	1.05
3300	1.11
5000	1.17
6600	1.24
8200	1.31

Changes in air density changes the physical and thermodynamic properties of air/water ratios in a mixture. Note that the air density is reduced by approximately 3.6% every 1,000 feet above 2,000 feet of altitude.

**SENSIBLE AND LATENT HEAT**

As previously discussed, sensible heating is that which causes an increase in temperature, whereas latent heat only causes a change in state. Latent and sensible are terms also used in reference to heating and cooling capacities. Total capacity is the sensible capacity, which is the capacity required to lower the temperature without effecting the moisture content of the air, along with latent capacity, which involves the capacity to remove the moisture from the air. As latent heat increases, moisture content increases. For example, water heated to 212°F will maintain that temperature even as heat is added. The temperature will not increase, but the water will vaporize. In regards to cooling: the continued removal of latent heat from the water at the freezing point will result in a decrease of moisture content and the change in state from liquid to solid, but will not lower the sensible temperature any further.

Sensible heat factor is the ratio of sensible heat to total heat. Utilizing a psychrometric chart, you can determine that the enthalpy for return air entering a cooling coil at 76°F at 50% RH is 28.7 by plotting the status point defined by the two parameters of temperature and humidity. The enthalpy for the resultant saturation temperature of 55°F @ 80% RH is 21.1. Subtracting 21.1 from 28.7 determines the total heat in this example - 7.6. Plotting the wet bulb temperatures, you can determine that the enthalpy at the wet bulb intersect at 60° is 26.5. To determine sensible heat, subtract the saturation temperature enthalpy 21.1 from the wet bulb enthalpy 26.5. Finally, to determine the sensible heat factor, divide the sensible heat 5.4 by the total heat 7.6, which results in a sensible heat factor of 0.71. Sensible heat factors are generally higher than .5 because cooling processes typically remove more sensible than latent heat. Sensible processes are typically shown in horizontal paths on the psych chart, vs. latent which are typically shown in vertical paths. Most of the processes that involve both result in angled or diagonal paths.

**TABLE 2: AIR DENSITY RATIO AT ALTITUDE**

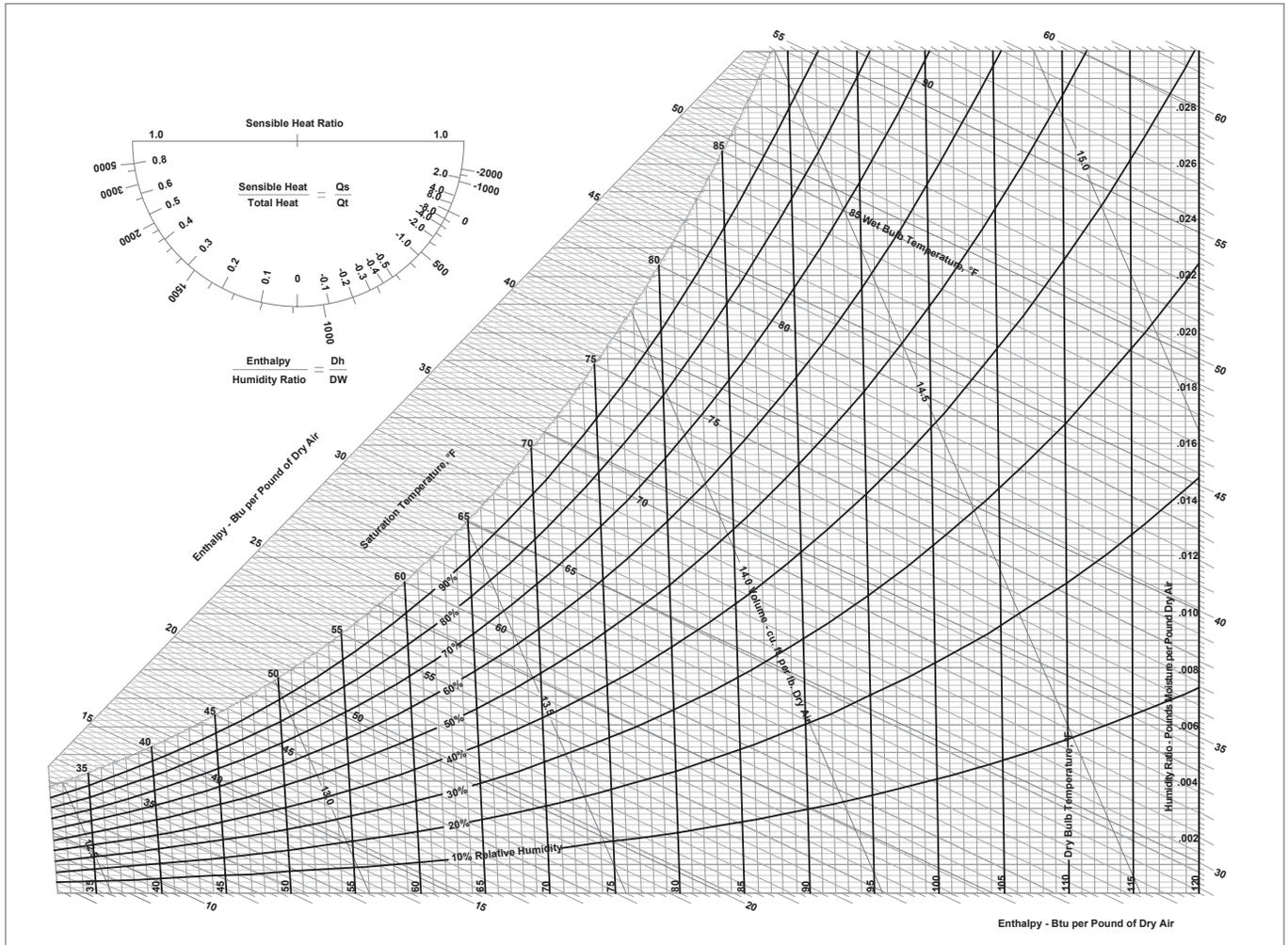
Altitude (Ft)	Air Density Ratio (Altitude / Sea Level)	Temperature (°F)	Barometric Pressure (mm Hg)	Barometric Pressure (in Hg)
0 ft (Sea Lvl)	1.0	59.0	750.0	29.53
1000	.9702	55.4	722.7	28.45
2000	.9414	51.9	696.3	27.41
3000	.9133	48.3	670.9	26.41
4000	.8862	44.7	646.4	25.45
5000	.8598	41.2	622.7	24.52
6000	.8342	37.6	599.8	23.62
7000	.8094	34.1	577.8	22.75
8000	.7853	30.5	556.6	21.91
9000	.7619	26.9	536.1	21.11
10,000	.7392	23.4	516.3	20.33
11,000	.7172	19.8	497.3	19.58
12,000	.6959	16.2	478.9	18.85
13,000	.6752	12.7	461.1	18.16
14,000	.6551	9.1	444.0	17.48

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**Psychrometrics**

**PSYCHROMETRIC CHART**



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