Related Commercial Resources

CHAPTER 2

DECENTRALIZED COOLING AND HEATING

FOR MOST small to mid-size installations, decentralized cooling and heating is usually preferable to a centralized system (see Chapter 3). Frequently classified as packaged unit systems (although many are far from being a single packaged unit), decentralized systems can be found 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 some of the equipment addressed here can be applied as a single unit, this chapter covers applying multiple units to form a complete air-conditioning system for a building and the distribution associated with some of these systems. For guidance on HVAC system selection, see Chapter 1.

SYSTEM CHARACTERISTICS

Decentralized systems can be one or more individual HVAC units, each with an integral refrigeration cycle, heating source, and direct or indirect outside air ventilation. Components are factory-designed and assembled into a package that includes fans, filters, heating source, cooling coil, refrigerant compressor(s), controls, and condenser. Equipment is manufactured in various configurations to meet a wide range of applications. Examples of decentralized HVAC equipment include the following:

- Window air conditioners
- Through-the-wall room HVAC units
- Air-cooled heat pump systems
- Water-cooled heat pump systems
- Multiple-unit systems
- Residential and light commercial split systems
- Self-contained (floor-by-floor) systems
- Outside package systems
- Packaged, special-procedure units (e.g., for computer rooms)

For details on window air conditioners and through-the-wall units, see Chapter 49; the other examples listed here are discussed further in Chapter 48. (Multiple-unit systems are also covered in Chapter 4.)

Commercial-grade unitary equipment packages are available only in preestablished increments of capacity with set performance parameters, such as the sensible heat ratio at a given room condition or the airflow per ton 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. See Chapters 48 and 49 for more specific information on pertinent industry standards and on decentralized cooling and heating equipment used in multiple-packaged unitary systems.

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.

For supplementary data on air-side design of decentralized systems, see Chapter 4.

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.

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

- Energy can be metered directly to each tenant.
- Air- or water-side economizers may be applicable, depending on type of decentralized system used.

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.
- 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 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.

DESIGN CONSIDERATIONS

Rating classifications and typical sizes for equipment addressed in this chapter can be found in Chapters 48 and 49, which also address available components, equipment selection, distribution piping, and ductwork.

Selection of a decentralized system should follow guidance provided in Chapter 1. The design engineer can use the HVAC system analysis selection matrix to analytically assess and select the optimum decentralized system for the project. Combined with the design criteria in Chapters 48 and 49, the basis of design can be documented.

Unlike centralized cooling and heating equipment, capacity diversity is limited with decentralized equipment, because each piece of equipment must be sized for peak capacity.

Noise from this type of equipment may be objectionable and should be checked to ensure it meets sound level requirements. Chapter 47 of the 2007 *ASHRAE Handbook—HVAC Applications* has more information on HVAC-related sound and vibration concerns.

Air-Side Economizer

With some decentralized systems, an air-side economizer is an option, if not an energy code requirement (check state code for criteria). 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, filter, actuator, and linkage. Controls are usually a factory-installed option.

Self-contained units usually do not include return air fans. A barometric relief, fan-powered relief fan, or return/exhaust fan may be provided as an air-side economizer. The relief fan is off and discharge/exhaust 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 take in 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 Economizer

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

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 air-handling unit's supply air or zone set point, factory-mounted controls integrate economizer and compressor operation to meet cooling requirements. For constant condenser water flow control using a economizer energy recovery coil and the unit condenser, two control valves are factory-wired for complementary control, with one valve 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/energy recovery loop is an on/off valve and is closed when the economizer is enabled. Water flow through the economizer coil is modulated by its automatic control valve, allowing variable cooling water flow as cooling load increases (valve opens) and reduced flow on a decrease in cooling demand. If the economizer is unable to satisfy the cooling requirements, factory-mounted controls integrate economizer and compressor operation. In this operating mode, the economizer valve 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.

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 55°F. 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.
- 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 and relief air ducts are unnecessary.

