

CHAPTER 3

IN-ROOM TERMINAL SYSTEMS

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IN-ROOM TERMINAL SYSTEMS condition spaces by distributing air and water sources to terminal units installed in habitable spaces throughout a building. In some systems the air is distributed to the space directly, not through the terminal unit. The air and water are cooled or heated in central equipment rooms. The air supplied is called primary or ventilation air; the water supplied is called secondary water. Sometimes a separate electric heating coil is included in lieu of a hot water coil. This chapter describes induction units and fan-coil units used in in-room terminal unit systems.

In-room terminal unit systems are applied primarily to exterior spaces of buildings with high sensible loads and where close control of humidity is not required. In some cases they may be applied to interior zones. They work well in office buildings, hospitals, hotels, schools, apartment buildings, and research laboratories. In most climates, these systems are installed in exterior building spaces and are designed to provide (1) all required space heating and cooling, (2) outside air for ventilation, and (3) simultaneous heating and cooling in different parts of the building during intermediate seasons.

EXTERIOR ZONE AIR-CONDITIONING LOADS

The variation in air-conditioning load for exterior building spaces causes significant variations in space cooling and heating requirements, even in rooms that have the same exposure. Accordingly, accurate environmental control in exterior building spaces requires individual control. The following basic loads must be considered.

Internal Loads. Heat gain from lights is always a cooling load, and in most buildings (other than residential) it is relatively constant during the day. Lights may be turned off manually or automatically when not required, which makes lighting loads more variable. Heat gain from occupants is also a cooling load and is commonly the only room load that contains a latent component. Heat gain from computers and other equipment can vary greatly and is an important factor in building design.

External Loads. Solar heat gain is always a cooling load. It is often the chief cooling load and is highly variable. For a given space, solar gain always varies during the day. The magnitude and rate of change of this load depend on building orientation, glass area, capacity to store heat, and cloud cover. Constantly changing shade patterns from adjacent buildings, trees, or exterior columns and nonuniform overhangs cause significant variations in solar load between adjacent offices on the same solar exposure.

Transmission load can be either a heat loss or a heat gain, depending on the outdoor temperature.

Moderate pressurization of the building with ventilation air is normally sufficient to offset summer infiltration provided it is uniformly positive. In winter, however, infiltration can cause a significant heat loss, particularly on the lower floors of high-rise buildings. The magnitude of this component varies with the wind

and stack effect, as well as with the temperature difference across the outside wall.

To perform successfully, an air-conditioning system must satisfy these load variations on a room-by-room basis and fulfill all other performance criteria, such as humidity control, filtration, air movement, ventilation, and noise.

SYSTEM DESCRIPTION

An in-room terminal unit system includes central air-conditioning equipment, a duct and water distribution system, and a room terminal. The terminal may be an **induction unit** or a **fan-coil unit**. Larger spaces may be handled by several terminals. Generally, the supply air volume is constant. (As noted in the first paragraph, supply air is called primary air or ventilation air to distinguish it from room air or secondary air that has been recirculated.) The quantity of primary air supplied to each space is determined by (1) the amount of outside air required for ventilation and (2) if used for sensible cooling, the required sensible cooling capacity at maximum room cooling load. In some low cost units with a fan coil, air for ventilation can be introduced through building apertures, which eliminates the primary air system.

In the cooling season, the air is dehumidified sufficiently in the central conditioning unit to maintain comfortable humidity conditions and to prevent condensation on the room cooling coil from the normal room latent load. In winter, moisture can be added centrally to limit dryness. As the air is dehumidified, it is also cooled to offset a portion of the room sensible loads. The air may be from outdoors, or may be a mixture of outdoor and return air. A preheater is usually required in areas with freezing weather. High-efficiency filters keep the induction unit nozzles clean. Whether or not reheaters are included in the air-handling equipment depends on the type of system, as explained in the section on Primary Air Systems.

In the ideal in-room terminal unit design, the secondary cooling coil is always dry; this greatly extends terminal unit life and eliminates odors and the possibility of bacterial growth. The primary air normally controls the space humidity. Therefore, the moisture content of the supply air must be low enough to offset the room latent heat gain and to maintain a room dew point low enough to preclude condensation on the secondary cooling surface. But even though some systems operate successfully with little or no condensate, a condensate drain is recommended for in-room terminal units.

In existing induction systems, the energy conservation technique of 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.

The water side, in its basic form, consists of a pump and piping to convey water to the heat transfer surface in each conditioned space. The water can be cooled by direct refrigeration, but it is more commonly cooled either by bleeding chilled water from the primary

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cooling system into the secondary water system or by transferring heat through a water-to-water exchanger. To distinguish it from the primary chilled water circuit, the water side is usually referred to as the secondary water loop or system.

In-room terminals are categorized as two-pipe, three-pipe, or four-pipe systems. They are basically similar in function and include both cooling and heating capabilities for year-round air conditioning. Sections at the end of this chapter discuss these piping arrangements in detail. [Chapter 12](#) discusses the arrangements of the secondary water circuits and their control systems, which differ depending on the type of secondary water.

INDUCTION UNITS

[Figure 1](#) shows a basic arrangement for an induction unit terminal. Centrally conditioned primary air is supplied to the unit plenum at medium to high pressure. The acoustically treated plenum attenuates part of the noise generated in the unit and duct. 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. Thus the primary air provides the energy required to circulate the secondary air over the coil in the terminal unit. This secondary air is either heated or cooled at the coil, depending on the season, the 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 startup. This condensed moisture then re-evaporates when the temporary latent loads are no longer present. Primary and secondary air is mixed and discharged to the room.

A lint screen is normally placed across the face of the secondary coil. Induction units are installed in custom enclosures designed for the particular installation or in standard cabinets provided by the manufacturer. These enclosures must permit proper flow of secondary air and discharge of mixed air without imposing excessive pressure loss. They must also allow easy servicing.

Induction units are usually installed under a window at a perimeter wall, although units designed for overhead installation are 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. A number of 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.

Advantages

- Individual room temperature control allows the adjustment of each thermostat for a different temperature at relatively low cost.

