

Even when outdoor air is pretreated, a condensate removal system should be installed for fan-coil units and unit ventilators. Drain pans should be integral for all units. For floor-mounted units along the perimeter of the building, condensate piping can run from the drain pan to the exterior grade. Where drainage by gravity will not be sufficient, provide condensate pumps. Condensate drain lines should be properly sized and maintained to avoid clogging with dirt and other materials. Condensation may occur on the outside of drain piping, which requires that these pipes be insulated. Many building codes have outlawed systems without condensate drain piping because of the potential damage and possibility of mold growth in stagnant water accumulated in the drain pan.

Capacity Control
Fan-coil and unit ventilator capacity is usually controlled by coil water flow, fan speed, or a combination of these. In addition, unit ventilators often are available with a face-and-bypass damper, which allows for another form of capacity control. For additional information, see the discussion on capacity control in the section on System Components and Configurations.

Maintenance
Fan-coil and unit ventilator systems require more maintenance than central all-air systems, and the work must be done in occupied areas. Units operating at low dew points require regular (multiple times per year) cleaning and flushing of condensate pans and drains to prevent overflow and microbial build-up. Coils should be cleaned at least once a year, and more often when they consistently are removing moisture. The physical restraints of in-room terminal units located high in rooms or concealed in ceilings, soffits, etc., can create challenges for proper coil cleaning. Water valves, controls, and dampers should also be checked yearly for proper calibration, operation, and needed repairs.

To allow heating to occur in one space while cooling occurs in an adjacent space, heat pump/heat recovery condensing units must be used and a set of three refrigerant pipes (suction, liquid, and hot gas) must be piped out into the building to the in-room terminal units. A reversing valve must be provided for each of the in-room terminal units, to allow them to use either liquid refrigerant to cool, or hot gas to heat. The specifics of long-run refrigerant piping are discussed further in [Chapter 1 of the 2015 ASHRAE Handbook—Fundamentals](#), and most manufacturers of these type of systems have very specific installation instructions that must be followed. As with any system that runs refrigerant piping through occupied areas of a building, ASHRAE Standard 15 must be complied with, as well.

VRF systems are discussed in more detail in [Chapter 18](#).

6. VARIABLE-REFRIGERANT-FLOW (VRF) SYSTEMS

Technological advances in compressor design and control as well as use of electronically controlled expansion valves have allowed design of DX systems in which a single compressor unit provides refrigerant to multiple in-room terminal units. These types of systems are commonly called variable-refrigerant-flow (VRF) systems. Configuration of in-room units is similar to fan-coils, but uses a DX coil instead of water.

In these systems, refrigerant piping to terminal units is also called primary piping, and the compressor unit can often be more than 100 ft from the in-room terminal units.

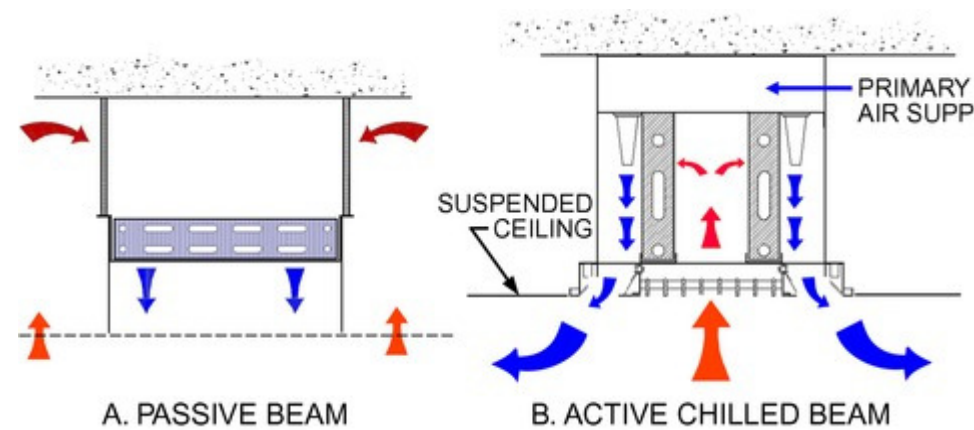
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7. CHILLED-BEAM SYSTEMS

Chilled beams are an evolution of chilled ceiling panels. Reports of energy savings over variable-air-volume (VAV) systems, especially in spaces with high concentrations of sensible loads (e.g., laboratories), have been touted in Europe and Australia. Applications such as health care, data centers, and some office areas may be well suited to chilled-beam systems.

Two types of chilled beams, passive and active, are in use ([Figure 2](#)). **Passive chilled beams** consist of a chilled-water coil mounted inside a cabinet. Chilled water is piped to the convective coil at between 58 and 60°F. Passive beams use convection currents to cool the space. As air that has been cooled by the beam's chilled-water coil falls into the space, warmer air is displaced, rises into the coil, and is cooled. Passive beams can provide approximately 400 Btu/ft and, to ensure proper dehumidification and effective ventilation to the spaces, require a separate ventilation system to provide tempered, dehumidified air. Heat can be provided by finned-tube radiation along the space perimeter. Overcooling must be avoided during cooling seasons, to prevent discomfort, condensation, and microbial growth in spaces. **Active chilled beams** can provide up to approximately 800 Btu/ft. They operate with induction nozzles that entrain room air and mix it with the primary or ventilation air that is ducted to the beam. Chilled water is piped to the coil at between 55 and 60°F. Primary air should be ducted to the beam at 55°F or lower to provide proper dehumidification. The primary air is then mixed with induced room air at a ratio of 1:2. For example, 50 cfm of primary air at 55°F may be mixed with 100 cfm of recirculated room air, and the active beam would distribute 150 cfm at around 65°F. If the low-temperature primary air alone will overcool spaces during any time of the year, there must be provision for reheat. Active beams can have either a two- or four-pipe distribution system. The two-pipe system may be cooling only or two-pipe changeover. Active beams can be designed to heat and cool the occupied space, but finned-tube radiation is still commonly used to provide heating in a space that is cooled with active beams.



Both active and passive beams are designed to operate dry, without condensate. In some models of active beams, a drain pan may be available if the coil is in a vertical configuration. Horizontal coils in passive beams cannot have drain pans, because the area directly below the coil is needed to allow the air in the convection current to circulate. Chilled beams can be used in various applications; however, they are best used in applications with high sensible loads, such as laboratory spaces with high internal heat gains. See manufacturers' information for beam cooling capacities at various water temperatures and flow rates. Several manufacturers have design guides available on the Internet.

The latest generation of chilled beams is multiservice: they can be either passive or active, and combine building operations such as lighting, security sensors, motion detectors, sprinkler systems, smoke detectors, intercoms, and power or fiber-optic distribution with the chilled beam. Proper implementation requires extensive integrated building design.

Types and Location
Passive beams are available in sections up to 10 ft long and 18 to 24 in. wide. They can be located above the ceiling with perforated panels below it, mounted into the frame of an acoustical tile ceiling, or mounted in the conditioned space. The perforated panels must have a minimum 50% free area and extend beyond either side of the beam for usually half of the unit's width, so the convection current is not hindered. Also, care must be taken to not locate passive beams too close to window treatments, which can also hinder air movement around the beam.

Active beams are available in sections up to 10 ft long and 12 to 24 in. wide. They can be mounted into the frame of an acoustical tile ceiling or in the conditioned space.

Ventilation Air Requirements
Passive beams require a separate ventilation system to provide tempered and dehumidified air to the space. The ventilation air should be ducted to low-wall diffusers or in an underfloor distribution system so that the ventilation air does not disturb the convection currents in the conditioned space. Ventilation air can be ducted directly into the active beams. If more ventilation air is needed to meet the space requirements, the volume of air can be split by the active beams and high-induction diffusers. Care must be taken in selecting diffuser locations to coordinate well with the convective currents required by the chilled beams.

Selection
Chilled beams are selected based on the calculated heat gain for the space less the cooling effect of the primary ventilation air.

Wiring
Chilled beams only require controls wiring. There is no fan or other electrical equipment to be wired.