Disadvantages

- Cooling tower water treatment cost is greater.
- Air-side pressure drop may increase with the constant added resistance of a economizer coil in the air stream.
- 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.

WINDOW-MOUNTED AND THROUGH-THE-WALL ROOM HVAC UNITS AND AIR-COOLED HEAT PUMPS

Window air conditioners (air-cooled room conditioners) and through-the-wall room air conditioners with supplemental heating 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. Ventilation can be through operable windows or limited outside air ventilation introduced through the self-contained room HVAC unit. These units are described in more detail in Chapter 49.

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 an equipment life of 10 to 15 years for these units.

Air-cooled heat pumps located on roofs or adjacent to buildings are another type of package equipment with most of the features noted here, with the additional benefit of supply air distribution and equipment outside the occupied space. This improved ductwork arrangement makes equipment accessible for servicing out the occupied space, unlike in-room units. See Chapter 48 for additional design, operating, and constructability discussion.

Advantages

- Installation of in-room unit 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.
- Installation of outside heat pumps is simple with rigging onto concrete pad at grade level or on the roof.
- 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 of in-room equipment can be quickly restored by replacing a defective chassis.

Disadvantages

- Equipment life may be less than for large central equipment, typically 10 to 15 years, and 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, which may cause dripping on walls, balconies, or sidewalks.
- Temperature control is usually two-position, which causes swings in room temperature.
- Ventilation and economy cycle capabilities are fixed by equipment design.
- 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

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 (see the discussion on controls following in this section).

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. See Figure 3 in Chapter 49 for unit configuration.

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 27 of the 2005 *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 65°F. 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.

Heating Equipment. The air-to-air heat pump cycle described in Chapter 48 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 outside temperature is above 35 to 40°F. 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** is either unit-mounted or remote wall-mounted.
- **Motel and hotel guest room controls** allow starting and stopping units from a central point.
- **Occupied/unoccupied 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** is used when multiple conditioners are operated by the same thermostat.
- **Emergency standby control** allows a conditioner to operate during an emergency, such as a power failure, so that the room-side blowers can operate to provide heating. Units must be specially wired to allow operation on emergency generator circuits.

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.

WATER-SOURCE HEAT PUMP SYSTEMS

Water-source heat pump systems use multiple cooling/heating units distributed throughout the building. For more in-depth discussion of water-source heat pumps, see Chapter 8. Outside air ventilation requires either direct or indirect supply air from an additional air-handling system.

Designed to cool and heat individual rooms or multiple spaces grouped together by zone, water-source heat pumps may be installed along the perimeter with a combination of horizontal and vertical condenser water piping distribution, or stacked vertically with condenser water piping also stacked vertically to minimize equipment space effects on the rooms they serve. They can also be ceiling mounted or concealed above the ceiling with duct distribution to the area served.

Water-source heat pump systems also require further decentralized equipment that includes a source of heat rejection such as a cooling tower or ground water installation. A supplemental heating source such as a boiler may be required, depending on the installation's location (e.g., in colder winter climates). Data on condenser water systems and the necessary heat rejection equipment can be found in Chapters 13 and 39.

Advantages

- Unit installation is simple for both vertical and horizontal installation and connection to electrical power.
- Outdoor heat pumps can be installed with a lift to rig horizontal units at or above a ceiling.
- Generally, the system is well suited to spaces requiring many zones of individual temperature control.
- Designers can specify energy recovery.

Disadvantages

- Energy use may be relatively high compared with other types of systems.
- Introducing outside air to the building can be a problem.
- Condensate drain piping installation and routine maintenance can be a problem, particularly for units installed above ceilings.
- No air-side economy cycle capabilities.
- 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 within occupied space is required to maintain capacity.

Design Considerations

Units are usually furnished with individual electric controls. However, control strategy considerations are similar to those for air-cooled heat pumps.

These units can be used for renovation of existing buildings where limited ceiling space would prevent other types of HVAC systems (e.g., all-air systems) from being installed. The equipment can be used in both low- and high-rise buildings; both applications require some form of outdoor ventilation to serve the occupants.