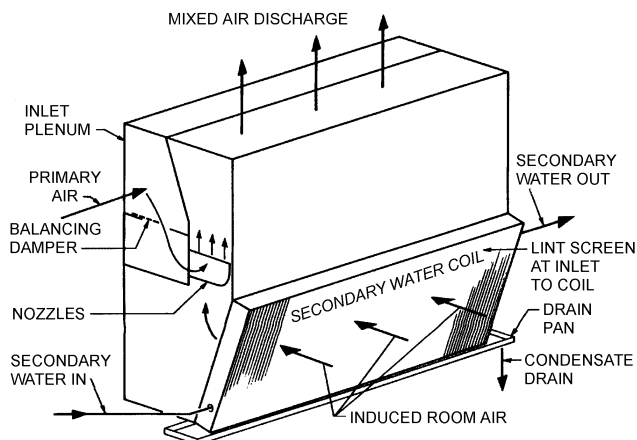


Fig. 1 Induction Unit

- Separate heating and cooling sources in the primary air and secondary water give the occupant a choice of heating or cooling.
- Less space is required for the distribution system when the air supply is reduced by using secondary water for cooling and high-velocity air. The return air duct is smaller and can sometimes be eliminated or combined with the return air system for other areas, such as the interior spaces.
- The size of the central air-handling apparatus is smaller than that of an all air system because little air must be conditioned.
- Dehumidification, filtration, and humidification are performed in a central location remote from conditioned spaces.
- Ventilation air supply is positive and may accommodate recommended outside air quantities.
- Space can be heated without operating the air system via the secondary water system. Nighttime fan operation is avoided in an unoccupied building. Emergency power for heating, if required, is much lower than for most all-air systems.
- Components are long-lasting. Room terminals operated dry have an anticipated life of 15 to 25 years. The piping and ductwork longevity should equal that of the building. Individual induction units do not contain fans, motors, or compressors. Routine service is generally limited to temperature controls, cleaning of lint screens, and infrequent cleaning of the induction nozzles.

Disadvantages

- For most buildings, these systems are limited to perimeter space; separate systems are required for other areas.
- More controls are needed than for many all-air systems.
- Secondary airflow can cause the induction unit coils to become dirty enough to affect performance. Lint screens used to protect these terminals require frequent in-room maintenance and reduce unit thermal performance.
- The primary air supply usually is constant with no provision for shutoff. This is a disadvantage in residential applications, where tenants or hotel room guests may prefer to turn off the air conditioning, or where management may desire to do so to reduce operating expense.
- A low primary chilled water temperature is needed to control space humidity adequately.
- The system is not appropriate for spaces with high exhaust requirements (e.g., research laboratories) unless supplementary ventilation air is provided.
- Central dehumidification eliminates condensation on the secondary water heat transfer surface under maximum design latent load. However, abnormal moisture sources (e.g., from open windows or people congregating) can cause condensation that can have annoying or damaging results.
- Energy consumption for induction systems is higher than for most other systems due to the increased power required by the primary air pressure drop in the terminal units.
- The initial cost for a four-pipe induction system is greater than for most all-air systems.

FAN-COIL UNITS

Fan-coil unit systems include cooling as well as heating, normally move air by forced convection through the conditioned space, filter the circulating air, and introduce outside ventilation air. Fan-coil units with chilled water coils, heating coils, blowers, replaceable air filters, drain pans for condensate, etc., are designed for these purposes. These units are available in various configurations to fit under window sills, above furred ceilings, in vertical pilasters built into walls, etc. These units must be properly controlled by thermostats for heating and cooling temperature control, by humidistats for humidity control, by blower control or other means for regulating air quantity, and they must have a method for adding ventilation air into the building.

Basic elements of fan-coil units are a finned-tube coil, filter, and fan section (Figure 2). The fan recirculates air continuously from the space through the coil, which contains either hot or chilled water. The unit may contain an additional electric resistance, steam, or hot water heating coil. The electric heater is often sized for fall and spring to avoid changeover problems in two-pipe systems.

A cleanable or replaceable 35% efficiency filter, located upstream of the fan, prevents clogging of the coil with dirt or lint entrained in the recirculated air. It also protects the motor and fan, and reduces the level of airborne contaminants in the conditioned space. The fan-coil unit is equipped with an insulated drain pan. The fan and motor assembly is arranged for quick removal for servicing. Most manufacturers furnish units with cooling performance certified as meeting Air-Conditioning and Refrigeration Institute (ARI) standards. The prototypes of the units have been tested and labeled by Underwriters' Laboratories (UL), or Engineering Testing Laboratories (ETL), as required by some codes.

Fan-coil units, with a dampered opening for connection to apertures in the outside wall, are available. These units are not suitable for commercial buildings because wind pressure allows no control over the amount of outside air that is admitted. Also,

freeze protection may be required in cold climates. However they are often used in residential construction because of simplicity of operation, low first cost, and the operable windows can unbalance a duct ventilation air system. Fan-coil units for the domestic market are generally available in nominal sizes of 200, 300, 400, 600, 800, and 1200 cfm, often with multispeed, high-efficiency fan motors. Where units do not have individual outside air intakes, means must be provided to introduce retreated outside air through a duct system that engages each room or space.

Types and Location

Fan-coil units are available in many configurations. Figure 3 shows several vertical units. Low vertical units are available for use under windows with low sills; however, in some cases, the low silhouette is achieved by compromising such features as filter area, motor serviceability, and cabinet style.

Floor-to-ceiling, chase-enclosed units are available in which the water and condensate drain risers are part of the factory-furnished unit. These units are used extensively in hotels and other residential buildings. The supply and return air must be isolated from each other to prevent air and sound interchange between rooms.

Vertical models or chase enclosed models located at the perimeter give better results in climates or buildings with high heating requirements. Heating is enhanced by under-window or exterior wall locations. Vertical units can be operated as convectors with the fans turned off during night setback.

Horizontal overhead units may be fitted with ductwork on the discharge to supply several outlets. A single unit may serve several rooms (e.g., in an apartment house where individual room control is not essential and a common air return is feasible). Units must have larger fan motors designed to handle the higher pressure drops of ductwork.

Horizontal models conserve floor space and usually cost less, but when located in furred ceilings, they create problems such as condensate collection and disposal, mixing of return air from other rooms, leakage of pans causing damage to ceilings, difficulty of access for filter and component removal, and air quality concerns.