Condensate
Chilled beams are designed to operate dry, with few exceptions. In some active beams with vertical coils, a drain pan may be installed. However, as a rule, a separate ventilation system should be sized to handle the latent cooling load in the space, and the relative humidity should be closely monitored. If the primary ventilation system fails to properly control the space humidity, condensation may form on the beams and their housings. Dripping of this condensate could damage building materials and contents.

Chilled-water valves should have drain pans to contain any normal condensate that occurs, when the space is properly dehumidified. In case of loss of humidity control of the space, uniped condensate drain pans will not be sufficient to avoid overflows and damage.

Capacity Control
Capacity of the chilled beam is controlled by a two-way valve on the chilled-water pipe, which is wired to a room thermostat. There is typically one valve per zone (e.g., office, lecture hall). Beams should be piped directly in a reverse/return piping design. Beams are not typically piped in series.

Maintenance
Maintenance on chilled beams requires blowing off the coils on a regular basis. Because coils are located throughout occupied spaces, this requires some coordination with occupants and housekeeping personnel to minimize effects on furniture and space contents.

Other Concerns
Consistent air movement with natural convection equipment is difficult to achieve. The designer should consult with the manufacturer to determine the proper spacing of chilled beams based on ceiling height, heat generation sources, occupant locations, and movement patterns. Prevention of cold air ponding on the floor, especially when heat sources vary, can be paramount in maintaining comfort. Occupant comfort is affected by more than temperature and humidity. Noise levels and nontagant air are also important. Some spaces may not achieve sufficient air movement or background noise to allow occupant comfort through use of passive chilled beams. Additionally, insufficient filtration of the air may occur without sufficient air movement and filtration devices in the space.

When introducing pretreated ventilation air to a space, be careful not to interfere with convection currents while still complying with the requirements of ventilation effectiveness and efficiency.

8. RADIANT-PANEL HEATING SYSTEMS

Radiant heating panels can use either hot water or electricity. The panels are manufactured in standard 24 by 24 or 24 by 48 in. panels that can be mounted into the frame of an acoustical tile ceiling or directly to an exposed ceiling or wall. Radiant panels are designed for all types of applications. They are energy efficient, providing a comfortable heat without lowering the moisture content of the room air the way heated air systems may. Occupants in a space heated by radiant heat are comfortable at lower room temperatures, which frequently reduces operational costs. See [Chapter 6](#) for more information on these systems.

Types and Location
Radiant panels are typically mounted on the ceiling near perimeter walls in a metal frame. Unlike finned-tube radiation, they do not limit furniture placement. Electric radiant panels are available from 250 to 750 W in standard single-phase voltages.

Ventilation Air Requirements
Radiant panels provide space heating. Ventilation air must be supplied by a central ventilation unit that can provide tempered, humidity-controlled air to the space.

Selection
Radiant panels are selected based on the calculated heat loss for the space.

Wiring
Electric radiant panels are available in standard single-phase voltages. Panels are often prewired, including the ground wire, with lead wires housed in flexible metal conduit and connector for junction box mounting.

Capacity Control
Panel capacity is usually controlled by coil water flow, or in the case of electric heat, capacity steps. Most radiant panels are controlled with a wall-mounted thermostat located in the space.

Maintenance
Because they have no moving parts, radiant panels require little maintenance. Water flow control valves require periodic verification that they are operating correctly.

9. RADIANT-FLOOR HEATING SYSTEMS

Radiant-floor heat is best applied under a finished floor that is typically cold to the touch. Radiant-floor heat systems in the past used flexible copper pipe heating loops encased in concrete. Unfortunately, the soldered joints could fail or the concrete's expansion and contraction or chemical composition could corrode the pipes, causing them to leak. However, new technologies include flexible plastic tubing (often referred to as PEX, or cross-linked polyethylene) to replace the old flexible copper tubing. PEX tubing is also available with an oxygen diffusion barrier, because oxygen entrained in the radiant heat tubing can cause corrosion on the ferrous connectors between the tubing and the manifold system. PEX tubing is also available in longer lengths than the flexible copper, which minimizes buried joints. The tubing is run back to a manifold system, which includes valves to balance and shut down the system and a small circulator pump. Multiple zones can be terminated at the same manifold.

Historically, radiant-floor heat was commonly designed for residential applications, when ventilation was provided by operable windows, and cooling was not mandatory. Like most other in-room terminal systems, the required ventilation air must be supplied by a central unit that can provide tempered and humidity-controlled air that allows comfort conditions in the space to be met. Common applications of radiant-floor heat systems include large open buildings, such as airplane hangars, where providing heat at the floor is more cost-effective than heating the entire volume of air in the space. Radiant-floor heat is becoming more common for preschools, elementary schools, exercise spaces, and other locations where children or adults sit or lie on floors. Water in the radiant-floor loop is often around 90°F, depending on the floor finish. This is a lower temperature than forced hot-air systems, and reduces the energy required to heat the building. Buildings that have high ceilings, large windows, or high infiltration rates or that require high air change rates may save energy by using radiant-floor heat.

Radiant-floor systems are commonly zoned by room. Each room may require multiple pipe circuits, depending on the room's area and the manifold's location. Maximum tubing lengths are determined based on tubing diameter and desired heat output. If tubing is installed in a slab on or below grade or over an unconditioned space, insulation should be incorporated to minimize heat losses. If a radiant-floor heat system is installed in a slab over a conditioned space, the radiant effect on that space must be considered as well.

See [Chapter 6](#) for more information on radiant panel heating systems.

Types and Location
Radiant-floor heating is located in the flooring or just below it with a heat-reflecting wrap. If the final floor finish is hardwood flooring, the radiant-floor piping can be installed in plywood tracks with a heat reflector, below the finished floor. Ensure that, as the final flooring is nailed down, the flexible tubing is not punctured. If the final floor is a ceramic tile or other surface requiring a poured concrete, the radiant floor can be laid out in the concrete, if hot-water systems are being used. Electric underfloor heating is also available, using a prefabricated mat that is applied on top of the subfloor and under with ceramic tile. Radiant-floor heating systems can also be mounted below the floor joists, with a heat reflector below the piping. This method is often used in renovations where removing existing flooring is not feasible.

Ventilation Air Requirements
Ventilation air must be supplied by a central ventilation unit that can provide tempered, humidity-controlled air to the space.

Selection
Spacing between rows of tubing that make up the radiant floor varies, depending on the heat loss of the space. Usually, the entire heat loss of the space is calculated and the tubing spaced accordingly. Another method is to place tubing closer together near the room's perimeter and increase the spacing in the interior. This method is more time consuming, and the difference is only noticeable in large spaces. Supply water temperature in the tubing is determined based on the flooring materials' resistance to heat flow, the temperature is a pad than for ceramic tile. The tubing is also available in different nominal diameters, the most common being 3/8 or 1/2 in.

Wiring
Circulator pumps at the manifolds require power. Additional controls for zone control valves may be selected for either line voltage or low voltage.

Capacity Control
Because radiant floors heat the mass of the floor, these systems are typically slow to respond to environmental changes. The circulator pumps start on a call for heat from a thermostat; however, rapid solar gains to a space with many windows could cause the space to overheat. Smart systems have been used to anticipate the needs of the space and overcome the thermal flywheel effects inherent to these types of systems. Smart systems anticipate the need for heating based on outdoor conditions and the conditions experienced in the recent past. They anticipate when set-point temperatures are about to be achieved and reduce heat generation, to minimize overshooting. They also learn patterns of operation that help overcome reasonably consistent daily solar gains.

Maintenance
The circulator pumps, valves, controls, and manifolds are the only components requiring maintenance. Once the tubing is laid out, it should be pressure-tested for leaks; once covered, it is extremely difficult and/or expensive to access.

10. INDUCTION UNIT SYSTEMS

Induction units are very similar to active chilled beams, although they have mostly been replaced by VAV systems. Only the specific differences of higher-pressure air induction units will be discussed here. Primary air is supplied to an induction unit's plenum at medium to high pressure. The acoustically treated plenum attenuates part of the noise generated in the unit and duct. High-velocity induction unit nozzles typically generate significant high-frequency noise. A balancing damper adjusts the primary-air quantity within limits.

