CHAPTER 5

DECENTRALIZED COOLING AND HEATING

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PACKAGED unit systems are used in almost all classes of buildings. They are especially suitable for smaller projects with no central plant where low initial cost and simplified installation are important. These systems are installed in office buildings, shopping centers, manufacturing plants, schools, health care facilities, hotels, motels, apartments, nursing homes, and other multiple-occupancy dwellings. They are also suited to air conditioning existing buildings with limited life or income potential. Applications also include facilities requiring specialized high performance levels, such as computer rooms and research laboratories.

Although the equipment can be applied as a single unit, this chapter covers applying multiple units to form a complete air-conditioning system for a building.

SYSTEM CHARACTERISTICS

Decentralized systems have several separate air-conditioning units, each with an integral refrigeration cycle. Components are factory-designed and assembled into a package that includes fans, filters, heating source, cooling coil, refrigerant compressor(s), refrigerant-side controls, air-side controls, and condenser. Equipment is manufactured in various configurations to meet a wide range of applications. Examples include window air conditioners, through-the-wall room air conditioners, unitary air conditioners for indoor and outdoor locations, air-source heat pumps, and water-source heat pumps. Specialized packages for computer rooms, hospitals, and classrooms are also available.

Commercial-grade unitary equipment packages are available only in pre-established increments of capacity with set performance parameters, such as the sensible heat ratio at a given room condition or the airflow per kilowatt of refrigeration capacity. Components are matched and assembled to achieve specific performance objectives. These limitations make manufacture of low-cost, quality-controlled, factory-tested products practical. For a particular kind and capacity of unit, performance characteristics vary among manufacturers. All characteristics should be carefully assessed to ensure that the equipment performs as needed for the application. Several trade associations have developed standards by which manufacturers may test and rate their equipment. Chapters 45 and 46 describe the equipment used in multiple-packaged unitary systems and pertinent industry standards.

Large commercial/industrial-grade equipment can be custom-designed by the factory to meet specific design conditions and job requirements. This equipment carries a higher first cost and is not readily available in smaller sizes.

Self-contained units can use multiple compressors to control refrigeration capacity. For variable-air-volume (VAV) systems, compressors are turned on or off or unloaded to maintain discharge air temperature. As zone demand decreases, the temperature of air leaving the unit can often be reset upward so that a minimum ventilation rate is maintained.

Multiple packaged-unit systems for perimeter spaces are frequently combined with a central all-air or floor-by-floor system. These combinations can provide better humidity control, air purity, and ventilation than packaged units alone. Air-handling systems may also serve interior building spaces that cannot be conditioned by wall or window-mounted units.

Advantages

- Heating and cooling can be provided at all times, independent of the mode of operation of other building spaces.
- Manufacturer-matched components have certified ratings and performance data.
- Assembly by a manufacturer helps ensure better quality control and reliability.
- Manufacturer instructions and multiple-unit arrangements simplify installation through repetition of tasks.
- Only one zone of temperature control is affected if equipment malfunctions.
- The system is readily available.
- One manufacturer is responsible for the final equipment package.
- For improved energy control, equipment serving vacant spaces can be turned off locally or from a central point, without affecting occupied spaces.
- System operation is simple. Trained operators are not usually required.
- Less mechanical and electrical room space is required than with central systems.
- Initial cost is usually low.
- Equipment can be installed to condition one space at a time as a building is completed, remodeled, or as individual areas are occupied, with favorable initial investment.
- Energy can be metered directly to each tenant.

Disadvantages

- Performance options may be limited because airflow, cooling coil size, and condenser size are fixed.
- Larger total building installed cooling capacity is usually required because diversity factors used for moving cooling needs do not apply to dedicated packages.
- Temperature and humidity control may be less stable, especially with mechanical cooling at very low loads.
- Standard commercial units are not generally suited for large percentages of outside air or for close humidity control. Custom or special-purpose equipment, such as packaged units for computer rooms, or large custom units, may be required.

The preparation of this chapter is assigned to TC 9.1, Large Building Air-Conditioning Systems.

- Energy use is usually greater than for central systems if efficiency of the unitary equipment is less than that of the combined central system components.
- Low-cost cooling by outside air economizers (see the section on Economizers) is not always available or practical.
- Air distribution control may be limited.
- Operating sound levels can be high, and noise-producing machinery is often closer to building occupants than with central systems.
- Ventilation capabilities are fixed by equipment design.
- Equipment's effect on building appearance can be unappealing.
- Air filtration options may be limited.
- Discharge temperature varies because of on/off or step control.
- Condensate drain is required with each air-conditioning unit.
- Maintenance may be difficult or costly because of multiple pieces of equipment and their location.

THROUGH-THE-WALL AND WINDOW-MOUNTED AIR CONDITIONERS AND HEAT PUMPS

Window air conditioners (air-cooled room conditioners), further described in Chapter 46, are designed to cool or heat individual room spaces. Window units are used where low initial cost, quick installation, and other operating or performance criteria outweigh the advantages of more sophisticated systems. Room units are also available in through-the-wall sleeve mountings. Sleeve-installed units are popular in low-cost apartments, motels, and homes.

Window units may be used as auxiliaries to a central heating or cooling system or to condition selected spaces when the central system is shut down. These units usually serve only part of the spaces conditioned by the basic system. Both the basic system and window units should be sized to cool the space adequately without the other operating.

A through-the-wall air-cooled room air conditioner is designed to cool or heat individual room spaces. Design and manufacturing parameters vary widely. Specifications range from appliance grade through heavy-duty commercial grade, the latter known as packaged terminal air conditioners (PTACs) or packaged terminal heat pumps (PTHPs) (ARI *Standard* 310/380). With proper maintenance, manufacturers project a life expectancy of 10 to 15 years for these units.

Advantages

- Initial cost is generally less than for a central system adapted to heat or cool each room under room occupants' control.
- Because no energy is needed to transfer air or chilled water from mechanical equipment rooms, energy consumption may be lower than for central systems. However, this advantage may be offset by the equipment's lower efficiency.
- Building space is conserved because ductwork and mechanical rooms are not required.
- Installation is simple. It usually only requires an opening in the wall or displacement of a window to mount the unit, and connection to electrical power.
- Generally, the system is well-suited to spaces requiring many zones of individual temperature control.
- Designers can specify electric, hydronic, or steam heat or use an air-to-air heat pump design.
- Service can be quickly restored by replacing a defective chassis.