When outside air is introduced from a central ventilation system it may be connected directly to the inlet plenums of horizontal units or introduced directly into the space. If introduced directly, provisions

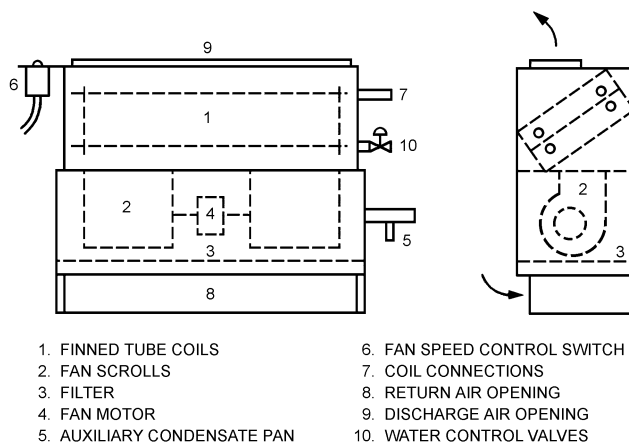


Fig. 2 Typical Fan-Coil Unit

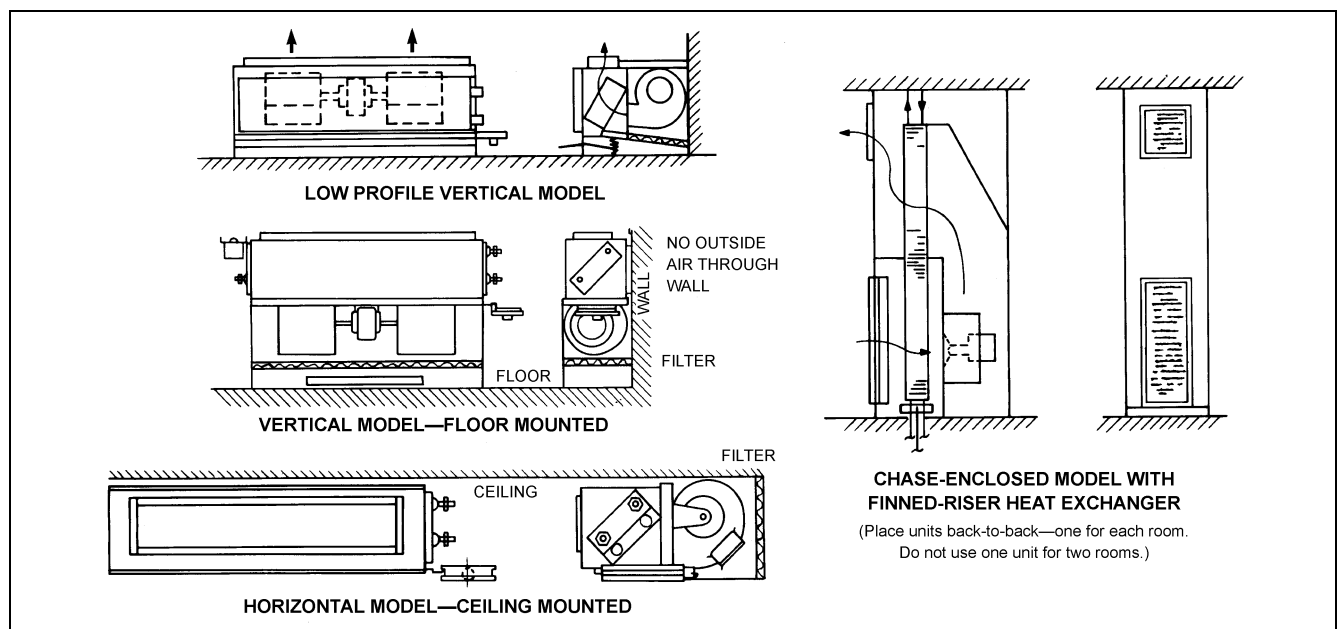


Fig. 3 Typical Fan-Coil Unit Arrangements

should be made to ensure that this air is pretreated and held at a temperature equal to the room temperature so as not to cause occupant discomfort when the unit is off. One way to prevent air leakage is to provide a spring-loaded motorized damper that closes off the ventilation air whenever the unit's fan is off. Coil selection must be based on the temperature of the entering mixture of primary and recirculated air, and the air leaving the coil must satisfy the room sensible and latent cooling and heating requirements.

Selection

Some designers size fan-coil units for nominal cooling at the medium speed setting when a three-speed control switch is provided. This method ensures quieter operation in the space and adds a safety factor, in that capacity can be increased by operating at high speed. Sound power ratings are available from many manufacturers.

Only the internal space heating and cooling loads need to be handled by the terminal fan-coil units when outside air is pretreated by a central system to a neutral air temperature of about 70°F. This pretreatment should reduce the size and cost of the terminal units. All loads must be considered when outside air is introduced directly through building apertures.

Wiring

Fan-coil conditioner fans are driven by small motors, generally shaded pole or capacitor start with inherent overload protection. Operating wattage of even the largest sizes rarely exceeds 300 W at the high speed setting. Running current rarely exceeds 2.5 A. Almost all motors on units in the United States are 120 V, single-phase, 60 Hz current, and they provide multiple (usually three) fan speeds and an off position. Other voltages and power characteristics may be encountered, depending on location, and should be investigated before determining the fan motor characteristics.

In planning the wiring circuit, required codes must be followed. Wiring methods generally provide separate electrical circuits for fan-coil units and do not connect them into the lighting circuit.

Separate electrical circuits connected to a central panel allow the building operator to turn off unit fans from a central point during unoccupied hours. While this panel costs more initially, it can lower operating costs in buildings that do not have 24 hour occupancy. In hot and humid climates care must be taken to avoid excess humidity when units are off to avoid formation of mildew. Use of separate electrical circuits allows a single remote thermostat to be mounted in a well-exposed perimeter space to operate unit fans.

Piping

Even when outside air is pretreated, a condensate removal system should be installed for fan-coil units. This precaution ensures that moisture condensed from air from an unexpected open window that bypasses the ventilation system is removed. Drain pans are an integral feature of all units. Condensate drain lines should be oversized to avoid clogging with dirt and other materials, and provision should be made for periodic cleaning of the condensate drains. Condensation may occur on the outside of the drain piping, which requires that these pipes be insulated. Many building codes have outlawed systems without condensate drain piping due to the damage they could cause.

Capacity Control

Fan-coil unit capacity is usually controlled by coil water flow, fan speed, or a combination of these. Water flow can be thermostatically controlled by either return air or wall thermostats.