Medium- to high-velocity air flows through the induction nozzles and induces secondary air from the room through the secondary coil. This secondary air is either heated or cooled at the coil, depending on the season, room requirement, or both. Ordinarily, the room coil does no latent cooling, but a drain pan without a piped drain collects condensed moisture from temporary latent loads such as at start-up. This condensed moisture then reevaporates when the temporary latent loads are no longer present. Primary and secondary (induced) air is mixed and discharged to the room.

Secondary airflow can cause induction-unit coils to become dirty enough to affect performance. Lint screens are sometimes used to protect these terminals, but require frequent in-room maintenance and reduce unit thermal performance.

Induction units are installed in custom enclosures, or in standard cabinets provided by the manufacturer. These enclosures must allow proper flow of secondary air and discharge of mixed air without imposing excessive pressure loss. They must also allow easy servicing. Although induction units are usually installed under a window at a perimeter wall, units designed for overhead installation are also available. During the heating season, the floor-mounted induction unit can function as a convector during off hours, with hot water to the coil and without a primary-air supply. Numerous induction unit configurations are available, including units with low overall height or with larger secondary-coil face areas to suit particular space or load needs.

Induction units may be noisier than fan-coil units, especially in frequencies that interfere with speech. On the other hand, white noise from the induction unit enhances acoustical privacy by masking speech from adjacent spaces.

In-room terminals operate dry, with an anticipated life of 15 to 25 years. Individual induction units do not contain fans, motors, or compressors. Routine service is generally limited to temperature controls, cleaning lint screens, and infrequently cleaning the induction nozzles.

In existing induction systems, conserving energy by raising the chilled-water temperature on central air-handling cooling coils can damage the terminal cooling coil, causing it to be used constantly as a dehumidifier. Unlike fan-coil units, the induction unit is not designed or constructed to handle condensation. Therefore, it is critical that an induction terminal operates dry.

Induction units are rarely used in new construction. They consume more energy because of the increased power needed to deliver primary air against the pressure drop in the terminal units, and they generate high-frequency noise from the induction nozzles. In addition, the initial cost for a four-pipe induction system is greater than for most all-air systems. However, induction units are still used for direct replacement renovation; because the architecture was originally designed to accommodate the induction unit, other systems may not be easily installed.

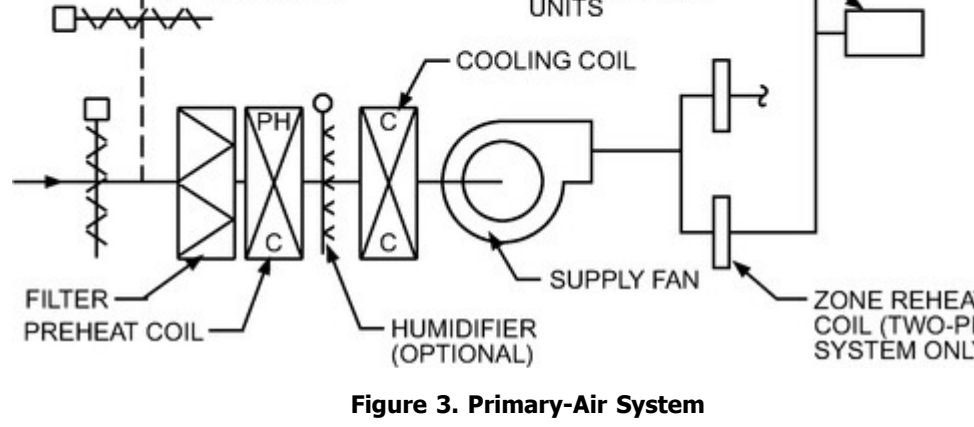
11. SUPPLEMENTAL HEATING UNITS

In-room supplemental heating units come in all sizes. Units can have either electric or hot-water heat, and sometimes steam; they can be surface-mounted, semirecessed, or recessed in the walls on the floor or horizontally along the ceiling. Baseboard radiation is usually located at the source of the heat loss, such as under a window or along a perimeter wall, and is usually rated for between 400 and 600 Btu/ft at 170°F. Other supplemental heating units include unit heaters, wall heaters, and cabinet heaters.

All supplemental heating units can be supplied with an integral or separate wall-mounted thermostat. If the heater is located low in the space, an integral thermostat is sufficient most of the time; however, if the unit is mounted horizontally near the ceiling, the thermostat should be wired so that it is located in the space, for accurate space temperature readings. In addition, units may have a summer fan option, which allows the fan to turn on for ventilation. Water flow to space supplemental heaters should be cut off anytime the water temperature to the coil is below 80°F, to avoid condensation and consequent damage or mold growth.

12. PRIMARY-AIR SYSTEMS

[Figure 3](#) illustrates a primary-air system for in-room terminal systems. The components are described in [Chapter 4](#). Some primary-air systems operate with 100% outdoor air at all times. In climates where moisture content is lower outdoors than indoors, systems using return air may benefit from a provision for operating with 100% outdoor air (economizer cycle) to reduce operating cost during some seasons. In some systems, when the quantity of primary air supplied exceeds the ventilation or exhaust required, excess air is recirculated by a return system common with the interior system. A good-quality filter (MERV = 8 to 10) is desirable in the central air treatment apparatus. If it is necessary to maintain a given humidity level in cold weather, a humidifier can usually be installed. Steam humidifiers have been used successfully. Water-spray humidifiers must be operated in conjunction with (1) the preheat coil elevating the temperature of the incoming air or (2) heaters in the spray water circuit. Water-spray humidifiers should be used with caution, however, because of the possible growth of undesirable organisms in untreated water. See [Chapter 22](#) for additional information on humidifiers.



The primary-air quantity is fixed, and the leaving primary-air temperature varies inversely with the outdoor temperature to provide the necessary amount of heating or cooling and humidity control. Proper leaving-air temperature must be determined based on climatic conditions and the influence of the ventilation air quantity on the final space temperature and relative humidity. In cooling season, many climates require primary air to be cooled to a point low enough to dehumidify the total system (cooling coil leaving temperature about 50°F or less, and almost completely saturated) and then reheated to be provided at an appropriate temperature and humidity level. During winter, primary air is often preheated and supplied at approximately 50°F to provide cooling. All room terminals in a given primary-air preheated zone must be selected to operate satisfactorily with the common primary-air temperature.

The supply fan should be selected at a point near maximum efficiency to reduce power consumption, supply air heating, and noise. Sound absorbers may be required at the fan discharge to attenuate fan noise.

Reheat coils are required in a two-pipe system. Reheat may not be required for primary-air supply of four-pipe systems. Formerly, many primary-air distribution systems for induction units were designed with 8 to 10 in. of water static pressure. With energy use restrictions, this is no longer economical. Good duct design and elimination of unnecessary restrictions (e.g., sound traps) can result in primary systems that operate at 4.5 to 6.0 in. of water or even lower. Low-initial-cost, smaller ductwork has to be weighed against operating costs during life-cycle evaluation, to provide a system that best meets the owner's long-term goals. Primary-air distribution systems serving fan-coil units can operate at pressures 1.0 to 1.5 in. of water or lower. Induction units and active chilled beams require careful selection of the primary-air cooling coil and the induction unit nozzles to achieve an overall medium-pressure primary-air system. Primary-air system distribution that is independently supplied to spaces for use with other in-room terminal systems may be low-velocity or a combination of low- and medium-velocity systems. See [Chapter 21 in the 2015 ASHRAE Handbook—Fundamentals](#) for a discussion of duct design. Variations in pressure between the first and last terminals should be minimized to limit the pressure drop required across balancing dampers.

Room sound characteristics vary depending on unit selection, air system design, and equipment manufacturer. Select units by considering the unit manufacturer's sound power ratings, desired maximum room noise level, and the room's acoustical characteristics. Limits of sound power level can then be specified to obtain acceptable acoustical performance. See [Chapter 8 in the 2013 ASHRAE Handbook—Fundamentals](#).