See Chapter 8 for data on refrigeration cycle, heating cycle, automatic controls, and other information on design and operation and maintenance.

MULTIPLE-UNIT SYSTEMS

Multiple-unit systems generally use single-zone unitary HVAC with a unit for each zone (Figure 1). Zoning is determined by (1) cooling and heating loads, (2) occupancy, (3) flexibility requirements, (4) appearance, 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.

The system configuration can be horizontal distribution of equipment and associated ductwork and piping, or vertical distribution of

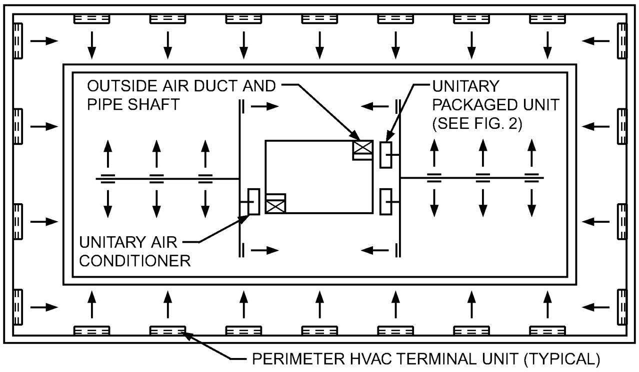

Fig. 1 Multiple-Unit Systems Using Single-Zone Unitary HVAC Equipment
(Courtesy RDK Engineers)

equipment and piping with horizontal distribution of ductwork. Outside air ventilation requires either direct or indirect supply air from an additional air-handling system.

Heating media may be steam or hot water piped to the individual units or electric heat at the unit and/or at individual air terminals that provide multiple-space temperature-controlled zones. Cooling media may be chilled water, refrigerant/direct expansion (DX), or heat pump condenser water piped to individual units. A typical system features zone-by-zone equipment with a central plant chiller and boiler, although electric heat and DX refrigerant cooling may be used.

Supply air may be constant or variable volume; outside ventilation is probably a fixed minimum, possibly with limited variable volume based on carbon dioxide ventilation control. Usually, multiple units do not come with a return air fan; the supply fan must overcome return air and supply air duct static resistance. A supplemental exhaust fan or multiple exhaust fans may be required to complete the design.

Multiple-unit systems require a localized equipment room where one or more units can be installed. This arrangement takes up floor space, but allows equipment maintenance to occur out of the building's occupied areas, minimizing interruptions to occupants.

Advantages

- Installation is simple. Equipment is readily available in sizes that allow easy handling.
- Equipment and components can be standardized.
- 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, night setback, and morning warm-up.
- Equipment is out of the occupied space, making the system quieter.
- Easy access to equipment facilitates routine maintenance.
- System is repetitive and simple, facilitating operator training.

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.
- Integral air-cooled condensing units for some direct-expansion cooling installations should be located outdoors within a limited distance.
- Multiple units and equipment closets or rooms may occupy rentable floor space.
- Multiple pieces of equipment may increase maintenance requirements.
- Redundant equipment or easy replacement may not be practical.

Design Considerations

Unitary systems can be used throughout a building or to supplement perimeter packaged terminal units (Figures 1 and 2). Because core areas frequently have little or no heat loss, unitary equipment with air- or water-cooled condensers can be applied. The equipment can be used in both low- and high-rise buildings; both applications require some form of outside ventilation to serve the occupants.

Typical application may be a interior work area, computer room, or other space requiring continual cooling. 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 (Figure 2). For more information, see Chapters 16 and 17 of the 2007 *ASHRAE Handbook—HVAC Applications*, as well as Chapters 48 and 49 of this volume.

In the multiple-unit system shown in Figure 3, one unit may be used to precondition outside air for a group of units. 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.

Units under 20 tons of cooling are typically constant-volume units. VAV distribution may be accomplished on these units 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. Variable-frequency drives can also be used.