Fan speed control may be automatic or manual. Automatic control is usually on-off with manual speed selection. Units are available with variable-speed motors for modulated speed control. Room thermostats are preferred where automatic fan speed control is used. Return air thermostats do not give a reliable index of room

temperature when the fan is off. Residential fan-coil units have manual three-speed fan control with the water temperature, both heating and cooling, scheduled by outside temperature. On-off speed control is poor because (1) alternating shifts in fan noise level are more obvious than the sound of a constantly running fan, and (2) air circulation patterns within the room are noticeably affected.

Maintenance

Room fan-coil units are equipped with either filters that should be cleaned or replaced when dirty. Good filter maintenance improves sanitation and provides full airflow, ensuring full capacity. The frequency of cleaning varies with the application. Units in apartments, hotels, and hospitals usually require more frequent filter service because of lint.

Fan-coil unit motors require periodic lubrication. Motor failures are not common, but when they occur, the entire fan can be quickly replaced with minimal interruption in the conditioned space. The condensate drain pan and drain system should be cleaned or flushed periodically to prevent overflow and microbial buildup. Drain pans should be trapped to prevent any gaseous backup.

Water Distribution

Chilled and hot water must run to the fan-coil units. The piping arrangement determines the quality of performance, ease of operation, and initial cost of the system.

Two-Pipe Changeover Without Central Ventilation. In this system either hot or cold water is supplied through the same piping. The fan-coil unit has a single coil. The simplest system with the lowest initial cost is the two-pipe changeover fan coil with (1) outside air introduced through building apertures, (2) manual three-speed fan control, and (3) hot and cold water temperatures scheduled by outdoor temperatures. This system is generally used in residential buildings with operable windows and relies on the occupant to control fan speed and open or close windows. The changeover temperature is set at some predetermined set point. If a thermostat is used to control water flow, it must reverse its action depending on whether hot or cold water is available.

The two-pipe system can not simultaneously heat or cool, which is required for most projects during intermediate seasons when some rooms need cooling and others need heat. This problem can be especially troublesome if a single piping zone supplies the entire building. This deficiency may be partly overcome by dividing the piping into zones based on solar exposure. Then each zone may be operated to heat or cool, independent of the others. However, one room may still require cooling while another room on the same solar exposure requires heating—particularly if the building is partially shaded by an adjacent building.

Another deficiency of the two-pipe changeover system is the need for frequent changeover from heating to cooling, which complicates the operation and increases energy consumption to the extent that it may become impractical. For example, two-pipe changeover system hydraulics must consider the water expansion (and relief) that occurs during the cycling from cooling to heating.

For these reasons, the designer should consider the disadvantages of the two-pipe system carefully; many installations of this type waste energy and have been unsatisfactory in climates where frequent changeover is required and where interior loads require cooling simultaneously as exterior spaces require heat.

Two-Pipe Changeover With Partial Electric Strip Heat. This arrangement provides simultaneous heating and cooling in intermediate seasons by using a small electric strip heater in the fan-coil unit. The unit can handle heating requirements in mild weather, typically down to 40°F, while continuing to circulate chilled water to handle any cooling requirements. When the outdoor temperature drops sufficiently to require heating in excess of the electric strip heater capacity, the water system must be changed over to hot water.

Two-Pipe Nonchangeover with Full Electric Strip Heat. This system is not recommended for energy conservation, but it may be practical in areas with a small heating requirement.

Four-Pipe Distribution

The four-pipe distribution of secondary water has cold water supply, cold water return, warm water supply, and warm water return pipes. The four-pipe system generally has the highest initial cost, but it has the best fan-coil system performance. It provides (1) all-season availability of heating and cooling at each unit, (2) no summer/winter changeover requirement, (3) simpler operation, and (4) use of any heating fuel, heat recovery, or solar heat. In addition, it can be controlled to maintain a “dead band” between heating and cooling so simultaneous heating and cooling cannot occur. For discussion of two, three, and four pipe systems with central ventilation see later sections of this chapter.

Central Plant Equipment

Central equipment size is based on the block load of the entire building at the time of the building peak load, not on the sum of individual in-room terminal unit peak loads. Cooling load should include appropriate diversity factors for lighting and occupant loads. Heating load is based on maintaining the unoccupied building at design temperature, plus an additional allowance for pickup capacity if the building temperature is set back at night.

If water supply temperature or quantities are to be reset at times other than at peak load, the adjusted settings must be adequate for the most heavily loaded space in the building. An analysis of individual room load variations is required.

If the side of the building exposed to the sun or interior zone loads require chilled water in cold weather, the use of condenser water with a water-to-water heat exchanger should be considered. Varying refrigeration loads require the water chiller to operate satisfactorily under all conditions.

Ventilation

The only reason to use central fan equipment for an in-room terminal unit system is to provide the correct amount of ventilation or makeup air to the various spaces being served by terminal units.

Ventilation air is generally the most difficult factor to control and represents a major load component. The designer must select the method that meets local codes, performance requirements, cost constraints, and health requirements.

A central, outside air pretreatment system, which maintains neutral air at about 70°F, best controls ventilation air with the greatest freedom from problems related to the building’s stack effect and infiltration. Ventilation air may then be introduced to the room through the fan-coil unit, or directly into the room as shown in [Figure 4](#). Any type of fan-coil unit in any location may be used if the ventilation system has separate air outlets.

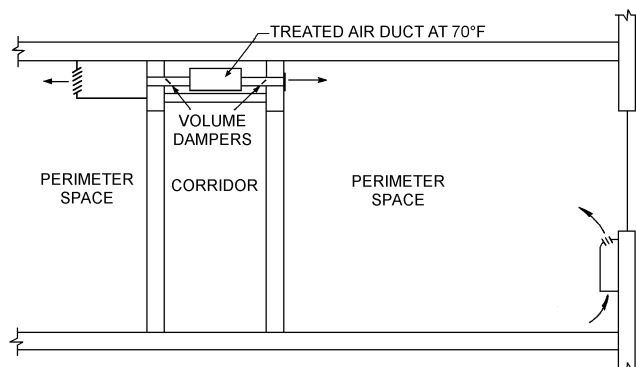


Fig. 4 Ventilation from Separate Duct System

Ventilation air contributes significantly to the room latent cooling load, so a dehumidifying coil should be installed in the central ventilation system to reduce room humidities during periods of high outside moisture content.

An additional advantage of the ventilation unit is that, if it is sized for the internal latent load, the terminal cooling coil remains dry, extending the life of the unit. However a piped condensate drain is recommended. This neutral temperature removes the outside air load from the terminal unit, so it can switch from heating to cooling and vice versa without additional internal or external heat loads.