13. PERFORMANCE UNDER VARYING LOAD

Under peak load conditions, the psychrometrics of induction units, chilled beams, unit ventilators, and fan-coil unit systems are essentially identical for two- and four-pipe systems. Primary air mixes with secondary air conditioned by the room coil in an induction unit before delivery to a room. Mixing also occurs in a fan-coil unit with a direct-connected primary-air supply. If primary air is supplied to the space separately, as in fan-coil systems with independent primary-air supplies, the same effect occurs in the space.

During cooling, the primary-air system provides part of the sensible capacity and all of the dehumidification. The rest of the sensible capacity is accomplished by the cooling effect of secondary water circulating through the in-room terminal unit cooling coils. In winter, when primary air is provided directly into the in-room terminal unit, it can be provided at a low temperature and humidified if necessary. This may allow cooling of internal spaces solely by the primary air, if quantities are sufficient to meet the full cooling requirements. Room heating where needed is then supplied by the secondary-water system circulating through the in-room terminal unit coils.

If the economizer cycle is used, cooling energy can be reduced when the moisture level of the outdoor air allows. For systems where primary air does not enter at the terminal unit, the primary air should enter the room at a temperature approximately neutral with the desired room condition and a relative humidity level that enhances room conditions. In buildings where cooling is required during heating conditions, care must be taken to avoid drafts caused by providing primary air at too low a temperature.

If interior spaces require cooling, a four-pipe system should be considered to allow cooling of those areas while heating exterior perimeter zones. During fall and spring months, the primary-air temperature may be reduced slightly to provide the limited amount of cooling needed for east and west exposures with low internal heat gains, because solar heat gain is typically reduced during these seasons. In the northern hemisphere, the north exposure is not a significant factor because solar gain is very low; for south, southeast, and southwest exposures, the peak solar heat gain occurs in winter, coincident with a lower outdoor temperature ([Figure 4](#)). Reducing the primary-air temperature may not be a viable alternative where primary air is supplied directly to the space, because this air could overcool spaces where solar heat gain or internal heat gain is low.

In buildings with large areas of glass, heat transmitted from indoors to the outdoors, coupled with the normal supply of cool primary air, does not balance internal heat and solar gains until an outdoor temperature well below freezing is reached. Double-glazed windows with clear or heat-absorbing glass aggravate this condition, because this type of glass increases the heating effect of the radiant energy that enters during the winter by reducing reverse transmission. Therefore, cooling must be available at lower outdoor temperatures. In buildings with very high internal heat gains from lighting or equipment, the need for cooling from the room coil, as well as from the primary air, can extend well into winter. In any case, the changeover temperature at which the cooling capacity of the secondary-water system is no longer required for a given space is an important calculation. All these factors should be considered when determining the proper changeover temperature.

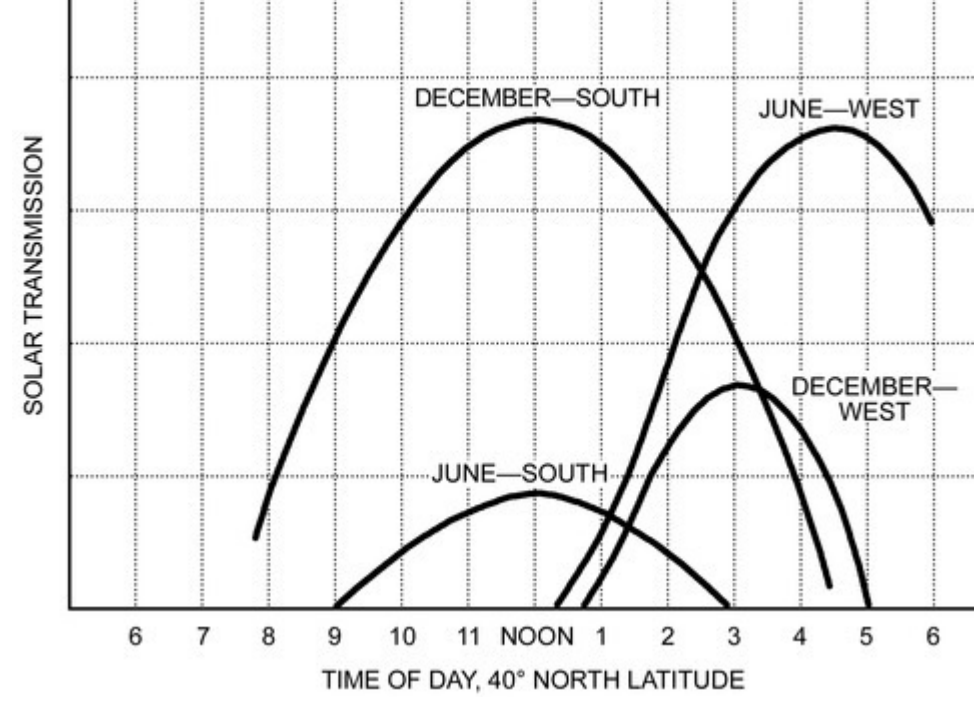


Figure 4. Solar Radiation Variations with Seasons

14. CHANGEOVER TEMPERATURE

For all systems using a primary-air system for outdoor air, there is an outdoor temperature (**balance temperature**) at which secondary cooling is no longer required. The system can cool by using outdoor air at lower temperatures. For all-air systems operating with up to 100% outdoor air, mechanical cooling is seldom required at outdoor temperatures below 55°F, unless the dew point of the outdoor air equals or exceeds the desired indoor dew point. An important characteristic of in-room terminal unit systems, however, is that secondary-water cooling may still be needed, even when the outdoor temperature is considerably less than 50°F. This cooling may be provided by the mechanical refrigeration unit or by a thermal economizer cycle. Full-flow circulation of primary air through the cooling coil below 50°F often provides all the necessary cooling while preventing coil freeze-up and reducing the preheat requirement. Alternatively, secondary-water-to-condense-water heat exchangers function well.

The outdoor temperature at which the heat gain to every space can be satisfied by the combination of cold primary air and the transmission loss is called the **changeover temperature**. Below this temperature, cooling is not required.

The following empirical equation approximates the changeover temperature at sea level. It should be fine-tuned after system installation (Carrier 1965):

$$t_{co} = t_r - \frac{q_{is} + q_{es} - 1.1 Q_p (t_r - t_p)}{\Delta q_{td}} \quad (1)$$

t_{co} = temperature of changeover point, °F
 t_r = room temperature at time of changeover, normally 72°F
 t_p = primary-air temperature at unit after system is changed over, normally 56°F
 Q_p = primary-air quantity, cfm
 q_{is} = internal sensible heat gain, Btu/h
 q_{es} = external sensible heat gain, Btu/h
 Δq_{tr} = heat transmission per degree of temperature difference between room and outdoor air

In two-pipe changeover systems, the entire system is usually changed from winter to summer operation at the same time, so the room with the lowest changeover point should be identified. In northern latitudes, this room usually has a south, southeast, or southwest exposure because the solar heat gains on these exposures reach their maximum during winter. If the calculated changeover temperature is below approximately 48°F, an economizer cycle should operate to allow the refrigeration plant to shut down. Although factors controlling the changeover temperature of in-room terminal systems are understood by the design engineer, the basic principles may not be readily apparent to system operators. Therefore, it is important that the concept and calculated changeover temperature are clearly explained in operating instructions given before operating the system. Some increase from the calculated changeover temperature is normal in actual operation. Also, a range or band of changeover temperatures, rather than a single value, is necessary to preclude frequent change in seasonal cycles and to grant some flexibility in operation. The difficulties associated with operator understanding and the need to perform changeover several times a day in many areas have severely limited the acceptability of the two-pipe changeover system.