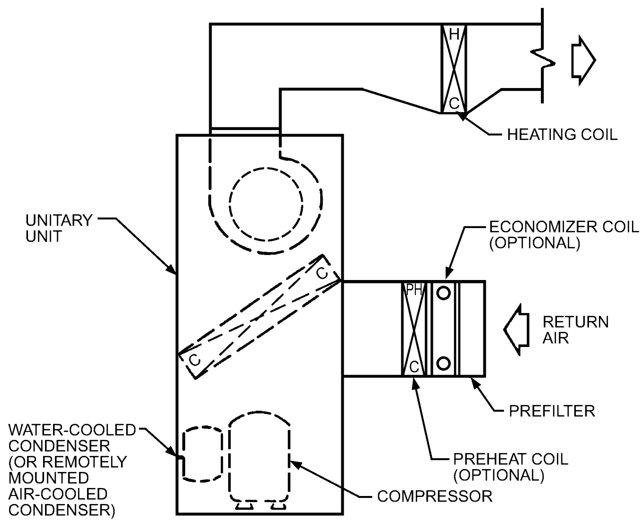

Fig. 2 Vertical Self-Contained Unit
(Courtesy RDK Engineers)

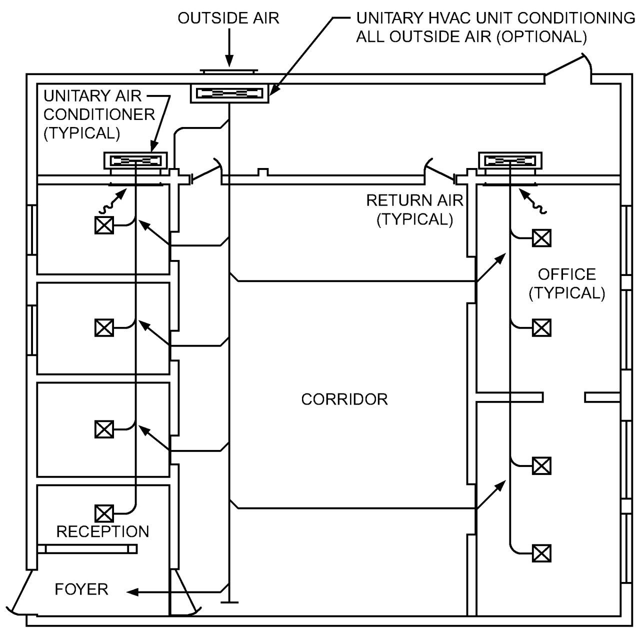

Fig. 3 Multiroom, Multistory Office Building with Unitary Core and Through-the-Wall Perimeter Air Conditioners (Combination Similar to Figure 1)
(Courtesy RDK Engineers)

Controls. Units are usually furnished with individual electric controls, but can be enhanced to a more comprehensive building management system.

Economizer Cycle. When outside temperature allows, 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 a water-side economizer cooling coil, with cold water obtained by sending the condenser water through a winterized cooling tower. Chapter 39 has further details.

Acoustics and Vibration. Because these units are typically located near occupied space, they can affect acoustics. The designer must study both the airflow breakout path and the unit's radiated sound power when coordinating selection of 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 2007 *ASHRAE Handbook—HVAC Applications* has more information on HVAC-related sound and vibration concerns.

RESIDENTIAL AND LIGHT COMMERCIAL SPLIT SYSTEMS

These systems distribute cooling and heating equipment throughout the building. 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 small projects 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.

The configuration can be horizontal distribution of equipment and associated ductwork and piping, or vertical distribution of equipment and piping with horizontal distribution of ductwork. These applications share some of the advantages of multiple-unit systems, but may only have one system installation per project. Outside air ventilation requires either direct or indirect supply from another source (e.g., operable window).

Heating is usually electric or gas, but may be steam, hot water, or possibly oil-fired at the unit. Cooling is usually by direct expansion, but could be chilled water.

Supply air may be constant or variable volume; outdoor ventilation is usually a fixed minimum or barometric relief economizer cycle. A supplemental exhaust fan may be required to completed the design.