In buildings where fan-coil units only serve exterior zones and a separate all-air system serves interior zones, it is possible to provide exterior zone ventilation air through the interior zone system. This arrangement can provide desirable room humidity control, as well as temperature control of the ventilation air. In addition, ventilation air held in the neutral zone of 70°F at 50% rh can be introduced into any fan-coil unit without affecting the comfort conditions maintained by the terminal units.

Applications

Fan-coil systems are best applied where individual space temperature control is needed. Fan-coil systems also prevent cross-contamination from one room to another. Suitable applications are hotels, motels, apartment buildings, and office buildings. Fan-coil systems are used in many hospitals, but they are less desirable because of the low-efficiency filtration and difficulty in maintaining adequate cleanliness in the unit and enclosure.

Advantages

A major advantage of the fan-coil unit system is that the delivery system (piping versus duct systems) requires less building space—it requires a smaller or no central fan room and little duct space. The system has all the benefits of a central water chilling and heating plant, while retaining the ability to shut off local terminals in unused areas. It gives individual room control with little cross-contamination of recirculated air from one space to another. Extra capacity for quick pull down response may be provided. Because this system can heat with low-temperature water, it is particularly suitable for solar or heat recovery refrigeration equipment. For existing building retrofit, it is often easier to install the piping and wiring for a fan-coil unit system than the large ductwork required for an all-air system.

Disadvantages

Fan-coil unit systems require much more maintenance than central all-air systems, and this work must be done in occupied areas. Units that operate at low dew points require condensate pans and a drain system that must be cleaned and flushed periodically. Condensate disposal can be difficult and costly. It is also difficult to clean the coil. Filters are small, low in efficiency, and require frequent changing to maintain air volume. In some instances, drain systems can be eliminated if dehumidification is positively controlled by a central ventilation air system.

Rooms are often ventilated by opening windows or by outside wall apertures, if not handled by a central system. Ventilation rates are affected by stack effect and wind direction and speed.

Summer room humidity levels tend to be relatively high, particularly if modulating chilled water control valves are used for room temperature control. Alternatives are two-position control with variable-speed fans and the bypass unit variable chilled water temperature control.

PRIMARY AIR SYSTEMS

[Figure 5](#) illustrates the primary air system for in-room terminal systems. The components are described in [Chapter 2](#). Some primary air systems operate with 100% outdoor air at all times. Systems using return air should have provision for operating with 100% out-

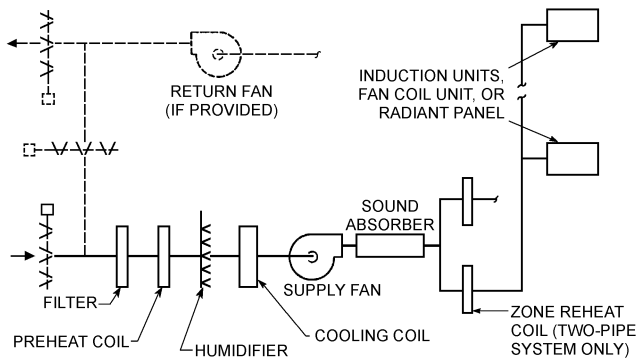


Fig. 5 Primary Air System

door air to reduce operating cost during certain seasons. In some systems, when the quantity of primary air supplied exceeds the ventilation or exhaust required, the excess air is recirculated by a return system common with the interior system. A quality filter 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. The water sprays 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.

The cooling coil is usually selected to provide primary air at a dew point low enough to dehumidify the system totally. The air leaves the cooling coil at about 50°F or less, and is almost completely saturated.

The supply fan should be selected at a point near maximum efficiency to reduce power consumption, heating of the supply air, 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 is not required for the 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 gage static pressure. With energy use restrictions, this is no longer economical. Good duct design and elimination of unnecessary restrictions (for example, sound traps) can result in primary systems that operate at 4.5 to 6.0 in. of water gage. Primary air distribution systems servicing fan-coil systems can operate at pressures 1.0 to 1.5 in. lower. Careful selection of the primary air cooling coil and induction units for reasonably low air pressure drops is necessary to achieve a medium-velocity primary air system. Distribution for fan-coil systems may be low velocity or a combination of low- and medium-velocity systems. See [Chapter 34 in the 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 across balancing dampers.

Room sound characteristics vary depending on unit selection, air system design, and the manufacturer. Units should be selected by considering the unit manufacturer's sound power ratings, the desired maximum room noise level, and the acoustical characteristics of the room. Limits of sound power level can then be specified to obtain acceptable acoustical performance.

PERFORMANCE UNDER VARYING LOAD

Under peak load conditions, the psychometrics of induction unit and fan-coil unit systems are essentially identical for two- and four-pipe systems. The primary air mixes with secondary air conditioned by the room coil in an induction unit prior to delivery to a room. Mixing also occurs in a fan-coil unit with a direct-connected air supply. If the primary air is supplied to the space separately, as in

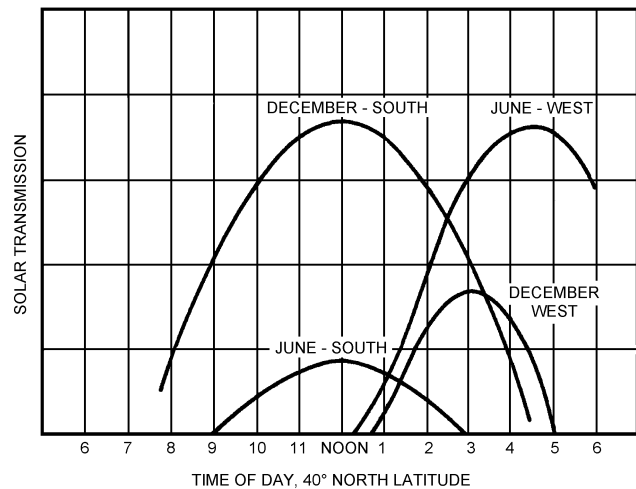


Fig. 6 Solar Radiation Variations with Seasons

fan-coil systems with independent primary air supplies, the same effect would occur in the space. The same room conditions result from two physically independent processes as if the air was directly connected to the unit.

During cooling, the primary air system provides a portion of the sensible capacity and all of the dehumidification. The remainder of the sensible capacity is accomplished by the cooling effect of the secondary water circulating through the unit cooling coils. In winter, primary air is provided at a low temperature, and if humidity control is provided, the air is humidified. All room heating is supplied by the secondary water system. All factors that contribute to the cooling load of perimeter space in the summer, with the exception of the transmission, add heat in the winter. The transmission factor becomes negative when the outdoor temperature falls below the room temperature. Its magnitude is directly proportional to the difference between the room and outdoor temperatures.