Disadvantages

- Equipment life is relatively short, typically 10 to 15 years; window units are built to appliance standards, rather than building equipment standards.
- Energy use may be relatively high.
- Direct access to outside air is needed for condenser heat rejection; thus, these units cannot be used for interior rooms.
- The louver and wall box must stop wind-driven rain from collecting in the wall box and leaking into the building. The wall box should drain to the outside.
- Condensate removal can cause dripping on walls, balconies, or sidewalks.
- Temperature control is usually two-position, which causes swings in room temperature.
- Air distribution control is limited.
- Ventilation and economy cycle capabilities are fixed by equipment design.
- Equipment's effect on building appearance can be unappealing.
- Air filtration options are limited.
- Humidification, when required, must be provided by separate equipment.
- Noise and vibration levels vary considerably and are not generally suitable for sound-critical applications.
- Routine maintenance is required to maintain capacity. Condenser and cooling coils must be cleaned, and filters must be changed regularly.

Design Considerations

Units are usually furnished with individual electric controls. However, when several units are used in a single space, controls should be interlocked to prevent simultaneous heating and cooling. In commercial applications (e.g., motels), centrally operated switches can de-energize units in unoccupied rooms.

A through-the-wall or window-mounted air-conditioning unit incorporates a complete air-cooled refrigeration and air-handling system in an individual package. Each room is an individual occupant-controlled zone. Cooled or warmed air is discharged in response to thermostatic control to meet room requirements. The section on Controls describes how controls allow using individual room systems during off-schedule hours, but automatically return all systems to normal schedule use.

Each PTAC or PTHP has a self-contained, air-cooled direct-expansion or heat pump cooling system; a heating system (electric, hot water, steam, and/or a heat pump cycle); and controls. Two general configurations are shown: a wall box, outdoor louver, heater section, cooling chassis, and cabinet enclosure (Figure 1); and a combination wall sleeve cabinet, plus combination heating and cooling chassis with outdoor louver (Figure 2).

A through-the-wall air conditioner or heat pump system is installed in buildings requiring many temperature control zones such as office buildings, motels and hotels, apartments and dormitories, schools and other education buildings, and areas of nursing homes or hospitals where air recirculation is allowed.

These units can be used for renovation of existing buildings, because existing heating systems can still be used. The equipment can be used in both low- and high-rise buildings. In buildings where a stack effect is present, use should be limited to areas that have dependable ventilation and a tight wall of separation between the interior and exterior.

Room air conditioners are often used in parts of buildings primarily conditioned by other systems, especially where spaces to be conditioned are (1) physically isolated from the rest of the building and (2) occupied on a different time schedule (e.g., clergy offices in a church, ticket offices in a theater).

Ventilation air through each terminal may be inadequate in many situations, particularly in high-rise structures because of the stack effect. Chapter 26 of the 2001 *ASHRAE Handbook—Fundamentals* explains combined wind and stack effects. Electrically operated outside air dampers, which close automatically when the equipment is stopped, can reduce heat losses in winter.

Refrigeration Equipment

Room air conditioners are generally supplied with hermetic reciprocating or scroll compressors. Capillary tubes are used in place of expansion valves in most units.

Some room air conditioners have only one motor to drive both the evaporator and condenser fans. The unit circulates air through the condenser coil whenever the evaporator fan is running, even during the heating season. Annual energy consumption of a unit with a single motor is generally higher than one with a separate motor, even when the energy efficiency ratio (EER) or the coefficient of performance (COP) is the same for both. Year-round, continuous flow of air through the condenser increases dirt accumulation on the coil and other components, which increases maintenance costs and reduces equipment life.

Because through-the-wall conditioners are seldom installed with drains, they require a positive and reliable means of condensate disposal. Conditioners are available that spray condensate in a fine mist over the condenser coil. These units dispose of more condensate than can be developed without any drip, splash, or spray. In heat pumps, provision must be made for disposal of condensate generated from the outside coil during defrost.

Many air-cooled room conditioners experience evaporator icing and become ineffective when outside temperatures fall below about 18°C. Units that ice at a lower outside temperature may be required to handle the added load created by high lighting levels and high solar radiation found in contemporary buildings.

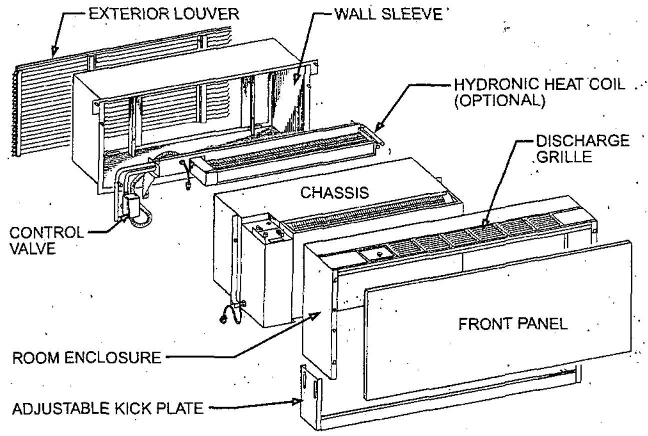

Fig. 1 Packaged Terminal Air Conditioner with Heating Section Separate from Cooling Chassis

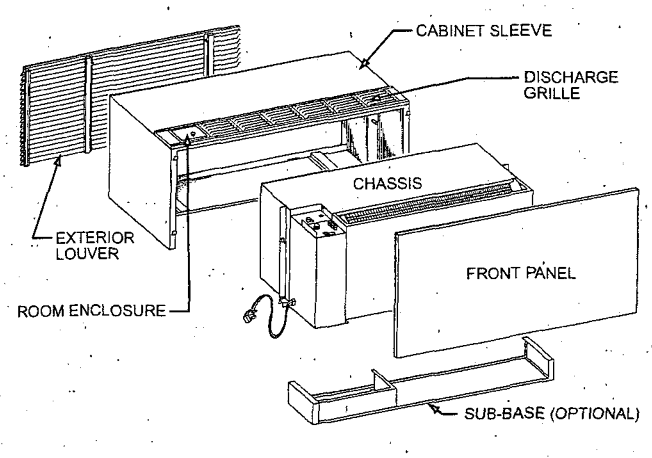

Fig. 2 Packaged Terminal Air Conditioner with Combination Heating and Cooling Chassis

Heating Equipment

The air-to-air heat pump cycle described in Chapter 45 of this volume is available in through-the-wall room air conditioners. Application considerations are similar to conventional units without the heat pump cycle, which is used for space heating when the outdoor temperature is above 2 to 5°C. Electric resistance elements supply heating below this level and during defrost cycles.