15. TWO-PIPE SYSTEMS WITH CENTRAL VENTILATION

Two-pipe systems for in-room terminal systems derive their name from the water-distribution circuit, which consists of one supply and one return pipe. Each unit or conditioned space is supplied with secondary water from this distribution system and with conditioned primary air from a central apparatus. The system design and control of primary-air and secondary-water temperatures must be such that all rooms on the same system (or zone, if applicable) can be satisfied during both heating and cooling seasons. The heating or cooling capacity of any unit at a particular time is the sum of its primary-air output plus its secondary-water output. The secondary-water coil (cooling-heating) in each space is controlled by a space thermostat and can vary from 0 to 100% of coil capacity, as required to maintain space temperature. The secondary water is cold in summer and intermediate seasons and warm in winter. All rooms on the same secondary-water zone must operate satisfactorily with the same water temperature. Figure 5 shows the capacity ranges available from a typical two-pipe system. On a hot summer day, loads from about 25 to 100% of the design space cooling capacity can be satisfied. On a 50°F intermediate-season day, the unit can satisfy a heating requirement by closing off the secondary-water coil and using only the output of warm primary air. A lesser heating or net cooling requirement is satisfied by the cold secondary-water coil output, which offsets the warm primary air to obtain cooling. In winter, the unit can provide a small amount of cooling by closing the secondary coil and using only the cold primary air. Smaller cooling loads and all heating requirements are satisfied by using warm secondary water.

Critical Design Elements
The most critical design elements of a two-pipe system are the calculation of primary-air quantities and the final adjustment of the primary-air temperature reset schedule. All rooms require a minimum amount of heat and latent capacity from the primary-air supply during the intermediate season. Using the ratio of primary air to transmission per degree (A/T ratio) to maintain a constant relationship between the primary-air quantity and the heating requirements of each space fulfills this need. The A/T ratio determines the primary-air temperature and changeover point, and is fundamental to proper design and operation of a two-pipe system.

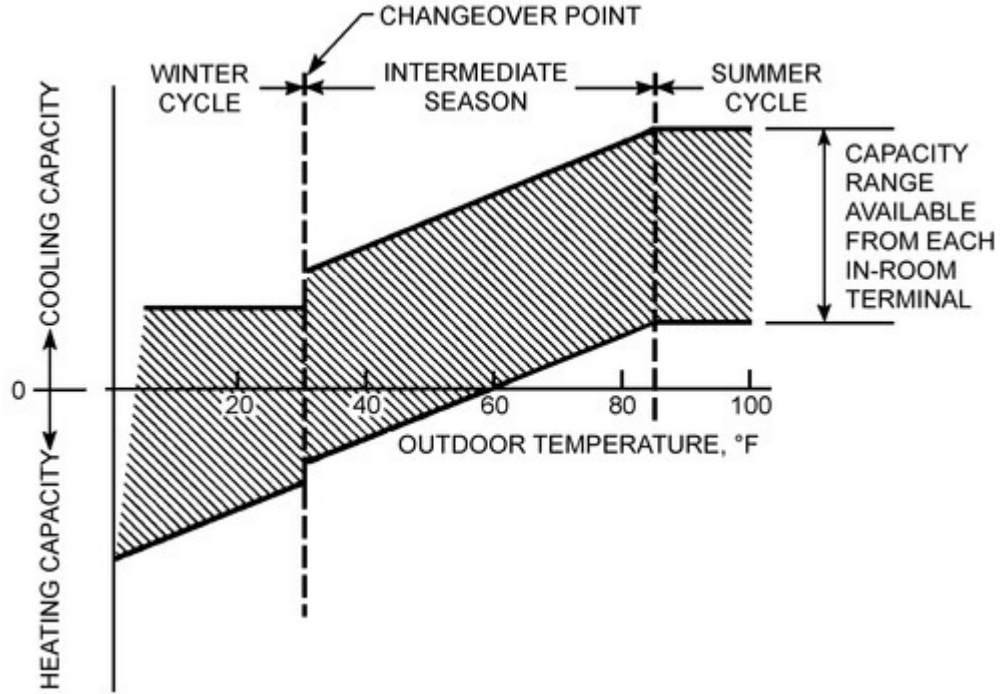


Figure 5. Capacity Ranges of In-Room Terminal Operating on Two-Pipe System

Transmission per Degree. The relative heating requirement of every space is determined by calculating the transmission heat flow per degree temperature difference between the space temperature and the outdoor temperature (assuming steady-state heat transfer). This is the sum of the (1) glass heat transfer coefficient times the glass areas, (2) wall heat transfer coefficient times the wall area, and (3) roof heat transfer coefficient times the roof area.
Air-to-Transmission (A/T) Ratio. The A/T ratio is the ratio of the primary airflow to a given space divided by the transmission per degree of that space: $A/T \text{ ratio} = \text{Primary air}/\text{Transmission per degree}$. Spaces on a common primary-air zone must have approximately the same A/T ratios. The design base A/T ratio establishes the primary-air reheat schedule during intermediate seasons. Spaces with A/T ratios higher than the design base A/T ratio tend to be overcooled during light cooling loads at an outdoor temperature in the 70 to 90°F range, whereas spaces with an A/T ratio lower than design lack sufficient heat during the 40 to 60°F outdoor temperature range when primary air is warm for heating and secondary water is cold for cooling.
The minimum primary-air quantity that satisfies the requirements for ventilation, dehumidification, and both summer and winter cooling is used to calculate the minimum A/T ratio for each space. If the system operates with primary-air heating during cold weather, the heating capacity can also be the primary-air quantity determinant for two-pipe systems. The design base A/T ratio is the highest A/T ratio obtained, and the primary airflow to each space is increased as required to obtain a uniform A/T ratio in all spaces. An alternative approach is to locate the space with the highest A/T ratio requirement by inspection, establish the design base A/T ratio, and obtain the primary airflow for all other spaces by multiplying this A/T ratio by the transmission per degree of all other spaces. For each A/T ratio, there is a specific relationship between outdoor air temperature and temperature of the primary air that maintains the room at 72°F or more during conditions of minimum room cooling load. Figure 6 illustrates this variation based on an assumed minimum room load equivalent to 10°F times the transmission per degree. A primary-air temperature over 122°F at the unit is seldom used. The reheat schedule should be adjusted for hospital rooms or other applications where a higher minimum room temperature is desired, or where a space has no minimum cooling load.