For in-room terminal unit systems, it is important to note that in applications where primary air enters at the terminal unit, the primary air is provided at summer design temperature in winter. For systems where primary air does not enter at the terminal unit, the primary air should be reset to room temperature in winter. A limited amount of cooling can be accomplished by the primary air operating without supplementary cooling from the secondary coil. As long as internal heat gains are not high, this amount of cooling is usually adequate to satisfy east and west exposures during the fall, winter, and spring, because the solar heat gain is reduced during these seasons. The north exposure is not a significant factor because the solar gain is very low. For the south, southeast, and southwest exposures, the peak solar heat gain occurs in winter, coincident with a lower outdoor temperature ([Figure 6](#)).

In buildings with large areas of glass, the transmitted heat from indoors to the outside, 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 permits constant inflow of solar radiation during the winter. However, the insulating effect of the double glass reduces the 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.

CHANGEOVER TEMPERATURE

For all systems using a primary air system for outdoor air, there is an outdoor temperature, a balance temperature, at which secondary cooling is no longer required. The system can cool by using outdoor air at lower temperatures, and heating rather than cooling is needed. For all-air systems operating with up to 100% outdoor air, mechanical cooling is seldom required at outdoor temperatures below 55°F. An important characteristic of in-room terminal unit systems, however, is that secondary water cooling may continue to 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 the primary air-cooling coil below 50°F often provides all necessary cooling while preventing coil freeze-up and reducing the preheat requirement. Alternatively, secondary-water-to-condenser-water heat exchangers function well. Some systems circulate condenser water directly. This system should be used with caution, recognizing that the vast secondary water system is being operated as an open recirculating system with the potential hazards that may accompany improper water treatment.

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 termed the **changeover temperature**. Below this temperature, cooling is not required.

The following empirical equation approximates the changeover temperature at sea level, and it should be adjusted after installation (Carrier 1965):

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

where

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_{td} = 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 the winter months.

If the calculated changeover temperature is below approximately 48°F, an economizer cycle should operate to allow the refrigeration plant to shut down.

Although the factors controlling the changeover temperature of induction unit systems are understood by the design engineer, the basic principles are often more difficult for system operators to understand. Therefore, it is important that the concept and the calculated changeover temperature are clearly explained in operating instructions given prior to 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 a necessary to preclude frequent change in the seasonal cycles and to grant some flexibility in the operating procedure. The difficulties associated with operator understanding and the need to change over several times a day in many areas have severely limited the acceptability of the two-pipe changeover system.

REFRIGERATION LOAD

The design refrigeration load is determined by considering the entire portion or block of the building served by the air-and-water system at the same time. Because the load on the secondary water system depends on the simultaneous demand of all spaces, the sum of the individual room or zone peaks is not considered.

The peak load time is influenced by the outdoor wet-bulb temperature, the period of building occupancy, and the relative amounts of the east, south, and west exposures. Where the magnitude of the solar load is about equal for each of the above exposures, the building peak usually occurs in midsummer afternoon when the west solar load and outdoor wet-bulb temperature are at or near concurrent maximums.

At sea level, the refrigeration load equals the primary air-cooling coil load plus the secondary system heat pickup:

$$q_{re} = q_s + 4.5Q_p(h_{ea} - h_{la}) - 1.1Q_p(t_r - t_s) \quad (2)$$

where

q_{re} = refrigeration load, Btu/h

q_s = block room sensible heat for all spaces at time of peak, Btu/h

h_{ea} = enthalpy of primary air upstream of cooling coil at time of peak, Btu/lb

h_{la} = enthalpy of primary air leaving cooling coil, Btu/lb

Q_p = primary air quantity, cfm

t_r = average room temperature for all exposures at peak time, °F

t_s = average primary air temperature at point of delivery to rooms, °F

Because the latent load is absorbed by the primary air, the resultant room relative humidity can be determined by calculating the block room latent load of all spaces at the time of the peak load. Then, recalling that there are 7000 grains in a pound, the rise in moisture content of the primary air at sea level is

$$W = \frac{7000v_a q_L}{60h_{fg}Q_p} = 1.48 \frac{q_L}{Q_p} \quad (3)$$

where

W = moisture content rise per lb dry air, grains

v_a = specific volume of air = 13.3 ft³/lb at sea level

q_L = block room latent load of all spaces at time of peak load, Btu/h

h_{fg} = latent heat of vaporization = 1050 Btu/lb

Then a psychrometric analysis can be made.

The secondary water cooling load may be determined by subtracting the primary air-cooling coil load from the total refrigeration load.

TWO-PIPE SYSTEMS

With Central Ventilation

Two-pipe systems for induction and fan-coil 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 the control of the primary air and secondary water temperatures must be such that all rooms on the same system (or zone, if the system is separated into independently controlled air and water zones) 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 the primary air output plus the secondary water output of that unit.

The primary air quantity is fixed, and the primary air temperature is varied in inverse proportion to the outside temperature to provide the necessary amount of heating during summer and intermediate seasons. During winter operation, the primary air is preheated and supplied at approximately 50°F to provide a source of cooling. All

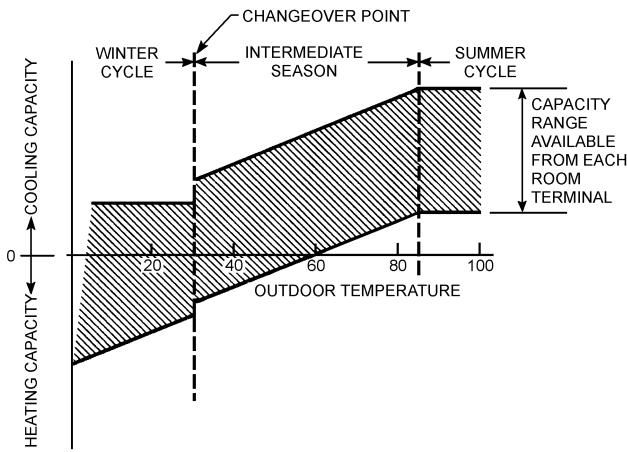


Fig. 7 Capacity Ranges of In-Room Terminal Operating on Two-Pipe System

room terminals in a given primary air reheat zone must be selected to operate satisfactorily with the common primary air temperature.