The prime advantage of the heat pump cycle is that it reduces annual energy consumption for heating. Savings in heat energy over conventional electric heating ranges from 10 to 60%, depending on the climate.

Controls

All controls for through-the-wall air conditioners are included as a part of the conditioner. The following control configurations are available:

Thermostat Control. Thermostats are either unit-mounted or remote wall-mounted.

Guest Room Control for Motels and Hotels. This has provisions for starting and stopping units from a central point.

Office Building and School Controls. These controls (for occupancies of less than 24 h) start and stop the equipment at preset times with a time clock. Conditioners operate normally with the unit thermostat until the preset cutoff time. After this point, each conditioner has its own reset control, which allows the occupant of the conditioned space to reset the conditioner for either cooling or heating, as required.

Master/Slave Control. This type of control is used when multiple conditioners are operated by the same thermostat.

Emergency Standby Control. Standby control allows a conditioner to operate during an emergency, such as a power failure, so that the roomside blowers can operate to provide heating. Units must be specially wired to allow operation on emergency generator circuits.

Acoustics and Vibration

Noise from these units may be objectionable and should be checked to ensure it meets sound level requirements. Chapter 47 of the 2003 *ASHRAE Handbook—HVAC Applications* has more information on HVAC-related sound and vibration concerns.

INTERCONNECTED ROOM-BY-ROOM SYSTEMS

Multiple-unit systems generally use single-zone unitary air conditioners with a unit for each zone (Figure 3). Zoning is determined

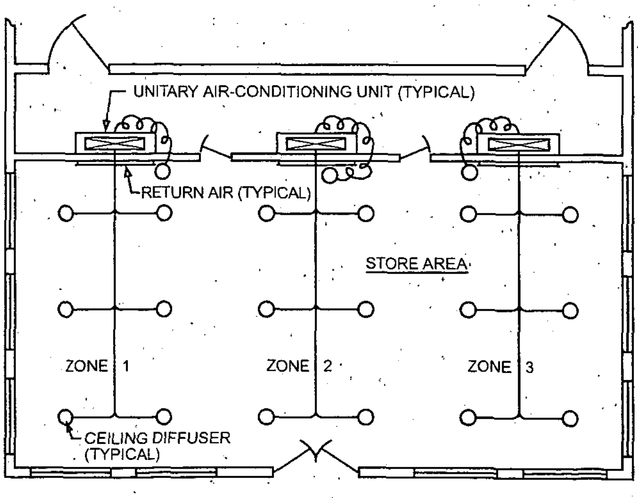

Fig. 3 Multiple Packaged Units

by (1) cooling and heating loads, (2) occupancy considerations, (3) flexibility requirements, (4) appearance considerations, and (5) equipment and duct space availability. Multiple-unit systems are popular for office buildings, manufacturing plants, shopping centers, department stores, and apartment buildings. Unitary self-contained units are excellent for renovation.

A typical system features zone-by-zone water-source heat pumps with a central cooling tower and a central boiler. A common condensing and heat source piping loop connects all units together. Heat rejected into the loop by units in cooling mode can be reclaimed by units in heating mode. During moderate weather and in buildings with highly diverse cooling and heating loads, these systems will tend to balance the building load. Heat from warm areas is, in effect, moved to cooler areas of the building. This minimizes the auxiliary loop heating and cooling required. Only when water loop temperature strays too far from limits do the boiler (heat addition) or cooling tower (heat rejection) need to operate.

Each packaged unit includes a fan, filter, compressor, condenser, and heat transfer coil. Compressors are usually hermetic, reciprocating, or scroll compressors. Capillary tubes are used for expansion. Condensers are water-cooled and connected to a central loop. The heating cycle on interconnected systems primarily uses an air-to-water heat pump. Figure 4 shows a typical unit with some commonly used components.

Advantages

- Installation is simple. Equipment is readily available in sizes that allow easy handling.
- Relocation of units to other spaces or buildings is practical, if necessary.
- Energy efficiency can be quite good, particularly where climate or building use results in a balance of heating and cooling zones.
- Units are available with complete, self-contained control systems that include variable-volume control, economizer cycle, night setback, and morning warm-up.
- Easy access to equipment facilitates routine maintenance.

Disadvantages

- Fans may have limited static pressure ratings.
- Air filtration options are limited.
- Humidification can be impractical on a unit-by-unit basis and may need to be provided by a separate system.

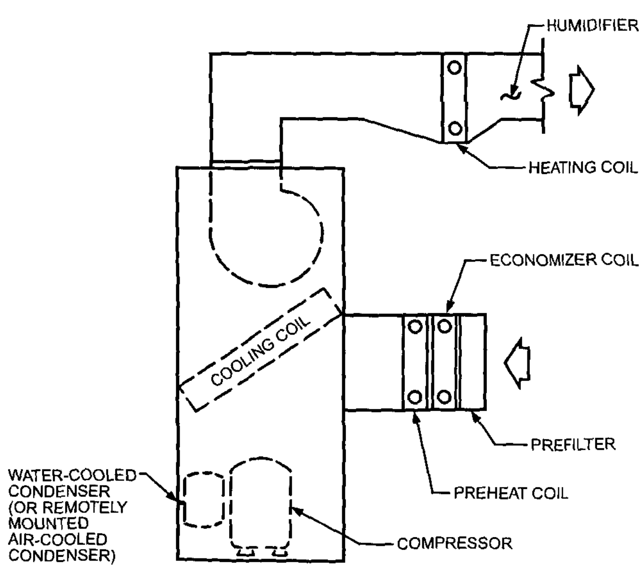

Fig. 4 Unitary Packaged Unit with Accessories

- Integral air-cooled units must be located along outside walls.
- Multiple units and equipment closets or rooms may occupy rentable floor space.
- Close proximity to building occupants may create noise problems.
- Discharge temperature may vary too much because of on/off or step control.
- Multiple pieces of equipment may increase maintenance requirements.