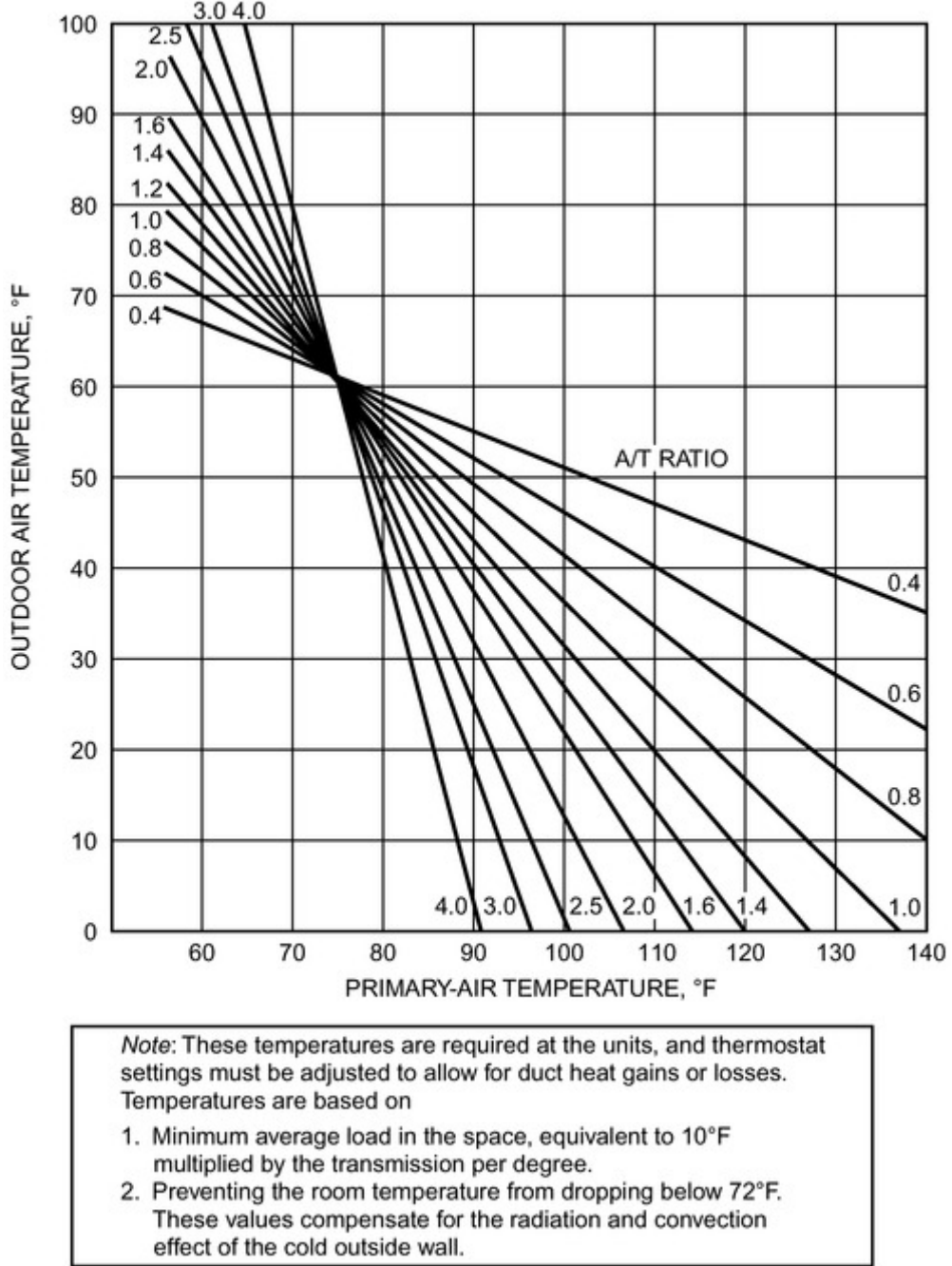


Figure 6. Primary-Air Temperature Versus Outdoor Air Temperature

Deviation from the A/T ratio is sometimes permissible. A minimum A/T ratio equal to 0.7 of the maximum A/T is suitable, if the building is of massive construction with considerable heat storage effect (Carrier 1965). The heating performance when using warm primary air becomes less satisfactory than that for systems with a uniform A/T ratio. Therefore, systems designed for A/T ratio deviation should be suitable for changeover to warm secondary water for heating whenever the outdoor temperature falls below 40°F. A/T ratios should be more closely maintained on buildings with large glass areas or with curtain wall construction, or on systems with low changeover temperature.
Changeover Temperature Considerations
Transition from summer operations to intermediate-season operation is done by gradually raising the primary-air temperature as the outdoor temperature falls, to keep rooms with small cooling loads from becoming too cold. The secondary water remains cold during both summer and intermediate seasons. Figure 7 illustrates the psychrometrics of summer operation near the changeover temperature. As the outdoor temperature drops further, the changeover temperature is reached. If the primary airflow is increased to some spaces to elevate the changeover temperature, the A/T ratio for the reheat zone is affected. Adjustments in primary-air quantities to other spaces on that zone will probably be necessary to establish a reasonably uniform ratio. System changeover can take several hours and usually temporarily upsets room temperatures. Good design, therefore, includes provision for operating the system with either hot or cold secondary water over a range of 15 to 20°F below the changeover point. This range makes it possible to operate with warm air and cold secondary water when the outdoor temperature rises above the daytime changeover temperature. Changeover to hot water is limited to times of extreme or protracted cold weather.

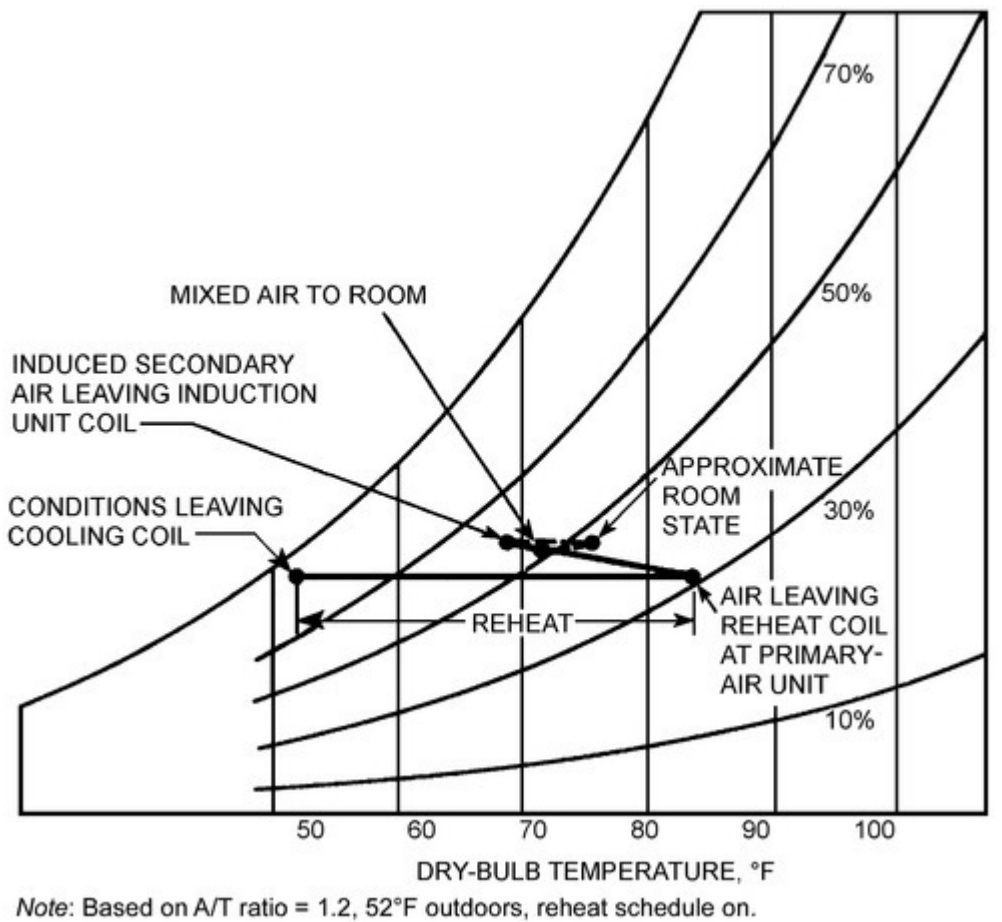


Figure 7. Psychrometric Chart, Two-Pipe System, Off-Season Cooling

Optional hot- or cold-water operation below the changeover point is provided by increasing the primary-air reheater capacity to provide adequate heat at a colder outdoor temperature. Figure 8 shows temperature variation for a system operating with changeover, indicating the relative temperature of the primary air and secondary water throughout the year and the changeover temperature range. The solid arrows show the temperature variation when changing over from the summer to the winter cycle. The open arrows show the variation when going from the winter to the summer cycle.
Nonchangeover Design
Consider using nonchangeover systems to simplify operation for buildings with mild winter climates, or for south exposure zones of buildings with a large winter solar load. A nonchangeover system operates on an intermediate-season cycle throughout the heating season, with cold secondary water to the terminal unit coils and with warm primary air satisfying all the heating requirements. Typical temperature variation is shown in Figure 9. Spaces may be heated during unoccupied hours by operating the primary-air system with 100% return air. This feature is necessary because nonchangeover design does not usually include the ability to heat the secondary water. In addition, cold secondary water must be available throughout the winter. Primary-air duct insulation and observance of close A/T ratios for all units are essential for proper heating during cold weather.