The secondary water coil (cooling-heating) within 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 7 shows the capacity ranges available from a typical two-pipe system. On a hot summer day, loads varying 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 the 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 the 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 from the primary air supply during the intermediate season. The concept of 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. This concept is fundamental to proper design and operation of a 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 outside temperature (assuming steady-state heat transfer). This is the sum of (1) the glass heat transfer coefficient times the glass areas, (2) the wall heat transfer coefficient times the wall area, and (3) the roof heat transfer coefficient times the roof area.

Air-to-Transmission 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 over-cooled during light cooling loads at an outdoor temperature in the 70 to 90°F range, while spaces with an A/T ratio lower than the design ratio lack sufficient heat during the 40 to 60°F outdoor temperature range when the primary air is warm for heating and the secondary water is cold for cooling.

The minimum primary air quantity that satisfies the requirements for ventilation, dehumidification, and both summer and winter cooling (as explained in the section on System Description) is used to calculate the minimum A/T ratio for each space. If the system will be operated 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 alternate 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 the outdoor air temperature and the temperature of the primary air that maintains the room at 72°F or more during conditions of minimum room cooling load. Figure 8 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.

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, with curtain wall construction, or on systems with low changeover temperature.

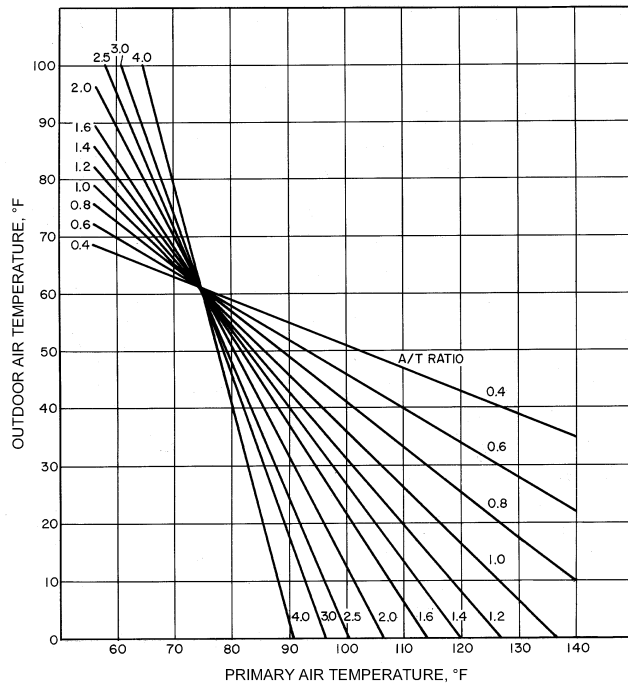
Changeover Temperature Considerations

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 9 illustrates the psychrometrics of summer cycle operation near the changeover temperature. As the outdoor temperature drops further, the changeover temperature will be reached. The secondary water system can then be changed over to provide hot water for heating.

If the primary airflow is increased to some spaces to elevate the changeover temperature, the A/T ratio for the reheat zone will be affected. Adjustments in the 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 outside temperature rises above the daytime changeover temperature. Changeover to hot water is limited to times of extreme or protracted cold weather.

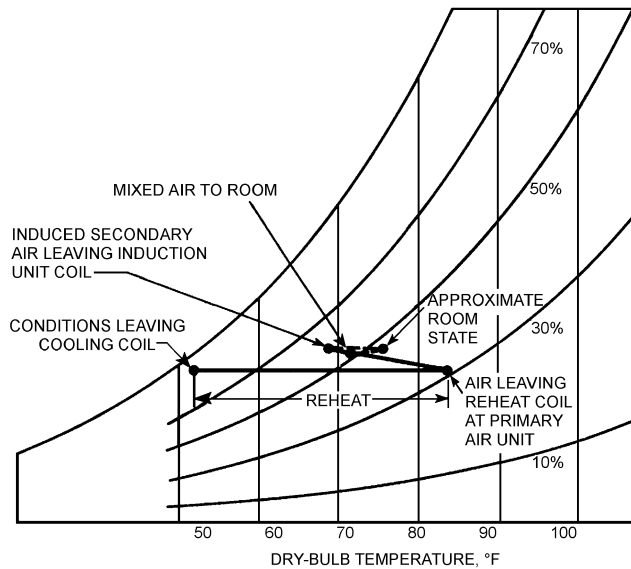
Optional hot or cold water operation below the changeover point is provided by increasing the primary air reheat capacity to provide adequate heat at a colder outside temperature. Figure 10 shows



Note: These temperatures are required at the units, and thermostat settings must be adjusted to allow for duct heat gains or losses. Temperatures are based on

1. Minimum average load in the space, equivalent to 10°F multiplied by the transmission per degree.
2. Preventing the room temperature from dropping below 72°F. These values compensate for the radiation and convection effect of the cold outdoor wall.

Fig. 8 Primary Air Temperature Versus Outdoor Air Temperature



Note: Based on A/T ratio = 1.2, 52°F outdoor, reheat schedule on.