Design Considerations

Unitary systems can be used throughout a building or to supplement perimeter packaged terminal units (Figure 5). Because core areas frequently have little or no heat loss, unitary equipment with water-cooled condensers can be applied with water-source heat pumps serving the perimeter.

In this multiple-unit system, one unit may be used to precondition outside air for a group of units (Figure 6). This all-outside-air unit prevents hot, humid air from entering the conditioned space during periods of light load. The outside unit should have sufficient capacity to cool the required ventilation air from outside design conditions to interior design dew point. Zone units are then sized to handle only the internal load for their particular area.

Special-purpose unitary equipment is frequently used to cool, dehumidify, humidify, and reheat to maintain close control of space temperature and humidity in computer areas. Chapter 17 of the 2003 *ASHRAE Handbook—HVAC Applications* has more information.

Auxiliary Equipment

A cooling tower or fluid cooler supplies supplemental cooling to the central loop as required. Supplemental heat is supplied to the loop via a central boiler. One or more pumps are needed to circulate water throughout the loop.

Controls

Units under 70 kW of cooling are typically constant-volume units. VAV distribution is accomplished with a bypass damper that allows excess supply air to bypass to the return air duct. The bypass damper ensures constant airflow across the direct-expansion cooling coil to avoid coil freeze-up caused by low airflow. The damper is usually controlled by supply duct pressure.

Economizer Cycle. When outside temperature permits, energy use can be reduced by cooling with outside air in lieu of mechanical refrigeration. Units must be located close to an outside wall or outside air duct shafts. Where this is not possible, it may be practical to add an economizer cooling coil (see the section on Economizers) adjacent to the preheat coil (see Figure 4). Cold water is obtained by sending the condenser water through a winterized cooling tower. Chapter 36 has further details.

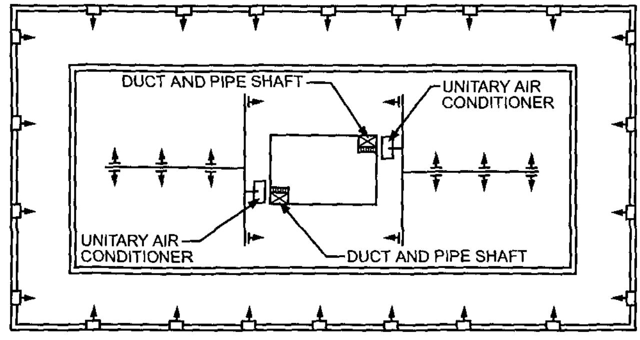

Fig. 5 Multiroom, Multistory Office Building with Unitary Core and Through-the-Wall Perimeter Air Conditioners

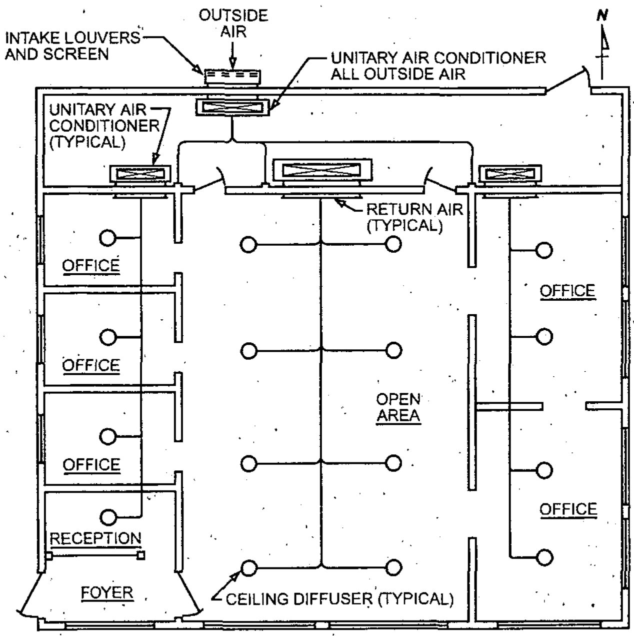

Fig. 6 Multiple-Packaged Units with Separate Outside Air Makeup Unit

Acoustics and Vibration

Because these units are typically located near occupied space, they can significantly affect acoustics. The designer must study both the airflow breakout path and the unit's radiated sound power when selecting wall and ceiling construction surrounding the unit. Locating units over noncritical work spaces such as restrooms or storage areas around the equipment room helps reduce noise in occupied space. Chapter 47 of the 2003 *ASHRAE Handbook—HVAC Applications* has more information on HVAC-related sound and vibration concerns.

RESIDENTIAL AND LIGHT-COMMERCIAL SPLIT SYSTEMS

A split system consists of an indoor unit with air distribution and temperature control with either a water-cooled condenser, integral air-cooled condenser, or remote air-cooled condenser. These units are commonly used in single-story or low-rise buildings, and in residential applications where condenser water is not readily available. Commercial split systems are well-suited to office environments with variable occupancy schedules.

Indoor equipment is generally installed in service areas adjacent to the conditioned space. When a single unit is required, the indoor unit and its related ductwork constitute a central air system, as described in Chapter 4.

Typical components of a split-system air conditioner include an indoor unit with evaporator coils, economizer coils, heating coils, filters, valves, and a condensing unit with the compressors and condenser coils.

Advantages

- Unitary split-system units (Figure 7) allow air-handling equipment to be placed close to the air-conditioning load, which allows ample air distribution to the conditioned space with minimum ductwork and fan power.
- Heat rejection through a remote air-cooled condenser allows the final heat rejector (and its associated noise) to be remote from the air-conditioned space.