Zoning
A two-pipe system can provide good temperature control most of the time, on all exposures during the heating and cooling seasons. Comfort and operating cost can be improved by zoning in the following ways:

- Primary air to allow different A/T ratios on different exposures
- Primary air to allow solar compensation of primary-air temperature
- Both air and water to allow a different changeover temperature for different exposures

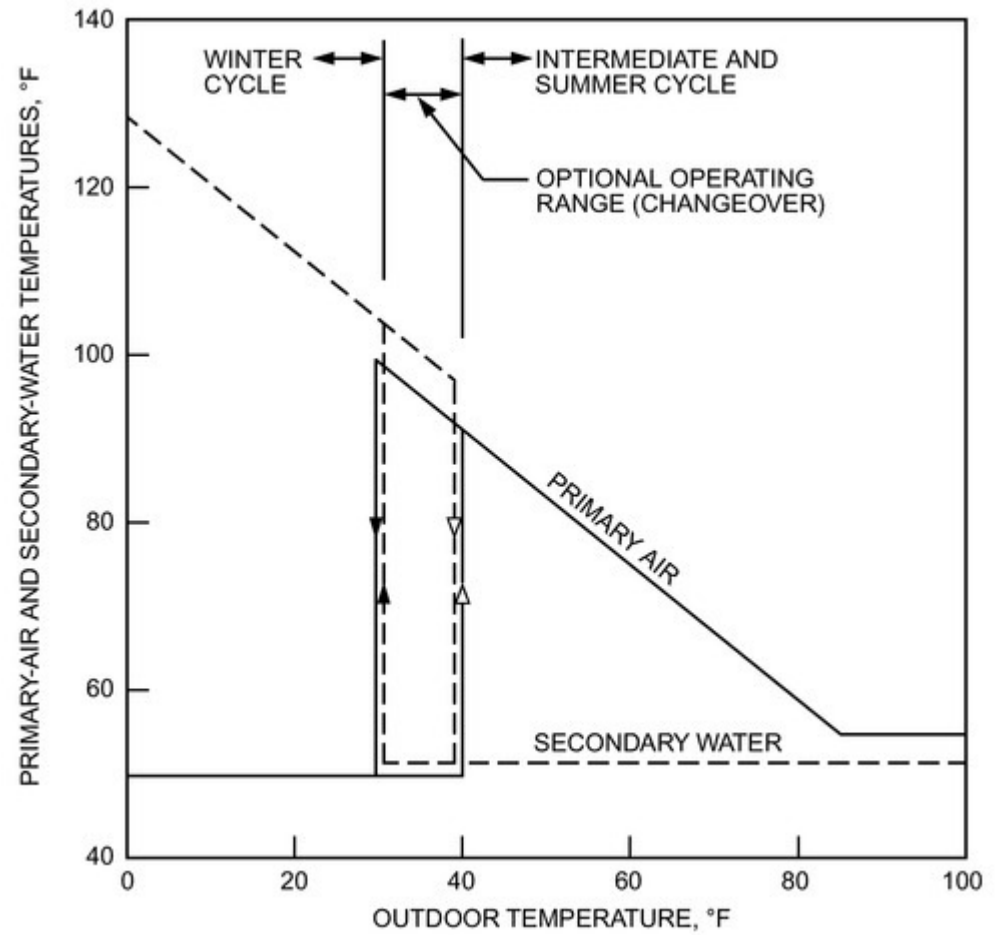


Figure 8. Typical Changeover System Temperature Variation

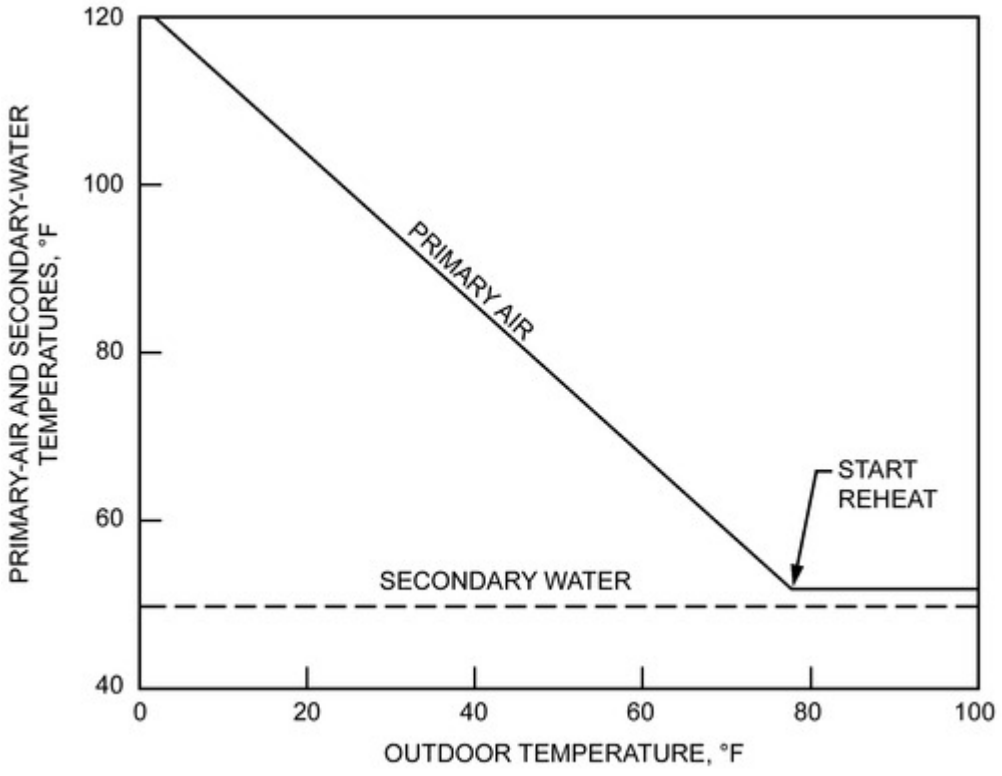


Figure 9. Typical Nonchangeover System Variations

All spaces on the same primary-air zone must have the same A/T ratio. The minimum A/T ratios often are different for spaces on different solar exposures, thus requiring the primary-air quantities to some exposures to be increased if they are placed on a common zone with other exposures. The primary-air quantity to units serving spaces with less solar exposure can usually be reduced by using separate primary-air zones with different A/T ratios and reheat schedules. Primary-air quantity should never be reduced below minimum ventilation requirements. The peak cooling load for the south exposure occurs during fall or winter when outdoor temperatures are lower. If shading patterns from adjacent buildings or obstructions are not present, primary-air zoning by solar exposure can reduce air quantities and unit coil sizes on the south. Units can be selected for peak capacity with cold primary air instead of reheated primary air. Primary-air zoning and solar compensators save operating cost on all solar exposures by reducing primary-air reheat and secondary-water refrigeration penalty. Separate air and water zoning may save operating cost by allowing spaces with less solar exposure to operate on the winter cycle with warm secondary water at outdoor temperatures as high as 60°F during the heating season. Systems with a common secondary-water zone must operate with cold secondary water to cool heavier solar exposures. Primary airflow can be lower because of separate A/T ratios, resulting in reheat and refrigeration cost savings.
Room Control
When room temperature rises, the thermostat must increase the output of the cold secondary coil (in summer) or decrease the output of the warm secondary coil (in winter). Changeover from cold to hot water in the unit coils requires changing the action of the room temperature control system. Room control for nonchangeover systems does not require the changeover action, unless it is required to provide gravity heating during shutdown.

Evaluation
Characteristics of two-pipe in-room terminal unit systems include the following:

- Usually less expensive to install than four-pipe systems
- Less capable of handling widely varying loads or providing a widely varying choice of room temperatures than four-pipe systems
- Present operational and control changeover problems, increasing the need for competent operating personnel

- More costly to operate than four-pipe systems

Electric Heat for Two-Pipe Systems

Electric heat can be supplied with a two-pipe in-room terminal unit system by a central electric boiler and terminal coils, or by individual electric-resistance heating coils in the terminal units. One method uses small electric-resistance terminal heaters for intermediate-season heating and a two-pipe changeover chilled-water/hot-water system. The electric terminal heater heats when outdoor temperatures are above 40°F, so cooling can be kept available with chilled water in the chilled-water/hot-water system. System or zone reheating of primary air is greatly reduced or eliminated entirely. When the outdoor temperature falls below this point, the chilled-water/hot-water system is switched to hot water, providing greater heating capacity. Changeover is limited to a few times per season, and simultaneous heating/cooling capacity is available, except in extremely cold weather, when little, if any, cooling is needed. If electric-resistance terminal heaters are used, they should be prevented from operating whenever the secondary-water system is operated with hot water.