Fig. 9 Psychrometric Chart, Two-Pipe System, Off-Season Cooling

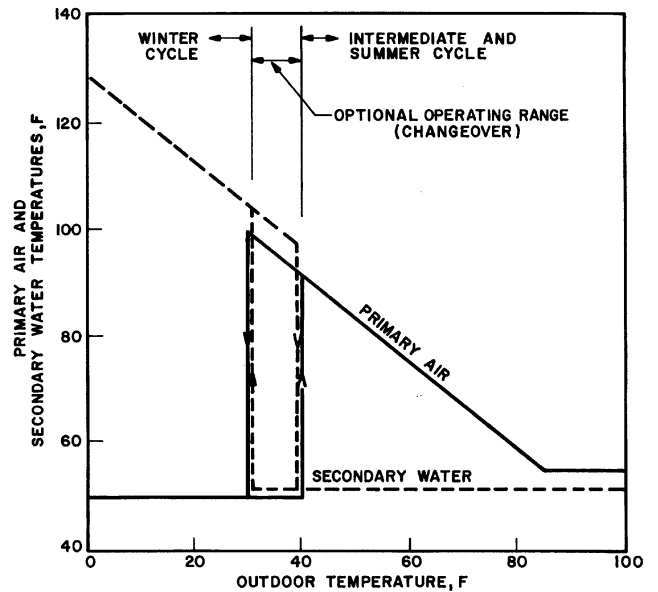


Fig. 10 Typical Changeover, System Variation

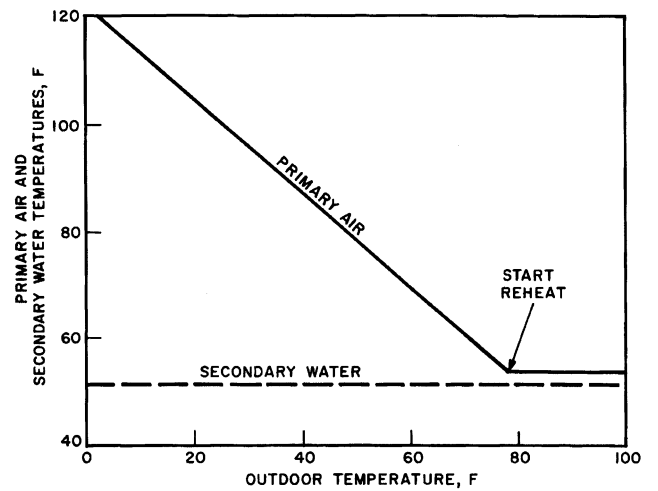


Fig. 11 Typical Nonchangeover System Variations

temperature variation for a system operating with changeover. This indicates 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

Nonchangeover systems should be considered 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 11](#).

Spaces may be heated during unoccupied hours by operating the primary air system with 100% return air. This feature is necessary, because the 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 properly designed single-zone, two-pipe system can provide good temperature control on all exposures during all seasons of the year. Initial cost or operating cost can be improved by zoning in several ways, such as the following:

- Zoning primary air to permit different A/T ratios on different exposures
- Zoning primary air to permit solar compensation of primary air temperature
- Zoning both air and water to permit a different changeover temperature for different exposures

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 on some exposures to be increased if they are placed on a common zone with other exposures. The primary air quantity to units serving the north, northeast, or northwest exposures 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 the fall or winter months when outside temperatures are lower. If present or future shading patterns from adjacent buildings or obstructions will not be 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 the secondary water refrigeration penalty.

Separate air and water zoning save operating cost by permitting north, northeast, or northwest exposures to operate on the winter cycle with warm secondary water at outdoor temperatures as high as 60°F during winter months. Systems with a common secondary water zone must operate with cold secondary water to cool south exposures. Primary airflow can be lower because of separate A/T ratios, resulting in reheat and refrigeration cost savings.

Room Control

During summer, the thermostat must increase the output of the cold secondary coil when the room temperature rises. During winter, the thermostat must decrease the output of the warm secondary coil when the room temperature rises. Changeover from cold water 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

The following are characteristics of two-pipe in-room terminal unit systems:

- 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 hot water 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, and cooling is available with chilled water in the chilled water/hot water system. System or zone reheating of the primary air is reduced greatly 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 to 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.

THREE-PIPE SYSTEMS

Three-pipe air-and-water systems for induction and fan-coil unit systems have three pipes to each terminal unit. These pipes are a cold water supply, a warm water supply, and a common return. These systems are rarely used today because they consume excess energy. Existing three-pipe systems are ideal candidates for energy conservation retrofit.

FOUR-PIPE SYSTEMS

Four-pipe systems have a cold water supply, cold water return, warm water supply, and warm water return. The terminal unit usually has two independent secondary water coils: one served by hot water, the other by cold water. The primary air is cold and remains at the same temperature year-round. 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. Any unit can be operated at or between these extremes without regard to the operation of other units.

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

Because the primary air is supplied at a constant cool temperature at all times, it is sometimes feasible for fan-coil unit systems to extend the interior system supply to the perimeter spaces, eliminating the need for a separate primary air system. The type of terminal unit and the characteristics of the interior system are determining factors.

Zoning

Zoning of primary air or secondary water systems is not required. 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.

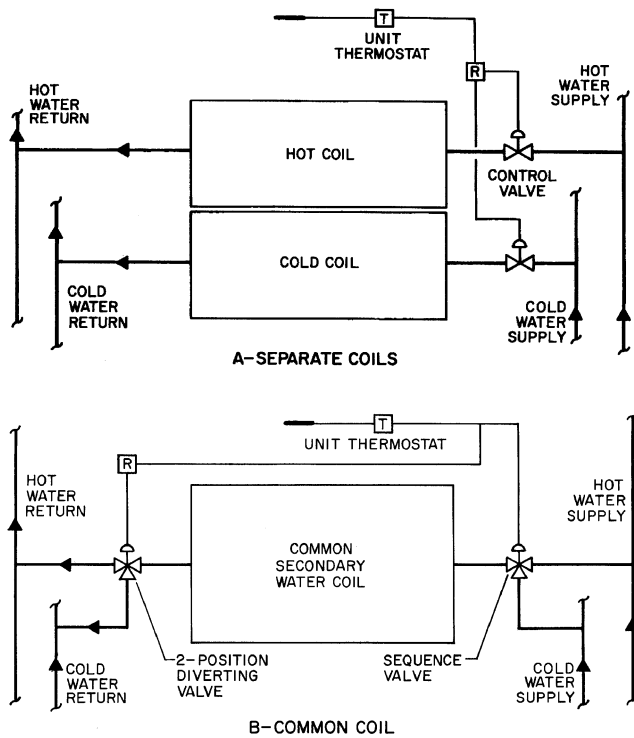


Fig. 12 Four-Pipe System Room Unit Control

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 water or cold water in varying amounts or else no flow is present, as shown in [Figure 12A](#). Adjustable, dead-band thermostats further reduce operating cost.

[Figure 12B](#) 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.

When all aspects are considered, the two-coil arrangement provides a superior four-pipe system. The 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 the 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 the hot and cold water secondary circuits, and the secondary system can be completely independent of the primary water piping

SECONDARY WATER DISTRIBUTION

Secondary water system design applies to induction and fan-coil systems. The secondary water system includes the portion of the water distribution system that circulates water to room terminal units when the cooling (or heating) of such water has been accomplished either by extraction from or heat exchange with another source in the primary circuit. In the primary circuit, water is cooled by flow through a chiller or is heated by a heat input source. Primary water is limited to the cooling cycle and is the source of the secondary water cooling. Water flow through the unit coil performs secondary cooling when the room air (secondary air) gives up heat to the water. The design of the secondary water system differs for two- and four-pipe systems. Secondary water systems are discussed in [Chapter 12](#).

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