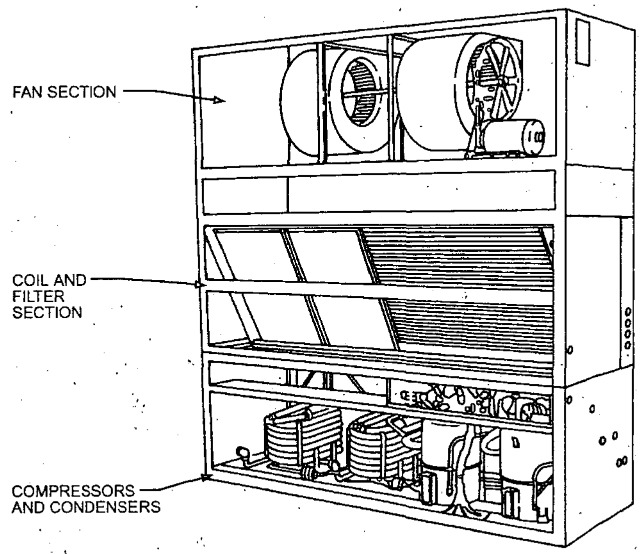

Fig. 7 Vertical Self-Contained Unit

- A floor-by-floor arrangement can reduce fan power consumption because air handlers are located close to the conditioned space.
- Large vertical duct shafts and fire dampers may be reduced or eliminated.
- Equipment is generally located in the building interior near elevators and other service areas and does not interfere with the building perimeter.

Disadvantages

- The proximity of the air handler to the conditioned space requires special attention to unit inlet and outlet airflow and to building acoustics around the unit.
- Ducting ventilation air to the unit and removing condensate from the cooling coil should be considered. Separate outside air systems are commonly used in conjunction with split systems.
- A unit that uses an air-side economizer must be located near an outside wall or outside air shaft. Split-system units do not generally include return air fans.
- A separate method of handling and controlling relief air may be required.
- Filter options and special features may be limited.
- Discharge temperature varies because of on/off or step control.

Design Considerations

Building characteristics that favor split systems include

- Multiple floors or zones
- Renovation work
- Historic structures
- Multiple tenants per floor with variable schedules
- Common return air paths
- Need for low installed first cost

The modest space requirements of split-system equipment make it excellent for renovations or for providing air conditioning to previously non-air-conditioned historic structures. Control is usually one- or two-step cool and one- or two-step or modulating heat. VAV operation is possible with a supply air bypass. Some commercial units can modulate airflow with additional cooling modulation via a hot-gas bypass.

Commercial split-system equipment can incorporate an integral water-side economizer coil and controls, thus allowing an interior location. In this configuration, the outside air shaft is reduced to meet only ventilation and space pressurization requirements.

Refrigeration Equipment

Compressors supplied on these units are usually hermetic or semihermetic reciprocating or scroll compressors. Smaller units have capillary tubes; larger units have thermostatic expansion valves and may also use multiple- or two-speed compressors. Compressors are usually located in the remote condensing unit instead of with the indoor equipment.

Heating Equipment

Heating systems available include electric resistance, indirect fired gas, or air-to-air heat pumps. Larger systems may also have available hot-water or steam heating coils.

Controls

Commercial split-system units are available as constant-volume equipment for use in atriums, public areas, and industrial applications. Basic temperature controls include a room-mounted or return-air-mounted thermostat that cycles the compressor(s) as needed. Upgrades include fan modulation and VAV control. When applied with VAV terminals, commercial split systems provide excellent comfort and individual zone control.

Acoustics and Vibration

As with any unit with components in the occupied space, noise is a concern. However, the fact that compressors are usually located in a remote condensing unit decreases some of the noise potential. Many commercial split-system units include a factory-engineered acoustical discharge plenum, which facilitates a smooth supply air discharge from the equipment room. This allows lower fan power and lower sound power levels and also reduces equipment room size. Chapter 47 of the *ASHRAE Handbook—HVAC Applications* has more information on HVAC-related sound and vibration concerns.

COMMERCIAL SELF-CONTAINED (FLOOR-BY-FLOOR) SYSTEMS

Commercial, self-contained systems provide central air distribution, refrigeration, and system control on a zone or floor-by-floor basis. Typical components include compressors, water-cooled condensers, evaporator coils, economizer coils, heating coils, filters, valves, and controls (Figure 8). To complete the system, a building needs cooling towers and condenser water pumps. See Chapter 36 for more information on cooling towers.

Advantages

- Units are well-suited for office environments with variable occupancy schedules.
- The floor-by-floor arrangement can reduce fan power consumption.
- Large vertical duct shafts and fire dampers are eliminated.
- Electrical wiring, condenser water piping, and condensate removal are centrally located.
- Equipment is generally located in the building interior near elevators and other service areas and does not interfere with the building perimeter.
- Integral water-side economizer coils and controls are available, which allow an interior equipment location and eliminate large outside air and exhaust ducts and relief fans.
- This equipment integrates refrigeration, air-handling, and controls into a factory package, thus eliminating many field integration problems.
- An acoustical discharge plenum is available, which allows lower fan power and lower sound power levels.

Disadvantages

- Units must be located near an outside wall or outside air shaft to incorporate an air-side economizer.
- A separate relief air system and controls must be incorporated if an air-side economizer is used.
- Close proximity to building occupants requires careful analysis of space acoustics.
- Filter options may be limited.
- Discharge temperature varies because of on/off or step control.

Design Considerations

Commercial self-contained units can serve either VAV or constant-volume systems. These units contain one or two fans inside the cabinet. The fans are commonly configured in a draw-through arrangement.

The size and diversity of the zones served often dictate which system is optimal. For comfort applications, self-contained VAV units coupled with terminal boxes or fan-powered terminal boxes are popular for their energy savings, individual zone control, and acoustic benefits. Constant-volume self-contained units have low installation cost and are often used in noncomfort or industrial air-conditioning applications or in single-zone comfort applications.

Unit airflow is reduced in response to terminal boxes closing. Several common methods used to modulate airflow delivered by the fan to match system requirements include inlet guide vanes, fan speed control, inlet/discharge dampers, and multiple-speed fan motors.