Advantages

- Unitary split-system units allow air-handling equipment to be placed close to the heating and cooling 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.
- 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.
- 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

Characteristics that favor split systems are their low first cost, simplicity of installation, and simplicity of training required for operation. Servicing is also relatively inexpensive.

The modest space requirements of split-system equipment make it excellent for renovations or for spot cooling a single zone. Control is usually one- or two-step cooling 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 using hot-gas bypass.

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.

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

Commercial self-contained (floor-by-floor) systems are a type of multiple-unit, decentralized cooling and heating system. Equipment is usually configured vertically, but may be horizontal. Supply air distribution may be a discharge air plenum, raised-floor supply air plenum (air displacement), or a limited amount of horizontal duct distribution, installed on a floor-by-floor basis. Outside air ventilation requires either direct or indirect supply air from an additional air-handling system.

Typical components include compressors, water-cooled condensers, evaporator coils, economizer coils, heating coils, filters, valves, and controls (Figure 4). To complete the system, a building needs cooling towers and condenser water pumps. See Chapter 39 for more information on cooling towers.

Advantages

- This equipment integrates refrigeration, heating, air handling, and controls into a factory package, thus eliminating many field integration problems.
- Units are well suited for office environments with variable occupancy schedules.
- 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 interior equipment location and eliminate large outside air and exhaust ducts and relief fans.
- An acoustical discharge plenum is available, which allows lower fan power and lower sound power levels.

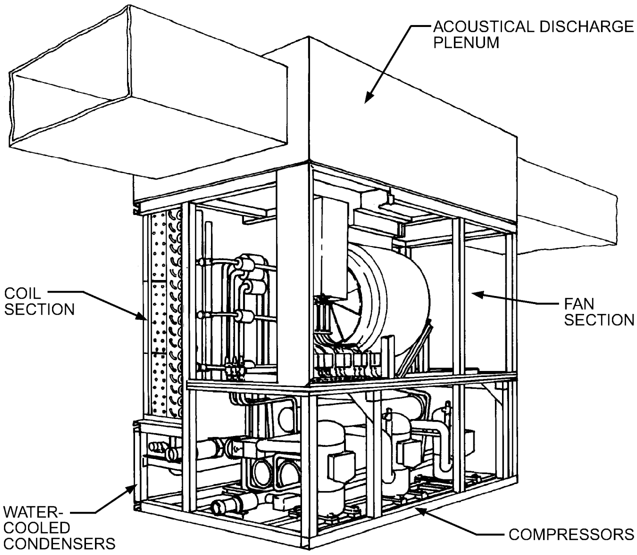

Fig. 4 Commercial Self-Contained Unit with Discharge Plenum

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 have criteria similar to those for multiple and light commercial units, and 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.

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, but could be by a gas- or oil-fired heat exchanger.

Controls. Self-contained units typically have built-in capacity controls for refrigeration, economizers, and fans. Although units under 15 tons 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 15 tons 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 4). Reducing airflow in one direction reduces the sound that breaks out from the discharge duct. Several feet 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.

COMMERCIAL OUTDOOR PACKAGED SYSTEMS

Commercial outdoor packaged systems are similar to air-cooled heat pump and commercial self-contained (floor-to-floor) systems, and are usually of horizontal configuration.

Heating is usually electric or gas but may be steam, hot water, or possibly oil-fired at the unit. Cooling is usually by direct expansion, but could be chilled water.

Supply air distribution usually has a limited amount of horizontal duct distribution and is installed on a floor-by-floor basis. Outdoor air ventilation can be provided by barometric relief, fan-powered relief, or return air/exhaust air fan.

Equipment is generally mounted on the roof [rooftop units (RTUs)], but can also be mounted at grade level. 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.

For additional information, see Chapter 48.

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.
- With all rooftop equipment, safe access to the equipment is a concern. Even slightly sloped roofs are a potential hazard.
- 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, if not already required by associated energy codes. In addition, ductwork should be (1) sealed to prevent condensation in insulation during the heating season and (2) weatherproofed to keep it from getting wet.