Another method is to size electric resistance terminal heaters for the peak winter heating load and operate the chilled-water system as a nonchangeover cooling-only system. This avoids the operating problem of chilled-water/hot-water system changeover. In fact, this method functions like a four-pipe system, and, in areas where the electric utility establishes a summer demand charge and has a low unit energy cost for high winter consumption, it may have a lower life-cycle cost than hydronic heating with fossil fuel. A variation, especially appropriate for well-insulated office buildings with induction units where cooling is needed in perimeter offices for almost all occupied hours because of internal heat gain, is to use electric heaters in the terminal unit during occupied hours and to provide heating during unoccupied hours by raising primary-air temperature on an outdoor reset schedule.

16. FOUR-PIPE SYSTEMS

Four-pipe systems have a chilled-water supply, chilled-water return, hot-water supply, and hot-water return. The terminal unit usually has two independent secondary-water coils: one served by hot water, the other by cold water. During peak cooling and heating, the four-pipe system performs in a manner similar to the two-pipe system, with essentially the same operating characteristics. Between seasons, any unit can be operated at any level from maximum cooling to maximum heating, if both cold and warm water are being circulated, or between these extremes without regard to other units' operation.

In-room terminal units are selected by their peak capacity. The A/T ratio does not apply to four-pipe systems. There is no need to increase primary-air quantities on units with low solar exposure beyond the amount needed for ventilation and to satisfy cooling loads. The available net cooling is not reduced by heating the primary air. The changeover point is still important, though, because cooling spaces on the sunny side of the building may still require secondary-water cooling to supplement the primary air at low outdoor temperatures.

Zoning
Zoning primary-air or secondary-water systems is not required with four-pipe systems. All terminal units can heat or cool at all times, as long as both hot and cold secondary pumps are operated and sources of heating and cooling are available.

Room Control

The four-pipe terminal usually has two completely separated secondary-water coils: one receiving hot water and the other receiving cold water. The coils are operated in sequence by the same thermostat; they are never operated simultaneously. The unit receives either hot or cold water in varying amounts, or else no flow is present, as shown in [Figure 10B](#). Adjustable, dead-band thermostats further reduce operating cost.

[Figure 10B](#) illustrates another unit and control configuration. A single secondary-water coil at the unit and three-way valves located at the inlet and outlet admit water from either the hot- or cold-water supply, as required, and divert it to the appropriate return pipe. This arrangement requires a special three-way modulating valve, originally developed for one form of the three-pipe system. It controls the hot or cold water selectively and proportionally, but does not mix the streams. The valve at the coil outlet is a two-position valve open to either the hot or cold water return, as required.

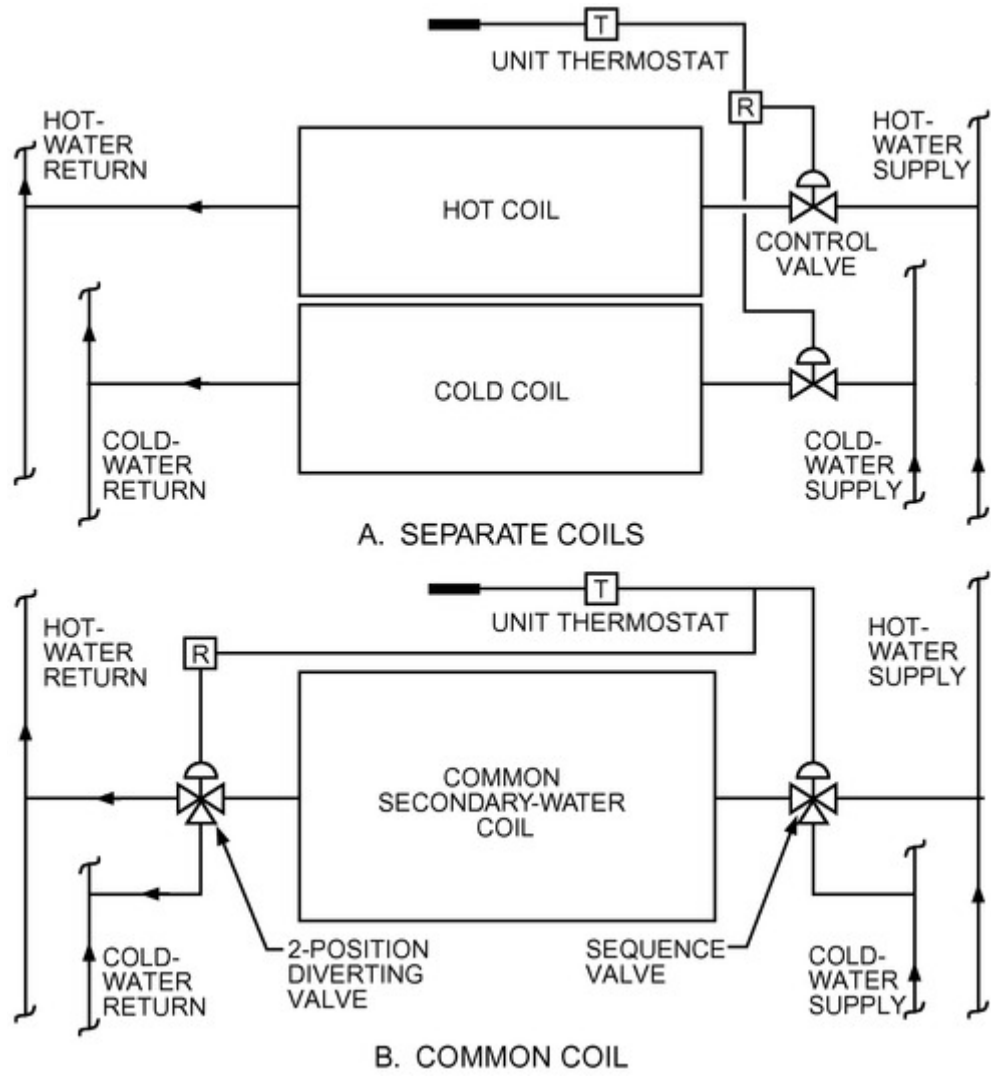


Figure 10. Fan-Coil Unit Control

Overall, the two-coil arrangement provides a superior four-pipe system. Operation of the induction and fan-coil unit controls is the same year-round.

Evaluation

Compared to the two-pipe system, the four-pipe air-and-water system has the following characteristics:

- More flexible and adaptable to widely differing loads, responding quickly to load changes
- Simpler to operate
- Operates without the summer-winter changeover and primary-air reheat schedule
- Efficiency is greater and operating cost is lower, though initial cost is generally higher
- Can be designed with no interconnection of hot- and cold-water secondary circuits, and the secondary system can be completely independent of the primary-water piping

17. AUTOMATIC CONTROLS AND BUILDING MANAGEMENT SYSTEMS

[Chapter 47 of the 2015 ASHRAE Handbook—HVAC Applications](#) and [Chapter 7 of the 2013 ASHRAE Handbook—Fundamentals](#) discuss automatic controls. The information and concepts discussed there apply to in-room terminal system equipment and systems, as well.

The designer should discuss the complexity, technical expertise, and local resources with the facility's owner/operator before specifying a overly complex or sophisticated control system, because many facilities using in-room terminal units have limited maintenance staff.

18. MAINTENANCE MANAGEMENT SYSTEMS AND BUILDING SYSTEM COMMISSIONING

[Chapter 1](#) discusses both of these topics. In-room terminal systems, like every other system, benefit from consideration and implementation of these practices.

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