Appropriate outside air and exhaust fans and dampers work in conjunction with the self-contained unit. Their operation must be coordinated with unit operation to maintain design air exchange and building pressurization.

Refrigeration Equipment

Commercial self-contained units usually feature reciprocating or scroll compressors, although screw compressors are available in some equipment. Thermostatic or electronic expansion valves are used. Condensers are water-cooled and usually reject heat to a common condenser-water system serving multiple units. A separate cooling tower or other final heat rejection device is required.

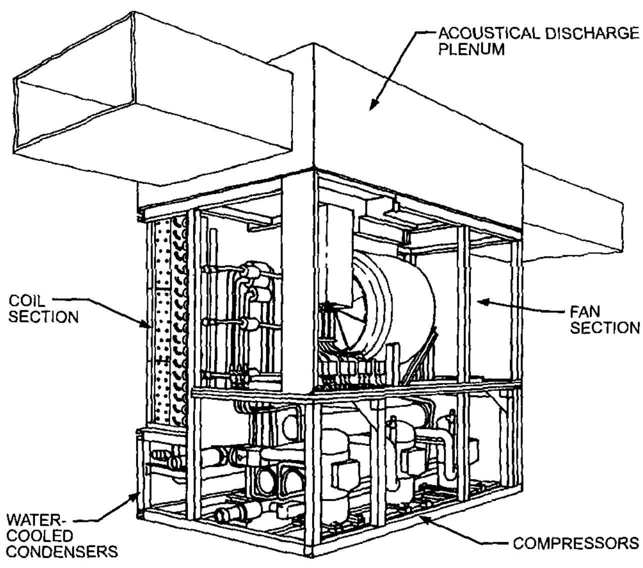

Fig. 8 Commercial Self-Contained Unit with Discharge Plenum

Self-contained units may control capacity with multiple compressors. For VAV systems, compressors are turned on or off or unloaded to maintain discharge air temperature. Hot-gas bypass is often incorporated to provide additional capacity control. As system airflow decreases, the temperature of air leaving the unit is often reset upward so that a minimum ventilation rate can be maintained. Resetting the discharge air temperature limits the unit's demand, thus saving energy. However, increased air temperature and volume increase fan energy.

Heating Equipment

In many applications, heating is done by perimeter radiation, with heating installed in the terminal boxes or other such systems when floor-by-floor units are used. If heating is incorporated in these units (e.g., preheat or morning warm-up), it is usually provided by hot-water coils or electric resistance heat.

Controls

Self-contained units typically have built-in capacity controls for refrigeration, economizers, and fans. Although units under 50 kW of cooling tend to have basic on/off/automatic controls, many larger systems have sophisticated microprocessor controls that monitor and take action based on local or remote programming. These controls provide for stand-alone operation, or they can be tied to a building automation system (BAS).

A BAS allows more sophisticated unit control by time-of-day scheduling, optimal start/stop, duty cycling, demand limiting, custom programming, etc. This control can keep units operating at peak efficiency by alerting the operator to conditions that could cause substandard performance.

The unit's control panel can sequence the modulating valves and dampers of an economizer. A water-side economizer is located upstream of the evaporator coil, and when condenser water temperature is lower than entering air temperature to the unit, water flow is directed through the economizer coil to either partially or fully meet building load. If the coil alone cannot meet design requirements, but the entering condenser water temperature remains cool enough to provide some useful precooling, the control panel can keep the economizer coil active as stages of compressors are activated. When entering condenser water exceeds entering air temperature to the unit, the coil is valved off, and water is circulated through the unit's condensers only.

Typically, in an air-side economizer an enthalpy or dry-bulb temperature switch energizes the unit to bring in outside air as the first stage of cooling. An outside air damper modulates flow to meet design temperature, and when outside air can no longer provide sufficient cooling, compressors are energized.

A temperature input to the control panel, either from a discharge air sensor or a zone sensor, provides information for integrated economizer and compressor control. Supply air temperature reset is commonly applied to VAV systems.

In addition to capacity controls, units have safety features for the refrigerant-side, air-side, and electrical systems. Refrigeration protection controls typically consist of high and low refrigerant pressure sensors and temperature sensors wired into a common control panel. The controller then cycles compressors on and off or activates hot-gas bypass to meet system requirements.

Constant-volume units typically have high-pressure cut-out controls, which protect the unit and ductwork from high static pressure. VAV units typically have some type of static pressure probe inserted in the discharge duct downstream of the unit. As terminal boxes close, the control modulates airflow to meet the set point, which is determined by calculating the static pressure required to deliver design airflow to the zone farthest from the unit.

Acoustics and Vibration

Because self-contained units are typically located near occupied space, their performance can significantly affect occupant comfort. Units of less than 50 kW of cooling are often placed inside a closet with a discharge grille penetrating the common wall to the occupied space. Larger units have their own equipment room and duct system. Common sound paths to consider include the following:

- Fan inlet and compressor sound radiates through the unit casing to enter the space through the separating wall.
- Fan discharge sound is airborne through the supply duct and enters the space through duct breakout and diffusers.
- Airborne fan inlet sound enters the space through the return air ducts, or ceiling plenum if unducted.

Discharge air transition from the self-contained unit is often accomplished with a plenum located on top of the unit. This plenum facilitates multiple duct discharges that reduce the amount of airflow over a single occupied space adjacent to the equipment room (see Figure 8). Reducing airflow in one direction reduces the sound that breaks out from the discharge duct. About a metre of internally lined round duct immediately off the discharge plenum significantly reduces noise levels in adjacent areas.

In addition to the airflow breakout path, the system designer must study unit-radiated sound power when determining equipment room wall and door construction. A unit's air-side inlet typically has the highest radiated sound. The inlet space and return air ducts should be located away from the critical area to reduce the effect of this sound path.

Selecting a fan that operates near its peak efficiency point helps design quiet systems. Fans are typically dominant in the first three octave bands, and selections at high static pressures or near the fan's surge region should be avoided.

Units may be isolated from the structure with neoprene pads or spring isolators. Manufacturers often isolate the fan and compressors internally, which generally reduces external isolation requirements.