Use multiple single-zone, not multizone, units where feasible to simplify installation and improve energy consumption. For large areas such as manufacturing plants, warehouses, gymnasiums, etc., 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 0.5 in. of water 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 coastal environments, enclosure materials' resistance (e.g., to salt spray) must also be considered. 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) lightweight 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. Lightweight 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. Large systems incorporate reciprocating, screw, or scroll compressors. Chapter 37 has information about compressors and Chapters 42 and 48 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. These units can also serve core areas of buildings, with perimeter spaces served by PTACs.

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 lightweight structures. If external isolation is required, it should be coordinated with the unit manufacturer to ensure proper separation of internal versus external isolation deflection.

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.

AUTOMATIC CONTROLS AND BUILDING MANAGEMENT SYSTEMS

A building management system can be an important tool in achieving sustainable facility energy management. Basic HVAC system controls are electric or electronic, and usually are prepackaged and prewired with equipment at the factory. Controls may also be accessible by the building manager using a remote off-site computer. The next level of HVAC system management is to integrate the manufacturer's control package with the building management system. If the project is an addition or major renovation, prepackaged controls and their capabilities need to be compatible with existing automated controls. Chapter 39 of the 2007 *ASHRAE Handbook—HVAC Applications* discusses computer applications, and ANSI/ASHRAE *Standard* 135 discusses interfacing building automation systems.

MAINTENANCE MANAGEMENT

Because they are simpler and more standardized than centralized systems, decentralized systems can often be maintained by less technically trained personnel. Maintenance management for many packaged equipment systems can be specified with a service contract from a local service contracting firm. Frequently, small to midlevel construction projects do not have qualified maintenance technicians on site once the job is turned over to a building owner, and service contracts can be a viable option. These simpler decentralized systems allow competitive solicitation of bids for annual maintenance to local companies.

BUILDING SYSTEM COMMISSIONING

Commissioning a building system that has an independent control system to be integrated with individual packaged control systems requires that both control contractors participate in the process. Before the commissioning functional performance demonstrations to the client, it is important to obtain the control contractors' individual point checkout sheets, program logic, and list of points that require confirmation with another trade (e.g., fire alarm system installer).

Frequently, decentralized systems are installed in phases, requiring multiple commissioning efforts based on the construction schedule and owner occupancy. This applies to new construction and expansion of existing installations. During the warranty phase, decentralized system performance should be measured, benchmarked, and course-corrected to ensure the design intent can be achieved. If an energy analysis study is performed as part of the comparison between decentralized and centralized concepts, or life-cycle comparison of the study is part of a Leadership in Energy and Environmental Design (LEED™) project, the resulting month-to-month energy data should be a good electronic benchmark for actual energy consumption using the measurement and verification plan implementation.

Ongoing commissioning or periodic recommissioning further ensures that design intent is met, and that cooling and heating are reliably delivered. Retro- or recommissioning should be considered whenever the facility is expanded or an additional connection made to the existing systems, to ensure the original design intent is met.

The initial testing, adjusting, and balancing (TAB) also contributes to sustainable operation and maintenance. The TAB process should be repeated periodically to ensure levels are maintained.

When completing TAB and commissioning, consider posting laminated system flow diagrams at or adjacent to cooling and heating equipment indicating operating instructions, TAB performance, commissioning functional performance tests, and emergency shutoff procedures. These documents also should be filed electronically in the building manager's computer server for quick reference.

Original basis of design and design criteria should be posted as a constant reminder of design intent, and to be readily available in case troubleshooting, expansion, or modernization is needed.

As with all HVAC applications, to be a sustainable design success, building commissioning should include the system training requirements necessary for building management staff to efficiently take ownership and operate and maintain the HVAC systems over the useful service life of the installation.

Commissioning should continue up through the final commissioning report, approximately one year after the construction phase has been completed and the warranty phase comes to an end. For further details on commissioning, see Chapter 42 of the 2007 *ASHRAE Handbook—HVAC Applications*.

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