Chapter 47 of the 2003 *ASHRAE Handbook—HVAC Applications* has more information on HVAC-related sound and vibration concerns.

COMMERCIAL OUTDOOR PACKAGED SYSTEMS

Outdoor packaged systems include unitary equipment, ducted air distribution, and temperature control. Equipment is generally mounted on the roof (rooftop units), but can also be mounted at grade level. Rooftop units (RTUs) are designed as central-station equipment for single-zone, multizone, and VAV applications.

Systems are available in several levels of design sophistication, from simple factory-standard light commercial packaged equipment, to double-wall commercial packaged equipment with upgraded features, up to fully customized industrial-quality packages. Often, factory-standard commercial rooftop unit(s) are satisfactory for small and medium-sized office buildings. On large projects and highly demanding systems, the additional cost of a custom packaged unit can be justified by life-cycle cost analyses. Custom systems offer great flexibility and can be configured to satisfy almost any requirement. Special features such as heat recovery, service vestibules, boilers, chillers, and space for other mechanical equipment can be designed into the unit.

Advantages

- Equipment location allows easy service access without maintenance staff entering or disturbing occupied space.
- Construction costs are offset toward the end of the project because the unit can be one of the last items installed.
- Installation is simplified and field labor costs are reduced because most components are assembled and tested in a controlled factory environment.

- A single source has responsibility for design and operation of all major mechanical systems in the building.
- Valuable building space for mechanical equipment is conserved.
- It is suitable for floor-by-floor control in low-rise office buildings.
- Outside air is readily available for ventilation and economy cycle use.
- Combustion air intake and flue gas exhaust are facilitated if natural gas heat is used.
- Upgraded design features, such as high-efficiency filtration or heat recovery devices, are available from some manufacturers.

Disadvantages

- Maintaining or servicing outdoor units is sometimes difficult, especially in inclement weather.
- Frequent removal of panels for access may destroy the unit's weatherproofing, causing electrical component failure, rusting, and water leakage.
- Rooftop unit design must be coordinated with structural design because it may represent a significant building structural load.
- In cold climates, provision must be made to keep snow from blocking air intakes and access doors, and the potential for freezing of hydronic heating or steam humidification components must be considered.
- Casing corrosion is a potential problem. Many manufacturers prevent rusting with galvanized or vinyl coatings and other protective measures.
- Outdoor installation can reduce equipment life.
- Depending on building construction, sound levels and transmitted vibration may be excessive.
- Architectural considerations may limit allowable locations or require special screening to minimize visual effect.

Design Considerations

Centering the rooftop unit over the conditioned space reduces fan power, ducting, and wiring. Avoid installation directly above spaces where noise level is critical.

All outdoor ductwork should be insulated. In addition, ductwork should be (1) sealed to prevent condensation in the insulation during the heating season and (2) weatherproofed to keep it from getting wet.

Use multiple single-zone, not multizone, units where feasible. For large areas such as manufacturing plants, warehouses, gymnasiums, and so forth, single-zone units are less expensive and provide protection against total system failure.

Use units with return air fans whenever return air static pressure loss exceeds 125 Pa or the unit introduces a large percentage of outside air via an economizer.

Units are also available with relief fans for use with an economizer in lieu of continuously running a return fan. Relief fans can be initiated by static pressure control.

In a rooftop application, the air handler is outside and needs to be weatherproofed against rain, snow, and, in some areas, sand. In cold climates, fuel oil does not atomize and must be warmed to burn properly. Hot-water or steam heating coils and piping must be protected against freezing. In some areas, enclosures are needed to maintain units effectively during inclement weather. A permanent safe access to the roof, as well as a roof walkway to protect against roof damage, are essential.

Rooftop units are generally mounted using (1) integral frames or (2) light steel structures. Integral support frames are designed by the manufacturer to connect to the base of the unit. Separate openings for supply and return ducts are not required. The completed installation must adequately drain condensed water. Light steel structures allow the unit to be installed above the roof using separate, flashed duct openings. Any condensed water can be drained through the roof drains.

Accessories such as economizers, special filters, and humidifiers are available. Factory-installed and wired economizer packages are also available. Other options offered are return and exhaust fans, variable-volume controls with hot-gas bypass or other form of coil frost protection, smoke and fire detectors, portable external service enclosures, special filters, and microprocessor-based controls with various control options.

For projects with custom-designed equipment, it may be desirable to require additional witnessed factory testing to ensure performance and quality of the final product.

Refrigeration Equipment

Compressors in large systems are reciprocating, screw, or scroll compressors. Chapter 34 has information about compressors and Chapters 38 and 45 discuss refrigeration equipment, including the general size ranges of available equipment. Air-cooled or evaporative condensers are built integral to the equipment.

Air-cooled condensers pass outside air over a dry coil to condense the refrigerant. This results in a higher condensing temperature and, thus, a larger power input at peak conditions. However, this peak time may be relatively short over 24 h. The air-cooled condenser is popular in small reciprocating systems because of its low maintenance requirements.

Evaporative condensers pass air over coils sprayed with water, using adiabatic saturation to lower the condensing temperature. As with the cooling tower, freeze prevention and close control of water treatment are required for successful operation. The lower power consumption of the refrigeration system and the much smaller footprint from using an evaporative versus air-cooled condenser are gained at the expense of the cost of water used and increased maintenance costs.

Heating Equipment

Natural-gas, propane, oil, electricity, hot-water, steam, and refrigerant gas heating options are available. These are normally incorporated directly into the air-handling sections. Custom equipment can also be designed with a separate prepiped boiler and circulating system.

Controls

Multiple outdoor units are usually single-zone, constant-volume, or VAV units. Zoning for temperature control determines the number of units; each zone has a unit. Zones are determined by the cooling and heating loads for the space served, occupancy, allowable roof loads, flexibility requirements, appearance, duct size limitations, and equipment size availability. Multiple units are installed in manufacturing plants, warehouses, schools, shopping centers, office buildings, department stores, etc. These units also serve core areas of buildings with perimeter spaces are served by PTACs. These systems are usually applied to low-rise buildings of one or two floors, but have been used for conditioning multistory buildings as well.

Most operating and safety controls are provided by the equipment manufacturer. Although remote monitoring panels are optional, they are recommended to allow operating personnel to monitor performance.

Acoustics and Vibration

Most unitary equipment is available with limited separate vibration isolation of rotating equipment. Custom equipment is available with several (optional) degrees of internal vibration isolation. Isolation of the entire unit casing is rarely required; however, care should be taken when mounting on light structures. If external isolation is required, it should be coordinated with the unit manufacturer to ensure proper separation of internal versus external isolation deflection.

Noise concerns from rooftop units include outdoor radiated noise, indoor radiated noise, and duct discharge noise. Outdoor noise from unitary equipment should be reduced to a minimum. Sound power levels at all property lines must be evaluated. Indoor-radiated noise from the unit's fans, compressors, and condensers travels directly through the roof into occupied space below. Mitigation usually involves adding mass, such as two layers of gypsum board, inside the roof curb beneath the unit. Airborne duct discharge noise, primarily from the fans themselves, can be attenuated by silencers in the supply and return air ducts or by acoustically lined ductwork. Avoid installation directly above spaces where noise level is critical.

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ECONOMIZERS

Air-Side Economizers

The air-side economizer uses cool outside air to either assist mechanical cooling or, if the outside air is cool enough, provide total cooling. It requires a mixing box designed to allow 100% of the supply air to be drawn from outside. It can be a field-installed accessory that includes an outside air damper, relief damper, return air damper, filters, actuator, and linkage. Controls are usually a factory-installed option.

Self-contained units usually do not include return air fans. A variable-volume relief fan must be installed with the air-side economizer. The relief fan is off and discharge dampers are closed when the air-side economizer is inactive.

Advantages

- Substantially reduces compressor, cooling tower, and condenser water pump energy requirements, generally saving more energy than a water-side economizer
- Has a lower air-side pressure drop than a water-side economizer
- Reduces tower makeup water and related water treatment
- May improve indoor air quality by providing large amounts of outside air during mild weather

Disadvantages

- In systems with larger return air static pressure requirements, return or exhaust fans are needed to properly exhaust building air and intake outside air.
- If the unit's leaving air temperature is also reset up during the air-side economizer cycle, humidity control problems may occur and the fan may use more energy.
- Humidification may be required during winter.
- More and/or larger air intake louvers, ducts, or shafts may be required.

Water-Side Economizers

The water-side economizer is another option for reducing energy use. ASHRAE *Standard* 90.1 addresses its application. The water-side economizer consists of a water coil located in the self-contained unit upstream of the direct-expansion cooling coil. All economizer control valves, piping between the economizer coil and the condenser, and economizer control wiring can be factory-installed (Figure 9).

The water-side economizer uses the low cooling tower or evaporative condenser water temperature to either (1) precool entering air, (2) assist mechanical cooling, or (3) provide total system cooling if the cooling water is cold enough. If the economizer is unable to maintain the supply air set point for VAV units or zone set point for constant-volume units, factory-mounted controls integrate economizer and compressor operation to meet cooling requirements.

Cooling water flow is controlled by two valves (Figure 9), one at the economizer coil inlet A and one in the bypass loop to the condenser B. Two control methods are common: constant and variable flow. In constant-flow control, the two control valves are factory-wired for complementary control, where one valve is driven open while the other is driven closed. This keeps water flow through the condenser relatively constant. In variable-flow control, condenser water flow varies during unit operation. The valve in bypass loop B is an on/off valve and is closed when the economizer is enabled. Water flow through the economizer coil is modulated by valve A, thus allowing variable cooling water flow. As cooling load increases, valve A opens, increasing water flow through the economizer coil. If the economizer is unable to satisfy the cooling requirements, factory-mounted controls integrate economizer and compressor operation. In this operating mode, valve A is fully open. When the self-contained unit is not in cooling mode, both valves are closed. Reducing or eliminating cooling water flow reduces pumping energy.

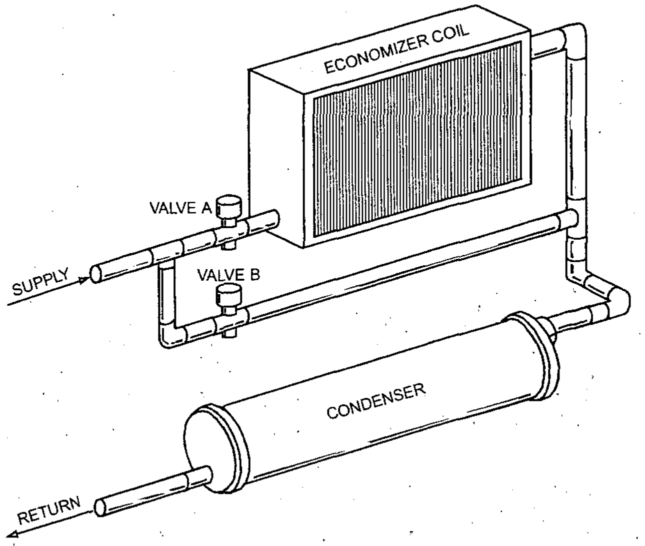

Fig. 9 Water-Side Economizer and Valves

Advantages

- Compressor energy is reduced by precooling entering air. Often, building load can be completely satisfied with an entering condenser water temperature of less than 13°C. Because the wet-bulb temperature is always less than or equal to the dry-bulb temperature, a lower discharge air temperature is often available.
- Building humidification does not affect indoor humidity by introducing outside air.
- No external wall penetration is required for exhaust or outside air ducts.
- Mechanical equipment rooms can be centrally located in a building.
- Controls are less complex than for air-side economizers, because they are often inside the packaged unit.
- The coil can be mechanically cleaned.
- More net usable floor area is available because large outside air and relief air ducts are unnecessary.

Disadvantages

- Cooling tower water treatment cost is greater.
- Air-side pressure drop may increase.
- Condenser water pump pressure may increase slightly.
- The cooling tower must be designed for winter operation.
- The increased operation (including in winter) required of the cooling tower may reduce its life.

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